

**COMPARISON OF RECENT AND MIOCENE
FORAMINIFERA FROM EASTERN
SAUDI ARABIA**

BY
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MASTER OF SCIENCE

In

GEOLOGY

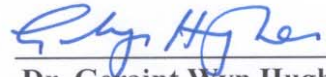
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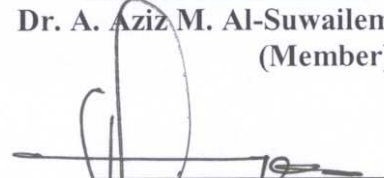
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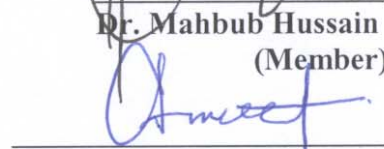
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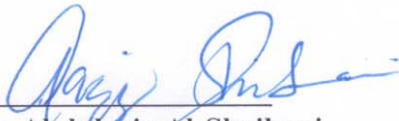
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DEDICATION

My thesis is dedicated to my lovely daughter Raghad who suffered from being away from her father for long time during preparation of this thesis work.

ACKNOWLEDGMENTS

Acknowledgment is due to the King Fahd University of Petroleum and Minerals (KFUPM) for supporting this research.

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THESIS ABSTRACT

NAME: Saleh Sfoog M. Al-Enezi

TITLE: Comparison of Recent and Miocene foraminifera from Eastern Saudi Arabia

MAJOR FIELD: Geology

DATE OF DEGREE: 29 May 2006

To improve understanding and interpretation of the Middle Miocene foraminifera, samples of Recent foraminifera from the nearshore Arabian Gulf was examined and compared with similar foraminiferal biocomponents of the Dam Formation carbonates at Jabal Midra Al-Janubi. Eleven samples from the Arabian Gulf and 60 samples from the Dam Formation at Eastern Saudi Arabia were collected and analyzed using standard micropaleontological techniques. A total of 47 species from the Gulf were identified to be Recent origin, consisting of 2 agglutinated, 21 miliolid and 24 rotalid species. The Dam Formation had 51 species, consisting of 3 agglutinated, 37 miliolid and 11 rotalids. The presence of species *Borelis melo* in the Dam Formation confirms its Middle Miocene age.

Analysis of the Arabian Gulf foraminiferal environment revealed that foraminiferal diversity tends to increase with depth but decrease with salinity. Similar trends in the foraminiferal biocomponents at the Dam Formation have been interpreted to provide a new palaeoenvironmental understanding, and similarities of the foraminiferal biofacies of the Middle Miocene and Recent.

Results further indicate the foraminiferal fossils at the Dam Formation commenced deposition following a slight marine transgression over an eroded Palaeogene surface during the Middle Miocene, under highly adverse, hypersaline conditions. Successive small-scale marine transgressions, with normal salinity, led to foraminiferal colonization and the accumulation of foraminiferal wackestones, packstones and grainstones. These minor fluctuations led to the development of shoaling-upwards cycles, in which the foraminifera and grain sizes responded to increasing energy conditions as well as slight elevations in salinity, as evidence by the concentrations of hypersaline-tolerant miliolid foraminifera.

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CHAPTER ONE

INTRODUCTION

1.1. INTRODUCTION

In Saudi Arabia, the home of the world's largest oil and gas reserves, the successful development of the hydrocarbon resources depends on the best understanding of the three dimensional distribution of the various reservoir facies. As these are primarily determined by the original lithofacies and their depositional environment, great efforts are made to ensure that such palaeoenvironmental interpretations are as precise as possible.

One of the main sources of palaeoenvironmental information in marine sediments is the fossil content, of which foraminifera are the most significant component. Microfossils, such as foraminifera, are used extensively to establish three dimensional depositional models for the Permian to Miocene reservoir carbonates in Saudi Arabia. However, interpretation of such extinct species relies heavily on the experience of the micropalaeontologist in using forms that may have had a similar lifestyle to similarly-shaped species that live today. Under such circumstances, the adage "the present is the key to the past" is used, although with caution because of our understanding that with increasing geological time, there is expected to have been a "drift" in certain palaeoenvironmental preferences of certain species during their evolution. Nevertheless, the palaeoenvironmental preference of Miocene foraminiferal

species is considered to have been not too dissimilar to those of morphologically similar extant species.

The present study is established on the need to learn such comparative morphological studies to reveal the recent distribution of foraminiferal species for the purpose of understanding and interpreting the palaeoenvironment of Middle Miocene foraminifera. Foraminifera from the nearshore western Arabian Gulf have been examined and compared with the foraminifera identified in thin sections from the carbonates of the Middle Miocene Dam Formation that outcrops along the eastern margin of the Arabian Peninsula. In this way, a learned technique could be used to support similar studies in reservoir carbonates of Miocene and pre-Miocene age, and the link between academic research and its industrial application will gain strength.

1.2 OBJECTIVE

Pioneering studies of the 1930's (Natland, 1933) established that many late Neogene species had living representatives which provide means for deducing palaeoecological conditions. The main objective of this study is to provide a refined palaeoenvironmental interpretation of the Middle Miocene Dam Formation, in the Eastern province of Saudi Arabia, using micropalaeontology and calibration with extant recent foraminiferal biofacies. This study is based on the premise that there is a morphological adaptation of foraminifera to their environment, and that such similarities can be used to extend known Recent environmental parameters to interpret Middle Miocene environments where only fossil foraminifera are available, i.e. *the present is a key to the past*. Such application of Recent

foraminifera to interpret the fossil environment is an important activity in oil-field and geological investigations, and is currently used to provide the most accurate reservoir layering models in the hydrocarbon industry.

1.3. LOCATION AND PHYSIOGRAPHY OF THE STUDY AREAS

The Arabian Gulf is located on the northeast flank of the Arabian Peninsula (Figure 1.1). The Peninsula consists of Arabian Precambrian shield, exposed in the west that is covered by Paleozoic, Mesozoic and Cenozoic sedimentary rocks (Figure 1.2) (Al-Hinai et al., 1997). In this region, carbonate deposition has been extensive since the Permian to the Miocene, varying lithologically from deep water marls to shallow water calcarenites and oolite, with occasional clastics and evaporites. Tertiary folding was followed by deposition of a vast thickness of continental sediments of Pleistocene to Recent age (Ziegler, 2001).

The topography of the region has been affected by regional tectonic events associated with Red Sea spreading, and the compressional affects related to Zagros subduction. Further complex structural features result from uplift above Infracambrian salt diapiric movement. Such deep-seated diapiric movement is considered to be a possible cause of the localized hills like the present Dammam Dome. (Kassler, 1973).

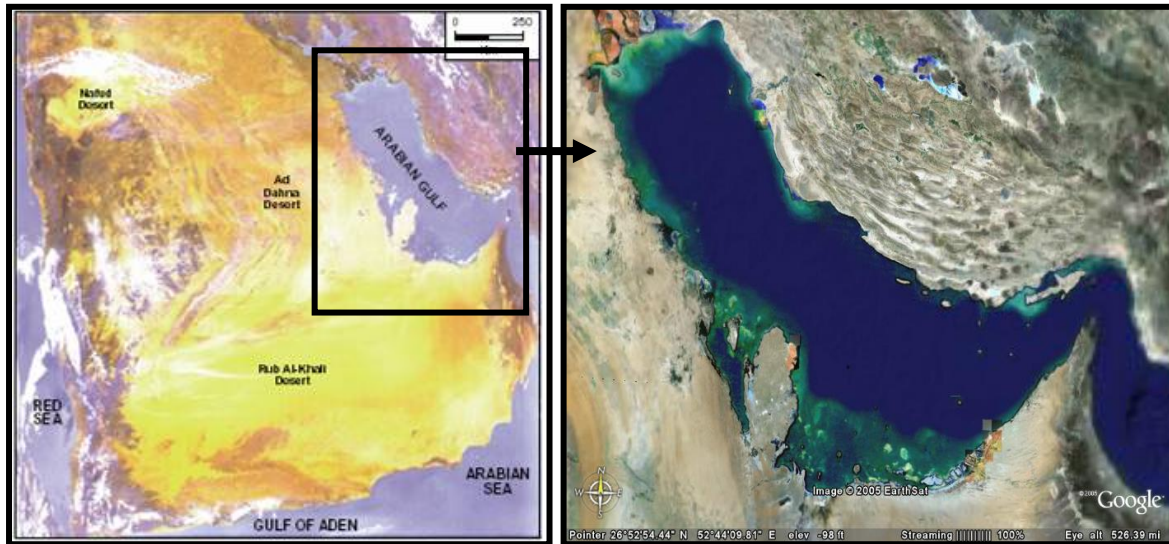


Figure 1.1. Aerial view of the Arabian Peninsula (left). This Image was taken from (NOAA-7) (after Al-Hinai et al., 1997), and close-up view of a satellite image of the Arabian Gulf (Google-Earth, 2005, URL: <http://www.google.com.sa/>) (right).

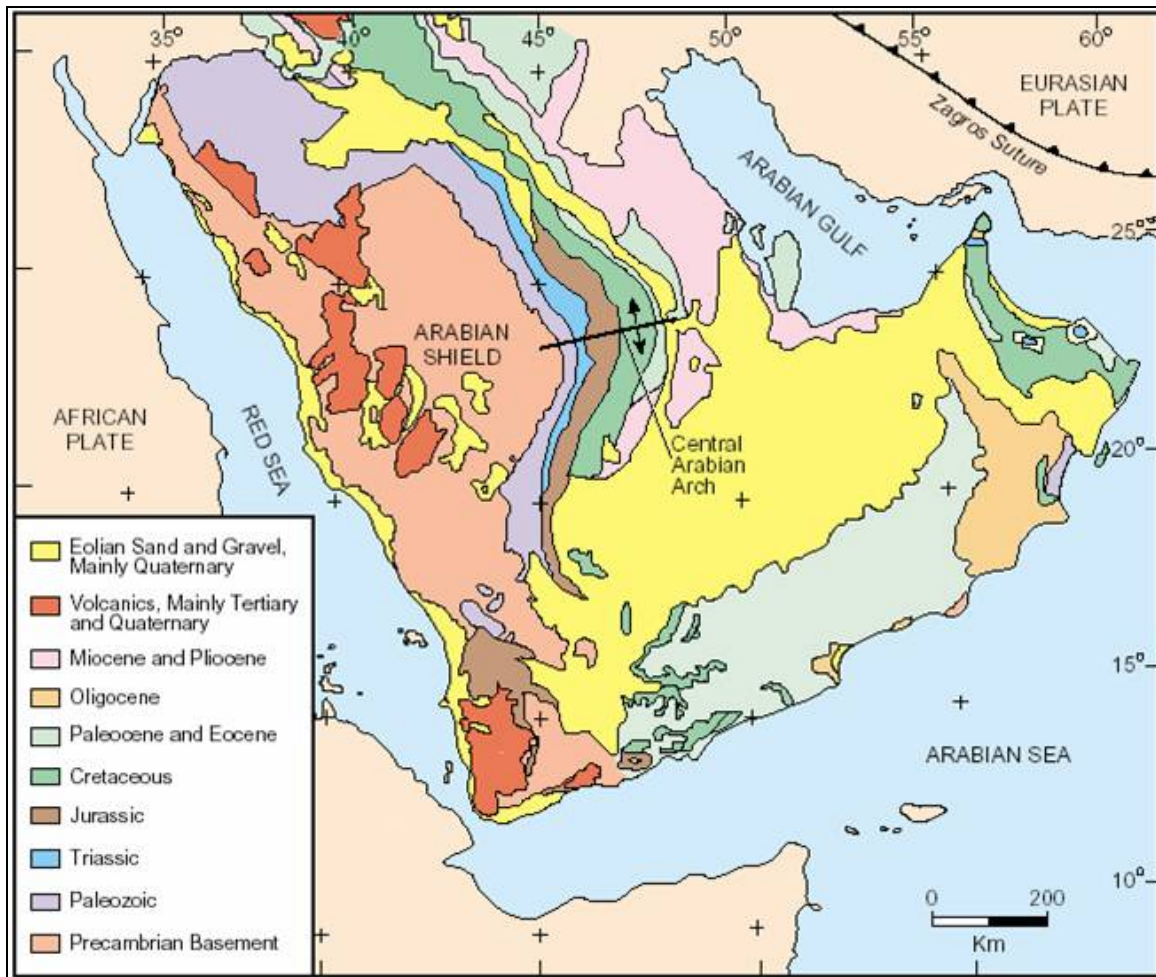


Figure 1.2. Generalized geological map of the Arabian Peninsula showing the main geological provinces (Al-Hinai et al., 1997).

The Arabian Gulf is an appropriate region to study the recent shallow marine foraminiferal distribution and to apply any observed trends to their fossil equivalents in the Neogene of Eastern Arabia because both environments are considered to represent submarine ramps. Two regions were selected for this study include the recent, shallow part of the Western Arabian Gulf along the east seashore of Saudi Arabia (along the coastline from Abu-Ali Island in the north to Half Moon Bay in the south) and the Middle Miocene exposure of the Dam Formation at Jabal Al-Midra Al-Janubi on the west flank of the Dammam Dome. The regions are situated close to each other, and present a convenient juxtaposition of recent carbonate sediments and Middle Miocene limestones.

1.3.1. The Arabian Gulf Study Area

The Arabian Gulf is a shallow marginal sea that extends as an arm of the Indian Ocean. It is a shallow tectonic depression formed during late in the Tertiary. The Gulf is approximately 1000 km long and varies in width from 340 km to its narrowest of 55 km in the Strait of Hormuz, and occupies an area of approximately 23900 m² (Kassler, 1973). The Gulf basin is bathymetrically asymmetrical, as the Arabian side is shallow and slopes very gently towards Iran where the water depth reaches over 100 m (Kassler, 1973). It has an average depth of approximately 35 m of which the average depth of the Western Arabian side is less than 20 m (Figure 1.3) (Kassler, 1973). The Arabian Gulf is characterized by high temperature and salinity. During the summer season, the water temperature reaches an average of 36° C while during winter nights it decreases to 10° C (Basson et al., 1977). The

high temperatures, low precipitation, limited fresh water inflow and isolation of the Gulf enhance the evaporation processes, and increase the water salinity. The mean salinity is between 37-40 ‰ while the surface water salinity is between 36.6-41.6 ‰ (Basson et al., 1977). This salinity is very high in large areas within the Gulf, particularly in the lagoons and bays (Figure 1.4). In these areas the salinity can reach between 60-70 ‰ and the normal salinity along the Eastern Arabia is about 45 ‰ (Figure 1.4). The overall water movement of the Gulf is anticlockwise and, combined with the prevailing northerly wind direction results in variable degrees of southeasterly longshore drift along the Saudi Arabian shoreline (Basson et al., 1977).

The Arabian Gulf sediments are generally calcareous, especially on the Arabian side. Because of the effect of the high shamal winds on the shallow water area, the sediments are mostly coarse skeletal sands that gradually decrease in size towards the center of the Arabian Gulf Basin (Figure 1.5). The carbonate content in this area is very high and reaches 80 % of the sediment composition. The sediments on the Arabian side are characterized by abundant skeletal tests of foraminifera (Purser, 1973).

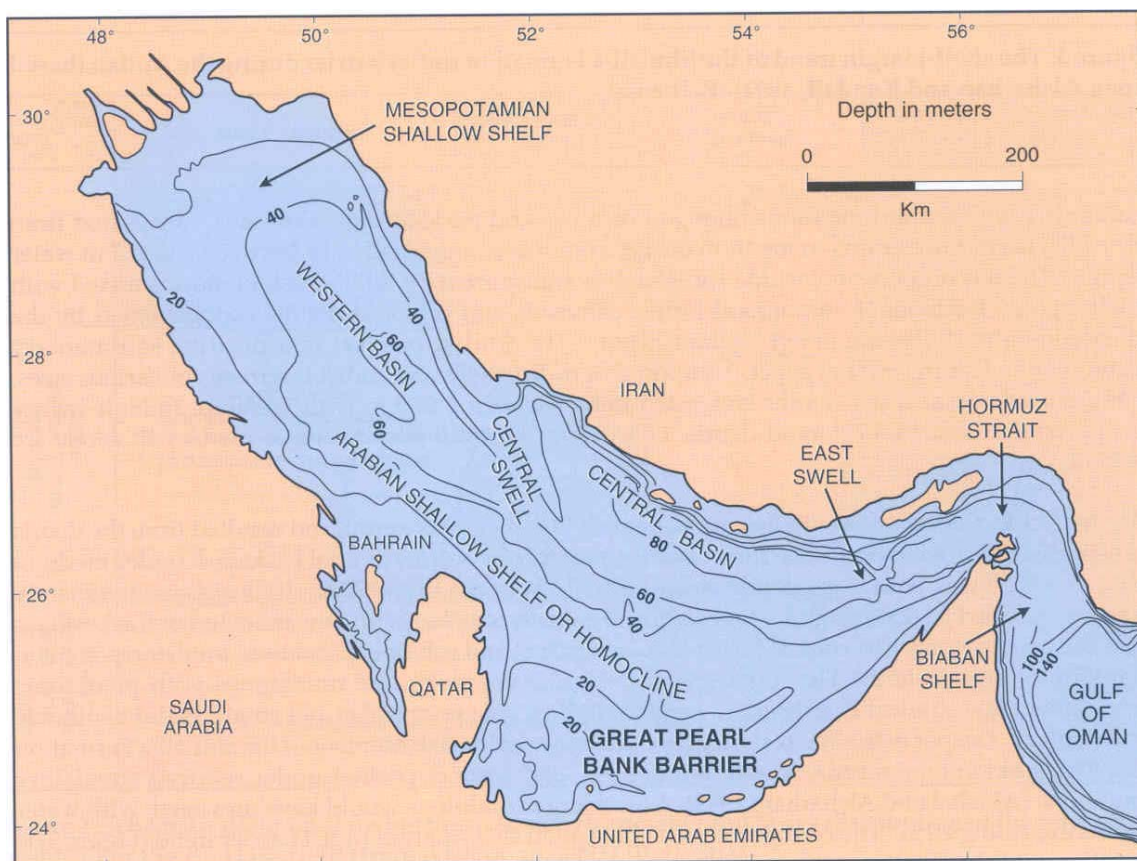


Figure 1.3. Map of the Arabian Gulf showing the main bathymetric provinces (Hughes, 1997, adapted from Purser, 1973).

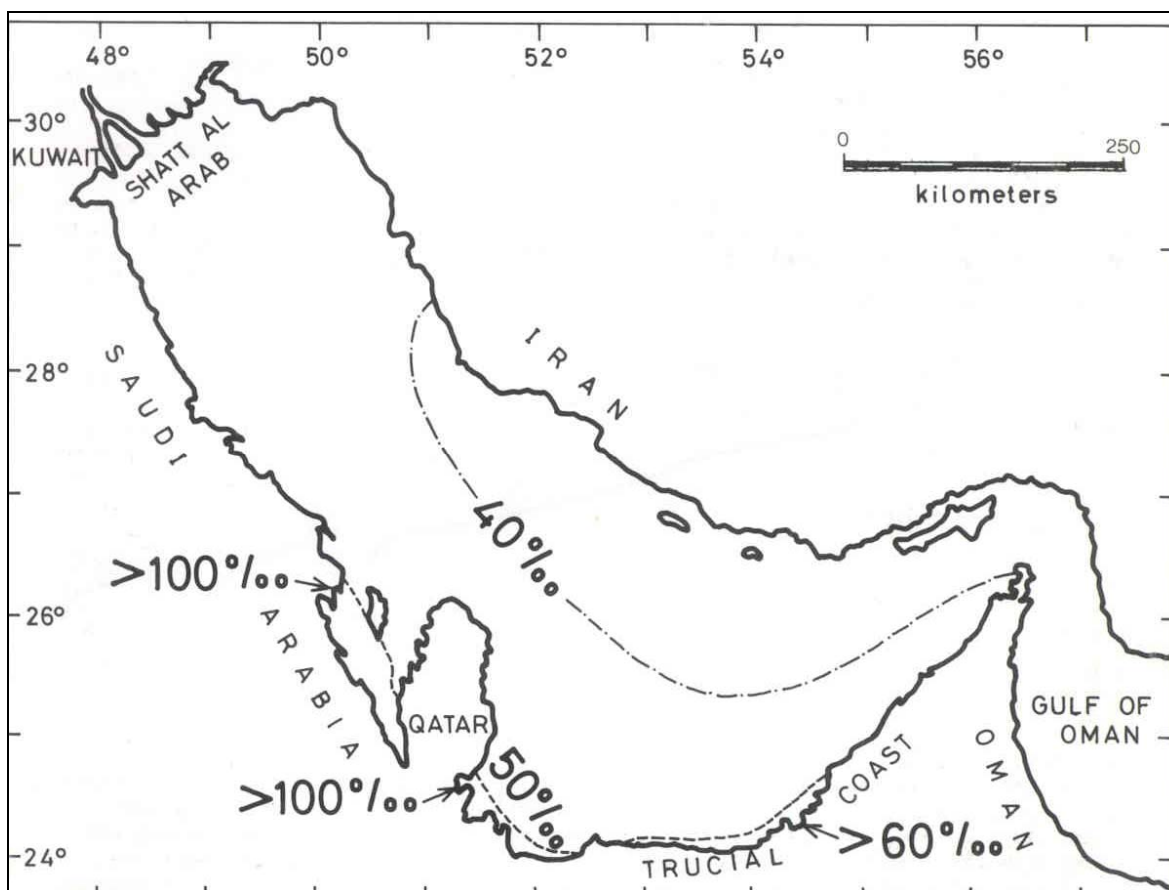


Figure 1.4. Salinity trends map of the Arabian Gulf displaying the major salinity trends in ppt (parts per thousand). (Purser, 1973).

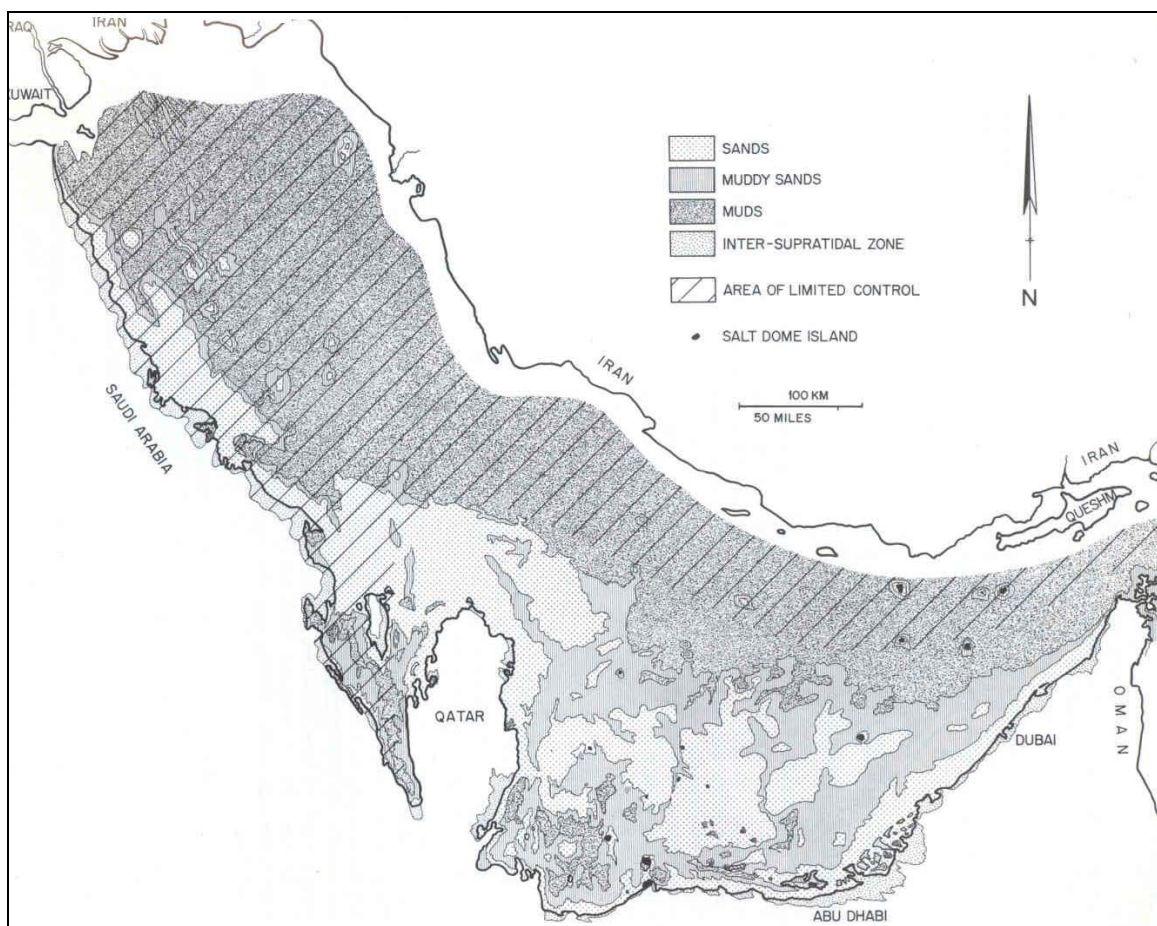


Figure 1.5. Map showing the regional distribution of principal sedimentary textures (Purser, 1973).

1.3.1.1. Coastal Physiography:

The study area for the recent sediments is located along the eastern Saudi Arabian coast between 26°N to 27°N latitude and between 50°E to 51°E longitude. This coastline extends for over 450 km from Ras Al-Khafji in the northwest to Salwah in the southeast. (Basson, et al, 1977) have divided the coastline on the basis of physical and biological factors into two sections equal in length connected by a transitional zone in the middle. The study locations are within these sections and were chosen accordingly. The three study locations are displayed in Figure 1.6.

1.3.1.1.1. The Northern Section. This section is located between Ras al-Mishab and Ras Tanura and lies partly on the northwest-southeast trending gentle ridge that continues across the Bahrain islands to the northern part of Qatar Peninsula. It is an open water environment having relatively active wave regime generated mostly from the predominant shamal wind.

It is characterized by open marine salinities that range from 38.5 ‰ to 41 ‰ with the lowest salinities located at the northern end and the highest ones found at the southern end of this section (Basson et al, 1977). The tidal range of this part reaches 2m and is dominated by regular diurnal or semi-diurnal tides (Basson et al, 1977). Five sample locations were selected in this section based on their environmental physiographical characteristics (Table 1.1). These locations are the southern part of Abu-Ali Island, Jubail, and Ras Al-Ghar offshore, Berri offshore, and Ras Tanura where one sample were collected from each location.

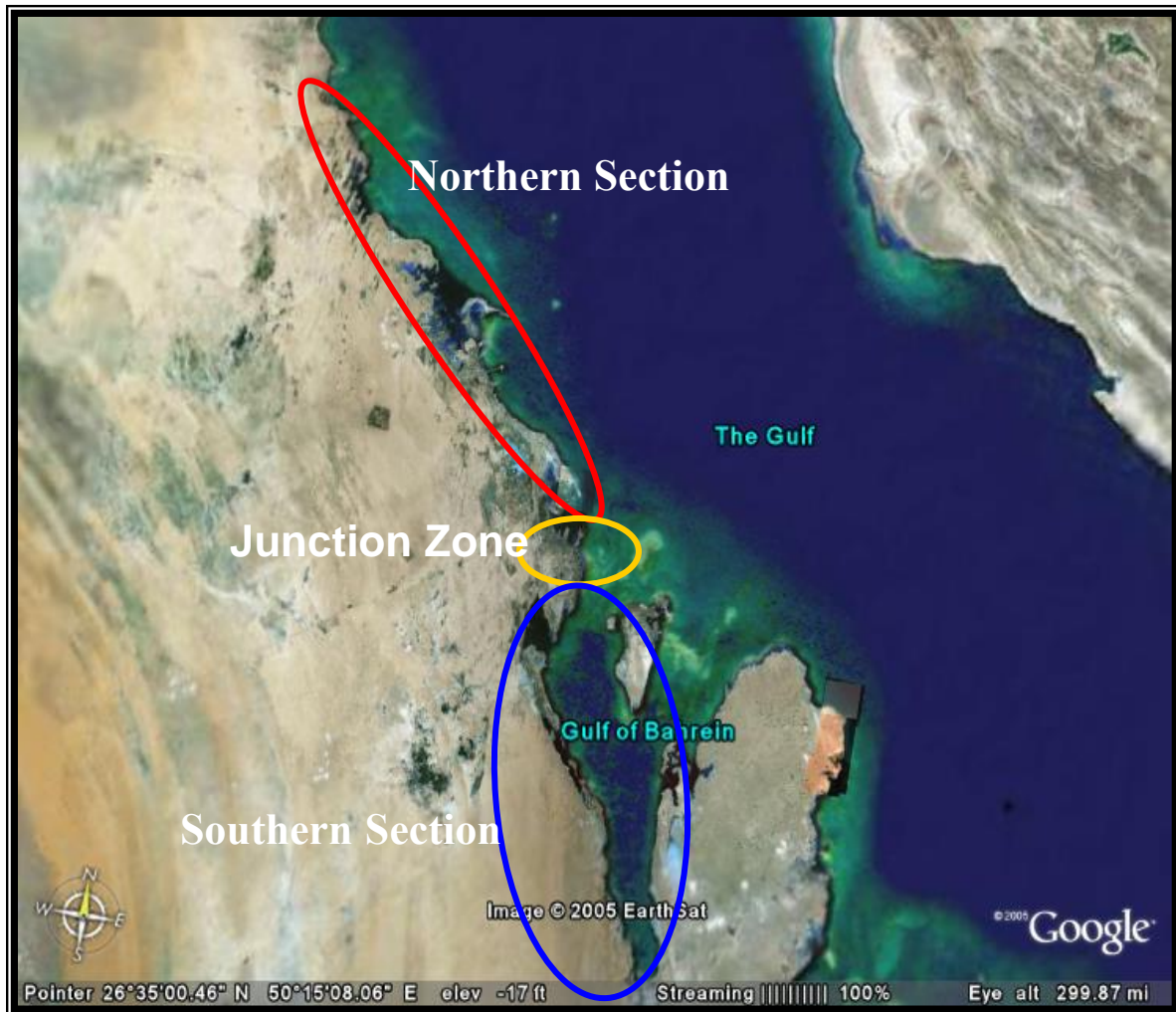


Figure 1.6. Satellite image showing the two coastline sections of the Saudi Arabian Eastern coast (Google-Earth, 2005, URL: <http://www.google.com.sa/>).

1.3.1.1.2. The Transitional Section. This junction zone between the northern section and the southern section is located between Ras Tanura and Dammam. Within this area, Tarut Bay displays an unrestricted marine embayment. Tarut Bay is unique in the high productivity of its tidal flats and sea-grass beds which make a habitat rich in numerous types of marine life. This area is known to have been the center for human activity for centuries such as marine ports, fishing, agricultural and recently developed oil facilities and residential communities. This region shares many characteristics of the bays examined in the other two sections in terms of salinities and energy levels. It has relatively normal salinity of 41 ‰, which is close to the open marine localities, and high salinity 50 ‰ in the protected landward lagoons. Sea water energy levels range from moderate to low due to the protection from the immediate affect of the high and low tides and prevailing winds. Three sampling locations were selected nearby Saffwa Bay, the southeastern part of Tarut Island, and the offshore between Tarut Island and Dammam, from which one sample was collected from each location.

1.3.1.1.3. The Southern Region. This extends from Dammam to Salwa. The coastline of this region has a north-south trend that is parallel to the prevailing shamal wind. Most of this section is protected from wave action because it lies within the Gulf of Salwa and is also within a wide extension of the shallow water depths between Saudi Arabia, Bahrain and Qatar that form barriers to tidal water movements and the tidal amplitude. The salinities are generally the highest in the Arabian Gulf, and range from 55 ‰ at the entrance to 70 ‰ at the southern extreme part of Salwa Gulf and can reach 100 ‰ during the evaporative summer season (Bathurst, 1986). Although this section is protected, the landward lagoon of the Half Moon Bay is much more protected and contains very high salinity levels

reach 70 ‰. Half Moon Bay (Dawhat Zalum) forms part of this region, located directly south of the Dammam Peninsula. Semi-enclosed nature of the lagoon restricts circulation and tidal movements with the Gulf's open water environment. It is characterized by very high salinities that affect the biological character of this lagoon. Three samples were collected from this section, one from the southern part of the Half Moon Bay (onshore), one from the offshore of the Half Moon Bay and one from an open marine locality adjacent to Al-Aziziah desalination plant.

Name	Abu Ali Island	Safwa Bay	Half Moon Bay Shallow	Jubail	DC-5	DC-12
Depth m	0.5	0.5	0.5	1	2	2
Salinity ‰	47	50	55	39.3	40	42
Temperature	31	34	27	21.4	31.5	31.6
Translucency	0.5 m visibility	0.25 m visibility	0.5 m visibility	2m visibility	Not available	Not available
Date of collection	20/08/2002	25/06/2002	08/04/2004	05/12/2003	23/09/2003	23/09/2003
Collector	Saleh Al-Enezy	Saleh Al-Enezy	Saleh Al-Enezy	Saleh Al-Enezy	Research Institute	Research Institute
Name	WQ-15, Ras Tanura Coast Outfall	Half Moon Bay Offshore	Azizyah desal.	WQ-18, Ras Al-Ghar Offshore	Berry Offshore	
Depth m	4	6	11.5	17	18	
Salinity ‰	40	48	48	40	Not available	
Temperature	31	30.8	31.2	31.4	Not available	
Translucency	4 m visibility	6 m visibility	8 m visibility	10.5 m visibility	Not available	
Date of collection	01/10/2002	05/10/2003	06/10/2003	08/10/2002	/2001	
Collector	Research Institute	Research Institute	Research Institute	Research Institute	Saudi ARAMCO	

Table1.1. Table showing the recent samples localities from the Arabian Gulf with their characteristics of salinity, temperature, translucency and other collection information. The North Section, Transitional Section, and Southern Section are shaded in red, yellow and blue respectively.

1.3.2. Dam Formation at Jabal Midra Al-Janubi

The coastal area of eastern Saudi Arabia is essentially a broad structural terrace that was only intermittently submerged during the Tertiary. The Miocene succession in the area can be subdivided into three formations which, in stratigraphic order, are the Hadruk, Dam, and Hofuf. The Dam Formation is named after Jabal al Lidam (Powers et al., 1966) and at the Dammam Dome is found at Jabal Midra Al-Janubi, which is 92 m high, located due west of the crest of the Dome (Figure 1.7). Unfortunately, Jabal Midra al Janubi has been physically removed by a local land developer in 2005, and the source of samples in this study has now been eliminated (Figure 1.8). The Dam unconformably overlies rocks of the Rus and Dammam formations (Figure 1.9) (Table 1.2). Only part of the Dam Formation occurs at the Dammam Dome crest, as the upper part has been eroded away. At Jabal Midra Al-Janubi, the basal unit of the Dam Formation consists of 1.8m of yellowish gray, microcrystalline sandy limestone resting unconformably on top of the Midra Shale Member of the Dammam Formation (Figure 1.10). Stromatolitic limestone, 1m thick, with pink to purple weathering, is overlain by a 31m thick sequence of alternating grainstones and packstones. These are of interbedded molluscan, pelletal and foraminiferal grainstones, packstones and argillaceous limestones. This section is followed by 6m thick of calcirudite with pebbles and boulders of cryptocrystalline limestone and calcarenites. The Dam Formation is capped by 9m cliff forming, massive, and cryptocrystalline limestones (Table 1.2) (Powers et al., 1966).

The Dam Formation was deposited during a major Neogene transgression and dominated by shallow marine, warm-water macrofossils such as stromatolites, corals, and

benthonic foraminifera. The stromatolites indicate highly adverse depositional conditions, probably related to hypersalinity. In the Dammam Peninsula, the mollusk, echinoid and foraminiferal limestones above the basal stromatolites indicate shallow-marine deposition with fluctuating sea levels. Tleel (1973) believes that the sea gradually covered the dome, producing tidal flats around a central island, and later when the sea covered the entire dome, a pinnacle-type coral reef on the highest parts were formed. In the surrounding shallow-marine waters, grainstones were formed in high-energy areas while carbonate mud were deposited in quiet lagoons.

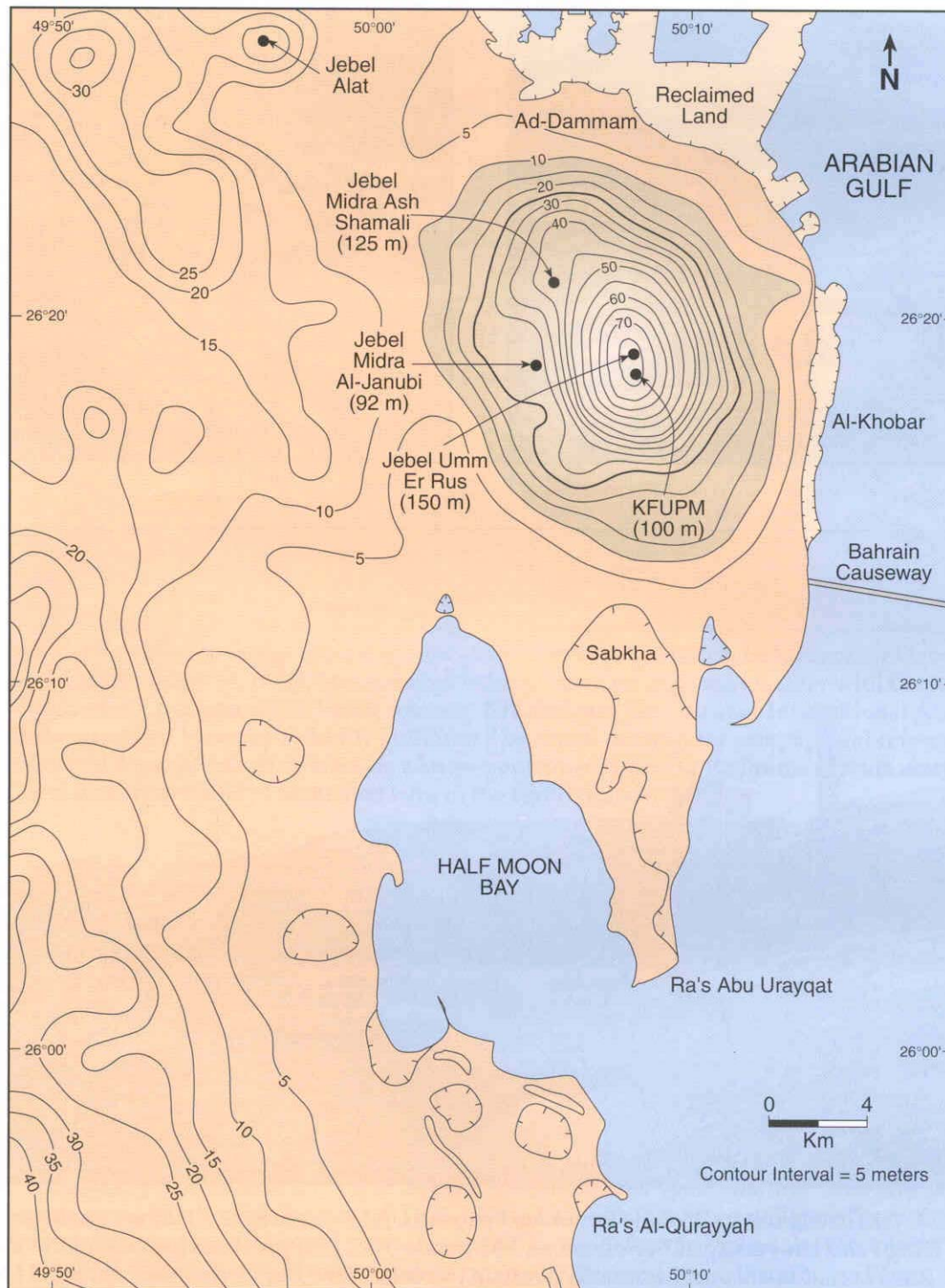


Figure 1.7. Generalized topographic map of the Dammam Dome including the location of Jabal Midra Al-Janubi. Contour interval is 5 m (Weijermars 1999).



Figure1.8. Four photographs showing the removal process for Jabal Midra Al-Janubi by a local land developer during the year 2004.

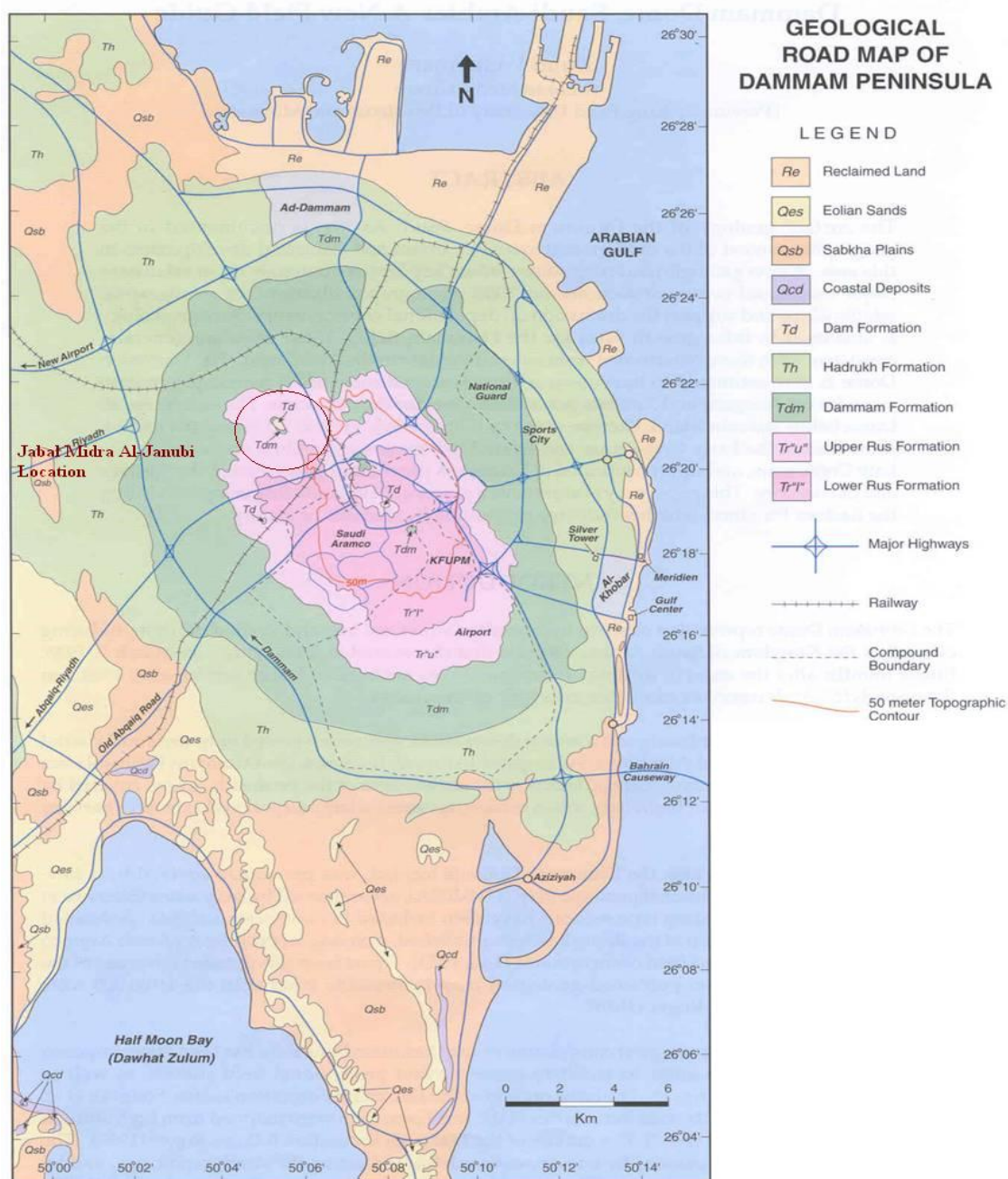


Figure 1.9. Geological map of the Dammam Peninsula showing the study location at Jabal Midra Al-Janubi (Weijermars 1999). This map indicates the geological boundaries as explained in the legend.

PERIOD	EPOCH	AGE	Ma	DEPOSITION	Producing Reservoir	Uplift Rates		TECTONICS	
						Dammam	Awali		
TERTIARY	NEOGENE	Quaternary	0.01	Sabkha Eolian Sand				Formation of Half Moon Bay ↑ Continued Zagros Collision ↑ Opening of Red Sea ↑ Formation of Mesopotamian Foredeep of Zagros Fold Belt ↑ Closure of Sanandaj-Sirjan Suture in Zagros Hinterland ↑ Slumping of lower Rus beds due to Dammam doming ↑ Meteoric Impact at Xugulub (Extinction of dinosaurs)	
			1.8						
		PLIOCENE	3.4	Piacenzian					
			5.3	Zanclian					
			6.5	Messinian					
		MIOCENE	Tortonian						
			11.2		Hofuf Formation		7.5 m/Ma		
			Serravallian						
			15.1						
			16.6	Langhian					
	Burdigalian			Dam Formation					
	21.8		Hadrukh Formation						
	PALEOGENE	OLIGOCENE	23.7		Pre-Neogene Unconformity		7 m/Ma		
			30.0	Chatthian					
			Rupelian		Hiatus				
			38.6						
		EOCENE	Priabonian						
			40.0						
			Bartonian						
			43.8						
		PALEOCENE	Lutetian			Dammam Formation	Hasbah Dammam	5.6 m/Ma	
				52.0					
	Ypresian				Rus Formation				
			57.8						
Thanetian				Umm Er Radhuma Formation					
	60.8		unnamed						
Danian			Hiatus						
CRETACEOUS	Senonian	66.4		Hiatus		?			
		74.5	Maastrichtian						
		84.0	Campanian		Aruma Group		Lawhah	9 m/Ma	
		87.5	Santonian						
		89.5	Coniacian		Hiatus				
		91.0	Turonian						
	97.5	Cenomanian		Wasia Group	Mishrif Rumaila Ahmadi Mara Mauddud Safaniya Khafji	2.6 m/Ma			
	Neocomian	Albian					2.5 m/Ma		
		113							
		Aptian							
		119	Barremian						
		124	Hauterivian		Thamama Group	Shu'aiba Zubair Buwaib Upper Ratawi Lower Ratawi			
		131							
138		Valanginian							
144		Berriasian							
JURASSIC	Late	Tithonian		Riyadh Group	Manifa Rimthan Arab A-D	Onset of uplift of Dammam and Awali Domes Opening of South Atlantic Onset of halokinesis of Hormuz Salt in the Zagros area Extensional growth faults in Tethys Margin - Oxfordian break-away of India from Africa			
		157							
		158	Kimmeridgian						
	Middle	Oxfordian							
		163							
		169	Callovian		Tuwaik Group		Jubaila Hanifa Hadriya Upper Fadhili Lower Fadhili Sharar Faridah Marrat		
		176	Bathonian						
	Early	Bajocian							
		183	Aalenian						
		187	Toarcian						
Pliensbachian			Upper Minjur Formation	Minjur	Break-up of Pangea into Gondwanaland and Laurasia				
190									
193	Sinemurian								
Hettangian									
200									
204									

Table 1.2. Tectonostratigraphic Timetable for the Dammam Region, (Weijermars, 1998).

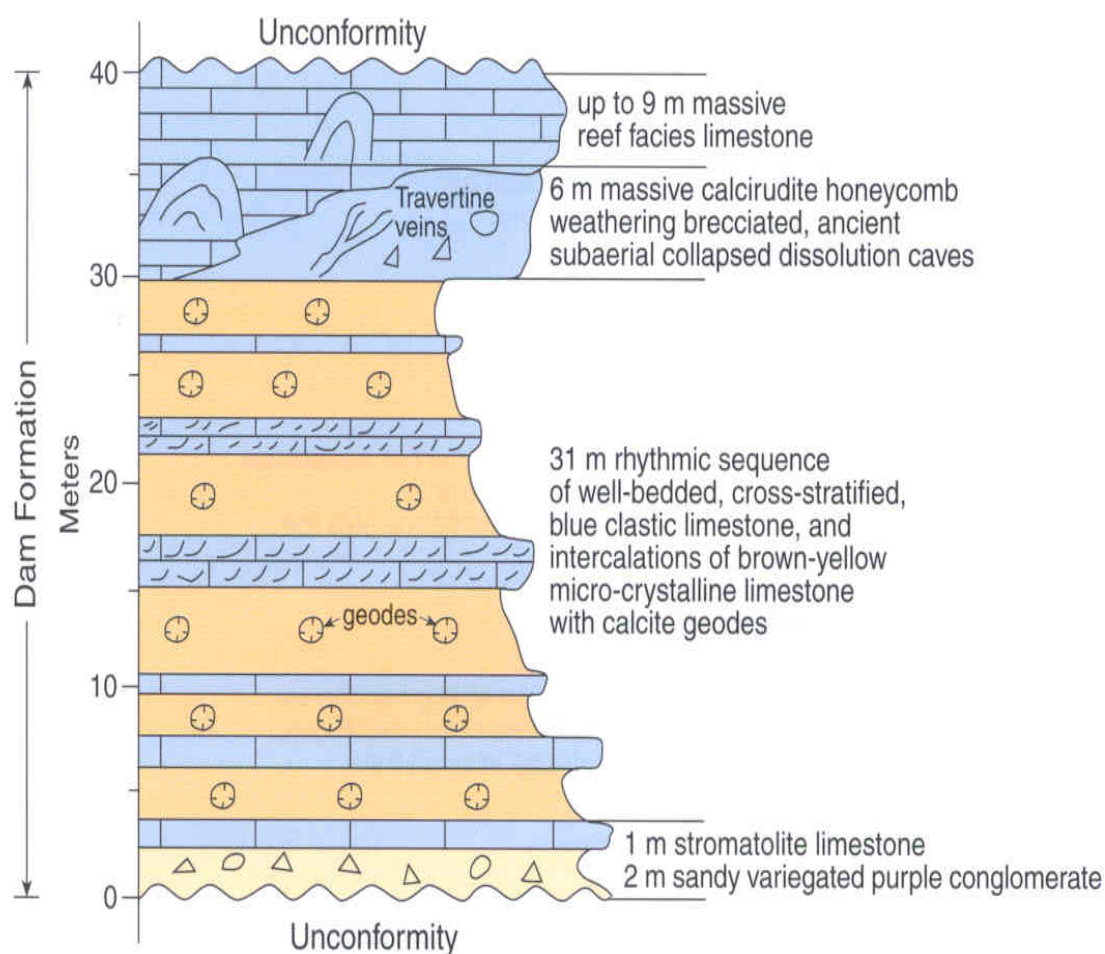


Figure 1.10. Schematic stratigraphic column for the Dam Formation of the Dammam Dome (Weijermars, 1998).

1.4. REVIEW OF PREVIOUS WORKS ON THE STUDY AREAS

The present study is the first to examine the microfauna of the Saudi Arabian Gulf to elucidate the palaeoenvironments of the microfossils, and especially those of the Miocene Dam Formation. The only comparable work is that carried out by Dr. G. Wyn Hughes from Saudi Aramco in which he used the recent foraminifera and macrofauna of the Great Pearl Bank Barrier, UAE coast, of the Arabian Gulf to interpret the depositional environment of the rudists and microfossils of the Lower Aptian Shu'aiba carbonates in the subsurface Shaybah oilfield in Saudi Arabia (Hughes, 1997; 2000).

1.4.1. Previous Works on the Arabian Gulf Study Area

The first known study of Arabian Gulf carbonate sedimentology was by Houboult (1957), who investigated the bathymetry, lithofacies and foraminifera assemblages relationships. This study was followed by followed by Sugden (1963), Evans (1969), Kendal (1966), Skipwith (1966), Wagner and Togh (1973), Evans *et al.* (1973) and Stoffers and Ross (1978). Murray (1965a, 1965b, 1966a, 1966b, 1966c, 1970a, 1970b) published a series of publications on the taxonomy of the UAE Coast foraminifera. Other taxonomic notes followed are by Al Abdul-Razzaq and Bhalla (1987), Abou-Ouf (1991), Haake (1970, 1975).

Foraminiferal ecological studies include Murray (1991) and Coles and McCain (1990). Temporal variations in four infaunal foraminiferal taxa of Bahrain intertidal sediments were described by Basson and Murray (1994). In Kuwait, subtidal foraminiferal

assemblages of the western part of the Shatt Al-Arab Delta were studied by Al-Zamel and Cherif (1998), and Qatar foraminifera were analyzed by Bathurst (1986). The biology and ecology of the marine life of the Saudi Arabian part of the Gulf is presented by Basson *et al.* (1977). A study to investigate the role of marine organisms including foraminifera as carbonate sediments producers and environmental indicators focused on the foraminiferal distribution and abundance (Hughes Clarke *et al.*, 1973). In the hypersaline lagoons, *Peneroplis* species were noted to frequently show aberrant growth forms.

Of significant value in the interpretation of Recent foraminiferal biofacies and their depositional environments are the works by Boltovskoy (1976), Lipps *et al.* (1979) and Murray (1991).

1.4.2. Previous Works on Dam Formation and Jabal Midra Al-Janubi

A number of stratigraphic studies have been carried out on the Arabian Gulf hinterlands including the study location and the Dam Formation. This area was first studied by Steineke and Koch (1935), although formal names first appeared in a paper by Thralls and Hasson (1956). A detailed description of the type section of the Dam Formation was provided by Steineke *et al.* (1958). Powers *et al.* (1966) have mentioned many fossils that reveal the age of the Dam Formation. Tleel (1972, 1973) in his thesis work and a published paper on the surface geology of the Dammam Dome mentioned some fossils and microfossils including foraminifera. He presented a detailed measured section of the Dam Formation at Jabal Midra Al-Janubi and interpreted the depositional environment. Irtem *et al.* (1986) published a paper

on the stromatolites of the Dam Formation at Jabal Lidham. Weijamars (1998) described the surface geology and lithostratigraphy of the Dammam Dome.

The Dam Formation of Qatar has been of interest to many scientists, commencing with Cavelier (1970) who subdivided the formation into the lower and upper Dam subformations. Others, such as Abu-Zied and Khalifa (1983) modified Cavelier's work and divided the formation into members A and B. Abu-Zied and Khalifa (1989) investigated the clay components of the formation in Qatar. The foraminifera of the formation were studied first time by Hewaidy (1991) in the Jebel Al-Nakhash and Al-Kharrara areas where they were dated as Burdigalian-Helvetian (Early to Middle Miocene). More recently, Khalifa and Mahmoud (1993) identified three types of algal stromatolites in member B of the Dam Formation at Jebel Al-Nakhash. They proposed a protected tidal environment for the deposition of the formation. Al-Saad and Ibrahim (2000) carried out the most recent work on Dam Formation. They studied aspects of stratigraphy, micropaleontology and paleoecology and found that microfossils are predominantly benthic foraminifera and are represented by 38 species of which most are milioline and one is a larger form.

CHAPTER TWO

MATERIALS AND METHODOLOGY

This study has been based on an adaptation of well-tested procedures, as described comprehensively by Douglas (1979). The use of modern faunal concepts to interpret extinct fossil faunas rests on the assumption that modern faunal distributional patterns are analogous to those of the past and that homeomorphs of modern species, and especially groups of species, had similar environmental adaptations.

The methodology used to achieve the objective of this study may be summarized in three clearly-defined procedures:

1. Catalogue semi-quantitatively the distribution of foraminifera in recent shallow marine sediments of the Arabian Gulf and the Dam Formation.
2. Catalogue semi-quantitatively the distribution of foraminifera in Miocene carbonate sediments of the Dam Formation in the eastern part of the Saudi Arabia.
3. Compare and contrast the Recent Foraminifera assemblages with those of the Miocene carbonates and use this information to interpret the palaeoenvironment of the Miocene succession.

Two types of samples were collected, treated, and analyzed for foraminiferal analysis in this study. They included the recent marine sediments of the Arabian Gulf (Figure 2.1) and the Miocene carbonate rocks of the Dam Formation exposed onshore of the Saudi Arabian mainland. In this chapter, the recent sample localities were described and the

processes involved in the foraminiferal extraction were explained. For the Miocene carbonates of the Dam Formation, the sample locations and methods of thin section preparation and study were described.

2.1 ARABIAN GULF SAMPLE LOCALITIES AND SEDIMENT TYPES

2.1.1 Abu Ali Island

Sediment Color: Light brownish gray.

Sediment type: Silty quartz sand derived by the north south winds. Rare fragments over 2 mm.

Sieve analysis: Mainly medium sand and silty mud and minor fine sand, coarse sand, and very fine sand.

Some associated flora and fauna: Rare bivalves.

2.1.2. Saffwa Bay

The sample was collected from shallow very fine soft sediment from an area typified by scattered patches of sea plants and algae. It has brown color in very low translucency sea water that contains floating algae. Beneath the soft substrata is a hard ground.

The sample location is located about 500 m seaward from the mangroves marshes.

Sediment Color: Grayish black.

Sediment type: Nearly equal mud and medium sand and over with significant constitute of alga remains and organic materials. Common bivalve and gastropods are over 10 mm in size.

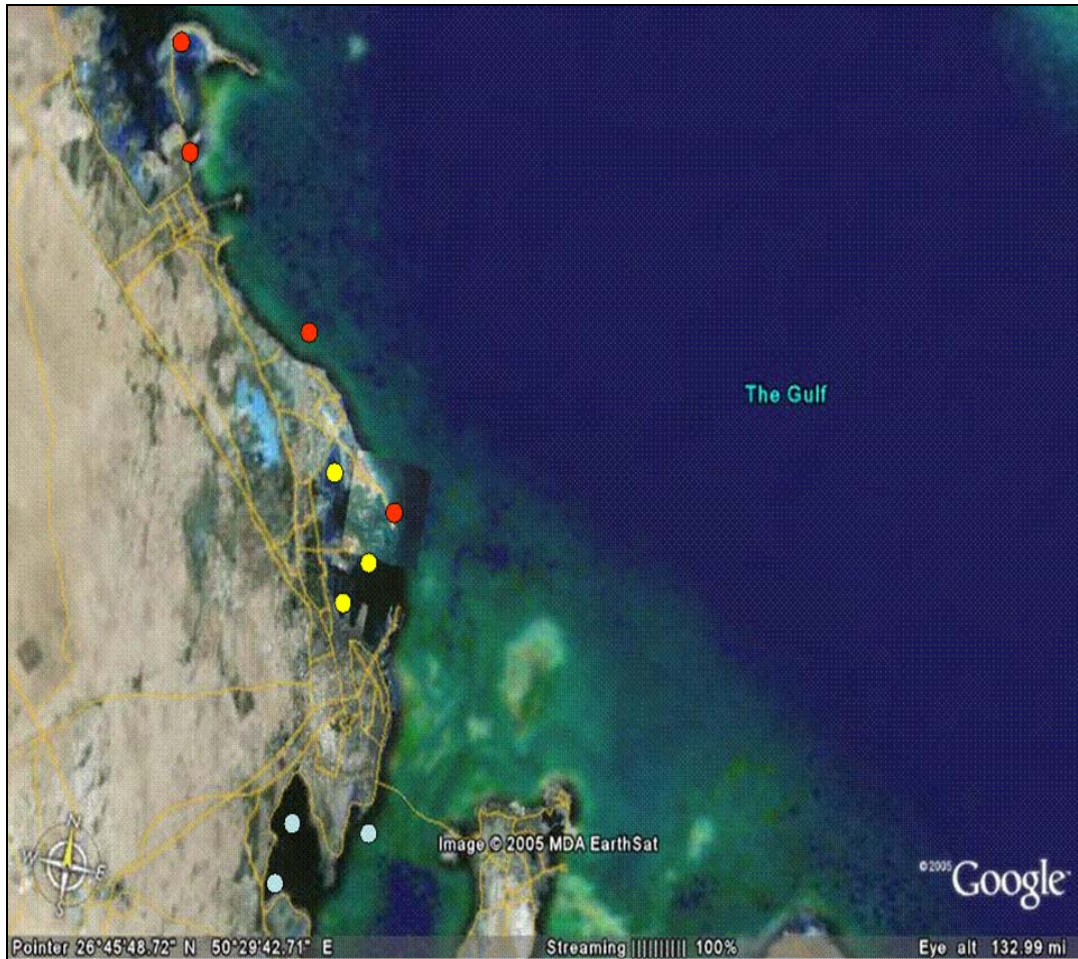


Figure 2.1. Satellite image showing the sampling locations in the Arabian Gulf study area (Google-Earth, 2005). The red, yellow and blue sky points belong to the Northern Section, Transition Sone and the Southern Section of the Saudi Coastline respectively.

Sieve analysis: Mainly sand and mud with minority of fine and very fine sand.

Some associated flora and fauna: Large bivalves especially venus clams (Veneridae) that have size up to 24 mm. Gastropoda of Cerithoides size over 10 mm and *Nassarius* spp.

Sediments are very rich with algae and sea grass remains.

2.1.3. Half Moon Bay (Intertidal)

The sample was collected from the southern part of the Half Moon Bay.

Sediment Color: Light gray.

Sediment type: Silty sand.

Sieve analysis: Majority of very fine sand followed by medium size sand and then silt.

Some associated flora and fauna: The sediments are very rich with large milioline (*Peneroplis* spp.), agglutinated annelids worm tubes, calcitec worm tubes, bryozoans, and annelids, that attached to lower parts of the stones very small quantities of thin walled bivalves.

2.1.4. Half Moon Bay (offshore, centre)

Grab sample collected by the KFUPM Research Institute on the boat, as part of the water quality monitoring project.

Sediment Color: Black

Sediment type: Sandy mud, that is Very rich with organic material.

Sieve analysis: Mainly mud of organic materials, and sand from medium to course mainly *Peneroplis planatus* few fine to very fine sands composed dominantly of miliolids.

Some associated flora and fauna: Some algal remains, thin walled bivalves, visible rich *Peneroplis*, and worm tubes.

2.1.5. Jubail (nearshore)

The sample was collected from the Jubail beach close to the boat station.

Sediment Color: Light gray.

Sediment type: Silty sand.

Sieve analysis: Mainly composed of medium and fine sand with few very fine sand, coarse sand and silt.

Some associated flora and fauna: Some sea grass remains are present, small gastropods (2 mm), small bivalves.

2.1.6. Tarut Bay (DC-5)

Grab sample collected by the KFUPM Research Institute from the boat as part of the Dammam contamination project.

Sediment Color: Tan gray, yellowish gray.

Sediment type: Medium to coarse sand.

Sieve analysis: Medium, fine to coarse sand and very few silt.

Some associated flora and fauna: Less common thin walled smooth bivalves of size over 5mm.

2.1.7. Tarut – Dammam Bay (DC-12)

Grab sample collected by the KFUPM Research Institute from the boat as part of the Dammam corniche project.

Sediment Color: Black.

Sediment type: mud, very rich with organic materials. It has a bad, sulphide type odor because of the decomposed organic materials.

Sieve analysis: Mainly mud and very few sand and bivalves over 20 mm in size.

Some associated flora and fauna: Mainly smooth bivalves, thick walled, and some algae.

2.1.8. Ras Tanura coast (WQ-15)

Grab sample collected by the KFUPM Research Institute from the boat as part of the water quality monitoring project.

Sediment Color: Gray.

Sediment type: Sand.

Sieve analysis: Mainly medium sand, coarse sand, fine sand and minority of very fine sand and silt.

Some associated flora and fauna: large smooth gastropoda (Hydatinidae), over 20 mm in size, and small gastropoda of *Cerithium*, and *Rhinoclavis*. Small smooth thin walled bivalves and Dentaliidae, Scaphopoda are common. Sea grasses and plant remains are common.

2.1.9. Aziziyah desalination plant (offshore)

Grab sample collected by the KFUPM Research Institute from the boat as part of the water quality monitoring project.

Sediment Color: Green yellowish gray.

Sediment type: Course to medium sand, contains pebbles to 3×1 cm in sizes made of sand aggregates. Organic materials are present. Rich with bivalve shells and skeletal fragments.

Sieve analysis: Majority of sand and scares very fine sand.

Some associated flora and fauna: Mainly small and large bivalves that some of them have spines and ribbed, some green algae, pearl bivalves, worm tubes, absence of gastropoda.

2.1.10. Ras Al-Ghar (offshore) (WQ-18)

Grab sample collected by the KFUPM Research Institute from the boat as part of the water quality monitoring project.

Sediment Color: Orange tan, light orange.

Sediment type: Coarse sand to pebble size of skeletal fragments that has white color and medium sand has reddish color.

Sieve analysis: Few silt and fine sand, majority of coarse and medium sand.

Some associated flora and fauna: Mainly thin walled small bivalves smooth to rib.

2.1.11. Berri Well-124 location, bottom sediment sample #3 (SC 970594)

Grab sample collected by Saudi Aramco marine research project.

Sediment Color: Gray.

Sediment type: Shell fragments from sand fraction to fine gravel size. Shells are white to light reddish brown. Sand fraction color is light gray.

Sieve analysis: Slightly silty, fine to coarse grained sand.

Some associated flora and fauna: Small sea urchin, small crabs, small bivalves and gastropoda.

2.2 SEDIMENT COLLECTION AND PREPARATION TECHNIQUES

Recent sediments were obtained at 11 sites, including lagoonal and open marine (onshore and offshore), in the Arabian Gulf (Figure 2.1). Sample collection was done either by hand-picking, grab sampling, or scuba diving using sediment scoop by author or the staff of KFUPM and Saudi Aramco. All samples were described, processed and analyzed for foraminifera and associated microbiota using standard micropaleontological techniques. Portions of the samples were also dried and sieved for grain size analysis (Haynes, 1981).

The collected sediment samples were placed in plastic bags, and labeled for each station. The location of the sampled station and details of sediment character, associated macrofauna and flora, were entered in a logbook immediately upon sample collection. The samples can be plotted on a base chart and the details transferred to reference cards on arrival to the laboratory. The marine samples were dried out in the air and processed in the following procedure:

- (1) A 100 gm of dried marine sample from each sample were soaked in clean water for ten days to disaggregate their clay and mud contents and to separate all the particles in marine samples.
- (2) The soaked samples were washed clean of mud and preservative under a fine spray of water over a fine mesh screen (B.S. 240 with openings of 63 μm) and to remove stain from the sediment and from the shell walls of foraminifera.
- (3) The washed samples were transferred into porcelain dish dried on hot plate.
- (4) The residue of samples was sieved by brass sieves with meshes sizes of 30, 60, 100, and 200 μm in order to sort them according to grain size. The weight of samples in each mesh size was measured in grams. The residue for each mesh was then placed in small bottles marked with sample number and mesh size.
- (5) The residue of meshes 30 μm and some time 60 μm were easily spread over a standard picking tray.
- (6) The foraminifera of the residue of meshes 60, 100 and 200 μm were concentrated by floatation technique using commercial carbon tetrachloride (CCl_4), as described by Cushman (1948), as this has a specific gravity of 1.59 and is sufficiently high to float hollow foraminiferal tests, despite the specific gravity of calcite being 2.72. The samples were placed in a 100ml glass beaker and 60ml carbon tetrachloride was poured over it. The foraminifera, fine molluscs and ostracods floated to the surface and were separated from the solvent by pouring the surface liquid through a fine filter paper. The sample retained by the filter paper was entirely dry and ready for examination within a few minutes.

- (7) The residue and the concentrated materials were tapped gently on to a small tray of metal or black card for easy separation of microfauna. The tray is marked out in squares of approximately the area of the field of the binocular microscope and at a convenient magnification (25X) for general appraisal of the residue.
- (8) The foraminifera were picked up using artist's brush of 01 size. They were transferred to a cavity slide where preserved loose for later examination. A one-hole cavity slide of punched white card with a matt black scratchboard base and coverglass held by gummed tape was used for slides and representative specimens. While rectangular cavity slides with a grid of white painted squares (5 to 100) were used to mount representative faunas, as individual specimens being stuck down with water soluble gum.
- (9) Various taxa of foraminifera, microfauna and flora were identified using many illustrated published references and counted (Barker, 1960; Murray, 1965, 1966, 1970, 1971; Robbins, 1983; Al-Zamel and Cherif, 1998).

2.3 MIOCENE SAMPLES FROM DAM FORMATION

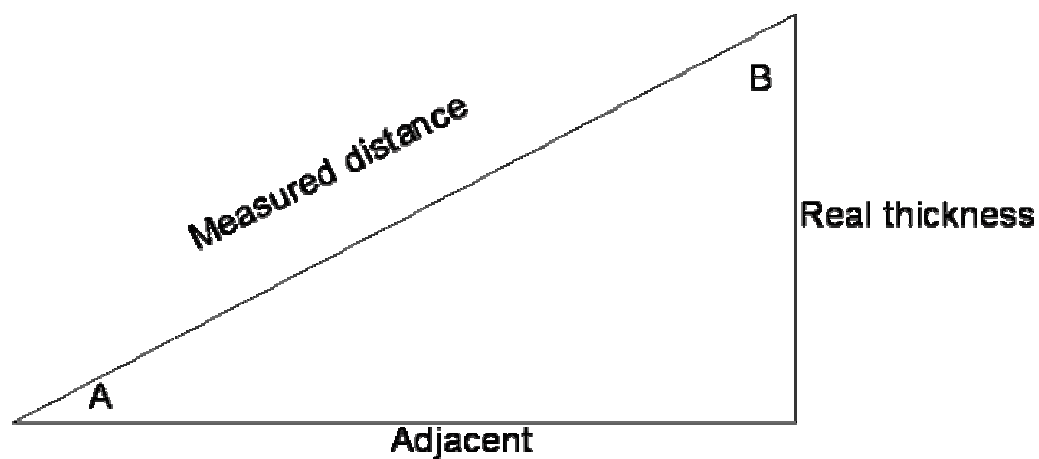
Hard carbonate samples were collected from Jabal Midra Al-Janubi from the base of the exposure to top with the spacing distance measurement between each collected sample. The vertical distance between each sample was obtained by using trigonometry of the inclined lateral sample spacing distance, for which the slope angle was measured (Figure 2.2).

The Dam Formation at Jabal Midra Al-Janubi unconformably overlies the top of Midra Shale Member (Tleel, 1973) of the Dammam Formation and is over 56m (168 feet) thick. In this study, the top of the Jabal Midra Al-Janubi has not been included. The top is made of 9 m (27 feet) of massive chert that overlies 6 m (18 feet) of massive packstone of ancient subaerial collapsed dissolution caves. This 15 m (45 feet) section is not part of the 56 m (168 feet) measured sections of the Dam Formation at Jabal Midra Al-Janubi. The Formation comprises great varieties of carbonate lithofacies and microfossil and macrofossil biocomponents. These are described with thickness in feet of beds and the elevation of the taken samples from the base. This study has different description from Tleel (1973) in which he did not use Dunham (1962) depositional texture classification for the carbonates and differences in beds thicknesses and more micropaleontological descriptions were added for each exposed bed.

A total of 60 samples from the Dam Carbonates were collected and described in the field and in the lab. The sample positions were selected with reference to the clearly visible three bedding cycles in order to sample the variety of environments represented within each

cycle. In the field, the elevation from the ground, color, sedimentary structures, bed thickness, lithological description, fossil content, and Dunham classification were described. 77 thin sections were prepared from the carbonate rock samples were texturally classified within the Dunham scheme and used for foraminiferal analysis based on micropaleontological techniques.

The surface carbonate rocks of Dam Formation at Jabal Midra Al-Janubi were collected from only vertical section and studied with the hand lens aid and polarized microscope for the thin sections. Standard staining for carbonate mineralogy used 10% of hydrochloric acid and alizarin (Friedman, 1959). Lithologic classification and description was conducted according to Dunham's Classification (1962) and according to the carbonates depositional textures. This was in association with macrofossils and microfossils identification. However, the descriptions represent some slight differences from those of Tleel (1973), especially in bed thickness and fossil description and identification.



$$A = 90 - B$$

$$\text{Real thickness} = \sin A \times \text{Measured distance}$$

Where

A: is the angle between Measured distance and Adjacent

B: is the Measured angle by the Branton Compass

Figure2.2. Trigonometric functions of acute angles used in order to get an exact thickness for the beds of Jabal Midra Al-Janubi.

2.4 CARBONATE PROCESSING

Foraminifera in hard dense limestones must be studied in thin section made in the following way:

- (1) By use of a diamond saw, a parallel-sided slice was cut about 3 cm long by 2 cm wide by 5 mm thick.
- (2) The slice was polished by grinding with 80-grade carborundum on an iron plate.
- (3) The slice was washed and transferred to a glass plate and ground with very fine carborundum.
- (4) The prepared surface was cemented to a glass slide with Canada balsam that heated on the necessary hardness on a hot plate. Specimen after mounted and slightly reheated, a drop of balsam was put on the slice as well as on the slide.
- (5) The other side of the slice was grinded in successive grades of carborrhundum till the required thinness was attained and the fauna could be seen under the microscope.
- (6) The slide was warmed (when cleaned) to 100 Celsius. A drop of Canada balsam was placed on a coverslip and placed over the specimen.
- (7) Horizontal and vertical slides were prepared for some specimens.
- (8) Foraminifera appeared only as two-dimensional sections. Specimens illustrated in 3 dimensions as published in journals were then identified in 2 dimensions. The identification of the wall structure was enabled to make preliminary classification of the Foraminifera species followed by a detailed study of the internal chamber

arrangement. Publications used to identify the foraminifera included carefully selected reference books (Loeblich and Tappan, 1955; Barker, 1960).

CHAPTER THREE

GEOLOGY OF THE REGION AND OF THE DAM FORMATION

3.1 TECTONIC SETTING AND GEOLOGY OF THE ARABIAN GULF

3.1.1. Tectonic Setting.

The Arabian Gulf regional tectonic setting is an epicontinental sea within a foreland basin, between the geologically stable, low-lying, Precambrian Arabian Shield and the high, geologically unstable Tertiary fold belt of the Zagros Mountains of Iran. The latter result from compression associated with subduction of the Arabian Plate beneath the Eurasian Plate along the Zagros Thrust Zone since the Early Miocene (Stocklin, 1974; Stoneley, 1974). The Arabian Gulf is relatively shallow, with average depths of 35m (Purser and Siebold, 1973). The south-eastern part of the Arabian Gulf is a very gently sloping ramp (Wilson and Jordan, 1983). The Qatar peninsula forms a distinct feature on the near-linear Arabian coastline, and causes anomalous trends in current direction, and possibly of sedimentation, along the south-western Gulf. Shallow seismic investigations (Kassler, 1973) indicate that the northern limit of the Great Pearl Bank Barrier coincides with a 'hinge line' that approximately coincides

with a gravity anomaly and may suggest fault-control (Hughes, 1997). During the Middle Miocene, when the sediments of the Dam Formation were being deposited, the region was the site of a very extensive carbonate platform (Ziegler, 2001) (Figure 3.1)

3.1.2. Recent carbonate sedimentation

Pure carbonate sediments characterize the Arabian half of the basin, but some siliciclastic input in the north and western parts is derived from the Shatt al Arab delta and smaller rivers from the Iranian coast (Houbolt, 1957; Stoffers and Ross, 1979). The depth of the euphotic zone is approximately 20 m in the turbid waters above the muddy sediments along the Abu Dhabi coastline, but increases to 30 m in the clearer waters in the axial parts of the basin (Figure 1.5).

Carbonate sediments of the Arabian Gulf mainly result from the dead skeletons and remains of marine organisms that are dominated by mollusks, calcareous algae, corals, foraminifera, bryozoans and echinoderms. Some marine organisms groups prefer high energy environments and firm substrates such as coral/algal reefs and pearl oyster banks. The muddy low energy environments commonly support epifaunal molluscs, or sediment-surface dwellers, such as *Chama*, *Spondylus*, *Pinctada* group occur in reefs, while a group of infaunal species, or within sediment dwellers, which includes species of *Corbula*, *Nucula* and *Phacoides* (Hughes Clark et al., 1973).

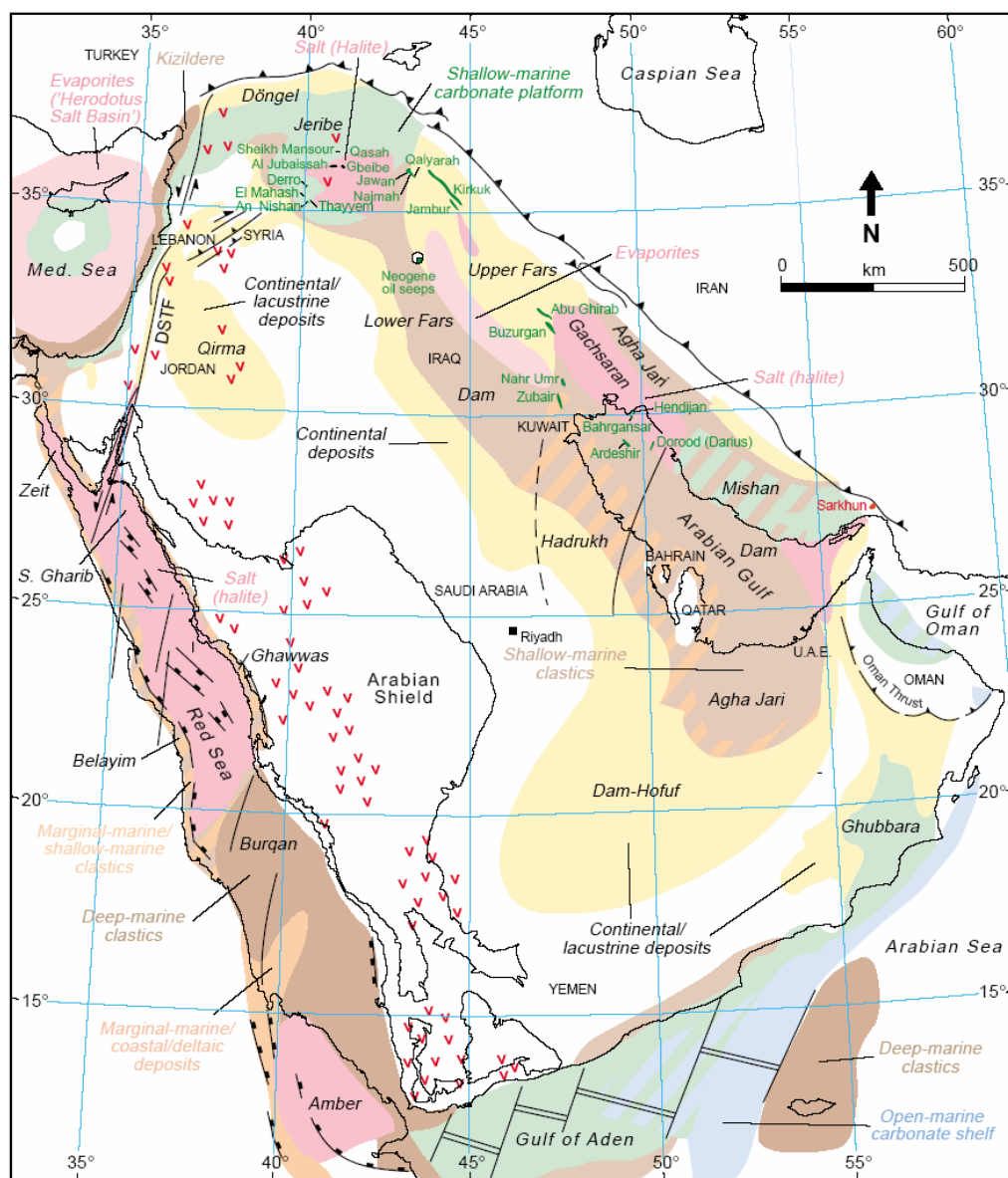


Figure 3.1. Palaeofacies of the Miocene of the Arabian Peninsula (Aquitanian to Messinian) (Ziegler, 2001, Figure 20).

3.1.3. Arabian Gulf Benthic Foraminifera

Benthic foraminifera are those that live on the sea bottom. They are much more diverse than the planktonic foraminifera but they are less in number per species. They live at all depths of the oceans including those areas subject to periodic inundation. They are well adapted to live in a wide range of environments that include brackish, very shallow to deep marine environment. In the Arabian Gulf, only dead planktonic foraminiferal will be transported from the Indian Ocean (Murray, 1991). The evaporative loss from the Gulf is replenished by the inflow of surface waters from the Gulf of Oman, but the planktonic species die in the entrance to the Gulf, presumably as a result of the adversely high salinity level (Hughes Clark et al., 1973).

The Arabian Gulf region is dominated by the warm water faunas of the West African-Indian Ocean foraminiferal province (Figure 3.2) (Boltovskoy et al., 1976). This is typified by the following typical warm shallow water benthonic foraminifera:

Rotalia spp., *Pseudononion* spp., *Ammonia becarii*, *Ammonia* spp., *Asterorotalia dentata*, *Quinquiloculina* spp., *Elphidium* spp. *Triloculina* spp., *Spiroloculina* spp., *Spirolna arietina*, *Peneroplis planatus*, *Eponides murrayi*, *Peneroplis pertusus*, *Textularia* spp. and *Eggerelloides scabra*.(Abou-Ouf, 1991).

Because foraminiferal species exhibit tendency to be restricted to certain depths and influenced by various ecological factors such as temperature, and salinity, they are three inhabiting environmental zones (Abou-Ouf, 1991):

- 1- Supratidal zone

This zone is exposed to the air for most of the year and the foraminifera are found above the level of the average high tide (Figure 3.3), within the tidal pools of moist sand. The physiochemical environment in these pools varies considerably with time because of the irregular input of sea water. The specific content of the fauna varies little from the intertidal zone fauna but are quantitatively poorer and exhibit a greater proportion of deformed specimens as a consequence of the abnormal hypersaline and high temperature conditions.

1- Intertidal zone (littoral zone)

This zone is situated between the high and low tide levels and it is subjected to considerable changes in environmental conditions. Those species capable of surviving in this zone can resist the rapid water movement, daily changes in water depth, temperature, salinity and other ecologically significant factors (Figure 3.3) (Table 3.1). The foraminifera at this zone have generally adapted their tests, to become flattened and to shapes that fit to the substratal grain sizes. They are capable of tolerating the elevated energy conditions associated with surf activity. Most of the specimens have a strong thick wall to withstand this high energy environment.

2- Sublittoral-Nearshore shelf / Inner shelf zone (turbulent zone)

This zone extends seawards from the low tide level where the water is subject to movement from storms, tides, and surfs. The average depth is about 20 m, and lies within normal wave base, but varies from place to place as a result of local conditions (Figure 3.3). The foraminiferal diversity in this zone is more than the intertidal zone and it composed mostly of rotalids and miliolids. The textularids become more abundant in the deeper environment and in the less agitated parts of this environment (Abou-Ouf, 1991).

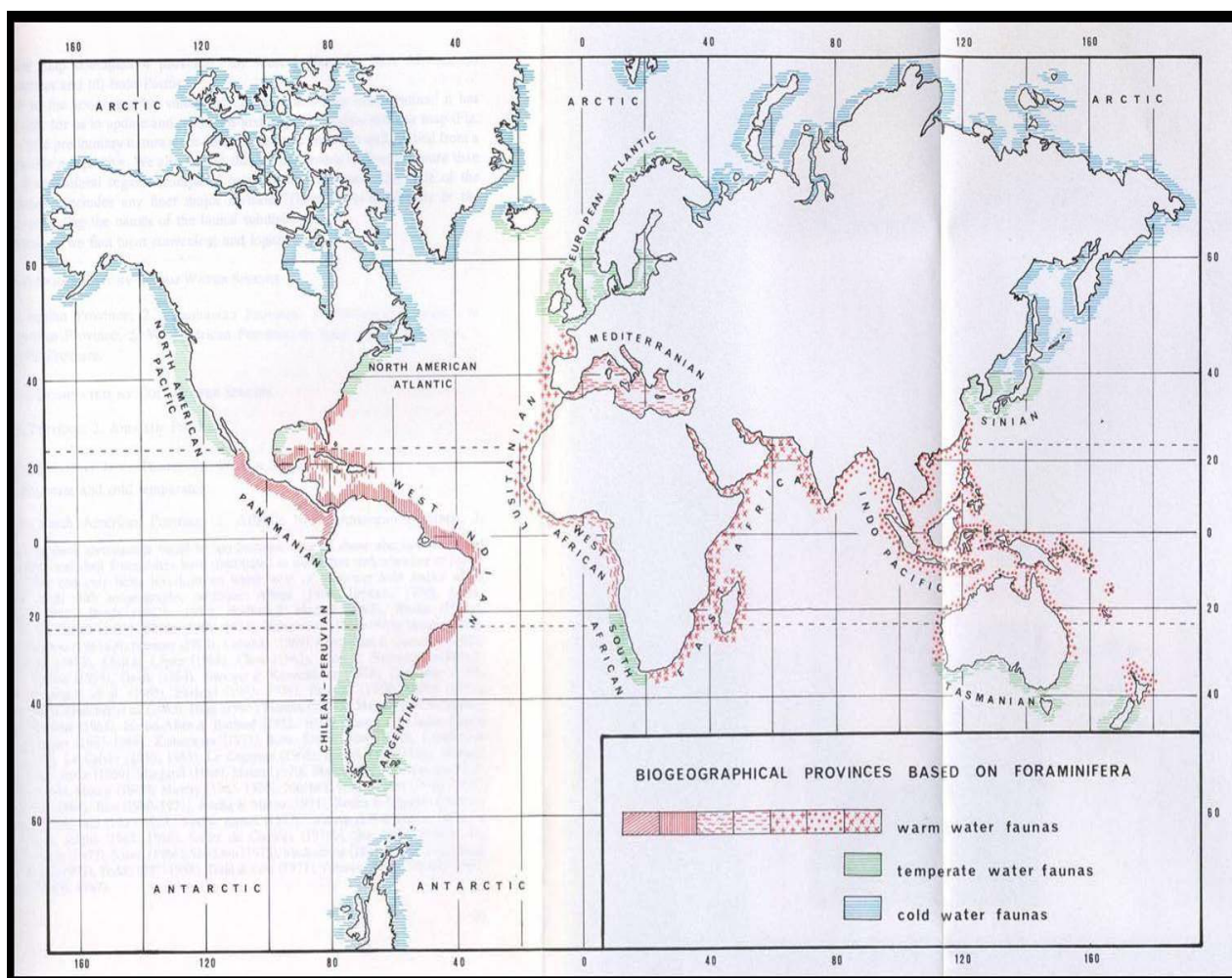


Figure 3.2. Benthic foraminifera zoogeography (Boltovskoy and Wright, 1976).

As in the case of the littoral zone, foraminiferal specimens that live attached to plants or rocks display thick strong walls. The most common genera are *Elphidium*, *Quinqueloculina*, *Eponides* and *Textularia*. This zone has been subdivided into two subzones that include the high energy shallow subtidal subzone (with a depth equal or less than 3 m) and low energy deeper subtidal subzone (with a depth of more than 3 m). Foraminifera are abundant in two distinct environments. Shallow protected embayment and lagoons are characterized by abundant miliolids and Peneroplidae and can often constitute most of the sediment. *Peneroplis* species can display aberrant growth forms in hypersaline lagoons where salinity reaches 60 ppt. (Hughes Clark et al., 1973). The large rotalids, such as *Amphistegina* and *Heterostegina*, are found abundantly within certain offshore shoals at moderate depths. (Hughes Clark et al., 1973).

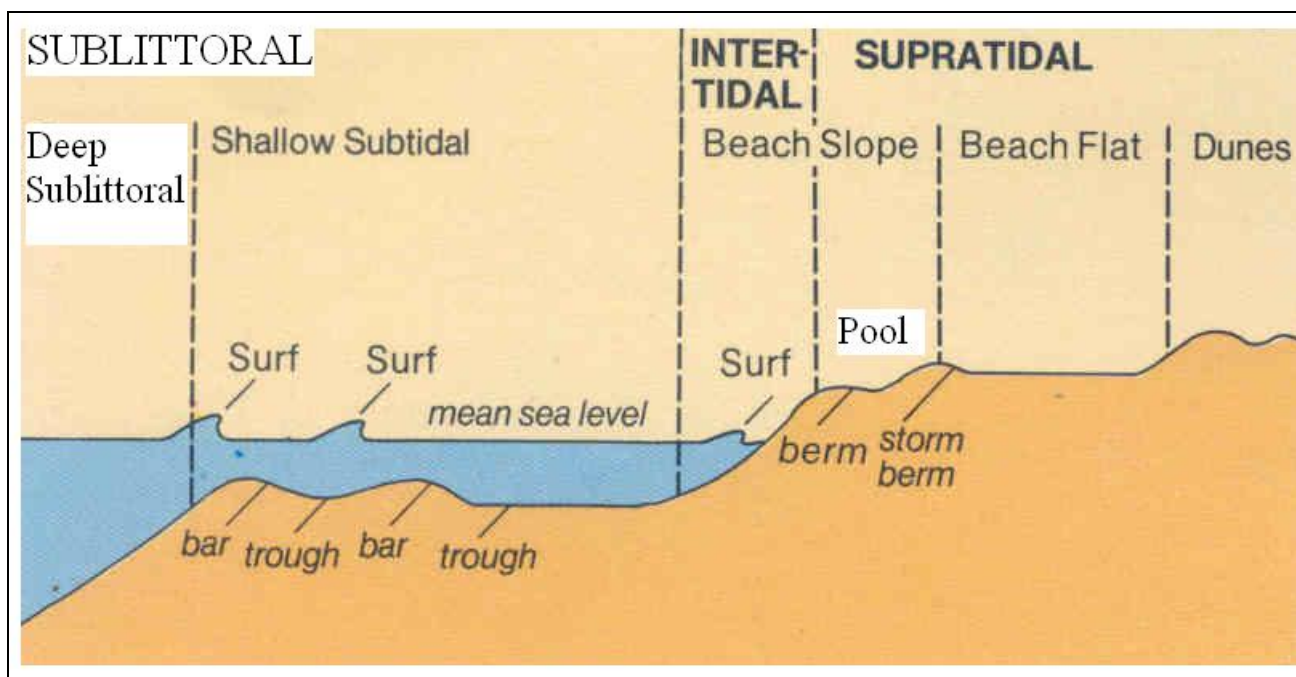


Figure 3.3. Three environmental zones of the Saudi Arabian sand beach that host the benthic foraminifera according to their depth preference (modified from Basson et al, 1977).

Percent (%)		Intertidal zone		Shallow subtidal zone		Deeper subtidal zone	
	Foraminiferal species	Live	Dead	Live	Dead	Live	Dead
1	<i>Quinqueloculina</i> spp.	18	20	20	18	21	18
2	<i>Ammonia beccarii</i> (Linne)	25	19	19	3.5	2.3	6
3	<i>Elphidium</i> sp. aff. <i>E. advena</i>	17	18	9.5	11	0.8	2
4	<i>Triloculina</i> spp.	4	4	7	8	14.8	7
5	<i>Spiroloculina</i> spp.	0.5	1.6	6	8.4	10.6	13
6	<i>Spirolina arietina</i> (Batsch)	16	15	7.9	6	5.8	4.8
7	<i>Peneroplis planatus</i> (Fitchel & Moll)	14	11	8.6	6.6	1.5	2.7
8	<i>Eponides murrayi</i> (Heron. Allen & Earland)	0	0.2	4	6	2	5.2
9	<i>Elphidium reticulosum</i> (Cushman)	4	4	4	3.6	2.2	0.7
10	<i>Elphidium</i> sp. aff. <i>E. discoidal</i> (d'Orbigny)	0.5	0.8	2	4	0	0
11	<i>Peneroplis pertusus</i>	0.4	1.2	2	2	0.7	1.2
12	<i>Textularia</i> spp.	0	0	0.2	0.3	7.2	7
13	<i>Eggerelloides scabra</i> (Williamson)	0	0	1	0.2	18.5	3.4

Table 3.1 Relative abundance of living and dead specimens of the 13 common taxa of foraminifera in Tarut Bay (Abou-Ouf, 1991).

3.2. THE GEOLOGY OF THE DAM FORMATION

3.2.1. Dam Formation and Adjacent Formations.

The coastal area of eastern Saudi Arabia is fundamentally a broad structural terrace that was only intermittently submerged during the Tertiary. This area is about 50-100 kilometers wide between As Summan Plateau and the Arabian Gulf coast (Figure 3.4) (Sayari and Zotel, 1978). The sedimentary rock cover in the Eastern Arabia region ranges from Paleocene to Middle Eocene age and Miocene to Pliocene age. A significant regional unconformity, that spanned the Late Eocene and Oligocene, is considered to have been caused by non-deposition and erosion related to a global sea level fall, probably related also to thermal doming and rifting related to opening of the Gulf of Aden and the Red Sea and tectonic compression in Oman (Steinhauff and Liu, 2004). These regional tectonic events possibly reactivated upward motion of the Hormuz salt at great depth beneath the Dammam and Awali Domes (Weijermars, 1999).

The Tertiary lithostratigraphic succession, from the base upwards, consists of the following formations: Umm er Radhuma, Rus, Dammam, Hadrukh, Dam, Hofuf and Quaternary sedimentary cover. Of these, the Miocene succession includes the Hadrukh, Dam, and Hofuf, of which the Dam Formation is the subject of the present investigation. The Dam Formation is named for Jabal al Lidam (Powers, 1966), and consists of carbonates that were deposited as a result of a major Neogene transgression over unconformity surfaces produced by pre-Neogene episode of erosion and non-deposition. It unconformably overlies the

Palaeogene Rus, Dammam, and Hadruk formations, depending on the locality. The pre-Neogene unconformity represents one of the nine major sequence boundaries recognized in the Arabian Platform Cenozoic strata (Steinhauff and Liu, 2004). The Dam Formation forms scattered outcrops with a distribution that extends from south of Qatar to the eastern edge of the Arabian Shield, and around the northern end of Ghawar and then on to Jibal an Nu'ayriyah. At type locality, it is 90 meters thick and consists of pink, white and gray marl, and red, green and olive clay with interbedded sandstone, chalky limestone and coquina. The Dam Formation has a gradational change from marine rocks to continental deposits toward the interior. The abundant marine fossils markers are found at the base of dam and they are made of numerous small echinoids, *Echinocyamus* sp. and the associated *Archaias* sp. (Powers et al., 1966).

3.2.2. Biostratigraphy of the Dam Formation

A Middle Miocene age is assigned to the carbonates of the Dam Formation, based on the presence of the age diagnostic larger benthic foraminifera species *Borelis melo melo* within Dam Formation (Figure 3.5) (Al-Saad and Ibrahim, 2002). The latest, revised Arabian Plate sequence stratigraphy model of Sharland et al. (2004), suggests that both maximum flooding surfaces MFS Ng20 and MFS Ng10 are located within the Dam Formation carbonates and this would therefore extend the range of the carbonates into the Early Miocene, early to late Burdigalian.

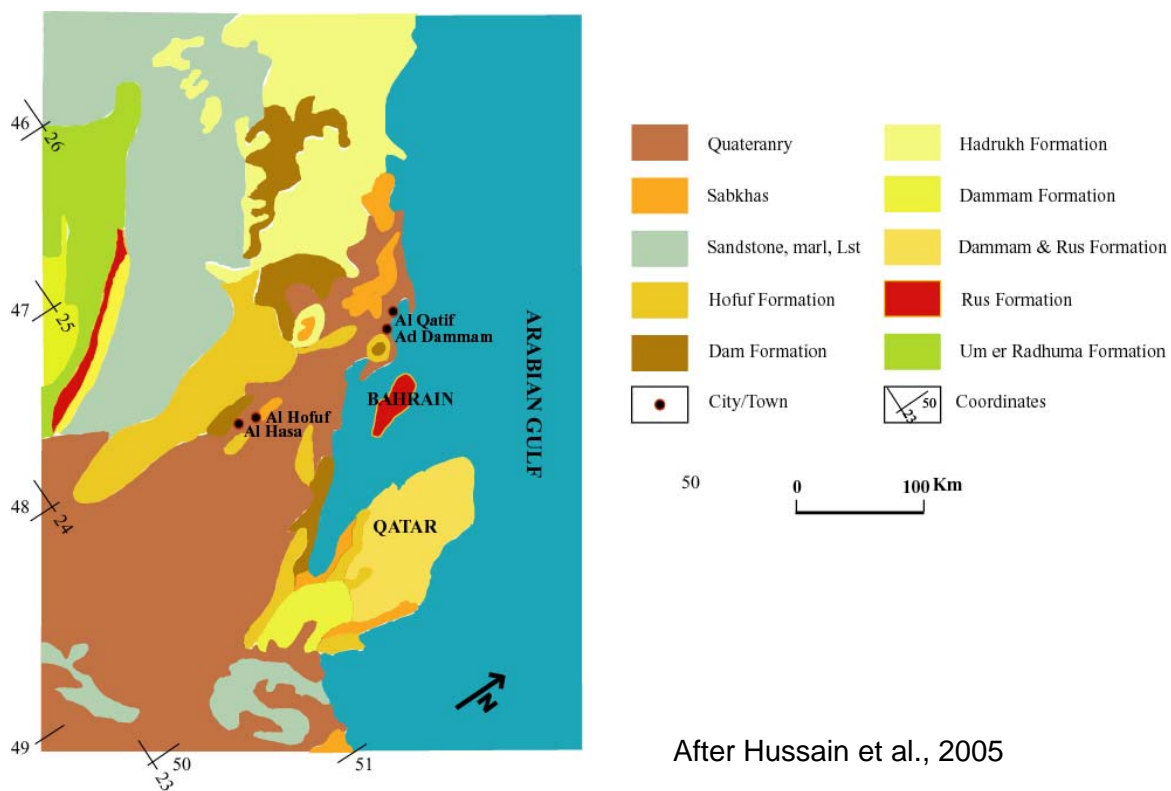


Figure 3.4. Generalized geological map of the Eastern Arabia showing the distribution of Dam Formation and adjacent formations (Hussain et al., 2006).

Echinoderms, mollusks, ostracodes, corals, fossil wood, vertebrate fragments, crab claws and foraminifera such as *Archaias angulatus*, *Archaias* sp., *Elphidium* sp., *Operculina* sp., *Peneroplis* spp., *Quinqueloculina* sp, *Triloculina* sp, and miliolids were recorded from the Dam Formation carbonates by Powers et al. (1966). In a biostratigraphic and paleoecologic study that was supported by microlithofacies analysis and foraminiferal assemblages it was found that the microfossils of Dam Formation in Qatar consist mainly of benthic foraminifera represented by 38 species that belong to 29 genera representing 14 families (Al-Saad and Ibrahim, 2002). The recovered foraminifera was characterized by the domination of miliolina fauna that includes species of *Quinqueloculina*, *Triloculina*, *Peneroplis*, *Dendritina*, *Sigmolina*, *Pyrgo*, *Spirolina*, and *Archaias*, that predominated over the textularid and rotalid foraminiferal components. The distribution of the foraminifera in the Al-Kharrara Member and the overlying Al-Nakhash Member of the Dam Formation of Qatar is represented in figure 3.6 (Al-Saad and Ibrahim, 2002). *Borelis melo melo*, is abundant only in the Al-Nakhash Member of Qatar.

The Al-Nakhash Member is equivalent of the Dam Formation of the Dammam Dome because of the abundance of *Borelis melo melo* and stromatolitic limestone (Figures 3.5 and 3.6).

In a study of the micropaleontology of the Dam Formation in the Dammam Dome Tleel (1973) listed the following fossils: *Echinocymis* sp., *Peneroplis farensis*, *Sorites orbiculus*, *Borelis melo*, *Taberina malabarica*, *Archaias angulatus*, miliolids, siderastrian-type corals, mollusks, and stromatolites. Stromatolites were reported by Irtem (1986) from the top of the third cycle in the lower part of the Dam Formation in Saudi Arabia, where it consisted of three upward-deepening cycles in the Al Lidam area. The stromatolites are

characterized by closely spaced discrete columnar structures that range from 2 to 5 cm in cross section and 3 to nearly 20 cm in height (Figure 3.5). The stromatolite columns are made of fine laminae with well-developed fenestral fabric and intraclasts of oolitic grainstone that overlie and fill spaces between stromatolite columns. Three types of stromatolites were recognized at Qatar by Khalifa and Mahmoud (1993) within Al-Nakhash Member. These are stratiform cryptalgal laminates at the base, laterally linked hemispheroids (type-LLH) in the middle, and vertically stacked hemispheroids (type-SH) at the top. These stromatolites suggested littoral zone tidal flats environments (Al-Saad and Ibrahim, 2002).

3.2.3. Paleoenvironment of the Dam Formation

In the Dammam Dome region, the Dam formation consists of carbonates that were deposited in a restricted carbonate platform environment. They were deposited in very shallow tidal-flat setting under warm climatic hypersaline conditions, as suggested by the predominance of shallow marine, warm-water fossils such as stromatolites, benthic foraminifera, siderastrain-type corals and mollusks. The stromatolite sedimentary environment at the base of the succession at Jabal Midra al Janubi represents a shallow subtidal to lower intertidal, hypersaline tidal flat environment, and is consistent with the interpretation made for Jabal Lidam by Irtem (1986). At the Dammam Dome, the fossils of mollusc, echinoid, and foraminifera above the stromatolites suggest a lagoonal shallow-marine deposition. The Umm Er Rus pinnacle-type corals suggest local reef development possibly located on a local palaeobathymetric “high” related to localized uplift of this area.

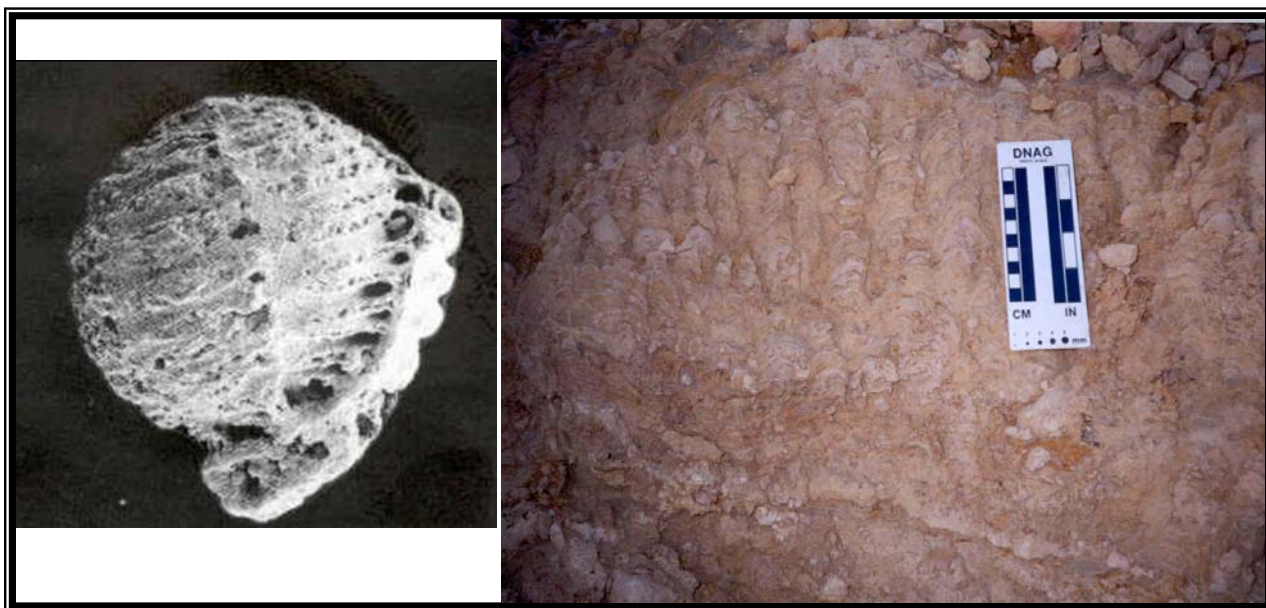


Figure 3.5 Photomicrograph of *Borelis melo melo* (Al-Saad and Ibrahim, 2002) (left) and a stromatolite, 1 m (3 feet) thick (right), from the base of Jabal Midra al-Janubi. The Dam formation at Jabal Midra Al-Janubi is equivalent to the Al-Nakhash Member in Qatar, due the consistent presence of *Borelis melo melo* and thickness of the stromatolite limestone.

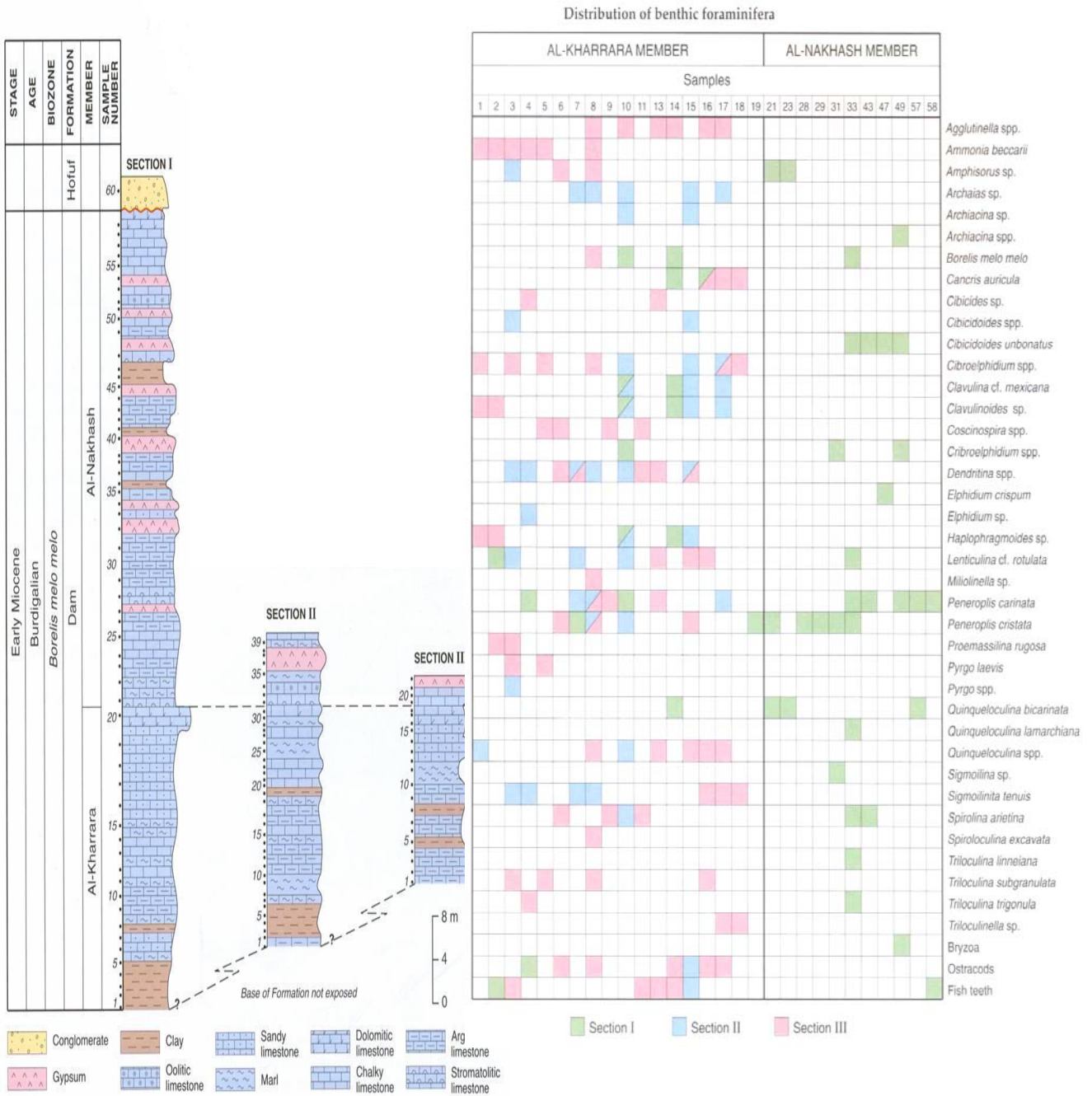


Figure 3.6 Al-Nakhash and Al-Kharrara Members of the Dam Formation in Qatar in three studied sections with their lithology, thickness and correlation (left) and the distribution of the benthic foraminifera in these three sections (right).

In Qatar, the Al-Kharrara Member was deposited in warm (25°-30°C), clear, shallow water within the inner neritic zone (0-35 m deep) with salinity levels from 35 to 50 ppt. The Al-Nakhash Member sediments are suggested to have been deposited in warm littoral to sabkha (hypersaline environments of deposition) (Al-Saad and Ibrahim, 2002).

3.2.4. Dam Formation Settings at Jabal Midra Al-Janubi

At the Dammam Dome lies at Jabal Midra Al-Janubi, which is 92 meters high, where the Dam Formation unconformably overlies the top of Midra shale Member of the Dammam Formation (Tleel, 1973). This part of the Dam Formation is belonging to the Al-Nakhash Member which described at Qatar at Jabal Al-Nakhash type locality (Saad and Ibrahim, 2002). Al-Nakhash Member is the upper part of the Dam Formation (Figure 3.6).

At Jabal Midra four depositional cycles are clearly visible on the weathering profile of the Jabal (Figure 3.7). This study has excluded the top fourth cycle because it was disturbed by ancient dissolution and cave infill that did not allow this part to be studied.

Each stratum for each cycle of the three cycles was described by using Dunham carbonate rocks texture classification and the stratigraphic structures description (Figure 3.8). Most of the rocks mineralogy is dolomite and limy dolomite. The stratigraphic column of the study area is mostly made of packstone, mudstone and grainstone. Very few beds of wackstone and mud-lean packstone are present. These beds are found in variety of sedimentary structures of package of 56.1 meters (168,3 feet) thick. The thickness and the arrangement of each bed and stratum depend on the cycle type whether it shallowing-upward or deepening-upward (Figure 3.8).

The first cycle at the base represent shallowing upward sequence that made of 5.33 meters (16 feet) of conglomerated packstone at the base followed by 0.33 m (one foot) of wackstone and one meter (three feet) of columnar or digitatec stromatolitic mudstone.

On top of the stromatolite is developed 0.5 m (1.5 foot) of soft fossiliferous packstone which is the start of the second deepening-upward cycle. This is made of two sub-cycles. The first sub-cycle, the lower, made of the thickest 2.33 m (7 feet) bed of hard, massive and fossiliferous grainstone, that caped by 3.77 m (11.3 feet) of massive, and soft packstone. This packstone started with 0.33 m (one foot) of planar stromatolite followed by 0.33 m (one foot) of bedded stratum and ended by 3.1 m (9.3 feet) structureless, pinkish weathered bed. The second sub-cycle made is made of thinner grainstone 1.33 m (4 feet) and thicker packstone, which is mostly fossiliferous, 19.3 m (58 feet), capped by massive to bedded mudstone 2.33 m (7 feet) thick.

The third cycle includes shallowing-upward sequences made of four sub-cycles. The first one is made of 1.33 m (4 feet) of transitional soft, massive and fossiliferous packstone. This is followed by 2.17 m (6.5 feet) of massive mudstone that is poor in fossils, and then by 3.33 m (10 feet) of fossiliferous wackstone, which is bedded at the base and then structureless, come after. The end of the first sub-cycle consists of 1.17 m (3.5 feet) bedded, fossiliferous packstone. The second sub-cycle is composed of very thin beds of 0.33 m (one foot) of massive mudstone followed by cross-bedded to bedded 1.5 m (4.5 feet) packstone. A 0.5 meter (1.5 foot) unit of massive mud-lean packstone capped by 0.33 m (one foot) of cross-bedded grainstone then follows. The sequences in the third sub-cycle are much thicker in comparison with the second sub-cycle. This is made of 3.67 m (11 feet) of massive packstone followed by 0.83 m (2.5 feet) of massive mud-lean packstone that capped by 0.33

m (one foot) of bedded grainstone. The last sub-cycle sequences display increased thickness, commencing with 0.33 m (one foot) of laminated mudstone followed by 0.83 m (2.5 feet) of laminated to bedded wackstone, and the final bed consisting of 3.33 m (10 feet) of massive packstone.

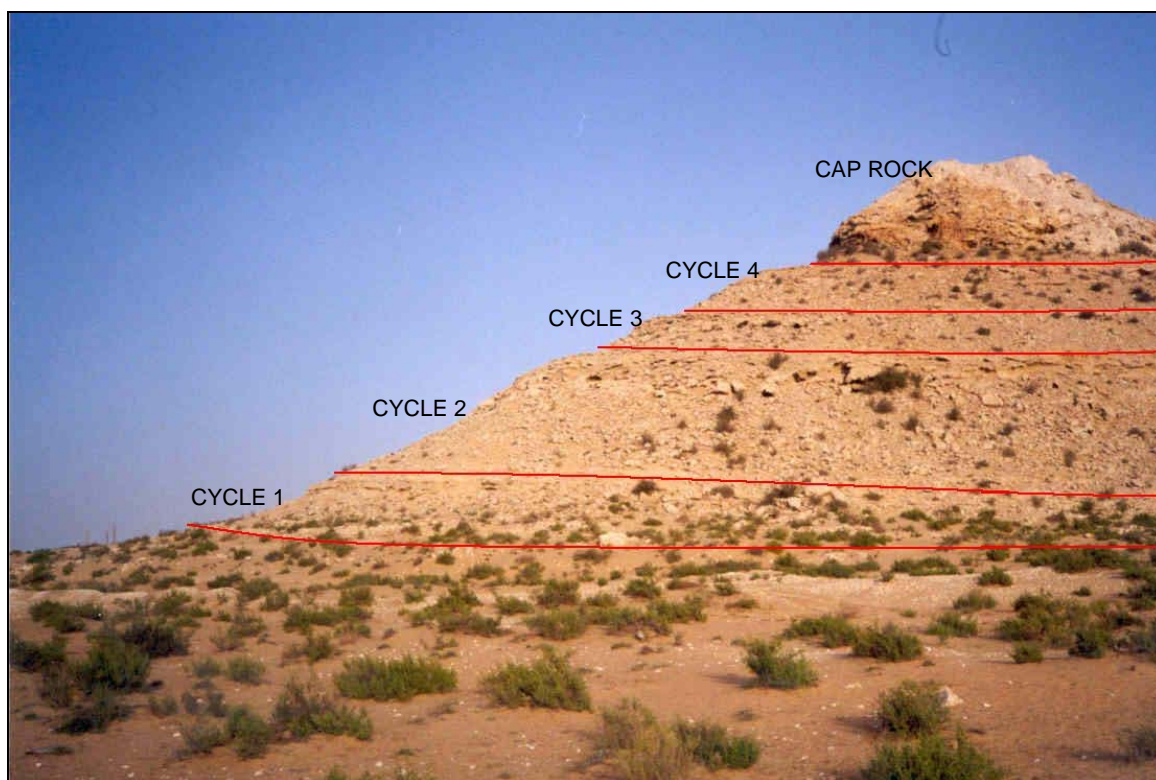


Figure 3.7. Photo of Jabal Midra Al-Janubi in 2002 showing the four main cycles of the Al-Nakhash Member, the upper part of the Dam Formation.

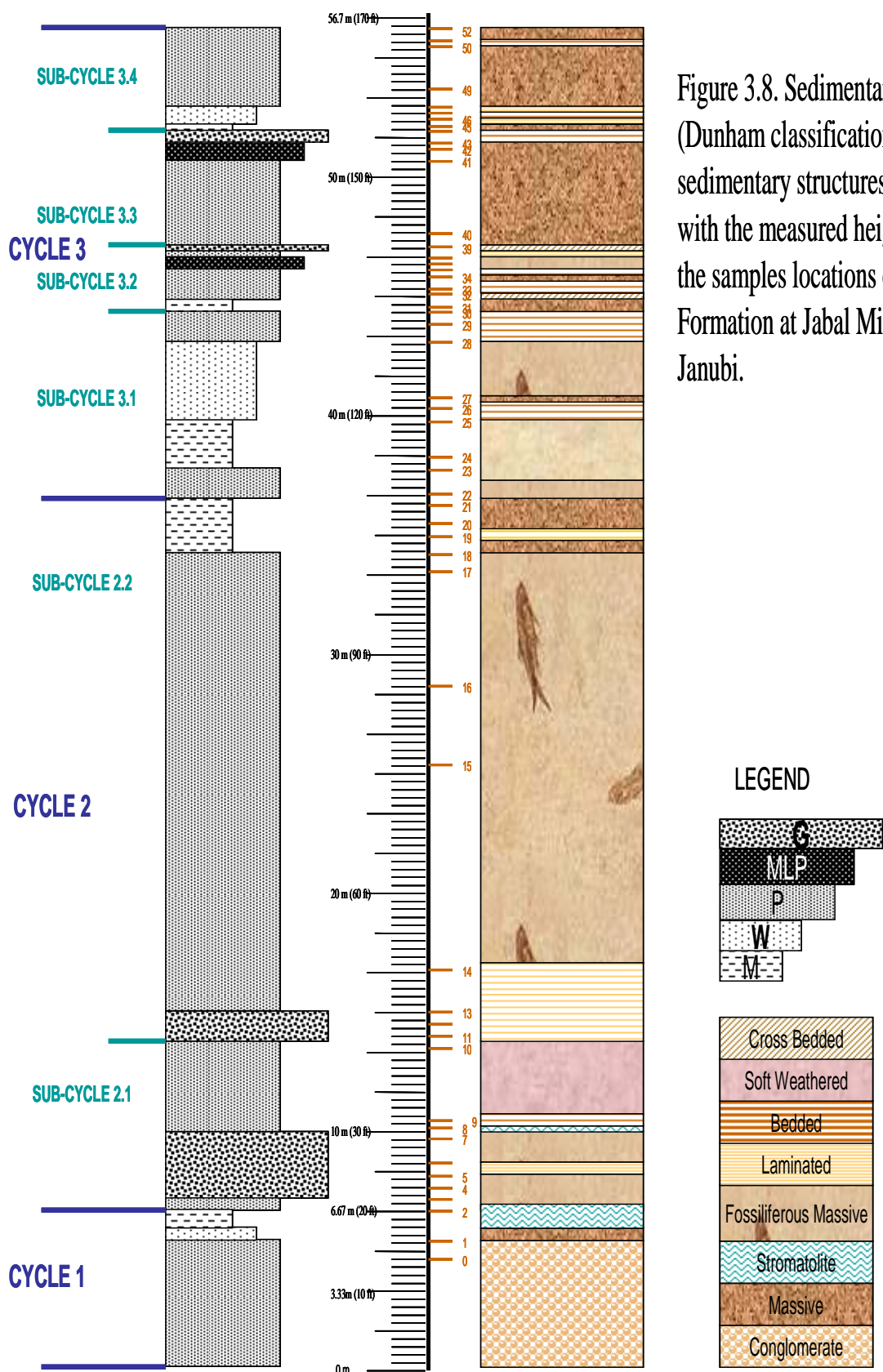


Figure 3.8. Sedimentary texture (Dunham classification) and sedimentary structures columns with the measured height and the samples locations of Dam Formation at Jabal Midra Al-Janubi.

CHAPTER FOUR

BIOFACIES OF RECENT SEDIMENTS OF THE COASTAL ARABIAN GULF

4.1 INTRODUCTION

Samples of the Recent sediments from various locations have been collected, as described in Chapter 2. The intention of this exercise was to examine the biofacies from each location, together with the environmental variants at each site. Microscopic analysis of the sediment and identification of the biocomponents was conducted to establish if any regional variations existed, and to relate such variations to their respective environmental parameters. The common foraminifera identified in these sediments have been photographed, and are illustrated in Plates 4.1 to 4.3.

4.2 BIOFACIES

Biofacies is a term used to define a particular assemblage of biocomponents, and in this study the biofacies refers to foraminifera. Discrete assemblages of benthonic foraminiferal species are known to preferentially occupy certain environments, as fully

described by Murray (1991). Within the study area, samples were collected from sites that ranged in depth from 0.5 m to 18 m, and the entire foraminiferal content of each sample has been recorded and illustrated in Enclosure 4.1. It is interesting to note that each sample contains a background of common species, but certain species are also present in different samples and it is these different species that will be selected to characterize the various biofacies.

With reference to Enclosure 4.1, the following species are present at most localities: Of these, five genera are miliolids (*Quinqueloculina* spp., *Triloculina* spp., *Miliolina* spp., *Peneroplis pertusus*, *Peneroplis planatus*) and only two are rotalids (*Ammonia beccarii* and *Elphidium* spp.).

It should be noted that within the relatively small bathymetric range used in this study, certain species with a particular shallow limit will also be present at the deeper locations. It is for this reason that the additions of new species within samples from increasingly deep locations are the most critical for biofacies determination. The following analysis of biofacies will highlight those species that make their first appearance in order of increasing sample depth.

For the present study, the following information is planned to be used to interpret the depositional environment of foraminiferal-bearing assemblages from the Dam Formation, and the appearance of new species with increasing depth will be a useful guide to apply to the fossil assemblages. This exercise is possible with the Dam Formation because most of the Miocene benthonic foraminiferal species are extant, i.e. still live today. Hence, we assume that the environmental preferences of these species have not changed drastically since the Miocene.

Biofacies typical of 0.5 m

The shallowest environment, at 0.5m, includes three localities (Abu Ali Island, Saffwa Bay, and Half Moon Bay Shallow). The foraminiferal diversity is high, with over 28 species. Dominant species include *Cyclogyra planorbis*, *Quinqueloculina* spp., *Quinqueloculina agglutinans*, *Triloculina* spp., *Miliolina* spp., *Massilina* spp., *Schlumbergerina* sp., *Peneroplis pertusus*, *Peneroplis planatus*, *Ammonia beccarii*, *Elphidium* spp., *Sorites marginalis*, *Trilocularena* sp., *Dendritina elegans*, *Rotaliina* spp., *Glabratella patelliformis*, and *Nonion depressulus*.

Other microfossils include ostracoda spp., gastropoda spp., bivalve spp., scaphopod spp., worm tubes, agglutinated worm tubes, crab fragments, bryozoan remains, calcareous algal remains and algal remains.

Species that are found in addition to those listed in shallower samples include: *Sorites marginalis*, *Trilocularena* sp., *Dendritina elegans*, *Rotalina* spp., *Glabratella petalliformis* and *Nonion depressulus*.

Biofacies typical of 1m

One locality was sampled at 1.0 m (Jubail). The foraminiferal diversity is moderately high with over 17 species. Dominant species include *Quinqueloculina* spp., *Quinqueloculina agglutinans*, *Triloculina* spp., *Miliolina* spp., *Peneroplis pertusus*, *Peneroplis planatus*, *Ammonia beccarii*, *Elphidium* spp., *Sorites marginalis*, *Dendritina elegans*, *Spiroloculina* spp., and *Spirolina arietina*.

Other microfossils include ostracod spp., gastropod spp., bivalve spp., agglutinated worm tubes and crab fragments.

Species that are found, appeared in 1 m depth, in addition to those listed in shallower samples include: *Spiroloculina* spp. and *Spirolina arietina*.

Biofacies typical of 2m

Two localities were sampled at 2.0 m depth (Tarut Bay DC 5 and Tarut-Dammam DC 12). The foraminiferal diversity is high with over 28 species. Dominant species include *Quinqueloculina* spp., *Quinqueloculina agglutinans*, *Triloculina* spp., *Miliolina* spp., *Peneroplis pertusus*, *Peneroplis planatus*, *Ammonia beccarii*, *Elphidium* spp., *Sorites marginalis*, *Rotaliina* spp., *Spiroloculina* spp., *Spirolina arietina*, *Textularia* spp., *Articulina pacifica*, *Miliolina* sp.?, *Rotaliina* sp., *Cibicides* spp., *Planorbulina mediterraneaensis*, *Spiroloculina grata*, *Bolivina spathulata*.

Other microfossils include ostracoda spp., gastropoda spp., bivalve spp., crab fragments, algal remains, echinoderm remains, and fish bones.

Species that are found in addition to those listed in shallower samples include: *Textularia* spp., *Articulina pacifica*, *Cibicides* spp., *Planorbulina mediterraneaensis*, *Spiroloculina grata* and *Bolivina spathulata*

Biofacies typical of 4 m and 6 m

One locality was sampled at 4.0 m depth (Ras Tanura coast outfall WQ 15) and one at 6 m depth (Half Moon bay offshore (centre)). Foraminiferal diversity is high, with over 34

species. Dominant species include *Quinqueloculina* spp., *Quinqueloculina agglutinans*, *Triloculina* spp., *Miliolina* spp., *Peneroplis pertusus*, *Peneroplis planatus*, *Spirillina* spp., *Ammonia beccarii*, *Elphidium* spp., *Sorites marginalis*, *Trilocularena* sp., *Dendritina elegans*, *Rotaliina* spp., *Glabratella patelliformis*, *Nonion depressulus*, *Spiroloculina* spp., *Spirolina arietina*, *Textularia* spp., *Planorbulina mediterraneaensis*, *Articulina queenslandica*, *Bolivina simpsoni*, *Reussella aculeate*, *Tretomphalus bulloides*, *Cibicides pseudoungerianus*, *Clavulina pacifica*.

Other microfossils include ostracod spp., gastropod spp., bivalve spp. worm tubes, crab fragments, scaphopod spp., algal remains, calcareous algal remains and echinoderm remains.

Species that are found at 4m in addition to those listed in shallower samples include: *Articulina queenslandica*, *Bolivina simpsoni*, *Reussella aculeate*, *Tretomphalus bulloides* and *Cibicides pseudoungerianus*.

Species that are found at 6m in addition to those listed from shallower samples include: *Clavulina pacifica*.

Biofacies typical of 11.5 m

One locality was sampled at 11.5 m depth (Azizyah Desalination Plant Offshore), from which no new species were recovered. Foraminiferal diversity is moderate, with over 17 species. Dominant species include *Quinqueloculina* spp., *Triloculina* spp., *Miliolina* spp., *Peneroplis planatus*, *Ammonia beccarii*, *Elphidium* spp., *Dendritina elegans*, *Rotaliina* spp., *Spiroloculina* spp., *Rotaliina* sp., *Clavulina pacifica*.

Other microfossils include ostracod spp., gastropod spp., bivalve spp. worm tubes and crab fragments.

Biofacies typical of 17 m and 18 m

One locality was sampled at 17.0 m depth (Ras Al-Ghar offshore WQ 18), and one sample from 18 m (Berri-8 Well-124 (SC 970594) Saudi Aramco bottom sample #3). Foraminiferal diversity is very high, with over 55 species. Dominant species include *Quinqueloculina* spp., *Quinqueloculina agglutinans*, *Triloculina* spp., *Miliolina* spp., *Massilina* spp., *Peneroplis pertusus*, *Peneroplis planatus*, *Ammonia beccarii*, *Elphidium* spp., *Sorites marginalis*, *Rotaliina* spp., *Glabratella patelliformis*, *Nonion depressulus*, *Spiroloculina* spp., *Spirolina arietina*, *Textularia* spp., *Articulina pacifica*, *Rotaliina* sp., *Cibicides* spp., *Planorbulina mediterraneaensis*, *Spiroloculina grata*, *Bolivina spathulata*, *Articulina queenslandica*, *Bolivina simpsoni*, *Reussella aculeate*, *Tretomphalus bulloides*, *Cibicides pseudoungerianus*, *Miliolina rupertiana*, *Ptychomiliola* spp., *Massilina secans*, *Reussella pulchra*, *Discorbis plana*, *Amphistigina lessoni*, *Elphidium craticulatom*, *Operculina gaymardi*, *Cibicides lobatulus*, *Patellinella* cf. *inconspicua*, *Pyrgo* sp., *Reussella* sp., *Cymbalopora tobagoensis*.

Other microfossils include diatom sp., ostracod spp., gastropoda spp., bivalve spp., worm tubes, crab fragments, bryozoa remains, scaphopod spp. and echinoderm remains.

Species that are found at 17.0 m depth, in addition to those listed from shallower samples include: *Miliolina rupertiana*, *Ptychomiliola* spp., *Massilina secans*, *Reussella*

pulchra, *Discorbis planatus*, *Amphistegina lessoni*, *Cellanthus craticulatum*, *Operculina gaymardi*, *Cibicides lobatulus* and *Patelinella* cf. *inconspicua*.

Species that are found at 18 m depth, in addition to those listed above include: *Pyrgo* sp., *Reussella* spp. and *Cymbaloporetta tobagoensis*.

4.3 RELATIONSHIP BETWEEN BIOFACIES AND ENVIRONMENTAL PARAMETERS

With reference to Enclosure 4.1, the various depths and salinity measurements for each sample locality are displayed. In addition, the foraminiferal diversity is displayed (figure 4.1).

The following observations can be made:

- Sample localities that display the highest salinity values display the lowest foraminiferal species diversity
- Sample localities from increasing depths display a corresponding increase in foraminiferal species diversity

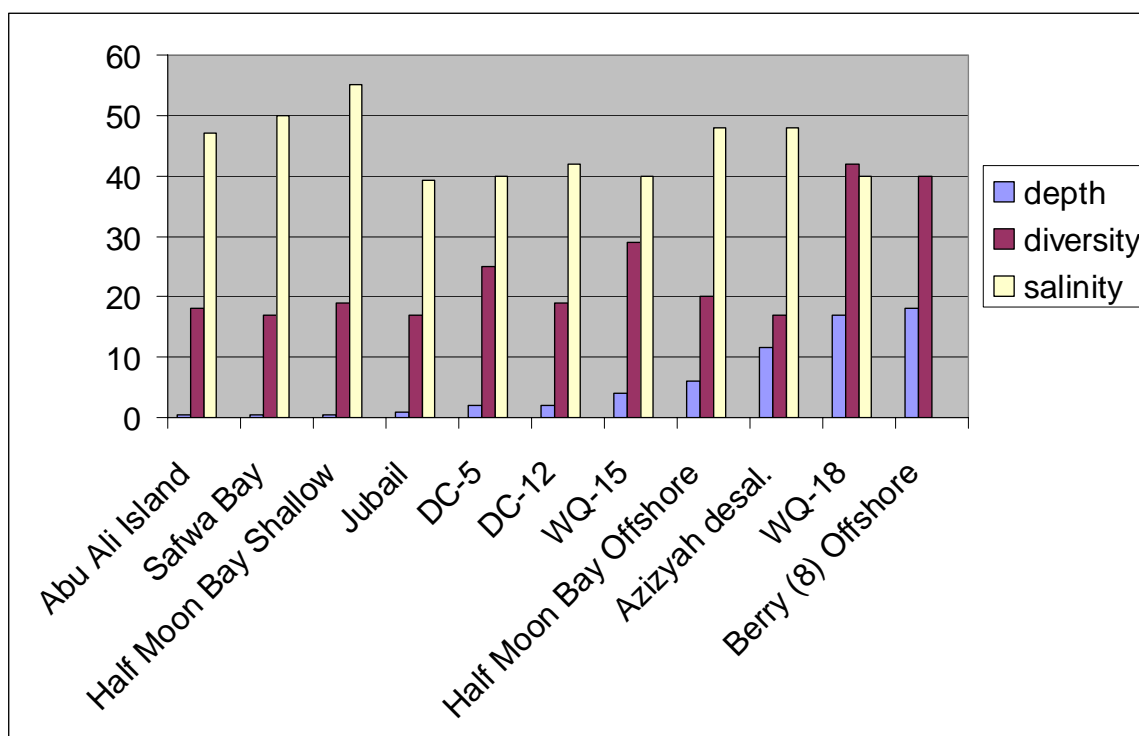


Figure 4.1. Chart of the foraminifera diversity for each sample at the Arabian Gulf study area showing the relationships with sample depth and salinity.

CHAPTER FIVE

BIOCOMPONENTS OF THE DAM FORMATION

5.1. BIOSTRATIGRAPHY

With the exception of sample 43H, the presence of the complex-walled miliolids benthonic foraminiferal subspecies *Borelis melo melo* throughout the entire measured and sampled section of the Dam Formation at Jabal Midra al Janubi provides a Middle Miocene age. This is equivalent to the Tertiary East Indian Classification Zone Te (Adams, 1970).

5.1.1 Micropalaeontological Biocomponents

The Dunham texture and the entire microfauna identified in 77 thin sections from 60 samples is displayed in Enclosure 5.1, and illustrated in Plates 5.1 to 5.12. 51 species of foraminifera have been identified, of which three species are agglutinated, 37 are miliolids and 11 are rotalid. In addition, associated microfauna and microflora include ostracods and fragments of calcareous algae, bivalves, echinoids, gastropods, scaphopods, brachiopods, worm tubes, bryozoa, and stromatolites.

The agglutinated foraminiferal species include *Textularia* spp., *Schlumbergerina* sp. and *Reophax* spp.

The miliolids foraminiferal species include Miliolid spp., *Quinqueloculina* spp. (16 species), *Triloculina* spp. (8 species), *Spiroloculina* spp. (4 species), *Peneroplis* spp. *Peneroplis pertusus*, *Sorites* sp., *Archaias hensoni*, *Alveolinella* sp., *Borelis melo melo*, *Spirolina* spp. and *Massilina* spp.

The rotalid foraminiferal species include *Ammonia* spp., *Rotalia* spp., *Elphidium* spp., rotalid spp., *Operculina* sp., *Cibicides* spp., *Planorbulina larvata*, *Ammodiscus* sp., *Ammobaculites* sp. and *Nonion* spp. (2 species).

With reference to Enclosure 5.1, the sample height above the base of the measured section is displayed against the semi-quantitative abundance of each recorded species, this being indicated as proportional lengths of the horizontal bar. From a detailed examination of the presence of certain species, it has been possible to determine a succession of biofacies that dominate the assemblages through the section. The following table (Table 5.1) displays the biofacies defined from the distribution of the various biocomponents displayed in Enclosure 5.1.

The Miliolid biofacies (14'–16.4') is characterized by brachiopod fragments, *Rotalia* spp., *Quinqueloculina* sp.1, *Quinqueloculina* sp.2, *Spiroloculina* sp.1 and *Triloculina* sp.1.

The *Halimeda* biofacies (16.4' – 17.10') is characterized by ostracod spp., scaphopoda (*Dentalium sexangulare*), gastropoda (smooth), brachiopod fragments, gastropod spp., echinoid spines, *spirorbis* spp. (worm tube), bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., *Quinqueloculina* sp.3, *Quinqueloculina* sp.5, *Rotalid* spp., *Elphidium* spp., *Peneroplis* spp., *Quinqueloculina* sp.1, *Quinqueloculina* sp.2, *Spiroloculina* sp.1, *Triloculina* sp.1, Dasyclad algal debris and *Halimeda* spp.

Upper contact	Lower contact	Biofacies
168.00'	161.00'	Miliolid- <i>Rotalia</i>
161.00'	158.30'	<i>Spiroloculina</i>
158.30'	155.00'	Miliolid
155.00'	154.00'	<i>Borelis-Rotalia</i>
154.00'	150.00'	Miliolid
141.50'	137.00'	<i>Borelis-Rotalia</i>
137.00'	133.00'	Miliolid- <i>Operculina</i>
133.00'	131.00'	<i>Rotalia</i>
131.00'	127.00'	<i>Archaias-Elphidium</i>
121.50'	120.50'	<i>Borelis-Rotalia</i>
120.50'	112.00'	Poor Fauna
112.00'	110.00'	<i>Borelis-Rotalia</i>
110.00'	102.50'	<i>Rotalia</i>
102.50'	102.00'	<i>Borelis-Rotalia</i>
87.50'	87.00'	<i>Operculina</i>
74.40'	74.00'	<i>Schlumbergerina-Peneroplis</i>
65.00'	64.50'	<i>Operculina-Schlumbergerina</i>
48.00'	47.50'	<i>Sorites-Reophax</i>
47.50'	41.20'	Gastropod
32.00'	27.00'	Stromatolite-Miliolid
27.00'	25.00'	<i>Peneroplis</i>
25.00'	22.50'	Poor Fauna
22.50'	20.00'	<i>Halimeda</i>
20.00'	17.10'	Stromatolite
17.10'	16.40'	<i>Halimeda</i>
16.40'	14.00'	Miliolid

Table 5.1. Biofacies of the Dam Formation. Depths relate to height above the base of the Dam measured section at Jabal Midra al Janubi.

The Stromatolite biofacies (17.10'-20.00') is characterized by digitate or columnar stromatolite.

The *Halimeda* biofacies (20.00' – 22.5') is characterized by ostracod spp., brachiopod fragments, gastropod spp., *spirorbis* spp. (worm tube), bivalve spp., Miliolid spp., *Quinqueloculina* sp.7, *Quinqueloculina* sp.6, Rotalid spp., *Spiroloculina* sp.2, *Triloculina* sp.2, *Triloculina* sp.4, Dasyclad algal debris and *Halimeda* spp.

The Poor Fauna biofacies (22.50' – 25.00') is characterized by brachiopod fragments, gastropod spp., echinoid spines and bivalve spp.

The *Peneroplis* biofacies (25.00' – 27.00') is characterized by brachiopod fragments, gastropod spp., echinoid spines, *spirorbis* spp. (worm tube), bivalve spp., *Ammonia* spp., *Elphidium* spp., *Peneroplis* spp., *Nonion* sp.2 and *Spiroloculina* sp.2.

The Stromatolite-*Miliolid* biofacies (27.00' – 32.00') is characterized by gastropoda (smooth), brachiopod fragments, gastropod spp., echinoid spines, spirorbis spp. (worm tube), *Peneroplis* spp., *Quinqueloculina* sp.1, *Quinqueloculina* sp.6, planar stromatolite, *Ammonia* spp., *Miliolid* spp., *Quinqueloculina* sp.3, *Quinqueloculina* sp.9, *Quinqueloculina* sp.7, *Quinqueloculina* sp.8, Rotalid spp., *Elphidium* spp., *Nonion* sp.1, *Planorbulina* sp., *Triloculina* sp.5 and Dasyclad algal debris.

The Gastropod biofacies (41.20' – 47.50') is characterized by gastropoda (smooth), brachiopod fragments, gastropod spp., echinoid spines, *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp. and *Elphidium* spp.

The *Sorites-Reophax* biofacies (47.50' – 48.00') is characterized by ostracod spp., brachiopod fragments, gastropod spp., echinoid spines, *spirorbis* spp. (worm tube), bivalve spp., *Ammonia* spp., Rotalid spp., *Elphidium* spp., *Nonion* sp.1, *Nonion* sp.2,

Quinqueloculina sp.9, *Reophax* spp., *Quinqueloculina lamarkiana*, *Quinqueloculina* sp.6, *Triloculina* sp.2, *Triloculina* sp.4, *Spiroloculina* sp.2, *Sorites* sp., *Quinqueloculina* sp.10.

The *Operculina-Schlumbergerina* biofacies (64.50' – 65.00') is characterized by gastropoda (smooth), brachiopod fragments, echinoid spines, spirorbis spp. (worm tube), bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp., *Quinqueloculina* sp.7, *Nonion* sp.1, *Quinqueloculina* sp.9, *Elphidium* spp., *Operculina* sp., *Reophax* spp., *Textularia* sp., *Archaias hensoni*, *Quinqueloculina lamarkiana*, *Quinqueloculina* sp.5, *Triloculina* sp.2, *Triloculina* sp.3, *Triloculina* sp.4, *Spiroloculina* sp.2, *Quinqueloculina* sp.11, *Quinqueloculina* sp.12, *Schlumbergerina* sp., *Spirolina* spp. and Dasyclad algal debris.

The *Schlumbergerina-Peneroplis* biofacies (74.00' – 74.40') is characterized by gastropoda (smooth), brachiopod fragments, echinoid spines, spirorbis spp. (worm tube), bivalve (spiny), bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp., *Quinqueloculina* sp.3, *Nonion* sp.1, *Quinqueloculina* sp.5, *Peneroplis* spp., *Quinqueloculina* sp.7, *Elphidium* spp., *Reophax* spp., *Triloculina* sp.1, *Archaias hensoni*, *Quinqueloculina* sp.6, *Triloculina* sp.2, *Triloculina* sp.3, *Triloculina* sp.4, *Sorites* sp., *Quinqueloculina* sp.10 and *Schlumbergerina* sp.

The *Operculina* biofacies (87.00' – 87.50') is characterized by brachiopod fragments, spirorbis spp. (worm tube), bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp., *Elphidium* spp., *Nonion* sp.1, *Operculina* sp., *Peneroplis pertusus*, *Reophax* spp., *Triloculina* sp.4 and *Archaias Hensoni*.

The *Borelis-Rotalia* biofacies (102.00' – 102.50') is characterized by gastropoda (smooth), brachiopod fragments, echinoid spines, spirorbis spp. (worm tube), branched bryozoa, bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp., *Elphidium* spp., *Nonion* sp.1, *Reophax* spp., *Triloculina* sp.2, *Quinqueloculina* sp.6, *Spiroloculina* sp.2 and Dasyclad algal debris.

The *Rotalia* biofacies (102.50' – 110.00') is characterized by branched bryozoa, bivalve spp., Rotalid spp., *Borelis melo melo*, Miliolid spp., *Elphidium* spp. and *Quinqueloculina* sp.3.

The *Borelis-Rotalia* biofacies (110.00' – 112.00') is characterized by gastropoda (smooth), brachiopod fragments, *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp., and *Elphidium* spp.

The Poor Fauna biofacies (112.00' – 120.50') is characterized by gastropoda (smooth), brachiopod fragments, echinoid spines, bivalve spp., *Borelis melo melo*, *Miliolid* spp., Rotalid spp., *Elphidium* spp., *Reophax* spp., *Archaias hensoni* and *Quinqueloculina* sp.6.

The *Borelis-Rotalia* biofacies (120.50' – 121.50') is characterized by gastropoda (smooth), brachiopod fragments, echinoid spines, bivalve spp., *Ammonia* spp., *Borelis melo melo*, *Miliolid* spp., Rotalid spp., *Elphidium* spp., *Quinqueloculina* sp.7, *Operculina* sp., *Archaias hensoni*, *Triloculina* sp.4, *Quinqueloculina* sp.6 and *Spiroloculina* sp.2.

The *Archaias-Elphidium* biofacies (127.00' – 131.00') is characterized by gastropoda (smooth), brachiopod fragments, echinoid spines, bivalve spp., Miliolid spp., Rotalid spp., *Elphidium* spp., *Quinqueloculina* sp.7, *Reophax* spp., *Ammodiscus* sp., *Archaias hensoni*, *Quinqueloculina* sp.10 and *Spiroloculina* sp.1.

The *Rotalia* biofacies (131.00' – 133.00') is characterized by ostracod spp., gastropoda (smooth), brachiopod fragments, echinoid spines, *Ammonia* spp., Miliolid spp., Rotalid spp., *Elphidium* spp., *Quinqueloculina* sp.7, *Operculina* sp., *Ammodiscus* sp., *Archaias hensoni*, *Triloculina* sp.2, *Triloculina* sp.4, *Schlumbergerina* sp. and *Peneroplis pertusus*.

The *Miliolid-Operculina* biofacies (133.00' – 137.00') is characterized by ostracod spp., gastropoda (smooth), brachiopod fragments, echinoid spines, bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp., *Elphidium* spp., *Peneroplis* spp.,

Quinqueloculina sp.7, *Quinqueloculina* sp.9, *Operculina* sp., *Reophax* spp., *Textularia* spp., *Triloculina* sp.1, *Archaias hensoni*, *Quinqueloculina* sp.6, *Triloculina* sp.2, *Triloculina* sp.4, *Quinqueloculina* sp.8, *Quinqueloculina* sp.10, *Peneroplis pertusus.*, *Spiroloculina* sp.3 and *Triloculina* sp.6

The *Borelis-Rotalia* biofacies (137.00' – 141.50') is characterized by ostracod spp., scaphopoda spp., gastropoda (smooth), brachiopod fragments, echinoid spines, bivalve spp., *Ammonia* spp., *Borelis melo melo*, Miliolid spp., Rotalid spp. , *Elphidium* spp., *Peneroplis* spp., *Quinqueloculina* sp.7, *Nonion* sp.2, *Quinqueloculina* sp.9, *Reophax* spp., *Textularia* spp., *Quinqueloculina* sp.1, *Spiroloculina* sp.1, *Triloculina* sp.1, *Archaias hensoni*, *Quinqueloculina* sp.6, *Triloculina* sp.2, *Triloculina* sp.4, *Quinqueloculina* sp.8, *Triloculina* sp.5, *Spiroloculina* sp.3, *Triloculina* sp.6, *Quinqueloculina* sp.13, *Quinqueloculina* sp.14, *Quinqueloculina* sp.15, *Quinqueloculina* sp.16, *Spiroloculina* sp.4, *Triloculina* sp.7, *Masillina* spp. and Dasyclad algal debris.

The Miliolid biofacies (150.00' – 154.00') is characterized by gastropoda (smooth), brachiopod fragments, Miliolid spp., *Elphidium* spp., *Quinqueloculina* sp.7, *Reophax* spp., *Ammobaculis* sp., *Triloculina* sp.1, *Quinqueloculina* sp.6, *Triloculina* sp.3, *Triloculina* sp.5, *Spiroloculina* sp.3, *Triloculina* sp.6, *Quinqueloculina* sp.13, *Quinqueloculina* sp.16, *Spiroloculina* sp.4, *Triloculina* sp.7 and *Triloculina* sp.8.

The *Borelis-Rotalia* biofacies (154.00' – 155.00') is characterized by ostracod spp., gastropoda (smooth), brachiopod fragments, bivalve spp., *Borelis melo melo*, Miliolid spp., Rotalid spp. , *Elphidium* spp., *Quinqueloculina* sp.3, *Quinqueloculina* sp.5, *Quinqueloculina* sp.7, *Nonion* sp.2, *Reophax* spp., *Triloculina* sp.1, *Archaias hensoni* and *Triloculina* sp.6.

The Miliolid biofacies (155.00' – 158.30') is characterized by gastropoda (smooth), Miliolid spp., Rotalid spp., *Elphidium* spp., *Nonion* sp.2, *Reophax* spp., *Archaias hensoni*,

Quinqueloculina sp.10, *Quinqueloculina* sp.16, *Triloculina* sp.6 and *Quinqueloculina* sp.15.

The *Spiroloculina* biofacies (158.30' – 161.00') is characterized by Rotalid spp., *Elphidium* spp., *Quinqueloculina* sp.7, *Ammobaculites* sp., *Spiroloculina* sp.2, *Quinqueloculina* sp.8, *Triloculina* sp.5, *Quinqueloculina* sp.11, *Quinqueloculina* sp.14, *Quinqueloculina* sp.16, *Triloculina* sp.6 and *Triloculina* sp.8.

The Miliolid biofacies (161.00' – 168.00') is characterized by gastropoda (smooth), brachiopod fragments, bivalve spp., *Ammonia* spp., Miliolid spp., *Quinqueloculina* sp.3, *Quinqueloculina* sp.5, Rotalid spp., *Elphidium* spp., *Peneroplis* spp., *Quinqueloculina* sp.7, *Nonion* sp.2, *Nonion* sp.1, *Operculina* sp., *Planorbulina larvata*, *Reophax* spp., *Textularia* spp., *Ammobaculis* sp., *Quinqueloculina* sp.1, *Spiroloculina* sp.1, *Triloculina* sp.1, *Archaias hensoni*, *Quinqueloculina* sp.6, *Triloculina* sp.2, *Triloculina* sp.3, *Spiroloculina* sp.2, *Quinqueloculina* sp.8, *Triloculina* sp.5, *Quinqueloculina* sp.10, *Quinqueloculina* sp.12, *Quinqueloculina* sp.13, *Quinqueloculina* sp.16, *Spiroloculina* sp.4 and *Triloculina* sp.6.

CHAPTER SIX

APPLICATION OF RECENT MICROBIOFACIES TO INTERPRET THE MIDDLE MIOCENE MICROBIOFACIES OF THE DAM FORMATION

Palaeoenvironmental interpretations have been made for each biofacies, using a comparison between the recent foraminiferal species from the Arabian Gulf (Chapter 4) and their Miocene equivalents from the Dam Formation (Chapter 5). Species considered being comparable between the Recent and Miocene successions is displayed in Table 6.1. It must be remembered that species assignment is easier when entire specimens from the Recent are available for analysis, unlike the random thin sections of species encountered from the Dam Formation. This interpretation is based on morphological similarity between the species, and not on any published data. The assumed equivalence between the Recent and Miocene species, in terms of palaeobathymetric and environmental preference, has been used to interpret the palaeoenvironment of each biofacies recognized for the Dam Formation, and these are summarized in Table 6.2.

With reference to Table 6.1, it is noted that the biofacies consisting of rotalids *Ammonia beccarii*, *Rotalina* spp., *Glabratella petalliformis* and *Nonion depressulus* with the miliolids *Sorites marginalis*, *Triloculina* spp. and *Dendritina elegans* is typical of 0.5 m

water depth, and of a shallow lagoon environment. It compares well with the Dam Formation biofacies consisting of the rotalids *Ammonia* spp. and *Elphidium/Rotalia* spp. and the miliolids *Archaias hensoni*, *Triloculina* spp., and *Peneroplis / Borelis melo melo*, for which a palaeobathymetry of 0.5 m has been interpreted, within a shallow lagoon.

The biofacies including the miliolids *Spiroloculina* spp. and, *Spirolina arietina*, from 1.0 m water depth has been used to infer similar palaeowater depth forth at Dam Formation sediments characterised by the presence of the miliolids *Archaias hensoni* and *Spiroloculina* spp.

The Recent biofacies typified by the presence of the agglutinated species *Textularia* spp., and the miliolids *Articulina pacifica* and *Spiroloculina grata*, and rotalids *Cibicides* spp., *Planorbulina mediterraneensis*, *Bolivina spathulata* are equated with the following Dam Formation species and a water depth of 2 m has been inferred: *Textularia* spp. *Borelis melo melo* *Spiroloculina* spp., *Cibicides* spp., *Planorbulina larvata* and *Bolivina* spp.

Recent species indicative of 4m water depth include the miliolid *Articulina queenslandica*, and rotalids *Bolivina simpsoni*, *Bolivina* spp., *Reusella aculeata*, *Cibicides pseudoungerianus* and *Tretomphalus bulloides* and considered to equate with the Dam biofacies that includes *Borelis melo melo*, *Bolivina* spp. and *Cibicides* spp.

At 6.0 m, Recent foraminifera include the characteristic agglutinates species *Clavulina pacifica* and this is tentatively equated with *Reophax* spp. in the Dam Formation.

Species characteristic of 17 m water depth include the miliolids *Miliolina rupertiana*, *Ptychomiliola* spp., *Massilina secans* and the larger rotalids *Operculina gaymardi* and *Amphistegina lessoni* together with rotalids *Reusella pulchra*, *Discorbis planatus*, *Cellanthus craticulatum* and *Cibicides lobatulus*. These are equated with Dam Formation

foraminifera including undifferentiated miliolids spp., *Massilina* sp. and rotalids *Planorbulina larvata*, *Operculina* spp., *Elphidium* spp. and *Cibicides* spp.

The 18 m recent biofacies is characterised by the presence of *Patelinella* cf. *inconspicua*, *Planorbulina larvata*, *Pyrgo* spp., *Reussella* spp. and *Cymbaloporeta tobagoensis*. These are used to infer similar water depths for the Dam Formation specimens that contain *Pyrgo* spp./*Schlumbergerina* with *Planorbulina larvata*.

The unconformable nature of the basal contact between the Dam Formation at the studied section and the underlying succession implies a sedimentological response to a Middle Miocene marine transgression. It is evident that its basal lithofacies, as sampled in the measured section, commenced deposition within an intertidal, hypersaline environment in which elevated salinity and temperature levels precluded colonization and caused the construction of layered and columnar stromatolites. A “freshening” of the environment, presumably in response to a successive marine transgression during the Middle Miocene that permitted colonization by a variety of organisms, including foraminifera has led to the cessation of stromatolite development.

By comparison with the Recent foraminifera biofacies, the entire measured section is concluded to have been deposited under warm, clear water conditions, as evidenced by the high proportion of forms known to contain zooanthellae photosynthetic algae. With the exception of the basal stromatoporoid succession in which elevated salinity levels are concluded, the rest of the Formation is considered to have been deposited under normal to slightly elevated salinity levels. The elevated salinity levels are suggested by the predominance of miliolids species. A total of eleven deepening pulses, with depths interpreted to be in excess of 17 m are recorded by the localized presence of the deeper

marine foraminifera *Operculina* spp., together with *Rotalia* spp., that alternated with slightly shallow conditions in which such species were absent, but in which miliolids, especially *Borelis melo melo*, were well represented. This interpretation based on the micropalaeontological evidence is supported by the Dunham texture, in which the deeper pulses tend to be characterized by the wackestones and packstone fabrics, whereas the shallower pulses are typically of grainstones. Mouldic porosity is present throughout most of the upper part of the section, with interparticle and intraparticle porosity being confined to the lower part. Palaeoenvironmental regimes ranged from the “moderately deep lagoon”, with depths of 17 m and deeper, to shallow lagoon with normal salinity, and depths of around 6m, to shallow lagoon with hypersalinity and depths of between 4m and 0.5 m, and the most adverse, hypersaline, very shallow to possibly intertidal conditions, as represented by the basal stromatolite biofacies.

Recent Foraminifera	Middle Miocene Foraminiferal Equivalent	Palaeobathymetry	Environment
<i>Ammonia beccarii</i>	<i>Ammonia</i> spp.	0..5	Shallow lagoon
<i>Sorites marginalis</i>	<i>Archaias hensoni</i> / <i>Sorites</i> sp.	0..5	Shallow lagoon
<i>Triloculina</i> spp.	<i>Triloculina</i> spp.	0..5	Shallow lagoon -hypersaline
<i>Dendritina elegans</i>	<i>Peneroplis/Borelis melo melo</i>	0..5	Shallow lagoon
<i>Rotalina</i> spp.	<i>Elphidium/Rotalia</i> spp.	0..5	Shallow lagoon
<i>Glabratella petalliformis</i>	(No equivalent)	0..5	Shallow lagoon
<i>Nonion depressulus</i>	<i>Rotalia</i> spp.	0..5	Shallow lagoon
<i>Spiroloculina</i> spp.	<i>Spiroloculina</i> spp.	1.0	Shallow lagoon
<i>Spirolina arietina</i>	<i>Archaias hensoni</i>	1.0	Shallow lagoon
<i>Textularia</i> spp.	<i>Textularia</i> spp.	2.0	low lagoonShal
<i>Articulina pacifica</i>	<i>Borelis melo melo</i>	2.0	Shallow lagoon
<i>Cibicides</i> spp.	<i>Cibicides</i> spp.	2.0	Shallow lagoon
<i>Planorbulina mediterraneensis</i>	<i>Planorbulina larvata</i>	2.0	Shallow lagoon
<i>Spiroloculina grata</i>	<i>Spiroloculina</i> spp.	2.0	Shallow lagoon
<i>Bolivina spathulata</i>	<i>Bolivina</i> spp.	2.0	Shallow lagoon
<i>Articulina queenslandica</i>	<i>Borelis melo melo</i>	4.0	Shallow lagoon
<i>Bolivina simpsoni</i>	<i>Bolivina</i> spp.	4.0	Shallow lagoon
<i>Reusella aculeata</i>	(No equivalent)	4.0	Shallow lagoon
<i>Tretomphalus bulloides</i>	(No equivalent)	4.0	Shallow lagoon
<i>Cibicides pseudoungerianus</i>	<i>Cibicides</i> spp.	4.0	Shallow lagoon
<i>Clavulina pacifica</i>	<i>Reophax</i> spp.	6.0	Shallow lagoon
<i>Miliolina rupertiana</i>	Miliolids spp.	17.0	Moderately deep lagoon
<i>Ptychomiliola</i> spp.	Miliolids spp.	17.0	Moderately deep lagoon
<i>Massilina secans</i>	<i>Massilina</i> sp.	17.0	Moderately deep lagoon
<i>Reusella pulchra</i>	(No equivalent)	17.0	Moderately deep lagoon
<i>Discorbis planatus</i>	<i>Planorbulina larvata</i>	17.0	Moderately deep lagoon
<i>Amphistegina lessoni</i>	<i>Operculina</i> spp.	17.0	Moderately deep lagoon
<i>Cellanthus craticulatum</i>	<i>Elphidium</i> spp.	17.0	Moderately deep lagoon
<i>Operculina gaymardi</i>	<i>Operculina</i> spp.	17.0	Moderately deep lagoon
<i>Cibicides lobatulus</i>	<i>Cibicides</i> spp.	17.0	Moderately deep lagoon
<i>Patelinella cf. inconspicua</i>	<i>Planorbulina larvata</i>	18.0	Moderately deep lagoon
<i>Pyrgo</i> spp.	<i>Pyrgo</i> spp./ <i>Schlumbergerina</i>	18.0	Moderately deep lagoon
<i>Reussella</i> spp.	(No equivalent)	18.0	Moderately deep lagoon
<i>Cymbaloporetta tobagoensis</i>	<i>Planorbulina larvata</i>	18.0	Moderately deep lagoon

Table 6.1. Recent foraminifera from the Arabian Gulf and their interpreted Middle Miocene equivalents and bathymetric minimum, used to interpret the palaeoenvironment of the Dam Formation foraminiferal biofacies.

Upper contact	Lower contact	Biofacies	Ranges of interpreted depositional environments	
168.00'	161.00'	Miliolid- <i>Rotalia</i>	Shallow lagoon (hypersaline)	Shallow lagoon (hypersaline)
161.00'	158.30'	<i>Spiroloculina</i>	Shallow lagoon (hypersaline)	Shallow lagoon (hypersaline)
158.30'	155.00'	Miliolid	Shallow lagoon (hypersaline)	Shallow lagoon
155.00'	154.00'	<i>Borelis-Rotalia</i>	Shallow lagoon (hypersaline)	Shallow lagoon (hypersaline)
154.00'	150.00'	<i>Miliolid</i>	Shallow lagoon (hypersaline)	Shallow lagoon
141.50'	137.00'	<i>Borelis-Rotalia</i>	Shallow lagoon (hypersaline)	Shallow lagoon (hypersaline)
137.00'	132.50'	Miliolid- <i>Operculina</i>	Shallow lagoon	Shallow lagoon
132.50'	131.00'	<i>Rotalia</i>	Shallow lagoon (hypersaline)	Shallow lagoon
131.00'	127.00'	<i>Archaias-Elphidium</i>	Shallow lagoon	Shallow lagoon
121.50'	120.50'	<i>Borelis-Rotalia</i>	Shallow lagoon	Shallow lagoon
120.50'	112.50'	Poor Fauna	Shallow lagoon	Shallow lagoon
112.50'	110.00'	<i>Borelis-Rotalia</i>	Shallow lagoon (hypersaline)	Shallow lagoon
110.00'	103.50'	<i>Rotalia</i>	Shallow lagoon	Shallow lagoon
103.50'	102.00'	<i>Borelis-Rotalia</i>	Shallow lagoon (hypersaline)	Shallow lagoon
87.50'	87.00'	<i>Operculina</i>	Moderately deep lagoon	Moderately deep lagoon
74.40'	74.00'	<i>Schlumbergerina-Peneroplis</i>	Moderately deep lagoon	Moderately deep lagoon
65.00'	64.50'	<i>Operculina-schlumbergerina</i>	Moderately deep lagoon	Moderately deep lagoon
48.00'	47.50'	<i>Sorites-Reophax</i>	Shallow lagoon	Moderately deep lagoon
47.50'	41.20'	Gastropod	Moderately deep lagoon	Moderately deep lagoon
32.00'	27.00'	<i>Stromatolite-Miliolid</i>	Restricted very shallow lagoon	Restricted very shallow lagoon
27.00'	25.00'	<i>Peneroplis</i>	Restricted very shallow lagoon	Shallow lagoon
25.00'	22.50'	Poor Fauna	Shallow lagoon (hypersaline)	Shallow lagoon (hypersaline)
22.50'	20.00'	<i>Halimeda</i>	Restricted very shallow lagoon	Restricted very shallow lagoon
20.00'	17.00'	Stromatolite	Restricted very shallow lagoon	Restricted very shallow lagoon
17.00'	16.40'	<i>Halimeda</i>	Restricted very shallow lagoon	Restricted very shallow lagoon
16.40'	14.00'	Miliolid	Restricted very shallow lagoon	Restricted very shallow lagoon
14.00'	14.00'	Miliolid	Restricted very shallow lagoon	Restricted very shallow lagoon

Table 6.2. Depth ranges, biofacies and interpreted depositional environments of samples collected from the Dam Formation at Jabal Midra al Janubi. Sample measurements refer to height above the base of the exposed section.

CONCLUSIONS

This study of the microbiocomponents of the Recent sediments of the Saudi Arabian coastal regime of the Arabian Gulf, and comparison with the Middle Miocene biocomponents of the Dam Formation, as exposed in the Eastern Province of Saudi Arabia, has revealed the following conclusions:

- Rich and variably diverse, exclusively benthonic foraminiferal assemblages are recoverable from the Arabian Gulf, and staining for living forms has revealed the presence of living species.
- The dead assemblages, or thanatocoenosis, are similar to those of the living assemblages, or biocoenosis, and permit use of these biofacies to characterize the environmental parameters recorded at each sample locality.
- Certain recent foraminiferal species display a preference for deeper marine conditions, and discrete biofacies are recognizable for samples collected from different depths
- Salinity and depth are environmental parameters that have an important role in controlling the foraminiferal diversity. There is an inverse relationship between increasing salinity and foraminiferal diversity, but a positive relationship between increasing depth and foraminiferal diversity.
- The Dam Formation has been confirmed as Middle Miocene in age, on the foraminiferal content.

- The Dam Formation carbonates yield rich and variably diverse, exclusively benthonic foraminiferal assemblages
- The Dam Formation contains foraminiferal species of sufficient similarity with the Recent, that palaeoenvironmental interpretation has been made possible
- Using this approach, the Dam Formation at the studied locality is successfully concluded to have commenced deposition following a slight marine transgression over an eroded Palaeogene surface, in the Middle Miocene under highly adverse, hypersaline conditions. Successive small-scale marine transgressions led to foraminiferal colonization and the accumulation of foraminiferal wackestones, packstones and grainstones. These minor fluctuations led to the development of shoaling-upwards cycles, in which the foraminifera and grain sizes responded to increasing energy conditions as well as slight elevations in salinity, as evidenced by concentrations of hypersaline-tolerant miliolids foraminifera.

RECOMMENDATIONS

As this kind of study of the Recent foraminifera of the Arabian Gulf has not been previously performed, the conclusions reached are necessarily based on a rather limited database. In order to refine the conclusions achieved in this work, it is recommended that future studies should:

- Sample as many different environmental locations within the region, extending from the very shallow to the deepest part of the Gulf. This would provide a greater range of palaeoenvironments from which to identify discrete environmentally-limited biofacies.
- Sample numerous exposures of the Dam Formation to increase the potentially diverse palaeoenvironments that may be represented in the rock record.
- Extend the study to include the Palaeogene carbonates that are well-exposed in the Eastern province.
- Extend the study to the Mesozoic carbonates to investigate the possibility that morphotypes are indeed environmentally controlled, regardless of the age unit, and therefore use the Arabian Gulf more effectively as a potential source of foraminiferal analogues for palaeoenvironmental interpretation of their fossil equivalents.

REFERENCES

- Al-Abdul Razzaq, S. K. and S. N. Bhalla, 1987a. *Microfauna from Al-Khiran Area, Southern Kuwait*. *Revue de Paleobiologie*, v. 6, p. 139-142.
- Abou-Ouf, S. A., 1991. *Recent benthic Foraminifera from Tarut Bay, Arabian Gulf coast of Saudi Arabia*. *Micropaleontology*, 10 (1), p. 33-38.
- Abou-Ouf, S. A., 1992. *Foraminiferal distribution in recent sediments of Jizan Shelf, Red Sea, Saudi Arabia*. *J.K.A.U.: Mar. Sci*, v. 3. p. 25-38.
- Abou-Ouf, S. A. and A. El-Shater, 1991. *The relationship between the environmental conditions of the Jeddah Coast, Red Sea, and Benthic Foraminifera*. *J.K.A.U.: Mar. Sci*, v. 2. p. 49-64.
- Abou-Ouf, S. A. and A. El-Shater, 1993. *Black benthic Foraminifera in carbonate facies of a coastal sabkha, Saudi Arabian Red Sea Coast*. *J.K.A.U.: Mar. Sci*, v. 4. p. 133-141.
- Abu-Zied, M. and H. Khalifa, 1983. *Sedimentological and paleoenvironmental aspects of the Miocene succession in Jebel Nakhash, Qatar, Arabian Gulf*. *Neues Jahrbuch fur Geologie und Palaontologie Monatshefte*, v. 7, p. 334-399.
- Adams, C.G., 1970. *A reconsideration of the East Indian Letter Classification of the Tertiary*. *Bulletin of the British Museum (Natural History)*, v.18, no.1, 137p.
- Al-Hinai, K.G., A. E. Dabbagh, W. C. Gardner, M. A. Khan and S. Saner, 1997. *Shuttle Imaging Radar Views of Some Geological Features in the Arabian Peninsula*. *GeoArabia*, v. 2, no. 2.

- Al-Saad, H. and M. I. Ibrahim, 2002. *Stratigraphy, Micropaleontology, and Paleoecology of the Qatar Miocene Dam Formation, Qatar*. *GeoArabia*, v. 7, no. 1.
- Al-Sayari S. and J. Zotel, 1978. *Quaternary period in Saudi Arabia*. New York, Springer-Verlag/Wien.
- Al-Zamel, A. D. and O. H. Cherif, 1998. *Subtidal Foraminiferal assemblages of the western part of the Shatt Al-Arab Delta, Kuwait, Arabian Gulf*. *Journal of Foraminiferal Research*. V. 28 no. 4. p. 327-244.
- Barker, R. W., 1960. *Taxonomic Notes*. Society of Economic Paleontologists and Mineralogists, Special Publication no. 9. Tulsa, Oklahoma, USA.
- Basson P. W, J. E. Burchard, J. T. Hardy, A. R. G. Price, 1977. *Biotopes of The Western Arabian Gulf*. *Arabian American Oil Company, Dhahran*. Saudi Arabia p 284.
- Basson P. W. and J. Murray, 1995. *Temporal variations in four species of intertidal Foraminifera, Bahrain, Arabian Gulf*. *Micropaleontology*, v.41, no. 1, p. 69-76.
- Bathurst R.G.C., 1986. *Carbonates Sediments and Their Diagenesis*. *Developments in Sedimentology* 12, 2nd enlarged edition, Elsevier Scientific Publishing Company, Amsterdam-Oxford-New York, p. 178-181.
- Bolotovskoy, E. and R. Wright 1976. *Recent Foraminifera*. The Hague.
- Coles, S. and J. McCain. 1990. *Environmental factors affecting benthic infauna communities of the western Arabian Gulf*. *Mar. Env. Sci.* 29:289-215.

- Cushman, J.A., 1948. *Foraminifera, their classification and economic use*. Harvard University Press, 605p.
- Douglas, R.G., 1979. *Benthic foraminiferal ecology and paleoecology: a review of concepts and methods*. In Lipps, J.H. et al., *Foraminiferal ecology and paleoecology*. Society of Economic Paleontologists and Mineralogists, Short Course No.6, Houston, p.21-53.
- Dunham, R.J., 1962. *Classification of Carbonate Rocks According to Depositional Texture*. In Ham (Ed.) *Classification of Carbonate Rocks. Memoir 1*, American Association of Petroleum Geologists. p. 108-121.
- Evans, G., J. W. Murray, H. E. Biggs, R. Bate and R. P. Bush, 1973. *The Oceanography, Ecology, Sedimentology and Geomorphology of parts of the Trucial Coast Barrier Island Complex, Persian Gulf*. In B. H. Purser (Ed.), *The Persian Gulf*, Springer-Verlag, New York p. 233-277.
- Evans, G., V. Schmidt, P. Bush, and H. Nelson, 1969. *Stratigraphy and Geologic History of the Sabkha, Abu Dhabi, Persian Gulf*. *Sedimentology*, v. 12, p. 145-149.
- Friedman, G. M., 1959. *Identification of carbonate minerals by staining methods*. *Journal of Sedimentary Research*, v. 29, no. 1, p. 87-89.
- Friedman, G. M. and W. E. Krumbien. *Hypersaline ecosystems- The Gavish Sabkha*. Springer-Verlage, Berlin, Heidelberg, New York, Tokyo, p. 72-102.
- Haynes, J. R., 1981. *Foraminifera*. New York, John Wiley and Sons.
- Hewaidy, A., 1991. *Contribution to the stratigraphy of Miocene sediments in Qatar*. Middle East Research Center, Ain Shams University, Egypt, Earth Science Series, v. 5, p. 160-170.

- Houbolt, J.J.H.C., 1957. *Surface Sediments of the Persian Gulf Near the Qatar Peninsula*.
The Hague, Netherlands, Mouton and Co., 113 pp.
- Hughes Clarke, M. W. and A. J. Keij, 1973. *Organisms as producers of Carbonate Sediment and indicators of environment in the Southern Persian Gulf*. In B. H. Purser (Ed.),
The Persian Gulf. Springer-Verlage, p.115-122.
- Hughes, G.W., 1997. *The Great Pearl Bank Barrier of the Arabian Gulf as a possible Shu'aiba analogue*. *GeoArabia*, v. 2, no. 3.
- Hughes, G.W., 2000. *Bioecostratigraphy of the Shu'aiba Formation, Shaybah Field, Saudi Arabia*. *GeoArabia*, v.5, no.4, p.545-578.
- Hughes, G.W, 2002. *The Geology of the Dammam Dome, Field trip Guide*, Geological R&D Division, Aramco.
- Hussain, M., Al-Khalifah, F., and Khandaker, N.I., 2006, *The Jabal Al Qarah caves of the Hofuf area, northeastern Saudi Arabia: A geologic investigation*. *Journal of Cave and Karst Studies*, v.68, p. 12-21.
- Irtem, O., 1986. *Miocene Tidal Flat Stromatolites of the Dam Formation, Saudi Arabia*.
Arabian Journal of Science and Engineering, v. 12, no. 2, p.145-153.
- Jenking, D. G. and J. W. Murray, 1981. *Stratigraphical atlas of fossil Foraminifera*. England,
Ellis Horwood limited.
- Kassler, P., 1973. *The Structural and Geomorphic Evolution of the Persian Gulf*. In B. H. Purser (Ed.), The Persian Gulf. Springer-Verlage, p.11-32.

- Khalifa, H. and M. Mahmoud, 1993. *New occurrence of algal stromatolites and benthic Foraminifera from the Miocene of Al-Nikhsh area, southwest Qatar Peninsula: Implication on their palaeoenvironmental meaning*. Arabian Gulf Journal of Science research, v. 11, no. 3, p. 325-338.
- Laporte, L. and C. Newton, 1989. *Ancient environments*. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.
- Lipps, J.H., W. H. Berger, M. A. Buzas, R. G. Douglas and C. A. Ross, 1979. *Foraminiferal ecology and paleoecology*. Society of Economic Paleontologists and Mineralogists, Short Course No.6, Houston, 198p.
- Loeblich, A. R., Jr. and H. Tappan, 1964. *Treatise on invertebrate paleontology*. Kansas, USA, the University of Kansas Press.
- Loeblich, A. R., Jr. and H. Tappan, 1998. *Foraminiferal genera and their classification*. Van Norstrand Reinhold, New York.
- Murray J. W., 1965a. *The Foraminiferida of the Persian Gulf 1. The Abu Dhabi Region*. Palaeogeography, Palaeoclimatology, Palaeoecology v.1, p. 307-332.
- Murray J. W., 1965b. *The Foraminiferida of the Persian Gulf 2. The Abu Dhabi Region*. Palaeogeography, Palaeoclimatology, Palaeoecology v.1, p. 307-332.
- Murray J. W., 1966a. *The Foraminiferida of the Persian Gulf 3. The Halat al-Bahrain Region*. Palaeogeography, Palaeoclimatology, Palaeoecology v. 2, p. 59-68.
- Murray J. W., 1966b. *The Foraminiferida of the Persian Gulf 4. Khor Al-Bazam*. Palaeogeography, Palaeoclimatology, Palaeoecology v. 2, p.153-69.

- Murray J. W., 1966c. *The Foraminiferida of the Persian Gulf 5. The Shelf of the Trucial coast*. Palaeogeography, Palaeoclimatology, Palaeoecology v. 2, p. 267-78.
- Murray J. W., 1970a. *The Foraminiferida of the Persian Gulf 6. Living Forams in Abu Dhabi region*. Palaeogeography, Palaeoclimatology, Palaeoecology v. 2, p. 59-68.
- Murray J. W., 1970b. *The Foraminiferida of the hypersaline Abu Dhabi lagoon, Persian Gulf*. Lethaia v. 3, p. 51-68.
- Murray J. W., 1971. *An atlas of British Recent Foraminiferids*. New York, American Elsevier Publishing Company, Inc.
- Murray, J.W., 1991. *Ecology and Palaeoecology of Benthic Foraminifera*. Longman Scientific & Technical, Bath Press, Avon, U.K. , 397p.
- Natland, M.L., 1933. *The temperature and depth distribution of some Recent and fossil foraminifera in the southern California region*. Scripps Inst. Oceanogr. Tech. Ser., v. 3, p. 225-230.
- Powers, R. W., L. F. Ramirez, C. D. Redmond and E. L. Elberg Jr., 1966. *Geology of the Arabian Peninsula, Sedimentary Geology of Saudi Arabia*. United States Geological Survey Professional Paper 560-D, 147 p.
- Purser, B.H., and E. Seibold, 1973. *The Principal Environmental Factors Influencing Holocene Sedimentation and Diagenesis in the Persian Gulf*. In B. H. Purser (Ed.), *The Persian Gulf*. Springer-Verlag, p.1-9.
- Purser, M., 1973. *The Persian Gulf, Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea*. Springer-Verlage, New York, 471 p.

- Robbins, L., 1983. *Catalog of Near Shore Benthic Foraminifera of the Arabian Gulf: Manifa to Bandar Al-Mishab*. Rosenstiel School of Marine and Atmospheric Science, University of Miami, USA.
- Robertson, B. F., 1998. *Systematics and paleoecology of the benthic Foraminiferida from the Buff Bay section, Miocene of Jamaica*. *Micropaleontology*, v. 44, suppl. 2, p. 1-266.
- Sharland, P. R., R. Archer, D. M. Casey, R. B. Davies, S. H. Hall, A. P. Heward, A. D. Horbury and M. D. Simmons, 2001. *Arabian Plate sequence stratigraphy*. *GeoArabia* Special Publication 2, Gulf PetroLink, Bahrain, 371 p., with 3 charts.
- Sharland, P. R., D. M. Casey, R. B. Davies, O. E. Sutcliffe and M. D. Simmons, 2004. *Arabian Plate sequence stratigraphy-revision to SP2*. *GeoArabia*, v.9 no. 1, Gulf PetroLink, Bahrain, with tow charts.
- Stienke, M., t. f. Harris, K. R. Parsons and E. L. Berg, 1958. *Geologic Map of the Western Arabian Gulf Quadrangel, Kingdom of Saudi Arabia*. United States Geological Survey, Miscellaneous Geological Investigations. Map 1-208 A, Scale 1:500,000. Reprinted in 1977 as GM-108 B.
- Stienke, M. and T. W. Koch, 1935. *Geological Reconnaissance of the Coastal Plain of Hasa Province, Northeastern Saudi Arabia*. Arabian Oil Company, Dhahran, Saudi Arabia (unpublished).
- Stoffers, P. and D. A. Ross, 1978. *Late Pleistocene and Holocene sedimentation in the Persian Gulf-Gulf of Oman*. *Sedimentary Geology*, p. 181-208.

- Stocklin, J., 1974. *Possible Ancient Continental Margins in Iran*. In C.A. Burk and C.L. Drake (Eds.), *The Geology of the Continental Margins*. Springer-Verlage, New York, p.873-887.
- Stoneley, R., 1974. *Evolution of the Continental Margins Bounding a Former Southern Tethys*. In C.A. Burk and C.L. Drake (Eds.), *The Geology of the Continental Margins*. Springer-Verlage, New York, p. 889-903.
- Sutcliffe, O. E., C. Liu and G. J. Grabowsky Jr., 2004. *Cenozoic Sequence Stratigraphy, Arabian Platform and Gulf*. 273-Poster, GEO 2004, *GeoArabia*, v.9 no. 1, Gulf PetroLink, Bahrain.
- Thralls, H. w. and R. C. Hasson, 1956. *Geology and oil resources of eastern Saudi Arabia*. 20th International Geology Congress, Mexico and Symposium sobre Yacimientos de Petroleum and Gas, v. 2, p. 9-32.
- Tleel, J. W., 1972. *Surface geology of Dammam Dome, Eastern Province, Saudi Arabia*. Master of Science from Texas Christian University.
- Tleel, J. W., 1973. *Surface geology of Dammam Dome, Eastern Province, Saudi Arabia*. Bulletin of American Association of Petroleum Geologists, v.57, no. 3, p. 558-576.
- Tucker, M. E., 1981. *Sedimentary Petrology, an introduction*. New York.
- Wagner, C. W. and C. Van Der Togt, 1973. *Holocene Sediment Types and Their Distribution in the Southern Arabian Gulf*. In B. H. Purser (Ed.), *The Persian Gulf*. Springer-Verlag, New York, p. 123-156.
- Weijermars, R., 1999. *Surface geology, lithostratigraphy and Tertiary growth of the Dammam Dome, Saudi Arabia: A new field guide*. *GeoArabia*, v. 4, no. 2, p. 199-226.

- Whybrow, P.J., H. A. McClure and G. F. Elliot, 1987. *Miocene stratigraphy, geology and flora (algae) of Eastern Saudi Arabia and the Ad Dabtiyah locality*. Bulletin of the British Museum (Natural History), v. 41, p. 371-382.
- Wilson, J.L. and C. Jordan, 1983. *Middle Shelf Environment*. In P.A. Scholle et al. (Eds.), Carbonate Depositional Environments. American Association of Petroleum Geologists, Memoir 33, p. 297-343.
- Ziegler, M. A., 2001. *Late Permian to Holocene Paleofacies Evolution of the Arabian Plate and its Hydrocarbon Occurrences*. GeoArabia. V. 6, p. 445-504.

PLATES

PLATE 4.1

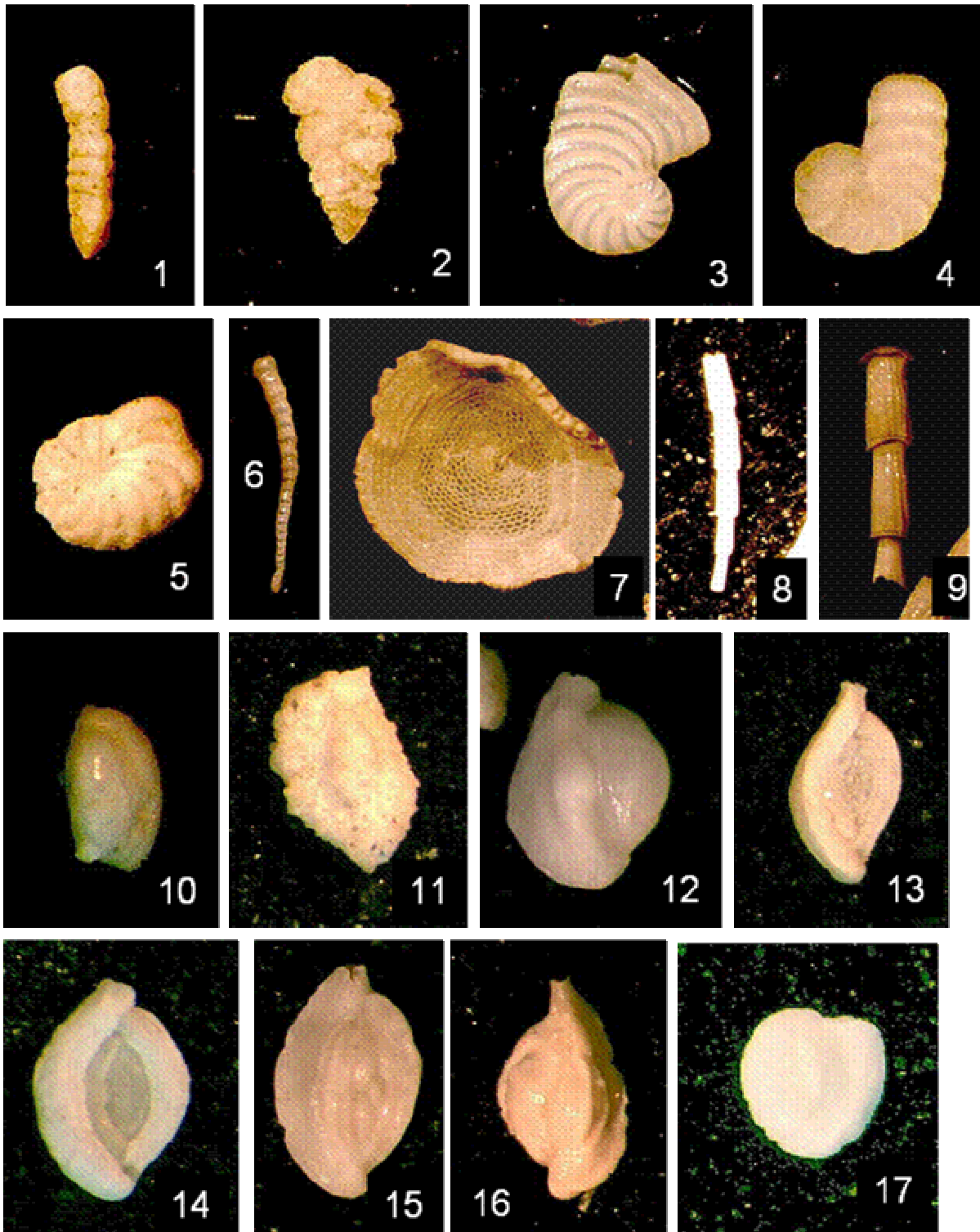


Plate 4.1

The scale is longest dimension of the specimen in millimeters (mm)

1. *Clavulina pacifica* (Azizyah desalination plant) (1.5mm).
2. *Textularia* spp (WQ-18) (1mm).
3. *Peneroplis planatus* (1.5mm) (WQ-18).
4. *Peneroplis pertusus* (Abu Ali Is) (2mm).
5. *Spirolina arietina* (WQ-18) (2mm).
6. *Dendritina elegans* (WQ-18) (3.5mm).
7. *Sorites marginalis* (DC-5) (3.0mm).
8. *Articulina queenslandica* (WQ-18) (2.5mm).
9. *Articulina pacifica* (WQ-18) (2mm).
10. *Quinqueloculina* spp. (Abu Ali Is.) (1mm).
11. *Quinqueloculina agglutinans*. (Abu Ali Is.) (1mm).
12. *Triloculina* spp (WQ-18) (1mm).
13. *Spiroloculina grata* (WQ-18) (1mm).
14. *Spiroloculina* spp. (WQ-18) (1.25mm).
15. *Miliolina* spp. (WQ-18) (1.25 mm).
16. *Ptychomiliolina* spp. (WQ-18) (1mm).
17. *Massilina* sp. (Abu Ali Is.) (1mm).

PLATE 4.2

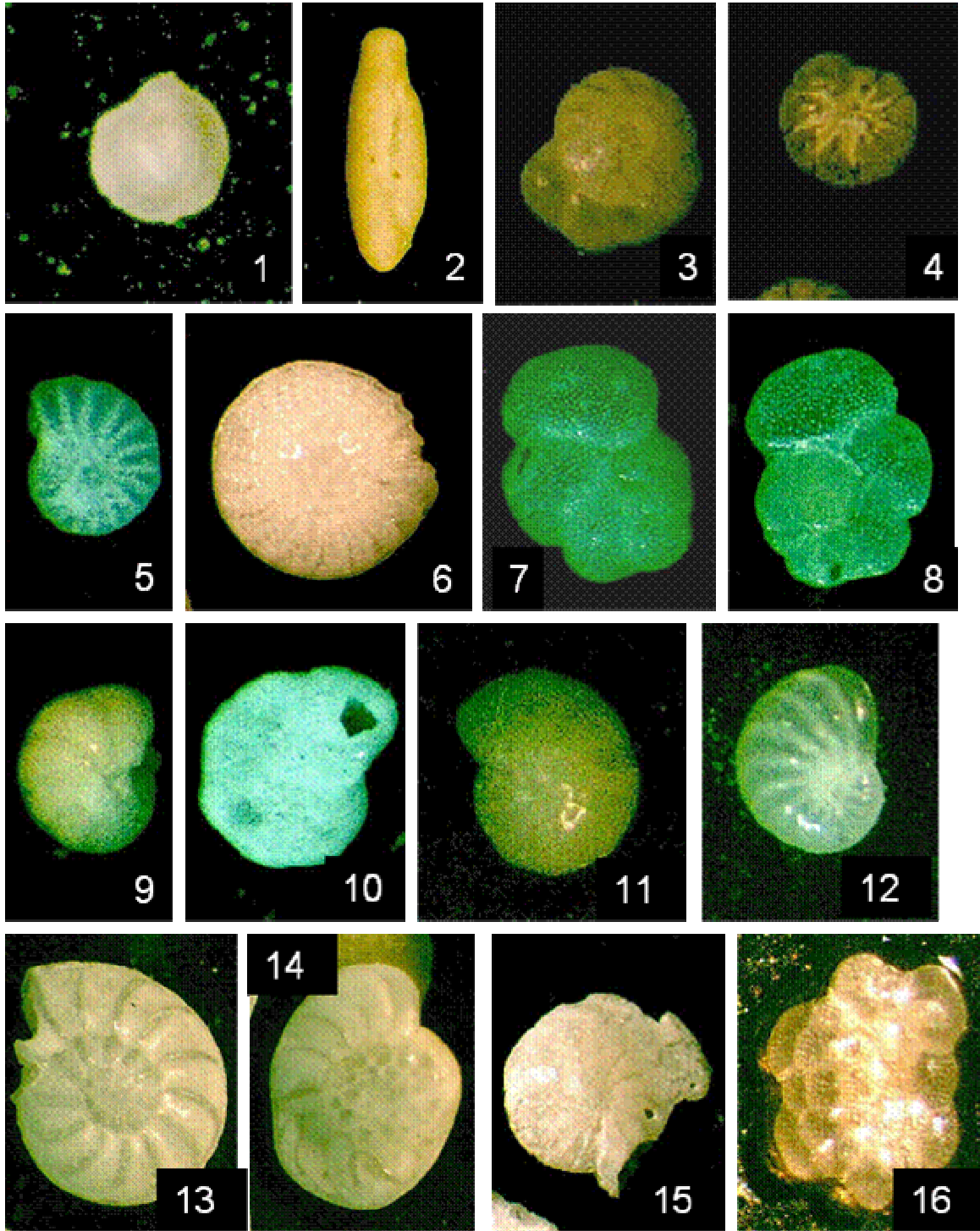


Plate 4.2

The scale is longest dimension of the specimen in millimeters (mm)

1. *Massilina secans* (WQ-18) (1mm).
2. *Miliolina rupertiana* (WQ-18) (2mm).
3. *Ammonia beccari* (0.5mm) (Abu Ali Is.).
4. *Ammonia beccari* (evolute) (0.5mm) (Abu Ali Is.).
5. *Elphidium* spp. (Abu Ali Is.) (0.35mm).
6. *Elphidium craticulatum* (WQ-18) (1.25mm).
7. *Cibicides lobatulus* (WQ-18) (1.0mm).
8. *Cibicides lobatulus* (evolute) (WQ-18) (1.0mm).
9. *Cibicides* spp. (Berri) (0.35mm).
10. *Cibicides* spp. (Berri) (0.35mm).
11. *Cibicides* sp. cf. *pseudoungerianus* (WQ-18) (0.35mm).
12. *Nonion depressulus* (Berri) (0.5mm).
13. *Operculina gaimardi* (2.0mm) (WQ-18).
14. *Operculina gaimardi* (stressed) (2.0mm) (WQ-18).
15. *Amphistegina lessoni* (WQ-18) (2.5 mm).
16. *Planorbulinella mediterranea* (WQ-18) (0.3 mm).

PLATE 4.3

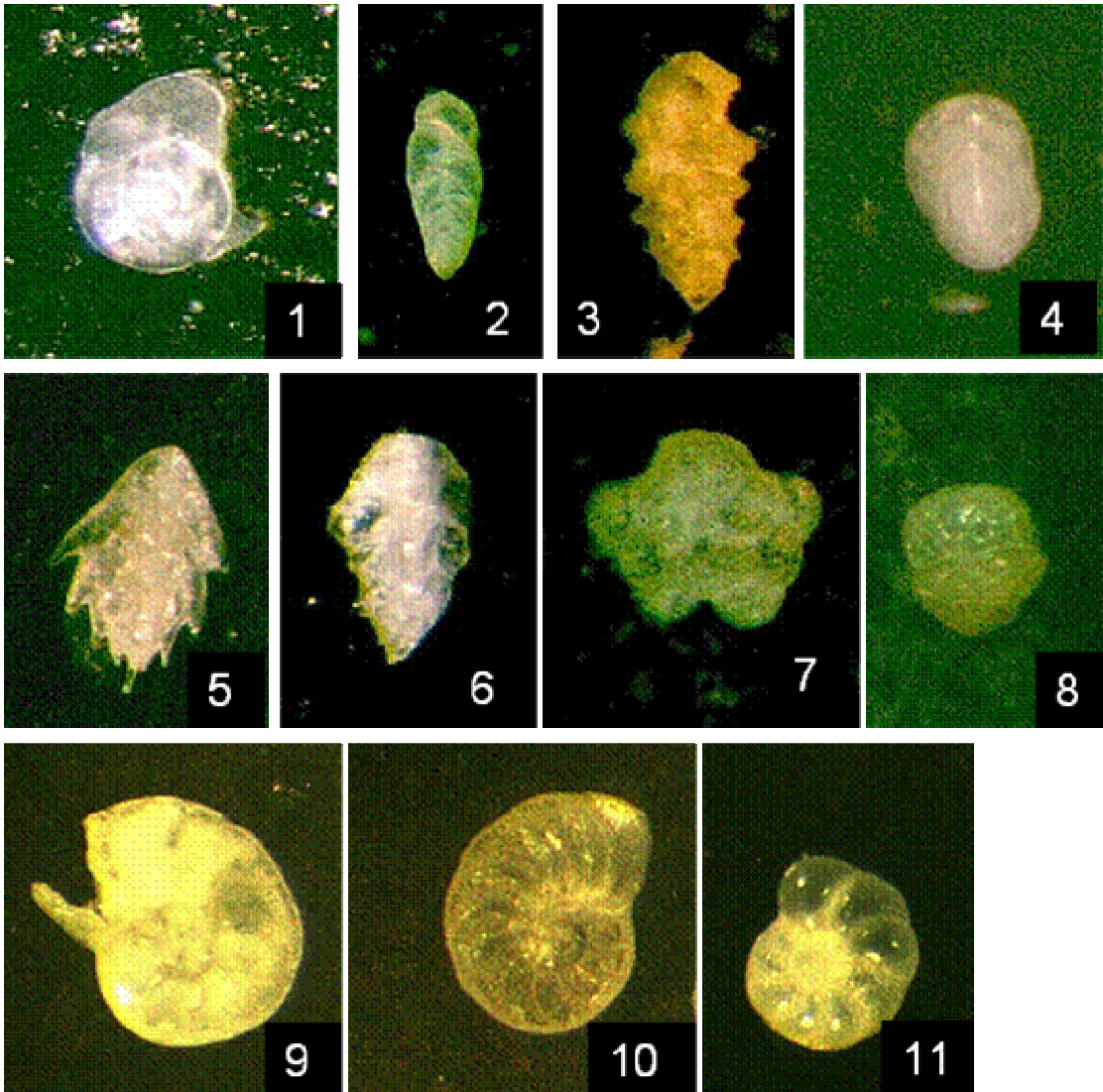


Plate 4.3

The scale is longest dimension of the specimen in millimeters (mm)

1. *Discorbis plana* (WQ-18) (0.5 mm).
2. *Bolivina spathulata* (WQ-18) (0.4mm).
3. *Bolivina simpsoni* (0.35mm) (WQ-18).
4. *Patellinella* cf. *inconspicua* 0.3mm (WQ-18) (0.3mm).
5. *Reusella aculeata* (WQ-18) (0.4mm).
6. *Reusella pulchra* (WQ-18) (0.4mm).
7. *Cymbalopora tobagoensis* (Berri) (0.4mm).
8. *Tretomphalus bulloides* (Berri) (0.2mm).
9. *Rotalia* spp. (WQ-18) (0.45mm).
10. *Rotalia* spp. (WQ-18) (0.4mm).
11. *Rotalia* spp. (WQ-18) (0.35mm).

PLATE 5.1

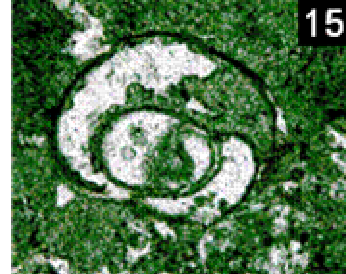
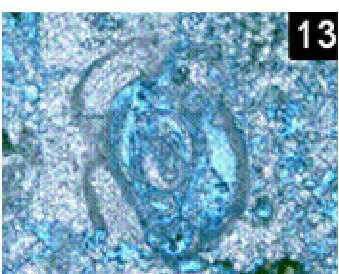
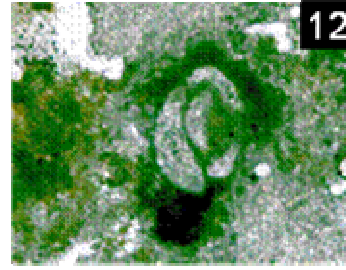
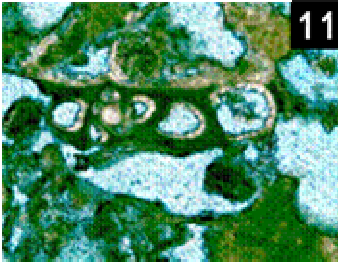
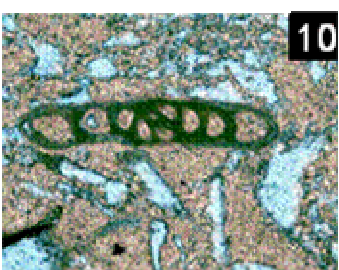
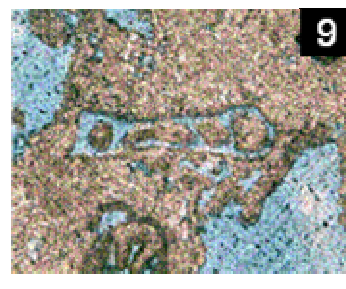
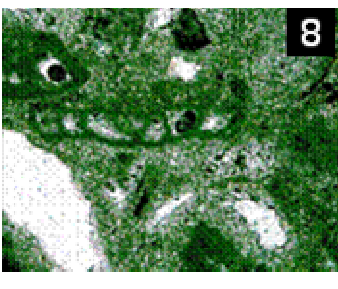
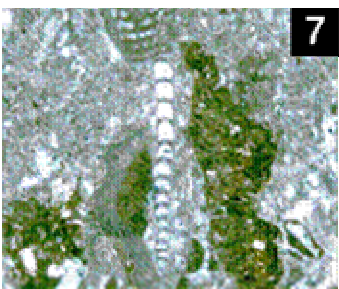
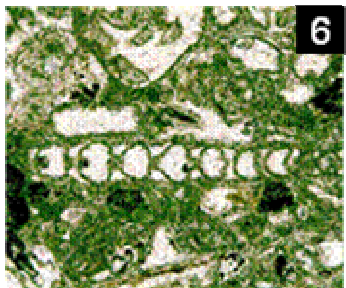
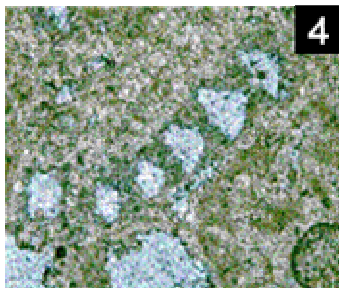
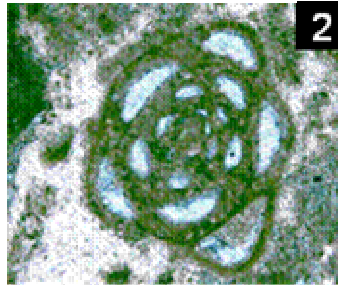


Plate 5.1

Dimension in mm is the maximum width of images

1. *Textularia* sp. (JMJ-34LH) (1mm).
2. *Schlumbergerina* sp. (JMJ-15.2) (1mm).
3. cf. *Reophax* sp. (JMJ-40V) (1mm).
4. *Reophax* sp. (JMJ-17V) (1mm).
5. *Reophax* sp. stressed (JMJ-51V) (2mm).
6. cf. *Reophax* sp. (agglutinated uniserial form) (JMJ-7) (1mm).
7. cf. *Reophax* sp. (uniserial agglutinated, multiple apertures) (JMJ-15.2) (2mm).
8. *Spiroloculina* sp.1 (JMJ-0) (1mm).
9. *Spiroloculina* sp.3 (JMJ-34UV) (1mm).
10. *Spiroloculina* sp.4 (JMJ-35V) (1mm).
11. *Spiroloculina* sp.2 (JMJ-14H) (1mm).
12. Miliolid sp. (JMJ-D3) (1mm).
13. Miliolid sp. in wackstone (JMJ-26H) (2mm).
14. *Triloculina* sp.5 (JMJ-1V) (2mm).
15. *Triloculina* sp.4 (JMJ-D3.2) (1mm).

PLATE 5.2

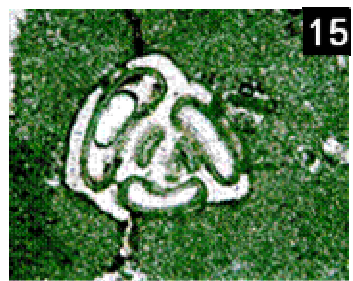
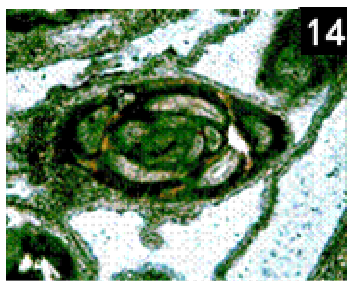
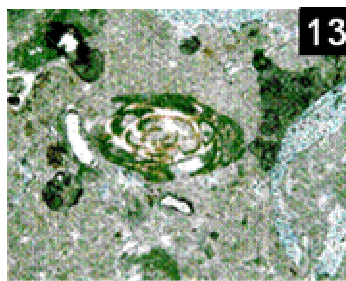
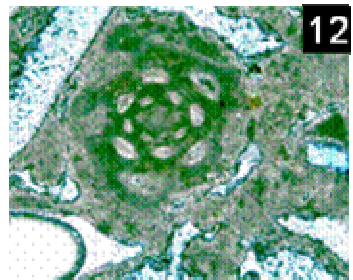
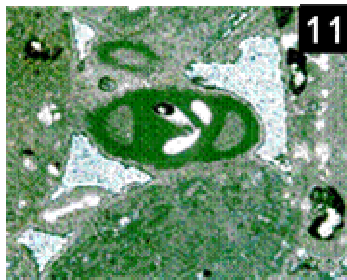
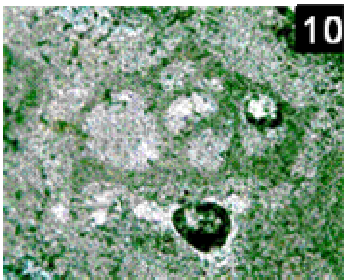
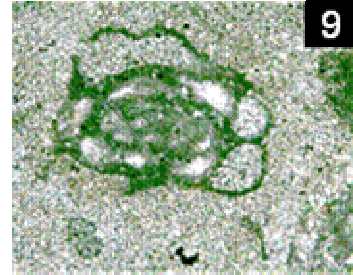
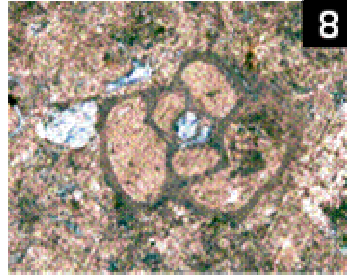
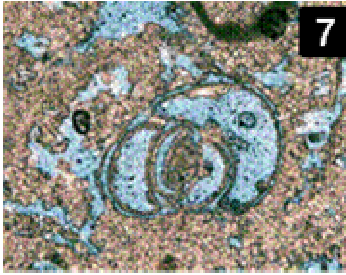
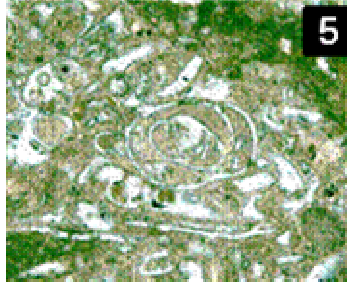
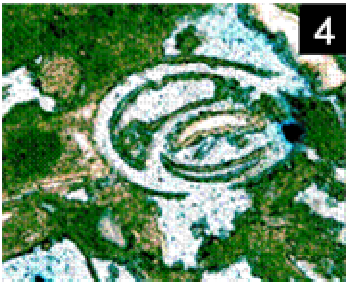
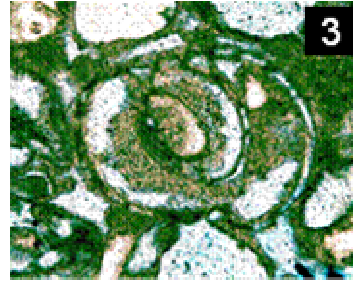
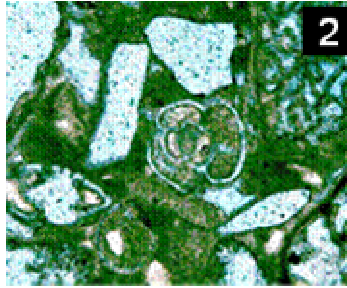


Plate 5.2

Dimension in mm is the maximum width of images

1. *Triloculina* sp.2 (JMJ-D7B) (1mm).
2. *Triloculina* sp.2 (JMJ-14V) (1mm).
3. *Triloculina* sp.4 (JMJ-14V) (1mm).
4. *Triloculina* sp.1 (JMJ-14V) (1mm).
5. *Triloculina* sp. (JMJ-15V) (1mm).
6. *Triloculina* sp.2 (JMJ-16V) (1mm).
7. *Triloculina* sp.6 (JMJ-34LV) (1mm).
8. *Triloculina* sp.8 (JMJ-42H) (1mm).
9. *Quinqueloculina* sp.2, ribbed (JMJ-0) (1mm).
10. *Quinqueloculina* sp.4, ribbed (JMJ-1) (1mm).
11. *Quinqueloculina* sp.3 (JMJ-1) (2mm).
12. *Quinqueloculina* sp.1 (JMJ-1) (1mm).
13. *Quinqueloculina* sp.3 (JMJ-1) (2mm).
14. *Quinqueloculina* sp.5 (JMJ-1) (1mm).
15. *Quinqueloculina* sp.6 (JMJ-D3.2) (1mm).

PLATE 5.3

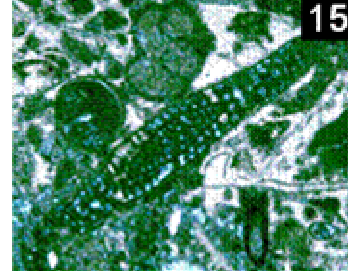
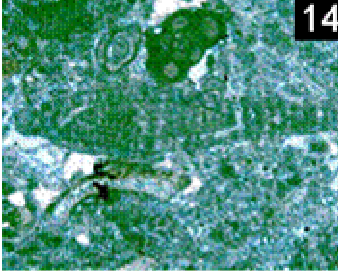
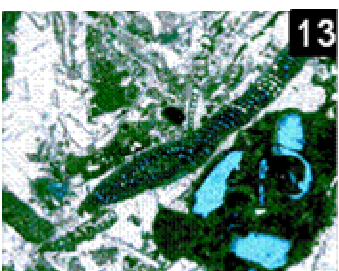
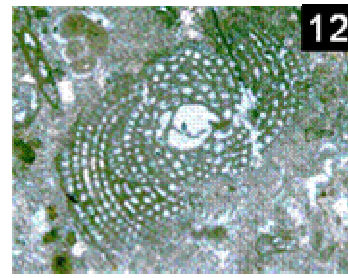
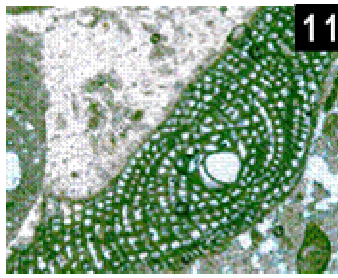
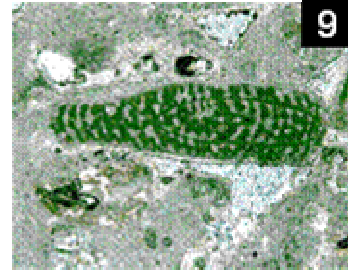
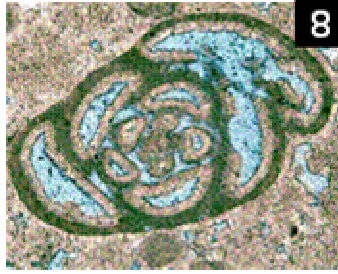
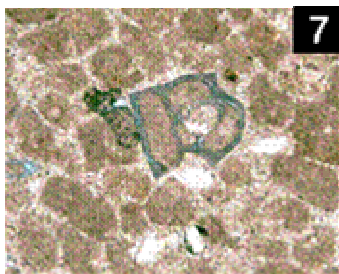
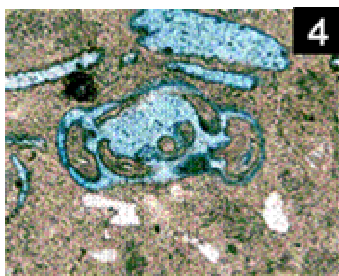
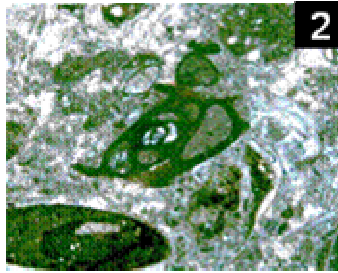
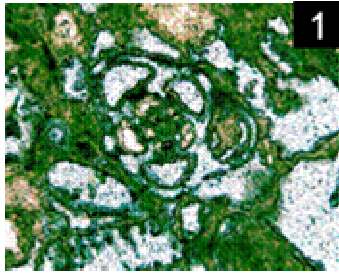


Plate 5.3

Dimension in mm is the maximum width of images

1. *Quinqueloculina* sp.6 (JMJ-14V) (1mm).
2. *Quinqueloculina* sp.12, costate (JMJ-15) (2mm).
3. *Quinqueloculina* sp.3 in mudstone (JMJ-19H) (1mm).
4. *Quinqueloculina* sp.8 (JMJ-35V) (1mm).
5. *Quinqueloculina* sp.15 (JMJ-35V) (1mm).
6. *Quinqueloculina* sp.7 (JMJ-36) (1mm).
7. *Quinqueloculina* sp.13 (JMJ-36) (1mm).
8. *Quinqueloculina* sp.16 (JMJ-48H) (1mm).
9. *Archaias hensoni* (JMJ-1V) (2mm).
10. *Archaias hensoni* (JMJ-15.1) (2mm).
11. *Archaias hensoni* (JMJ-15.1) (2mm).
12. *Archaias hensoni* (JMJ-15.2) (2mm).
13. *Archaias hensoni* (JMJ-15.1) (4mm).
14. *Archaias hensoni* (JMJ-15.1) (2mm).
15. *Archaias hensoni* (JMJ-15.1) (2mm).

PLATE 5.4

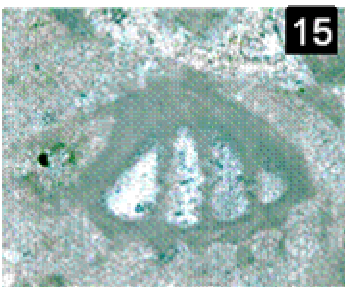
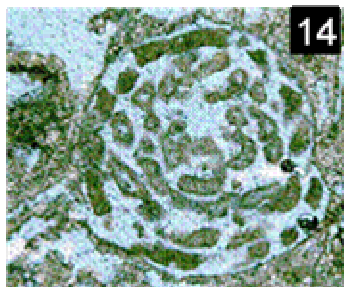
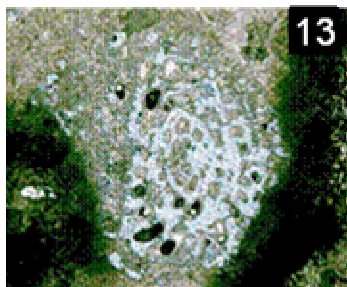
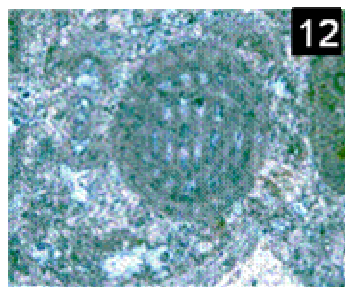
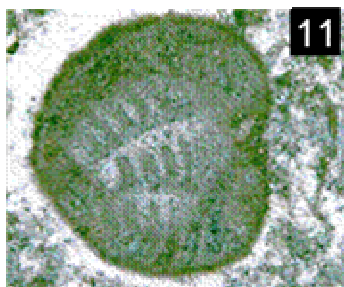
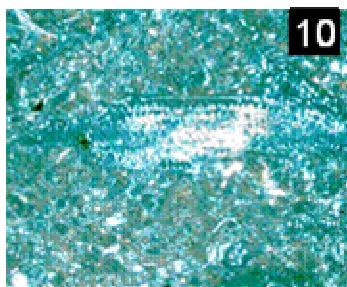
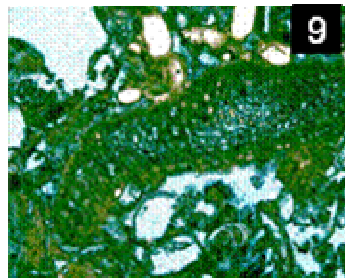
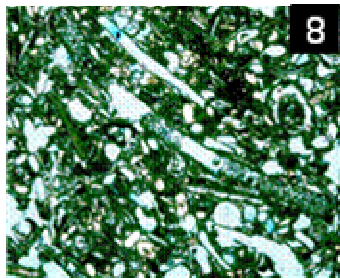
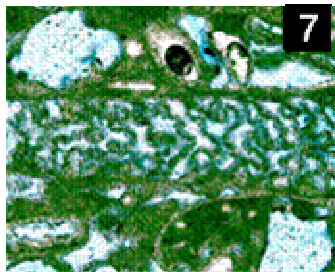
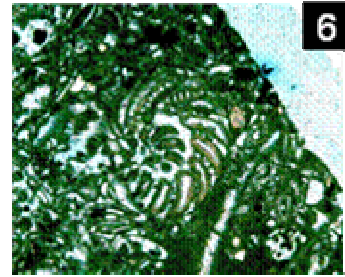
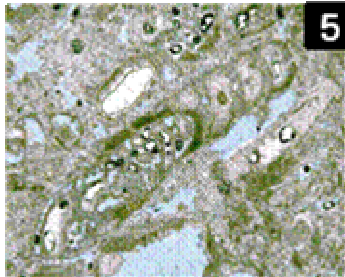
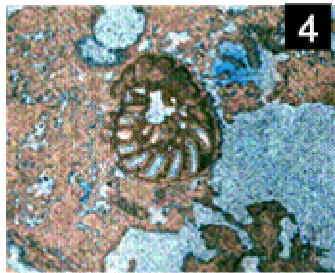
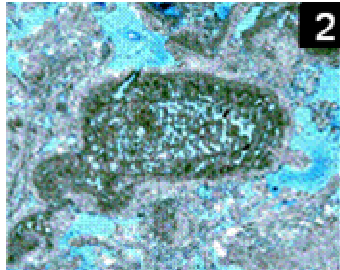
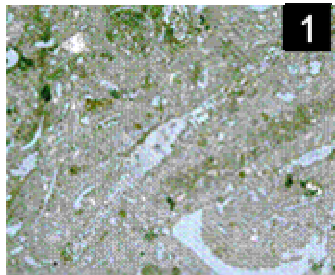


Plate 5.4

Dimension in mm is the maximum width of images

1. *Archaias hensoni* mould (JMJ-16V) (1mm).
2. *Archaias hensoni* in packstone (JMJ-29H) (2mm).
3. cf. peneroplid sp. (JMJ-35H) (1mm).
4. cf. peneroplid or rotalid (JMJ-35H) (1mm).
5. *Peneroplis pertusus* (JMJ-17V) (2mm).
6. *Peneroplis* sp. cf. *pertusus* (JMJ-15V) (2mm).
7. *Sorites* sp. (JMJ-14V) (1mm).
8. *Sorites* sp. (JMJ-14V) (2mm).
9. *Sorites* sp. (JMJ-14H) (1mm).
10. *Alveolinella* sp. (JMJ-15H) (4mm).
11. *Borelis melo melo* (JMJ-15.1) (1mm).
12. *Borelis melo melo* (JMJ-15.1) (1mm).
13. *Borelis melo melo* mould (JMJ-18V) (2mm).
14. *Borelis melo melo* mould (JMJ-16V) (1mm).
15. *Ammonia* sp. (JMJ-1) (1mm).

PLATE 5.5

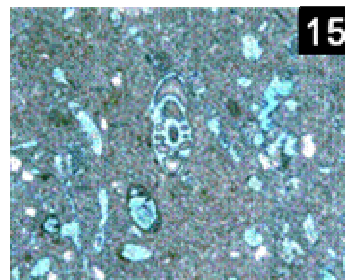
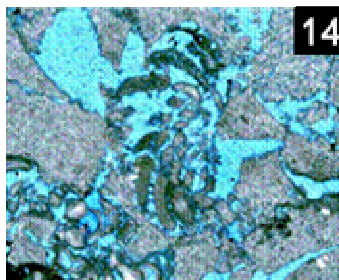
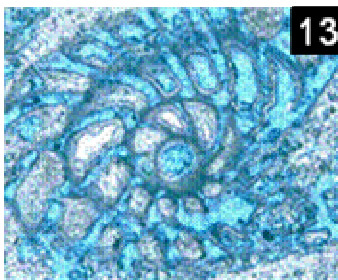
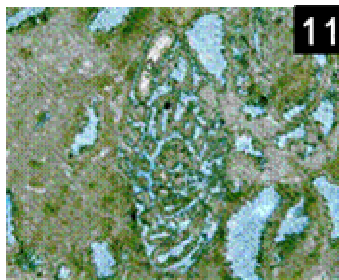
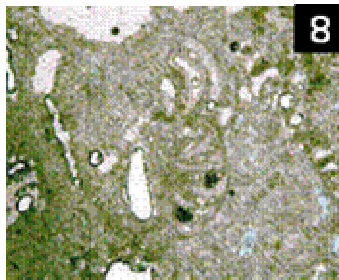
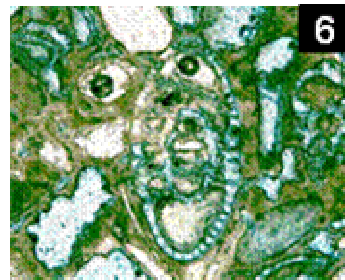
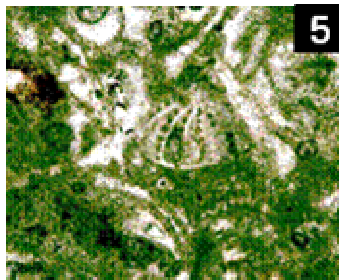
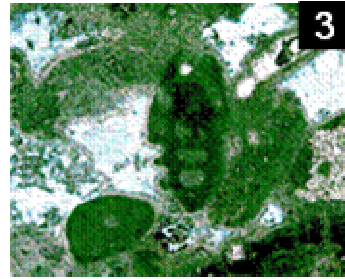
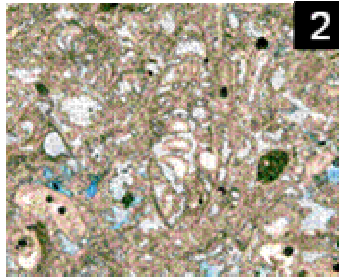
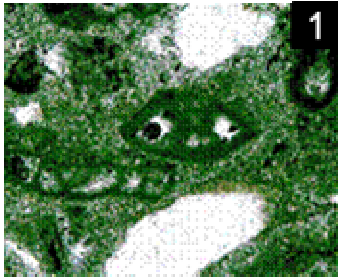


Plate 5.5

Dimension in mm is the maximum width of images

1. *Rotalia* sp. (JMJ-0) (1mm).
2. *Elphidium* sp. (JMJ-51H) (2mm).
3. cf. *Elphidium* sp. (JMJ-1V) (2mm).
4. cf. *Elphidium* sp. (JMJ-D6) (1mm).
5. *Elphidium* sp. (JMJ-7) (1mm).
6. *Elphidium* sp. (JMJ-14) (1mm).
7. *Elphidium* sp. (JMJ-15V) (1mm).
8. cf. *Elphidium* sp. (JMJ-17H) (2mm).
9. *Elphidium* sp. (JMJ-17V) (1mm).
10. *Elphidium* sp. (JMJ-22V) (1mm).
11. *Elphidium* sp. (JMJ-23H) (2mm).
12. *Elphidium* sp. (JMJ-23V) (2mm).
13. *Elphidium* sp. mould in wackstone (JMJ-26H) (2mm).
14. *Elphidium* sp. in wackstone (JMJ-26H) (2mm).
15. *Elphidium* sp. mould (JMJ-27V) (2mm).

PLATE 5.6

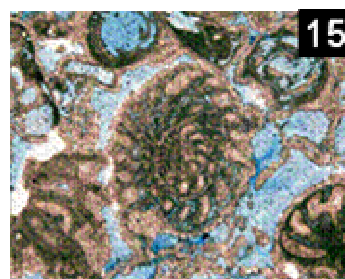
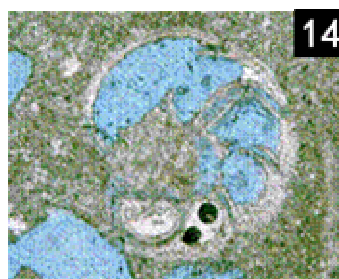
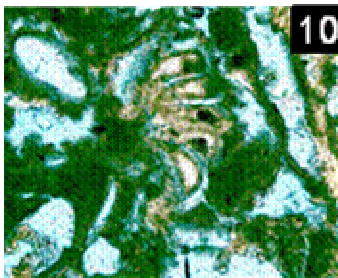
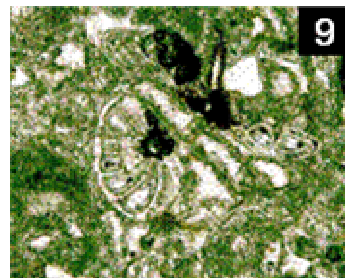
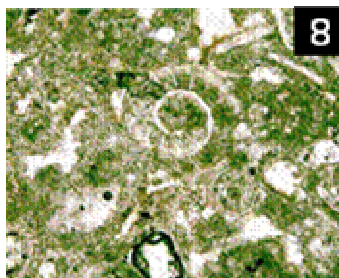
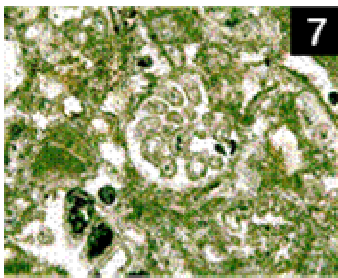
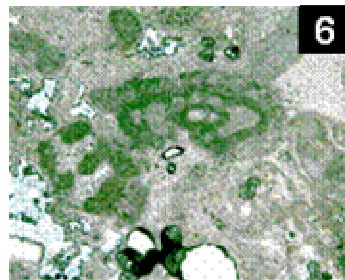
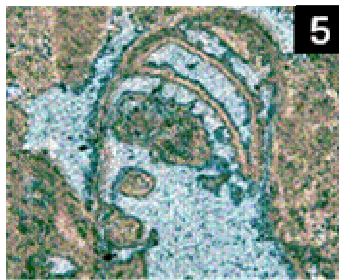
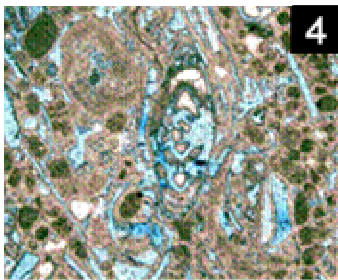
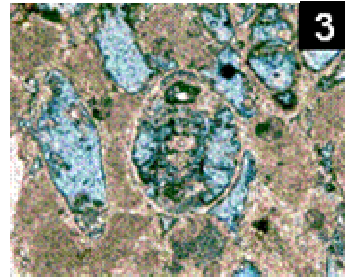
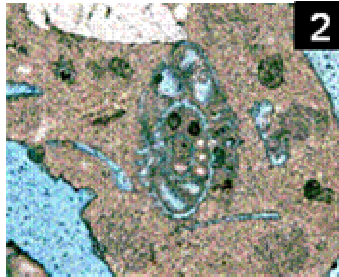


Plate 5.6

Dimension in mm is the maximum width of images

1. *Elphidium* sp. (JMJ-31) (1mm).
2. *Elphidium* sp. (JMJ-35H) (1mm).
3. *Elphidium* sp. (JMJ-36) (1mm).
4. *Elphidium* sp. (JMJ-38V) (1mm).
5. *Elphidium* sp. (JMJ-44H) (1mm).
6. rotalid sp. (JMJ-1) (1mm).
7. rotalid sp. (JMJ-7) (1mm).
8. rotalid sp. (JMJ-7) (1mm).
9. Two rotalids (JMJ-7) (1mm).
10. rotalid sp. (JMJ-14H) (1mm).
11. Pelloidal packstone with rotalid (JMJ-30H) (1mm).
12. rotalid sp. (JMJ-35H) (1mm).
13. rotalid sp. (JMJ-35V) (1mm).
14. rotalid sp. (JMJ-18H) (1mm).
15. large rotalid sp. (JMJ-43H) (2mm).

PLATE 5.7

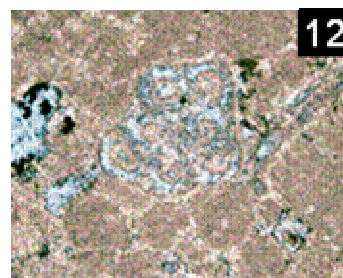
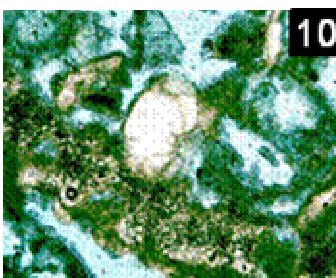
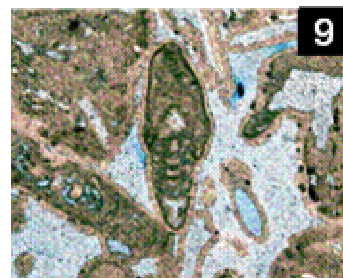
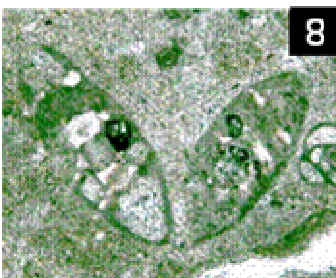
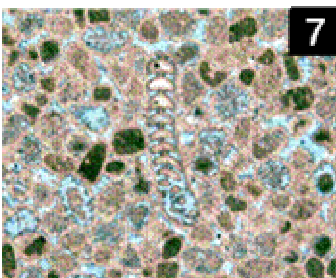
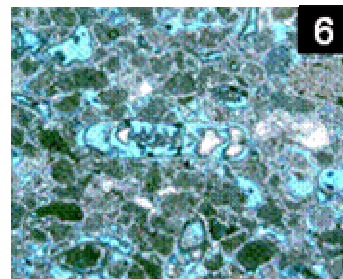
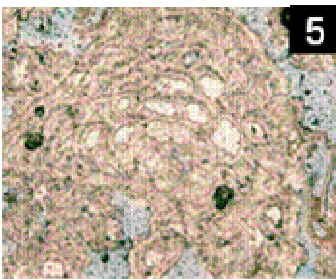
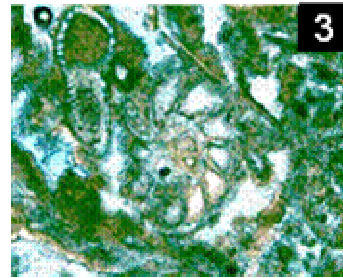
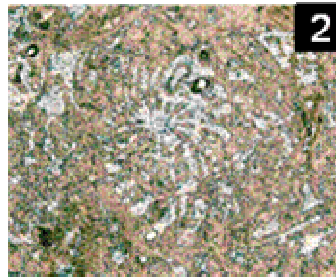
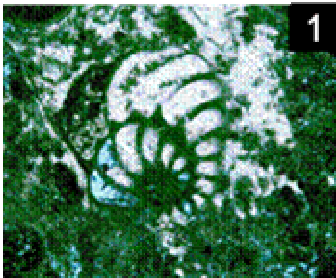
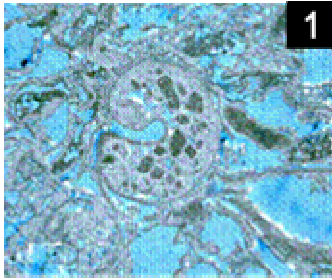


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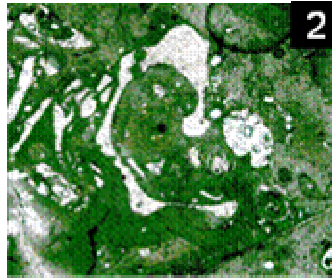
Dimension in mm is the maximum width of images

1. *Operculina* sp. (JMJ-15.1) (2mm).
2. rotalid cf. *Operculina* (JMJ-50V) (2mm).
3. rotalid *Cibicides* sp. (JMJ-14H) (1mm).
4. *Cibicides* sp. and *Spiroloculina* sp. (JMJ-15V) (1mm).
5. *Planorbulina larvata* (JMJ-51V) (2mm).
6. cf. *Ammodiscus* in pelloidal packstone (JMJ-30V) (2mm).
7. *Ammobaculites* sp. (JMJ-41V) (2mm).
8. cf. *Nonion* sp. (JMJ-1V) (8mm).
9. cf. *Nonion* sp. (JMJ-43V) (2mm).
10. *Nonion* sp. (JMJ-14H) (2mm).
11. *Nonion* in reworked intraclast (JMJ-15V) (1mm).
12. indeterminate form of foraminifera (JMJ-36) (1mm).

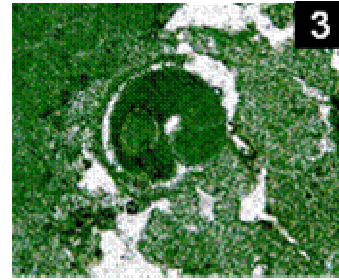
PLATE 5.8



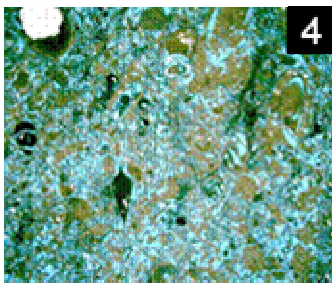
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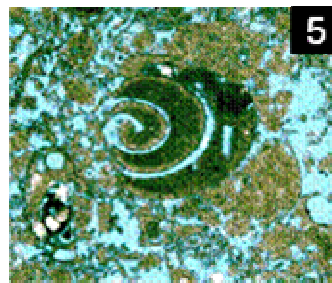
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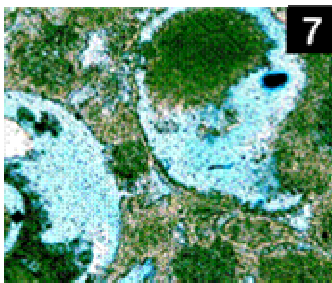
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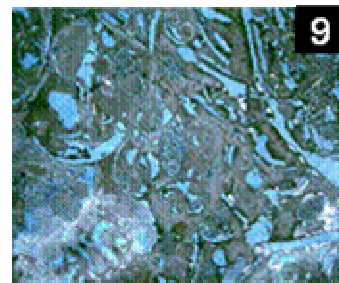
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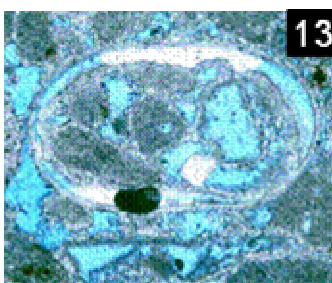
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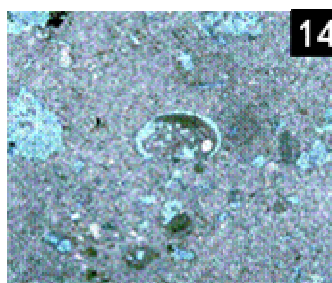
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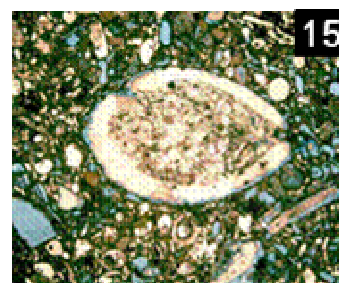
12



13



14



15

Plate 5.8

Dimension in mm is the maximum width of images

1. gastropod with pelloid infill in packstone (JMJ-29H) (8mm).
2. Gastropod TS (JMJ-D3.1) (4mm).
3. Gastropod (JMJ-D3.2) (1mm).
4. general view of gastropods and pelloids (JMJ-D5) (8mm).
5. Gastropod (JMJ-5) (2mm).
6. gastropod within packstone (geopetal sediment fill) (JMJ-9H) (4mm).
7. pelloidal grainstone with brachiopods and gastropods and well cemented (JMJ-12H) (1mm).
8. gastropod and echinoid spine (JMJ-14V) (1mm).
9. gastropod packstone with moldic porosity (JMJ-23H) (8mm).
10. smooth gastropod (JMJ-15.2) (2mm).
11. entire bivalve (JMJ-1V) (4mm).
12. bivalve with growth lines (JMJ-18V) (4mm).
13. pelloidal packstone with ostracod (JMJ-30H) (1mm).
14. Ostracod in mud (JMJ-27V) (2mm).
15. Brachiopod (JMJ-52H) (8mm).

PLATE 5.9

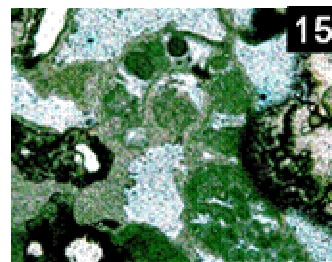
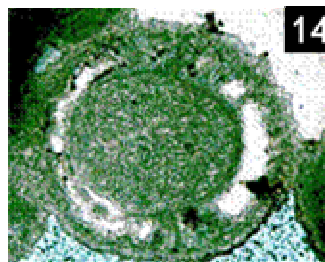
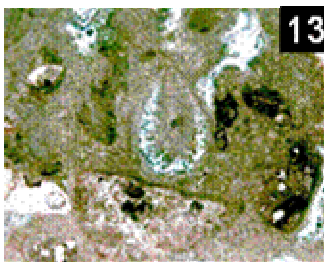
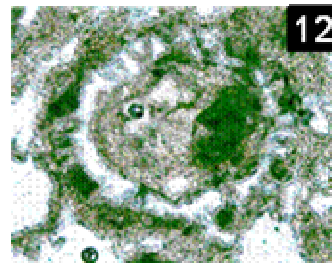
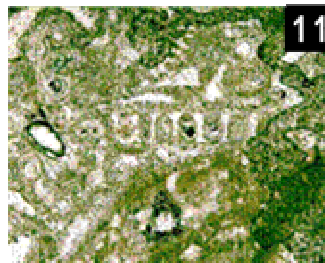
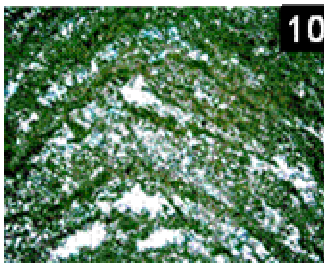
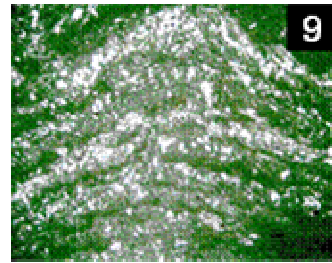
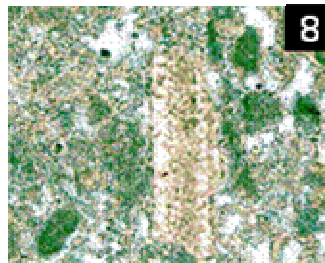
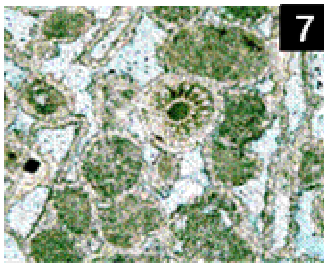
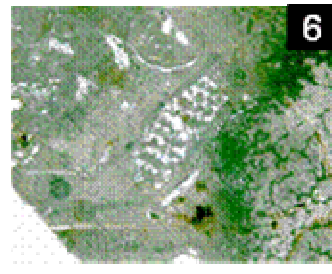
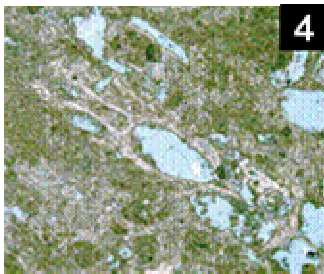
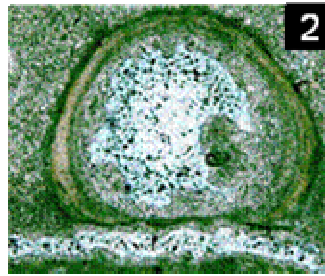
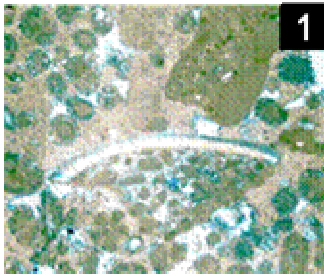


Plate 5.9

Dimension in mm is the maximum width of images

1. brachiopod with fine grain pelloidal packstone (JMJ-9V) (8mm).
2. *Spirorbis* sp. (worm tubes) on shell fragment (JMJ-1V) (1mm).
3. Worm tube (JMJ-17V) (1mm).
4. branched bryozoan (JMJ-18V) (2mm).
5. branched bryozoan (JMJ-18V) (2mm).
6. echinoid spine (JMJ-D3.1) (2mm).
7. echinoid spine TS (JMJ-13V) (1mm).
8. echinoid spine in pelloidal packstone (JMJ-10) (1mm).
9. Stromatolite vertical section (JMJ-2) (8mm).
10. Stromatolite vertical section (JMJ-2) (8mm).
11. *Dasyclad calcareous alga* (JMJ-7) (1mm).
12. *Dasyclad calcareous alga* (JMJ-1V) (1mm).
13. flask shaped *dasyclad calcareous alga* (JMJ-1V) (2mm).
14. *Dasyclad calcareous alga* (JMJ-1) (1mm).
15. *Dasyclad calcareous alga* (JMJ-1) (2mm).

PLATE 5.10

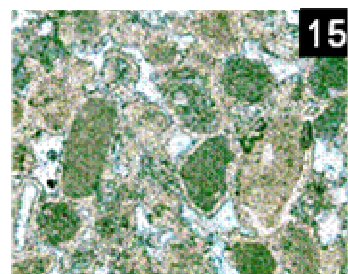
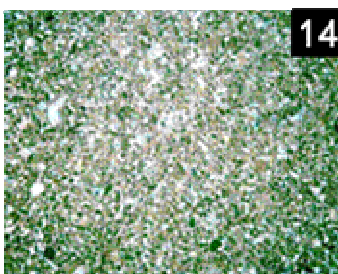
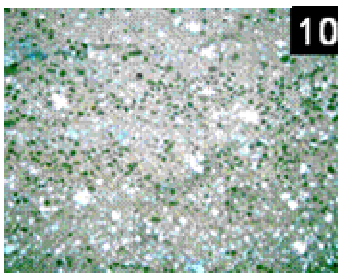
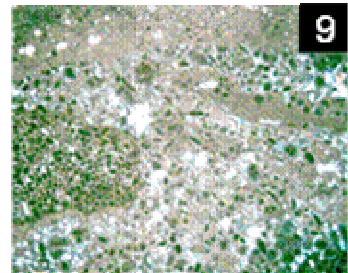
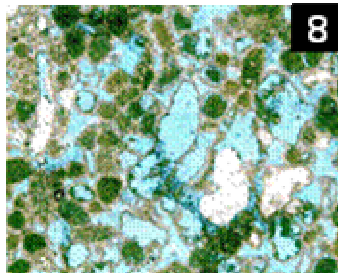
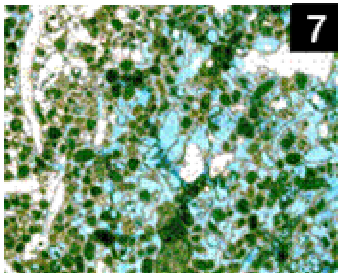
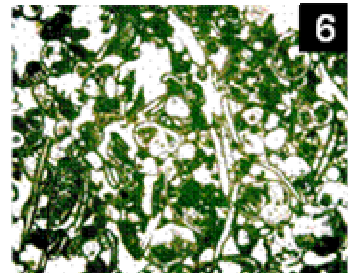
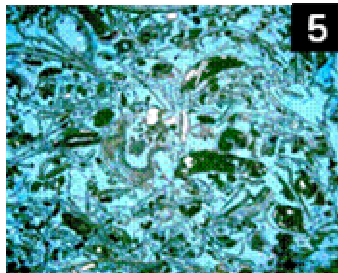
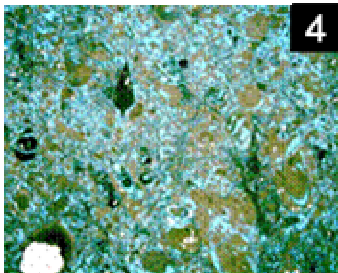
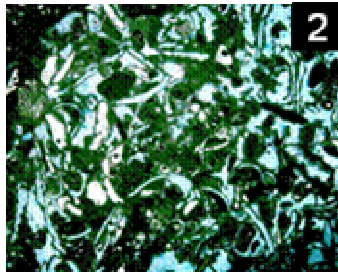
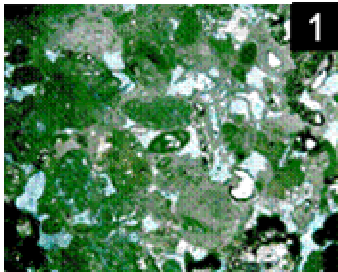


Plate 5.10

Dimension in mm is the maximum width of images

1. general view (JMJ-1) (8mm).
2. Brachiopod moulds and gastropods (JMJ-1v) (8mm).
3. Coated grains oolitic (JMJ-D4.1) (2mm).
4. general view of gastropods and pelloids (JMJ-D5) (8mm).
5. general view mouldic porosity and bivalve grainstone (JMJ-D4a) (8mm).
6. gastropods common (JMJ-D6) (8mm).
7. pelloidal grainstone (JMJ-D7a) (4mm).
8. pelloids (JMJ-D7a) (2mm).
9. stromatolite with pelloids (JMJ-8H) (8mm).
10. stromatolite with pelloids (JMJ-8V) (8mm).
11. fragments of pelloidal packstone and mudstone intraclasts within coarse packstone (JMJ-9H) (8mm).
12. micrite cement rim (JMJ-9H) (4mm).
13. fragments of pelloidal mud-lean packstone within coarse packstone (JMJ-9V) (8mm).
14. pelloidal grainstone (JMJ-11H) (8mm).
15. pelloidal grainstone with rim cement (JMJ-11H) (1mm).

PLATE 5.11

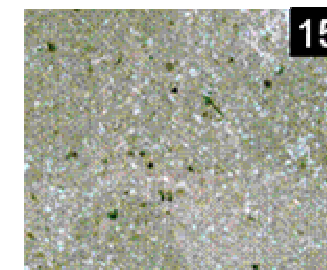
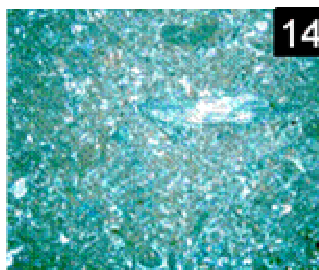
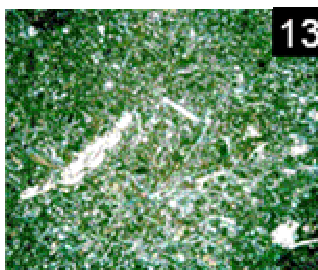
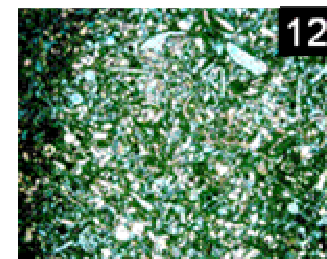
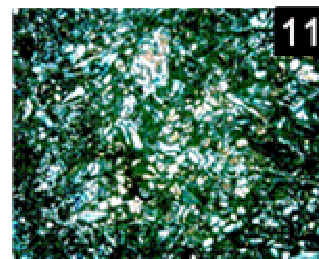
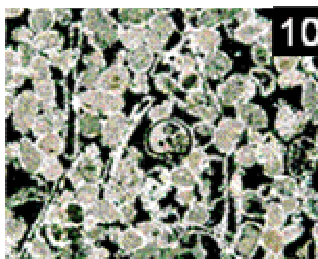
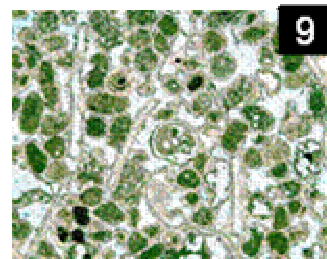
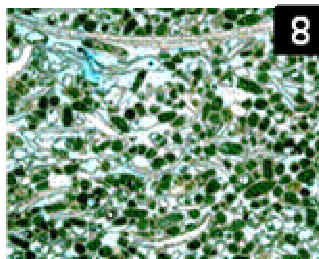
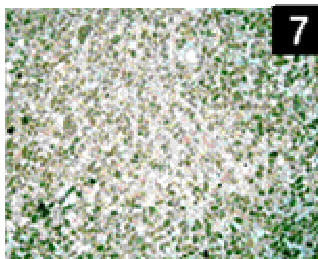
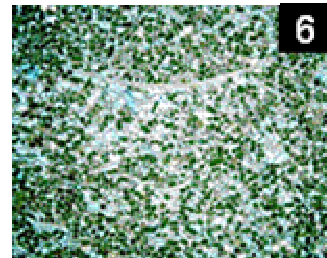
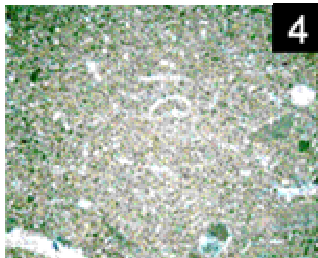
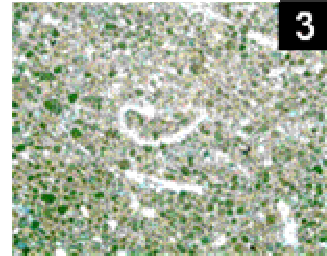
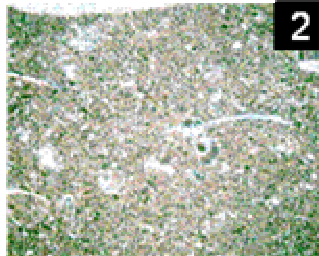
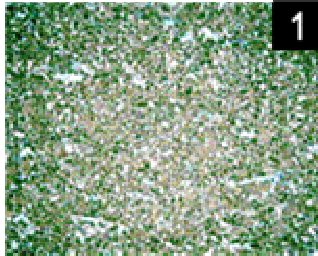


Plate 5.11

Dimension in mm is the maximum width of images

1. pelloidal grainstone (JMJ-11V) (8mm).
2. pelloidal grainstone with brachiopod and gastropods (JMJ-12H) (8mm).
3. pelloidal grainstone with brachiopod and gastropods and well cemented (JMJ-12V) (1mm).
4. pelloidal grainstone with brachiopod and gastropods and well cemented (JMJ-12V) (4mm).
5. pelloidal, brachial, gastropodal grainstone with rim cement (JMJ-13H) (8mm).
6. pelloidal, brachial grainstone (JMJ-13V) (8mm).
7. pelloidal, brachial grainstone with rim cement (JMJ-13V) (4mm).
8. pelloidal, brachial grainstone with rim cement (JMJ-13V) (2mm).
9. PPL pelloidal, brachial grainstone with rim cement (JMJ-13V) (2mm).
10. XPL pelloidal, brachial grainstone with rim cement (JMJ-13V) (2mm).
11. pelloidal, brachial mud-lean packstone (JMJ-14H) (8mm).
12. pelloidal mud-lean packstone with brachiopods and gastropods (JMJ-14V) (8mm).
13. pelloidal, brachial mud-lean packstone (JMJ-15V) (8mm).
14. mud-lean packstone with *Alveolinella* (JMJ-15H) (8mm).
15. barren mudstone (JMJ-20H) (1mm).

PLATE 5.12

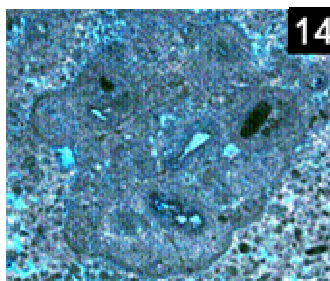
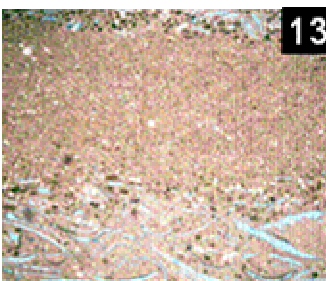
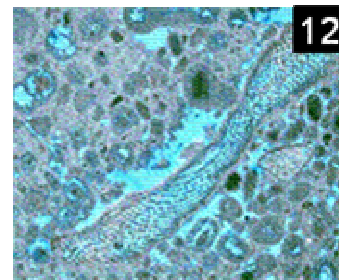
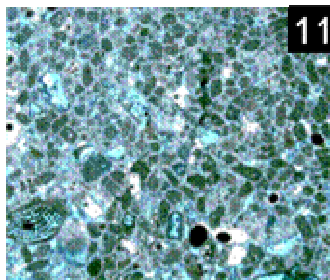
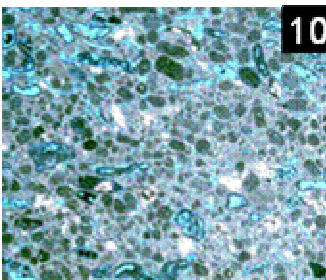
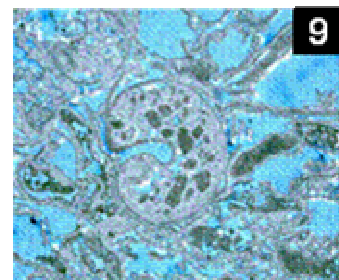
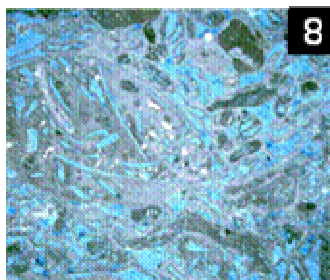
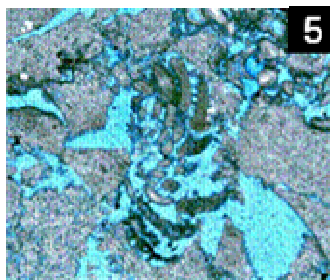
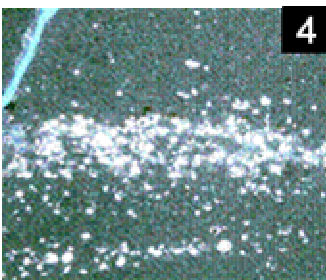
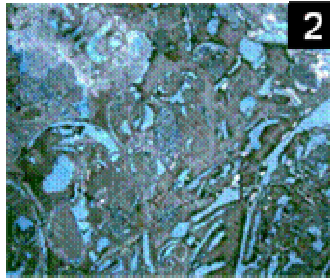


Plate 5.12

Dimension in mm is the maximum width of images

1. rotalid in mudstone (JMJ-21V) (1mm).
2. gastropod packstone with moldic porosity (JMJ-23H) (8mm).
3. mud lithoclast (JMJ-23) (8mm).
4. laminated mud with alternation with quartz grains (JMJ-25bH) (4mm).
5. *Elphidium* in wackstone (JMJ-26H) (2mm).
6. Ostracod in mud (JMJ-27V) (2mm).
7. pelloids in wackstone (JMJ-28H) (2mm).
8. brachial, gastropodal, elphidial packstone (JMJ-29H) (8mm).
9. gastropod with pelloid infill in packstone (JMJ-29H) (8mm).
10. pelloidal packstone (JMJ-30V) (4mm).
11. pelloidal packstone with *Archaias* (JMJ-30H) (4mm).
12. *Archaias* in pelloidal packstone (JMJ-33aH) (4mm).
13. bed boundry-depening event (JMJ-38V) (8mm).
14. Ooid cluster in pelloidal packstone (JMJ-33bH) (4mm).

APPINDEXES

Appendix A

Systematic paleontology of the all foraminifera fossils of this study (Loeblich and Tappan, 1955) (Robbins, 1983) (Barker, 1960) (Murray, 1966- 1991) (Al-Zamel and Al-Cherif, 1998).

Order FORAMINIFERIDA Eichwald, 1830

Suborder TEXTULARIINA Delage and Herouard, 1896

Superfamily LITUOLACEA de Blainville, 1825

Family HORMOSINIDAE Haeckel, 1894

Subfamily HORMOSININAE Haeckel, 1894

Genus *Reophax* Montfort, 1808*Reophax* sp.

Family RZEHAKININDAE Cushman, 1933

Genus *Trilocularena* Loeblich and Tappan, 1955*Trilocularena* sp.

Family LITUOLIDAE de Blainville, 1825

Subfamily LITUOLINAE de Blainville, 1825

Genus *Ammobaculites* Cushman, 1910*Ammobaculites* sp.

Superfamily AMMODISCACEA Reuss, 1862

Family AMMODISCIDAE Reuss, 1862

Subfamily AMMODISCINAE Reuss, 1862

Genus *Ammodiscus* Reuss, 1862*Ammodiscus* sp.

Superfamily ASTRORHIZIDA

Family TEXTULARIIDAE Ehrenberg, 1838

Subfamily TEXTULARIINAE Ehrenberg, 1839

Genus *Textularia* Defrance, 1824*Textularia agglutinans* d'Orbigny, 1839*Textularia* spp.*Clavulina pacifica* Cushman, 1924

Suborder MILIOLINA Delage and Herouard, 1896

Superfamily MILIOLACEA Ehrenberg, 1839

Family FISCHERINDAE Millet, 1839

Subfamily CYCLOGYRINIDAE Loeblich and Tappan, 1961

Genus *Cyclogyra* Wood, 1842

Cyclogyra planorbis (Schultze), 1854

Subfamily SPIROLOCULININAE Wiesner, 1931

Genus *Spiroloculina* d'Orbigny, 1826

Spiroloculina grata var. *angulata* Cushman, 1917

Spiroloculina spp.

Family MILIOLIDAE Ehrenberg, 1839

miliolid spp.

Subfamily MILIOLINAE Ehrenberg, 1839

Genus *Pyrgo* DeFrance, 1824

Pyrgo sp.

Genus *Quinqueloculina* d'Orbigny, 1826

Quinqueloculina agglutinans d'Orbigny, 1839

Quinqueloculina spp.

Genus *Triloculina* d'Orbigny, 1826

Triloculina spp.

Subfamily MILIOLINELLINAE Vella, 1957

Genus *Miliolinella* Wiesner, 1931

Genus *Miliolina*

Miliolina rupertiana, Brady, 1881

Miliolina spp.

Genus *Massilina* Schlumberger, 1893

Massilina secans var. *reticulata* Heron-Allen and
Earland, 1915

Massilina spp.

Genus *Ptychomiliola* Eimer and Fickert, 1899

Ptychomiliola spp.

Genus *Schlumbergerina* Munier-Chalmas, 1882

Subfamily TUBINELLA Rhumbler, 1906

Genus *Articulina* d'Orbigny, 1826

Articulina pacifica Cushman, 1944

Articulina queenslandica Collins 1954

Family SORITIDAE Ehrenberg, 1839

Subfamily SORITINAE Ehrenberg, 1839

Genus *Sorites* Ehrenberg, 1839

Sorites marginalis (Lamark), 1816

Subfamily PENEROPLINAE Schultze, 1854

Genus *Peneroplis* De Montfort, 1808

Peneroplis pertusus (Forsk.) 1775

Peneroplis planatus (Fichtel and Moll), 1798

Genus *Spirolina* Lamark, 1804

Spirolina arietina (Batsch), 1791

Dendritina elegans d'Orbigny, 1840

Subfamily ARCHAIASINAE Cushman, 1927

Genus *Archaias* Montfort, 1808

Archaias hensoni Smout and Eames, 1958

Family ALVEOLINIDAE Ehrenberg, 1839

Genus *Alveolinella* Douville, 1906

Alveolinella sp.

Genus *Borelis* Montfort, 1808

Borelis melo melo Fichtel & Moll, 1798

Suborder ROTALIINA Delage and Herouard, 1896

Rotalia spp.

Superfamily BULININACEA Jones, 1875

Family BOLINVINITIDAE Cushman, 1927

Genus *Bolivina* d'Orbigny, 1839

Bolivina simpsoni Heron-Allen and Earland, 1915

Bolivina spathulata (Williamson), 1858

Family BULIMINIDAE Jones, 1875

Genus *Reussella* Galloway, 1933

Reussella aculeata Cushman, 1945

Reussella pulchra Cushman, 1945

Reussella spinulosa Reuss, 1850

Superfamily DISCORBACEA Ehrenberg, 1838

Family DISCORBADEA Cushman, 1927

Subfamily DISCORBANEAE Cushman, 1927

Genus *Rosalina* d'Orbigny, 1826

Discorbis plana Heron-Allen and Earland, 1932

Tretomphalus bulloides (d'Orbigny), 1924

Genus *Patellinella* Cushman, 1928

Patellinella cf. *inconspicua* (Brady), 1884

Subfamily BAGGINIDAE

Genus *Glabratella*

Glabratella patelliformis (Brady), 1884

Subfamily ASTERIGERINITAE

Genus *Asterigerinata*

Amphistigina lessoni d'Orbigny, 1826

Family ROTALIIDAE Ehrenberg, 1839

rotalid spp.

Subfamily ROTALIINAE Ehrenberg, 1839

Genus *Ammonia* Brunnich, 1772

Ammonia beccarii (Linnaeus), 1758

Family ELPHIDIIDAE Galloway, 1933

Subfamily ELPHIDIINAE Galloway, 1933

Genus *Elphidium* De Montfort, 1808

Elphidium craticulatum (Fichtel and Moll), 1873

Elphidium spp.

Family NUMMULITIDAE De Biainville, 1825

Subfamily NUMMULITINAE Reuss, 1862

Genus *Operculina* d'Orbigny, 1826

Operculina gaymardi d'Orbigny, 1832

Superfamily ORBITOIDACEA Schwager, 1876

Family CIBICIDIDAE Cushman, 1927

Subfamily CIBICIDINAE Cushman, 1927

Genus *Cibicides* De Montfort, 1808

Cibicides lobatulus (Walker and Jacob), 1758

Cibicides pseudoungerianus Cushman, 1922

Cibicides spp.

Family CYMBALOPORIDAE Cushman, 1927

Genus *Cymbalopora* Von Hagenow, 1851

Cymbalopora tobagoensis Bronnimann, 1949

Family PLANORBULINIDAE Schwager, 1877

Genus *Planorbulina* d'Orbigny, 1826

Planorbulina mediterranea d'Orbigny, 1826

Planorbulina larvata

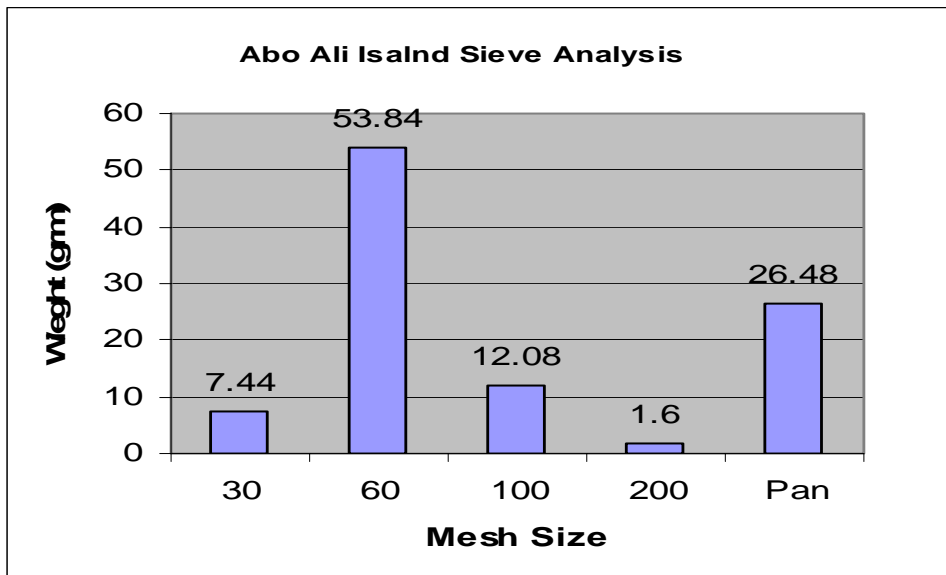
Superfamily CASSIDULINACEA

Nonion depressulus (Walker and Jacop), 1798

Nonion spp.

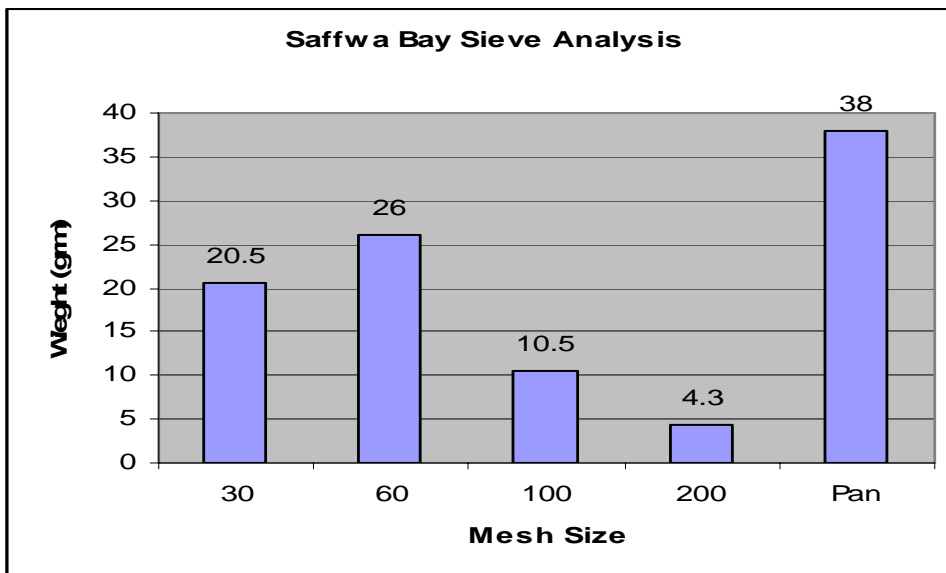
Appendix B

Histogram illustrating the results of grain size analysis of all Recent sediment samples from the Arabian Gulf.



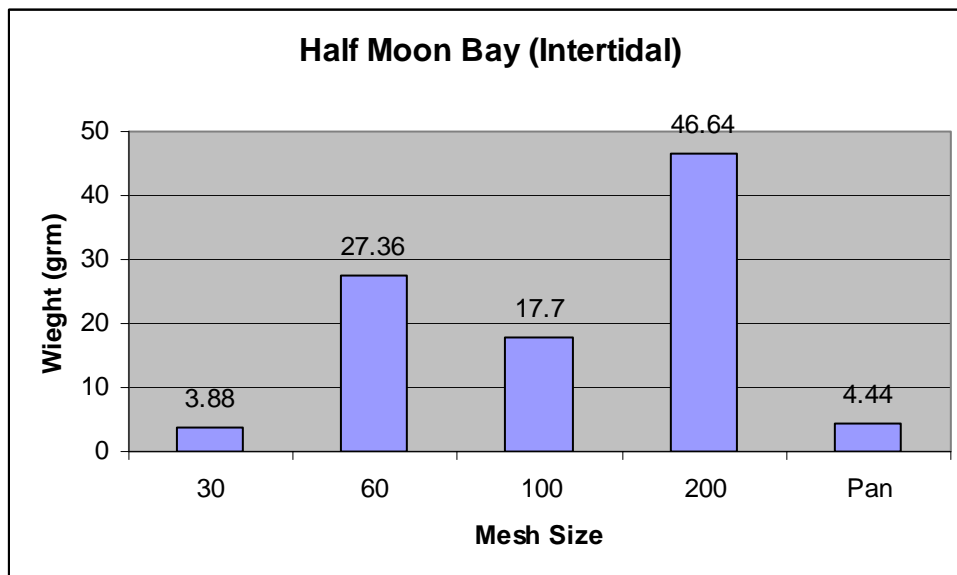
1- Sample Name: Abu Ali Island

Sample weight before sieving= 101.44 grams



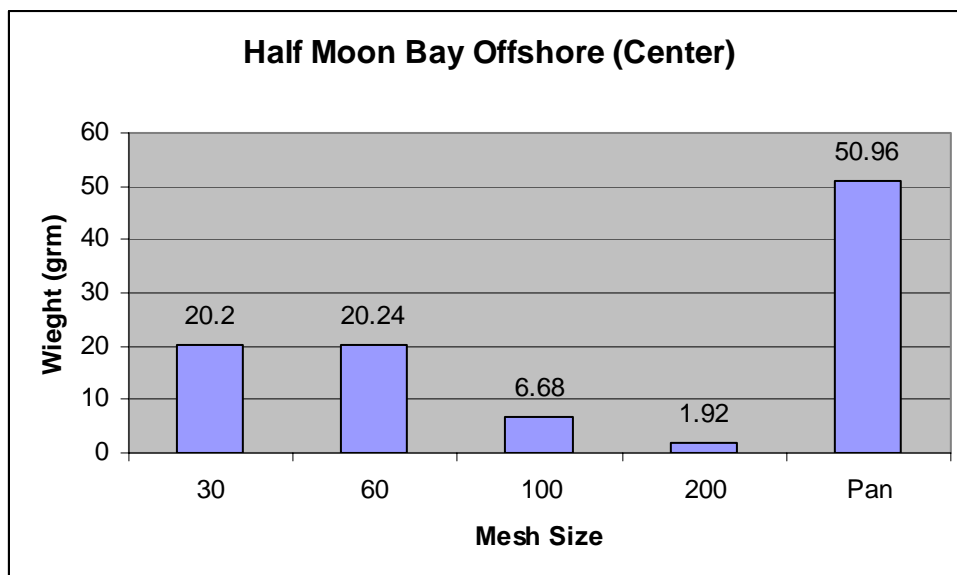
2- Sample Name: Saffwa Bay

Sample weight before sieving= 99.3 grams



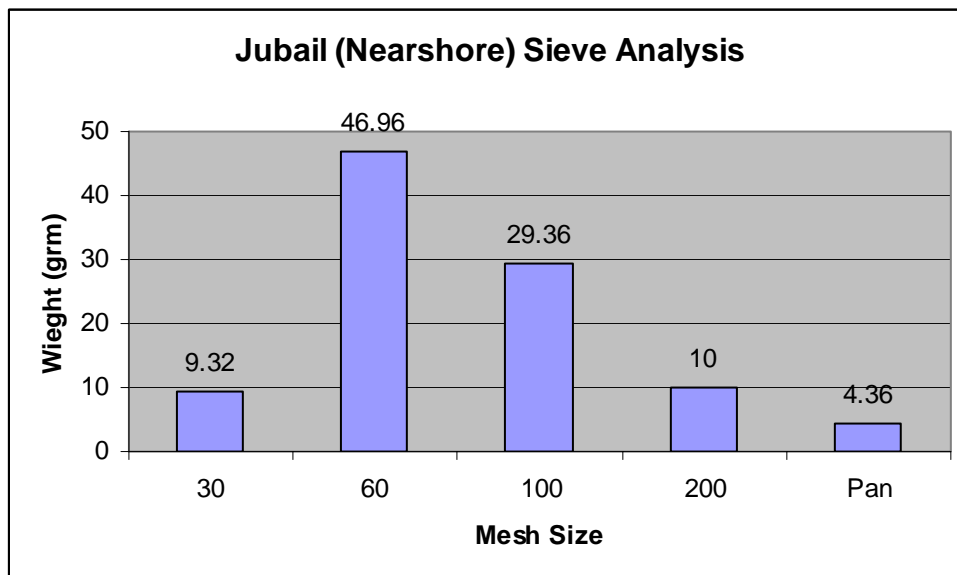
3- Sample Name: Half Moon Bay (Intertidal)

Sample weight before sieving= 100.02 grams



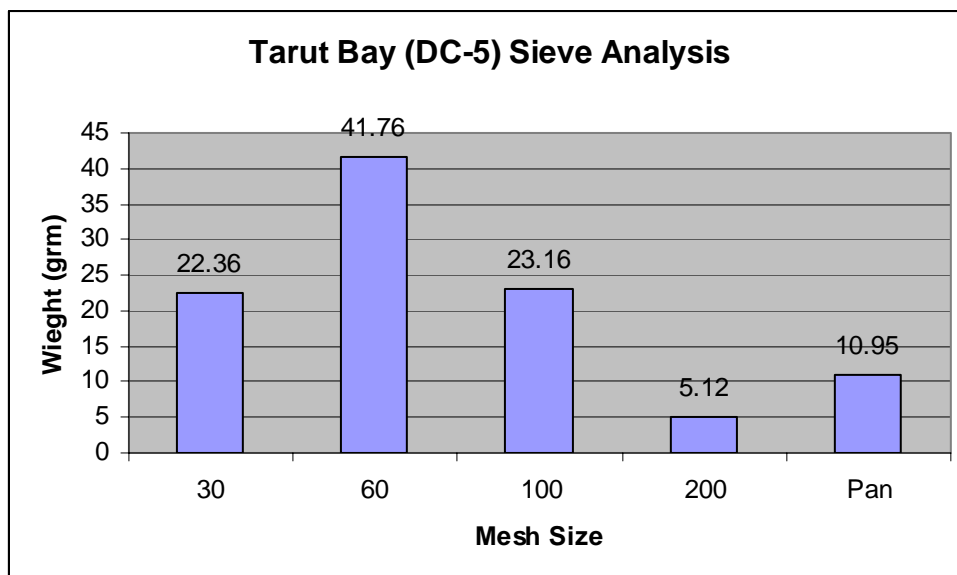
4- Sample Name: Half Moon Bay (offshore, centre)

Sample weight before sieving= 100 grams



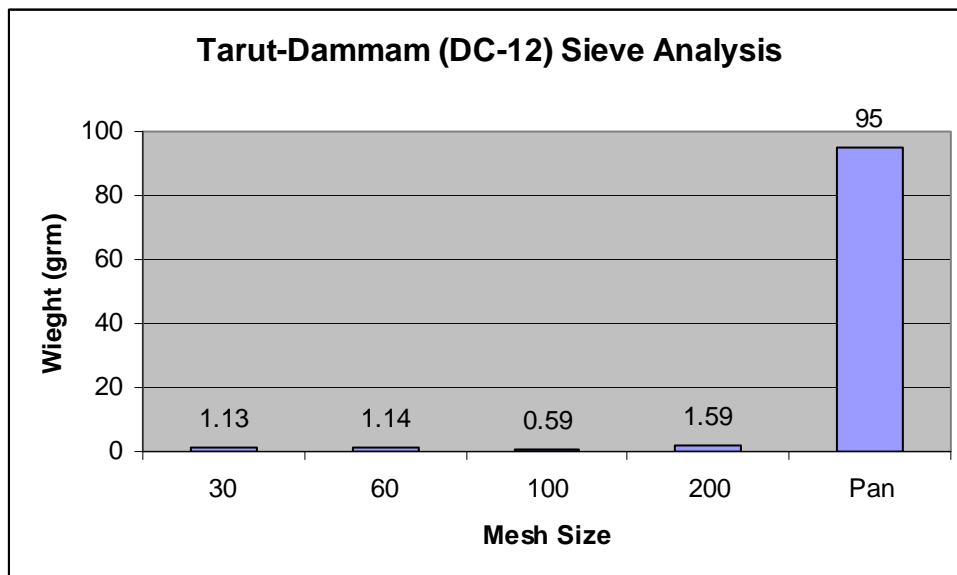
5- Sample Name: Jubail (nearshore)

Sample weight before sieving= 100 grams



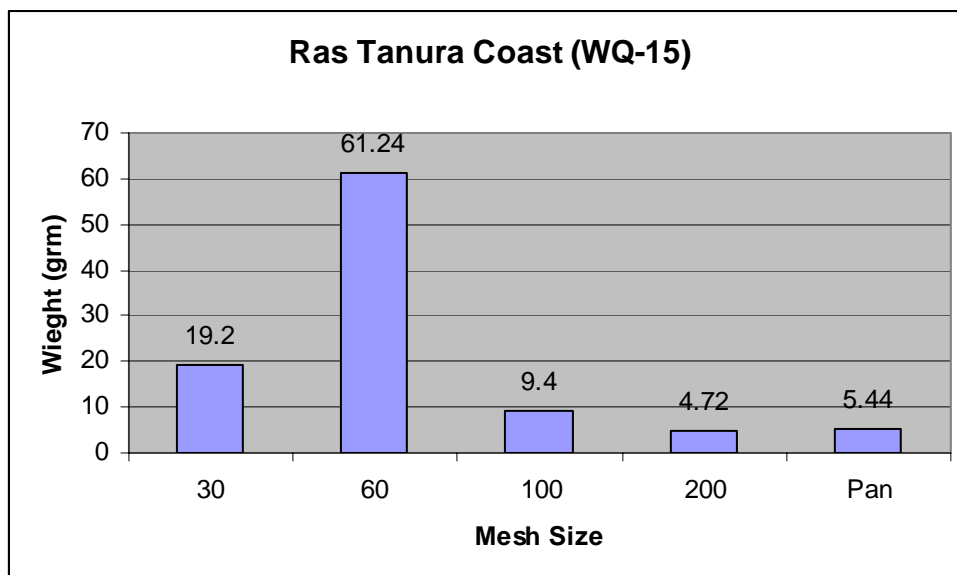
6- Sample Name: Tarut Bay (DC-5)

Sample weight before sieving= 103.35 grams



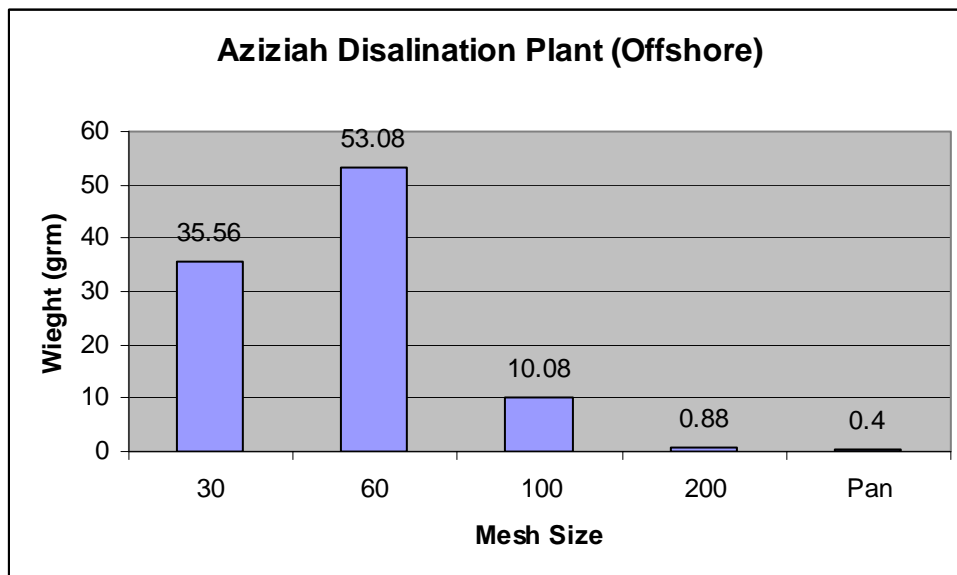
7- Sample Name: Tarut – Dammam Bay (DC-12)

Sample weight before sieving= 99.45 grams



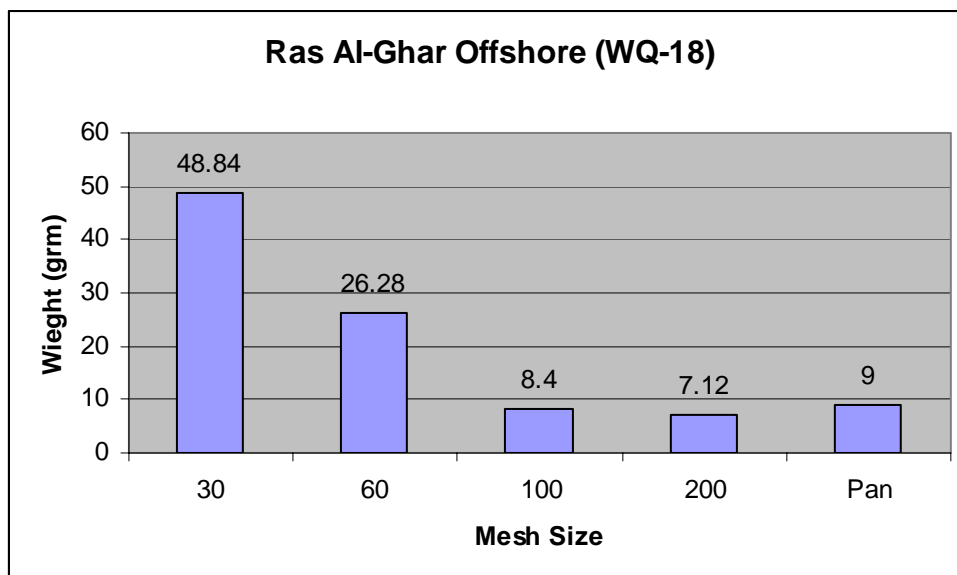
8- Sample Name: Ras Tanura coast (WQ-15)

Sample weight before sieving= 100 grams



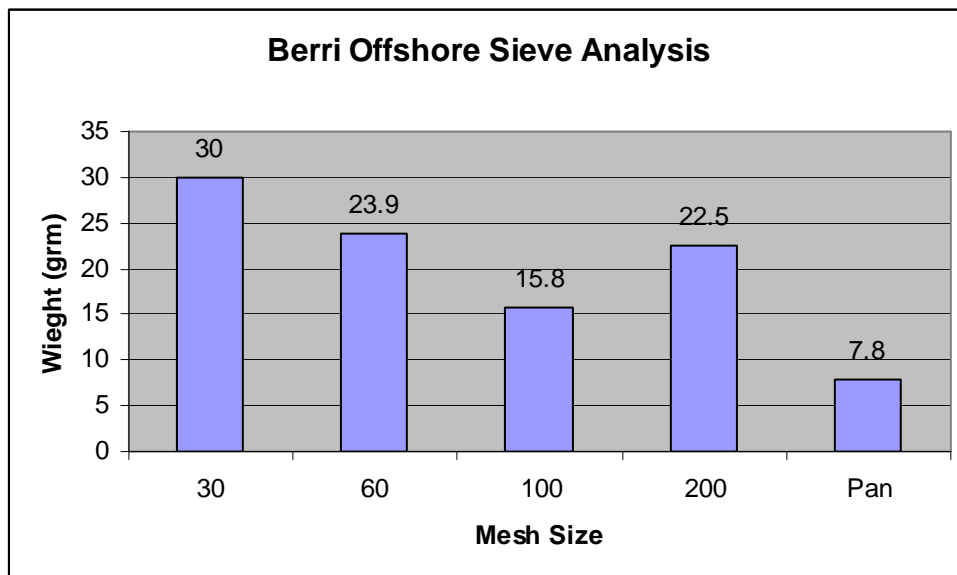
9- Sample Name: Aziziyah Desalination Plant (Offshore)

Sample weight before sieving= 100 grams



10- Sample Name: Ras Al-Ghar (offshore) (WQ-18)

Sample weight before sieving= 99.64 grams



11- Sample Name: Berri Well-124 location, bottom sediment sample #3 (SC 970594)

Sample weight before sieving= 100 grams

Vita

Saleh S. Al-Enezy, son of Mr. Sfoog Marzoog Al-Feda'ani Al-Enezi, was born in Al-Badya of Al-Khafji town on May 24, 1974. After graduating from Ibn Sina High School at Al-Khobar on 1993, after the second Gulf war (Kuwait liberation war), he entered King Abdul Aziz University in 1993. In the summer of 1997, he earned his B.Sc. degree in Marine Geology. In 1998 he jointed the Earth Sciences Department at King Fahd University of Petroleum and Minerals as Graduate Assisstant. He attended a one-year English language program at KFUPM. He started his Master Program at KFUPM in 1999. He received the Master of Science (Msc.) degree in Geology from Earth Scinces Department, KFUPM, in June 2006.

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