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A New Look at the Middle to Lower Cretaceous Stratigraphy, Offshore Kuwait

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ABSTRACT

Offshore exploration in Kuwait commenced in 1961 with the award of a 5,600 square kilometre offshore concession to Shell. Some 6,300 kilometres of 3-fold analogue seismic were acquired in 1961, and 3 wells were drilled during 1962 and 1963. In the same period, Kuwait Oil Company (KOC) also drilled their first 3 offshore exploration wells. In 1981, KOC embarked upon a second offshore exploration campaign, acquiring some 6,000 kilometres of seismic data and, during 1983 and 1984, drilling two wells. None of these wells was a commercial discovery.

Between 1995 and 1997, an integrated team of KOC and Shell explorers undertook a review of the hydrocarbon potential of Offshore Kuwait. In order to establish an integrated sequence-stratigraphical framework for the prospective Lower to Middle Cretaceous interval, a quantitative biostratigraphical study was made. Some 790 biostratigraphical analyses (10% core samples; 90% cuttings) from eleven wells were carried out: the nanno-fossil data was particularly important in providing accurate chronostratigraphical calibration, and this data has been used to constrain a "Time-Rock Synopsis".

KOC's lithostratigraphical nomenclature proved to be basically sound and has been maintained as the basis for the present stratigraphical framework. However, the study revealed the existence of two substantial and hitherto unsuspected hiati: one between the Ratawi and Zubair formations of Early Valanginian to Mid-Hauterivian age; and the other, representing the whole of the Early Albian, within the Burgan Formation. This latter result, if it can be further substantiated by more exhaustive study in the onshore area, would neccessitate a re-definition of the Burgan Formation and the erection of a new formation to describe the clastic sequence of Late Aptian age which lies between the Early Albian hiatus and the top of the Shu'aiba Formation, and which has hitherto been included within the Lower Burgan Formation.

INTRODUCTION

On 27 September, 1995, a Joint-Study Agreement was signed between Shell International Exploration and Production B.V. and Kuwait Oil Company (KOC) whereby an integrated team of Shell and KOC geologists and geophysicists was established in The Hague (The Netherlands) to undertake a review of the hydrocarbon potential of Offshore Kuwait, including Kuwait Bay and Bubiyan Island (Figure 1).

The results of the Study regarding plays and prospectivity of the Offshore area are still deemed to be confidential by both parties and so will not be discussed here. This paper, however, presents the results of one aspect of the work, on the Cretaceous Stratigraphy of Offshore Kuwait, which has no confidentiality implications and which, it is hoped, may be of interest to the wider community.

Prior to the discussion of the details of the work, overviews of the history of exploration of Offshore Kuwait, and of the tectono-stratigraphic evolution of Kuwait through the Cretaceous, will be presented.

The standard international sub-division of the Cretaceous comprises of an Upper and Lower Cretaceous, with the boundary being at the top of the Albian. However, in the Middle East a three-fold Cretaceous

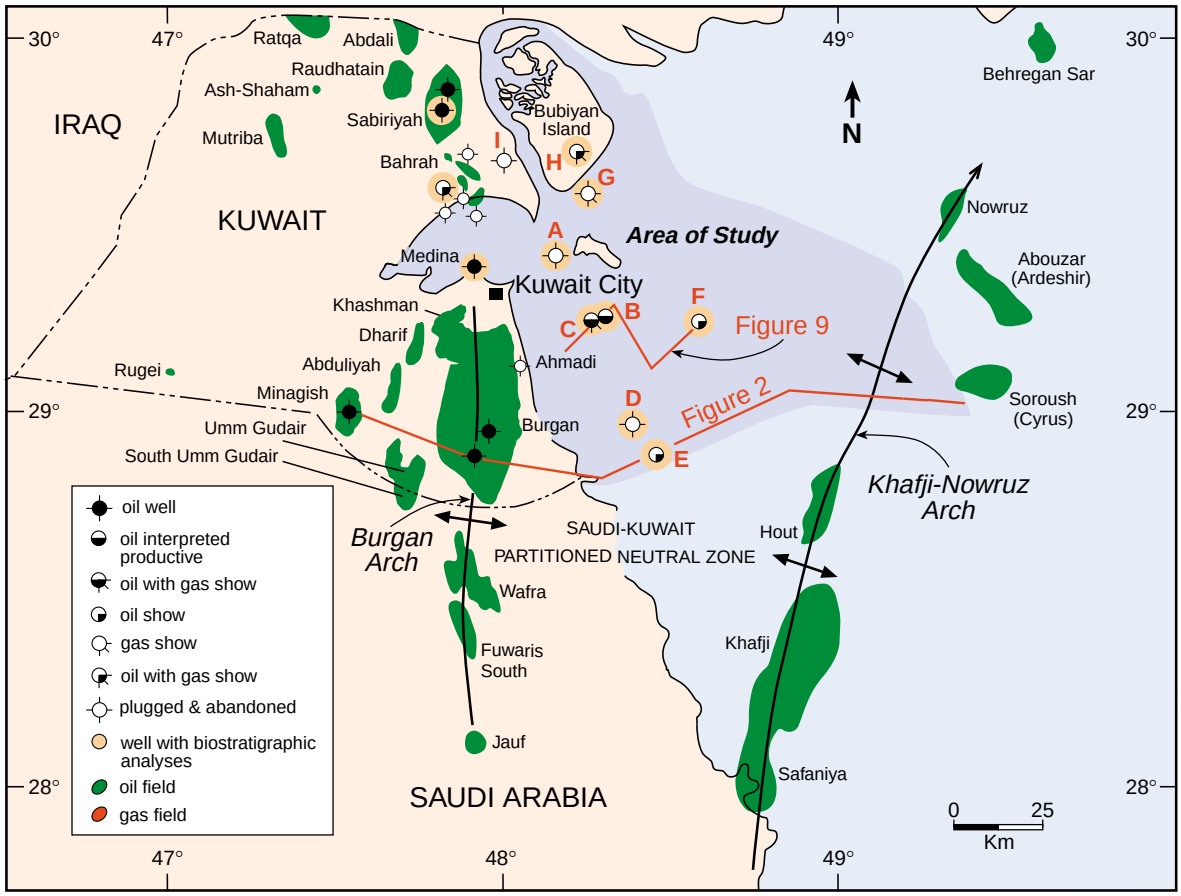


Figure 1: Location map of Kuwait Offshore Study Area and location of wells from which samples were taken for biostratigraphic analyses. The locations of the cross-section in Figure 2, and the seismic line in Figure 9, are indicated.

sub-division has traditionally been used (Christian, 1997), with boundaries at the top of the Aptian and at the top of the Turonian, respectively. This practice reflects, far more usefully, the tectono-stratigraphic evolution of the area, and is maintained in this account.

HISTORY OF PREVIOUS EXPLORATION

A brief history of onshore exploration and an overview of the geology and oil fields of onshore Kuwait is most recently provided by Carman (1996), whilst detailed accounts of the Burgan and Raudhatain fields are presented by Brennan (1990a, b). The first, and arguably still the best, discussion of the Tertiary and Cretaceous stratigraphy of Kuwait was provided by Owen and Nasr (1958). Yousif and Nouman (1997) provide the latest overview of the Jurassic stratigraphy of Kuwait, whilst Khan (1989) reviews the Permo-Triassic stratigraphy. An excellent list of additional references is provided by Carman (1996).

Offshore exploration in the Northern Gulf commenced in the mid-1950s in the Partitioned Neutral Zone of Kuwait and Saudi Arabia, and the first offshore oil field was discovered in 1958 (Khafji: the northern continuation of Saudi Aramco's Safaniya field). Possibly prompted by this and by the IPAC consortium's exploratory activity in Iranian waters, offshore exploration in Kuwait commenced in 1961 with the award of a 5,600 square kilometre (sq km) offshore concession to Shell, of which the eastern part of the area was effectively 'off-limits' due to boundary disputes between Kuwait, Iran, and Saudi Arabia.

In 1961 Shell shot 6,300 km of 3-fold analogue seismic, from which it became apparent that the 'open' part of the concession comprised a gentle, north-easterly-dipping monocline, and the only three

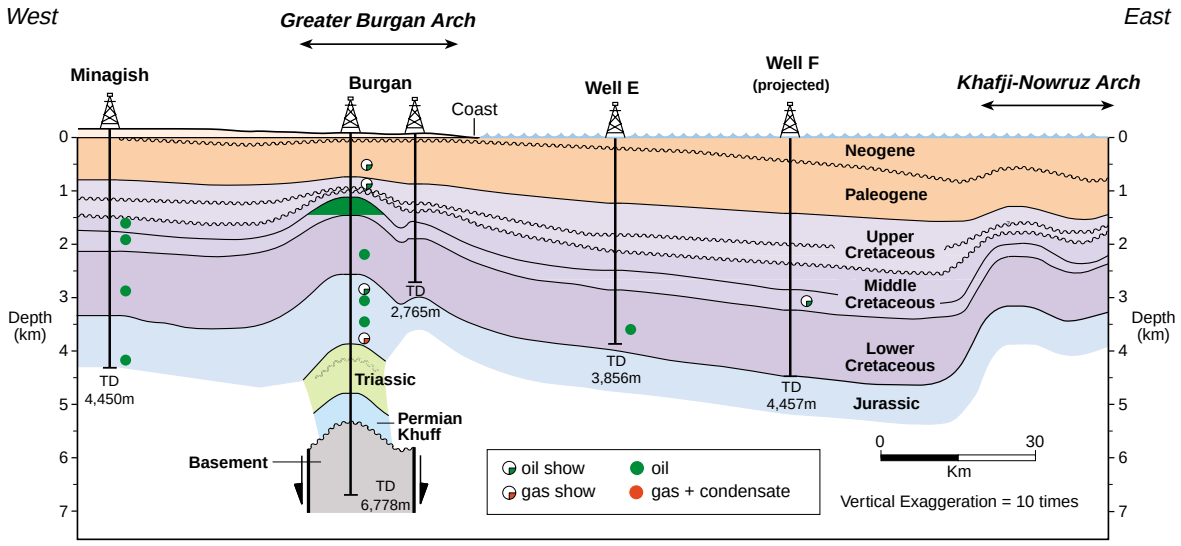


Figure 2: Geological cross-section, Kuwait Offshore and coastal area. For location see Figure 1.

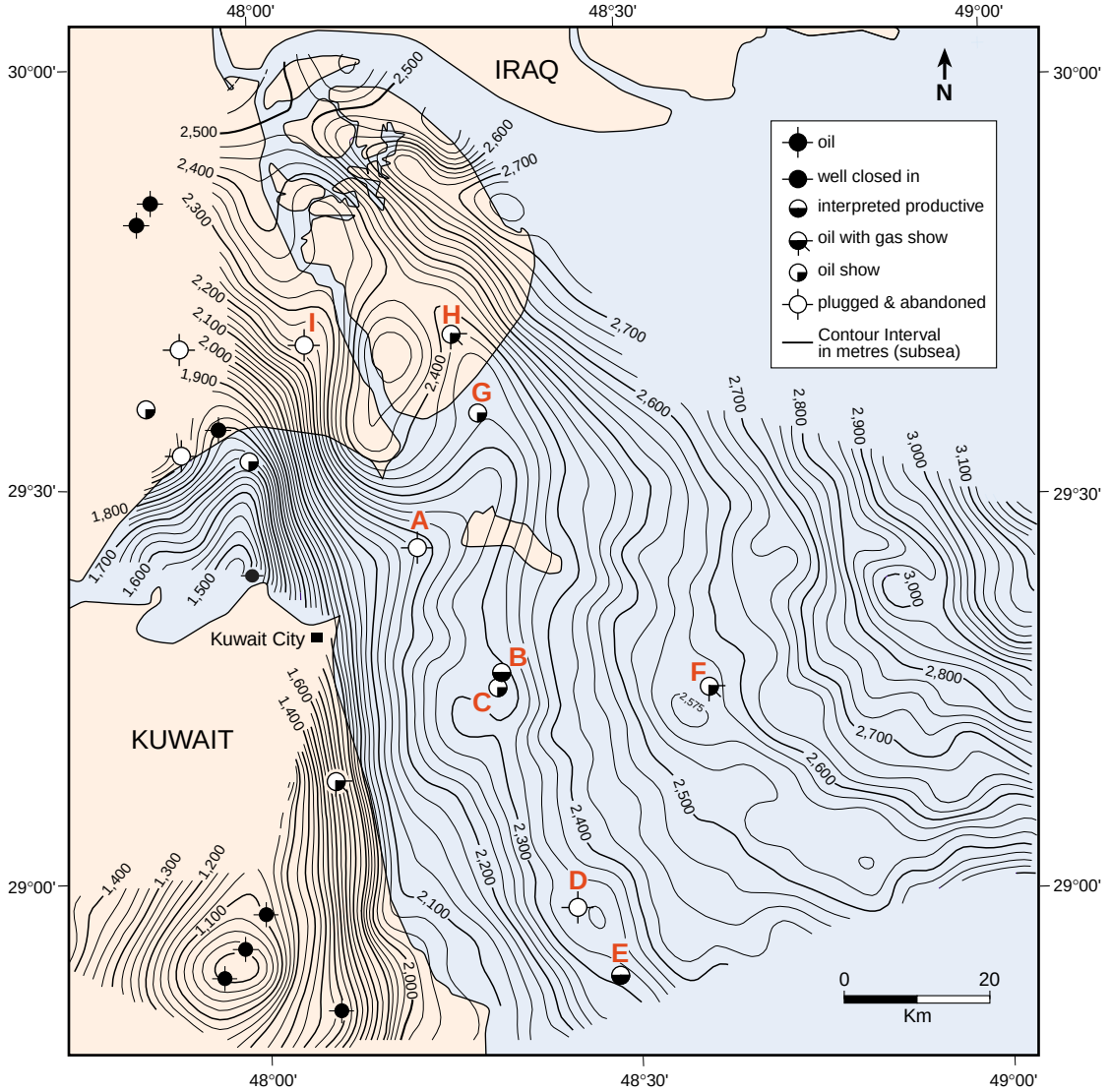


Figure 3: Kuwait Offshore: Depth Map, Top Ahmadi Formation (in metres subsea).

structures which could be identified were of very low relief, with mapped closures of less than 35 metres (m). These were drilled between 1962 and 1963. The least discouraging results were obtained from the first well drilled, which tested at an initial rate of 720 barrels of oil per day (bopd) of 38°-40° API oil from Lower Cretaceous Ratawi limestones. Unfortunately, production declined to only 103 bopd after 5 days. Only minor oil and gas shows were noted in the other two wells. All three wells were abandoned. In the same 1962-63 period, KOC also drilled their first offshore exploration wells, in the Bubiyan Island-Kuwait Bay area.

In 1981, the then-nationalised KOC embarked upon a second offshore and shallow-water exploration campaign, acquiring some 6,000 km of seismic data. The new seismic data was interpreted in the light of the results of the three Shell wells, and a detailed review was made of the stratigraphy and hydrocarbon potential of Offshore Kuwait (Al-Kandari, 1981). Between 1983 and 1984, KOC drilled two wells: the first, a follow-up of the Shell non-commercial discovery, was a dry hole with only shows of oil; the second recovered a maximum of 420 bopd on test from the Minagish Formation.

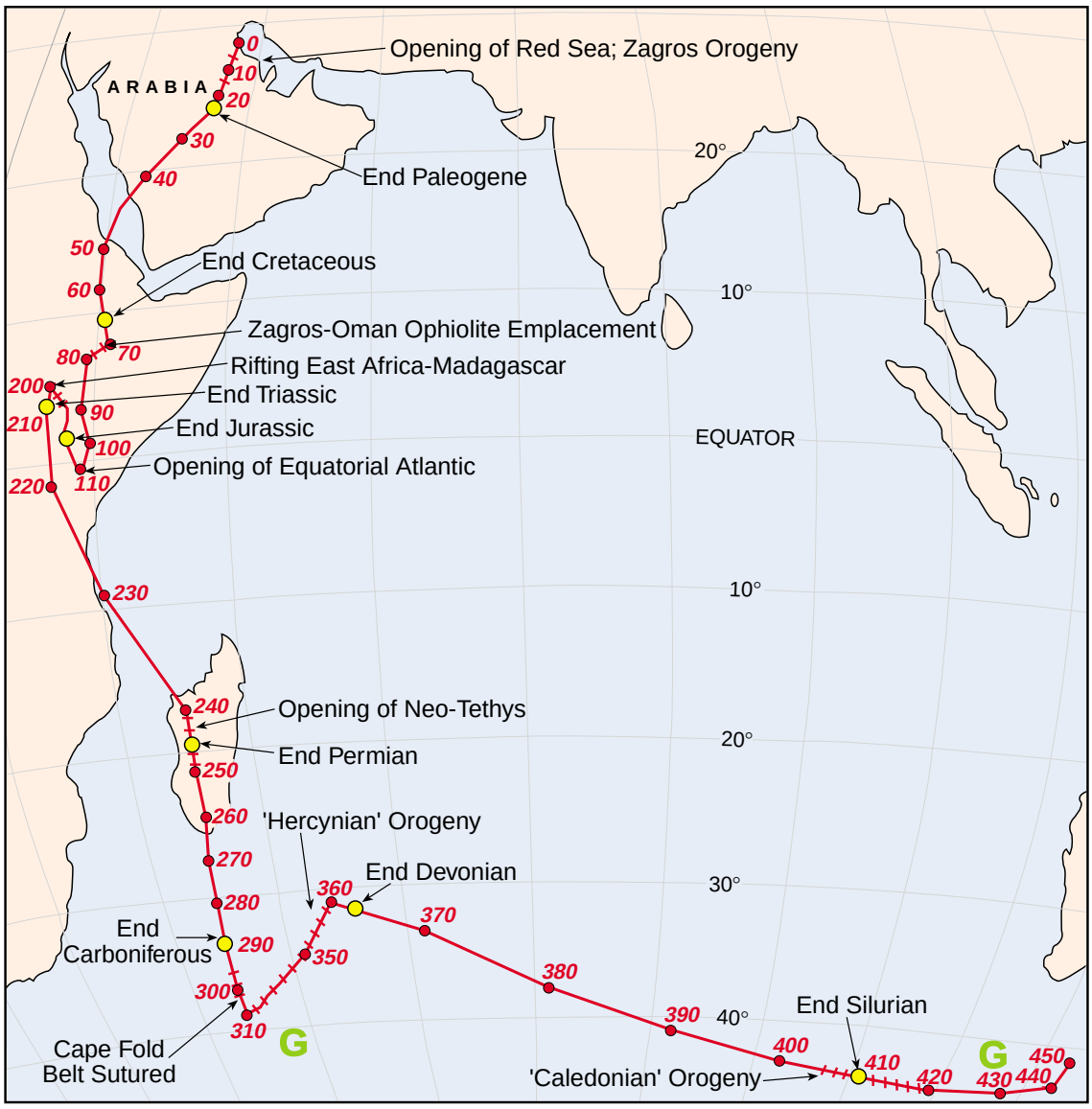


Figure 4: Plate Wander Path (in red) for Kuwait, Late Ordovician to Recent. Numbers (in red) indicate age in million years before present. Green 'G' indicates timing of Paleozoic glaciations and the red hash marks '/ / / /' indicate timing of periods of major rifting or deformation. Shell internal compilation.

STRUCTURAL OVERVIEW OF THE KUWAITI OFFSHORE AREA

As shown by the geological cross-section and the seismic depth map (Figures 2 and 3), the structure in Offshore Kuwait is dominated by a gentle regional dip to the north-east with no significant structuration intervening between the Burgan Arch to the west, and the Khafji-Nowruz Arch to the east. Consequently, all the offshore wells to date have been drilled on very low relief structures.

The most prominent offshore feature is the north-northeast-trending Khafji-Nowruz Arch, located in the extreme east of the Kuwaiti Offshore. The structure plunges gently to the north-northeast; is asymmetric with a steeper western flank; and, in common with the Burgan Arch, the upper part of the Middle Cretaceous sequence appears to be truncated below the Base Upper Cretaceous Unconformity over the structure. Structural growth is also apparent during Neogene times.

KUWAIT DURING THE CRETACEOUS: AN OVERVIEW

The geological history and stratigraphic succession of Kuwait has been determined by its location on the north-eastern margin of the Afro-Arabian Plate, and by the motions and stresses (near and far-

Figure 5: Paleogeographic reconstruction, Late Cretaceous times (~85 Ma, approximating Base Upper Cretaceous Unconformity time. Shell internal compilation).

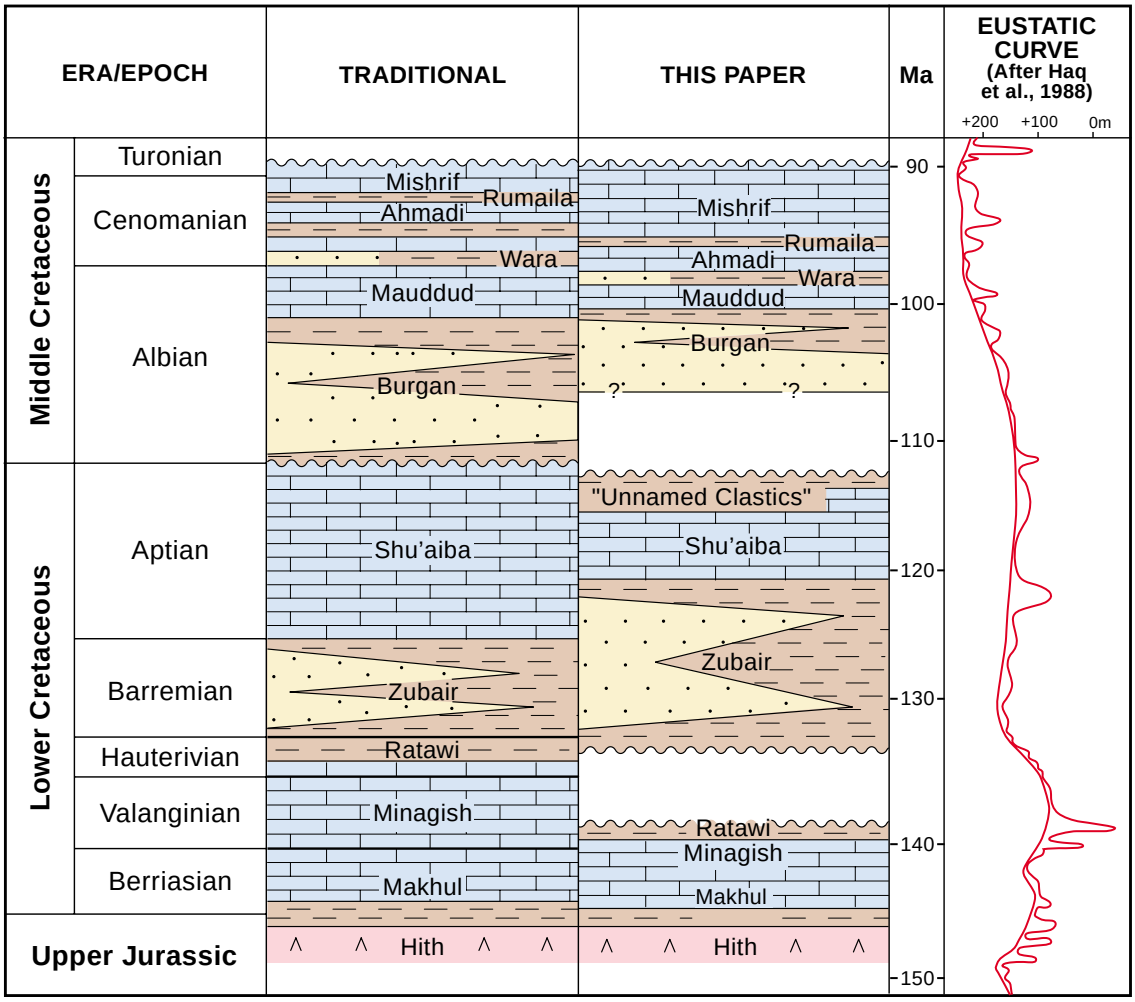


Figure 6: Traditional Lower - Middle Cretaceous lithostratigraphy of Kuwait, and the revised stratigraphy described in this paper, with the eustatic sea-level curve in red (after Haq et al., 1988). Timescale is after Harland et al., 1990.

field) to which that plate has been subject throughout its evolution. Hence this overview will attempt to place the key elements of Kuwait's Cretaceous history in a global plate-tectonic context, as illustrated in Figures 4 and 5**.**

At the beginning of Cretaceous times, Kuwait was located just north of the Equator, and the large scale basin configuration had just changed from one of a differentiated passive-margin of shallow shelves and deeper, intra-shelf basins which characterized the Jurassic (Murris, 1980) to that of a very low relief passive-margin ramp setting, with the stable Arabian shelf passing northeastwards into the deeper water realm of the Mesopotamian-Northern Gulf Basin. Although the location of the shelf-to-basin transition oscillated through time with successive eustatic sea-level changes, the overall ramp architecture remained little changed in Offshore Kuwait throughout the Cretaceous.

Consistent with its equatorial location throughout the Cretaceous, and the low-relief nature of the Arabian margin, the Cretaceous succession in Offshore Kuwait is dominated by carbonates, generally mud-supported (Figure 6). However, around 130 million years before present (Ma), the opening of the South Atlantic, and then, some 25 Ma later, the opening of the Central Atlantic Ocean, induced a major change in plate motion direction (Figure 4) with consequent impact, through far-field stresses, on the Afro-Arabian Plate. Uplift of the cratonic hinterland of Arabia resulted in the flooding of the passive margin with extensive tongues of deltaic, shallow-marine sands, forming the Zubair and Burgan reservoirs, of Barremian-Early Aptian and Mid-Late Albian age, respectively. Reduced clastic influx,

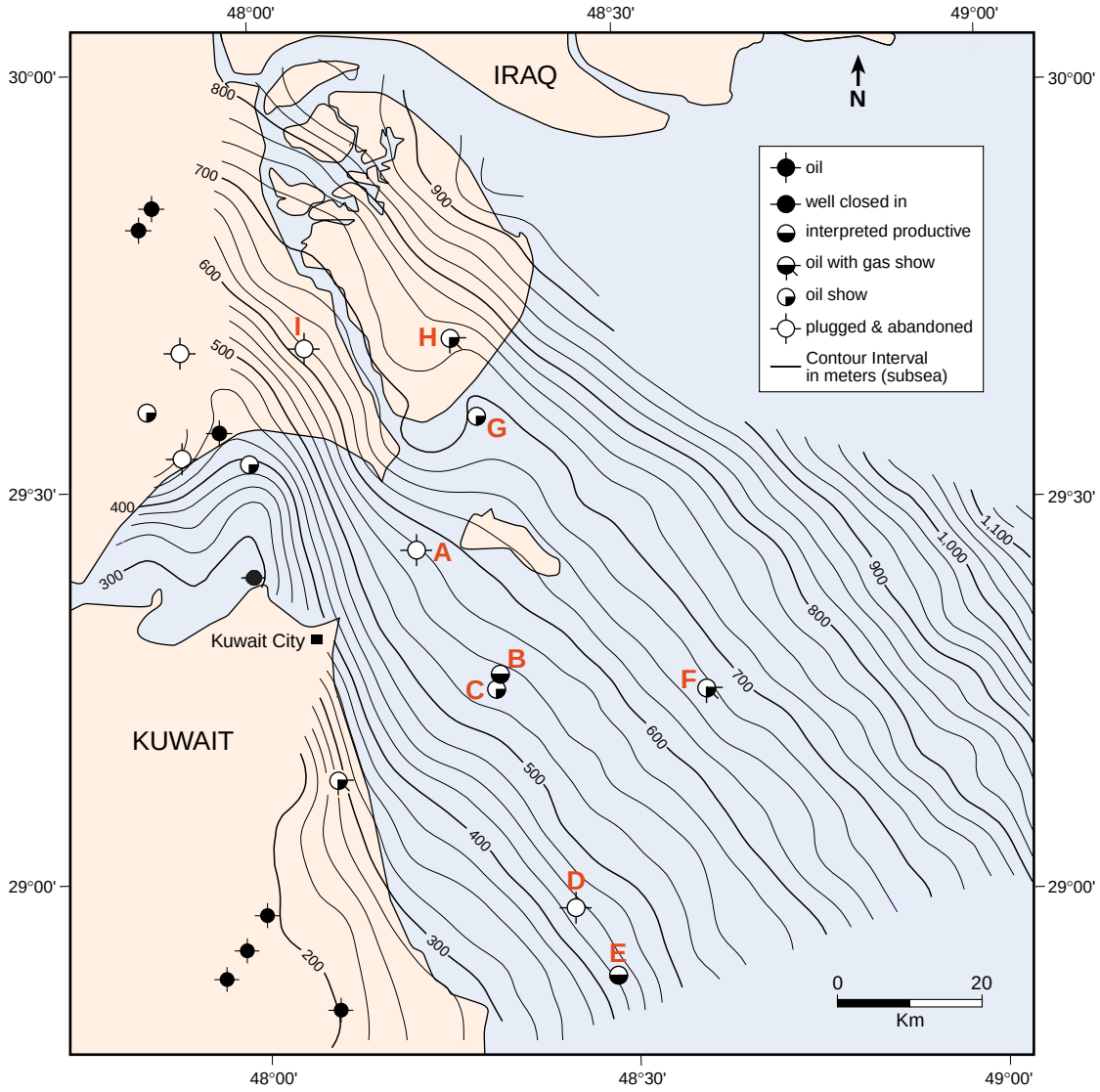


Figure 7: Kuwait Offshore: Depth Map, Top Rus Formation (in metres subsea.)

coupled with rising sea-level, resulted in the re-establishment in Offshore Kuwait of cyclic carbonate-shale deposition through the balance of the Middle Cretaceous.

At approximately 90 Ma, there occurred a pause in the steady northwards progress of Kuwait, which reflects the onset of ophiolite obduction and nappe emplacement at the leading edge of the Arabian Plate, the site of the present-day Zagros Suture. In Kuwait, this deformation reactivated older structural features, and generated the Base Upper Cretaceous Unconformity, which downcuts progressively towards the west and south, causing significant thinning and loss of section of the Middle Cretaceous over the major anticlines of coastal Kuwait. Growth, though more subdued, of these major structures continued throughout the Upper Cretaceous, which in Kuwait developed in a dominantly carbonate shelf setting, whilst to the east, in the Mesopotamian-Northern Gulf Basin, a marl and shale-dominated foredeep developed.

The effectiveness of far-field stresses as a mechanism for generating tectono-stratigraphic responses over large areas of craton is illustrated by a comparison between Arabia and Central Africa. Guiraud and Maurin (1992) describe two phases of intra-cratonic rifting from Central Africa which appear to be co-eval with the Zubair and Burgan sand influxes of Arabia, and with the two-phase opening of the Atlantic. In the reverse direction, the Santonian obduction event on the Arabian margin is co-eval with the inversion of many of the Cretaceous rifts in Central Africa (Guiraud and Maurin, 1992).

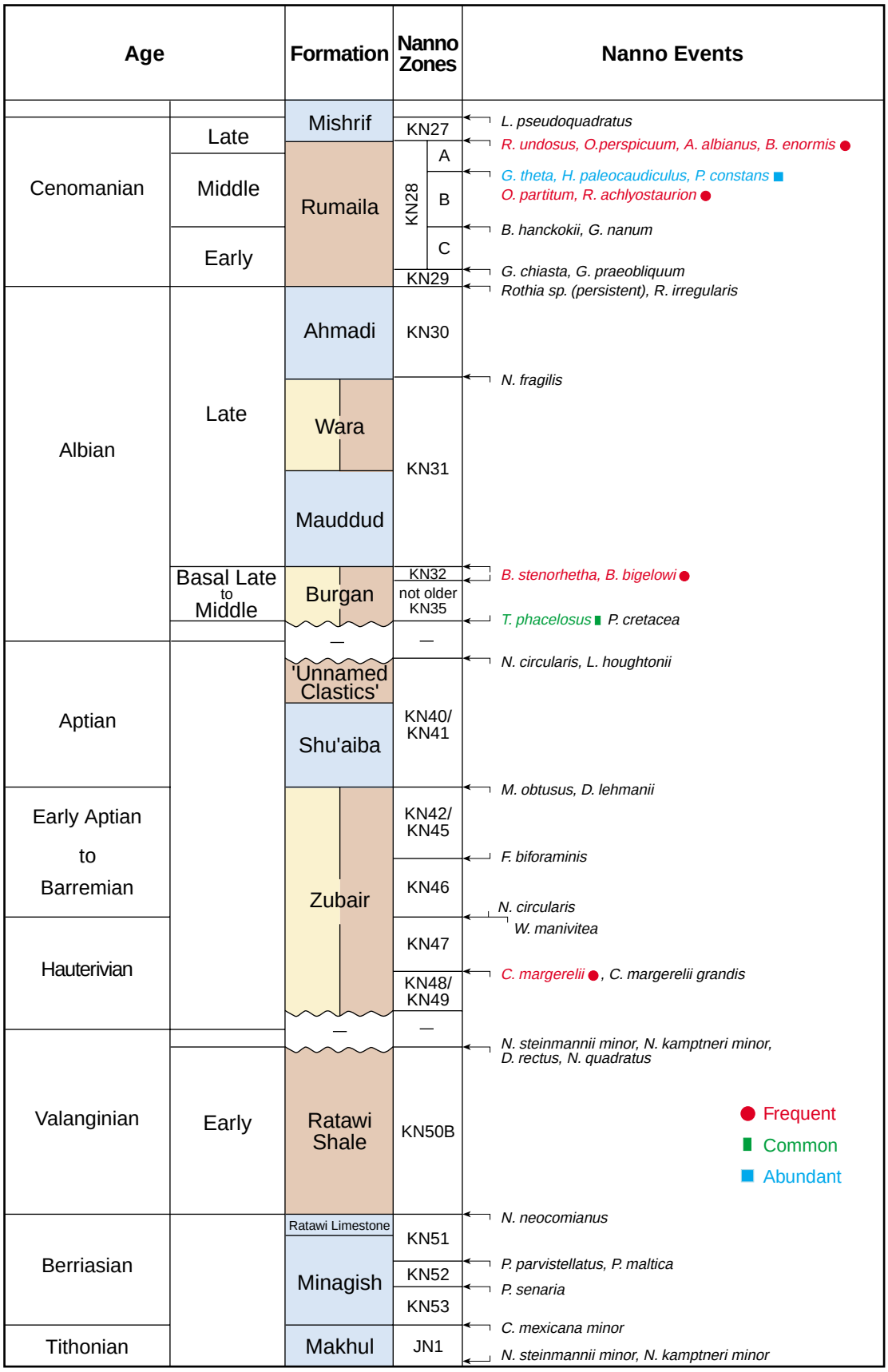


Figure 8: Middle to Lower Cretaceous nanno-fossil zones and major nanno-fossil events, Offshore Kuwait (after Varol Research, 1996).

Tectonic quiesence and shallow-water carbonate deposition characterized the Paleogene of Kuwait. The onset, in Lower Miocene times, of the Zagros Orogeny, representing the final collision of Arabia and Eurasia caused uplift and erosion in Kuwait, represented by the Top Dammam Unconformity which shows truncation and gentle arching over most of the major oil fields, whilst the succeeding development and infill of the Zagros foredeep generated the regional north-easterly dip which is such a feature of the Offshore area today (Figure 7).

STRATIGRAPHY OF THE LOWER-MIDDLE CRETACEOUS SEQUENCE

Introduction

Given the low relief, monoclinal nature of much of Offshore Kuwait, it was felt that stratigraphic trapping would provide the only possibility of significant hydrocarbon entrapment within the Lower-Middle Cretaceous reservoirs (prolific producers in the Onshore fields). In order to explore for stratigraphic traps, a high-resolution sequence-stratigraphic framework is essential, building on quantitative biostratigraphical data in order to provide as detailed a chronostratigraphical and paleo-environmental calibration of this sequence as possible.

Over 500 samples were collected from eleven wells (highlighted in orange in Figure 1): most of these samples were split, and a total of some 790 biostratigraphic analyses were made, by Robertson Research International Ltd. (foraminifera), and Varol Research (nannoplankton). Approximately 90% of the samples analyzed were cuttings. Previous analyses commissioned by KOC on ostracod distribution were re-evaluated by Lacustrine Basin Research (LBR).

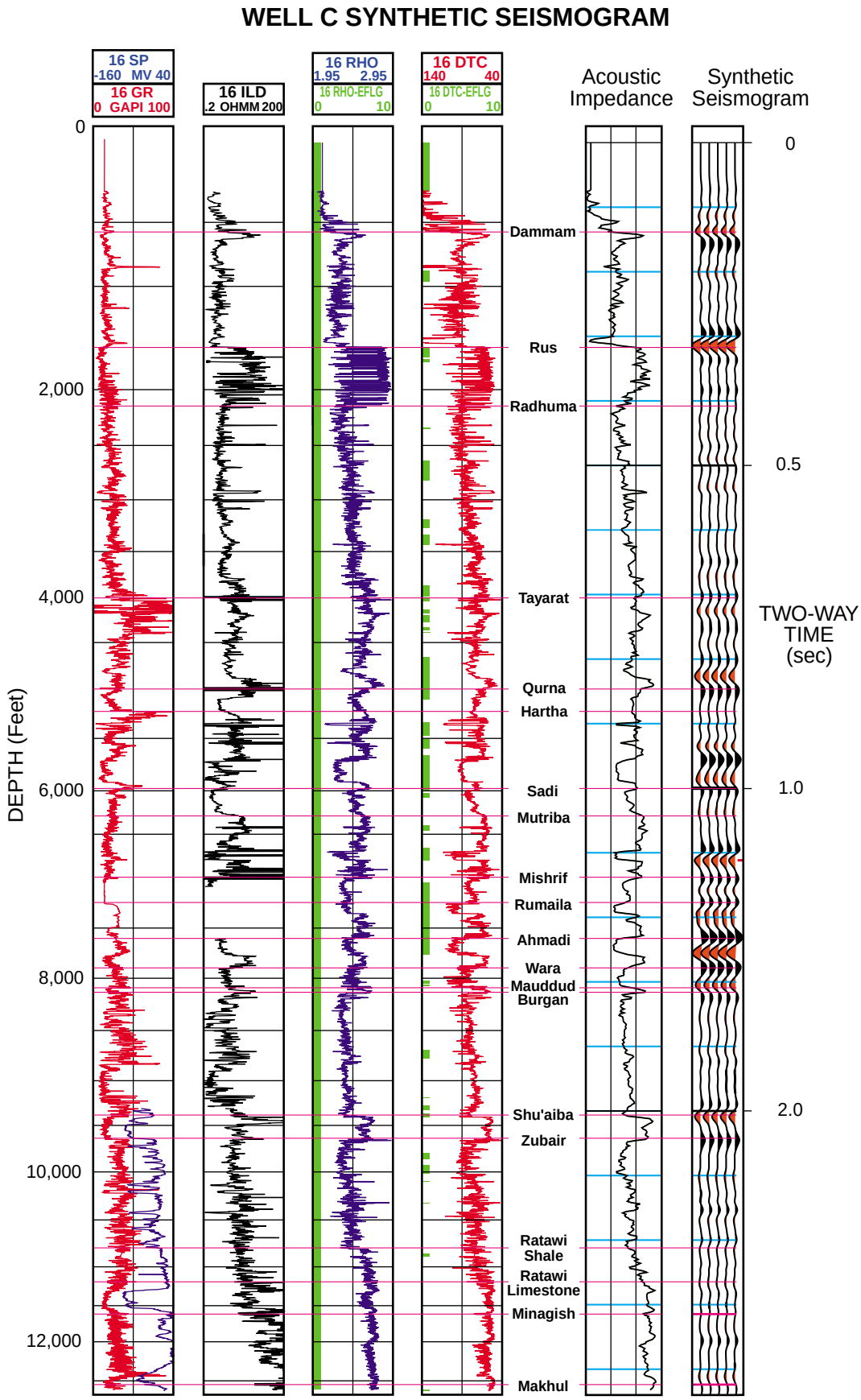
This study is the first to utilize nannoplankton analysis on Kuwait samples, and the data so obtained were crucial in providing accurate chronostratigraphical calibration, far more than would have been obtained from the microfaunal data alone. A zonation scheme specific to Offshore Kuwait has been developed (Figure 8). It utilizes a combination of global markers and local nanno-fossil events which are consistently recognizable in the wells studied (Varol, 1996).

Results

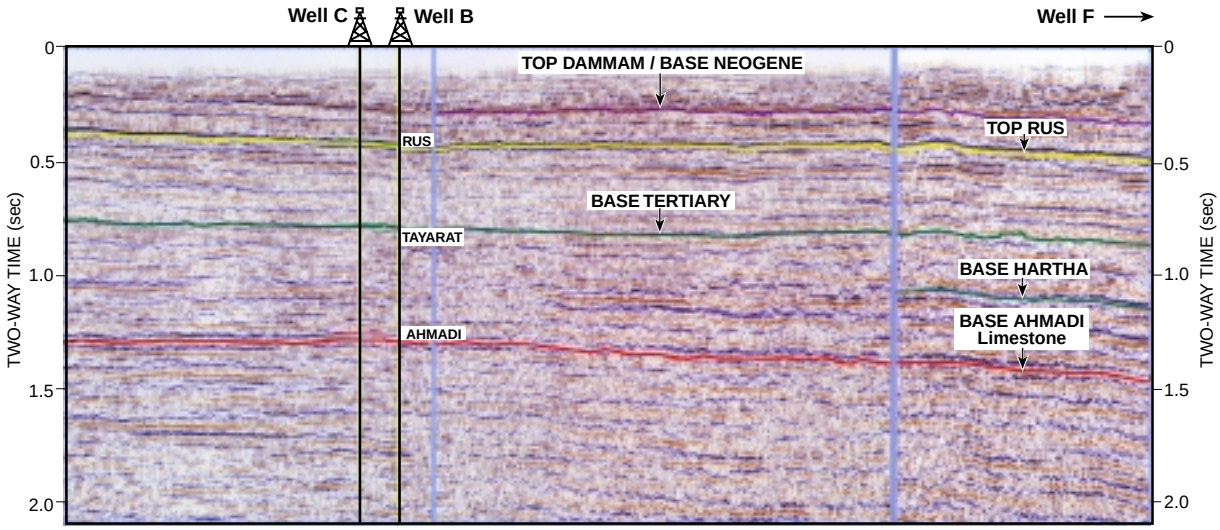
The quantitative biostratigraphic data was plotted on a well-by-well basis and a well log and seismic correlation framework established (Figure 9). From this it was apparent that the parallel reflection geometry seen on the seismic data concealed no significant diachronicity in the investigated sequence, and that KOC's lithostratigraphical nomenclature was sound. Hence it was retained as the basis for the Offshore stratigraphical framework. A new Time-Rock Synopsis (Figure 10) was constructed. The parallel nature of the formation boundaries reflects the lack of diachronicity and the parallel nature of the seismic reflections across the area**.**

Plotting of the biostratigraphic and well-data revealed the presence of two major disconformities / hiati, with no data representing the Late Valanginian-Early Hauterivian, or Latest Aptian-Early Albian being recorded. It was also apparent that the age and stratigraphic position of these gaps may have been incorrectly identified in the past, namely:

(1) that the regionally-identified Aptian-Albian disconformity does not occur at the Burgan-Shu'aiba contact, but within the lower part of the Burgan Formation, and that the basal shales of the Burgan Formation lie below this hiatus, and are of Late Aptian age. The age control on the Lower Burgan sands is poor, and the hiatus is assumed to lie just below the incoming of the massive Burgan Fourth sands. The presence of a major hiatus at this time is attributed to the significant change in plate motion that affected Arabia at ~110 Ma (Figure 4).



Figures 9a: Synthetic Seismogram for Well C, typical of Offshore Kuwait. The fine pink lines represent formation boundaries; the heavier blue lines correspond to seismic reflectors or other markers.



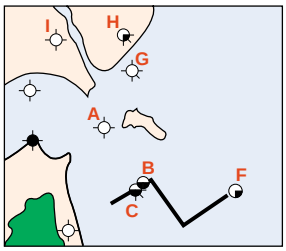


Figure 9b : Seismic line, Offshore Kuwait, illustrating the monoclinical nature of the offshore area between the Burgan and the Khafji-Nowruz Arches (Figure 1). The key interpreted reflections correspond to the Middle Cretaceous Ahmadi, Upper Cretaceous Tayarat and the Tertiary Rus formations. Blue vertical lines indicate bends in the seismic line (see inset map). The synthetic seismogram for Well C is shown on Figure 9a.

(2) that the disconformity separating the Zubair and Ratawi formations is of Early Valanginian-Early Hauterivian age, and not co-incident with the Hauterivian-Barremian boundary as previously suggested. A hiatus of similar age is reported from southwest Iran by Shakib (in Simmons, 1994), and corresponds to a major global eustatic sea-level lowstand.

Summary of the Lower Cretaceous Stratigraphy

The Lower Cretaceous sequence of Kuwait ranges in thickness from 3,800 ft to 4,400 ft (Figure 11), becoming thicker to the north-northeast as the Mesopotamian trough is approached. The sequence can be sub-divided into two cycles:

Makhul, Minagish and Ratawi Formations

The sequence comprises a relatively featureless succession of mud-supported limestones and interbedded shales. The Makhul Formation is composed of dense grey-dark grey limestones and interbedded dark grey shales and averages 450 ft in thickness in the Offshore area. The succeeding Minagish Formation ranges in thickness from 800 ft in the south of the area to 1,200 ft in the north and comprises a sequence of grey argillaceous lime mud-wackestones with interbedded green-grey calcareous shales. The oolitic grainstones that characterize this formation in Onshore Kuwait have not been encountered in the Offshore. The Ratawi Formation is divided into two members, the Lower Ratawi Limestone and the Upper Ratawi Shale, reflecting the proportion of lime mud-wackestone and calcareous shales and marls in each unit, which average about 500 feet in thickness.

The environment of deposition based on ostracod analysis is overall inner shelf (i.e. low tide down to ~40 m) with a conjectural 20-50 m water-depth towards the north (Lacustrine Basin Research, 1996).

The age of the sequence is ?latest Tithonian to Early Valanginian (Varol Research, 1996).

Zubair, Shu'aiba and "Unnamed Clastics" Formations

High global sea-level prevailed during Late Hauterivian to Late Aptian but despite this, uplift of the Arabo-Nubian craton resulted in the influx of the Zubair delta from the west, inundating the entire

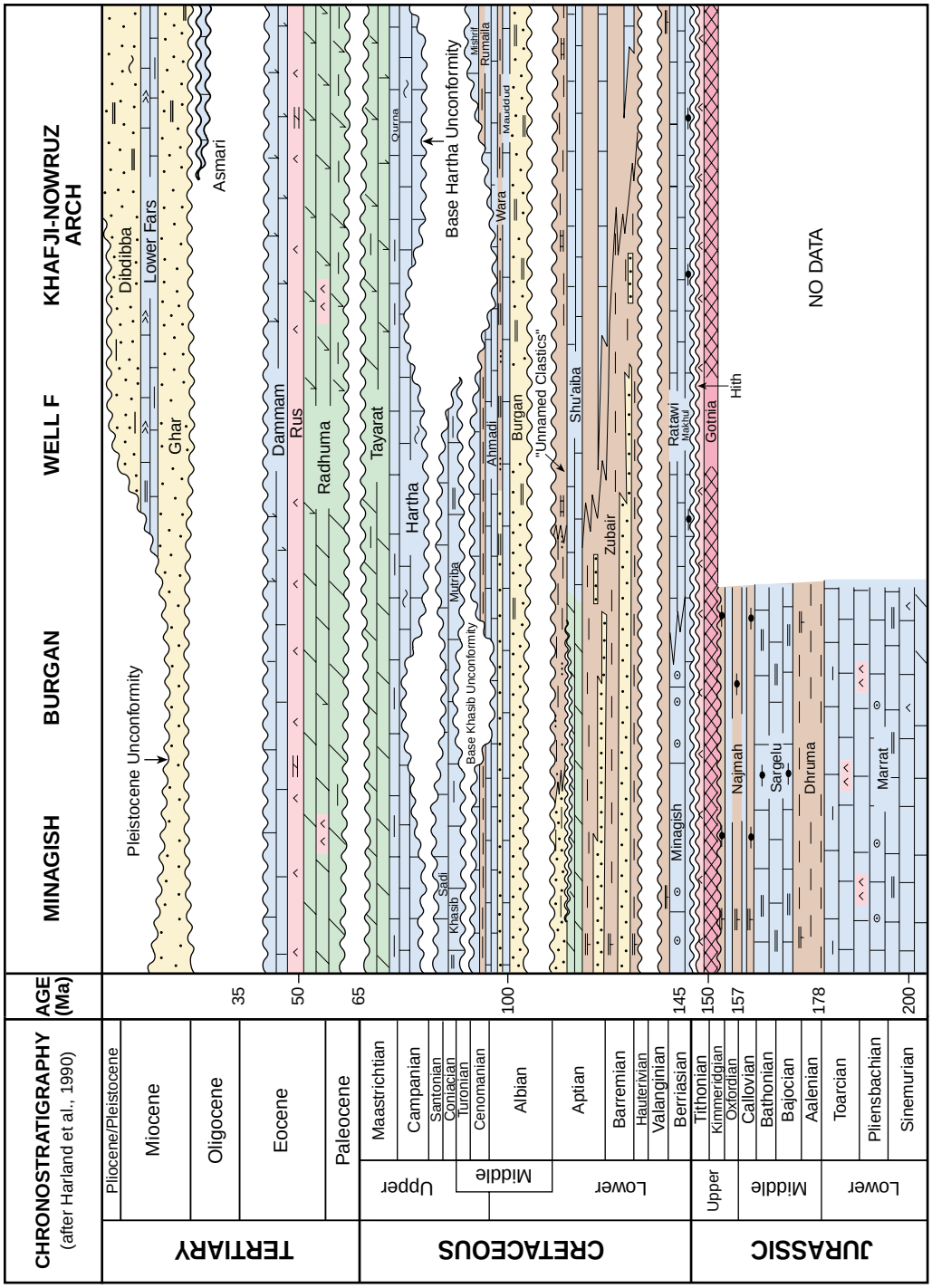


Figure 10: Stratigraphic Summary Profile across coastal and Offshore Kuwait. (The line of profile approximates that of Figure 2, and is approximately 200 km in length).

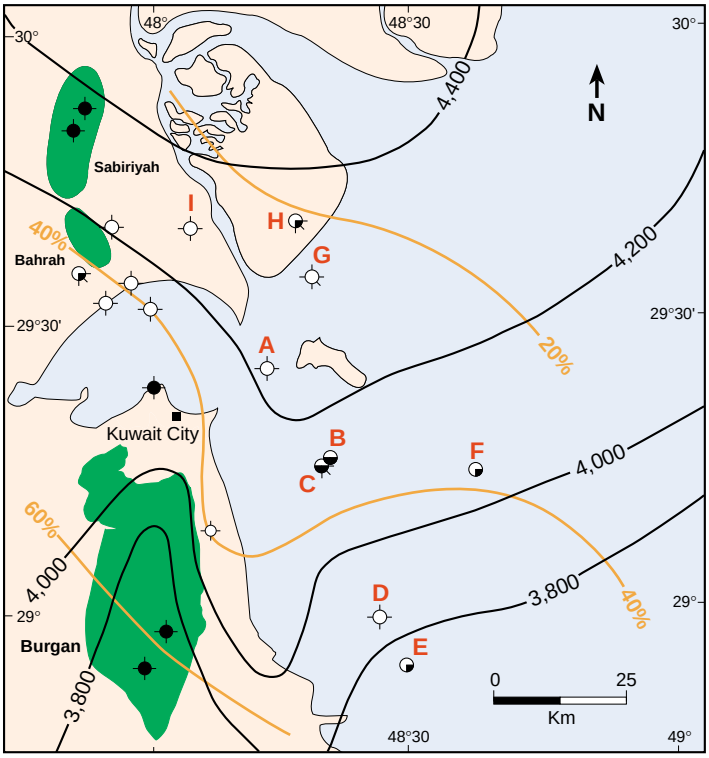


Figure 11: Kuwait Offshore, Lower Cretaceous isopach map in feet (black); and Net-to-Gross (i.e sand percentage) contours for the Zubair Formation (orange).

Offshore area with an interbedded sequence of sands (fine-very fine grained) and shales. The sequence thins from ~1,350 ft to less than 1,000 ft, and the sand percentage decreases, in a northeasterly direction, from 50% near the southern coast to ~20% in the vicinity of Bubiyan Island (Figure 11).

Ostracod faunas indicate that the Zubair Formation was deposited on a broad, relatively shallow continental shelf with average water depths between 20 and 40 metres (Lacustrine Basin Research, 1996). Nannoplankton ages for the Zubair range from Late Hauterivian to Early Aptian.

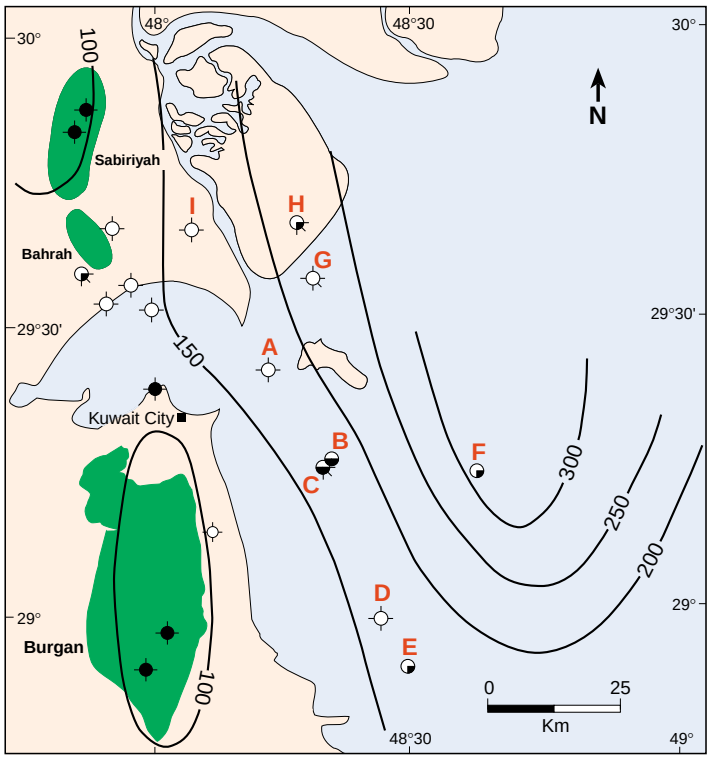


Figure 12: Kuwait Offshore, "Unnamed Clastics" isopach map in feet.

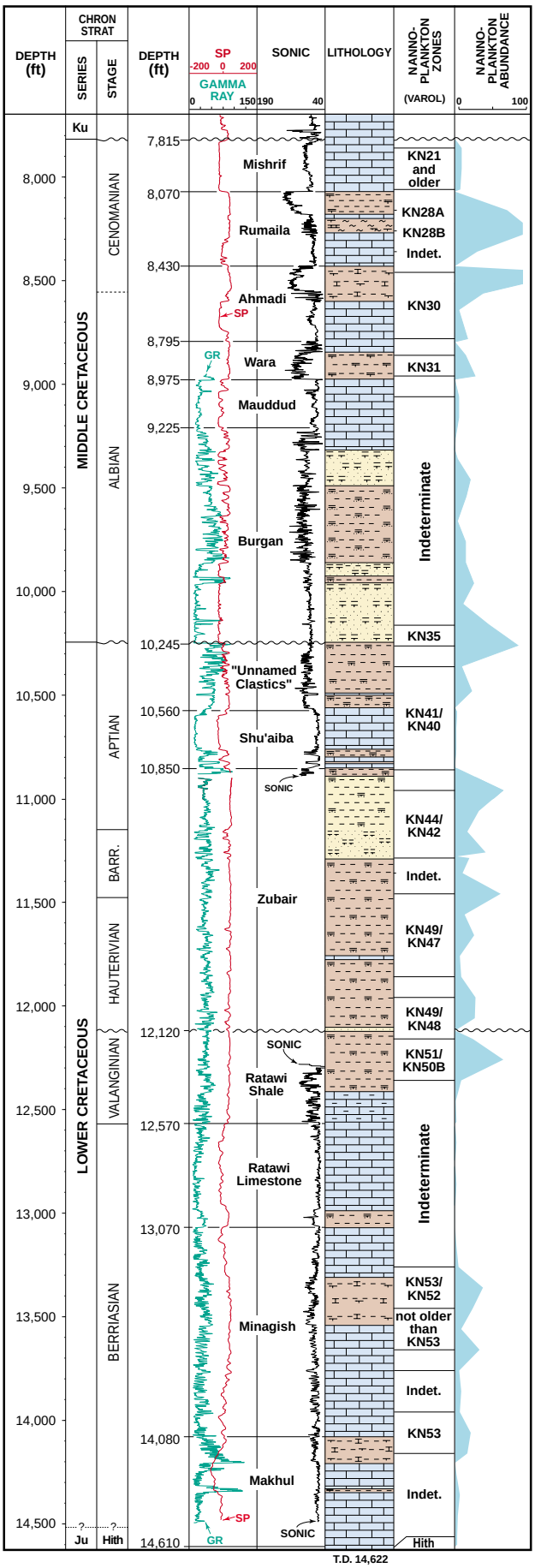


Figure 13: Representative Log for the Offshore Kuwait Lower-Middle Cretaceous sequence, and suggested Type Log for the 'Unnamed Clastics' Formation (Well F).

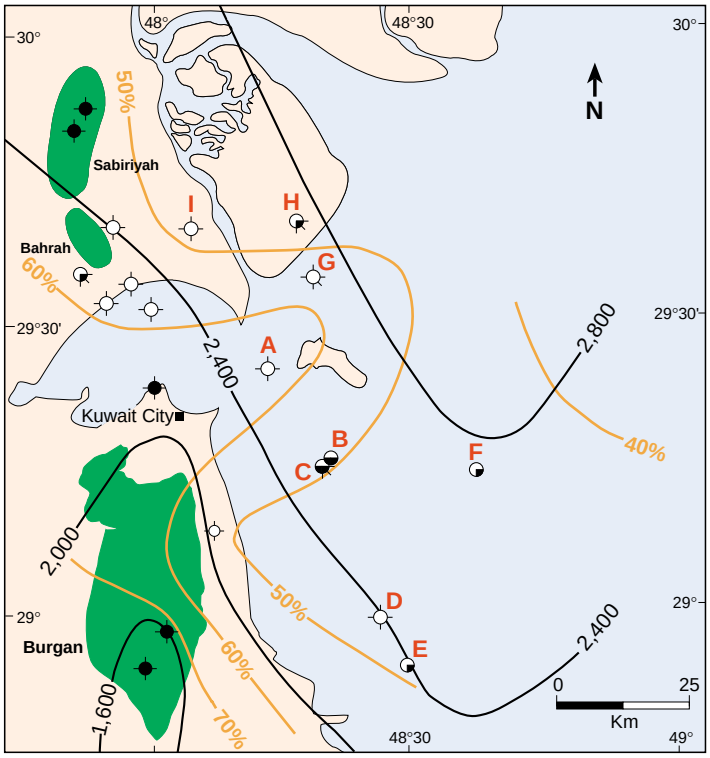


Figure 14: Kuwait Offshore, Middle Cretaceous isopach map in feet, (black); and Net-to-Gross (sand percentage) contours for the Burgan Formation (orange).

The Shu'aiba Formation (Early-Late Aptian in age) marked a temporary return to shallow marine carbonate deposition, and it comprises a light grey-buff, lime wackestone, which is frequently fractured, locally vuggy (and hence a frequent lost circulation zone) and averages 300 ft in thickness.

At the close of Shu'aiba times, clastic sedimentation resumed through to the end of the Aptian. This shale sequence is considered to conformably overlie the Shuaiba (as observed by Owen and Nasr, 1958), and has hitherto been referred to the lowermost part of the Burgan Formation. As a result of this study, however, a major hiatus or disconformity has been identified seperating these shales from the rest of the Burgan Formation, and hence it is felt that a new formation name is required (the informal term 'Unnamed Clastics Formation' has been used in Study Team reports). This interval ranges in thickness from ~80 ft in Burgan field, to some 300 ft in the east of the Offshore (Figure 12), and was deposited in an open marine inner neritic environment (Robertson Research, 1996). The easternmost offshore well has been selected as the proposed type log for the 'Unnamed Clastics', which were encountered between 10,245 ft and 10,560 ft (depths below derrick floor) (Figure 13).

Summary of the Middle Cretaceous Stratigraphy

During the Middle Cretaceous, global sea level rose to its highest level in Mesozoic-Cenozoic history, reaching a maximum during the Cenomanian/Turonian. However, across the entire Arabian passive margin, a renewed clastic influx occurred, spreading clastics across large parts of the basin. Two sedimentation cycles can generally be recognised during this period, both ranging from clastics at the base to carbonates at the top. In Offshore Kuwait the lower cycle (Burgan and Mauddud formations) is readily distinguished. However the upper cycle (Wara, Ahmadi, Rumaila and Mishrif formations) in the offshore consists essentially of carbonates and shales only. The isopach of the Middle Cretaceous sequence (Figure 14) increases from 1,600 ft to 2,800 ft, though the 'thin' over the Burgan Arch is the result of erosion below the base Upper Cretaceous unconformity.

Burgan and Mauddud Formations

After the deposition of the Zubair and Shu'aiba formations and the (as yet unnamed) basal shale of the Burgan Formation, the Middle Cretaceous commences with a newly-recognised hiatus of approximately six (to possibly 11) million years duration. (Due to age dating problems within the Burgan sandstones (only ditch cuttings were used) no firm conclusions can yet be drawn regarding the precise duration of this hiatus).

Uplift of the cratonic source areas to the west caused a renewed influx of sands over large parts of the basin in the early Middle Albian. The Burgan Formation is characterised by thick deltaic sands in the west, thinning somewhat to an average thickness of 1,100 ft in the Offshore (including the basal shales). Towards the east the sand percentage diminishes but not so dramatically as in the Zubair, such that a net-to-gross of ~45% is still apparent in the easternmost well of Offshore Kuwait (Figure 14). Carbonates onlapped in a westerly direction and progressively displaced the clastics westward into interior Kuwait, resulting in the deposition of the Upper Albian Mauddud carbonates. The Mauddud Formation shows a gradual overall thickening towards the east and northeast, ranging from the depositional feather-edge in the Minagish area to some 425 ft in the Bubiyan area.

Wara, Ahmadi, Rumaila and Mishrif Formations

Following the deposition of the thick Albian Burgan-Mauddud sequence a number of relatively short-duration carbonate-shale cycles comprise the balance of the Middle Cretaceous.

The original depositional thickness of these intervals gradually increases towards the northeast, but this pattern is highly modified by the syn-depositional thinning, and end-Middle Cretaceous erosion, over the Burgan and Khafji-Nowruz Arches, from which the Rumaila and the Mishrif formations have been completely removed.

The lithologies in the offshore area are relatively uniform and are characterised by alternations of ("highstand") carbonates (i.e. mainly wackestones) and ("transgressive") shales. Water depths based on ostracods consistently range from ~20 m (shallow inner shelf) to a possible maximum of ~70 m (middle shelf) during deposition of the Ahmadi shale (Lacustrine Basin Research, 1996).

CONCLUSIONS

The principal conclusions from this study are as follows:

- There is no significant diachronicity apparent in the Lower and Middle Cretaceous sequences across Offshore Kuwait. The layer-cake appearance of the Time-Rock Synopsis mirrors the parallel nature of the seismic reflectors across the area.

- Nanno-fossils have the potential to provide a far more detailed sub-division of the Cretaceous of Kuwait than has hitherto been available.

- A significant hiatus or disconformity is present across the Aptian-Albian boundary, but it is thought to lie, not at the Shu'aiba-Burgan contact, but within the Burgan at the contact of the basal shales (now thought to be of Late Aptian age) with the base of the Burgan Main or Fourth sand (of ?Mid-Albian age).

- A second major hiatus or disconformity is thought to lie at the contact of the Ratawi Shale (now thought to be no younger than Early Valanginian) with the base of the Zubair Formation (of Late Hauterivian age).

The majority of the samples studied were cuttings, and hence the above results should be regarded as provisional or indicative until they can be substantiated by more detailed examinations based on cores and sidewall samples. If the assignment of the basal Burgan shales to the Late Aptian as indicated here can be substantiated by more detailed work, then it is recommended that this sequence be elevated to formation status and a formal name, preferably local, be assigned.

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