Stratigraphical and Microfacies Analysis of Some Selected Late Cretaceous Surface and Subsurface Section in Arabia

by

Asem Mahmoud Abdou

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

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DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
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بسم الله الرحمن الرحيم

"وَقُل رَّبِّ زِدْنِي عِلْماً"

(طه – ١١٤)

In the name of Allah, the Beneficient, the Merciful

"And say : My Lord ! Increase me in knowledge !"

(Taha - 114)

This thesis is
Dedicated to
my Parents

ACKNOWLEDGEMENTS

The present work was carried out under the supervision of Prof. Dr. Z.R. El-Naggar to whom the author is deeply indebited for suggesting the problem, providing the research material and data, laying out the plan of research and the thorough checking of the identification of the fossil remains and of the thesis. Grateful acknowledgement is foremost due the spirit of fatherhood and the tremendous encouragement and support Dr. El-Naggar has flooded me with throughout all phases of this work.

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Sincere appreciation is due to Mr. A. Al-Sheikh (KFUPM, Intergraph Center), Mr. W. Hamdi (KFUPM, Library) and to the staff of the Department of Earth Sciences, KFUPM for their unfailing assistance.

I am also indebited to my colleagues Mr. Sa'ad Kamel, Mr. Hany El-Sahn and Mr. Aus Al-Tawil for their spirit of brotherhood and continued support.

The patience and encouragement of my family, teachers and friends backhome in Egypt were instrumental in completing this work in the present form.

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ABSTRACT

Name : Asem Mahmoud Abdou

Thesis Title : Stratigraphical and microfacies analysis of some selected Late Cretaceous surface and subsurface sections in Arabia.

Major Field : Geology

Date : June, 1989

The cored Late Cretaceous succession in the Umm Gudair#1 crestal Well (including the type Gudair Formation) has been studied in thin section. The cored interval which is 223 m (= 733' between the drilled depths 3763' and 4496') has been carefully sampled, and the selected samples have been thin sectioned. A total of 110 thin sections have been used for both the litho- and biostratigraphical as well as the microfacies analysis of the succession. One group, three distinctive formations, four different biozones and 10 successive microfacies have been recognized. This is the first revision of the type Gudair Limestone since its introduction and the first application of the microfacies analysis for the Late Cretaceous succession in the region. The type Gudair Formation has been proved to be of late Early to Middle Campanian age, despite its previous assignment to older ages.

The magnitude of the Middle/Late Cretaceous unconformity across the Umm Gudair structure has been assessed by about 8.5 m.y. as it incorporates the Late Turonian, Coniacian, Santonian and most of the Early Campanian. Correlation with nearby wells indicates that this regional break varies markedly in magnitude from one well to another (depending on its position with respect to the structure) and from one structure to the other (depending on the differential growth of such structures from the bottom of the Late Cretaceous sea).

Another unconformity between the Gudair and the overlying Hartha Limestones has also been detected and is taken to substantiate tectonic instability in the region during the Late Campanian time which, is known to have been a phase of world-wide rise in sea-level.

The recognized microfacies have been correlated with corresponding Standard Microfacies Types wherever possible, and this has led to the interpretation that the analyzed section had been deposited under conditions that fluctuated between shallow platform and shelf environments. Several stratigraphic phenomena as well as diagenetic features in support of this interpretation have been explained in the light of the current ideas on carbonate geology.

The assemblage biozones recognized in the studied succession have been correlated with corresponding local and international biozones of the Late Cretaceous time.

MASTER OF SCIENCE DEGREE
KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
Dhahran, Saudi Arabia
June, 1989

الخلاصة

الاســـــــم : عاصم محمود عبده
عنوان الدراسة : تحليل سحني وطباقي لبعض المقاطع السطحية والتحت سطحية للعهد الطباشيري المتأخر في الجزيرة العربية .
التخصص : جيولوجيا
تاريخ الشهادة : يونيو ١٩٨٩م

لقد تم اختيار بئر أم قدير رقم (١) لهذه الدراسة لاعتباره قطاعا نموذجيا لأحد المتكونات الصخرية الممثلة للعصر الطباشيري المتأخر وهو المتكون الذي يحمل اسم البئر (متكون أم قدير) .

وتقع البئر المدروسة في الجزء الجنوبي الشرقي من الكويت في أحد حقول النفط الهامة والمعروفة بنفس الاسم .

ومن ميزات هذه البئر أن العينات التي استخرجت منها كانت في أغلبها عينات لبية مما زاد في قيمتها الدراسية .

وقد قامت هذه الدراسة بتحليل سحني وطباقي للعينات اللبية المأخوذة من ثلاث متكونات صخرية مر بها البئر وهي – من أسفل الى أعلى – كما يلي : متكون أم قدير (وهذا هو القطاع النموذجي للمتكون) ، ومتكون الحارثة ، ومتكون القرنة .

وقد تم عمل أكثر من (١١٠) قطاعا صخريا رقيقا تمثل سمكا قدره (٢٢٣) مترا (= ٧٣٣ قدما بين عمق ٣٧٦٣ قدما ، ٤٤٩٦ قدما تحت سطح البئر) . وقد تم تقسيم التتابع المدروس الى ثلاث نطق على أساس من بقايا الحياة الدقيقة التي تم التعرف عليها في القطاعات الصخرية الرقيقة . وقد قورنت هذه النطق الحياتية مع نظيراتها من النطق المعروفة عالميا ، وتلك التي سبق التعرف عليها محليا في منطقة الخليج العربي . وقد خلصت الدراسة الى اعتبار التتابع ممثلا للعمرين الكمباني والماسترختي وهما فترتان متميزتان في العهد الطباشيري المتأخر .

كذلك تم تقسيم التتابع الى عشرة سحن دقيقة بناء على كل من الصفات الصخرية والحياتية المجهرية للعينات المدروسة ، وتمت مقارنة هذه السحن الدقيقة بعدد من سحن وأحزمة الترسيب النموذجية المعروفة من قبل مما أدى الى استنتاج البيئات القديمة التي تم تحتها ترسيب صخور التتابع المدروس ، وقد تراوحت هذه بين كل من ظروف الرصيف والرف القاريين طوال العهد الطباشيري المتأخر .

كذلك أسفرت الدراسة عن التعرف على سطحي لاتوافق هامين أحدهما عند قاعدة القطاع المدروس ، ويفصل بين صخور عهدي الطباشيري المتأخر والوسيط وهو حد مميز في المنطقة كلها ، أما السطح الآخر فيفصل بين كل من متكون أم قدير ومتكون الحارثة الذي يعلوه .

درجة الماجستير في العلوم
جامعة الملك فهد للبترول والمعادن
الظهران – المملكة العربية السعودية
يونيو ١٩٨٩

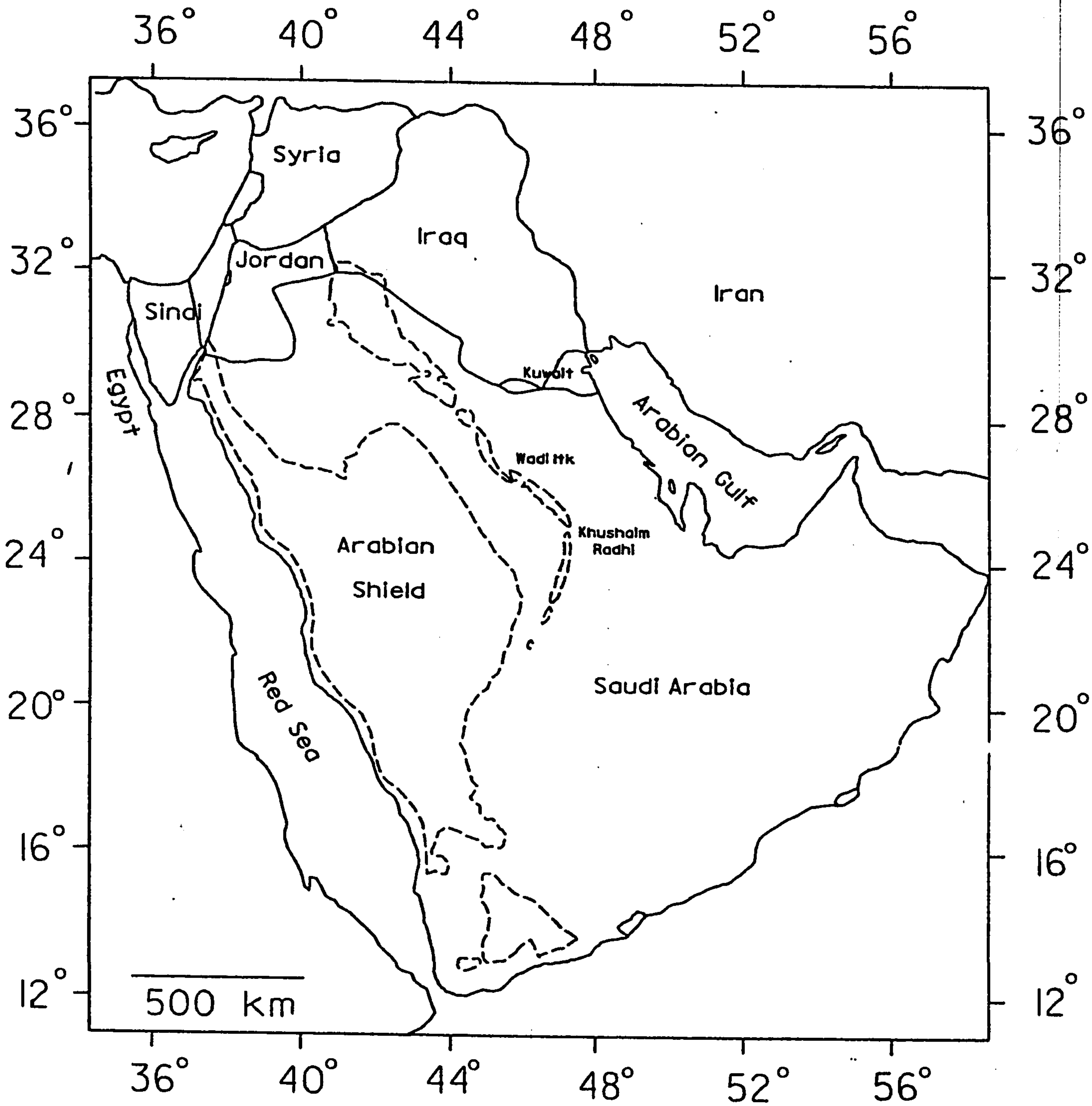
I. INTRODUCTION

Very little has -so far- been published on the stratigraphy of the Late Cretaceous succession in Arabia despite both its academic and economic importances. The succession is oil-producing in a number of large fields in the region, and its deposition has witnessed major tectonic events that have seriously affected the Arabian Plate.

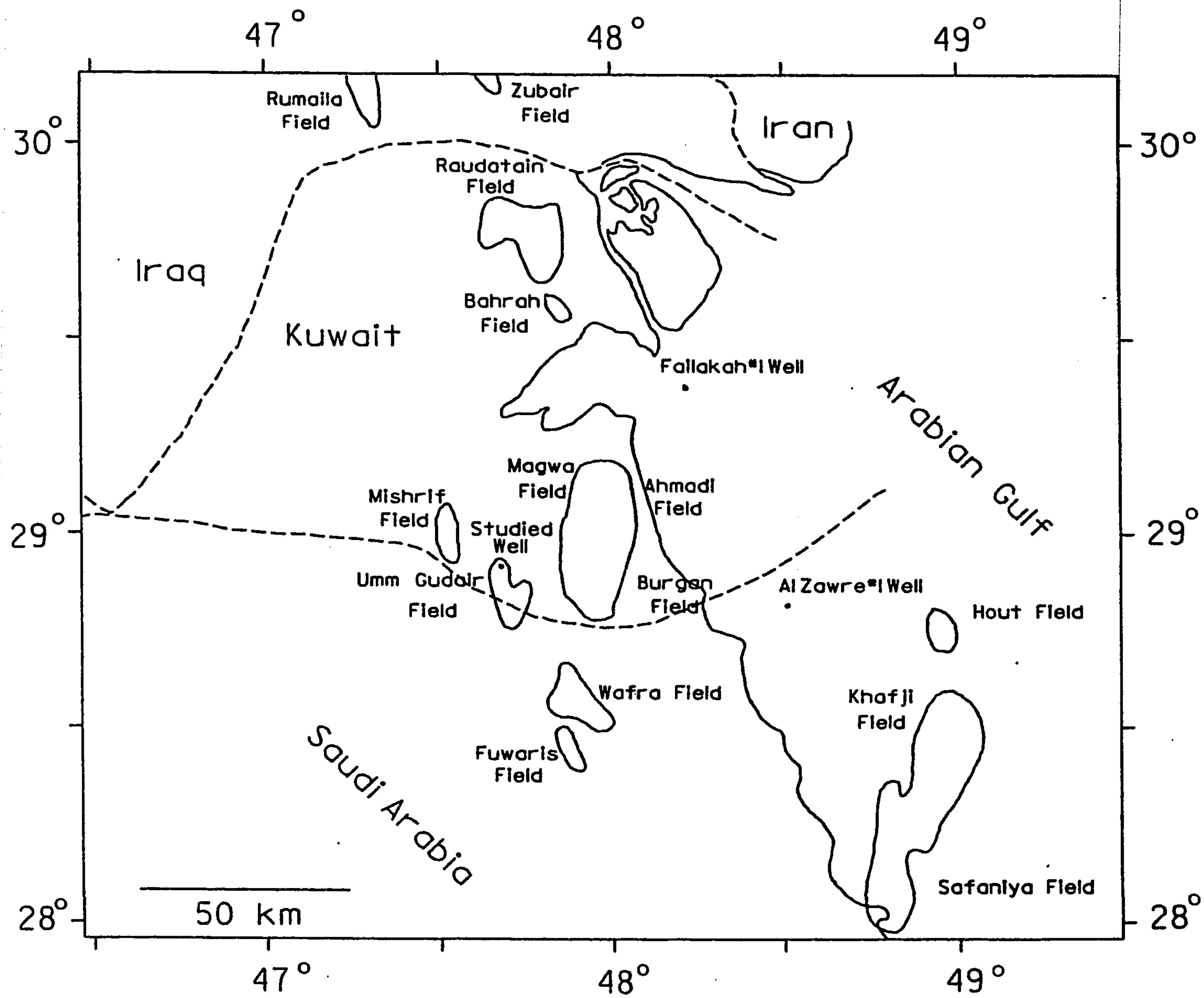
All over the Arabian Peninsula, the Late Cretaceous rocks are separated from the Middle Cretaceous ones by a regional break which is generally known as the Wasi'a / Aruma (or the Middle / Late Cretaceous) unconformity. The magnitude of this break varies from one place to another in the region, with maxima at the crests of positive areas such as the drilled structures of oil fields. This has been taken to support the reasonable assumption that such structures had experienced a process of gradual growth from the bottom of the Late Cretaceous sea. Such syn-depositional growth structures have resulted in the differential truncation of both the Middle and the Late Cretaceous successions by either erosion, thinning-out or even non-deposition of various segments of the succession. This has caused the introduction of many rock units' names, which are -in most cases- lateral equivalents for each other or -at least- partially overlapping (e.g. the Tayarat, Bahrah, Qurna, Hartha, Shiranish, Gudair, Zawre, Sa'di, Tanuma, Khasib, Simsima, Muti, Fiqa, Juweiza, etc.).

Indeed, the Late Cretaceous was one of the most crucial episodes in the geologic history of both Arabia and nearby countries. Here, subduction at the Zagros geosuture, and obduction at the Oman line, together with the consequent tectonic events have seriously left their marks in the region (*cf.* Murris, 1980). Thick ophiolite belts, large overthrusts of deep oceanic allochtonous successions, faults and folds of various types and magnitudes, marked growth structures and regional breaks, diastems as well as thinning-outs of the Late Cretaceous succession all over the region can testify to this. These Late Cretaceous tectonics accompanied by both the reactivation of older structures, and the differential mobilization of ancient evaporite deposits (such as the Hormuz Complex and the Hith Anhydrite or its partial equivalent, the Gotnia Salt), have eventually led to the structural closures of the giant oil fields of the region. The Late Cretaceous rocks in the area are not remarkably rich in hydrocarbons, but in some places they are (e.g. in the Saudi Arabia / Kuwait Divided Neutral Zone, in northern Iraq, southwestern and offshore Iran, Syria and southeastern Turkey). However, the succession with its lithological composition, fossil content, stratigraphic and structural relationships, bears several clues that can definitely improve our understanding of the geologic history of the region.

The objective of this study is to carry out a detailed stratigraphical and microfacies analysis for the Late Cretaceous succession penetrated by the Umm Gudair#1 Well, southeastern Kuwait (Text-Figs. 1, 2), which constitutes the type Gudair Formation. The study also tries to correlate this part of the Late Cretaceous succession with coeval units in the region in order to substantiate the usage of the term Gudair Formation or its abandonment, and intends to interpret the tectono-sedimentational history of the studied section.



Text-Fig. 1: Outcrop Map Of The Late Cretaceous Aruma Group In The Arabian Peninsula (modified after El-Asa'ad, 1983a)



Text-Fig. 2: Location Map For The

Umm Gudair And Nearby Oil Fields

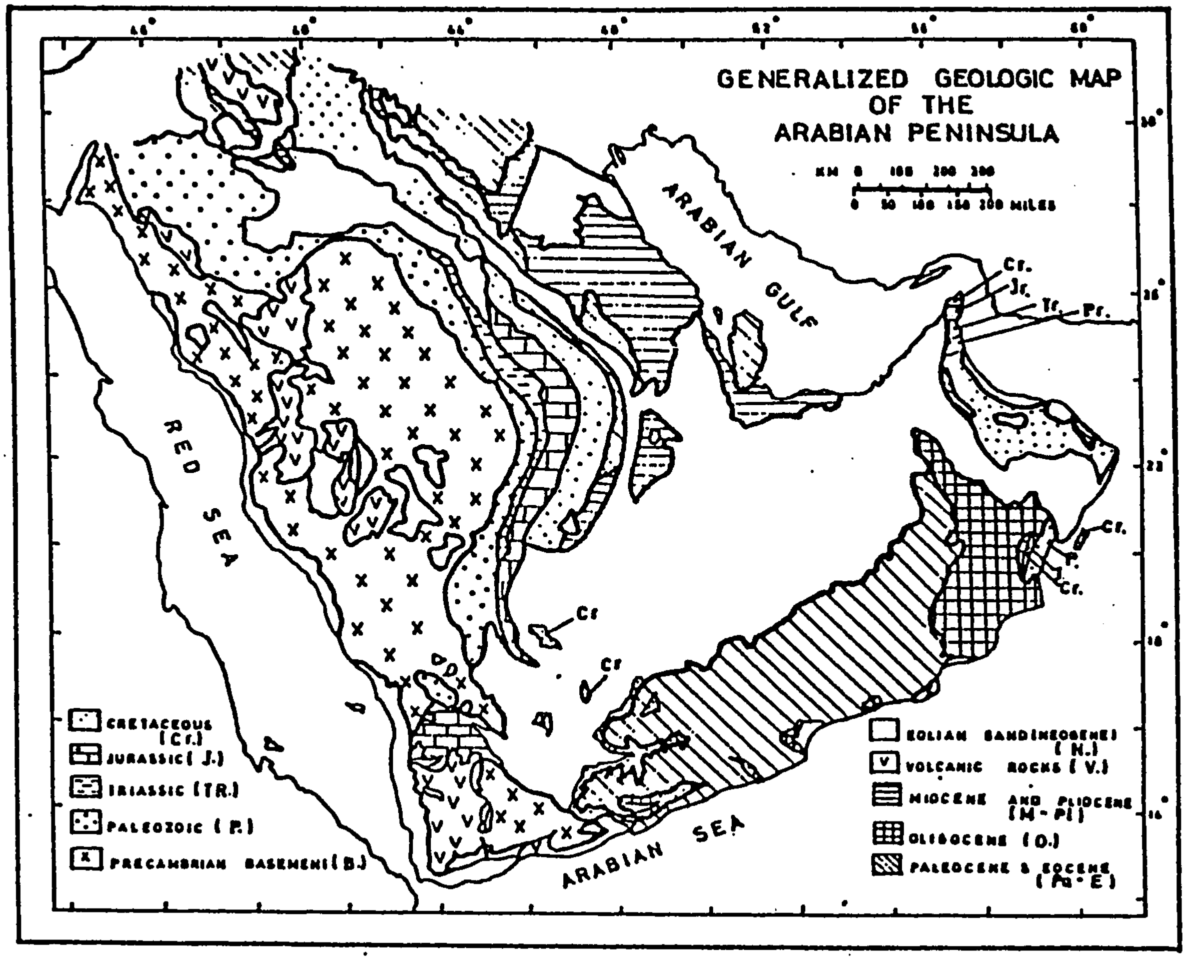
I.1 Location and geologic setting:

The Umm Gudair #1 Well (lat. 28° 55' 13.8" N and long. 47° 40' 34.5" E) was drilled in the northern tip of the Umm Gudair Oil Field which is situated across the border between Kuwait and the Kuwait / Saudi Arabia Divided Neutral Zone, (Text-Fig. 2). The Neutral Zone between both Saudi Arabia and Kuwait has already been divided between the two countries. Nevertheless, the usage of the name is kept in this thesis because it has been repeatedly mentioned in the geologic literature of Arabia. The area has a desert topography of relatively low relief, a gentle slope towards the Arabian Gulf, and outcropping rocks of Eocene to Holocene age that become progressively older towards the west and the southwest. This gradual ageing of the outcropping rocks towards the west continues (except where locally disturbed) untill the Pre-Cambrian rocks of the Arabian Shield which constitute most of the highlands of western and southwestern Arabia are reached (Text-Fig. 3). Generally speaking, the sedimentary rock units of Arabia dip gently towards the east, the northeast and the north (unless it is interrupted by a local structure). These are typically platform deposits that display all known facies from continental sediments and coastal sabkhas to open sea shelf and basinal deposits. However, the Arabian shelf experienced successive phases of extensional and compressive stresses that produced a number of intra-shelf troughs and swells. These were periodically reactivated or levelled out depending on both tectonics and the rates of sedimentation, and hence have seriously affected the pattern of sedimentation. On these basis, the Arabian Peninsula was subdivided into a number of tectono-sedimentational domains that controlled the pattern of deposition throughout the geologic history of the region (Text-Fig. 4). The Umm Gudair # 1 Well, which is the focus of the present study, was positioned in the interior platform of the Late Cretaceous sea over Arabia.

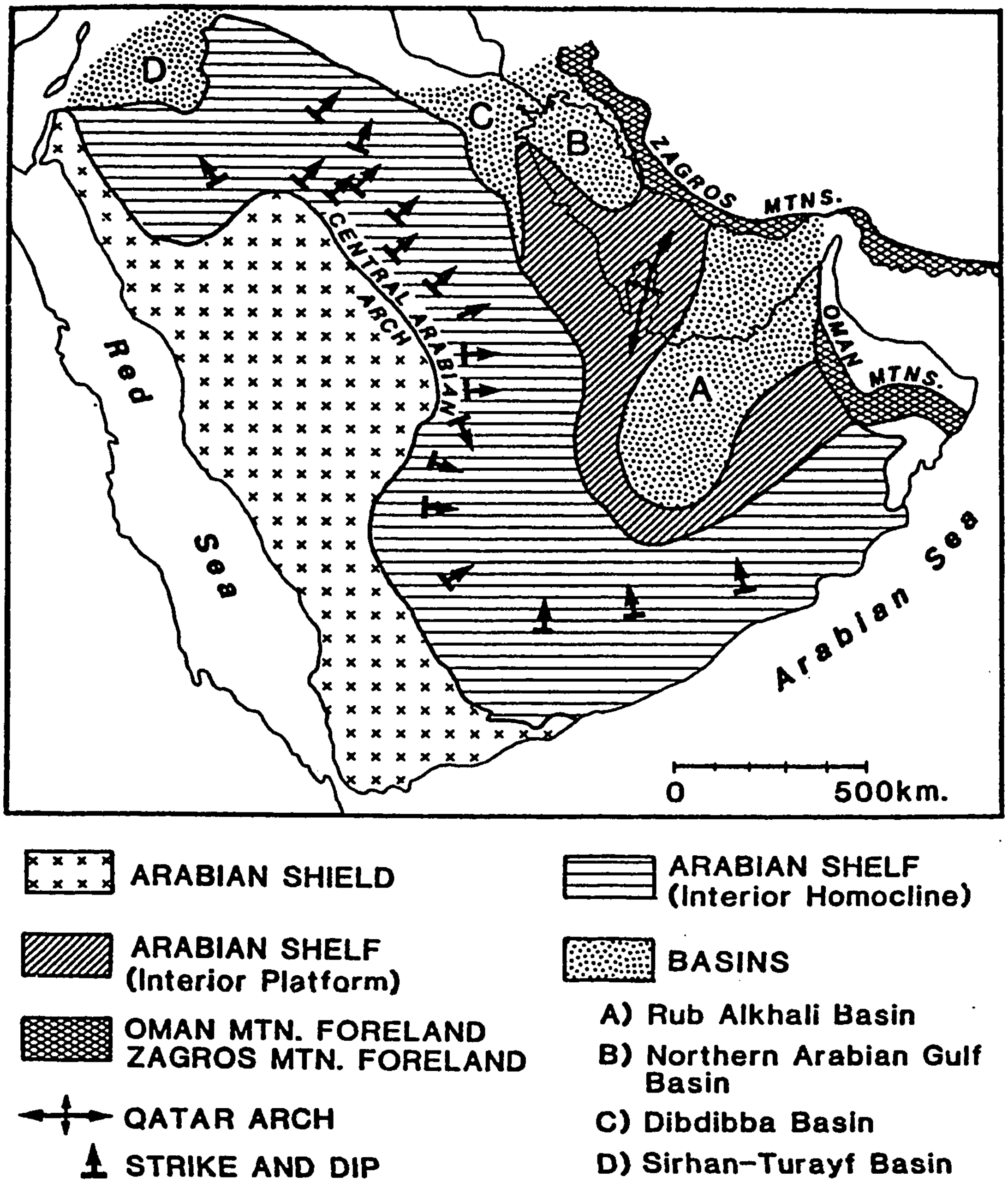
I.2 Studied Samples:

This study is based on 110 core samples that represent the Late Cretaceous succession in the Umm Gudair # 1 Well, southeastern Kuwait. The location of the samples and their general description are included in Text-Figure 5 and Table 1.

A number of samples, collected from the Wasi'a/Aruma contact at Khushaim Radhi, were also studied in thin section. These samples were found to be completely dolomitized, and hence, they could not be correlated with equivalent sequences in the subsurface of eastern Arabia, or with samples of the present study.



Text-Fig. 3: Generalized geologic map of Arabia.



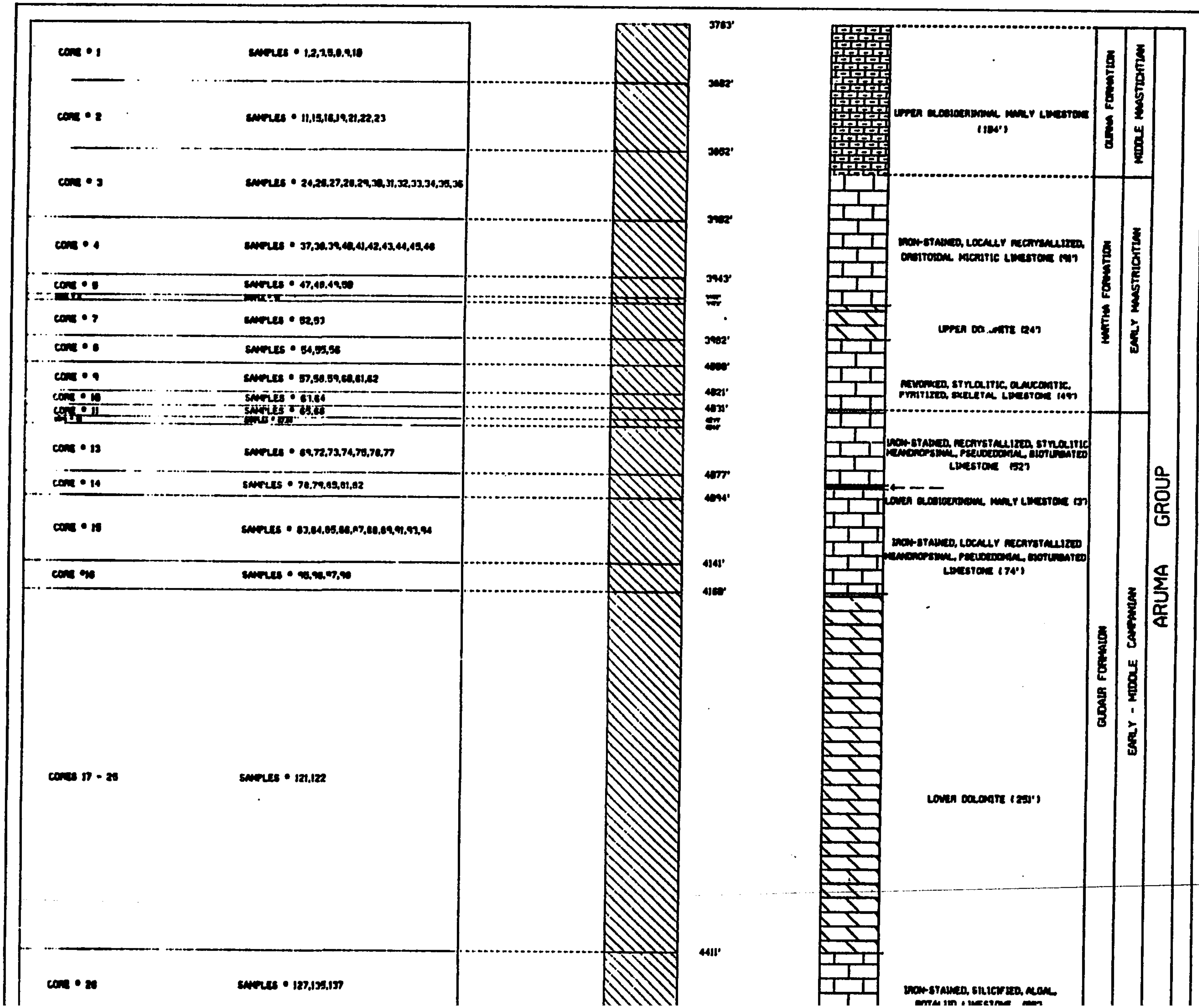
Text-Fig. 4: Tectono-stratigraphic elements of Arabia. (after Al-Sharhan and Nairn, 1986).

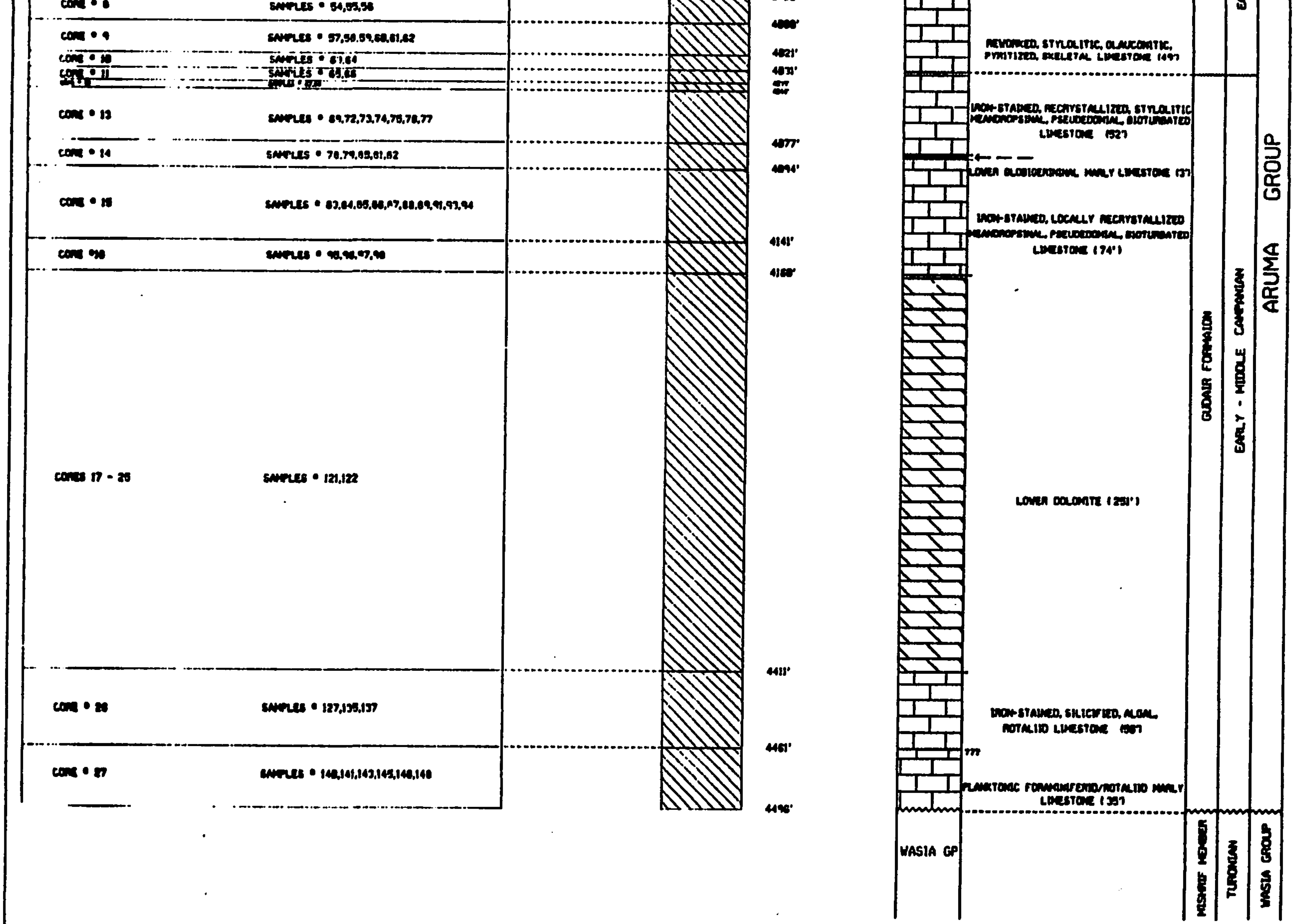
Table 1: Analyzed samples of the Late Cretaceous succession in the Umm Gudair#1 well

Core Sample #	Depth Interval	Description
1,2,3,5,8,9,10,11, 13,15,16,19,21,22, 23,24,26,27,28,29	3763'-3867'	globigerininal marly limestone (bioclastic wackestone to packstone) flooded by planktonic foraminferid remains.
30,31,32,33,34,35, 36,37,38,39,40,41, 42,42,43,44,45,46 47,48,49,50,51	3867'-3958'	bioclastic packstone to grainstone with interbedded wackestone intervals. The fauna include orbitoidal remains,corals,algae in addition to benthonic as well as planktonic foraminiferids. Recrystallization and iron staining are frequent.
52,53	3958'-3982'	iron-stained dolomite.
54,55,56,57,58,59, 60,61,63,64	3982'-4031'	bioclastic wackestone to packstone. Intensive reworking and iron-staining characterize this interval in addition to stylolites.
65,66,67,68,69,72, 73,74,75,76,77,78, 79	4031'-4083'	bioclastic wackestone to packstone, flooded by remains of *Pseudedomia* and other foraminiferid remains. this interval is characterized by recrystallization patches, sytlolites and frequent iron staining.

Table 1: (Cont.) Analyzed samples of the Late Cretaceous succession in the Umm Gudair#1 well

Core Sample #	Depth Interval	Description
80	4083'-4086'	globigerininal marly limestone (bioclastic wackestone to packstone) flooded by planktonic foraminiferids.
81,82,83,84,85,86, 87,88,89,91,93,94, 95,96,97,98	4086'-4160'	bioclastic wackestone to packstone, flooded by remains of *Pseudedomia* and other foraminiferid remains. Iron -staining and recrystallization are frequently observed.
121,122	4160'-4411'	dolomite and dolomitic limestones.
127,135,137	4411'-4461'	bioclastic wackestone to packstone, with signs of reworking (e.g silicification and iron staining), in addition to glauconite grains. Fauna include algal, echinodermal, ostracod and foraminiferid remains.
140,141,143,145, 146,148	4461'-4496'	bioclastic wackestone, occasionally marly and locally recrystallized. The bioclastic content includes planktonic and benthonic foraminiferids in addition to ostracod, echinodermal and pelecepod remains.


CORE # 1
SAMPLES # 1,2,3,5,8,9,10
CORE # 2
SAMPLES # 11,15,18,19,21,22,23
CORE # 3
SAMPLES # 24,26,27,28,29,30,31,32,33,34,35,36
CORE # 4
SAMPLES # 37,38,39,40,41,42,43,44,45,46
CORE # 5
SAMPLES # 47,48,49,50
CORE # 7
SAMPLES # 52,53
CORE # 8
SAMPLES # 54,55,56
CORE # 9
SAMPLES # 57,58,59,60,61,62
CORE # 10
SAMPLES # 61,64
CORE # 11
SAMPLES # 65,66
CORE # 13
SAMPLES # 69,72,73,74,75,76,77
CORE # 14
SAMPLES # 78,79,80,81,82
CORE # 15
SAMPLES # 83,84,85,86,87,88,89,91,93,94
CORE #16
SAMPLES # 95,96,97,98
CORES 17 - 25
SAMPLES # 121,122
CORE # 26
SAMPLES # 127,135,137
3783'
3882'
3882'
3902'
3943'
3982'
4000'
4021'
4031'
4077'
4094'
4141'
4168'
4411'
UPPER GLOBIGERINAL MARLY LIMESTONE (184')
IRON-STAINED, LOCALLY RECRYSTALLIZED, ORBITOIDAL MICRITIC LIMESTONE (91')
UPPER DO..ITE (24')
REWORKED, STYLOLITIC, GLAUCONITIC, PYRITIZED, SKELETAL LIMESTONE (49')
IRON-STAINED, RECRYSTALLIZED, STYLOLITIC MEANDROPSINAL, PSEUDEDOMIAL, BIOTURBATED LIMESTONE (52')
LOWER GLOBIGERINAL MARLY LIMESTONE (3')
IRON-STAINED, LOCALLY RECRYSTALLIZED MEANDROPSINAL, PSEUDEDOMIAL, BIOTURBATED LIMESTONE (74')
LOWER DOLOMITE (251')
IRON-STAINED, SILICIFIED, ALGAL,
GURNA FORMATION
MIDDLE MAASTICHTIAN
MARTHA FORMATION
EARLY MAASTRICHTIAN
GUDAIR FORMATION
EARLY - MIDDLE CAMPANIAN
ARUMA GROUP



TEXT-FIG. 5• STUDIED CORE SAMPLES OF THE LATE CRETACEOUS SUCCESSION IN THE UMM GUDAIR • 1 WELL

I.3 Previous Work

Published works on the Late Cretaceous rocks of Arabia are far behind expectations for such a key succession in the sedimentary history of the peninsula. These works range in nature from local to regional studies, and although both are reviewed here, it was found advisable to treat the local studies first, followed by regional ones which are remarkably few in number. The local studies are reviewed here in a geographical order so that they may be easily correlated.

I.3.1 Review of Previously Published Local Studies:

In Saudi Arabia :

The Late Cretaceous succession of central Arabia was first described by Burchfiel and Hoover under the name Aruma Formation in an unpublished report for the Arabian-American Oil Company (ARAMCO, now SAUDI ARAMCO) as early as 1935 (see Powers and others, 1966). The name was derived from Al-Armah Plateau which is a broad upland surface that forms the easternmost shoulder of the Najd escarpment, where rocks of this age outcrop in a belt more than 1600 km long, 20 - 200 km wide (increasing steadily in width from south to north) and over 140 m thick. Seventeen years later, the name was first published by Steineke and Bramkamp (1952) with essentially the same definition as originally described.

Thralls and Hasson (1956) included both the Aruma and the underlying Wasi'a Formations in their upper Cretaceous section, considered the Aruma to be of Campanian age, and correlated the Late Cretaceous surface section with its eastern subsurface equivalents.

Steineke and others (1958) suggested a Maastrichtian age for the Aruma Formation on the basis of both its micro- (foraminiferal) and macrofossil remains.

Powers and others (1966) composited a reference section for the Aruma Formation which they subdivided into smaller lithologic units. These authors (*op. cit.*) also observed a disconformity within the Aruma outcrop section. They considered the Aruma Formation to be of Campanian - Maastrichtian age, with a possible Santonian age for its lowermost part.

Powers (1968) correlated this composited reference section with its subsurface equivalents which he considered to be slightly more complete towards its base, and hence suggested that the subsurface basal Aruma could possibly be of Coniacian age. However, he (*op. cit.*) confirmed the presence of a stratigraphic break within the subsurface Aruma succession, but continued to treat it as a formation.

El-Asa'ad (1983 a,b) revised the stratigraphy of the Aruma Formation at several sites of its outcrop belt and introduced a composited reference section for this rock unit, which he zoned into 9 faunal assemblages that were taken to date the succession as Coniacian to late Maastrichtian.

In later publications, El-Asa'ad (1984,1986a,1986b,in press) studied several litho- and biostratigraphical aspects of the Aruma Formation, including its rudistid and coralline remains, the paleogeographic distribution of its fossil content and the paleo-environmental interpretation of some of its horizons.

Al-Furaih (1984,1986) described some ostracod remains from both surface and subsurface Aruma rocks, recognizing a number of new forms which were considered to be of Maastrichtian age.

In Southeastern Kuwait :

In a study for the stratigraphy of the Kuwait-Basrah area, Owen and Nasr (1958) raised the Aruma to group status, and described it to include (from top to bottom) the Tayarat, Bahrah (= both the Qurna and the Hartha) and Gudair Formations. A type section for each of these formations had already been chosen by operating oil companies in the region either in the outcrop or in the subsurface. Both the Tayarat and the Bahrah Formations were assigned a Maastrichtian age while the Gudair Formation was assigned a Senonian age despite the fact that Eames and Smout (1955) had already proposed a Campanian age for the latter formation. Owen and Nasr (1958) noted the presence of a major unconformity with varying magnitudes along the Middle / Late Cretaceous boundary of the drilled positive structures throughout the Kuwait - Basrah area.

In their study of the type Magwa Formation (Middle Cretaceous) in the Umm Gudair#1 Well, El-Naggar and Al-Rifaiy (1972 a,b, 1973) confirmed the unconfomable relationship between the Middle and Late Cretaceous rocks in the area.

In both northeastern Kuwait and southeastern Iraq :

Owen and Nasr (1958) divided the Aruma Group in the area into six formations that are Khasib (Early Senonian), Tanuma and Sa'di (Late Senonian), Hartha (Late Campanian -Maastrichtian), Qurna and Tayarat (Maastrichtian). The authors (*op. cit.*) included a type section for each of these formations which had already been chosen by operating oil companies in the region.

The ages of the introduced formations as well as their upper and lower contacts have been reviewed by a number of authors including Dunnington and others (1959), Al-Naqib (1967), Chatton and Hart (in Al Naqib, 1967) and Darmoin (1975).

In the kuwait / Saudi Arabia Divided Neutral Zone area :

In a study on the stratigraphy of the Wafra Field, Nelson (1968) subdivided the Late Cretaceous rocks into the Sa'di Formation (Senonian-Campanian) and the Hartha and the Tayarat Formations (Maastrichtian).

El-Naggar and Jaber (Ms.) criticized the informal subdivision of the Late Cretaceous rocks in the area that had already been proposed by Jaber (1965). These authors (

op. cit.) included in the Aruma Group (of the Divided Neutral Zone Offshore area) 3 formations that are "Zawre" (Coniacian - Campanian), Bahrah (Early - Middle Maastrichtian) and Tayarat (Late Maastrichtian). The new rock term "Zawre" was introduced to include the shaly sequences at the base of the Aruma Group in the Divided Neutral Zone Offshore area and was equated, on one side, with the Gudair Formation of southeastern Kuwait and on the other, with the Sa'di, Tanuma and Khasib Formations of both northeastern Kuwait and southeastern Iraq. A biostratigraphical zonation for the Late Cretaceous succession in the studied wells (across the Khafji structure) was included and the ages of the various rock units were interpreted. A detailed systematic description of the recorded microfossils was covered including 56 species and subspecies of the planktonic foraminiferal genera ***Globotruncana*, *Rugoglobigerina*, *Praeglobotruncana*, *Hedbergella*** and ***Globigernilloids***. Many of these planktonic foraminiferids were described for the first time in the region. The Middle / Late Cretaceous unconformity was emphasized and a Cretaceous / Paleogene break was suggested.

El-Naggar and El-Nakhal (1981, 1982, 1983a, 1983b, 1984, 1985a, 1985b and 1987) correlated the subsurface Late

Cretaceous succession in a number of wells across Kuwait. These authors (*op. cit.*) observed a marked decrease in the thickness of the Late Cretaceous succession from northern Kuwait towards the south which made it difficult to identify the several rock units, recognized in the subsurface of the northern Kuwait oil fields, in the south.

El-Naggar and El-Nakhal (*op. cit.*) proposed a biostratigraphical zonation for the analyzed Late Cretaceous succession based mainly on planktonic foraminiferid remains and concluded the ages of the respective rock units. A detailed systematic description of the recorded microfossils was covered including 9 genera and 96 species and subspecies, a number of which were new and most of which were described in the region for the first time. The Middle / Late Cretaceous as well as the Mesozoic / Cainozoic breaks in the region were also emphasized, and the sequence was both intra- and inter-regionally correlated.

I.3.2 Review of Previously Published Regional Studies

Kamen-kaye (1970) summarized the depositional history, diastrophism and structures of the Middle East sedimentary basins in an attempt to account for its great hydrocarbon potentialities. The author (*op. cit.*) included an isopach map for the Cretaceous succession in the region, showing an ovoid grain of shoaling conditions centered on the present Iranian shores of the Arabian Gulf, and emphasized the role of tectonic instability in the development of several stratigraphic features in such a succession.

A few years later, Saint-Marc (1978) reviewed the stratigraphy of the Mesozoic rocks across the Arabian Peninsula, stressing the fact that relatively more complete Late Cretaceous sequences can be located in depressions, bounded by positive highs over which such sequences are either reduced or even completely absent. This author (*op. cit.*) also emphasized the vast marine transgression during the Late Campanian - Maastrichtian time in the region and summarized the various facies belts deposited during such a transgression.

Using data from the operating oil companies in the region, Murris (1980) summarized the sedimentary history of the Middle East from the Permian to the Holocene through a number of facies maps. This author (*op. cit.*) regarded the Turonian in the region as the time of the very early beginnings of the Alpine Orogeny which had been manifested in the reactivation of the older structural elements that subsequently controlled the depositional framework during the Late Cretaceous time. The different facies belts that had developed during the time of deposition of the Late Cretaceous succession in the region were also summarized, starting with the foredeeps along the Zagros and Oman sutures and ending with shoreline and/or continental sediments deposited along the border of the positive Arabian Shield.

In an analysis of regional unconformities within the Cretaceous succession of the Arabian Peninsula and the depositional cycles bounded by them, Harris and others (1984) emphasized the three, previously recognized major unconformities during the Middle Aptian, the Turonian and at the end of the Cretaceous time. These authors (*op. cit.*) emphasized the economic importance of such unconformities on the basis of the fact that during episodes of subaerial exposure and erosion, carbonates usually develop appropriate reservoir characteristics through diagenesis. They also (

loc. cit.) correlated the interpreted sea level changes for the Cretaceous succession in southeastern Arabia with global sea level curves.

I.4 Present Status of the Problem :

Since the publication of its formal definition by Owen and Nasr (1958), the type Gudair Formation has not yet been studied in any detail. The problem is further complicated by the fact that the number of publications available on the Late Cretaceous succession of Arabia is remarkably few being mostly either of a very generalized or a very localized nature. No microfacies analysis has yet been attempted, despite the fact that these could have been instrumental in the verification of both litho- and biostratigraphical boundaries within the succession as well as in its correlation, in age and paleoenvirnmental interpretations and in the construction of facies models. Facies models can be used for the explanation of vertical as well as lateral relationships within the succession and hence can enhance our understanding of the sedimentary history of Arabia during the Late Cretaceous time.

II. STRATIGRAPHY OF THE LATE CRETACEOUS ROCKS IN ARABIA

The Late Cretaceous rocks in Arabia are predominantly composed of platform and shelf carbonates over most of the Peninsula that grade eastwards into deep water pelagic facies (*cf.* Koop and Stoneley, 1982). The tectonic instability that prevailed during the Late Cretaceous time due to subduction along the Zagros and Oman geosutures had greatly influenced the pattern of sedimentation. The reactivation of the intrashelf structural elements had resulted in truncations, thinning-outs and onlaps of the sediments across these structures and the deposition of deeper water sediments in the basins rimmed by the rising structures. Consequently, this has resulted in the deposition of varied lithologies and numerous rock units that are characterized by sharp thickness variations and complicated lateral relationships.

The stratigraphy of the Late Cretaceous rocks in Arabia has been briefly reviewed in a geographical framework. It was found advisable to treat the stratigraphy of each area in terms of the recognized rock units in that particular area. This is followed by a general view of the regional stratigraphy of the Late Cretaceous rocks across Arabia.

II.1 Stratigraphy of the Late Cretaceous rocks in Saudi Arabia

The outcropping Late Cretaceous section in central Saudi Arabia was first grouped under the term Aruma Formation by Burchfiel and Hoover (1935, see Powers and others, 1966). The name was derived from Al Armah Plateau which is a broad upland surface that forms the easternmost shoulder of the Najd Escarpment. In 1952, Steineke and Bramkamp had first published the term Aruma Formation with essentially the same original definition. Thralls and Hasson (1956), briefly described the newly defined formation and correlated it with its eastern subsurface equivalents. These authors (*op. cit.*) divided the Cretaceous succession into "Lower" and "Upper" Cretaceous only, and hence their Upper Cretaceous included both the Aruma and the underlying Wasia Formations. The type Aruma, described as being composed of limestones and shales of about 470' (143m) thick, was assigned a Campanian age while the type Wasia, which is mainly composed of sandstones and shales (with subordinate limestone) of about 140' (43m) thick, was said to be Cenomanian in age. Thralls and Hasson (1956) emphasized that the contact of the Aruma Formation with the underlying Wasia Formation is unconformable and they contrasted such contact with the upper contact of the Aruma with the overlying Um-er-Radhuma Formation which they mistakingly considered to be conformable.

Steineke and others (1958) studied the sections dealt with by Thralls and Hasson (1956) using foraminifera and other macrofossil remains for dating, on which basis, they assigned a Maastrichtian age to the Aruma Formation. They supported the idea of disconformable contact between the Aruma Formation and the underlying Wasia Formation while they did not mention the nature of the upper contact with the Umm-er-Radhuma Formation.

Powers and others (1966) introduced a reference section for the Aruma Formation that was composited from several sections measured in the vicinity of Khashm Khanasir (Lat. 25 38'12"N, long. 46 22'29"E). This composited section was subdivided into four lithologic units from top to bottom as follows :

4- Shale and dolomite	32.9m
3- Dolomite	27.6m

2- Limestone and shale	41m
1- Calcarenite	40m

According to Powers and others (1966), Roach, in an unpublished report suggested to group the four lithologic units into two members. The upper member, namely "the Lina Shaly Limestone Member" includes the upper shale and impure carbonates and is equivalent to the uppermost lithologic unit of Powers and others (1966). The lower member, namely "the Atj Limestone Member" includes the cleaner carbonate sequence of the underlying three lithologic units. Powers and others (*op. cit.*) stated that such a two-fold subdivision of the Aruma Formation in its type section can get acceptance as Redmond (unpublished work) described the contact between the two members as being disconformable. However, this subdivision was not formally adopted.

The main belt of the Aruma outcrop extends from Wadi al-Dawasir in the south to beyond the Saudi Arabian / Iraqi border in the north, a distance of more than 1600 km long (Text-Fig. 1). The strike of this belt swings occasionally as a reflection of the main structural elements along its course such as both the Central Arabian and the Hail Archs. The width of this outcrop belt is very erratic but generally increases northwards. In addition to this main belt, the Aruma or its lateral equivalents crops out in several areas, the most important of which is the outcrop along the northeastern margin of the Jauf-Skakah basin.

This huge extension of the Aruma outcrop exhibits facies changes southwards as well as northwards. South of Wadi As-Sahba, the Aruma Limestone gradually changes into sandstones untill it becomes totally replaced by an exclusively arenaceous facies in the vicinity of Wadi Jabaliyah. In the north, the Aruma outcrop in the Sirhan-Turayf area is characterized by a basal sandstone unit, namely the Zallum Sandstone, and an upper dolomitic limestone and dolomite unit.

Powers and others (1966) introduced a list with the fossil content of the Aruma Formation at its type locality, and on the basis of this they assigned the Aruma Formation a Campanian-Maastrichtian age. Worthy of mention in this fossil content was the presence of ***Monolepidorbis sanctae-pelagiae*** Astre in the lower part, and of both ***Omphalocyclus macroporus*** Lamarck and ***Orbitoides gensascicus*** Leymerie in the upper part. However, the possibility of a Santonian age for the lowermost part of the Aruma unit was not excluded on the basis of the presence of ***Meandropsina vidali*** Schlumberger.

Powers (1968) recognized an extensive stratigraphic break in the subsurface Aruma section east of the outcrop belt, thus, he subdivided the Aruma there into "Upper Aruma" and "Lower Aruma". The "Upper Aruma" was considered to be the lateral equivalent of the upper three lithologic units in the type section, while the "Lower Aruma" was partly correlated with the basal lithologic unit. Powers (1968) introduced a list of diagnostic foraminiferids that characterize each of the four lithologic units as follows :

Upper Aruma :

Unit 4 - ***Elphidiella multiscissurata*** Smout, ***Fissoelphidium operculiferum*** Smout, ***Omphalocyclus macroporus*** Lamarck, ***Loftusia sp.,*** ***Minouxi steineki*** Redmond, ***Glyphostomelloides globosus*** Redmond, ***Arumella ornata*** Redmond and ***Fissoelphidium nastum*** Redmond.

Unit 3 - ***Lepidorbitoides spp.,*** ***Chrysalidina hensoni*** Redmond, ***Glaessnerella cretacica*** Redmond, ***Messinaella vesta*** Redmond, ***Loeblichella gallowayi*** Redmond and ***Cryptoglymphs arabicus*** Redmond.

Unit 2 - Preservation is poor but it probably carries ***Orbitoides gensacicus*** Leymeric and the lowest occurance of ***Omphalocyclus macroporus.***

Lower Aruma :

Unit 1 - ***Monolepidorbis sanctaepelagiae*** Astre in the upper part, ***Rotalia trochidiformis*** Lamarck and ***Meandropsina vidali*** Schlumberger.

Powers (1968) related the eastward increase in the thickness of the "Aruma Formation" in the subsurface (which attains 2200' (670m) on the flanks of the Abu Hadriya structure) to both the normal basinward increase in thickness as well as the addition of bottom beds in the subsurface which are older than any of the exposed beds. These bottom limestone beds were assigned a Santonian age at the Safaniya Oil Field because of the presence of ***Kathina sp*** and ***Cosinella sp.*** The upper part of the Lower Aruma in the subsurface was described as characterized by the presence of some planktonic foraminiferids that include ***Globotruncana calcarata*** Cushman, ***Globotruncana sp. cf. G. elevata*** and ***G. fornicata***, despite the fact that ***G. calcarata*** has been taken as a zonal marker for the latest Campanian.

Powers (1968) noted the presence of a basal shale interval throughout most of the coastal wells. The upper beds of this shale were considered to be as old as Coniacian in age because of the presence of ***Planoglobulina sp.*** while the age of the lower part of this basal interval is still doubtful.

El-Asa'ad (1983a,b) revised the stratigraphy of the outcropping Aruma rocks, where these were subdivided into three stratigraphic units from top to bottom as follows :

1- The Khanasir Limestone Member which is mainly composed of nodular limestone and is considered to be the equivalent of the informal lower Atj Member of Powers and others (1966).

2- The Hajajah Limestone Member which is composed of shale overlain by slightly dolomitic chalky limestone followed upwards by highly dolomitic limestone, and is equated with the informal middle and upper Atj Member of Powers and others (*op. cit.*).

3- The Lina Shale Member which was kept as originally introduced by Powers and others (1966) as the uppermost unit of the outcropping Aruma succession. El-Asa'ad (1983a,b) composited a reference section for the Aruma Formation (163 m) after the study of its outcrop in seven localities along the Armah escarpment and noted the unconformity at the Aruma / Wasia contact. El-Asa'ad (*op. cit.*) considered the Aruma contact with the overlying Umm-er-Radhuma Formation to be conformable despite the fact that he had recorded the presence of thin conglomeratic beds along the contact in some localities in addition to the overstepping nature of the Umm-er-Radhuma rocks in some other localities.

Biostratigraphically, El-Asa'ad (1983b) suggested the subdivision of the Aruma succession into 9 faunal zones on the basis of the recorded macrofossils as well as larger foraminiferids as follows :

9- The ***Omphalocyclus macroporus / Fissoelphidium operculiferum*** Assemblage Zone (Late Maastrichtian).

8- The ***Spondylus / Cymatoceras*** Assemblage Zone (Maastrichtian)

7- The ***Orbitoides / Lepidorbitoides*** Assemblage Zone (Maastrichtian)

6- The ***Cyclolites*** Assemblage Zone (Early Maastrichtian)

5- The ***Gryphaea*** Assemblage Zone (Campanian - Early Maastrichtian)

4- The ***Cardium / Protocardium*** Assemblage Zone = The ***Monolepidorbis sanctae pelagiae / orbitoides tissoti*** Local Range Zone (Campanian)

3- The ***Sphaerulites / Biradiolites*** Assemblage Zone (Santonian)

2- The ***Lopha / Ostrea*** Assemblage Zone (Santonian)

1- The ***Tissotia*** Assemblage Zone (Coniacian)

The paleogeographic distribution of these fossils was studied by El-Asa'ad (1984) where he proved the presence of strong faunal links with northern Africa during the Turonian - ?Coniacian time and with both Iran and southern India during the Santonian. The Maastrichtian fauna of the Aruma rocks however, was recognized along a wide geographic extension that starts from northern India, Afghanistan, Pakistan, Iran, Baluchistan and Iraq on the east, and extends westwards into northern Africa, Spain and Portugal.

El-Asa'ad (1986a) studied the origin and paleoenvironment of the nodular limestones that form the bulk of the Khanasir Limestone Member, and attributed these to bioturbation and mottling textures where early diagenetic marly dolomites filled in burrows, mud-cracks and fractures. The paleoenvironment of this basal part of the Khanasir Limestone Member was interpreted to have been subtidal in the south, supratidal and intertidal-supratidal in the central part and intertidal-supratidal in the north. Postdepositional dolomitization in subaerial conditions was noticed and the paleoclimate was inferred to have been either humid or semiarid due to the absence of evaporites in the sequence (*cf.* El-Asa'ad, *op. cit.*).

The rudist fauna at the top of the Khanasir Limestone

Member was also studied by El-Asa'ad (1986b), where he concluded that the early diagenetic cementation of the underlying nodular limestone might have provided suitable hardgrounds for the rudist to grow on either solitary or in the form of biostrome builders. Consequently, the paleoenvironment of this interval was interpreted to have varied from shallow, inner sublittoral, warm marine shelf for the biostrome builders to open marine shelf with quieter water conditions for the solitary ones.

El-Asa'ad (1986b) introduced the name "*Durania* Assemblage Zone" for the Santonian rudist fossil assemblage instead of the earlier name " ***Sphaerulites / Biradiolites*** Assemblage Zone" of El-Asa'ad (1982b).

Corals of the Hajajah Limestone Member, represented by the *Cyclolites* Assemblage Zone of El-Asa'ad (1982b) were studied by the same author (in press) who described eight species of the Genus *Cuniolites* Barrere.

Al-Furaih (1984, 1986) studied the ostracods of the Aruma succession in both surface and subsurface sections. He introduced a number of Maastrichtian ostracods that reflect primarily shallow water conditions.

II.2 Stratigraphy of the Late Cretaceous rocks in southeastern Kuwait

Owen and Nasr (1958) studied the stratigraphy of the Kuwait - Basrah area, using subsurface data from mainly crestal wells as exploration at that time was directed to positive structures. These authors (*op. cit.*) considered the Kuwait - Basrah area to have represented an intermediate shelf environment between the Arabian geosyncline to the northeast and the Arabian massive to the southwest at least since the Triassic. They raised the Aruma to Group status and included in it the following formations (from top to bottom): the Tayarat, Bahrah and Gudair Formations.

The Tayarat Formation :

The type section of the Tayarat Formation was taken at Jabel Tayarat, southwestern Iraq, where it was described to be composed of 98' (30m) of dolomitized and locally sandy limestone. It overlies unconformably th Cenomanian M'sad Formation, but, generally, it is uncovered and incomplete. The formation was assigned a Maastrichtian age on the basis of the presence of ***Loftusia morgani*** Dourillee and ***Omphalocyclus macroporus*** Lamarck (*cf.* Dunnington and others, 1959, Al-

Naqib, 1967).

In the subsurface, a reference section was chosen for the Tayarat Formation in the Burgan Well#10, between the drilled depths 2640 feet and 3095 feet (*cf.* Owen and Nasr, 1958). There, the formation is composed of dolomitic, locally anhydritic limestone with minor bituminous shale interbeds. The formation, was described to have contacts with both the overlying Umm-er-Radhuma and the underlying Bahrah Formations, and was assigned a Late Maastrichtian age on the basis of the presence of ***Lepidorbitoides sp., Loftusia sp.*** and ***Omphalocyclus macroporus.***

The Bahrah Formation :

The type section of the Bahrah Formation was taken in the Burgan Well#10, between the drilled depths 3095 feet and 3440 feet (*cf.* Owen and Nasr, 1958). The type Bahrah was said to comprise two members; an upper microcrystalline, slightly cherty limestone member (270' or 82m thick) and a lower one composed of detrital and oolitic limestone with interbedded black shales (75' or 23m thick). Owen and Nasr (*op. cit.*) noted the variable thickness of the lower member in the area and related it to the irregular paleotopography prior to its deposition. The Bahrah Formation which is disconformably underlain by the Gudair Formation, was assigned a Maastrichtian age on the basis of the presence of ***Globotruncana spp.*** in the upper member in addition to ***Omphalocyclus macroporus*** in the shaly interbeds of the lower member.

The two members of the type Bahrah were considered as equivalents of the Hartha and Qurna Formations of southern Iraq and were taken as supplementary reference sections for them (*cf.* Dunnington and others, 1959).

The Gudair Formation :

The type section of the Gudair Formation was chosen by Owen and Nasr (1958) to be in the Umm Gudair#1 Well, at the drilled depths 4045 feet and 4505 feet, (460' or 140m thick). The formation was described to be composed of detrital locally glauconitic limestone with few shaly horizons, and its detrital nature together with its variable thickness were interpreted as reflecting syn-depositional deformation. The Gudair Limestone was assigned a Senonian age by Owen and Nasr (1958) although Eames and Smout (1955) had already proposed a Campanian age for the whole formation on the basis of the presence of *Pseudedomia sp.*, *Rotalia skourensis* Pfender and *Archaecyclus sp.*

Owen and Nasr (1958) suggested that the Gudair Formation in the Burgan-Magwa-Ahmadi structures may be equivalent to most of the Hartha and the upper Sa'di Formations of southeastern Iraq, with the lower part of the Sa'di and the underlying Tanuma and Khasib Formations of Iraq being absent through progressive overlap against these highs, as the thickness of the Gudair Formation is reduced to 50' (15m) over the axis of the Burgan structure.

The lower contact of the Gudair Limestone with the underlying Middle Cretaceous succession has been described as being unconformable (*cf.* Owen and Nasr, 1958, El-Naggar and Al-Rifaiy, 1972a and many other authors). El-Naggar and Al-Rifaiy (1972a,b, 1973) substantiated the unconformable relationship between the Gudair Formation and the underlying Mishrif Limestone Member (upper member of the Magwa Formation) by a number of evidences including the marked shallowing of facies in the upper part of the Mishrif, the absence of the charophyte-bearing, fresh water, limonitic limestone of the Mishrif Member in the overlying Gudair Formation, the brecciated nature of the uppermost Mishrif with shaly infillings, worm tracks and pyrite bands in addition to the abundant glauconitic grains in the basal part of the Gudair Limestone.

II.3 The stratigraphy of the Late Cretaceous rocks in both northeastern Kuwait and southeastern Iraq.

Owen and Nasr (1958) divided the Aruma Group here into six formations that are (from top to bottom): The Tayarat, Qurna, Hartha, Sa'di, Tanuma and Khasib Formations. These were correlated with coeval sections in southeastern Kuwait on the basis of the fact that the Tayarat Formation is used in both areas, of the equation of both the Qurna and Hartha Formations with the upper and lower members of the Bahrah Formation and of the equation -at least in part- of the Sa'di, Tanuma and Khasib Formations with the Gudair Formation.

The Qurna Formation:

The type section of the Qurna Formation was taken in the Zubair Well#3 between the drilled depths 5210 feet and 5990 feet where it is composed of locally dolomitic, globigerininal marl with some marly limestone interbeds. Owen and Nasr (*op. cit.*) assigned this formation a Late Maastrichtian age on the basis of the presence of a rich microfossil assemblage including, ***Nodosarina sp., Globotruncana spp., Cristellaria sp., Gyrodina naranjoensis*** White , ***Marsonella oxycona*** Reuss , ***Bolivina incrassata*** Reuss , ***Buliminella laevis*** and ***Bolivinoides draco*** Marsson.

However, on the basis of its planktonic foraminiferid content, Darmoin (1975) equated the Qurna Formation with the ***Globotruncana gansseri*** Zone, and hence, he assigned it a Middle Maastrichtian age. Again, while the Qurna Formation was described by Owen and Nasr (1958) to range in thickness between 250' (76m) to 450' (137m) in the area, and to overlie the Hartha Formation disconformably, Chatton (in Al-Naqib, 1967) regarded this contact as being conformable.

The Qurna Formation is equivalent to the Shiranish Formation whose type locality occurs in northern Iraq where it is represented by 750' (229m) of globigerininal marl. The Shiranish Formation is overlain unconformably by the Paleocene - Early Eocene Aaliji Formation and underlain unconformably by the Late Campanian, Bekhme Limestone.

The Hartha Formation:

The type section of the Hartha Formation is in the Zubair Well#3, at the drilled depths 5590 and 6013 feet where it is composed of organic, detrital, glauconitic limestone with interbedded marls and green shales. The Hartha Formation was assigned a Late Campanian - Maastrichtian age on the basis of its fossil content which includes: ***Cosinella* sp.**, ***Valvulammina* sp.**, ***Ammobaculites* sp.**, ***Monolepidorbis* sp.**, ***Pseudedomia cf. complanata*** Eames and Smout and ***Globotruncana cf. stuarti*** de Lapparent (*cf.* Owen and Nasr, 1958). Darmoin (1975) supported this age determination of the Hartha Formation on the basis of its stratigraphic position. The Hartha Formation, whose thickness was reported to decrease to 370' (113m) in the Basrah Oil Fields, was described to overlie conformably the Sa'di Formation but to be unconformably overlain by the Qurna Marl. However, the lower contact of the Hartha with the Sa'di Formation was reported as being unconformable by Dunnington and others (1959), and such break can be correlated with the disconformable contact between the Gudair Formation and the lower member of the overlying Bahrah Formation in southeastern Kuwait.

The Sa'di Formation:

The type section of the Sa'di Formation is in the Zubair Well#3 between the drilled depths 6013 and 6943 feet where it is composed of chalky, marly, globigerininal limestone with relicts of many foraminiferid genera such as : *Nodosaria, Palmula, Marginulina, Cristellaria, Globotruncana, Heterohelix,* etc. This formation, whose thickness varies considerably from 315' (96m) to 1279' (390m), was assigned a Late Senonian age by Owen and Nasr (1958). However, Al-Naqib (1967) considered the formation to be of Santonian to Early Campanian age on the basis of the presence of *Globotruncana* including *G. angusticarinata* Gandolfi, *G. fornicata* Plummer, *G. lapparenti lapparenti* Brotzen, *G. lapparenti coronata* Bolli, *G. sigali* Reichel, *G. marginata* Reuss, and *G. concovata* Brotzen. A third opinion, by Chatton and Hart (in Al-Naqib, 1967) suggested a Late Coniacian - Early Campanian age regarding the presence of *G. concovata.* Darmoin (1975) in his biostratigraphic zonation of the Late Cretaceous of southeastern Iraq, considered the Sa'di Formation to be equivalent to three biostratigraphic zones that are (from top to bottom): *Globotruncana stuartiformis/G. stephensoni, G. fornicata* and *G. concovata* Zones. These reflect a Santonian to Early Campanian age, thus, supporting the former results of

Al-Naqib (1967).

The Tanuma Formation:

The type section of the Tanuma Formation was taken in the Zubair Well#3, at the drilled depths 6943 and 7040 feet where it is composed of black shale and intercalating detrital limestone streaks. The Tanuma Formation was assigned a Late Senonian age by Owen and Nasr (1958) on the basis of its fossil content that includes: ***Monolepidorbis sp.*, *Globotruncana sp.*, *Cristellaria sp.*,** ostracod and bryozoan remains. However, Dunnington and others (***op. cit.***) interpreted the fossil content as indicating a Late Campanian age, while Chatton and Hart (in Al-Naqib, 1967) suggested a Late Coniacian age for the formation. This latter opinion was supported by both El-Naggar and Jaber (Ms) and Darmoin (1975). Al-Naqib (1967) tried to explain the disagreement about the age of the Tanuma Formation as being due to the diachronous nature of the formation.

Owen and Nasr (1958) described the contacts of the Tanuma Formation with the overlying Sa'di and underlying Khasib Formations as being conformable, and these three formations were considered by Dunnington (***op. cit.***) to be the northern and basinward equivalents of the Gudair Formation of southeastern Kuwait.

The Khasib Formation:

The type section of the Khasib Formation is in the Zubair Well#3 between the drilled depths 7040 and 7204 feet where the upper 95' (29m) are composed of fine grained, marly limestone while the lower 69' (21m) are mainly composed of alternating shales and limestones.

Owen and Nasr (1958) interpreted the fossil association of the Khasib Formation, that includes ***Globigerina sp.*** (= ***Hedbergella sp.***), ***Heterohelix sp.***, oligostegerinal remains, as indicating an early Senonian age. However, Dunnington and others (1959) assigned the Khasib Formation a Late Campanian age on the basis of the presence of ***Globotruncana lapparenti*** and *G. **leupoldi*** Bolli in the Zubair Well#1 and the presence of *G. **staurti*** de Lapparent in the Nahr Omar Well#1. Chatton and Hart (in Al-Naqib, 1967) considered the Khasib Formation as being of Middle Turonian - Early Coniacian age regarding its stratigraphic position. In a later publication, Dunnington (1967) considered the age of the Khasib to be Turonian, suggesting that his earlier results were based on contaminated fossils from the overlying formations.

The contact between the Khasib Formation and the underlying Middle Cretaceous - Mishrif Formation was considered to be conformable by Owen and Nasr (1958) who stated that this contact is prominently unconformable in southern Kuwait, but such a break dies out northwards towards the Basrah area. However, Dunnington and others (1959) interpreted the facies change from the limonitized algal limestone of the Mishrif Formation to the globigerininal marly limestone of the overlying Khasib Formation as strongly indicating non-sequence and an emergent episode that resulted in the truncation of the Mishrif Formation at various degrees.

Al-Naqib (1967) supported the idea of an unconformity between the Khasib Limestone and the underlying Mishrif Formation. He noticed that this unconformity is reflected in the thinning out of sediments in addition to the presence of fresh-water, limonitic, charid-bearing limestone at the top of the Mishrif, which is overlain by the transgressive Late Cretaceous Khasib Formation.

Darmoin (1975) correlated the upper part of the Khasib Limestone as well as the whole of the Tanuma Formation with the *Globotruncana renzi* Zone which he assigned a Coniacian age.

II.4 Stratigraphy of the Late Cretaceous rocks in the Kuwait - Saudi Arabia Divided Neutral Zone (both offshore and onshore)

The Tayarat Formation:

In the Wafra Field, Nelson (1968) described the Tayarat Formation as a unit of alternating limestones and shales of 700'-800' (or 213m-244m) in thickness. He subdivided the formation informally into five stratigraphic horizons that are , in descending order, the "First Maastrichtian Shale", the "First Maastrichtian Limestone", the "Second Maastrichtian Shale", the "Second Maastrichtian Limestone" and the lowermost "Maastrichtian B Zone". The shaly units, each of them is 20'-60' (6m-18m) thick, are black to grey in color with varying amounts of limy partings and some pyrite. The limestone interbeds, that range in thickness between 90'-200' (27m-61m), are tan to grey, generally granular but partly fine to medium crystalline or vuggy in some areas.

The basal "Maastrichtian B Zone" is a marly limestone sequence of 200' (61m) or more in thickness. However, as El-Naggar and Jaber (Ms) remarked, the basal unit can be correlated -at least in part- with the Qurna Marl.

The Tayarat Formation was studied by El-Naggar and Jaber (*op. cit*) in the Zawre Well#1 which is a flank well in the Zawre structure. The formation there, attains a thickness of 1130' (344m) and is composed of shallow water limestone which is impure in the upper part (interbedded with shales and dolomites) and pure in the lower part (skeletal limestone). These two distinctive facies have also been recognized in the Khafji wells studied by El-Naggar and Jaber (Ms). The argillaceous horizons in the upper impure limestone as well as the lower pure limestone are richly fossiliferous with abundant remains of larger and smaller foraminiferids, ostracods, algae and other macrofossil debris but planktonics are almost absent. El-Naggar and Jaber (*op. cit.*) assigned the Tayarat Formation a Late Maastrichtian age and considered its contact with the underlying Bahrah Formation to be conformable, while its upper contact with the Umm-er-Radhuma Formation was said to be paraconformable as the shallow facies on both sides of the contact obscures the recognition of the world-wide unconformity at the Mesozoic/Cainozoic contact.

The Bahrah Formation:

In a preliminary study, of the Middle and Upper Cretaceous rocks in the Khafji Oil Field, Jaber (1965) proposed the informal name " *Lepidorbitoides* Limestone" which has been equated later by both Jaber and Loutfi (1970) and El-Naggar and Jaber (Ms) to both the Bahrah Formation and the lower pure limestone part of the Tayarat Formation. According to Jaber (1965), this horizon contains *Lepidorbitoides sp.*, *Fissoelphidium sp.* and *Rotalia skourensis* Pfender and can thus be assigned a Maastrichtian age.

Nelson (1968), in his study of the Wafra Field, described the Hartha Formation as a unit of shaly and detrital limestone of 50'-100' (15m-30m) in thickness which unconformably overlies the Sa'di Formation. It contains *Lepidorbitoides sp.* and is thus assigned a Maastrichtian age.

El-Naggar and Jaber (Ms) subdivided the Bahrah Formation in the area of the Zawre and Khafji Oil Fields into an upper Qurna Limestone Member and a lower Hartha Limestone Member. In the Zawre Well#1 the Qurna Member is composed of 240'

(73m) of light grey , compact, locally cherty, dolomitic, micritic limestone with about 50' (15m) of brown marl at its base. This basal marl is rich in lagenids and planktonic foraminiferids that include : *Rugoglobigerina* (*R.*) *hexacamerata* Bronnimann, *R.* (*R.*) *macrocephala* Bronnimann, *R.*(*R.*) *ornata* Bronnimann, *R.*(*R.*) *pustulata* Bronnimann, *R.*(*R.*) *rugosa* Plummer; *Globotruncana* (*G.*) *arca* Cushman, *G.*(*G.*) *gansseri gansseri* Bolli, *G.*(*G.*) *adamsi* El-Naggar, *G.*(*G.*) *stuarti stuarti* de Lapparent, *G.*(*G.*) *fornicata fornicata* Plummer, *G.*(*G.*) *aegyptiaca aegyptiaca* Nakkady, *G.*(*G.*) *gagnebini* Tilev, *G.*(*G.*) *nothi* Bronnimann and Brown, *G.*(*G.*) *austinensis* Gandolfi and *G.*(*G.*) *trinidadensis* Gandolfi. El-Naggar and Jaber (*op. cit.*) interpreted the facies of the Qurna Limestone Member as reflecting deposition in deep water conditions of the outer shelf zone. In the Khafji Wells, the thickness of the Qurna Member is reduced to 40'-60' (12m-18m) that are made up of dolomitic and micritic limestone. The absence of the basal marly horizon as well as of a large part of the overlying limestone in the Khafji Wells indicates a break between the Qurna and the underlying Hartha Limestone Members. On the basis of both stratigraphic position and fossil content, the former member was assigned to the Middle Maastrichtian, while the latter was considered to be of Early Maastrichtian age.

According to El-Naggar and Jaber (Ms) the Hartha Limestone Member in the Zawre Well#1 is composed of 380' (116m) of light grey and creamy, pyritic, glauconitic, detrital and oolitic limestone with subordinate black shale interbeds. Although planktonic foraminiferids were not recorded in analyzed rock samples from the Hartha Member, its rich benthonic foraminiferids were described to include: ***Fissoelphidium* sp., *Goupilaudina dagnini*** Marie, ***Loftusia* spp., *Pseudosiderolites* sp., *Rotalia* spp., *Omphalocyclus macroporus*, *Orbitoides* sp.,** algae and other macrofossil debris. In the Khafji crestal wells, the thickness of the Hartha Member is reduced to 40'-90' (12m-27m) of the same facies with evidence of truncation at its top and onlap convergence against the Khafji structural high at its base.

Equivalents to the Gudair Formation:

Jaber (1965) subdivided the Middle - Late Cretaceous rocks in the Khafji Oil Field using a crestal and a flank well into informal horizons since, at that early time, the correlation between these rocks and their equivalents in nearby areas was not established yet. Later, El-Naggar and

Jaber (Ms) criticized that subdivision and related it to the regional stratigraphic divisions in the area. They equated the "Lower Aruma Shale" horizon to the shaly part of the Gudair Formation, while the "intercalated Limestone" horizon was equated to the lowermost part of the Gudair Formation. The formation was described to be very rich in planktonic foraminiferids including ***Globotruncana elevata*** Brotzen, ***G. stuarti stuartiformis*** Dalbiez, ***G. ventricosa*** White, ***G. gagnebini*** Tilev and ***G. aegyptiaca aegyptiaca*** Nakkady in addition to ***Rugoglobigerina*** and ***Hedbergella*** species. Benthonic foraminiferids were also reported to be represented by ***Bolivinoides decoratus decoratus*** Jones, ***B. decoratus austrialis*** Edgell and many others that, together with the planktonic forms constitute a fossil association of Santonian - Campanian age.

In his study of the Late Cretaceous rocks of the Wafra Oil Field, Nelson (1968) equated the Gudair Limestone (which is composed of 0'-70' (0m-21m) feet of glauconitic, detrital limestone with sand and shale lenses) with the Sa'di Formation of southeastern Iraq, and assigned it a Senonian - Campanian age on the basis of its planktonic foraminiferid content. The formation was described to be bounded by unconformities, of which the basal (the Wasia/Aruma

Unconformity) is most pronounced and increases in magnitude in the central and southern parts of the field.

El-Naggar and Jaber (Ms) proposed the term "Zawre Formation" to include the shaly sequences at the base of the Aruma Group in the Divided Neutral Zone Offshore Area. This formation was considered to be equivalent to the Gudair Formation of southern Kuwait and to the Sa'di, Tanuma and Khasib Formations of both northeastern Kuwait and southeastern Iraq. The type section of the Zawre Formation was chosen between the drilled depths 5470 and 5710 feet in the Zawre Well#1. The formation was described to be composed of dominantly grey, highly calcareous shale and shaly marls, with abundant planktonic and benthonic foraminiferids which give a Coniacian to Campanian age. The planktonic formaniferids include: *Globotruncana* (*G.*) *angusticarinata*, *G.*(*G.*) *arca*, *G.*(*G.*) *concovata*, (*G.*(*G.*) *coronata*, *G.*(*G.*) *elevata*, *G.*(*G.*) *fornicata fornicata*, *G.*(*G.*) *fornicata manaurensis*, *G.*(*G.*) *hilli*, *G.*(*G.*) *lapparenti*, *G.*(*G.*) *linneiana*, *G.*(*G.*) *marginata*, *G.*(*G.*) *pierrei*, *G.*(*G.*) *renzi*, *G.*(*G.*) *schneegansi*, *G.*(*G.*) *stuarti*, *G.*(*G.*) *sublaevigata* Marie and *G.*(*G.*) *ventricosa*; *Rugoglobigerina* (*R.*) *tradinghousensis*; *Praeglobotruncana hagni* Scheibnerova, *P. imbricata* Mornod, and *P. pseudolinneiana* Pessagno in addition to other species that belong to the planktonic genera *Hedbergella, Heterohelix, Pseudoguemblina, Gublerina* and *Ventilabrella*. The benthonic foraminiferids include the genera *Alabamina, Bolivinoides, Cibicides, Dentalina, Gavelinella, Gyroidionoides, Lenticulina, Nodosaria, Praebulimina, Vaginulina, Vaginulinopsis* and *Vavulineria*.

The contact between the Zawre Formation (=Gudair Limestone) and the overlying Hartha Limestone Member was considered to be disconformable due to the absence of the *Globotruncana calcarata* Zone which has been taken to represent the latest Campanian. This was also supported by the abrupt facies change across this contact, from globigerininal shales below to shallow-water, detrital, reefal limestone above.

The lower contact of the Zawre Formation with the underlying Mishrif Limestone Member was considered to be unconformable due to the sudden facies change from the shallow-water facies of the limonitized , algal/miliolid limestones of the Mishrif Member, to the deep-water, globigerininal shales of the overlying Zawre Formation. This was further substantiated by the fact that along the Khafji structure, the Zawre Shale successively overlaps different levels of the Middle Cretaceous - Wasia Group according to the position of the well relative to the crest of the structure.

In a recent attempt to correlate the subsurface Late Cretaceous successions of Kuwait, El-Naggar and El-Nakhal (1981, 1982, 1983a, 1983b, 1984, 1985a, 1985b and 1987) studied the succession in a number of wells in northern Kuwait (al Raudhtain Well#51), central Kuwait (Failaka Well#1) and in the Divided Neutral Zone Offshore Area (Al Hout Well#11). These authors (*op. cit.*) suggested a biostratigraphic zonation based on the first appearance of taxa since the samples, they studied, were rock cuttings. This biostratigraphic zonation includes the following zones (from base to top):

1- The *Globotruncana renzi* Zone:

This zone was said to coincide with the Khasib Limestone Member (=the Khasib Formation of southeastern Iraq) and to include in addition to *Globotruncana renzi* itself, *G. fornicata fornicata* (most probably caved from higher levels), *G. linneiana*, *G. thalmanni*; *Rugoglobigerina tradinghousensis*; *Praeglobotruncana coarctata*, *P. wilsoni*; *Globigerinelloides alvarezi*, *G. asperum*, *G. bolli*, *G. volutus*, *G. multispinata*, *G.*

praiviehillensis; *Heterohelix complanata*, *H. globifera*, *H. globulosa*, *H. papula*, *H. plummerae*, *H. pseudotessera*, *H. reussi*, *H. robusta*, *H. rumseyensis*, *H. ultimatumida*; *Gublerina deflaensis*, *G. reniformis* and *Archaeoglobigerina cretacea*.

Rocks representing this zone were described to be bounded by breaks from both sides and the zone was assigned a Coniacian age on the basis of both its fossil content and stratigraphic position.

2- The *Globotruncana elevata* / *G. coronata* Zone:

This zone was said to coincide with the Mutriba Limestone Member (=the Tanuma Formation of southeastern Iraq) and as its base is marked by an unconformity, the equivalent rocks of the *Globotruncana concovata* Zone were said to be missing in the studied sections.

This biozone is characterized by the presence of *Rugoglobigerina tradinghousensis*; *Globotruncana adamsi*, *G. arca*, *G. coronata*, *G. cretacea*, *G. elevata*, *G. fornicata ackermanni*, *G. fornicata cesarensis*, *G. fornicata fornicata*, *G. fornicata globulocamerata*, *G. G. fornicata manaurensis*, *G. gagnebini*, *G. hilli*, *G. tricarinata colombiana*, *G. ventricosa*; *Praeglobotruncana* *coarctata, P. inornata; Globigerinelloides alvarezi, G. bollii, G. volutus, G. multispinata; Heterohelix complanata, H. globifera, H. globulosa, H. plummerae, H. pseudotessera, H. reussi, H. robusta, H. rumseyensis, H. ultimatumida* and *Gublerina reniformis*.

On the basis of both its fossil content and stratigraphic position, this zone was assigned a Santonian age.

3- The *Globotruncana stuarti stuartiformis* Zone:

This zone was said to coincide with the Sa'di Limestone Member (=the Sa'di Formation of southeastern Iraq), its top was described to be truncated by an unconformity and hence the absence of the equivalent of the *Globotruncana calcarata* Zone in the studied sections.

The *Globotruncana stuarti stuartiformis* Zone was described to include the following planktonic foraminiferids: *Archaeoglobigerina cretacea; Globotruncana arca, G. angusticrinata, G. austinensis, G. bulloides, G. convexa, G. calciformis, G. cretacea, G. fornicata fornicata, G. fornicata ackermanni, G. fornicata cesarensis, G. gagnebini, G. marginata, G. rosseta pettersi, G. stuarti parva, G. stuarti stuarti, G. subcircumnodifer, G. tricarinata colombiana, G. ventricosa; Praeglobotruncana* *coarctata, P. inornata, P. wilsoni; Globigerinelloides alverezi, G. asperum, G. bolli, G. escheri, G. volutus, G. multispinata, G. praiviehillensis; Heterohelix complanata, H. globulosa, H. papula, H. plummerae, H. reussi, H. robusta, H. pseudotessera, H. rumseyensis, H. ultimatumida; Gublerina carinata, G. deflaensis, G. reniformis* and *Pseudoguemblina costulata*.

On the basis of both its fossil content and stratigraphic position , the *Globotruncana stuarti stuartiformis* Zone was assigned a Campanian age.

4- The First Zone with no Planktonics:

This zone was said to coincide with the Hartha Limestone Member and to be bounded from both the base and the top by unconformity surfaces. It was assigned an Early Maastrichtian age on the basis of its stratigraphic position.

5- The *Globotruncana gansseri* Zone:

This zone coincides with the Qurna Marl Member (=Qurna Formation of southeastern Iraq). It is bounded from the base by an unconformity surface.

The *Globotruncana gansseri* Zone is characterized by the presence of *Rugoglobigerina hexacamerata, R. macrocephala, R. ornata, R. pustulata, R. rugosa, R. tradinghousensis; Globotruncana adamsi, G. aegyptiaca, G. arca, G. austinensis, G. bulloides, G. calciformis calciformis, G. calciformis scutilla, G. convexa, G. cretacea, G. esnehensis, G. fornicata ackermanni, G. fornicata fornicata, G. fornicata globulocamerata, G. gagnebini, G. gansseri, G. gansseri gansseri, G. gansseri subgansseri, G. rosetta pettersi, G. rosetta rosetta, G. stuarti stuarti, G. stuarti stuartiformis, G. subcircumnodifer, G. tricarinata colombiano, G. ventricosa; Hedbergella petaloidea; Praeglobotruncana coarctata; Globigerinelloides alvarezi, G. asperum, G. escheri, G. volutus, G. multispinata, G. prairiehillensis; Heterohelix complanata, H. globifera, H. globocarinata, H. globulosa, H. papula, H. plummerae, H. pseudotessera, H. reussi, H. robusta, H. rumseyensis, H. ultimatumida; Gublerina reniformis; Pseudoguemblina costulata* and *P. punctulata*.

On the basis of the fossil assemblage and the stratigraphic position, this zone was assigned a Middle Maastrichtian age.

6- Second Zone with no Planktonics:

This zone was said to coincide with the Tayarat Formation and was given a Late Maastrichtian age on the basis of its stratigraphic position. However, this age was thought to be incomplete due to the presence of a marked unconformity at its top.

The correlation chart presented by El-Naggar and El-Nakhal (*op. cit.*) shows the decrease in the thickness of the Late Cretaceous succession from northern to southern Kuwait. The increased thickness in the north (Al Raudhtain Field) has permitted the subdivision of the Late Cretaceous succession into different rock units, while in the south (Al Hout Field), the thickness is reduced and the rock units recognized in the north could not be differentiated anymore. This idea is clear in the case of the Khasib, Mutriba and Sa'di Members of Al Raudhtain Well#51 that merge southwards to form the Gudair Formation in Al Hout Well#11.

II.5 Regional Stratigraphy of the Late Cretaceous rocks in Arabia

Kamen-Kaye (1970) constructed an isopach map for the Cretaceous sediments across the Arabian Peninsula. The map shows an ovoid area of shoaling conditions centered on the present Iranian shore of the Arabian Gulf where thicknesses as small as 1200' (366m) represent a nearly complete Cretaceous section. Kamen-Kaye (*op. cit.*) interpreted this ovoid nucleus as being the result of arching that had led to shoaling conditions rather than emergence as indicated by the continuous Late Cretaceous carbonate section in this ovoid area. Similar arching could be revealed along the Ghawar, Abqaiq and Bahrain structures. This tectonic instability is also manifested in the renewed uplifting in the western areas of the platform and the erosion of the uplifted Paleozoic - Early Mesozoic rocks, which supplied sands for the Middle Cretaceous sandstones that are currently important reservoirs in the Arabian Oil Fields. The instability is also evidenced by the numerous unconformities in the Cretaceous succession, of which the most important is the Wasia / Aruma (Middle / Late Cretaceous) unconformity.

Saint-Marc (1978) introduced a concise regional study of the Late Cretaceous rocks in Arabia and nearby areas. According to that study, the western part of central Arabia as far as Khurais in the east was emergent at the beginning of the Late Cretaceous in addition to numerous highs that existed along the Arabian Gulf. This land-sea configuration has led to the deposition of the ?Turonian, Coniacian, Santonian and ?Early Campanian sediments lying transgressively and discordantly upon the Cenomanian in depressions while they are generally absent over the emergent highs. A vast marine transgression covered central Arabia in the Late Campanian and particularly in the Maastrichtian time. A belt of marine sediments, as shales and limestones with ***Globotruncana*** , covered eastern Arabia in the vicinity of Ghawar and in the eastern part of al-Rub'al-Khali (Abu Dhabi). Shelf carbonates with benthonic foraminiferids and rudists covered an area to the west of the first belt in the central Rub'al-Khali and in wells in central Arabia that extend westwards to the outcrop of the Aruma Group.

The Late Cretaceous period in southwestern Arabia was a period of emergence with clastic and continental facies predominating. The Hadhramout-Dhufar area was inundated only by the sea during the Maastrichtian transgression. In Aden, active volcanicity started and continued to the beginning of the Paleogene. In Oman, important orogenic movements prevailed during the Late Cretaceous resulting in the emplacement of the nappes of both the Hawasina Group and the Semail Ophiolites.

Kuwait was probably covered by the Late Cretaceous sea since the Turonian or at least the Early Senonian, as no well-dated Turonian deposits have so far- been recorded (*cf.* Saint-Marc, 1978), although El-Naggar and Al-Rifaiy (1972a,b, 1973) have already described a Turonian succession in Kuwait. During the Campanian and Early Maastrichtian, Kuwait was at the border between neritic facies southwestwards and pelagic facies to the north and to the east. In the subsurface of the Burgan structure (southeastern Kuwait), the Gudair Formation consists of detrital, neritic limestones with benthonic foraminiferids and shale interbeds. To the north and east (e.g. in the Zubair Field), deep water chalky and marly limestones with planktonic foraminiferids dominate, being intercalated with neritic detrital limestones and shales. At the end of the Maastrichtian, the whole area was covered -more or less- uniformly by the shallow-water, reefal limestones (with crystalline dolomites, anhydrites and shale interbeds) of the Tayarat Formation, followed by the Early Paleogene Umm-er-Radhuma Formation (*cf.* Saint-Marc, 1978).

In Iraq, Early Senonian rocks are known in both the southeast in the vicinity of Baghdad and in the northwest. In the former area, these rocks are made up of marls that are rich in planktonic foraminiferids, while in the northwest, the base of the Shiranish Formation consists of cherty and marly limestones. The Campanian-Maastrichtian transgression covered the whole Iraq with an east-west trending facies belts controlled by deep faults so that basin deposits of the Shiranish Formation accumulated in the troughs while shelf carbonates covered the bordering highs. Further eastwards, flysh deposits, radiolarites and ophiolites prevailed at the rim of the basin.

The Senonian rocks along the Mediterranean margin of the Arabian Peninsula are predominantly chalky or marly limestone with a variable amount of flint which is attributed to the nearby emergent land mass of the Hail/Rutba Arch. The pattern of sedimentation was also controlled by a basin-and-high topography with the Coniacian, Santonian and Early Campanian rocks deposited only in the basins. Late Campanian and Maastrichtian sediments covered the whole Mediterranean area over a flat and uniform topography formed by the infilling of the basins by the preceding deposits.

Murris (1980) regarded the Turonian as being the time of onset of the Alpine Orogeny in the area. This orogeny resulted in the reactivation of the older Mesozoic structural elements and the consequent erosion and non-deposition. A northwest-southeast trending foredeep was formed along the Zagros and Oman sutures. Nappes were emplaced along this orogenic front where they are composed of radiolarites and ophiolites in both the Oman Mountains and the southern Zagros area, while in the northern Zagros, they are formed of shelf carbonates and radiolarites without ophiolites. This distribution of the nappe composition was interpreted by Murris (*op. cit.*) to indicate true oceanic conditions in the Oman Mountains as well as in the southern Zagros while these oceanic conditions were absent in the northern Zagros area during the Late Cretaceous time. The nappes were accompanied by synorogenic flysh deposits, conglomerates and olistostromes.

The orogenic front was bordered southwestwards by an open-marine basin, in which marls and calcareous shales with globotruncanids and other planktonic foraminiferids were deposited. Westwards, the shelf extended to cover most of Arabia with predominant deposition of bituminous limestone, phosphate and chert beds. The orogenic activity had abated by the Late Maastrichtian with the normal depositional conditions retained.

Harris and others (1984) studied the Cretaceous sequences in Arabia with emphasis on the subsurface section in its southeastern part. The thickness of the Late Cretaceous succession, there, is in the order of 1500'-3000' (457m-914m) feet of deep water chalks and marls, and even turbidites and radiolarites in the deepest parts of the foredeep basin that had been formed during the Alpine Orogeny. While the Late Cretaceous rocks overlie the Turonian ones in the subsurface of the northern part of the Arabian Gulf area, the Middle-Late Turonian rocks are absent in the southern Gulf area. This Middle/Late Cretaceous unconformity separates the shallow-platform carbonates of the Middle Cretaceous from the deeper water deposits of the Late Cretaceous. This unconformity led to the development of secondary porosity in the important Middle Cretaceous hydrocarbon reservoirs and resulted in the missing sections that range in age from 3-3.5 million years in offshore Abu Dhabi to more than 15 million years in parts of Saudi Arabia that border the Arabo-Nubian massif (*cf.* Harris and others, 1984).

The Coniacian-Santonian sea transgression in the southern Gulf area resulted in the deposition of the basal Laffan Shale followed by the Ilam Formation and its equivalents that are characterized by two facies: shelf limestones and platform-slope marls. The Lower Fiqa Member was deposited during the rest of the Coniacian-Santonian in the form of non-calcareous shales with occasionally marly interbeds.

During the Campanian, an eustatic rise took place, which substantiates the effect of regional tilting and depression of the Arabian continental margin so that deep shelf or even slope conditions prevailed. This transgression deposited pelagic-biogenic marls and calcareous shales which show an increased specific diversity of Campanian fossils that attained a peak during the ***"Globotruncanita calcarata"*** Zone (*cf.* Harris and others, 1984).

The low specific diversity in the ***"Globotruncanita stuarti"*** Zone and the lower part of the ***Globotruncana gansseri*** Zone, was taken by these authors (*op. cit.*) to indicate a regression of the sea at the onset of the Maastrichtian. The Late Maastrichtian Simsima Formation was described as being composed of shelf limestones and deeper water marly facies. The shelf limestones consist of basal lithoclast conglomerate overlain by a shoaling carbonate cycle which becomes increasingly restricted and capped by shallow subtidal and tidal-flat lime mudstones and wackestones. Shoal conditions are manifested by buildups of corals, rudists and abundant larger benthic foraminiferids that include the index species ***Orbitoides apiculata*, *Omphalocyclus macroporus*** and ***Siderolites calcitrapoides*.**

Harris and others (1984) correlated the Late Cretaceous successions in the southern Arabian Gulf area with that of occupied Palestine, and proposed a sea-level paleodepth curve for the Arabian succession, which they compared with the global sea-level curves.

III. STRATIGRAPHICAL ANALYSIS OF THE STUDIED SUCCESSION

The Late Cretaceous section analyzed in the present study lies between the drilled depths 4496' and 3763' in the Umm Gudair # 1 Well, southeastern Kuwait (with a total thickness of 733 feet = 223m). This cored interval comprises (from bottom to top) the Gudair, Hartha and Qurna Formations. Samples from the topmost Cretaceous rocks, represented by the Tayarat Formation, were not available, and hence could not be studied.

Owen and Nasr (1958) choosed the Gudair Formation in the Umm Gudair # 1 Well to be the type section of the formation. Since that time, no attempt has been made to study this type section, at least in published literature.

The thickness of the formations are considerably reduced because of the position of the Umm Gudair#1 Well on the crest of the structure in the Umm Gudair Oil Field. The following is a discussion of the studied rock units in an ascending order.

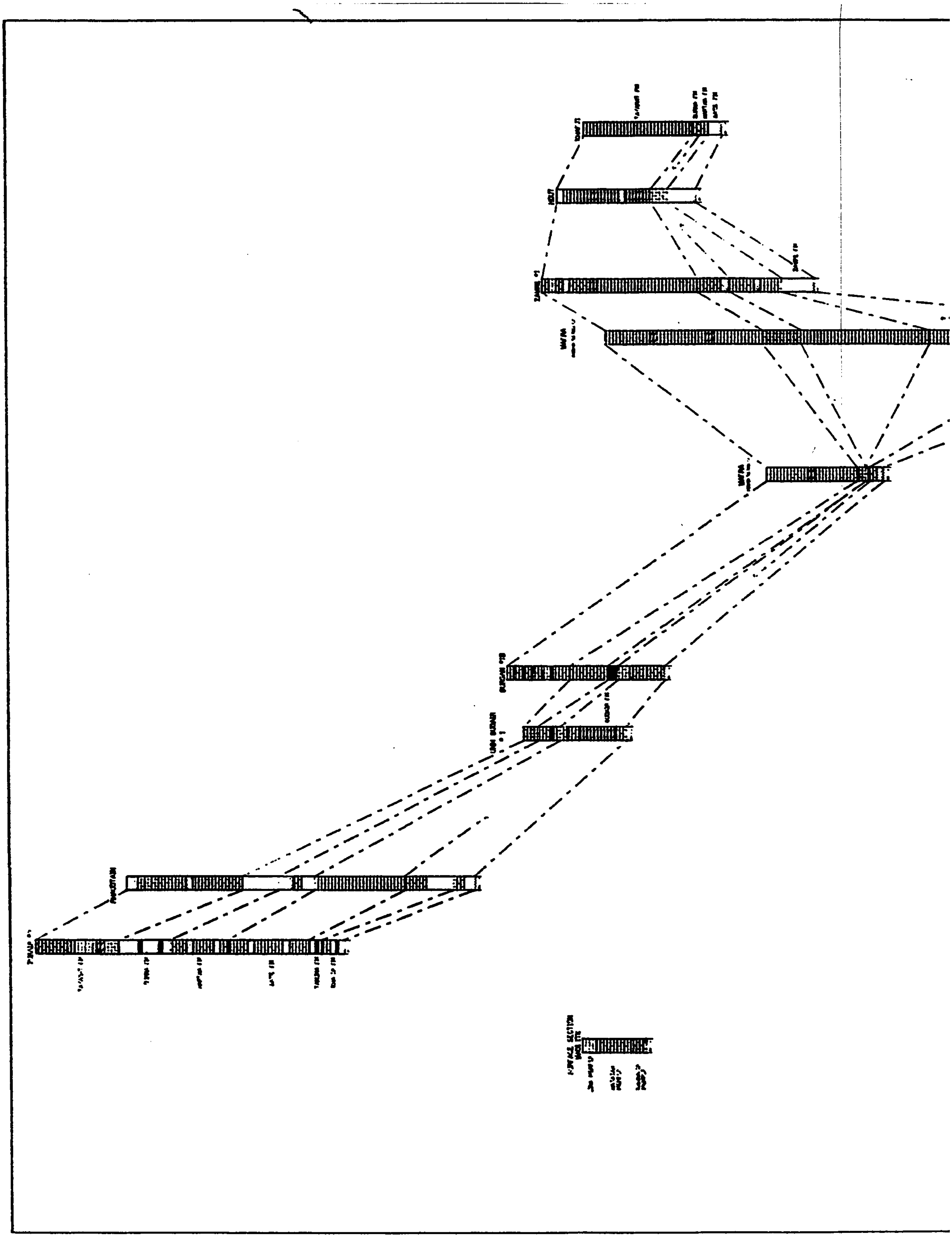
III.1 The Type Gudair Formation:

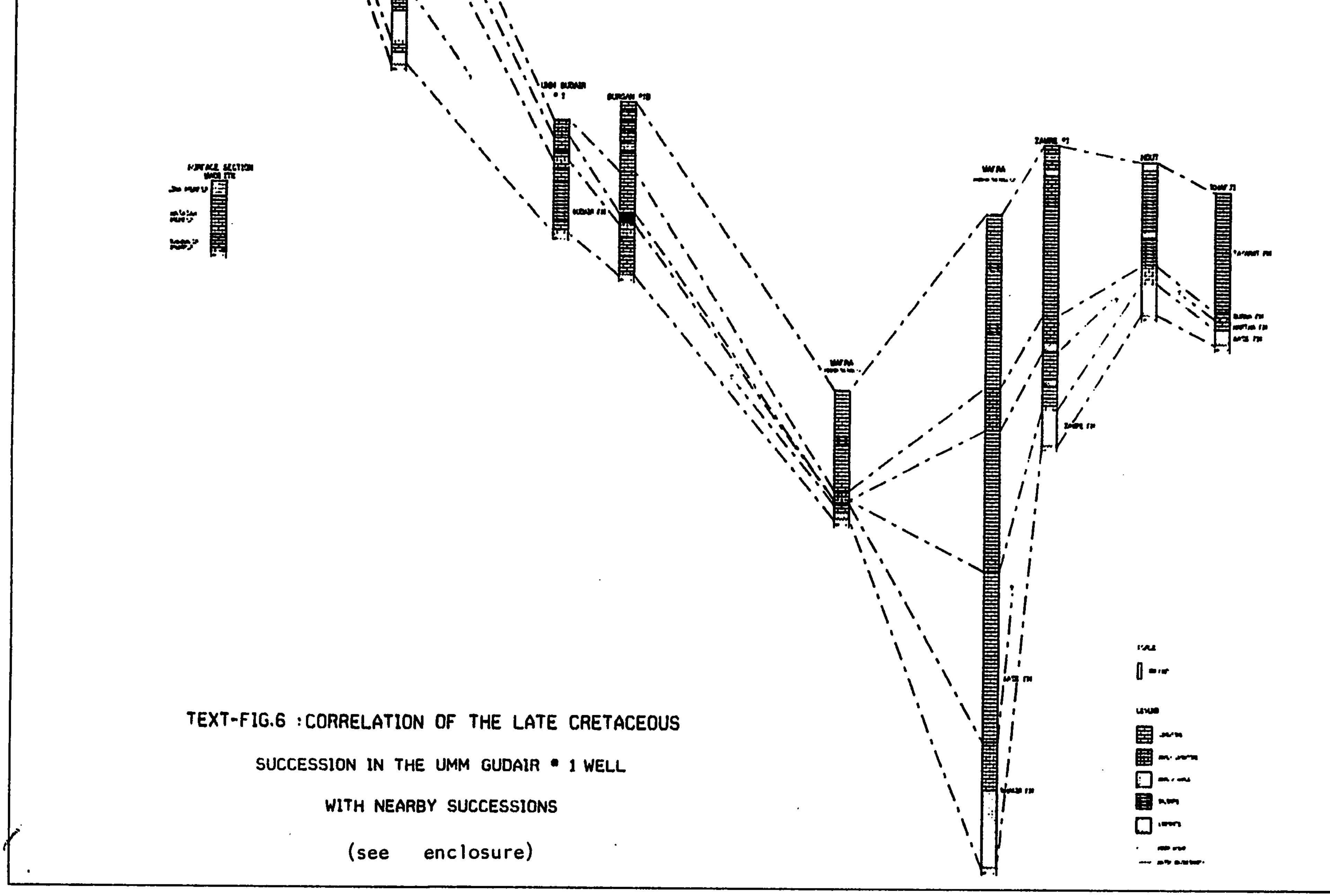
The Gudair Formation, at its type section, is represented by a 465' (142m)- thick carbonate section that varies from detrital, skeletal limestones that are locally pyritized, silicified or recrystallized, to dolomitized limestones and dolomites and finally to globigerininal marly limestones. The lower 35' (11m) of the formation are composed of micritic skeletal limestones which are occasionally marly and locally recrystallized. These are overlain by 50' (15m) of slightly pyritized, silicified, richly fossiliferous limestones with indications of some bioturbation, followed by a thick dolomitic interval (251' or 27m) with scattered patches of predolomitization features such as micritic matrix and fossil ghosts. This secondary dolomite interval is -in its turn- overlain by a section 126' (28m)-thick of detrital, skeletal limestones that are frequently recrystallized, iron-stained and stylolitized. An astonishing facies anomaly interrupts the top detrital limestone facies in the form of a 3' (1m)-thick section of globigerininal marly limestone which differs completely from the overlying and underlying detrital limestone facies.

Similarly, the type Gudair Limestone contains a very diverse fossil assemblage that includes planktonic and benthonic foraminiferids, ostracods, gastropods, pelecypods, echinoderms and some algal remains. Benthonic foraminiferids are represented by the genera *Pseudedomia*, *Meandropsina*, and *Cuneolina* in addition to the frequent rotaliids and milioliids. The planktonic foraminiferids are represented by *Globotruncana aegyptiaca duwi*, *G. atlantica*, *G. insignis*, *G. orientalis*, *G. patelliformis*, *G. stuartiformis*, *G. subspinosa*; *Rugoglobigerina macrocephala*, *R. rugosa*; *Hedbergella holmdelensis*; *Heterohelix globulosa* and *H. papula*. This diverse fossil assemblage was used for the biozonation of the succession into two biozones: a lower *Globotruncana stuartiformis/G. patelliformis* Zone (that can be correlated with the top of the Early Campanian - *Globotruncana elevata Zone* of Robaziniski and others, 1984) and an upper *Globotruncana atlantica/G. patelliformis* Zone (which can be equated with the Middle Campanian - *Globotruncana ventricosa* Zone of Robaziniski and others (*op. cit.*). Thus, the Gudair Formation in the type section is assigned a late Early to Middle Campanian age.

Because of the varied litho- and biostratigraphic characteristics of the Gudair Formation, its paleoenvironmental conditions of deposition are here interpreted to have been unstable and rapidly changing. Such instability is again substantiated by the marked thickness variation of the Gudair Formation and of its equivalents within short distances of eastern Arabia (Text-Fig. 6). The interpretation of the paleoenvironmental conditions of deposition of the Gudair Formation is discussed in the microfacies section (Microfacies I to V), but this can be summarized to have ranged from shelf lagoon (or open platform) to restricted platform conditions except for the 3' (1m) of globigerininal marly limestone near the top that reflect an environment of deep shelf margin.

The contact of the Gudair Formation with the underlying Mishrif Member (upper member of the Magwa Formation) is clearly unconformable with a missing section of Middle Turonian - late Early Campanian age. This is one of the most pronounced unconformity surfaces in the Phanerozoic history of Arabia. The unconformable relationship is also substantiated by the presence of abundant coralline, rudistid and bryozoan remains in the Mishrif Limestone Member as well as abundant glauconite grains, recrystallization patches, oxidation and silicification of the typical hardgrounds at the top of the Mishrif Member (see Plate 1). This unconformity is also supported by El-Naggar and Al-Rifaiy (1972 a,b, 1973) who have already





TEXT-FIG.6 :CORRELATION OF THE LATE CRETACEOUS

SUCCESSION IN THE UMM GUDAIR # 1 WELL

WITH NEARBY SUCCESSIONS

(see enclosure)

studied the Middle Cretaceous part in the Umm Gudair#1 Well. This Middle - Late Cretaceous unconformity is one of the most pronounced unconformities in the area even in the more basinward parts of the region (*cf.* Darmoin 1975 for southeastern Iraq and Setudhnia, 1978 for southeastern Iran). The duration of this unconformity varies considerably within the area, but its maxima are always in crestal wells such as the Umm Gudair#1 Well. This reflects the irregular topography that preceded the Late Cretaceous transgression over the area as well as tectonic instability of variable degrees during deposition.

The common consideration of the type Gudair Formation of southeastern Kuwait as the lateral equivalent of the Sa'di, Tanuma and Khasib Formations of both northeastern Kuwait and southeastern Iraq should be abandond. The type Gudair has been proved here to be of late Early to Middle Campanian age while the other three formations are of Senonian (Coniacian - Campanian) age. The type Gudair can be considered as a lateral equivalent to the Sa'di Formation only, since both formations are of Campanian age. Nevertheless, the two rock units have to be re-instated in the stratigraphy of the Late Cretaceous succession of eastern Arabia, due to their markedly different facies. While the Sa'di is represented by deep-water marls flooded with planktonic foraminiferid remains, the Gudair is dominantly composed of detrital limestones with pseudedomial remains.

III.2 The Hartha Formation

Rocks correlatable to the Hartha Formation are represented in the Umm Gudair#1 Well by a section 164' (50m)-thick, between the drilled depths 3867' and 4031'. The basal 49' (15m) of that section are in the form of intensively reworked, pyritized and ferruginated skeletal limestone with the reworked skeletal grains often cemented by recrystallized calcite and even dolomite cement. Stylolitic structures and glauconitic grains are frequently recorded through out this interval.

This basal, reworked interval is overlain by 24' (7m) of completely dolomitized facies with the original micritic matrix rarely preserved, but without any recognizable fossils, which if ever were there, have most probably been completely destroyed by the intensive dolomitization. The top 91' (28m) of this Hartha section is roughly divisible into an upper orbitoidal, micritic, skeletal limestone with frequent recrystallization patches and a lower recrystallized limestone with probably current-sorted, very small-sized microfossils, although the two facies are interbedded and no clear cuts can be recognized.

The fossils of the basal reworked interval are difficult to identify, but nevertheless, random sections of *Globotruncana atlantica*, *Pseudedomia sp*. and *Omphalocyclus macroporus* could be recognized. Contrary to this, the top orbitoidal limestone facies is flooded with the remains of a number of index fossils which include: *Orbitoides medius*, *Omphalocyclus macroporous*, *Globotruncana esnehensis*, *G. gansseri wiedenmaryi*, *G. falsostuarti*, *G. orientalis* and *G. subspinosa*. The *Orbitoides medius* Zone has been equated with the internationally recognized *Globotruncana falsostuarti* Zone of Robaziniski and others (1984). Consequently, the Hartha Formation, or -at least- its upper orbitoidal limestone interval, can be assigned an Early Maastrichtian age.

The paleodepositional environment of the Hartha Formation is here interpreted to have ranged from a restricted platform environment for the lower reworked and dolomitic intervals, to a platform margin environment (the seaward rim of the subtidal environment) for the upper orbitoidal facies. Such interpretation is dealt with in detail in the discussion of the microfacies of the Hartha Formation (Microfacies VII, VIII and IX).

The contact between the Hartha and the underlying Gudair Formations in the Umm Gudair#1 Well is here interpreted to be disconformable. The missing section is equivalent to, at least, the interval between the Early Maastrichtian - ***Orbitoides medius / Omphalocyclus macroporus*** Zone of the Hartha Formation and the underlying Middle Campanian - ***Globotruncana atlantica/G. patelliformis*** Zone of the Gudair Formation (see the discussion below on the biozonation of the succession). Such interpretation is supported by the presence of a reworked, pyritized and ferruginated zone along the contact as well as by the reduced thickness of the Hartha Formation in the Umm Gudair#1 Well compared to a more complete section in the nearby Zawre#1 Well, which has been drilled in the flank of the Khfaji structure, where the relationship has also been interpreted to be disconformable (*cf.* El-Naggar and Jaber, Ms)

As discussed later, it has been suggested here to re-instate the formational rank of the Hartha Limestone rather than lowering it to be the basal member of the Bahrah Formation because of its disconformable relationship with the overlying Qurna Formation.

III.3 The Qurna Formation

The thickness of the Qurna Formation in the Umm Gudair#1 Well is 104 feet (32m) as it occupies the interval between the drilled depths 3763' and 3867'. Lithologically, this formation is composed of marly limestone. The skeletal remains are almost exclusively planktonic foraminiferids that belong to the suborder Globigerinina. The uniformity of both the litho- and biofacies of the Qurna Formation from top to bottom has encouraged its inclusion into one microfacies (Microfacies X; see below).

Planktonic foraminiferid remains in the Qurna Formation are both flooding and beautifully preserved. These include ***Globotruncana aegyptiaca*, *G. arca*, *G.bulloides*, *G. contusa*, *G. falsostuarti*, *G. pettersi*; *Rugoglobigerina hexacamerata*, *R. macrocephala*, *R. pennyi*, *R. pustulata*, *R. rugosa*; *Heterohelix globifera*, *H. globulosa*** and ***Guembletria sp***. This fossil assemblage is interpreted to coincide with the ***Globotruncana gansseri*** Zone and thus can be assigned a Middle Maastrichtian age (***cf***. El-Naggar 1966a,b; El-Naggar and El-Nakhal, 1987; El-Naggar and Jaber, Ms; Robaziniski and others, 1984).

The depositional environment of the Qurna Formation is expected to be quiet and fairly deep, hence the absence of benthonics and the flooding of planktonics. These conditions characterize the deep shelf environment where dropping planktonic remains stand an excellent opportunity for preservation due to the extreme rarity of benthonic forms (see the discussion of Microfacies X).

The lower contact of the Qurna Limestone with the underlying Hartha Formation is very abrupt as it separates the iron-stained, orbitoidal, shallow-water limestones of the Hartha Formation from the overlying globigerininal marly limestones of the Qurna. No physical break was observed, but this abrupt facies change can be taken to mean some sort of a break.

Owen and Nasr (1958) mentioned that the globigerininal marl and marly limestone Qurna Formation of southeastern Iraq does not extend to southern Kuwait, but changes into microcrystalline limestone, and hence it could not be treated separately from the underlying Hartha Limestone. Consequently, these authors (*op. cit.*) lowered both the Qurna and Hartha Formations in southeastern Kuwait to member ranks and included both members within the Bahrah Formation.

The Bahrah Limestone of southeastern Kuwait, therefore included the Hartha Limestone Member (detrital and oolitic limestone) at its base and the Qurna Cherty Limestone Member at its top. However, in the present study, the Qurna rock unit in the Umm Gudair#1 Well was found to be composed of marly limestone with abundant planktonic foraminiferid remains, similar to the Qurna Formation of southeastern Iraq. Consequently, it was found advisable to treat the Qurna unit separately from the Hartha and to re-instate both to a formational rank as was originally defined in southeastern Iraq.

This is substantiated by the fact that the contact between these two rock units has been shown to be disconformable by a large number of authors (*cf.* El-Naggar and Jaber, Ms, El-Naggar and El-Nakhal 1987, Darmoin, 1975).

The present microstratigraphical analysis of the type Gudair Formation has led to the recognition of a number of remarkable sedimentary features.

III.4 The phenomenon of shoaling-upward carbonate sequences:

This phenomenon is represented at the base of the Gudair

Formation where it occupies more than the lower two thirds of the formation. The basal part of that shoaling-upward sequence is represented by an interval (35' or 11m- thick) of skeletal limestone. The limestone is typically of a subtidal origin with a diverse fossil association that includes planktonic and benthonic foraminiferids in addition to ostracod, gastropod, echinodermal and pelecypod remains (Microfacies I). This interval is overlain by a 50' or 15m-thick section of a reworked, ferruginated-silicified, algal limestone of intertidal origin (Microfacies II), and the cycle ends by a dolomite section (152' or 46m-thick) that exhibits clear mosiac structure, with patches of pre-dolomitization features (Microfacies III).

Similar shallowing-upward sequences have been described in the literature (e.g. both Wilson, 1975 and James, 1984). Shoaling-upward sequences are generally produced by the relative shallowing of the sea which differs from eustatic falls in the sea level. Relative shallowing of the sea can take place during periods of eustatic sea level rise if, for example, the rate of deposition exceeds both the rate of the eustatic sea level rise and subsidence. There are three possible mechanisms that can act, either separatly or in combination, to produce shoaling-upward carbonate sequences

(*cf.* Reeckman and Friedmann, 1982). These mechanisms are:

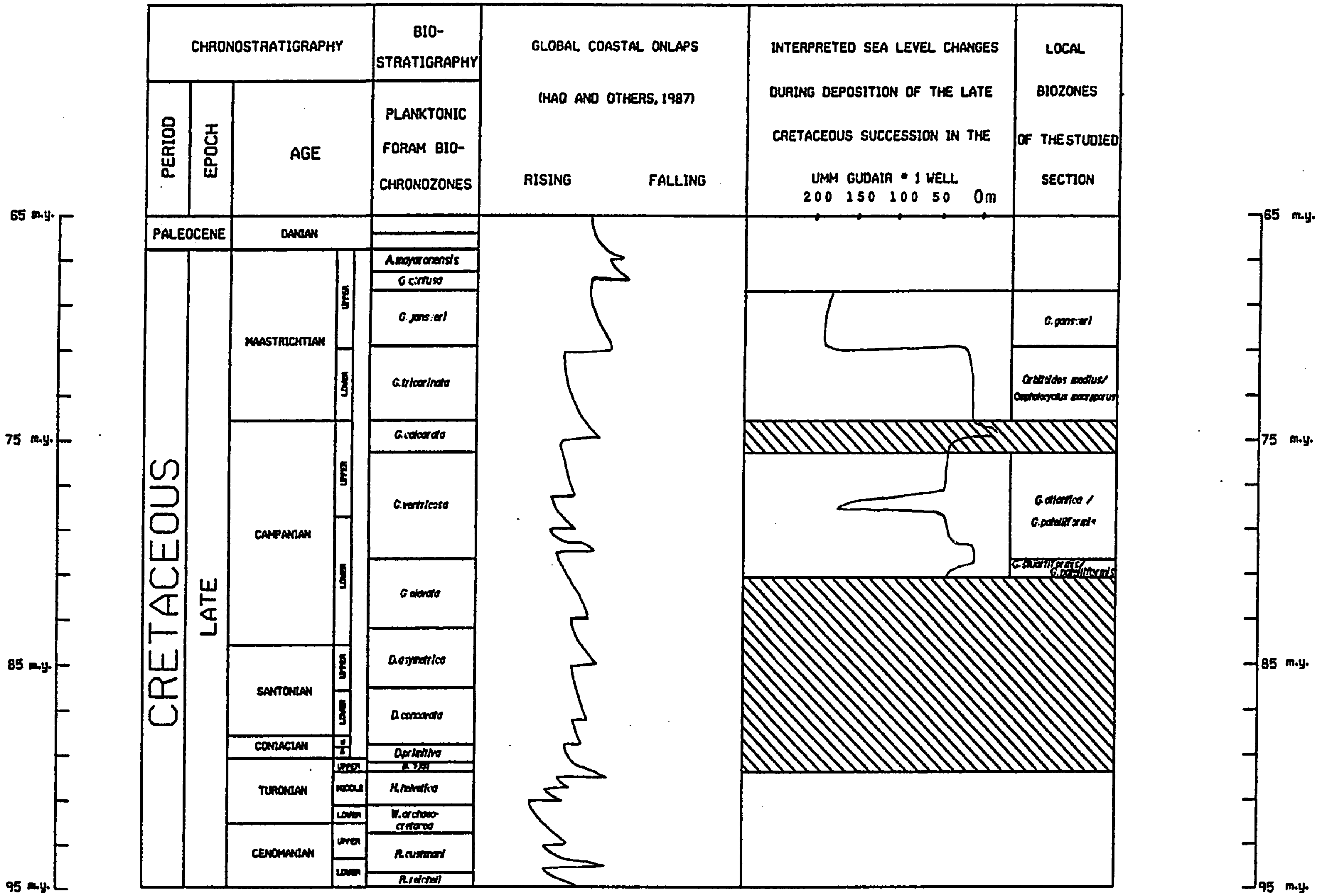
(1) Rapid growth rate of the carbonate-secreting organisms that can exceed the rates of any possible rise of the sea level or subsidence of land.

(2) Rapid rates of tectonic uplifting of parts of the platform that can exceed the rates of any possible rising in the sea level or subsidence of land.

(3) General eustatic fall in the sea level.

The third alternative is excluded ,here, as the eustatic sea level curves of Haq and others (1987) show a slight rise during the Early Campanian time, which is exactly the time of the beginning of the shoaling sequence (Text-Fig. 7). Again, any small eustatic fall in the sea level would have exposed the shallow, flat carbonate platform to a widespread unconformity (*cf.* Kendall and Schlager, 1981) which is not fulfilled in our case. Such unconformity usually develops because of the tendency of carbonate-platform sediments to build up to sea level.

As to the dominance of either of the other two alternatives for the formation of the shoaling-upward sequences, it has to be mentioned, here, that the growth



Text-Fig. 7: Correlation of the sea level changes during the deposition of the Late Cretaceous succession of the Umm Gudair # 1 Well with global coastal onlaps interpreted by Haq and others (1987) potential of the lower subtidal interval is not expected to have been too rapid to outpace the rise in the sea level. Such conclusion is based on the scarcity of typical reefal facies (that contain, among others, abundant remains of colonial corals, algae and bryozoa). Consequently, tectonic uplifting is expected to have played the major role in the development of the shoaling-upward sequence at the base of the Gudair Formation in the studied section and probably in many other structural highs in the region. The fact that the studied samples have been cored from a crestal well in the Umm Gudair Structure (the Umm Gudair#1 Well) may support the idea of tectonic uplifting.

The top dolomitic interval of this sequence is, here, interpreted to have formed through the mixing of both fresh and sea waters, following a model previously proposed by Badiozamani (1973) to explain the presence of dolomites along intra-shelf positive structures (see the discussion of Microfacies III). The model postulates the gradual uplifting of positive structures from the bottom of epicontinental seas in the form of shoals where the depth of marine waters could allow the mixing of both fresh and sea waters in proportions suitable for the dolomitization process.

The idea of differential tectonic uplifting from the bottom of the Late Cretaceous sea that has inundated eastern Arabia is further supported by the very erratic nature of the Gudair Formation as far as both thickness and facies are considered (Text-Fig. 6).

Another shallowing-upward sequence exists at the base of the Hartha Formation. It comprises a 49' (15m)-thick interval of intensively reworked limestone, cemented by recrystallized calcite (Microfacies VII) overlain by a completely dolomitized unit, 24' (7m)-thick (Microfacies VIII).

III.5 The phenomenon of drowning carbonate platforms:

Another striking stratigraphic phenomenon in the analyzed section is the presence of a 3' (1m)-thick band of deep shelf, planktonic-foraminiferid limestone (Microfacies V) interrupting a thick sequence of subtidal, skeletal limestones (both Microfacies IV and VI). This phenomenon is interpreted, here, as the result of a temporary drowning of the carbonate platform (*cf.* Schlager, 1981). Drowning of carbonate platforms is defined as an event of relative rise of the sea level to the extent of outpacing carbonate accumulation as the platform becomes submerged below the euphotic zone of prolific carbonate production (*cf.* Schlager, *op. cit.*). Long-term, slow geologic processes such as regional subsidence or eustatic rises are not capable of drowning carbonate platforms because in such cases, carbonate build-ups to the new sea level can always be maintained. However, drowning carbonate platforms with much deeper facies implies sudden environmental changes that minimizes and/or retards carbonate production. Possible reasons for drowning carbonate platforms were summarized by Schlager (1981) to be due to pulses of eustatic rise of the sea level, pulses of tectonic subsidence, sudden reduction of the growth potential of the carbonate-secreting organisms or increase in the slope height at the platform margin. There is no indication of local disturbances in the paleoenvironmental conditions of deposition that could have retarded the benthonic growth potential. Moreover, the alternative of the sudden increase in the slope of the platform margin can not be verified here because of numerous limitations. The choice of eustatic sea level pulses can possibly explain this phenomenon since it has been concurrent with an increase in the global sea level that occured in the Middle Campanian. However, the idea of pulses of tectonic subsidence may also provide a suitable explanation for the drowning of the platform in the Umm Gudair#1 crestal Well, although the verification of such possibility is beyond the limits of the available data in the present study. Nevertheless, it has already been suggested that pull-apart basins associated with wrench tectonics may provide sudden and sufficient subsidence for carbonate platforms to be drowned.

IV. BIOSTRATIGRAPHICAL ANALYSIS OF THE STUDIED SECTION

A major part of any microfacies analysis deals with the identification of the included organic remains (fossils) in thin section. This normally leads to the recognition of a number of fossil assemblages, but can -in no way- be a complete survey of the fossil content similar or even nearer to isolated fossils from disintegrated rock samples. This can hamper biostratigraphic zonation as well as inter-regional correlation with world-wide schemes. The problem can be further complicated by the presence of stratigraphic intervals that are either almost barren of index fossils or are completely non-fossiliferous. Again, the nonuniformity of the fossil content throughout the section (i.e. the repeated presence and absence of planktonic and/or benthonic microfossils at successive levels) can also hamper the following of a particular, unified zonal scheme and can make biostratigraphic zonation very difficult. This was faced in the analysis of the studied section, but, nevertheless an attempt was made for its biostratigraphical zonation.

The basis of biostratigraphical zonations by the use of planktonic foraminiferids and inter-regional correlations between the proposed zonal schemes for the Late Cretaceous - Early Paleogene time have already been discussed by El-Naggar (1969) and need not be repeated here. However, some of the later and most recent zonations are, here, reviewed (*cf.* Robaziniski and others, 1984, Text-Fig. 8), and used for correlating the studied section.

The biostratigraphical analysis of the Late Cretaceous succession in the Umm Gudair#1 Well has resulted in the recognition of four distinctive biozones from bottom upwards as follows :

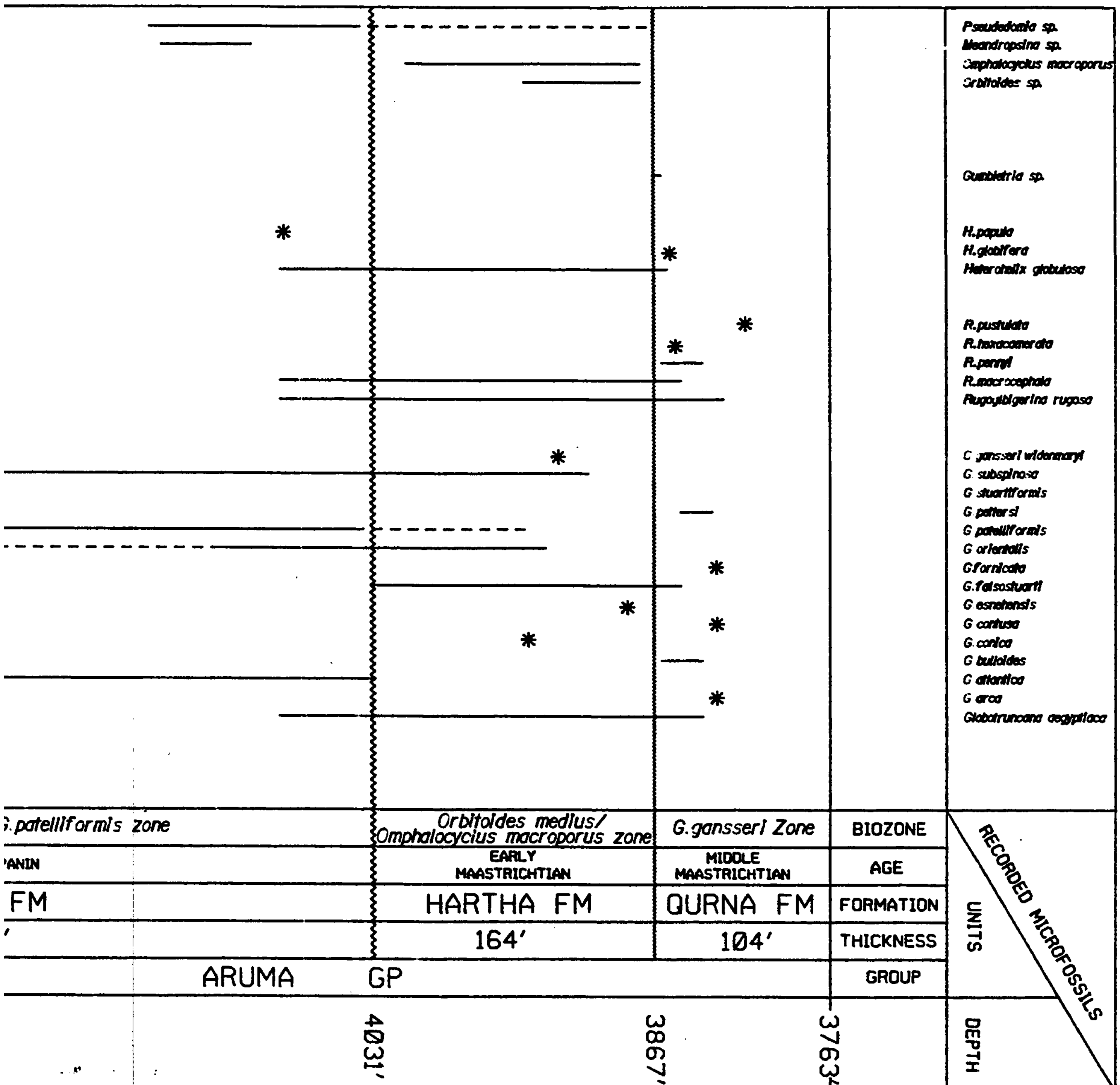
1- The *Globotruncana stuartiformis / G. patelliformis* Assemblage Zone :

The biozone coincides with the basal 85' (26m) of the type Gudair Limestone, and is characterized by abundant remains of ***Globotruncana patelliformis*, *G. stuartiformis*, *G. subspinosa*** and ***Hedbergella holmdelensis*** among other planktonic foraminiferids (Text-Fig. 9).

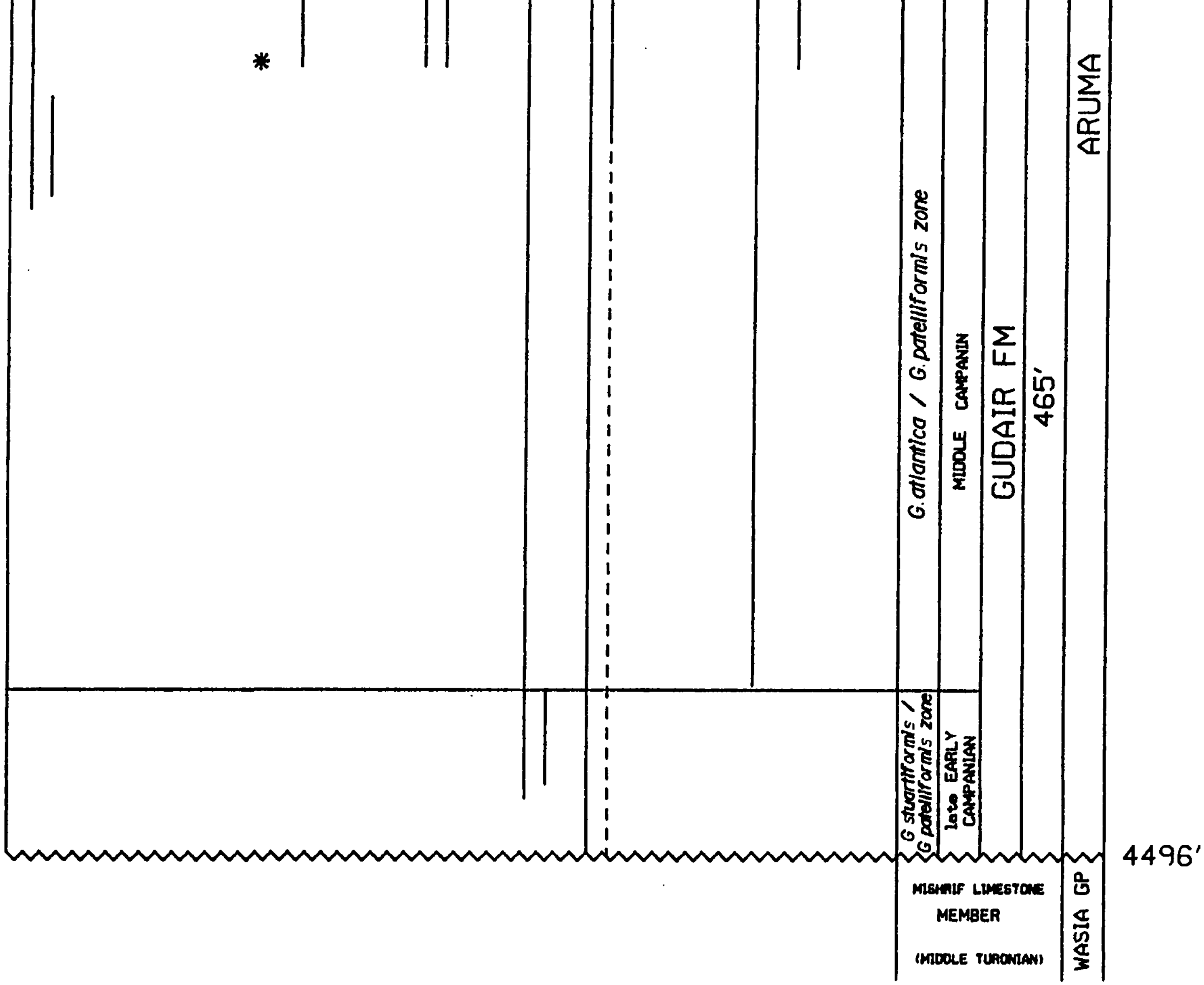
The ranges of the recorded forms in this zone cover the span from the top of the ***Dicarinella asymetrica*** Zone of Late Santonian age to the ***Abathomphalus mayaroensis*** Zone of Late

STAGE M.Y.	CARON (1986)	ROBAZINISKI AND OTHERS (1984)	WONDERS (1980)	SIGAL (1977)	VAN HINTE (1976)	POSTUMA (1971)	PASSAGNO (1967)		BOLLI (1966)	EL NAGGAR (1966)
65	*mayaroensis*	*mayaroensis*	*mayaroensis*	*mayaroensis*	*mayaroensis*	*mayaroensis*	*contusa*	*mayaroensis*	*mayaroensis*	*esnehensis*
MAASTRICHTIAN	*gansseri*	*gansseri*	*contusa* *gansseri*	*gansseri*	*contusa* *stuarti* *gansseri*	*gansseri*		*gansseri*	*gansseri*	*gansseri*
	aegyptiaca *havanensis*	*falsostuarti*	*tricarinata*	*stuarti* • *falsosturti*	*scutilla*	*stuartiformis*	*for.-stuartiformis*	*subcircumnodifer*	*lapperenti* *tricarinata*	*fornicata*
70	*calarata*	*calarata*	*calarata*	*calarata*	*calarata*	*calarata*		*calarata*	*calarata*	
CAMPANIAN	*ventricosa* *elevata*	*ventricosa* *elevata*	*ventricosa* *elevata*	*elevata* • *stuartiformis*	*subspinosa* *stuartiformis* *elevata*	*elevata*		*elevata* *A.blowi*	*stuarti s.l.*	
78 SANTONIAN	*asymetrica*	*asymetrica*	*carinata* *concavata*	*concavata* • *carinata*	*elevata* • *concavata*	*carinata* *concavata*	*bulliod*	*fornicata* *concavata*	*fornicata* *concavata*	
82 CONIACIAN	*concavata* *primitiva*	*concavata* *primitiva*	*primitiva*	*concavata* *sigali* • *schneegansi*	*concavata* • *sigali* *sigali* • *renzi*	*schneegansi*	*renzi*		*schneegansi*	
86 TURONIAN	*M.sigali* *helevetica* *archaeoretacea*	*M.sigali* *helevetica* *archaeoretacea*	*sigali* *helevetica* *archaeoretacea*	*helevetica*	*helevetica* *lehmani*	*helevetica*	*helev.*	*archaeoretacea* *sigali*	*helevetica* *gigantea*	
92										

Text-Fig. 8: Correlation of previously suggested biozonations for the Turonian-Maastrichtian time by the use of fossil planktonic foraminiferids



RECORDED MICROFOSSILS
UNITS
DEPTH
GROUP
THICKNESS
FORMATION
AGE
BIOZONE
3763'
3867'
4031'
ARUMA GP
104'
164'
QURNA FM
HARTHA FM
FM
MIDDLE MAASTRICHTIAN
EARLY MAASTRICHTIAN
G.gansseri Zone
Orbitoides medius/ Omphalocyclus macroporus zone
G.patelliformis zone
Pseudedomia sp.
Meandropsina sp.
Omphalocyclus macroporus
Orbitoides sp.
Gumbletria sp.
H.papula
H.globifera
Heterohelix globulosa
R.pustulata
R.hexacamerata
R.pennyi
R.macrocephala
Rugoglobigerina rugosa
G gansseri widenmayri
G subspinosa
G stuartiformis
G pattersi
G patelliformis
G orientalis
G.fornicata
G.falsostuarti
G esnehensis
G contusa
G.conica
G bulloides
G atlantica
G arca
Globotruncana aegyptiaca



TEXT-FIG. 9 : DISTRIBUTION CHART FOR THE RECORDED MICROFOSSILS IN THE LATE CRETACEOUS SUCCESSION IN THE UMM GUDAIR # 1 WELL

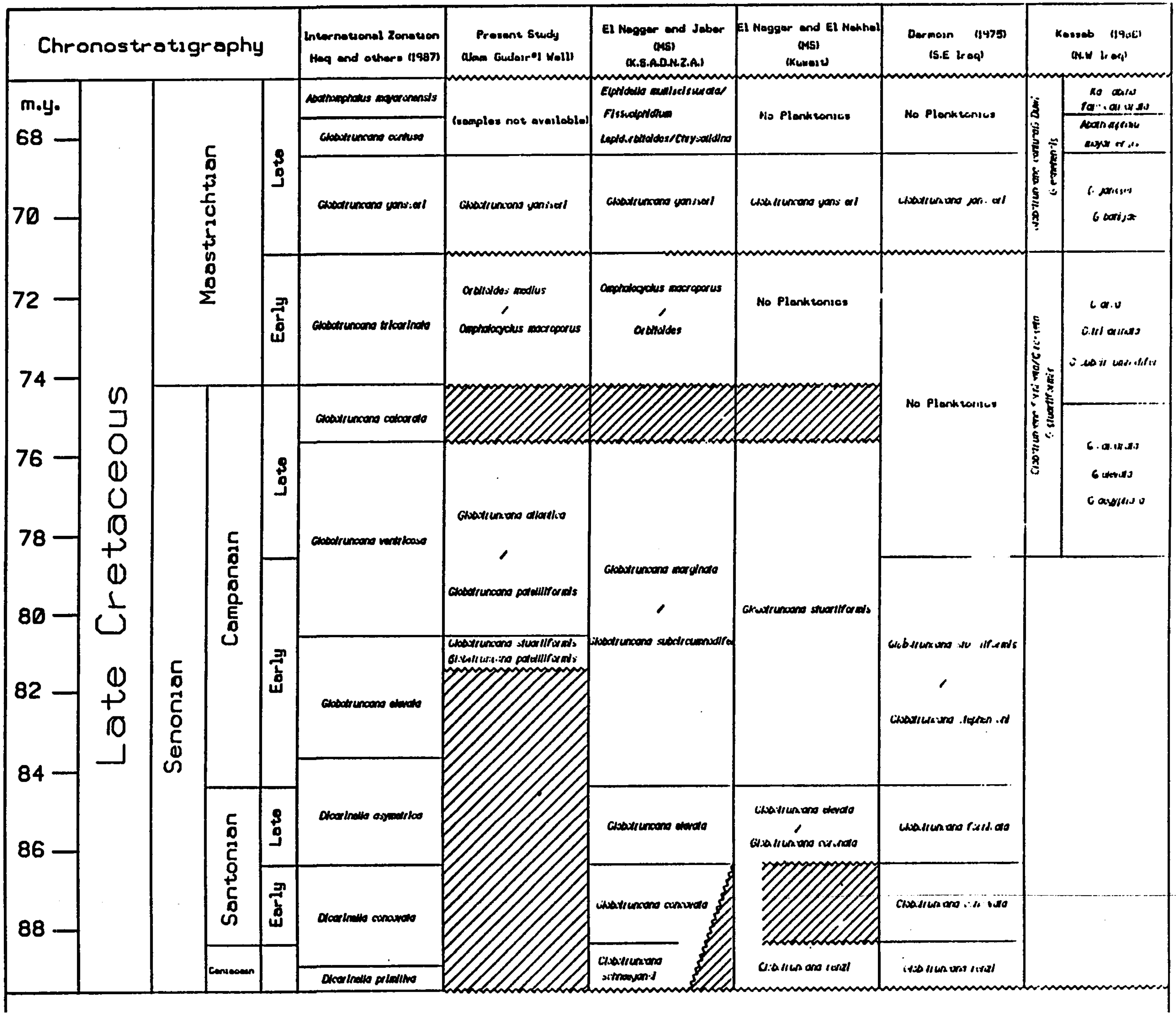
Maastrichtian age (*cf.* Robaziniski and others, 1984). However, the upper boundary of this local zone is marked by first appearance of ***Globotruncana atlantica*** which characterizes the overlying zone. This species has already been described to mark the base of the Middle Campanian - *G. ventricosa* Zone by its first appearance while *G. patelliformis* was described to have appeared near the end of the Early Campanian - *G. elevata* Zone (*cf.* Robaziniski and others, *op. cit.*). Therefore, it is, here, concluded that the biozone under discussion is restricted to the upper part of the *G. elevata* Zone of the international planktonic foraminiferid zonation (*cf.* Robaziniski and others, 1984; Caron, 1986, etc.). This lower interval of the *Globotruncana patelliformis* range is characterized by the association of *G. stuartiformis* (Text-Fig. 9) and hence the zone has been named as the *G. stuartiformis / G. patelliformis* Zone, despite the fact that the two forms range outside the zone.

The above discussion shows clearly that our *Globotruncana stuartiformis / G. patelliformis* Zone is equivalent to the upper part of the Early Campanian - *Globotruncana elevata* Zone of Robaziniski and others (1984) and hence can be assigned a late Early Campanian age. This *elevata* Zone is either totally or partially equivalent to synonymous zones suggested by

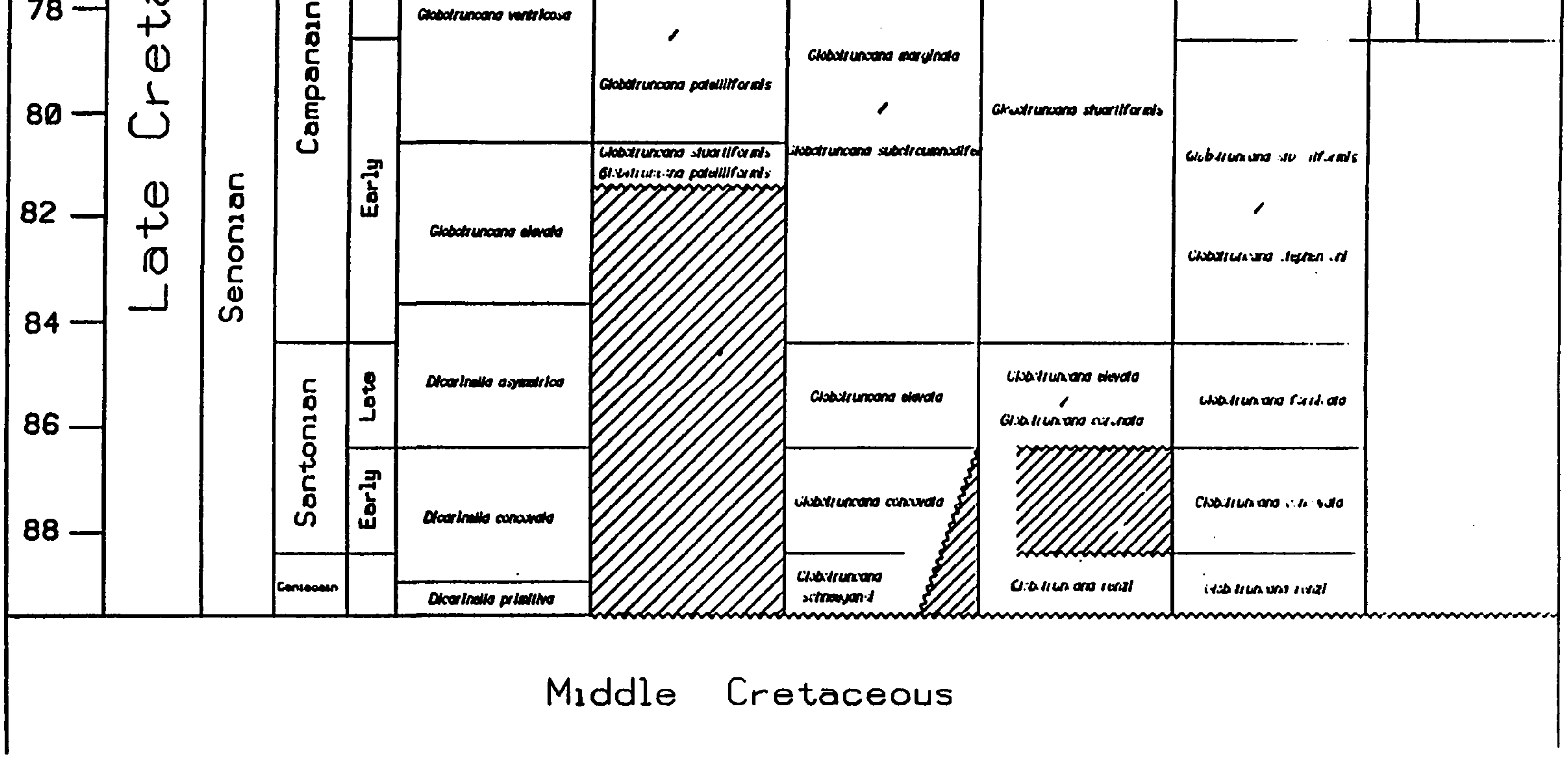
Caron (1986), Wonders (1980), Postuma (1971) as well as to the *G. elevata* / *G. stuartiformis* Zone of Sigal (1977), the *G. elevata* and the *G. stuartiformis* Zones of Van Hinte (1976), the *G. fornicata* / *G. stuartiformis* of Passagno (1967) and the *G. stuarti s.l.* of Bolli (1966), and has thus been assigned an Early Campanian age (Text-Fig. 8)

Locally, the *G. stuartiformis* / *G. patelliformis* Zone is partially equivalent (Text-Fig. 10) to the *G. marginata* / *G. subcircumnodifer* of El-Naggar and Jaber (Ms) in the Kuwait / Saudi Arabia Divided Neutral Zone area, the *G. stuartiformis* Zone of El-Naggar and El-Nakhal (1987) in Kuwait and the *G. Stuartiformis* / *G. stephenosoni* Zone of Darmoin (1975) in southeastern Iraq.

The *Globotruncana stuartiformis* / *G. patelliformis* Zone represents the lowermost biozone in the Late Cretaceous succession of the Umm Gudair#1 Well. The underlying Mishrif Limestone Member is of Cenomanian to Middle Turonian age (*cf.* El-Naggar and Al-Rifaiy, 1972a,b,1973).



Chronostratigraphy
International Zonation Haq and others (1987)
Present Study (Umm Gudair'l Well)
El Naggar and Jaber (MS) (K.S.A.D.N.Z.A.)
El Naggar and El Nakhal (MS) (Kuwait)
Darmoin (1975) (S.E Iraq)
Kassab (19__) (N.W Iraq)
m.y.
68
70
72
74
76
78
80
82
84
86
88
Late Cretaceous
Senonian
Maastrichtian
Campanian
Santonian
Coniacian
Late
Early
Abathomphalus mayaroensis
Globotruncana contusa
Globotruncana gansseri
Globotruncana tricarinata
Globotruncana calcarata
Globotruncana ventricosa
Globotruncana elevata
Dicarinella asymetrica
Dicarinella concavata
Dicarinella primitiva
(samples not available)
Orbitoides medius / Omphalocyclus macroporus
Globotruncana atlantica / Globotruncana patelliformis
Globotruncana stuartiformis
Globotruncana patelliformis
Elphidella multiscissurata/
Fissoelphidium
Lepidorbitoides/Chrysalidina
Omphalocyclus macroporus / Orbitoides
Globotruncana marginata / Globotruncana subcircumnodifer
Globotruncana concavata
Globotruncana schneegansi
No Planktonics
Globotruncana stuartiformis
Globotruncana elevata / Globotruncana concavata
Globotruncana renzi

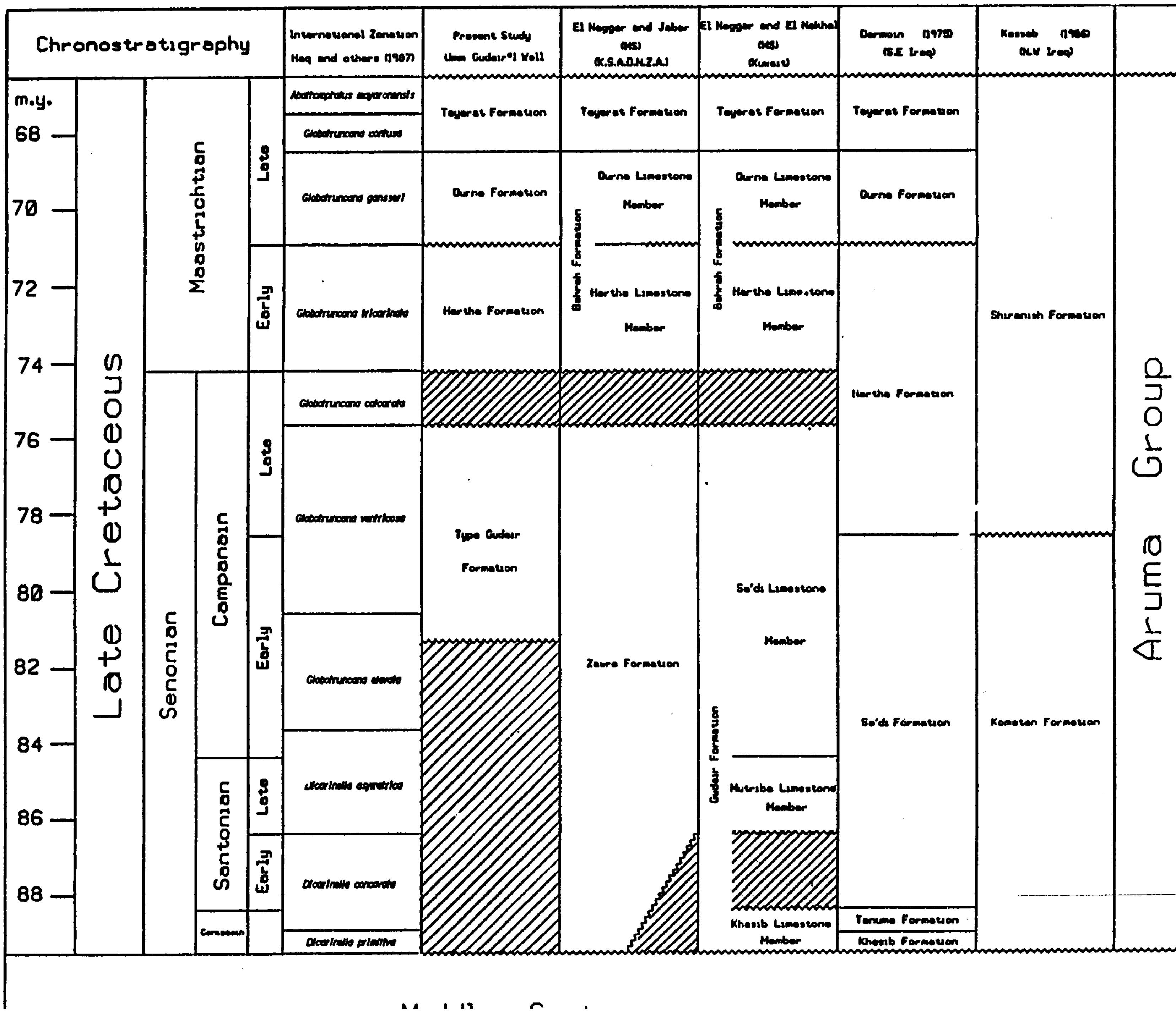


Text-Fig. 10: Correlation of suggested biozones for the Late Cretaceous succession penetrated by the Umm Gudair # 1 Well (including type Gudair Formation) with both previously suggested biozones in the region and the standard planktonic foraminiferid zones for the same time span.

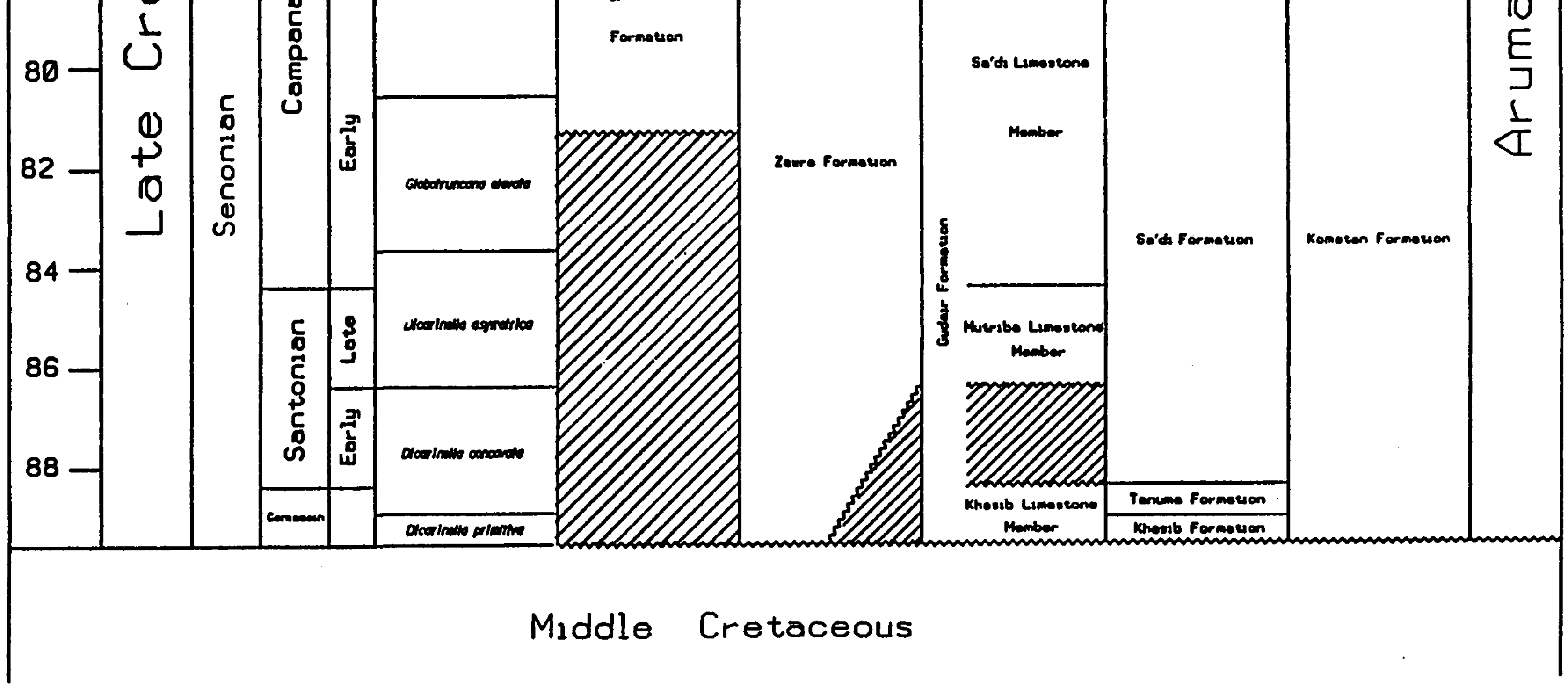
Consequently, the Middle/Late Cretaceous unconformity in the Umm Gudair#1 crestal Well encompasses the Late Turonian, Coniacian, Santonian, and part of the Early Campanian. This unconformity in the Umm Gudair#1 Well is found to be so huge that it exceeds its equivalents across the Khafji and some other Kuwaiti structures (Text-Figs. 10,11).

2- The *Globotruncana atlantica / G. patelliformis* Assemblage Zone :

This biozone occupies the top 380' (116 m) of the Gudair Formation. It is characterized by a rich fossil assemblage that includes both planktonic and benthonic foraminiferids. Identified planktonic foraminiferids include ***Rugoglobigerina macrocephala*, *R. rugosa*; *Globotruncana atlantica*, *G. gagnebini*, *G. insignis*, *G. orientalis*, *G. patelliformis*; *G. subspinosa*; *Heterohelix globulosa*** and ***H. papula*.** Among the benthonic foraminiferids, ***Pseudedomia sp.* (*cf. complanata*** and ***globulosa*), *Meandropsina sp.*** and ***Cuneolina sp.*** represent the most abundant forms (Text-Fig. 9).



Chronostratigraphy
m.y.
68
70
72
74
76
78
80
82
84
86
88
Late Cretaceous
Senonian
Maastrichtian
Campanain
Santonian
Coniacian
Late
Early
International Zonation Haq and others (1987)
Abathomphalus mayaroensis
Globotruncana contusa
Globotruncana gansseri
Globotruncana tricarinata
Globotruncana calcarata
Globotruncana ventricosa
Globotruncana elevata
Dicarinella asymetrica
Dicarinella concavata
Dicarinella primitiva
Present Study Umm Gudair-1 Well
Tayarat Formation
Qurna Formation
Hartha Formation
Type Gudair Formation
El Naggar and Jaber (1983) (K.S.A.D.N.Z.A.)
Qurna Limestone Member
Hartha Limestone Member
Bahrah Formation
Zaura Formation
El Naggar and El Nakhal (1983) (Kuwait)
Sa'di Limestone Member
Mutriba Limestone Member
Khasib Limestone Member
Gudair Formation
Darmoin (1975) (S.E Iraq)
Sa'di Formation
Tanuma Formation
Khasib Formation
Kassab (1986) (N.W Iraq)
Shiranish Formation
Kometan Formation
Aruma Group



Text-Fig. 11: Correlation of the suggested lithostratigraphic subdivisions for the Late Cretaceous succession in the Arabian Gulf region (including the type Gudair) with the standard planktonic foraminiferid zones for the same time span.

The lower boundary of this biozone is marked by the first appearance of ***Globotruncana atlantica***. This species has been described to mark the base of the Middle Campanian - *G. ventricosa* Zone by its first appearance (*cf*. Robaziniski and others, 1984). Thus, it is suggested that the lower boundary of this biozone coincides with the lower boundary of the Middle Campanian - *G. ventricosa* Zone of the international zonation of planktonic foraminiferids (*cf*. Robaziniski and others, 1984; Caron, 1986 etc.). The upper boundary of the *Globotruncana atlantica / G. patelliformis* Zone is here interpreted to coincide with the upper boundary of the international *G. ventricosa* Zone. This is due to the fact that *Globotruncana calcarata* - which is the international index fossil for the Late Campanian - has not been recorded in the studied section. This is substantiated by almost all the workers in the area who did not record either *G. calcarata* or its equivalents in their studied Late Cretaceous successions (*cf*. El-Naggar and Jaber, Ms; El-Naggar and El-Nakhal 1987, Text-Fig. 10). However, *G. calcarata* has been recorded by Kassab (1975) and Kassab and Al-Omari (1986) in northern Iraq which is very far basinward relative to the section studied here.

Therefore, it is here concluded that the ***Globotruncana atlantic / G. patelliformis*** Zone is of Middle Campanian age and is overlain by an unconformity that encompasses the Late Campanian. The presence of ***Pseudedomia sp.*** and ***Meandropsina sp.***, that are index benthonic foraminiferids for the Campanian, substantiates the interpreted age from planktonic foraminiferids recorded in the ***Globotruncana atlantica / G. patelliformis*** Zone.

The ***Globotruncana gagnebini*** was described to first appear in the Early Maastrichtian by Robaziniski and others (1984) who regarded it as a senior synonym of ***G. aegyptiaca***. However, in the present study, ***G. gagnebini*** has been recorded in the Middle Campanian ***G. atlantica / G. patelliformis*** Zone of the studied section. This species has also been recorded in the Campanian succession of nearby wells (*cf.* El-Naggar and Jaber, Ms; El-Naggar and El-Nakhal, 1987). According to El-Naggar (1966), ***G. gagnebini*** had already been recorded in the Campanian - Maastrichtian of northeastern Colombia by Gandolfi (1955).

Rugoglobigerina macrocephala has been described by Robaziniski and others (1984) to first appear in the Middle Maastrichtian. However, this species has been recorded in abundance in the Campanian of the studied section as well as of nearby wells (e.g Dorra Well Report by Dr. El-Naggar). Again, according to El-Naggar (1966), *R. macrocephala* has been recorded in the Campanian - Maastrichtian of northern Colombia by Gandolfi (1955).

The Middle Campanian - *Globotruncana ventricosa* Zone of Robaziniski and others (1984) is equivalent to the synonymous zone of Wonders (1980) and Caron (1986). Also, this zone is partially equivalent to the *G. stuarti* Zone of Bolli (1966), the *G. elevata* Zone of both Passagno (1967) and Postuma (1971), the *G. subspinosa* and *G. stuartiformis* Zones of Van Hinte (1976) and the *G. elevata / G. stuartiformis* Zone of Sigal (1977, Text-Fig. 8).

Locally, the *Globotruncana atlantica / G. patelliformis* Zone is partially equivalent to the *G. marginata / G. subcircumnodifer* Zone of El-Naggar and Jaber (Ms) and the *G. stuartiformis* Zone of El-Naggar and El-Nakhal (1987, Text-Fig. 10).

Since the range of the *Globotruncana patelliformis* covers exactly the two biozones, so far described, it was suggested to include *G. patelliformis* in the name of each of those biozones. So, the lower *G. stuartiformis / G. patelliformis* Zone is chosen to represent the lower interval of the *G.*

patelliformis range before the first appearance of the *G. atlantica* while the upper *G. atlantica / G. patelliformis* Zone represents the upper interval of the *G. patelliformis* range after the appearance of *G. atlantica*.

3- The *Orbitoides medius / Omphalocyclus macroporus* Assemblage Zone :

This biozone coincides exactly with the Hartha Formation. It is characterized by well developed larger foraminiferids that include *Orbitoides medius* and *Omphalocyclus macroporus* in addition to *Orbitolina sp.* and *Cuneolina sp. Pseudedomia sp. (cf. multistriata)* has also been recorded. Planktonic foraminiferids are generally rare in this biozone, but nevertheless, the following forms have been identified : *Globotruncana esnehensis, G. falsostuarti, G. gansseri widenmaryi, G. orientalis* and *G. subspinosa* (Text-Fig. 9).

Orbitoides medius and *Omphalocyclus macroporus* are generally considered as index fossils for the Maastrichtian (*cf.* Hanzawa, 1962; Ellis and Messina, 1966-1967; Salaj and Nairn, 1987). *Pseudedomia multistriata* is an index fossil for the Maastrichtian (Ellis and Messina, 1966-67).

In the Middle East, ***Orbitoides medius*** as well as ***Omphalocyclus macroporus*** have been proved to be index fossils for the Maastrichtian (*cf.* Bozoregina, 1964; Sampo, 1969; El-Naggar and Jaber, Ms; El-Asa'ad, 1984; Harris and others, 1984).

Locally, the ***Orbitoides medius / Omphalocyclus macroporus*** Zone of the Umm Gudair#1 Well coincides with the ***Omphalocyclus macroporus / Orbitoides*** Zone of El-Naggar and Jaber (Ms) and the ***Loftusia / Omphalocyclus*** Zone of Sampo (1969, Text-Fig. 10).

The ***Orbitoides medius*** Zone has been generally equated with the Early Maastrichtian - ***Globotruncana falsostuarti*** Zone in nearby Late Cretaceous section (e.g. in the U.A.E.). ***Globotruncana falsostuarti*** has also been recorded in the ***Orbitoides medius / Omphalocyclus macroporus*** Zone of the present study (Text-Fig. 9). However, although ***Globotruncana falsostuarti*** has been used as a zonal marker for the Early Maastrichtian by Robaziniski and others (1984), it was found advisable to name the zone after the more abundant larger foraminiferids.

The ***Globotruncana falsostuarti*** Zone of Robaziniski and others (1984) has been equated with the ***G. havanensis / G. aegyptiaca***

Zone of Caron (1986), the *G. tricarinata* Zone of Wonders (1980), the *G. stuarti / G. falsostuarti* Zone of Sigal (1977), the *G. scutilla* Zone of Van Hinte (1976), the *G. stuartiformis* Zone of Postuma (1971), the *G. subcircumnodifer* Zone of Passagno (1967), the *G. fornicata* Zone of El-Naggar (1966), and the *G. lapperenti tricarinata* Zone of Bolli (1966) and thus has been assigned an Early Maastrichtian age (Text-Fig. 8).

Thus, it is concluded that the *Orbitoides medius / Omphalocyclus macroporus* Zone in the Umm Gudair#1 Well is of Early Maastrichtian age. The biozone is underlain by an unconformity that encompasses the Late Campanian - *Globotruncana calcarata* Zone as discussed earlier. The upper contact of the *Orbitoides medius / Omphalocyclus macroporus* Zone is interpreted to be disconformable on the basis of the sharp lithologic change across this contact as discussed in the overlying biozone.

4- The *Globotruncana gansseri* Assemblage Zone :

This biozone coincides with the Qurna Formation. It contains a rich, well preserved fossil assemblage of almost exclusively planktonic foraminiferids. These include *Guembletria sp., Rugoglobigerina hexacamerata, R. macrocephala, R.*

pennyi, R. pustulata, R. rugosa; Globotruncana aegyptiaca, G. arca, G. bulloides, G. contusa, G. falsostuarti, G. fornicata, G. pettersi; Heterohelix globifera and *H. globulosa* (Text-Fig. 9).

Most of the recorded species have been described by Robaziniski and others (1984) to be confined to the late Early, Middle and Late Maastrichtian time. These include, among others, *Rugoglobigerina hexacamerata, R. pennyi; Globotruncana aegyptiaca, G. contusa* and *G. pettersi*. *Globotruncana bulloides* has been described by Robaziniski and others (1984) to disappear during the Early Maastrichtian, nevertheless, this species has been recorded in abundance in the Middle Maastrichtian of Arabia (*cf.* El-Naggar and Jaber, Ms; Kassab and Al-Omari, 1986; El-Naggar and El-Nakhal, 1987).

Similar fossil assemblages have already been included in the Middle Maastrichtian - *Globotruncana gansseri* Zone in the biozonation of the nearby Late Cretaceous sections (*cf.* El-Naggar and Jaber, Ms; El-Naggar and El-Nakhal, 1987). Thus, although *Globotruncana gansseri* itself could not be identified in the studied section, it was decided to name this biozone after *Globotruncana gansseri* since it is well recognized in all nearby sections.

The *Globotruncana gansseri* Zone in the Umm Gudair#1 Well is equivalent to its synonyms (Text-Fig. 10) of El-Naggar and Jaber (Ms), Darmoin (1975) and El-Naggar and El-Nakhal (1987). Also, it is equivalent to the *Globotruncana gansseri / G. bahijae / Gublerina cuvillieri* subzone of Kassab and Al-Omari (1986).

Fortunately, *Globotruncana gansseri* is widely used as an international zonal marker for the whole Middle Maastrichtian or sometimes part of it. The biozonation chart adapted in this study (Text-Fig. 8) shows that the *Globotruncana gansseri* Zone of Robaziniski and others (1984) is equivalent to its synonyms of Caron (1986), Sigal (1977), Postuma (1971), Passagno (1967), El-Naggar (1966) and Bolli (1966). Also, this zone is equivalent to the *Globotruncana contusa / G. gansseri* Zone of Wonders (1980) and *G. contusa / G. stuarti / G. gansseri* Zone of Van Hinte (1976).

Consequently, it can be easily concluded here that the *Globotruncana gansseri* Zone in the Umm Gudair#1 Well is of Middle Maastrichtian age. However, the zone is incomplete here as its lower boundary is believed to be disconformable. This is based on the abrupt facies change across this boundary from the underlying shallow marine, detrital limestone of the Hartha Formation to the overlying pelagic, marly limestone facies of the Qurna Formation, which is flooded by planktonic foraminiferid remains.

V. MICROFACIES ANALYSIS OF THE STUDIED SECTION

The term microfacies has been introduced to define the total of all the paleontological and sedimentological criteria which can be observed in thin sections, peels and/or polished slabs of sedimentary rocks (*cf.* Flugel, 1982). The term was independently introduced by both Brown (1943) and Cuvillier (1952), but since then, the microfacies concept has gained momentum particularly in the exploration for hydrocarbons in carbonate reservoirs. This technique has also been found useful in solving numerous paleontological problems especially in identifying larger microfossils with complex internal structures.

Microfacies analysis of sedimentary successions is regarded as an excellent tool for microstratigraphy due to the following reasons:

1- It allows for equal consideration of both the paleontological and the lithological characteristics of the studied sample.

2- It enables both the qualitative and the quantitative treatment of the litho- and biodata of the analyzed sample.

3- The study can be carried out on either thin sections, peels and/or polished slabs at any required magnification.

4- It enhances the application of small scale observations to larger scale ones (e.g. hand specimens and outcrop data).

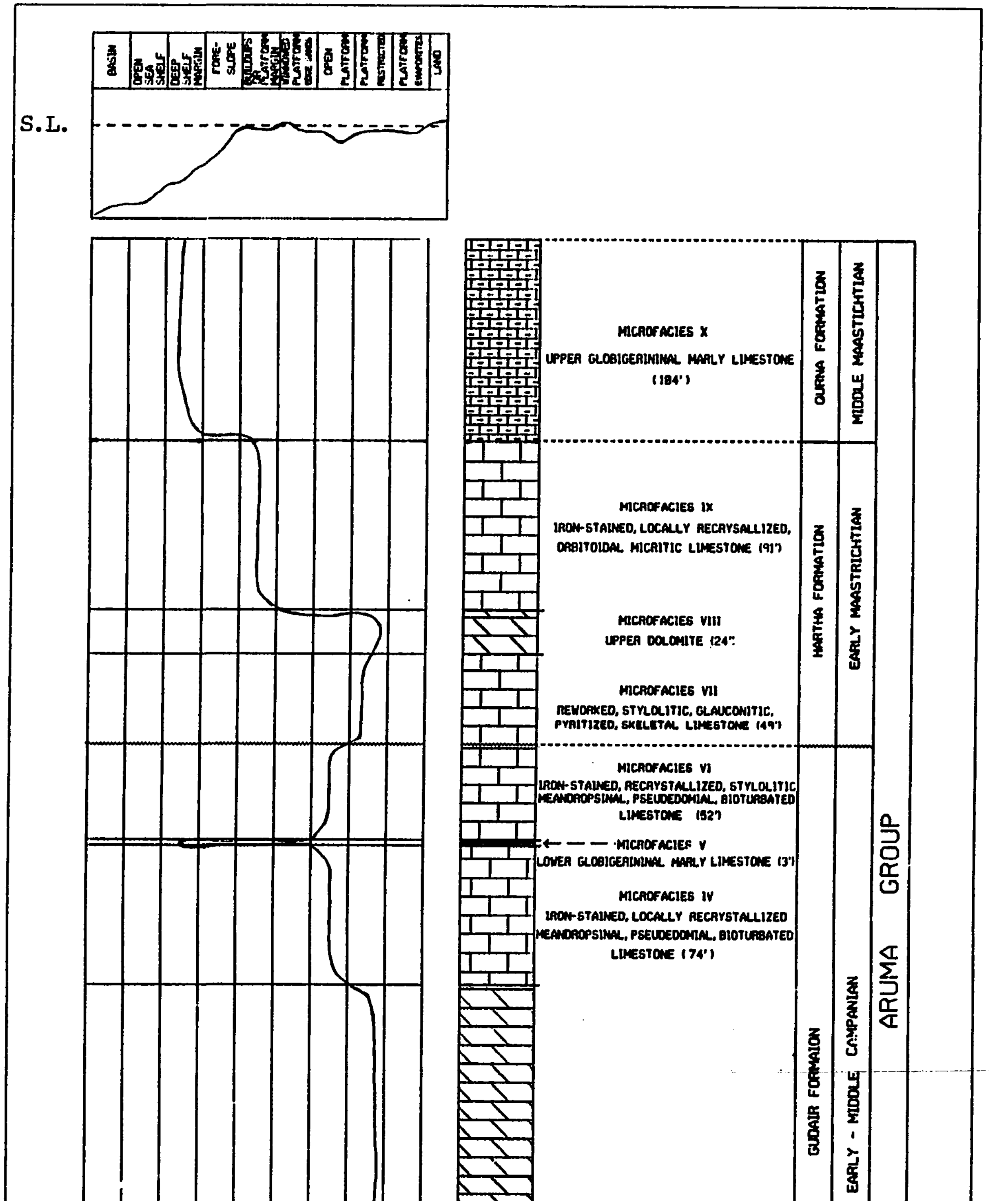
5- The introduction of both Standard Microfacies and Standard Facies Belts (Wilson, 1975) has enabled the general correlation of local microfacies with the standard ones. This can help in the construction of regional facies models and can contribute to the understanding of the analyzed sedimentary basins. However, it has to be understood that both the Standard Microfacies and Facies Belts are broad frameworks that can accommodate local environmental variations. These have to be improved upon with more detailed studies to accommodate as many local variations as possible.

Microfacies studies of the Late Cretaceous succession in both Arabia and nearby countries are very rare. These include both Bozoregnia and others (1964) and Sampo (1969) for Iran, Glennie and others (1970) for Oman and Schneidermann (1970) for occupied Palestine.

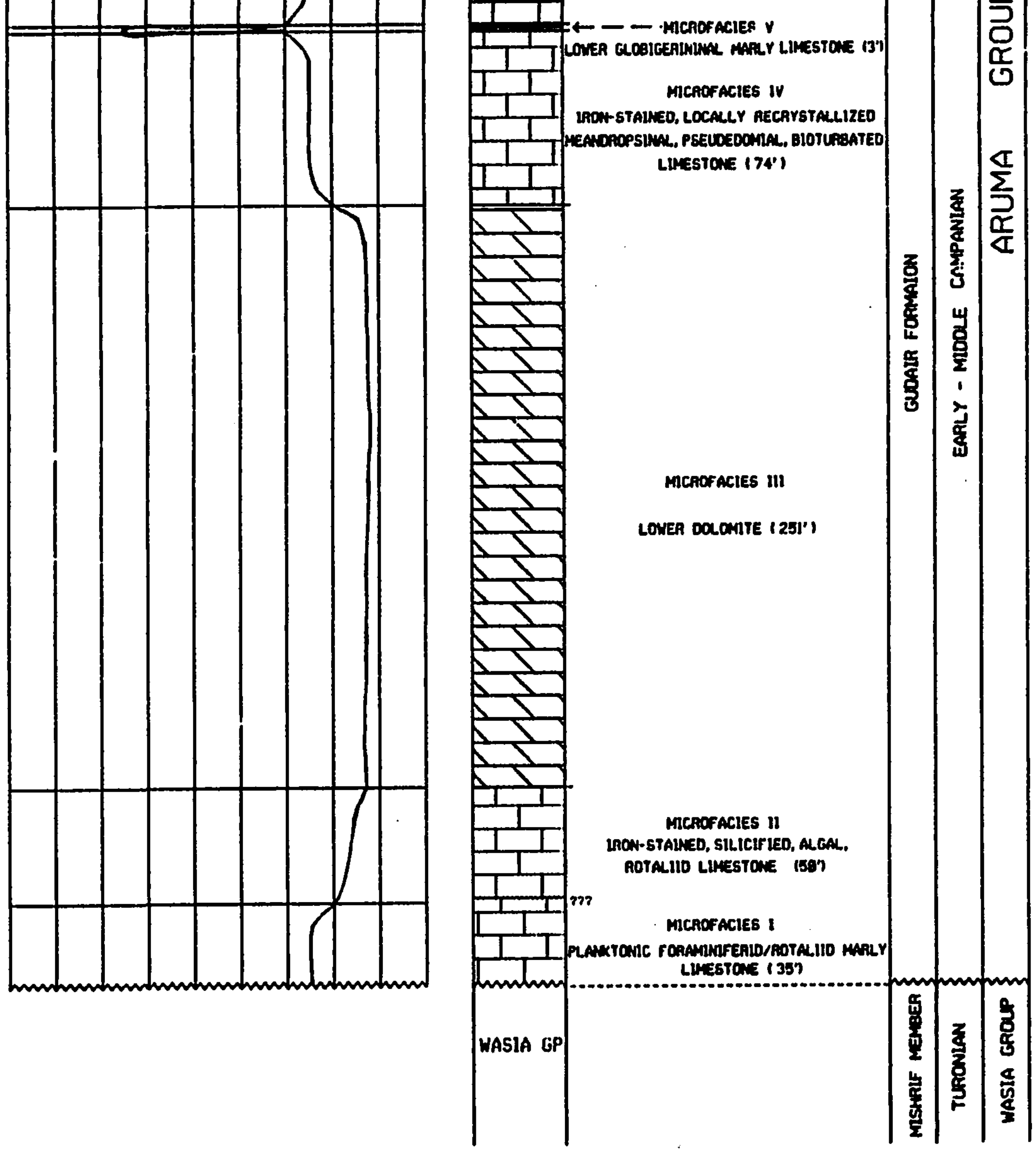
The microfacies analysis of the Late Cretaceous succession completes a previous analysis for the Middle Cretaceous succession by El-Naggar and Al-Rifaiy (1972 a,b,

1973) in the Umm Gudair#1 Well. This analysis has resulted in the recognition of ten successive microfacies in a vertical thickness of 733' (223m, Text-Fig. 12). These microfacies are here described from bottom to top with the interpretation of both age and paleo-environmental conditions of deposition. Age interpretation has been established on the basis of planktonic foraminiferids wherever available due to their world-wide distribution and their recognized value in both biostratigraphic zonation and regional as well as inter-regional correlation. However, in the absence of planktonic forms, index larger foraminiferids were used for age interpretation. Again, both fossil assemblages and rock composition were used for the paleoenvironmental interpretation of the succession as well as for its correlation with the Standard Microfacies of Wilson (1975) whenever possible.

The terminology used in describing the different carbonate rocks encountered is that of Leighton and Pendexter (1962). However, Dunham's (1962) terminologies are also included within brackets for ease of correlation. The recorded microfacies are described from base to top as follows:



BASIN
OPEN SEA SHELF
DEEP SHELF MARGIN
FORE-SLOPE
OPEN PLATFORM
RESTRICTED
LAND
S.L.
MICROFACIES X
UPPER GLOBIGERININAL MARLY LIMESTONE (184')
MICROFACIES IX
IRON-STAINED, LOCALLY RECRYSALLIZED, ORBITOIDAL MICRITIC LIMESTONE (91')
MICROFACIES VIII
UPPER DOLOMITE (24')
MICROFACIES VII
REWORKED, STYLOLITIC, GLAUCONITIC, PYRITIZED, SKELETAL LIMESTONE (49')
MICROFACIES VI
IRON-STAINED, RECRYSTALLIZED, STYLOLITIC MEANDROPSINAL, PSEUDEDOMIAL, BIOTURBATED LIMESTONE (52')
MICROFACIES V
LOWER GLOBIGERININAL MARLY LIMESTONE (3')
MICROFACIES IV
IRON-STAINED, LOCALLY RECRYSTALLIZED MEANDROPSINAL, PSEUDEDOMIAL, BIOTURBATED LIMESTONE (74')
QURNA FORMATION
HARTHA FORMATION
GUDAIR FORMAION
MIDDLE MAASTICHTIAN
EARLY MAASTRICHTIAN
EARLY - MIDDLE CAMPANIAN
ARUMA GROUP



TEXT-FIG. 12: STRATIGRAPHY, MICROFACIES AND PALEO-ENVIRONMENTAL INTERPRETATION OF THE LATE CRETACEOUS SUCCESSION IN THE UMM GUDAIR # 1 WELL CORRELATED WITH THE FACIES MODEL OF WILSON (1975)

V.1- Microfacies I; (Pl. 2); The Planktonic Foraminiferid / Rotaliid Marly Limestone Microfacies :

This microfacies is composed of micritic, skeletal limestone (bioclastic wackestone) which is occasionally marly and locally recrystallized. The bioclastic content of this microfacies includes some index globotruncanid, rotaliid and miliolid remains together with a few ostracod, gastropod, echinodermal and pelecypod skeletal fragments.

This microfacies represents the lowermost part of the type Gudair Formation and occupies an interval of 35' (11m) between the drilled depths 4496' and 4461' in the Umm Gudair#1 Well.

The recorded index globotruncanids in this microfacies include both ***Globotruncana patelliformis*** and *G.* ***subspinosa*** , among others. These two forms were used to equate this microfacies with the lower part of the ***Globotruncana stuartiformis*** / ***G. patelliformis*** Zone of late Early Campanian age (see discussion under the Biostratigraphical Analysis of the Studied Section).

The Planktonic/Rotaliid Marly Limestone Microfacies is here correlated with the bioclastic wackestone Standard

Microfacies (SMF) 9 of Wilson (1975). The paleoenvironmental conditions of deposition of this SMF has been interpreted by Wilson (*op. cit.*) to be either in the Standard Facies Belt 2 (open sea shelf) or in the Standard Facies Belt 7 (open platform or shelf lagoon). The latter interpretation is more applicable in our case due to the presence of miliolids and the scarcity of stenohaline elements such as brachiopods, corals and cephalopods (*cf.* Wilson, 1975).

V.2- Microfacies II; (Pl.3); The Iron-stained, Silicified, Algal, Rotaliid Limestone Microfacies :

This microfacies consists of richly fossiliferous, skeletal limestone (bioclastic wackestone) that is frequently pyritized and silicified, with numerous glauconite grains. The skeletal remains are also occasionally pyritized and silicified and include algal, echinodermal, ostracod and foraminiferid remains (with abundant rotaliids and rare planktonics) as well as some bone fragments.

In the type Gudair, this microfacies is represented by a thickness of 50' (15m) of rock sequence (between the drilled depths 4461' and 4411' in the Umm Gudair#1 Well).

Due to apparent reworking, most of the index planktonic foraminiferids in this microfacies have not been well preserved. Nevertheless, specimens of *Globotruncana atlantica*, *G. stuartiformis* and *Hedbergella holmdelensis* have apparently escaped reworking and hence could be identified. This association coincides with the upper part of the *Globotruncana stuartiformis* / *G. patelliformis* Zone that has been assigned a late Early Campanian age (see the above discussion under Biostratigraphical Analysis of the Studied Section).

The presence of a few planktonic remains together with scattered glauconite grains, abundant algal remains as well as patchy pyritization and silicification in this microfacies reflect the unstable depositional conditions in a shallow platform environment. These characteristics are indicative of possible subaerial exposure after the deposition of shallow facies. This is further substantiated by the fact that the overlying microfacies is completely dolomitized.

V.3- Microfacies III; (Pl. 4, Figs. 1-4); The Lower Dolomite Microfacies :

This microfacies is composed of well-developed, secondary dolomite with a prominent mosiac texture, and occasional preservation of the primary micritic matrix and some rare fossil fragments. It occupies a thickness of 251' (77m, between the drilled depths 4160' and 44411') in the Umm Gudair#1 Well, and is characterized by the almost complete absence of index fossils. This can be attributed to the process of dolomitization and has hampered any age determination. However, the stratigraphic position of this dolomitic microfacies suggests an early Middle Campanian age, since it falls within the lower part of the Middle Campanian *G. atlantica/G. patelliformis* Zone (see discussion above under Biostratigraphical Analysis of the Studied Section).

As to the interpretation of the paleoenvironmental conditions of deposition of this microfacies, its dolomitization has to be taken into consideration. Currently accepted dolomitization models belong to two main categories. The first advocates reflux dolomitization by Mg-rich brines in areas of high evaporation rates. Such brines are usually generated along coastal sabkhas and percolate into nearby platform limestones, replacing the available Ca ions by their load of Mg ions (*cf.* Adams and Rhoades, 1960). The second dolomitization model deals with dolomites that exist within shelf and platform environments, away from supratidal sabkhas. This model is based on the experimental fact that mixing meteoric ground water with up to 30% seawater results in undersaturation of calcite and supersaturation of dolomite (*cf.* Badiozamani, 1973). Consequently, such a mixture of fresh and sea waters can account for the diagenetic change of deposited calcite in shelf and platform environments into dolomite, especially along positive elements of such environments.

Indeed, this mixed-water model has already been applied to explain the presence of dolomite along structurally positive elements within shelf environments (*cf.* Badiozamani, *op. cit.*). Along such intrashelf highs, very shallow water conditions can prevail due to relative lowering of sea level, either as a result of eustacy or vertical movement. This can enable mixing of fresh (meteoric) and sea waters in proper portions to create a phreatic zone suitable for the replacement of these very shallow to almost emerging limestones into dolomites.

This model can be easily applied to explain the mode of formation of the present Dolomite Microfacies in a near-emergence, mixed water environment. Indeed, this represents the end phase of a shallowing-upward sequence, despite the fact that the basal part of the Gudair Formation was transgressive and overstepping (i.e. came after a long period of emergence of about 8.5 million years from the Late Turonian to the Early Campanian). Upward shallowing under such conditions can only be explained by local uplift (as outlined under Stratigraphical Analysis of the Studied Section). The Umm Gudair structure was apparently rising up during the Early Campanian time as evidenced by the upward change of facies from normal subtidal environment (Microfacies I), followed upward by a shallow intertidal condition with obvious reworking (Microfacies II) and finally to a near-emergence, mixed-water environment where diagenetic dolomitization did take place (Microfacies III).

Regarding the time of dolomitization, one can easily see that it must have taken place at a very early stage in the formation of these carbonates. This is substantiated by the fact that the dolomite crystals are usually very well developed with very little or no pre-dolomitization features. Such conditions suggest that the dolomitization occurred in a very porous medium that enabled the dolomitizing solutions to move freely within the medium. This highly porous medium can only be available in carbonate sediments prior to both cementation and compaction.

However, a number of recent studies (e.g Machel and Mountjoy, 1986, Gunatilaka, 1987) suspects the ability of the mixed-water model (and even the seepage reflux model) to produce thick dolomite sequences that exceed a few meters in thickness. Consequently, a number of additional models have been proposed to account for large thicknesses of dolomites. These include the shallow subtidal model, the subsurface dolomitization model and the thermal convection model (*cf.* Machel and Mountjoy, *op. cit.*). These models are still premature and need to be thoroughly studied and reviewed in order to be applied. Moreover, they imply the incorporation of intensive geochemical (e.g. isotope, thermodynamic, kinetic, etc.) and hydrologic data in addition to the classic stratigraphic and petrographic information. Such geochemical and hydrologic investigations are beyond the scope of the present work and even beyond the limits of the data available.

V.4- Microfacies IV; (Pl. 4, Figs. 5-16;Pl. 5;Pl. 6); The Iron-stained, Locally Recrystallized, Meandropsinal, Pseudedomial Bioturbated Limestone Microfacies :

This microfacies is mainly composed of skeletal limestone (bioclastic packstone) that grades occasionally to micritic skeletal limestone (bioclastic wackestone). Most of the skeletal remains belong to the larger foraminiferid genus ***Pseudedomia*** which dominates the microfacies with fragmented as well as occasionally whole tests. Such fragments are sometimes so highly reworked that they become well rounded and moderatly sorted. The microfacies is also characterized by occasional recrystallization which, in places, is well developed with clear cleavage planes and rhombohedral crystals. Iron oxides are also present either as small patches or in a disseminated form.

This microfacies occupies the middle part of the type Gudair Formation (in the Umm Gudair#1 Well) where it is represented by a 74' (23m)-thick succession between the drilled depths 4160' and 4086'.

The fossil assemblage of this zone is very diverse, but is dominated by the remains of the index benthonic foraminiferid genus ***Pseudedomia*** and hence it was taken to name the microfacies. These are in addition to meandropsinal, miliolid, rotaliid and cuneolinal remains as well as some planktonic foraminferid remains. The latter remains are generally scarce but include some minute forms of the index species: *Globotruncana insignis*, *G. orientalis*, *G. patelliformis* and *G. subspinosa*. Some rare echinodermal and algal remains are also present. The fossil assemblage can place this microfacies within the upper part of the *Globotruncana atlantica/G. patelliformis* Zone that has been assigned a Middle Campanian age (see discussion above).

This microfacies can be correlated with either the SMF 9 or the SMF 18 of Wilson (1975), as both facies can accommodate high foraminiferal abundance. However, the bioturbation, as well as the diversity of the skeletal fragments and the presence of micritic matrix can substantiate the correlation with the SMF 9. This Standard Microfacies is interpreted by Wilson (*op. cit.*) to be deposited in an open sea either on the shelf (Standard Facies Belt 2) or in an intra-platform sub-basin (an open platform shelf lagoon of the Standard Facies Belt 7). However, the scarcity of stenohaline forms (e.g. brachiopods, corals and cephalopods) as well as the presence of miliolids can support the latter interpretation of an open platform environment.

V.5- Microfacies V; (Pl. 7); The Lower Globigerininal Marly Limestone Microfacies:

This microfacies is composed of skeletal (exclusively globigerininal foraminiferid) marly limestone (pelagic wackestone). Most of the planktonic foraminiferids recorded here belong to the genera *Rugoglobigerina*, *Globotruncana*, *Hedbergella* and *Heterohelix*. These include *Rugoglobigerina hexacamerata*, *R. macrocephala*, *R. pennyi*, *R. rugosa*; *Globotruncana gagnebini*; *Heterohelix globulosa* and *H. papula*. Such rich association of index planktonic foraminiferid remains can clearly place this microfacies within the upper part of the *Globotruncana atlantica/G. patelliformis* Zone of Middle Campanian age (see discussion above). This exclusively planktonic foraminiferid wackestone is represented in the type Gudair Formation by only 3'(in the Umm Gudair#1 Well) between the drilled depths 4083' and 4086'.

Both its lithologic and paleontologic criteria can clearly equate this microfacies with the SMF 3 of Wilson (1975) which he has named the pelagic mudstone/wackestone microfacies. According to Wilson (*op. cit.*) this microfacies can characterize either the Standard Facies Belt

1 (basinal facies) or the Standard Facies Belt 3 (deep shelf facies). However, the absence of typical deep basin-criteria (such as turbidites, cherts, radiolarites or diatomites, etc.) clearly excludes the basinal environment. This leaves no other alternative except the deep shelf environment, despite the fact that deposition in such an environment is usually accompanied by the abundance of benthonic foraminiferids, (*cf.* Wilson, 1975). This is not the case here as we are dealing with an exclusively-planktonic foraminiferid microfacies. Such condition can prevail with the sudden rising of the sea level, which results in the migration of the benthonic forms towards the new coast line and the evacuation of the environment for only pelagic remains to accumulate. This may be possibly explained by the world-wide rising in the sea level during the Late Campanian time (*cf.* Haq and others, 1987, Text-Fig. 7), although such rising has been locally hampered by the rising ridges from the bottom of the Cretaceous sea as was the case with all positive structures in the area (such as all the known oil fields, including the Umm Gudair structure). However, this sudden relative rise in the sea level can be alternatively explained by tectonic forces due to the formation (for example) of pull-apart basins that are

usually associated with wrench faults, but the accurate interpretation of this 3'-thick, globigerininal marly limestone interval remains difficult untill the lateral continuity of this facies anomaly is verified.

V.6- Microfacies VI; (Pl. 8; Pl. 9, Figs 1-8); The Iron-stained, Recrystallized, Stylolitized, Meandropsinal, Pseudedomial, Bioturbated Limestone Microfacies:

This skeletal limestone (bioclastic packstone) microfacies is frequently intercalated with micritic, skeletal limestone (bioclastic wackestone), with various degrees of bioturbation, indicated by the highly brecciated, occasionally rounded and poorly sorted skeletal fragments. Coarsely recrystallized patches with clearly developed cleavage planes are often encountered, and stylolites are frequently observed with iron oxides filling and fringing their cavities. The skeletal fragments are dominated by remains of *Pseudedomia spp.* , together with other foraminiferid remains and bone fragments. The other foraminiferid remains include both benthonic (rotaliid, textulariid and Bolivinoid remains) as well as a few planktonic forms.

This microfacies characterizes the topmost 52' (16m) of the type Gudair Formation in the Umm Gudair#1 Well (between the drilled depths 4083' and 4031').

Index fossils recorded in this microfacies include remains of the two benthonic foraminiferid genera ***Pseudedomia*** and ***Meandropsina*** in addition to the planktonic foraminferid genus ***Globotruncana*** (eg. ***G. patelliformis*** and ***G. subspinosa***). Such association clearly places this microfacies at the topmost part of the Middle Campanian ***Globotruncana atlantica/G. patelliformis*** Zone (see discussion above).

This microfacies can be regarded as a natural extension of Microfacies IV, with the interruption of the pelagic Microfacies V inbetween. Indeed, both Microfacies (IV and VI) are closely similar in their fossil content, degree of bioturbation and diagenetic history (e.g. recrystallization and iron-staining) except for the stylolites which are frequently recorded in Microfacies VI. The similarity between the two Microfacies (IV and VI) can suggest their inclusion, together with the intervening Microfacies V, into one microfacies, subdivided by this pelagic tongue into three distinctive sub-microfacies. However, it was found advisable to treat them separately here, to avoid the overlooking of Microfacies V, which -despite its small thickness- represents a major change in the environmental conditions of deposition. Similar to Microfacies IV, Microfacies VI can be easily correlated with the SMF 9 of Wilson (1975) and its paleoenvironment can be interpreted as an open platform which coincides with the Standard Facies Belt 7 of Wilson (*op. cit.*).

V.7- Microfacies VII; (Pl. 9, Figs 9-16; Pl. 10, Figs 1-12); The Reworked, Stylolitic, Glauconitic, Pyritized, Skeletal Limestone Microfacies:

This microfacies is composed of skeletal limestone with micritic matrix (bioclastic wackestone-packstone) that usually grades to recrystallized calcite (bioclastic grainstone). Pyritization, ferrugination and intensive reworking are the main characteristics of this microfacies in addition to the presence of stylolites and glauconite grains. The fossils are generally damaged by reworking and masked by ferrugination, but some could still be identified. These include *Pseudedomia sp.*, *Omphalocyclus macroporus*, rotaliid, miliolid and a few planktonic foraminiferid remains in addition to echinoid spines and bryozoan skeletal fragments.

This microfacies characterizes the lowermost 49' (15m) of the Hartha Formation (between the drilled depths 4031' and 3982' in the Umm Gudair#1 Well), which overlies the type Gudair Limestone with a marked discontinuity. This break involves -at least- the whole of the Late Campanian (1.5 m.y.) and seems to be of a regional nature. It is manifested in the complete absence of the Late Campanian ***Globotruncana calcarata*** Zone all over Arabia and the Arabian Gulf region, as well as in the intensive reworking, pyritization, recrystallization and stylolitization of the basal part of the Hartha Formation.

The few recognizable index fossils of this microfacies clearly place it in the lower part of the Early Maastrichtian ***Orbitoides medius/Omphalocyclus macroporus*** Zone as discussed above.

The intensive pyritization and reworking of this microfacies as well as the frequent recrystallization are clear evidences of the unstable tectonic conditions in the region at the Campanian-Maastrichtian boundary. Such tectonic instability could have resulted in the uplifting of the Umm Gudair structure together with many other similar structures in the region, leading to the subaerial exposure of previously deposited shallow-water sediments and their consequent extensive diagenetic alterations. The presence of completely dolomitized facies above this reworked microfacies substantiates the idea of subaerial exposure of these Campanian deposits shortly after their deposition. A similar succession of reworking followed by dolomitization has also been noticed near the base of the Gudair Formation (Microfacies I and II).

V.8- Microfacies VIII; (Pl. 10, Figs. 13-16); The Upper Dolomite Microfacies:

This microfacies consists of secondary dolomite with euhedral to subhedral crystals arranged in a sub-mosiac texture. The pre-dolomitization micritic matrix, is occasionally preserved, and the rock is generally stained with sporadic patches of iron oxides which are particularly concentrated along the edges of the dolomite crystals.

The Upper Dolomite Microfacies characterizes a 24' (7.3m)-thick part of the Hartha section (between drilled depths 3982' and 3958') in the Umm Gudair#1 Well. Here, intensive dolomitization has almost completely destroyed the fossil content, if any, and hence no direct or indirect indications of organic remains were recorded. This has made it difficult to date this part of the succession, but on the basis of its stratigraphic position it is here considered to be of Early Maastrichtian age as it falls within the Early Maastrichtian ***Orbitoides medius/Omphalocyclus macroporus*** Zone.

Similar to the case of Microfacies III, above, the complete dolomitization here can be explained by the model of mixed fresh and sea waters over positive, intra-shelf, structural elements (*cf.* Badiozamani, 1973). Apparently, the dolomitizing solutions moved freely in a very porous medium prior to cementation, as evidenced by the complete dolomitization of the rock. This has probably taken place while the growth of the Umm Gudair structure (similar to many contemporaneous structures in the Arabian Gulf region) has just brought it to near emergence from the bottom of the Late Cretaceous sea.

V.9- Microfacies IX; (Pls. 11, 12); The Iron-stained, Locally Recrystallized, Orbitoidal Micritic Limestone Microfacies:

This microfacies varies from almost completely recrystallized limestone (bioclastic packstone-grainstone) with very small-sized (possibly current-sorted) microfossils at the base to micritic skeletal limestone (bioclastic wackestone) with frequent recrystallization patches and orbitoidal remains towards the top. These could not be split into two distinctive microfacies due to the fact that they interdigitate throughout this part of the succession, which is affected by varying degrees of staining with iron oxides. The fossils recorded in this microfacies include benthonic as well as planktonic foraminiferid, coralline, algal, poriferal and rare ostracod, echinodermal and molluscan remains. The main benthonic foraminiferids recorded are ***Orbitoides medius*** and ***Omphalocyclus macroporus*** in addition to ***Cuneolina*** *sp.*, ***Pseudedomia*** *sp.* and some rotaliid remains, while the identified planktonic foraminiferids are predominantly species of the two genera ***Globotruncana*** and ***Hedbergella***.

This microfacies characterizes the upper two thirds of the Hartha Formation, occupying an interval of 91' (28m)-thick (between the drilled depths 3958' and 3867') in the Umm Gudair#1 Well. It is flooded by skeletal remains of the larger foraminiferids: ***Orbitoides medius*** and ***Omphalocyclus macroporus*** , which have been taken to distinguish an Early Maastrichtian Biozone that incorporates the present as well as the underlying two microfacies. The Early Maastrichtian age of the ***Orbitoides medius/Omphalocyclus macroporus*** Zone has also been substantiated by the recorded planktonic foraminiferid remains which include: ***Globotruncana esnehensis, G. gansseri widenmaryi, G. orientalis*** and ***G. subspinosa.***

This microfacies is taken to reflect an open marine, shoal paleoenvironment. This is concluded from the abundance of both algal and coralline remains as well as the absence of miliolids, and is substantiated by a flood of the studied section with remains of the foraminferid Family Orbitoididae which are known to distinguish such paleoenvironment elsewhere. Indeed, remains of such foraminiferids have always been taken to indicate either the shallow marine paleoenvironments just on the seaward side of the marine shoals or the shoal environment itself (*cf.* Reeckmann and Friedman, 1982). Interpretation of shoal, open marine environment of deposition for the same orbitoidal fossil assemblage from other areas in the Tethys domain has been reached by a large number of authors (*cf.* Harris and others, 1984, for the Late Cretaceous Simsima Formation of the U.A.E.; Kuss, 1986, for the Late Cretaceous of the Eastern Desert of Egypt and Eliagoubi and Powell, 1980, for the Late Cretaceous succession of Libya). The latter authors (*op. cit.*) cosidered the orbitoidal genus ***Omphalocyclus macroporus*** to be indicative of very shallow, high energy carbonate shoal, an interpretation that was later supported by Salaj and Nairn (1987) for all the orbitoidal assemblages of the Late Cretaceous succession of Libya. The open marine, shoal paleoenvironmental conditions of deposition for this part of the section which is characterized by abundant algal, coralline and orbitoidal remains, is also substantiated by the oolitic nature of corresponding Early to Middle Maastrichtian subsurface sections in both the nearby Burgan and Zawre Wells (*cf.* El-Naggar and Jaber, Ms).

This microfacies can be correlated with the SMF 12 of Wilson (1975) which exists in the Standard Facies Belts 5 (buildup or platform margin) and 6 (winnowed platform edge sands).

V.10- Microfacies X; (Pls. 13,14); The Upper Globigerininal Marly Limestone Microfacies:

This microfacies is composed of skeletal, micritic, marly limestone (bioclastic wackestone-packstone), with dominant planktonic and very rare benthonic foraminiferid remains. The recorded planktonic foraminiferids belong to the genera *Globotruncana*, *Rugoglobigerina*, *Heterohelix* and *Guembletria*, while the benthonic forms are limited to a few bolivinoid remains.

The microfacies characterizes the Qurna Formation, at large, which is developed for a thickness of 104' (32m, between the drilled depths 3867' and 3763') in the Umm Gudair#1 Well.

The planktonic foraminiferids recorded include *Guembletria sp.*; *Rugoglobigerina hexacamerata*, *R. macrocephala*, *R. pennyi*, *R. pustulata*, *R. rugosa*; *Globotruncana aegyptiaca*, *G. arca*, *G. bulloides*, *G. contusa*, *G. falsostuarti*, *G. fornicata*, *G. pettersi*; *Heterohelix globifera* and *H. globulosa*. This assemblage clearly substantiates the Middle Maastrichtian age of this microfacies and equates it with the *Globotruncana gansseri* Zone which has already been taken as a typical Middle Maastrichtian biozone for many parts of the world.

As to the paleoecological interpretation, this microfacies can be easily correlated with the SMF 3 of Wilson (1975) which he placed in both the Standard Facies Belt 1 (basinal facies) and 3 (deep shelf facies). The former interpretation is here excluded because of the absence of typical basinal facies, and hence, the latter conclusion of deep shelf environment is believed to be more appropriate. This is substantiated by the presence of benthonic foraminiferids, despite the fact that such forms are rather scarce in the present microfacies.

VI. SUMMARY AND CONCLUSIONS

The micro-stratigraphical analysis of 110 thin sectioned, cored samples from the Late Cretaceous succession penetrated by the Umm Gudair#1 Well has led to the recognition of three distinctive formations from the base to top as follows: the Gudair, Hartha and Qurna Limestones which are included in the Aruma Group. The Gudair succession here was chosen as the type section for the formation (*cf.* Owen and Nasr, 1958), and it is represented by a 465' (124m) -thick sequence of locally dolomitized detrital limestone (mostly flooded by pseudedomial remains) with a thin band (3'-thick) of globigerininal limestone near the top. The overlying Hartha Formation is separated from the Gudair Formation by a well-developed disconformity of more or less regional nature and is similarly composed of locally dolomitized, detrital limestone with orbitoidal remains at intervals. The Hartha Formation is represented by a succession of 164' (50m) in thickness, the base of which is highly reworked. The topmost 104' (32m) of the studied section belong to the Qurna Formation and are composed of globigerininal marly limestone with almost exclusively planktonic foraminiferid remains. No samples from the overlying Tayarat Formation in the Umm

Gudair#1 Well were available for this study.

By the use of its dominant foraminiferid remains (both planktonic and benthonic), four distinctive biozones have been recognized in the succession as follows:

4- The *Globotruncana gansseri* Zone; Middle Maastrichtian

3- The *Orbitoides medius/Omphalocyclus macroporus* Zone; Early Maastrichtian

2- The *G. atlantica/G. patelliformis* Zone; Middle Campanian

1- The *Globotruncana stuartiformis/G. patelliformis* Zone; late Early Campanian.

These were correlated with the standard planktonic foraminiferid zones and with other zones in the region and their ages were concluded. This has also aided in the recognition and in defining the magnitudes of two major unconformities in the studied succession. The first separates the Turonian (Mishrif Limestone Member) from the Campanian (Gudair Formation) and involves the Late Turonian, Coniacian, Santonian and a part of the Early Campanian, a time span of more than 8.5 m.y. The second unconformity incorporates the Late Campanian (equivalent to the

Globotruncana calcarata Zone) and hence separates the Gudair Formation from the overlying Hartha Formation. A minor break has also been suggested between the Hartha detrital limestone and the overlying globigerininal, marly limestone of the Qurna Formation on the basis of the abrupt lithologic change.

The succession has also been found to display a number of stratigraphic phenomena that are frequently described with carbonate sequences. The first is the shoaling-upward sequences displayed by both the Gudair and the Hartha Formations, while the second is the phenomenon of drowned platforms, recorded in the Gudair Formation. Both features have been analyzed, and it was concluded that the tectonic element (along the Umm Gudair#1 crestal Well) had been the most influencing factor in developing these phenomena.

Microfacies analysis of the succession has resulted in the recognition of 10 successive microfacies (from the base upwards) as follows:

1- The Planktonic Foraminiferid/Rotaliid Marly Limestone Microfacies (M. I).

2- The Iron-stained, Silicified, Algal, Rotaliid Limestone

Microfacies (M. II).

3- The Lower Dolomite Microfacies (M. III).

4- The Iron-stained, Locally Recrystallized, Meandropsinal, Pseudedomial Bioturbated Limestone Microfacies (M. IV).

5- The Lower Globigerininal Marly Limestone Microfacies (M. V).

6- The Iron-stained, Recrystallized, Stylolitized, Meandropsinal, Pseudedomial, Bioturbated Limestone Microfacies (M. VI).

7- The Reworked, Stylolitic, Glauconitic, Pyritized, Skeletal Limestone Microfacies (M. VII).

8- The Upper Dolomite Microfacies (M. VIII)

9- The Iron-stained, Locally Recrystallized, Orbitoidal Micritic Limestone Microfacies (M. IX).

10- The Upper Globigerininal Marly Limestone Microfacies (M. X).

These microfacies have been correlated with the Standard Microfacies of Wilson (1975) -whenever possible- and their paleoenvironmental conditions of deposition were interpreted. The two dolomite intervals in the succession have been suggested to have formed through the mixed-water (meteoric and sea waters) model across intra-shelf positive structures (*cf.* Badiozamani, 1973). Such interpretation is in harmony with the stratigraphical visualization of deposition over rising ridges from the bottom of the Late Cretaceous sea as supported by the two phenomena of shoaling upward sequences in both the Gudair and Hartha Formations and of deposition over drowned platforms recorded in the former formation, but the door has been left open for other interpretations in the light of the rapidly evolving theories of dolomitization. This is the first revision for the type Gudair Formation since its introduction, and the first microfacies analysis for the Late Cretaceous succession in the region. The study involves the interpretation of both the age and the paleoenvironmental conditions of deposition of the succession in the light of evidences that were never available before.

The microfacies, as well as both the litho- and biostratigraphical analyses of the Late Cretaceous succession in the Umm Gudair#1 Well have led to the following conclusions:

1- The type Gudair Formation is a valid rock unit in the subsurface Aruma Group of eastern Arabia. It is here considered to be equivalent to both the ***Globotruncana stuartiformis/G. patelliformis*** and the ***G. atlantica/G. patelliformis*** Zones and is assigned a late Early-Middle Campanian age.

2- The Hartha Formation is also recognized as a valid rock unit in the subsurface Late Cretaceous succession of the region. It is distinguished by the Early Maastrichtian-***Orbitoides medius/Omphalocyclus macroporus*** Zone.

3- The Qurna is similarly considered to be a valid formation in the succession and is equated with the ***Globotruncana gansseri*** Zone, and hence is considered to be of Middle Maastrichtian age.

4- The Middle/Late Cretaceous regional unconformity (or the Wasia/Aruma unconformity) in the Umm GUdair#1 Well is here, proved to be of a great magnitude as it incorporates the Late Turonian, Coniacian, Santonian and a part of the Early Campanian, a span of time that exceeds 8.5 m.y.

5- The Campanian/Maastrichtian break, although of a much lesser magnitude has also been proved to be of a regional extent. It explains the complete absence of the latest

Campanian - ***Globotruncana calcarata*** Zone and has been recorded in most of the drilled wells in the region.

6- The common consideration of the type Gudair Formation of southeastern Kuwait as the lateral equivalent of the Sa'di, Tanuma and Khasib Formations of both northeastern Kuwait and southeastern Iraq should be abondand. The type Gudair has been proved here to be of late Early to Middle Campanian age while the other three formations are of Senonian (Coniacian-Campanian) age. The type Gudair can be considered as a lateral equivalent to the Sa'di Formation only, since both formations are of Campanian age. Nevertheless, the two rock units have to be re-instated in the stratigraphy of the Late Cretaceous succession of eastern Arabia, due to their markedly different facies. While the Sa'di is represented by deep-water marls flooded with planktonic foraminiferid remains, the Gudair is dominantly composed of detrital limestones with pseudedomial remains.

7- Contrary to previous practices of including both the Hartha and the Qurna rock units into one formation (the Bahrah Formation), the two rock units are recommended here to be treated as two distinctive formations due to the abrupt facies change across their contact from iron-stained, shallow-water, orbitoidal limestone of the Hartha to the relatively much deeper water, globigerininal marly limestone of the overlying Qurna Formation. This is substantiated by the fact that the contact between these two rock units has been described to be disconformable by a number of authors (*cf.* El-Naggar and Jaber, Ms; El-Naggar and El-Nakhal, 1987; Darmoin, 1975).

8- The recorded phenomenon of shoaling-upward sequences in both the Gudair and the Hartha Formations, as well as the phenomenon of deposition over drowned platforms recorded in the Gudair Formation, have been mainly attributed to syn-sedimentary tectonic instability during the Late Cretaceous time in Arabia.

9- Microfacies analysis of the studied succession has aided in the interpretation of the paleoenvironmental conditions of its deposition. These had fluctuated between shallow platform to shelf conditions with pulsating ridges from the bottom of such platforms and shelves. This was the case throughout the Late Cretaceous time, and was apparently so - at least - throughout the Middle Cretaceous.

10- A thin band of globigerininal marly limestone (3' or 1m-thick) has been recorded near the top of the Gudair

Formation, being sandwiched between shallow-water, detrital limestone. Such facies anomaly may imply a sudden and very short deepening of the basin of deposition. This can be explained either structurally or in the light of a sudden rise in the sea-level. However, neither hypothesis can be adapted until much more is known about the lateral continuity of this facies anomaly.

11- The study emphasizes the need for more detailed microfacies analyses in the region in order to construct both facies and depositional models particularly during key episodes in the geologic history of Arabia, such as the Cretaceous Period.

12- The study also emphasizes the need for a better understanding of the structural framework and the tectonic history of eastern Arabia in order to keep pace with the current trends in basin analysis. This implies the incorporation of lithostratigraphic, biostratigraphic, microfacies and structural data together with the plate tectonic settings in understanding both the evolution and the patterns of deposition in sedimentary basins.

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Plate 1

Microfacies of the Gudair/Magwa Contact

Depth interval from 4496' to 4505'

Fig. 1: Photomicrograph showing an axial section of an ostracod carapus in a micritic, skeletal limestone matrix (PP,x17).

Figs. 2,3: Photomicrographs showing random sections in coralline remains (PP,x17).

Fig. 4: Photomicrograph showing a ruduistid shell fragment (PP,x17).

Fig. 5: Photomicrograph showing coralline remains (PP,x27).

Figs. 6,7,8: Photomicrographs showing equatorial sections in ***Hensonella sp.*** (PP,PP,CN,x17,x27,x27 respectively).

Figs. 9,10: Photomicrographs showing transverse sections in bryozoan remains (PP,x17,x27 respectivly).

Figs. 11,12: Photomicrographs showing recrystallized molluscan fragments (x17,PP,CN respectively).

Fig. 13: Photomicrograph showing echinodermal remains (CN,x17).

Figs. 14,15: Photomicrographs showing recrystallized patches embedded in micrite (note the iron-oxide patches in Fig. 15) (CN,x21,x67 respectively).

Fig. 16: Photomicrograph showing glauconite grains scattered in micrite (PP,x17).

PLATE 1

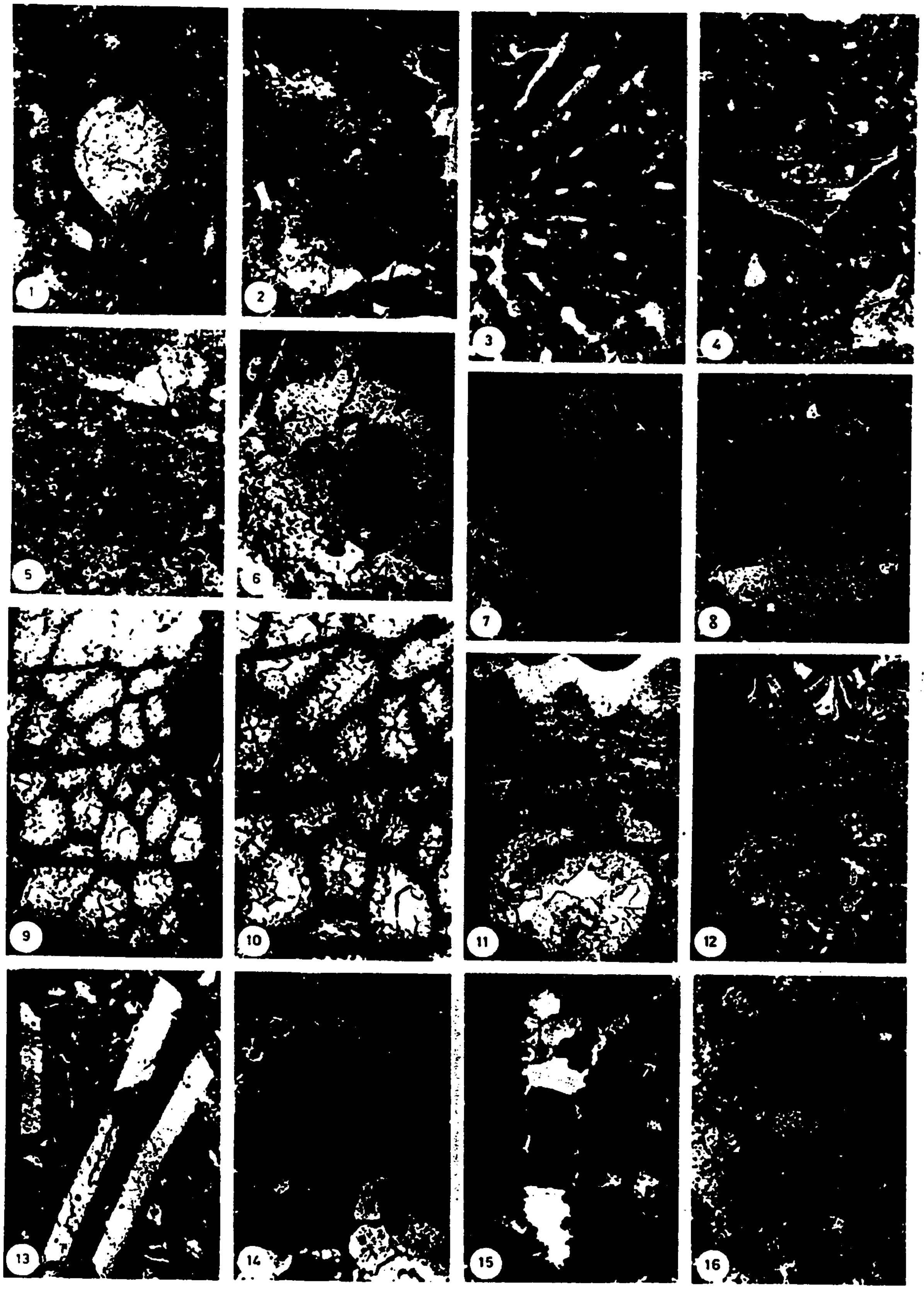

Plate 2

Microfacies I

Gudair Formation

Planktonic-Rotaliid Marly Limestone

Depth interval from 4496' to 4461'

Fig. 1: Photomicrograph representing this microfacies with abundant rotaliids and planktonic foraminiferid remains (PP,x22).

Figs. 2,3,5: Photomicrographs showing axial sections in ***Globotruncana patelliformis,*** note the dominance of micrite in Fig. 3 relative to others (PP,x106).

Fig. 4: Photomicrograph showing an axial section in ***Globotruncana subspinosa*** (CN,x106).

Figs. 6,7,8,9: Photomicrographs showing axial sections in rotaliids, note the presence of an axial section in ***Hedbergella sp.*** in Fig. 7 (CN,PP,CN,x67,x106 respectively).

Fig. 10: Photomicrograph showing a section in miliolids (PP,x67).

Fig. 11: Photomicrograph showing a section in ostracod sp. (PP,x106).

Fig. 12: Photomicrograph showing a section in echinodermal remains (PP,x106).

Fig. 13: Photomicrograph showing a section in larger foraminiferids (PP,x67).

Fig. 14: Photomicrograph showing section in a gastropods (PP,x67).

Fig. 15: Photomicrograph showing molluscan remains (PP,x106).

Fig. 16: Photomicrograph showing an equatorial section in an echinoid spine (PP,x106).

Fig. 17: Photomicrograph showing a recrystallized vein embedded in micritic matrix (PP,x106).

PLATE 2

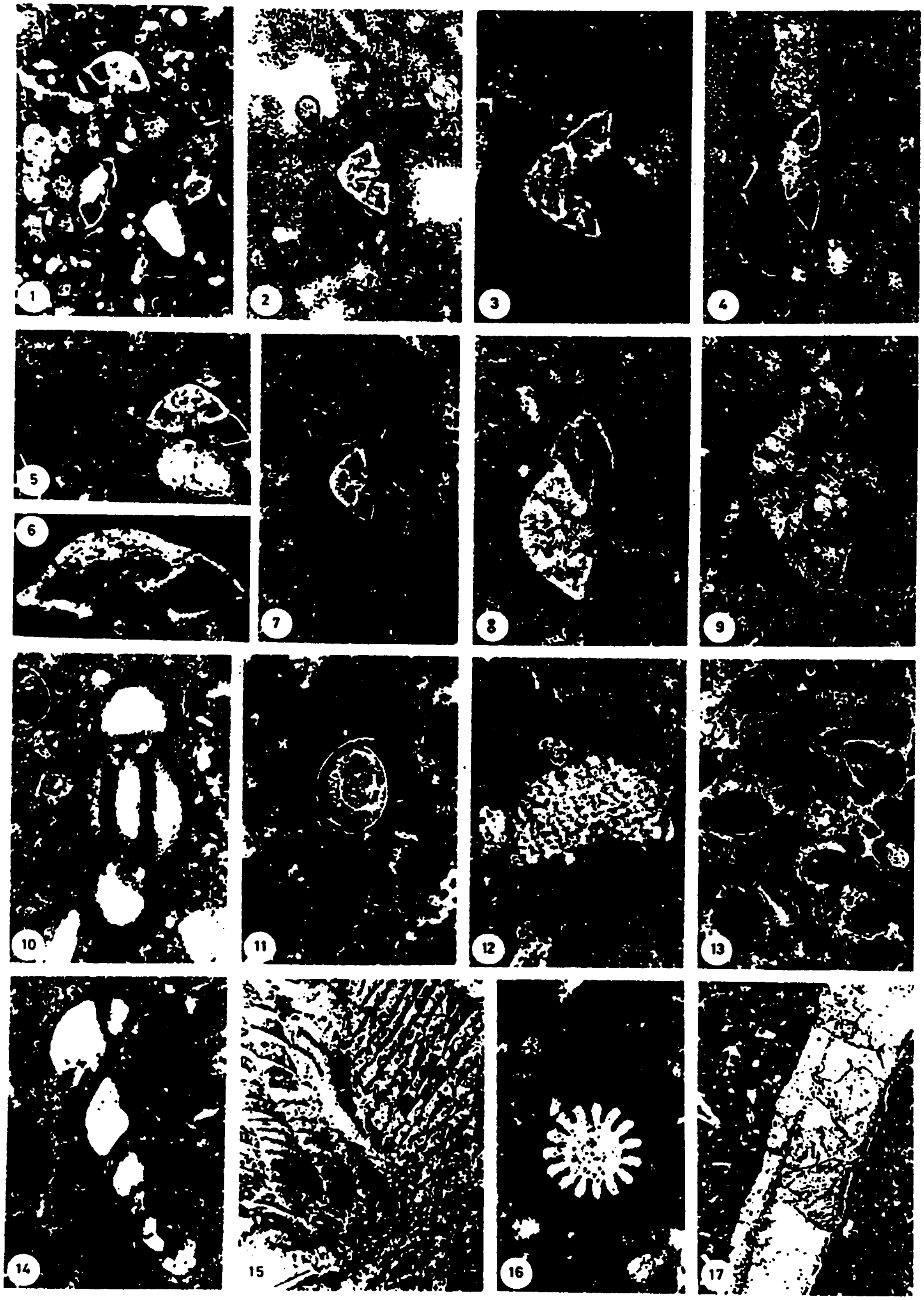

Plate 3

Microfacies II

Gudair Formation

Iron-stained, Silicified, Algal, Rotaliid Limestone

Depth interval from 4461' to 4411'

Fig. 1: Photomicrograph showing iron oxide patches, planktonic foraminiferids and other skeletal remains (PP,x22).

Fig. 2: Photomicrograph showing rotaliid as well as echinodermal remains (PP,x22).

Fig. 3: Photomicrograph showing algal remains (PP,x27).

Fig. 4: Photomicrograph showing a bone fragment (CN,x17).

Fig. 5: Photomicrograph showing a patch of iron oxides in contact with bioclastic wackestone (PP,x17).

Fig. 6: Photomicrograph showing an axial section in ***Globotruncana stuartiformis*** (CN,x106).

Fig. 7: Photomicrograph showing an axial section in ***Globotruncana atlantica*** (CN,x67).

Fig. 8: Photomicrograph showing an axial section in ***Hedbergella holdelmelensis*** (PP,x106).

Fig. 9: Photomicrograph showing an axial section in ***Globotruncana esnehensis*** (PP,x106).

Figs. 10,11,12,13: Photomicrographs showing sections in rotaliid foraminifera (PP,PP,PP,Cn;x106,x67,x67,x67 respectively).

Fig. 14: Photomicrograph showing a silicified section in an ostracod valve with an axial section in ***Globotruncana stuartiformis*** and another random section in planktonic foraminiferids trapped within the valve (PP, x44).

Fig. 15: Photomicrograph showing ostracod remains (PP, x84)

Fig. 16: Photomicrograph showing a random section in larger foraminiferids (CN, x67).

PLATE 3

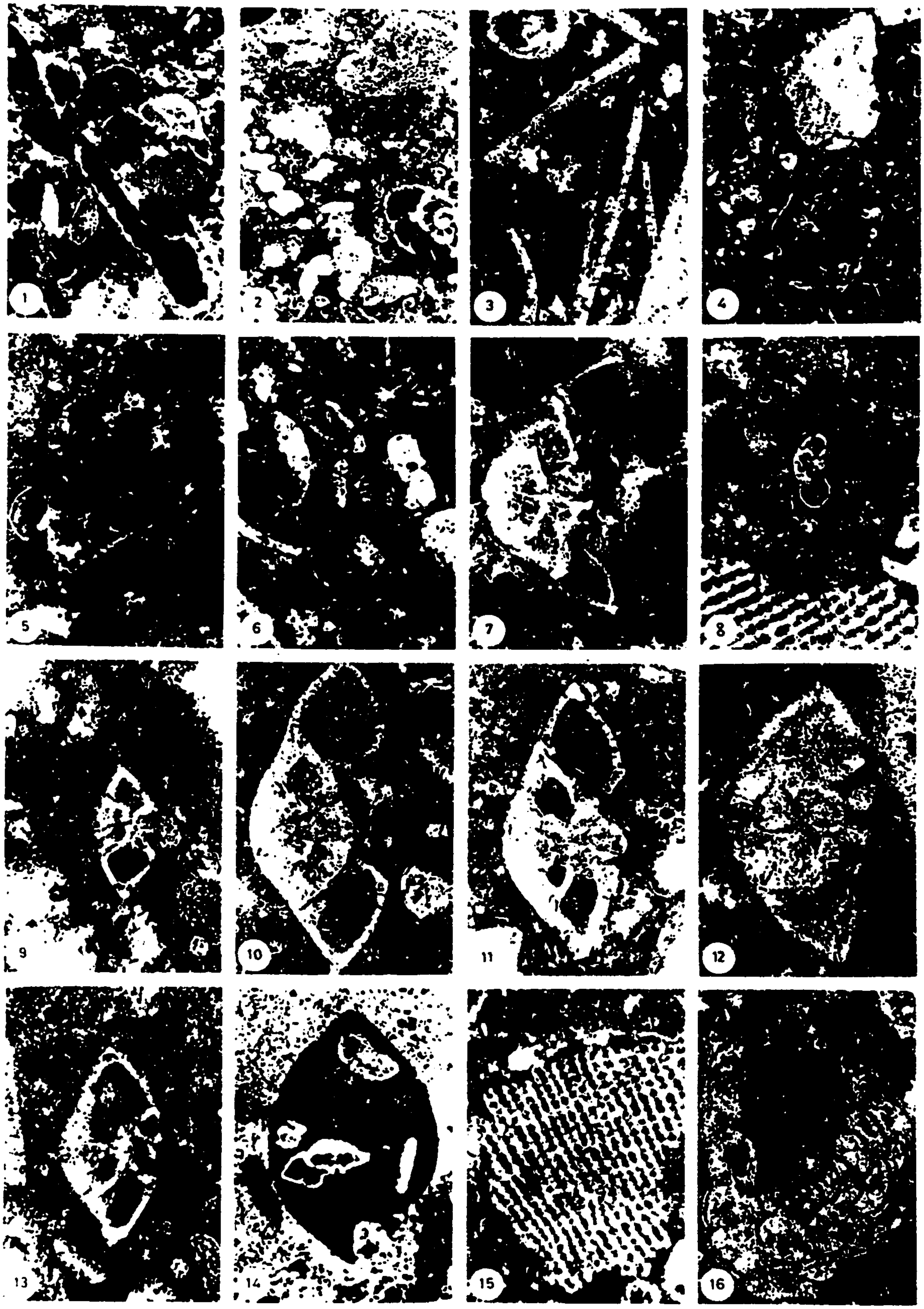

Plate 4

Microfacies III

Gudair Formation

Lower Dolomite

Depth interval from 4367' to 4409'

Figs. 1,2,3,4: Photomicrographs showing dolomite with rhombic crystalls and occasionally mosiac texture. Note the preservation of some of the original micrite in Figs. 3,4 (x28;PP,CN,PP,CN respectively).

Microfacies IV

Gudair Formation

Iron-stained, Recrystallized, Meandropsinal, Pseudedomial, Bioturbated Limestone

Depth interval from 4160' to 4086'

Fig. 5: Photomicrograph showing fragmented skeletal grains of large foraminiferids (mainly ***Pseudedomia sp.*** CN, x34).

Fig. 6: Photomicrograph showing coarser Pseudedomial fragments (PP, x22).

Figs. 7,8: Photomicrographs showing bioturbated facies with scattered sections in planktonic and benthonic foraminiferids in addition to echinodermal remains (PP, x30).

Fig. 9: Photomicrograph showing a patch of iron-oxides (PP, x22).

Figs. 10,11: Photomicrographs showing recrystallization patches with clear mosiac texture in Fig. 10 and sharp cleavage planes in Fig. 11 (x44, PP,CN respectively).

Fig. 12: Photomicrograph showing a replaced skeletal fragment (PP, x22).

Figs. 13,14,15,16: Photomicrographs showing different sections in miliolids (PP, x44,x22,x67,x67 respectively).

PLATE 4

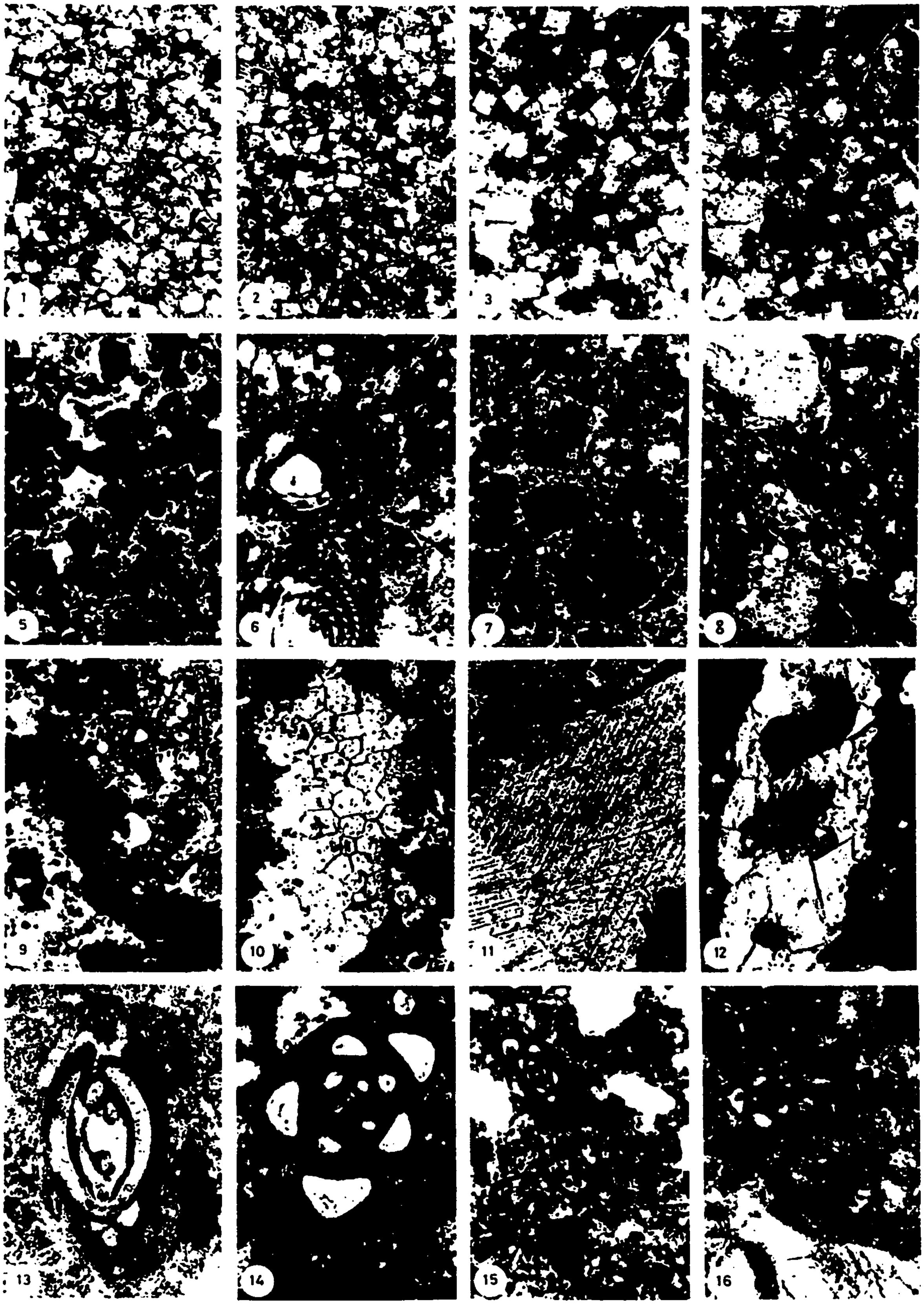

Plate 5

Figs. 1-12: Photomicrographs showing axial sections in ***Pseudedomia sp. (cf. globularis*** and ***complanata*).** Since ***Pseudedomia globularis*** is characterized by an initially globular test and a more wider test, species of Figs. 1,5,9 are expected to belong to this species. Speciemens of Figs. 2,3,10 are interpreted to belong to ***Pseudedomia complanata*** whose test is narrower and initially lenticular (PP,Fig.2:CN; Figs. 1,4,6,7,9,12: x30, Figs 2,3,5,10,11:x22, Fig.8: x44).

Figs. 13,14,15,16: Photomicrographs showing sections in Textulariids (CN,PP,PP,CN;x44,x22,x25,x55 respectively).

PLATE 5

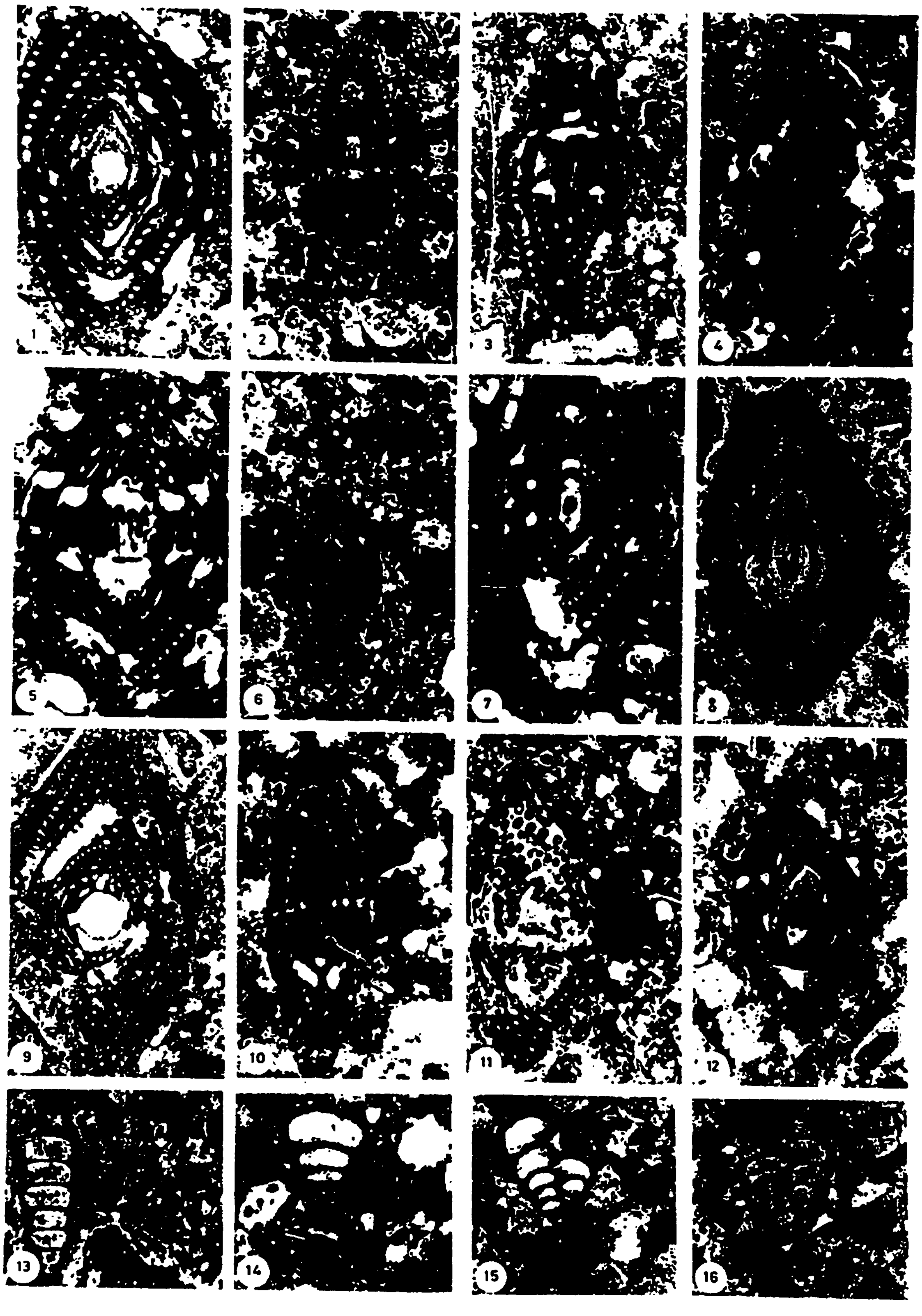

Plate 6

Figs. 1,2: Photomicrographs showing sections in ***Meandrpsina sp.*** (PP, x28,x44 respectively).

Fig. 3: Photomicrograph showing a section in ***Meandropsina sp.*** (PP, x67).

Fig. 4: Photomicrograph showing a section in ***Cuneolina sp.*** (PP, x67).

Figs. 5,6: Photomicrographs showing equatorial and axial sections in rotaliids (PP,CN;x55,x34 respectively).

Figs. 7,8,9: Photomicrographs showing axial sections in ***Globotruncana patelliformis*** (PP,CN,PP;x84 respectively).

Fig. 10: Photomicrograph showing an axial section in ***Globotruncana orientalis*** (CN,x135).

Figs. 11,12: Photomicrographs showing sections in ***Globotruncana subspinosa*** (PP,CN, x55 respectively).

Fig. 13: Photomicrograph showing an axial section in ***Globotruncana insignis*** (CN, x106).

Figs. 14,15: Photomicrographs showing echinodermal remains. (x22;CN,PP respectively).

Fig. 16: Photomicrograph showing algal remains. (PP,x5)

PLATE 6

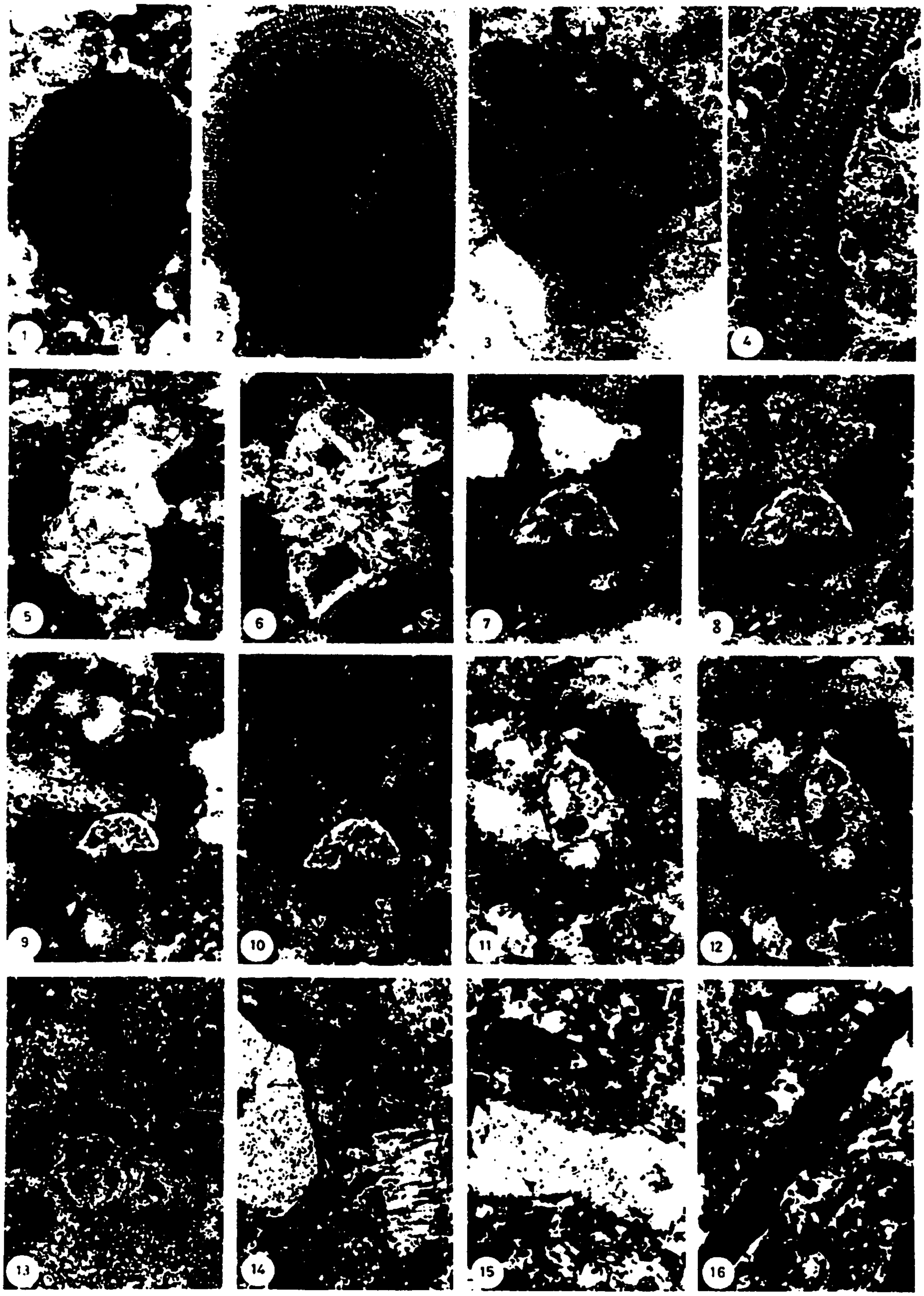

Plate 7

Microfacies V

Gudair Formation

Lower Globigerininal Marly Limestone

Depth interval from 4083' to 4086'

Figs. 1,2,3: Photomicrographs showing planktonic foraminiferids that flood this interval (PP,x30).

Figs. 4,6: Photomicrographs showing axial sections in *Rugoglobigerina macrocephala* (PP;x60,x160 respectively).

Fig. 5: Photomicrograph showing an axial section in *Rugoglobigerina macrocephala* in addition to an equatorial section in *Globotruncana sp.* (PP,x106)

Fig. 7: Photomicrograph showing an axial section in *Globotruncana gagnebini* (PP,x106).

Fig. 8: Photomicrograph showing an axial section in *Rugoglobigerina rugosa* (PP,x106).

Figs. 9,10: Photomicrographs showing equatorial sections in *Rugoglobigerina rugosa* (CN,PP;x106,x55 respectively).

Fig. 11: Photomicrograph showing an equatorial section in *Rugoglbigerina pennyi* (PP,x67).

Fig. 12: Photomicrograph showing an equatorial section in *Rugoglbigerina hexacamerata* (PP,x106).

Figs. 13,14: Photomicrographs showing sections in *Heterohelix globulosa* (PP,x106).

Figs. 15,16: Photomicrographs showing sections in *Heterohelix papula* (x84, PP,CN respectively).

PLATE 7

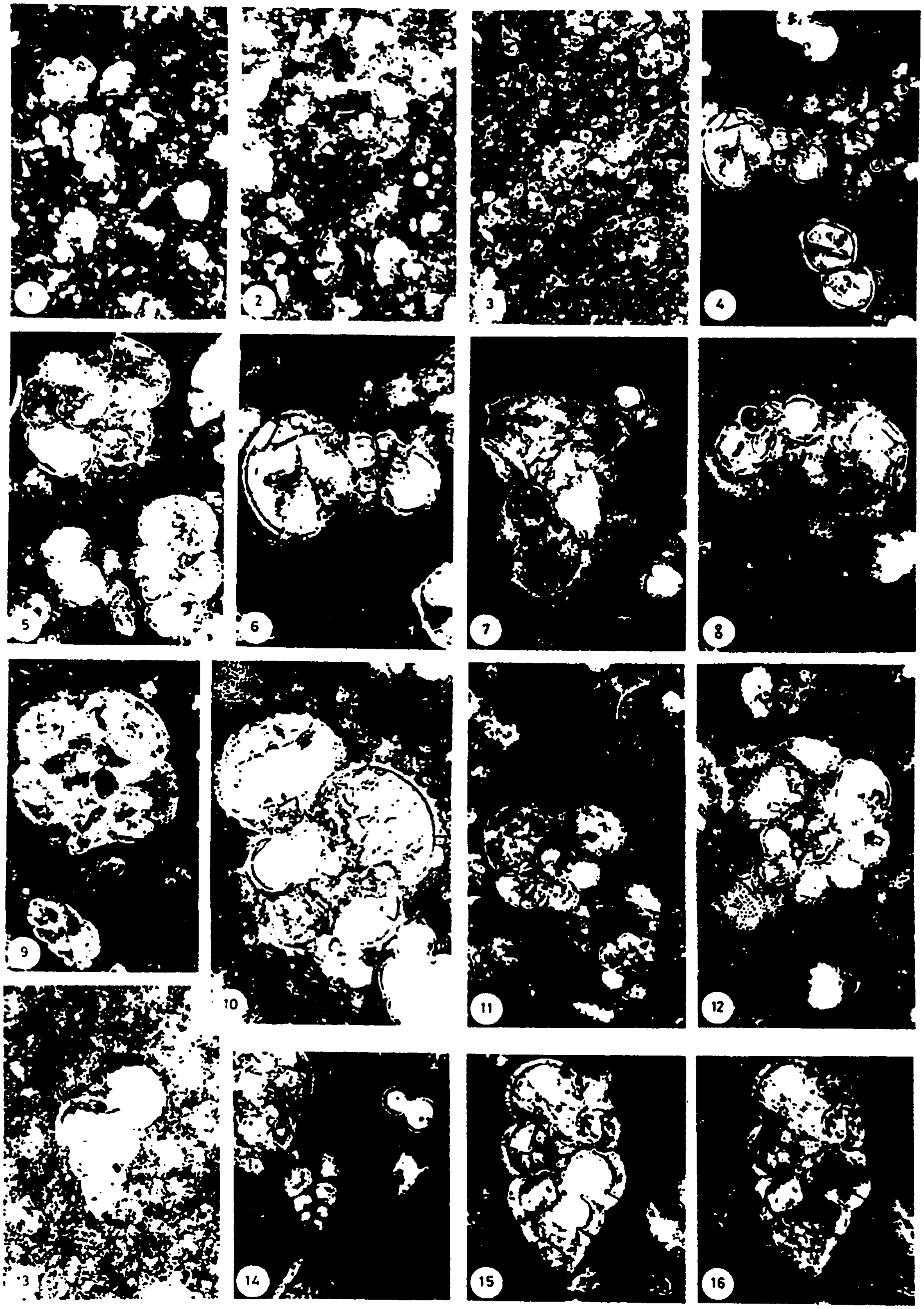

Plate 8

Microfacies VI

Gudair Formation

Recrystallized, Iron-stained, Stylolitized, Meandropsinal, Pseudedomial, Bioturbated Limestone

Depth interval from 4083' to 4031'

Figs. 1,2,3: Photomicrographs showing Pseudedomial (Fig. 1), Meandropsinal (Fig. 2) and rotaliid remains (Fig. 3) among other skeletal remains (PP, x22).

Figs. 4,5: Photomicrographs showing stylolitic structures (x44;CN,PP respectively).

Figs. 6,7,8: Photomicrographs showing recrystallization patches (x22;PP,PP,CN respectively).

Figs. 9,10,11: Photomicrographs showing axial sections of *Pseudedomia* *sp.* (x22,x44,x44;PP,CN,PP respectively).

Figs. 12,13: Photomicrographs showing remains of larger foraminiferids (*cf. Meandropsina sp.*) (CN,x44).

Figs. 14,15: Photomicrographs showing biserial benthonic remains. Note the presence of larger foraminiferid remains in Figure 14 (PP,CN;x55,x106 respectively)

Fig. 16: Photomicrograph showing a section in *Bolivinoid sp.* (PP, x106).

PLATE 8

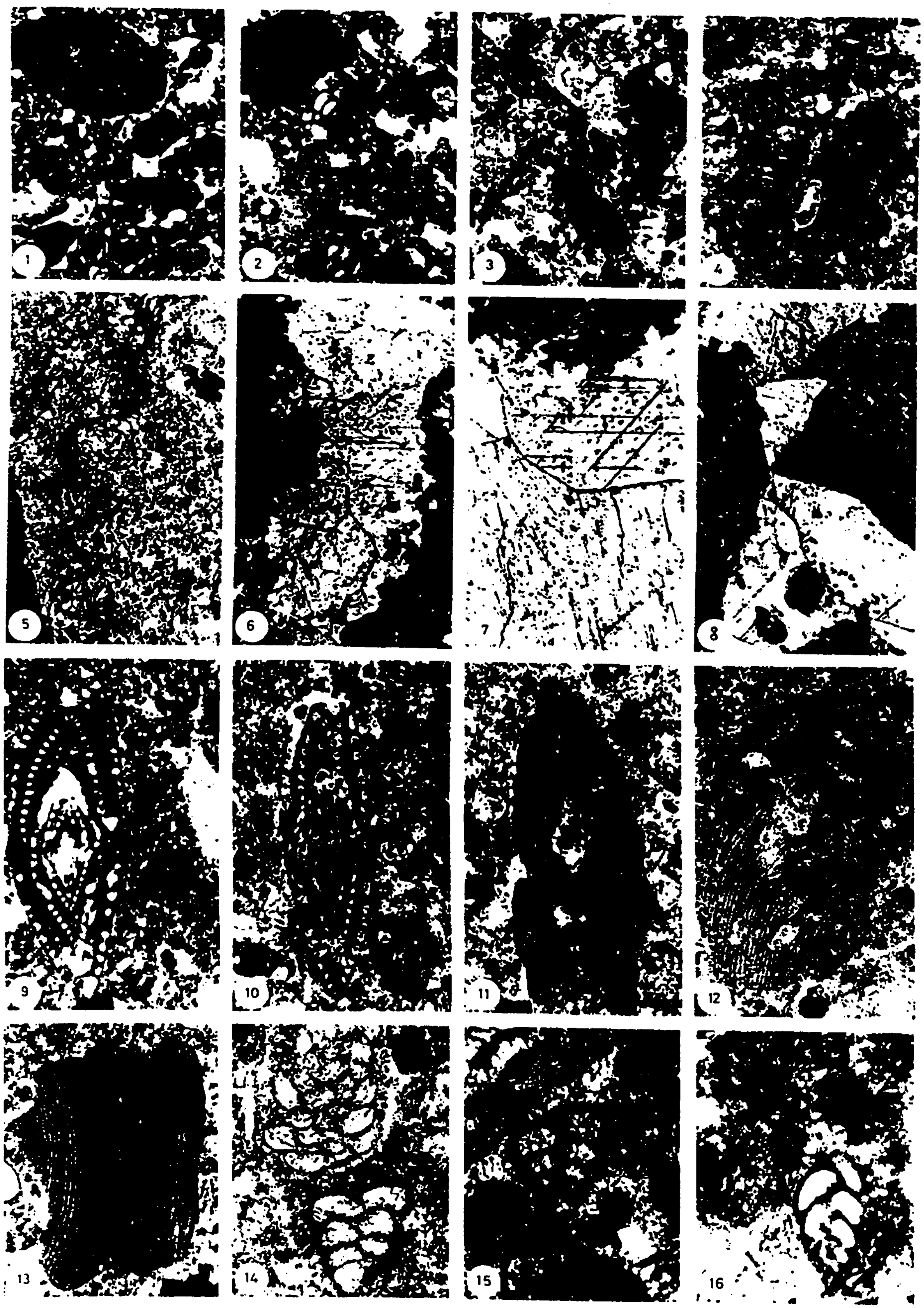

Plate 9

Figs. 1,2: Photomicrographs showing axial sections in rotaliid foraminifera (PP;x55,x67 respectively).

Figs. 3,4,5: Photomicrographs showing axial sections in *Globotruncana patelliformis* (PP;x67,x106,x106 respectively).

Fig. 6: Photomicrograph showing an axial section in *Globotruncana atlantica* (PP,x106).

Fig. 7: Photomicrograph showing an axial section in *Globotruncana subspinosa* (PP,x67).

Fig. 8: Photomicrograph showing a section in bone fragments (PP, x67).

Microfacies VII

Hartha Formation

Stylolitic, Glauconitic, Highly Pyritized, Intensively Reworked, Skeletal Limestone

Depth interval from 4031' to 3982'

Figs. 9-16: Photomicrographs representing this microfacies with abundant pyritized skeletal remains and frequent recrystallized cement. Note the presence of rotaliid remains (Fig. 9) and planktonic remains (Fig. 1). (PP except Figs. 10 and 16; x55,x55, x22,x22,x42,x44,x22,x44 respectively)

PLATE 9

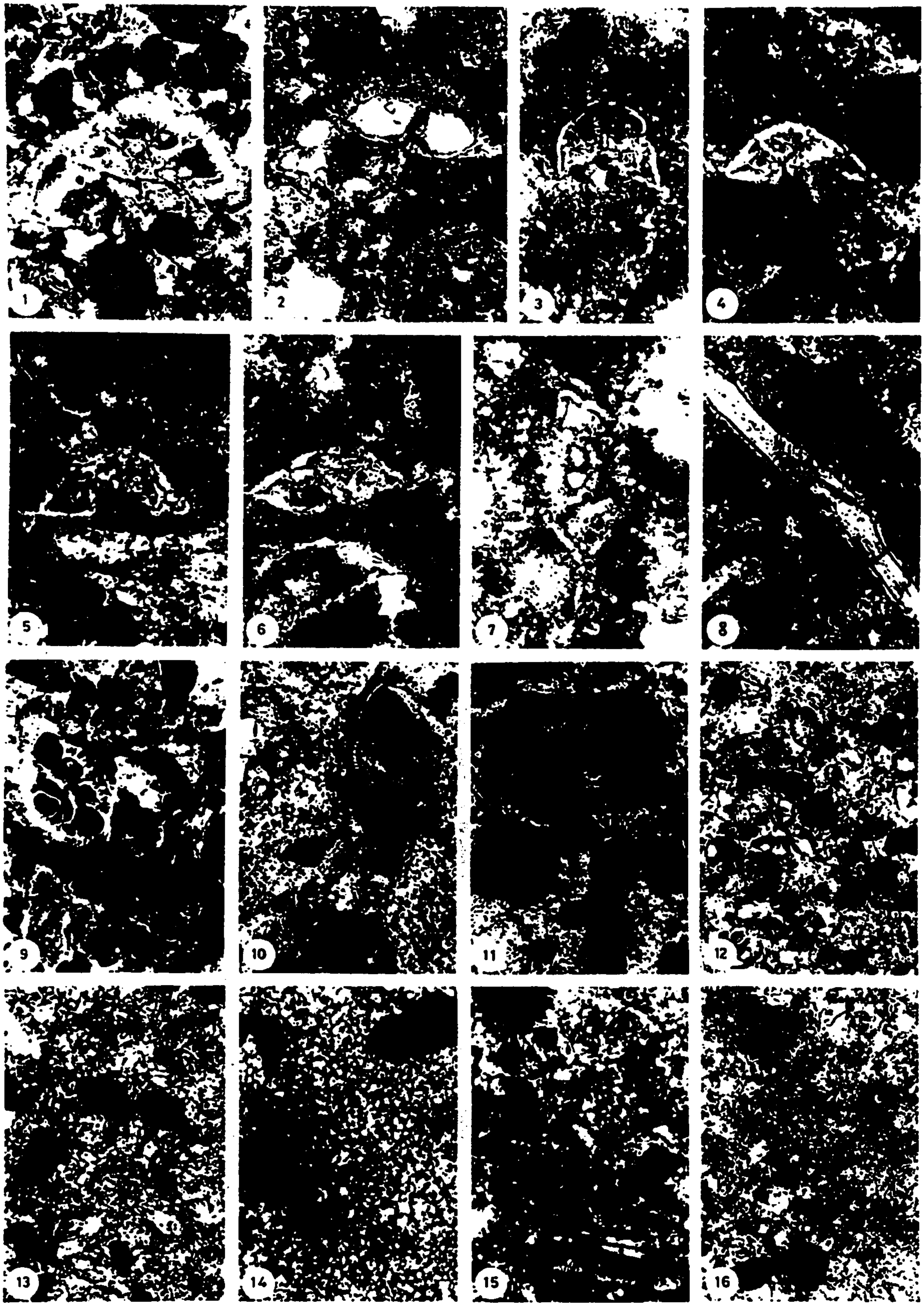

Plate 10

Figs. 1,2: Photomicrographs showing stylolitic structures (PP,CN;x30 respectively).

Fig. 3: Photomicrograph showing an equatorial section in benthonic foraminiferids (PP,x106).

Fig. 4: Photomicrograph showing an equatorial section in ***Pseudedomia sp.*** (PP,x84)

Fig. 5: Photomicrograph showing a section in miliolids (PP,x67).

Fig. 6: Photomicrograph showing a section in larger foraminiferid (***cf. Omphalocyclus macroporus***) (PP,x44).

Figs. 7,8: Photomicrographs showing sections in larger foraminiferids (PP,CN;x55,x44 respectively).

Fig. 9: Photomicrograph showing a section in ***Hedbergella sp.*** (PP, x106).

Fig. 10: Photomicrograph showing a random section in planktonic foraminiferids (PP, x84).

Fig. 11: Photomicrograph showing an axial section in ***Globotruncana falsostuarti*** (PP,x67)

Fig. 12: Photomicrograph showing echinodermal remains (PP, x22).

Microfacies VIII

Hartha Formation

Upper Dolomite

Depth interval from 3982' to 3958'

Figs. 13-16: Photomicrographs showing the mosiac texture typical for dolomites. Note the pervasive iron staining. (x22;PP,CN,CN respectively)

PLATE 10

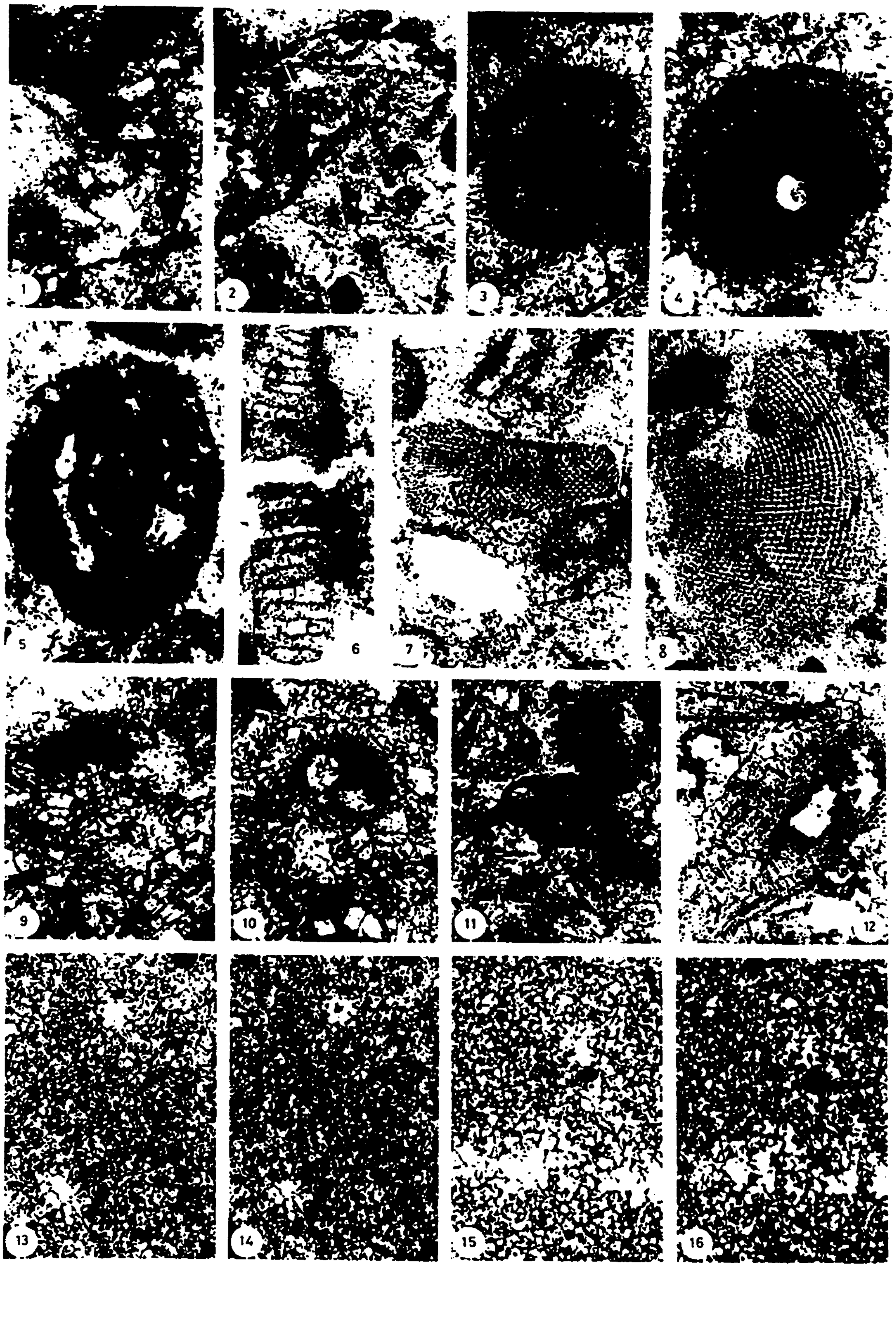

Plate 11

Microfacies IX

Hartha Formation

Iron-stained, Locally Recrystallized, Orbitoidal, Micritic Limestone

Depth interval from 3958' to 3867'

Fig. 1: Photomicrograph showing a recrystallized patch embedded in micritic matrix (CN,x22)

Fig. 2: Photomicrograph showing orbitoidal remains scattered in micritic matrix (CN,x22).

Figs. 3,4: Photomicrographs showing iron stained, small sized skeletal remains cemented by recrystallized calcite (CN, x22).

Fig. 5: Photomicrograph showing remains of planktonic foraminiferids scattered in micritic matrix with some echinodermal patches (CN, x22).

Fig. 6: Photomicrograph showing orbitoidal remains in association with planktonic foraminiferids (CN, x22).

Figs. 7,8,10: Photomicrographs showing orbitoidal remains. (PP;x44,x22,x22 respectively)

Fig. 9: Photomicrograph showing orbitoidal remains (*cf. Omphalocyclus macroporus*) (CN,x34).

Fig. 11: Photomicrograph showing a section in the nepionic chamber of *Orbitoides medius* (PP,x106).

Fig. 12: Photomicrograph showing an axial section in *Pseudedomia sp. (cf. multistriata)* (CN,x44).

Fig. 13: Photomicrograph showing a section in *Pseudedomia sp.* (CN,x106).

Fig. 14: Photomicrograph showing an equatorial section in benthonic foraminiferids (PP,x84).

Fig. 15: Photomicrograph showing a section in uniserial textulariid (PP,x44).

Fig. 16: Photomicrograph showing a section in *Cuneolina sp.* (CN,x44).

PLATE 11

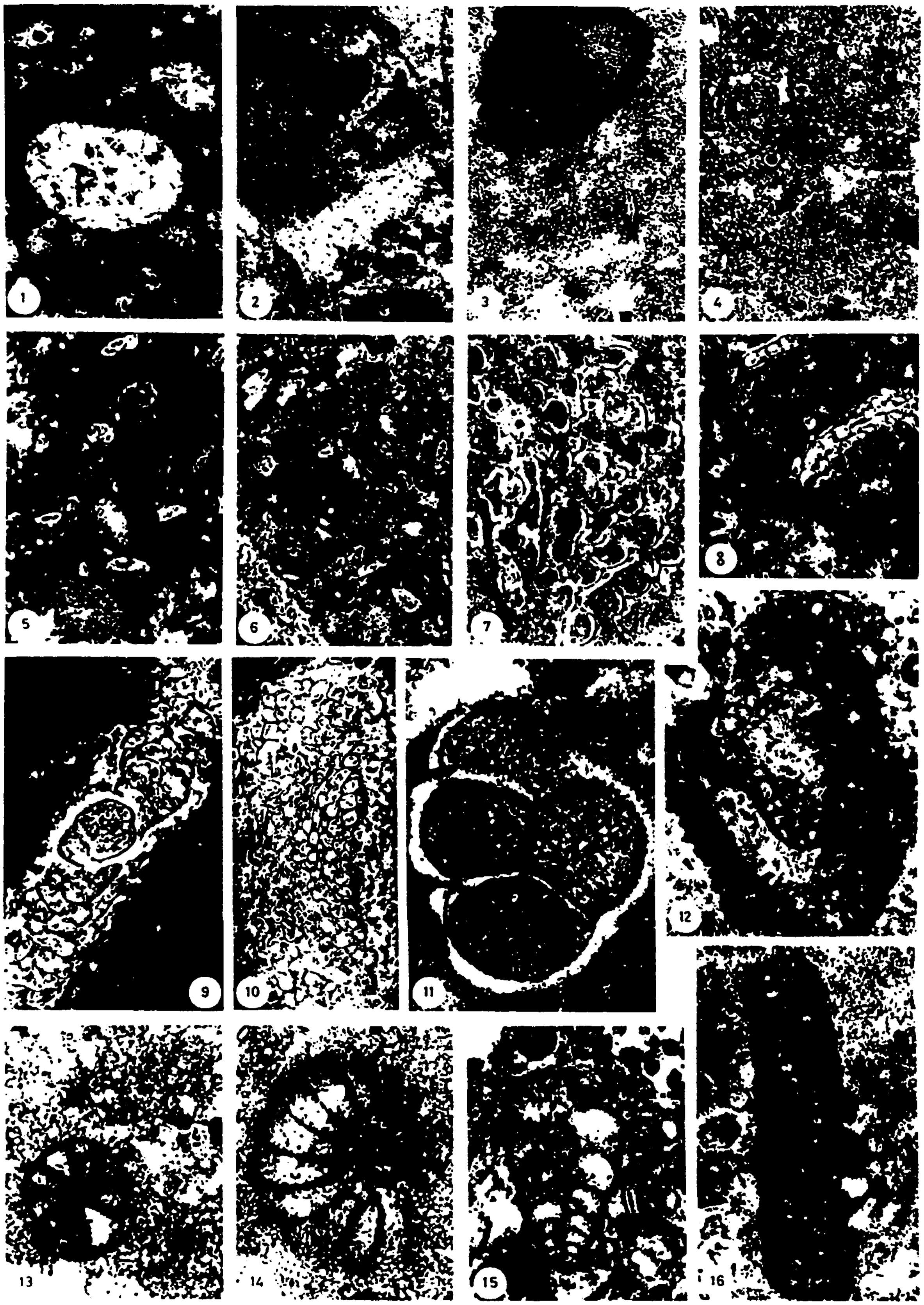

Plate 12

Fig. 1: Photomicrograph showing a section in ***Orbitolina sp.*** (PP,x44).

Fig. 2: Photomicrograph showing an axial section in ***Globotruncana orientalis*** (PP,x106).

Fig. 3: Photomicrograph showing an axial section in ***Globotruncana subspinosa*** (PP,x67).

Fig. 4: Photomicrograph showing an axial section in ***Globotruncana esnehensis*** (PP,x106).

Fig. 5: Photomicrograph showing an axial section in ***Globotruncana conica*** (PP,x44).

Fig. 6: Photomicrograph showing an axial section in ***Rugohedbergella sp.*** (PP,x55).

Fig. 7: Photomicrograph showing a section in ***Hedbergella sp.*** , note the replaced wall by iron oxides (PP, x106).

Fig. 8: Photomicrograph showing an axial section in ***Globotruncana gansseri widenmaryi*** (CN,x44).

Fig. 5: Photomicrograph showing an axial section in ***Globotruncana gansseri*** (CN,x84).

Fig. 10: Photomicrograph showing an equatorial section in rotaliids (PP,x67).

Fig. 11: Photomicrograph showing ostracod remains (CN,x55).

Fig. 12: Photomicrograph showing a section in sponge spicules (PP, x55).

Figs. 13,14: Photomicrographs showing coral remains (CN, x22).

Figs. 15,16: Photomicrographs showing algal remains (PP, x22).

PLATE 12

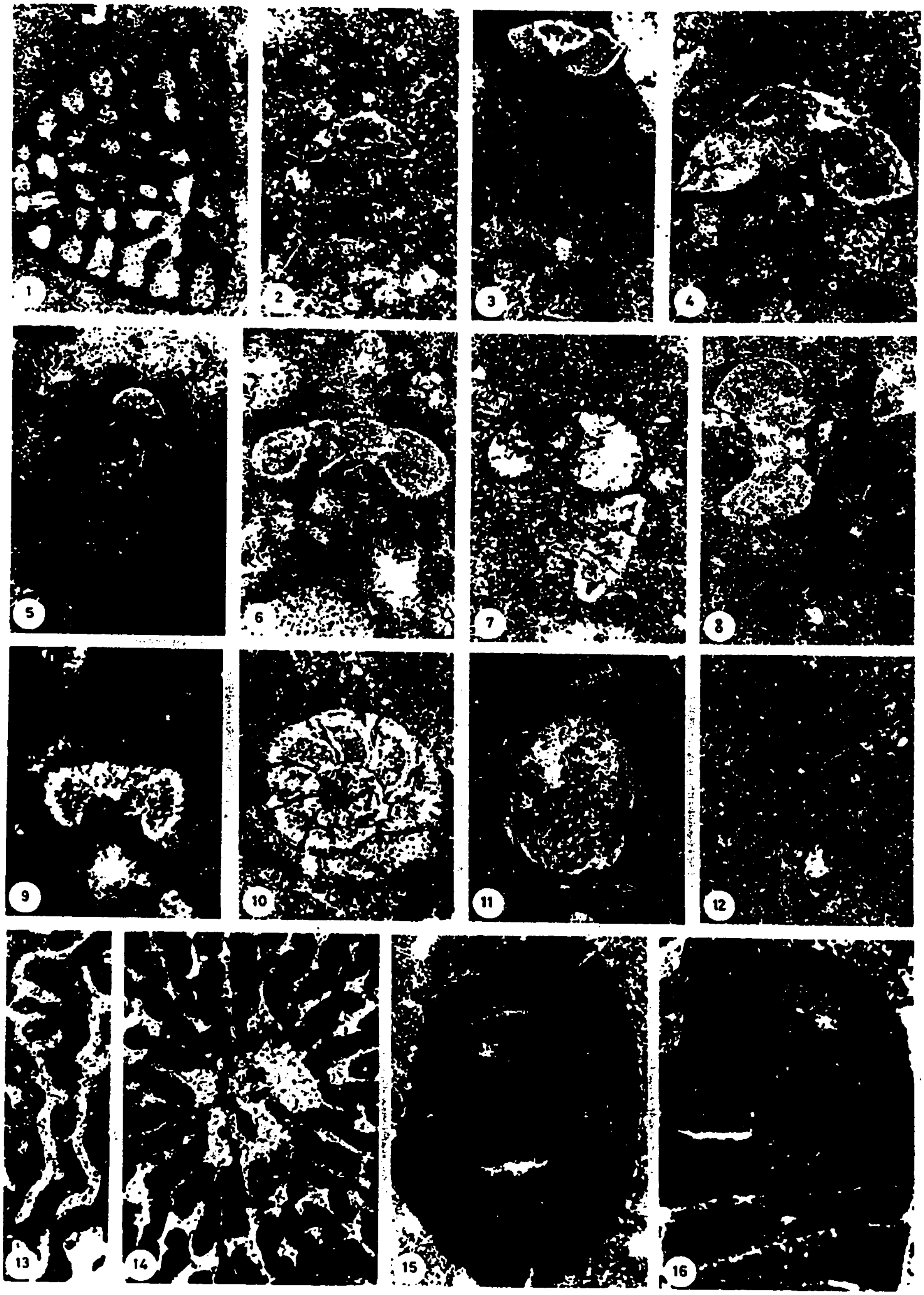

Plate 13

Microfacies X

Qurna Formation

Upper Globigerininal Marly Limestone

Depth interval from 3867' to 3763'

Figs. 1,2: Photomicrographs showing planktonic foraminiferid remains that dominate this interval (PP,x44).

Figs. 3,4,5: Photomicrographs showing axial sections in ***Globotruncana aegyptiaca*** , note the presence of an axial section of ***Rugoglobigerina macrocephala of*** at the base of Figure 5 (CN,PP,PP;x106,x135,x84 respectively).

Figs. 6,7: Photomicrographs showing axial sections in ***Globotruncana pettersi*** (PP;x135,x84 respectively).

Fig. 8: Photomicrograph showing an axial section in ***Globotruncana arca*** (CN,x106).

Fig. 9: Photomicrograph showing an axial section in ***Globotruncana contusa*** (PP,x106).

Fig. 10,11: Photomicrographs showing axial sections in ***Globotruncana bulloides*** (PP,x106,x170 respectively)

Fig. 12: Photomicrograph showing an equatorial section in ***Globotruncana bulloides*** at the base and an axial section in ***Globigerinelloides sp.*** at the top (PP,x106).

Figs. 13,14: Photomicrographs showing axial sections in ***Globotruncana falsostuarti*** (CN,PP;x135,x106 respectively)

Fig. 15: Photomicrograph showing an equatorial section in ***Globotruncana fornicata*** (CN,x84).

Fig. 16: Photomicrograph showing an equatorial section in ***Hedbergella sp.*** (CN,x170).

PLATE 13

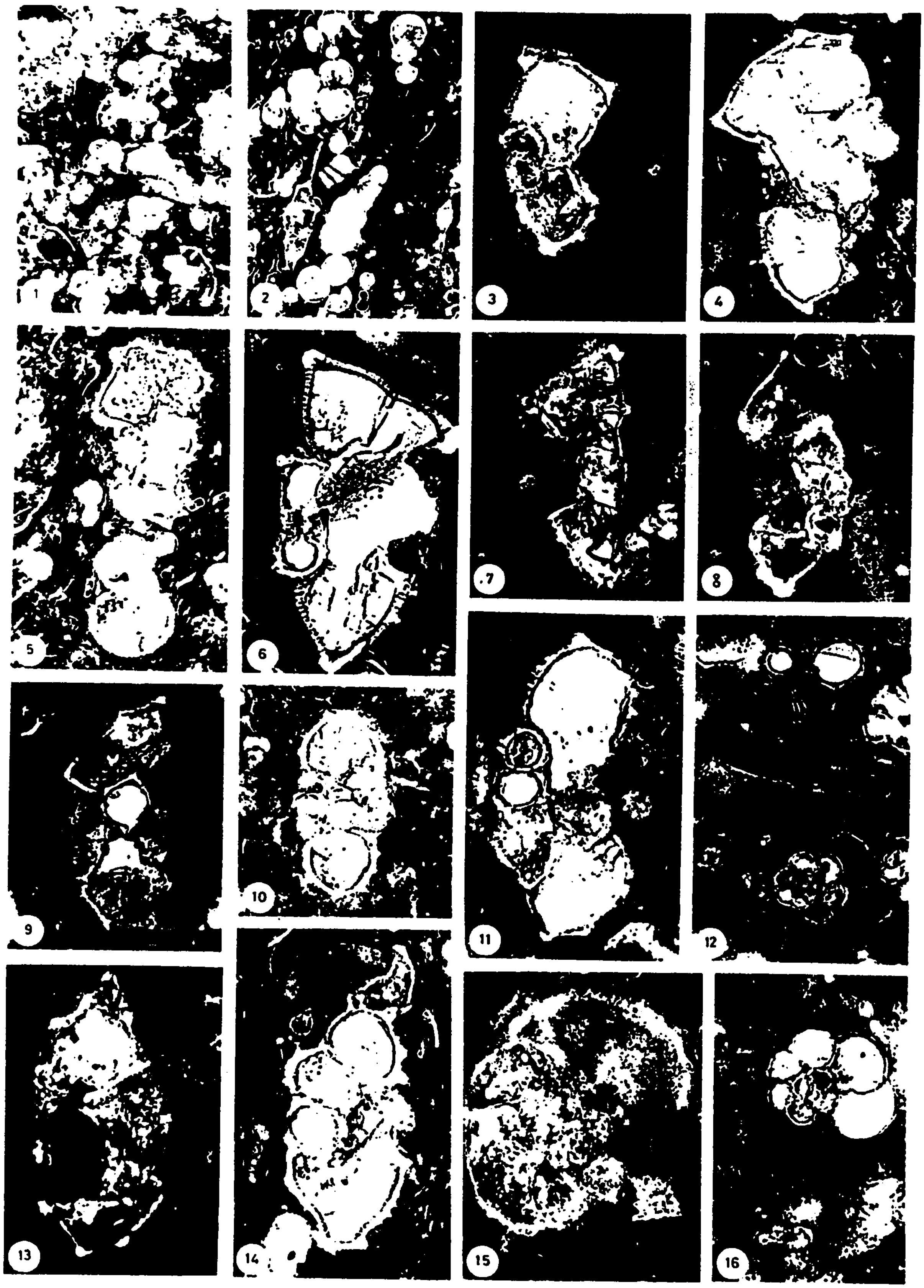

Plate 14

Figs. 1,3,4: Photomicrographs showing equatorial sections in *Rugoglobigerina rugosa*. (PP,PP,CN;x35,x106,x106 respectively)

Fig. 2: Photomicrograph showing an axial section in *Rugoglobigerina rugosa* (CN,x135).

Figs. 5,6,7: Photomicrographs showing equatorial sections in *Rugoglobigerina pennyi* (PP,PP,CN;x170,x84,x84 respectively).

Fig. 8: Photomicrograph showing an axial section in *Rugoglobigerina pustulata* (CN,x200).

Figs. 9,10: Photomicrographs showing equatorial sections in *Rugoglobigerina macrocephala* (PP,x106).

Fig. 11: Photomicrograph showing a section in *Heterohelix sp.* (CN,x106).

Figs. 12,13: Photomicrographs showing sections in *Heterohelix globulosa*. (PP,CN;x135,x106 respectively)

Figs. 14-17: Photomicrographs showing sections in *Guembletria sp.* (x84;PP,CN,PP,CN respectively)

PLATE 14