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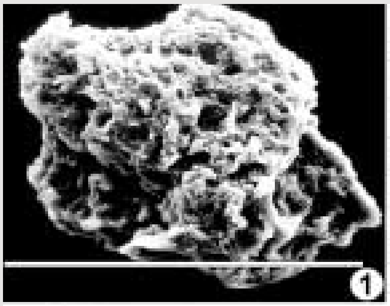

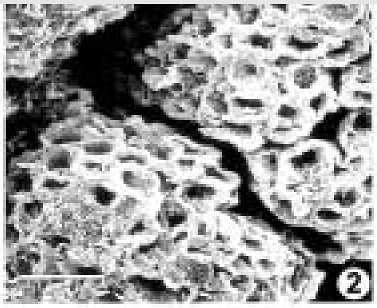

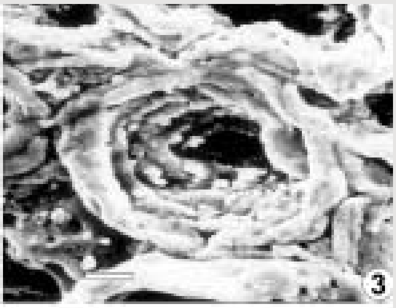

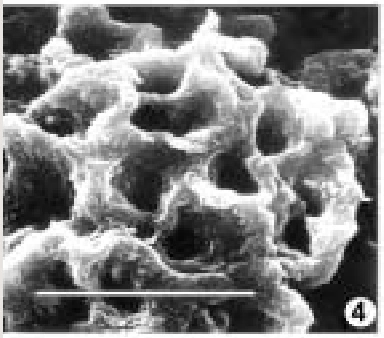

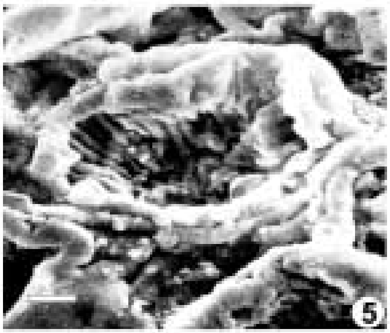

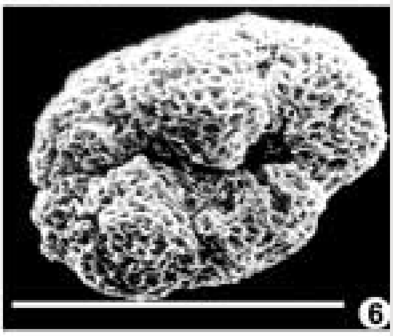

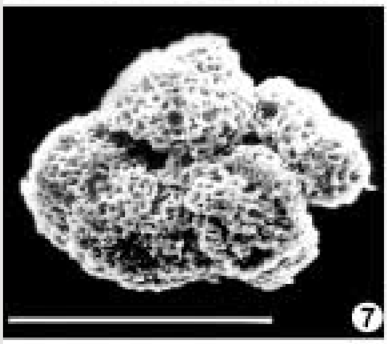

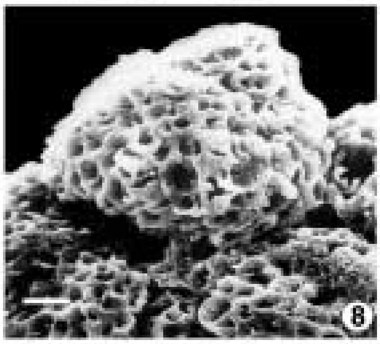

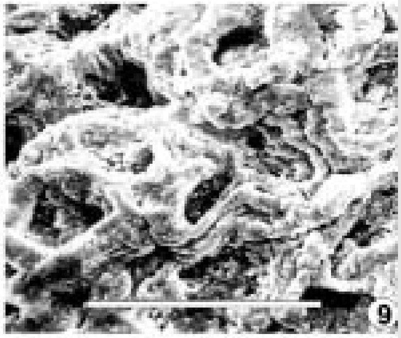

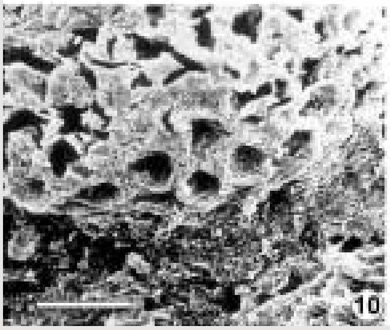

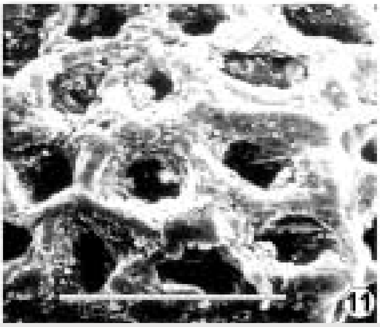

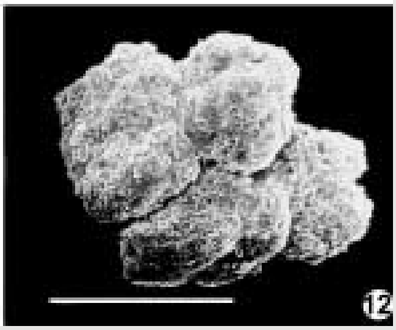

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Portada: Colonias de *Botryococcus* (Chlorococcales), del Triásico de Argentina. Escala gráfica: 100 µm en las figuras 1, 6, 7, 12; 10 µm en las figuras 2, 4, 8, 9, 10, 11, y 1 µm en las figuras 3 y 5.

Cover: Botryococcus *colonies (Chlorococcales), from the Triassic of Argentina. Scale bar: 100 µm, figures 1, 6, 7, 12; 10 µm, figures 2, 4, 8, 9, 10, 11; 1 µm, figures 3, 5.*

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LA APLICACIÓN DE *BOTRYOCOCCUS* (CHLOROCOCCALES) COMO INDICADOR PALEOAMBIENTAL EN EL TRIÁSICO DE ARGENTINA

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Resumen

Se realizó el estudio morfológico detallado de los estadios de desarrollo, forma y tamaño de las colonias de *Botryococcus* (Chlorococcales) encontradas en sedimentos lacustres de la sección basal de la Formación Casa de Piedra, Subcuenca triásica de Rincón Blanco, Argentina. A partir del estudio de las microalgas fósiles, y por analogía con los requerimientos ecológicos conocidos para las formas actuales, se obtuvieron nuevos datos para una posible interpretación paleoambiental de los niveles portadores. Las colonias de *Botryococcus* crecieron probablemente bajo condiciones climáticas variables. La relativa abundancia de las colonias, en ausencia de otro tipo de Chlorococcales, estuvo relacionada con la somerización de la subcuenca en un ambiente estresante (bajo contenido de O_2).

Palabras clave: Botryococcus, Chlorococcales, Triásico lacustre, Argentina.

Abstract

[*The application of* Botryococcus *(Chlorococcales) as palaeoenvironmental indicator in the Triassic of Argentina*]. The detailed study of stages of development, shape and size of *Botryococcus* colonies (Chlorococcales), from Triassic lacustrine intervals of the basal section of the Casa de Piedra Formation, Rincón Blanco Sub-basin, Argentina, have been carried out. The study of fossil microalgae provided, by analogy with ecological requirements of extant forms, new data for a palaeoenvironmental interpretation of *Botryococcus*-bearing levels. The colonies of *Botryococcus* probably grew under variable climatic conditions. The relative abundance of colonies, in absence of any other Chlorococcalean, is related to the shallowness of the Sub-basin under stressed conditions (low O_2 content).

Keywords: Botryococcus, Chlorococcales, Lacustrine Triassic, Argentina.

INTRODUCCIÓN

Este trabajo presenta el estudio morfológico de las colonias de *Botryococcus* (Orden Chlorococcales) encontradas en sedimentos lacustres triásicos de la subcuenca Rincón Blanco, provincia de San Juan, Argentina (Fig. 1). Los resultados se emplean como una herramienta para la interpretación paleoambiental.

La subcuenca Rincón Blanco incluye unos 2.300 metros de sedimentitas continentales, reconociéndose, de base a techo, los conglomerados aluviales y areniscas gruesas de las Formaciones Ciénaga Redonda, Cerro Amarillo y Panul; las facies fluviales y lacustres de la Formación Portezuelo; las facies lacustres profundas de la Formación Carrizalito y las facies lacustres y fluviales de sag de la Formación

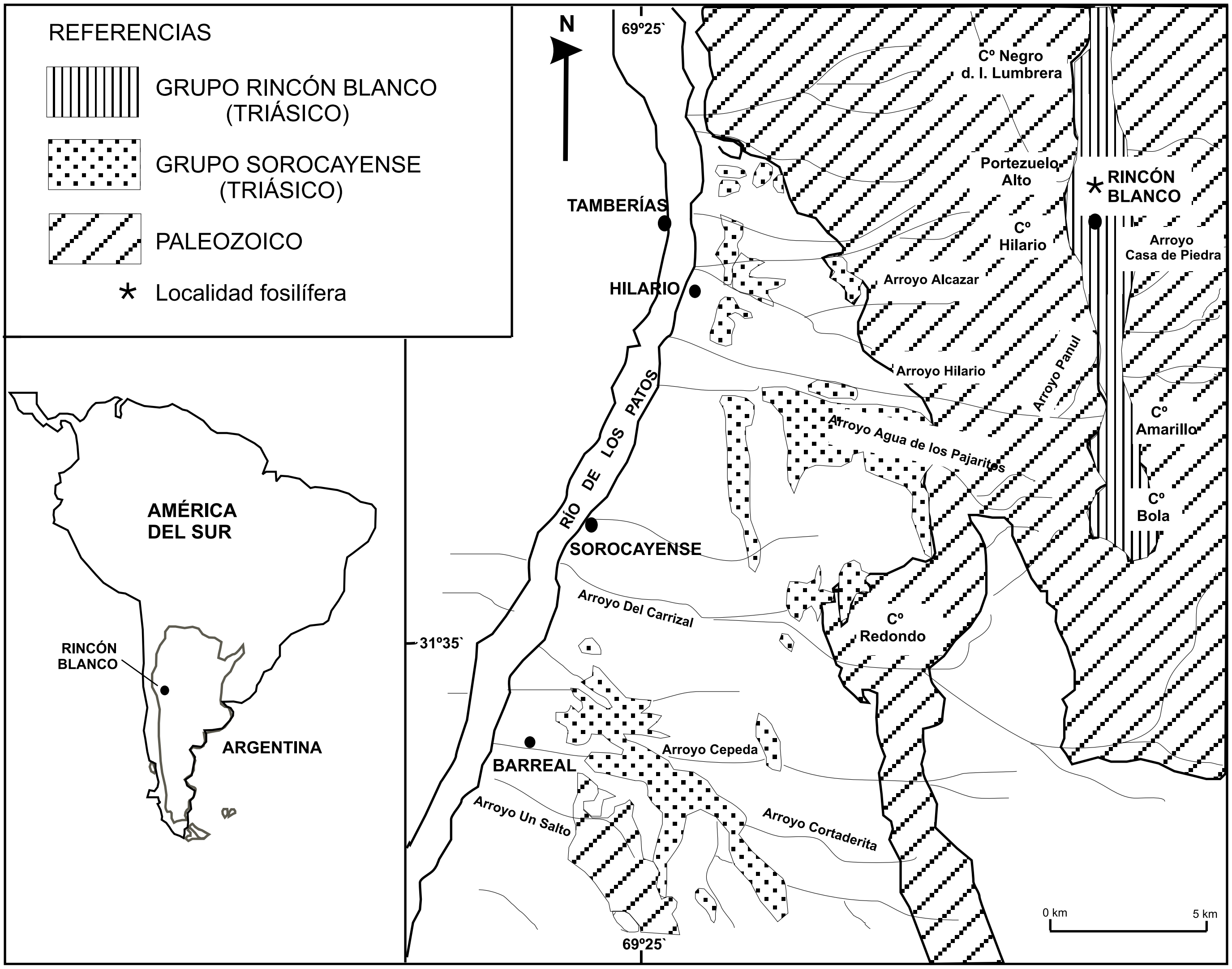


FIGURA 1–Mapa de ubicación. Modificado de Kokogian *et al.* (2001).
FIGURE 1–Location map. Modified from Kokogian *et al.* (2001).

Casa de Piedra (Barredo *et al.*, 1999). *Botryococcus* se encuentra principalmente en los niveles pelíticos de la sección basal de la Formación Casa de Piedra (Fig. 2). Esta unidad, atribuida al Triásico Medio a Tardío, representa el relleno final de la subcuenca e incluye facies lacustres en su parte basal, y facies de ríos entrelazados en su parte superior (Barredo *et al.*, 1999). Las facies lacustres contienen invertebrados fósiles dulceacuícolas tales como conchostráceos, macroflora representada por tallos de sphenophytas y una microflora del tipo Ipswich caracterizada por granos de polen del tipo *Alisporites*, bisacados diploxilonoides, inaperturados, esporas y abundantes colonias de *Botryococcus* (Ottone y Rodríguez Amenábar, 2001). Las facies fluviales también contienen el mismo tipo de microflora, aunque sin *Botryococcus*, mientras que la macroflora presenta pteridospermas, sphenophytas y madera fósil característicos de la flora de *Dicroidium* (Barredo *et al.*, 1999; Ottone y Rodríguez Amenábar, 2001). La unidad representa un sistema lacustre ligeramente alcalino (Citrinovitz *et al*., 1975), con desarrollo local de estromatolitos (Hauschke, 1991), que se someriza paulatinamente a medida que se produce la expansión de la cuenca (Barredo y Ramos, 1998). *Botryococcus* aparece en la subcuenca relacionado

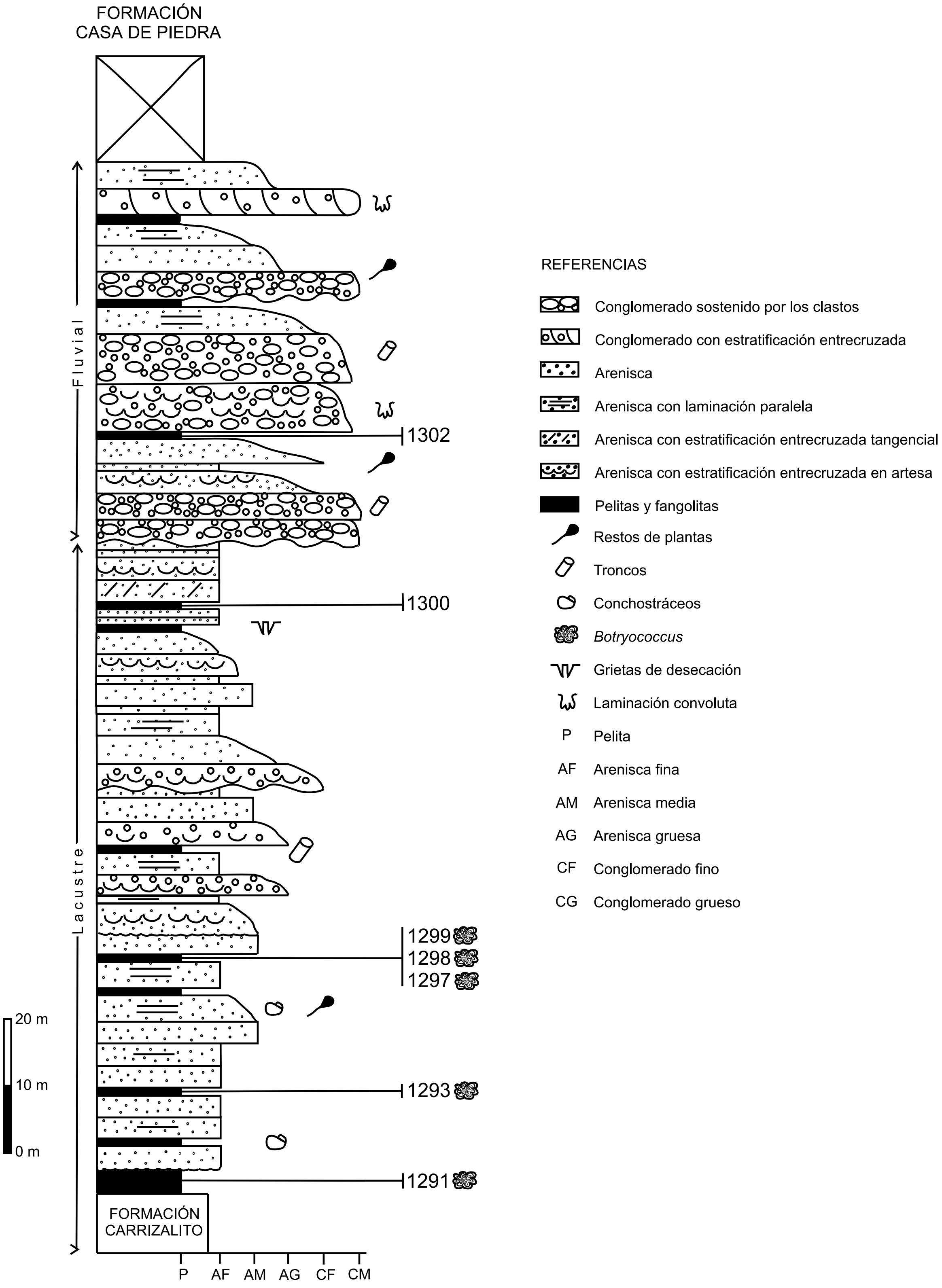


FIGURA 2–Columna estratigráfica sintética de la sección inferior de la Formación Casa de Piedra en Ciénaga Larga incluyendo niveles muestreados.

FIGURE 2–Synthetic stratigraphic log of the lower section of the Casa de Piedra Formation in Ciénaga Larga, with indication of levels sampled.

con facies lacustres marginales de la sección inferior de la Formación Casa de Piedra, siendo no sólo muy abundante (4 a 35% de *Botryococcus* sobre querógeno total) sino la única forma planctónica registrada en estos niveles.

Chlorococcales es un grupo de algas verdes que incluye especies unicelulares y coloniales. Muchas de las especies tienen paredes orgánicas resistentes y, por lo tanto, elevado potencial de fosilización (Batten y Grenfell, 1996).

Muchas son las investigaciones realizadas acerca de la composición química de los *Botryococcus* actuales y su potencial para generar hidrocarburos (Péniguel *et al.*, 1989), como así también los estudios morfológicos de los diferentes estadios de desarrollo en su ciclo de vida (Guy-Ohlson, 1992).

Las colonias de *Botryococcus* crecen a partir de una única célula inicial llamada autoespora que se sitúa dentro de una envoltura mucilaginosa en forma de copa. Esta célula, por sucesivas divisiones, genera una colonia simple de forma globosa, seguida luego de una colonia compuesta de forma botroidal, que finalmente se reproduce vegetativamente por medio de la fragmentación y/o liberación de nuevas autoesporas (Guy-Ohlson, 1992).

Las colonias muestran variaciones en su tamaño, morfología y estadio de desarrollo que se relacionan con cambios ambientales y/o climáticos tales como grado de humedad (Guy-Ohlson, 1992), intensidad de la luz (Guy-Ohlson y Lindström, 1994), salinidad (Guy-Ohlson y Lindström, 1994) y contenido de nitrógeno (Guy-Ohlson y Lindström, 1994; Tyson, 1995) y de oxígeno (Guy-Ohlson, 1992) en la columna de agua.

Botryococcus es en la actualidad una clorofita planctónica cosmopolita que se encuentra fundamentalmente en cuerpos de agua dulce tales como lagos, reservorios y pantanos (Tyson, 1995; Zalessky, 1926), siendo característica de lagos oligotróficos, aunque también se encuentra en aguas mesotróficas. Las formas encontradas bajo condiciones salobres, de cerca de 10 g l^{-1} NaCl, adoptan una morfología homogénea y globosa, mientras que las colonias que habitan en aguas dulces presentan una morfología botroidal, componiéndose de clústers conectados por cadenas de mucílago (Batten y Grenfell, 1996; Tyson, 1995; Zalessky, 1926).

Las Chlorococcales, en general, proliferan donde hay altas concentraciones de nutrientes y degradación de materia orgánica que aporta el nitrógeno necesario para el desarrollo de las colonias (Van den Hoek *et al.*, 1995; Batten y Grenfell, 1996). *Botryococcus* compite más satisfactoriamente con otros organismos planctónicos en aguas someras donde la precipitación es relativamente baja y las condiciones climáticas varían a lo largo del año (Guy-Ohlson y Lindström, 1994).

Las floridas (*blooms*) de *Botryococcus* se registran en lagos someros de aguas calmas, generalmente efímeros, tolerando cierto grado de salinidad (Guy-Ohlson, 1992; Tyson, 1995). Sin embargo, las condiciones que producen las floridas no están del todo establecidas (Batten y Grenfell, 1996).

El registro estratigráfico de *Botryococcus* abarca desde el Carbonífero hasta la actualidad, siendo una forma relativamente común en el Triásico de Gondwana (Brenner y Foster, 1994; Zavattieri, 1991). Los registros del Cámbrico-Ordovícico reflejan probablemente una sinonimia errónea con las cianobacterias marinas fósiles de tipo *Gloeocapsomorpha* (Tyson, 1995). Considerando que *Botryococcus* no ha variado desde el punto de vista morfológico desde sus primeros registros hasta nuestros días, se considera que los especímenes fósiles habrían vivido bajo condiciones ecológicas similares a sus equivalentes actuales. De ésta manera, la comparación de las colonias de *Botryococcus* fósiles con las actuales es muy útil para la interpretación paleoambiental (Batten y Grenfell, 1996; Guy-Ohlson, 1992; Guy-Ohlson y Lindström, 1994; Guy-Ohlson, 1998).

MATERIALES Y MÉTODOS

Se muestrearon siete niveles pelíticos correspondientes a la sección inferior de la Formación Casa de Piedra, en la quebrada de Ciénaga Larga, provincia de San Juan (Fig. 2). De los siete niveles, los cinco inferiores corresponden a facies lacustres, y aportaron *Botryococcus*. Los dos restantes, corresponden a facies fluviales y no incluyen *Botryococcus*.

Para determinar el carácter autóctono de *Botryococcus* se siguieron los criterios generales enunciados por Zippi (1998).

Las muestras fueron procesadas por los métodos palinológicos estándar, los cuales incluyen la molienda de las rocas, la eliminación de carbonatos con HCl y silicatos con HF 70%, y el filtrado del residuo orgánico obtenido con una malla de 25 µm. Parte del residuo orgánico fue montado en slides usando glicerogelatina como medio de fijación. Las colonias fueron estudiadas mediante un microscopio Leitz Orthoplan de luz transmitida.

Del residuo orgánico se extrajeron bajo lupa y microscopio colonias de *Botryococcus* de diferente tamaño (posibles distintos estadios de desarrollo). Las colonias fueron luego fijadas en un portaobjetos para su metalización y posterior observación en un microscopio electrónico de barrido Leitz-AMR 1200.

Para determinar la frecuencia de *Botryococcus* en cada preparado se contó el número de colonias por nivel sobre un total de 300 palinomorfos, en microscopía de luz transmitida, y se expresó luego el resultado en porcentajes de *Botryococcus* sobre querógeno total (Tabla 1). El material estudiado se halla depositado en el Departamento de Ciencias Geológicas, FCEN-UBA, donde se encuentra catalogado bajo la sigla BAFC-PL.

RESULTADOS E INTERPRETACIÓN PALEOAMBIENTAL

1. Descripción de las colonias fósiles de *Botryococcus*

Las colonias poseen un contorno redondeado a oval. Sus tamaños varían de 40 a 70 µm de diámetro en las colonias más pequeñas y de 110 a 220 µm de diámetro en las colonias de mayor tamaño. Estas últimas presentan lóbulos o clusters cuyo tamaño varía de 40 a 80 µm, que se conectan por cordones de mucílago. La mayoría de las colonias constan de copas pequeñas de 5 µm de diámetro, densamente empaquetadas y con paredes delgadas de entre 1,5 y 2 µm de espesor. Las

Muestra (BAFC-PL)	% de *Botryococcus* sobre el total de querógeno	TIPOS DE COLONIAS Y ESTADIOS DE DESARROLLO						Observaciones	Ejemplos	Interpretaciones paleoecológicas (según Guy-Ohlson,1992; Guy-Ohlson y Lindström, 1994; Guy-Ohlson,1998)
		Simple	Compuesta			Aspecto de la Colonia				
		Joven y/o adulta	Joven y/o adulta	Mayor tamaño µm	Autoesporas	Esqueleto de copas	Masa no estructurada			
1291	18		X	175		X		Un solo tipo de estadio de desarrollo. Ausencia de autoesporas. Formas de las colonias similares. Conservación de las colonias en las cuales permanece sólo el esqueleto de sus copas.	Lámina 1, Figs. 4, 6, 7, 8,11	Período breve de crecimiento bajo condiciones ambientales y/o climáticas uniformes. Depósito bajo condiciones favorables, probablemente en aguas someras oxigenadas tranquilas, y con un rápido enterramiento.
1293	10		X	100	X	X		Un solo tipo de estadio de desarrollo. Ausencia de autoesporas. Diferentes formas de las colonias. Colonias con buena conservación y otras con tendencia a formar una matriz “no estructurada”.	Lámina 1, Fig. 1	Período breve de crecimiento bajo condiciones ambientales y/o climáticas variables. Las colonias se depositaron en un ambiente con bajo contenido de oxígeno.
1297	16	X	X	200	X	X	X	Distintos estadios de desarrollo, presencia de “anillos de crecimiento” y autoesporas (escasas). Diferentes formas de las colonias. Colonias con buena conservación y otras con tendencia a formar una matriz “no estructurada”.	Lámina 1, Figs. 2, 3, 5, 9, 10	Prevalecen condiciones ambientales y/o climáticas variables durante un largo período de tiempo. El depósito se produjo en un ambiente somero sin marcadas perturbaciones y con un rápido enterramiento; con baja disponibilidad de oxígeno.
1298	35	X	X	220		X	X	Distintos estadios de desarrollo. Ausencia de autoesporas. Diferentes formas de las colonias. Colonias con buena conservación y otras con tendencia a formar una matriz “no estructurada”.		Prevalecen condiciones ambientales y/o climáticas variables durante un largo periodo de tiempo. El depósito se produjo en un ambiente con baja disponibilidad de oxígeno.
1299	4		X	110		X	X	Un solo tipo de estadio de desarrollo. Ausencia de autoesporas. Colonias de formas similares. Colonias con buena conservación y otras con tendencia a formar una matriz “no estructurada”.	Lámina 1, Fig. 12	Período breve de crecimiento bajo condiciones ambientales y/o climáticas uniformes. El depósito se produjo en un ambiente con bajo contenido de oxígeno.

TABLA 1–Análisis morfológico e interpretación paleoambiental de las colonias de *Botryococcus*.
TABLE 1–Morfological analysis and palaeoenvironmental interpretation of the *Botryococcus* colonies.

mismas se asemejan a las formas “tipo 2”, ilustradas por Batten y Grenfell (1996) para el Cretácico Inferior del Reino Unido (Batten y Grenfell, 1996. Plate 2, Fig. 5).

En ausencia de células o de material celular en las algas fósiles, la comparación con *Botryococcus braunii* Kützing 1849 debe ser realizada basándose en la estructura y morfología del complejo extra celular (Burns, 1982). Las colonias analizadas en este trabajo son, en este sentido, similares a la especie actual. Sin embargo, se prefiere mantener abierta la asignación específica de nuestro material por resultar imposible de probar la equivalencia entre la especie *braunii* y las formas fósiles más allá del estrecho parecido morfológico existente entre ambas.

2. Interpretación paleoambiental

En los trabajos paleoambientales realizados por Guy-Ohlson (1992 y 1998) y Guy-Ohlson y Lindström (1994) se toman en cuenta dos aspectos de las colonias de *Botryococcus* para la interpretación paleoambiental: los estadios de desarrollo de las colonias (basándose la presencia de formas simples y compuestas, en sus tamaños y formas); y el estado de conservación de las mismas. En este trabajo se realiza un análisis similar.

El nivel basal, BAFC-PL 1291 (18% de *Botryococcus*) presenta un solo estadio de desarrollo (colonias compuestas), sin autoesporas, y formas de las colonias similares. Esto indicaría un breve período de crecimiento bajo condiciones ambientales y/o climáticas uniformes (Guy-Ohlson y Lindström, 1994; Guy-Ohlson,1998). Las colonias exhiben una buena conservación de copas y esqueleto, sin autoesporas (Lámina 1, Figs. 4, 6, 7, 8 y 11), lo que sugiere que el depósito se produjo en condiciones favorables, probablemente en aguas someras oxigenadas y tranquilas, y con un rápido enterramiento (Guy-Ohlson, 1992).

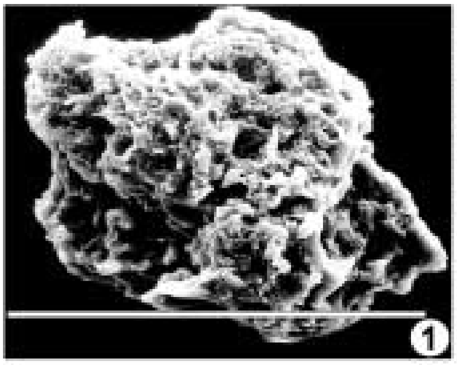
El siguiente nivel, BAFC-PL 1293 (18% de *Botryococcus*), también presenta un solo tipo de estadio de desarrollo (colonias compuestas), sin autoesporas, y con colonias de diferentes formas. Esto reflejaría un breve período de crecimiento bajo condiciones ambientales y/o climáticas variables (Guy-Ohlson y Lindström, 1994; Guy-Ohlson,1998). Presenta algunas colonias que muestran buena conservación de copas y esqueleto, mientras que en otras el esqueleto se reduce a una espesa matriz alterada (Lámina 1, Fig. 1). Las colonias que poseen esta tendencia a formar una matriz no estructurada sugieren que el depósito se produjo en un ambiente con bajo contenido de oxígeno (Guy-Ohlson, 1992).

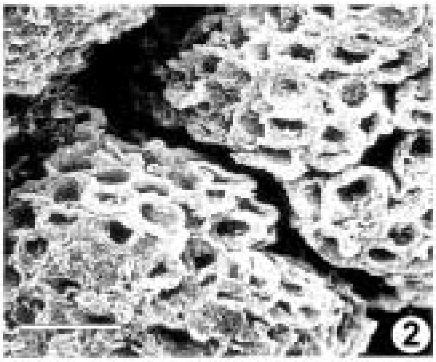
→

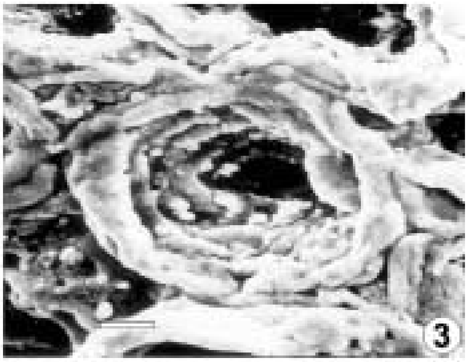
LÁMINA 1–*1-12*, *Botryococcus* sp. *1,* aspecto general de una colonia compuesta mostrando sectores con esqueleto y copas y otros sectores cuya masa está algo alterada, BAFC-PL 1293; *2,* detalle de copas bien conservadas de una colonia compuesta. En ciertos sectores de la colonia se observa masa no estructurada, BAFC-PL 1297; *3,* detalle de la figura 2 mostrando una copa bien conservada, con los anillos de crecimiento, BAFC-PL 1297; *4,* detalle una colonia en las que se conservó el esqueleto de las bases de las copas, BAFC-PL 1291; *5,* detalle de una copa mostrando anillos de crecimiento, BAFC-PL 1297; *6,* aspecto general de una colonia compuesta mostrando el esqueleto de las bases de sus copas bien definidas, BAFC-PL 1291; *7,* aspecto general de una colonia compuesta de forma botroidal, mostrando el esqueleto de las bases de sus copas bien definidas, BAFC-PL 1291; *8,* detalle de la colonia de la figura 7 en las que se conserva, bien delineado, el esqueleto de las bases de las copas, BAFC-PL 1291; *9,* colonia bien conservada, los bordes de las copas se encuentran algo deformados probablemente debido a la diagénesis, BAFC-PL 1297; *10,* detalle de una colonia mostrando sectores de masa no estructurada, BAFC-PL 1297; *11,* detalle una colonia en las que se conserva el esqueleto de las bases de las copas, BAFC-PL 1291; *12,* aspecto general de una colonia compuesta botroidal, mostrando sectores en los que se conserva el esqueleto con las copas y otros sectores cuya masa está algo alterada, BAFC-PL 1299. Escala gráfica: 100 µm, en las figuras 1, 6, 7,12; 10 µm, en las figuras 2, 4, 8, 9, 10, 11; 1 µm, en las figuras 3, 5.

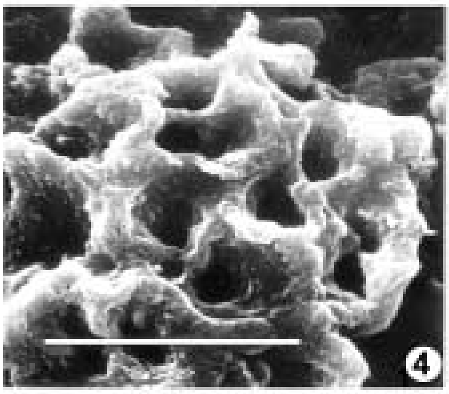
PLATE 1–*1-12*, *Botryococcus* sp. *1,* compound colony showing certain parts with skeleton and cups, and patchs of structureless mass, BAFC-PL 1293; *2,* detail of well-preserved cups of a compound colony. Part of the colony displays a structureless mass, BAFC-PL 1297; *3,* detail of the colony of figure 2 showing a well-preserved cup with growth rings, BAFC-PL 1297; *4,* detail of a colony showing the skeleton of the well-defined cups, BAFC-PL 1291; *5,* detail of a cup showing growth rings, BAFC-PL 1297; *6,* compound colony showing the skeleton of the well-defined cups, BAFC-PL 1291; *7,* botryoidal compound colony showing the skeleton of the well-defined cups, BAFC-PL 1291; *8,* detail of the colony of figure 7 showing the skeleton of the well-defined cups, BAFC-PL 1291; *9,* well-preserved colony, the edge of the cups are slightly deformed, probably due to diagenesis. BAFC-PL 1297; *10,* detail of a colony with patchs of structureless mass, BAFC-PL 1297; *11,* detail of a colony showing the skeleton of the cups, BAFC-PL 1291; *12,* compound botryoidal colony showing, in parts, skeleton and cups, and patches of structureless mass, BAFC-PL 1299. Scale bar: 100 µm, figures 1, 6, 7, 12; 10 µm, figures 2, 4, 8, 9, 10, 11; 1 µm, figures 3, 5.

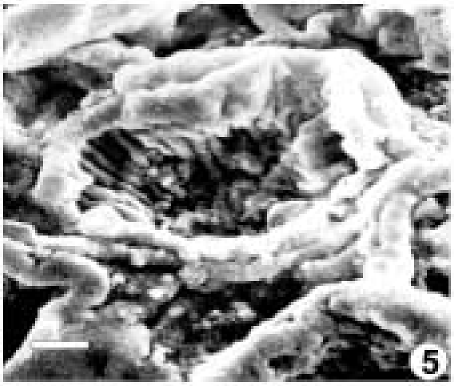
LÁMINA 1

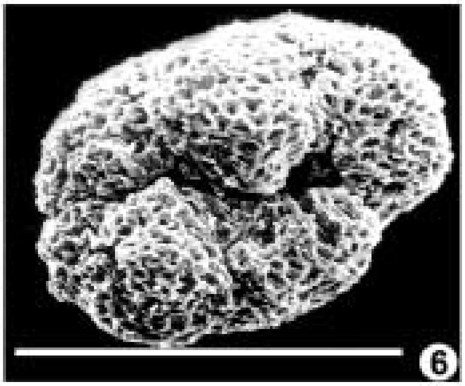


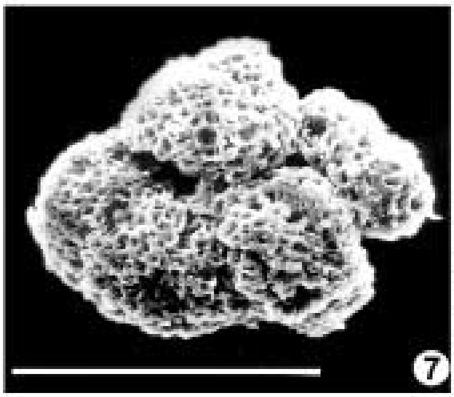


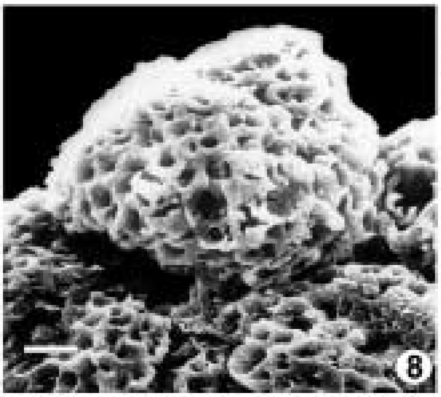


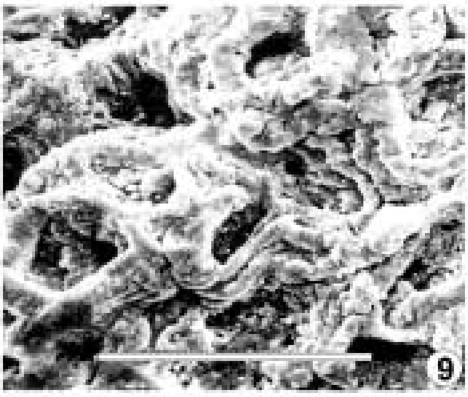


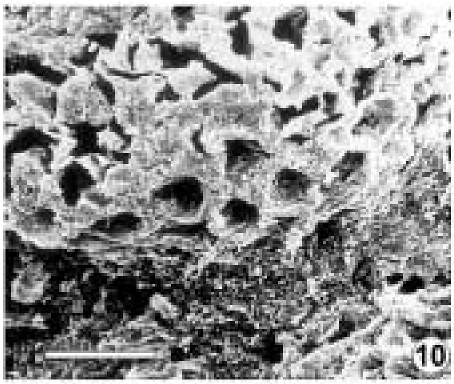


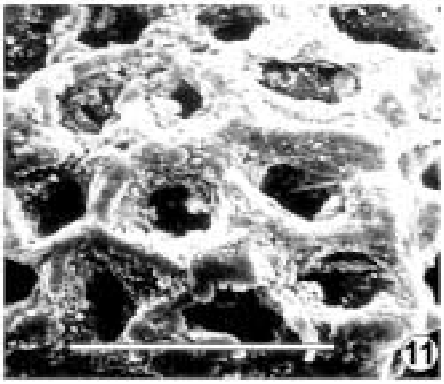


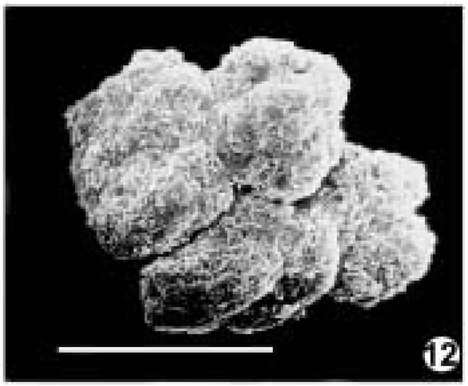












En el nivel BAFC-PL 1297 (16% de *Botryococcus*) coexisten distintos estadios de desarrollo (colonias simples y compuestas) y distintas formas de las colonias, con lo que se puede inferir el predominio de condiciones ambientales y/o climáticas variables durante un largo período de tiempo (Guy-Ohlson,1998). Este nivel se caracteriza por una buena conservación en algunas de las colonias, en las cuales se pueden observar anillos de crecimiento (Lámina 1, Figs. 2, 3, 5 y 9) y autoesporas, aunque estas últimas son escasas. En el mismo nivel otras colonias presentan una tendencia a formar una matriz no estructurada (Lámina 1, Figs. 2 y 10). La buena conservación de las colonias estaría señalando que el depósito se produjo en un ambiente somero sin marcadas perturbaciones y con un rápido enterramiento (Guy-Ohlson, 1992), mientras que la presencia de una matriz no estructurada en otras colonias sugeriría una baja disponibilidad de oxígeno en el medio durante el depósito (Guy-Ohlson, 1992).

En el nivel BAFC-PL 1298 (35% de *Botryococcus*) también coexisten distintos tipos de estadios de desarrollo de las colonias (simples y compuestas), con diferentes formas. Esto sugiere condiciones climáticas variables durante un largo período de tiempo (Guy-Ohlson, 1998). En cuanto a la conservación de las colonias, algunas exhiben sectores de matriz no estructurada, lo cual sugeriría que el depósito se produjo en un ambiente con limitado contenido de oxígeno (Guy-Ohlson, 1992).

El último nivel pelítico (BAFC-PL 1299) registra un bajo porcentaje de *Botryococcus* (4%). Se presenta un solo estadio de desarrollo (colonias compuestas), sin autoesporas, y colonias de formas similares. Esto indica que hubo un corto período de crecimiento bajo condiciones climáticas uniformes. Presenta algunas colonias que muestran buena conservación de copas y esqueleto, mientras que en otras el esqueleto tiene una tendencia a formar una espesa matriz alterada (Lámina 1, Fig.12). Las colonias que poseen esta tendencia a formar una matriz no estructurada sugieren que el depósito se produjo en un ambiente con bajo contenido de oxígeno (Guy-Ohlson, 1992).

Las características morfológicas generales de las colonias presentes en cada uno de los niveles analizados se resumen en la Tabla 1.

DISCUSIÓN

El estudio morfológico de las colonias de *Botryococcus* recuperadas de los niveles lacustres triásicos de la sección basal de la Formación Casa de Piedra permite inferir que las colonias se habrían desarrollado en un ambiente lacustre marginal bajo condiciones paleoambientales y/o paleoclimáticas variables, probablemente bajo un clima con estaciones alternantes húmedas y secas (Barredo, 1998). El medio habría sido ligeramente alcalino, somero y tranquilo, permitiendo la proliferación de estas Chlorococcales. Las riberas del lago estuvieron cubiertas por vegetación baja, fundamentalmente de sphenophytas (Barredo *et al.*, 1999). La somerización paulatina del sistema, que fue evolucionando desde un sistema lacustre profundo (Formación Carrizalito) a un sistema lacustre somero (facies con *Botryococcus* de la sección inferior de la Formación Casa de Piedra) y luego hacia facies fluviales de sag (sección superior de la Formación Casa de Piedra) (Barredo *et al.*, 1999), habría creado las condiciones ambientales adecuadas para la proliferación de *Botryococcus*. La presencia de colonias de matriz no estructurada permitiría inferir que el medio habría exhibido una reducción en su contenido de oxígeno hacia los niveles superiores de la sección estudiada, sin alcanzar, sin embargo, condiciones de anoxia.

Según su morfología funcional, *Botryococcus* es un S-estratega, es decir, una especie tolerante al estrés, caracterizada por un crecimiento lento y hábito colonial, con colonias que muestran una baja relación superficie/volumen. Dominan en condiciones de alta luminosidad y bajas concentraciones de nutrientes, y exhiben poco desarrollo en bajas temperaturas (Huszar y Carrasco, 1998). En este sentido, *Botryococcus* habría proliferado en el ambiente ligeramente estresante (y en ausencia de otras Chlorococcales) de los niveles basales de la Formación Casa de Piedra. *Botryococcus* posee adaptaciones para vivir bajo condiciones desfavorables como la habilidad para resistir a cambios ambientales y para reservar grandes cantidades de alimento, sus paredes son resistentes a la desecación y se reproducen vegetativamente (Guy-Ohlson, 1992).

Botryococcus no está representado en las facies fluviales de ríos entrelazados desarrolladas en la parte superior de la Formación Casa de Piedra, posiblemente debido a la renovación continua del agua superficial característica de este ambiente.

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DINOFLAGELLATE CYST BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF THE LOWER-MIDDLE JURASSIC SUCCESSION OF QATAR, ARABIAN GULF

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Abstract

Dating of the Izhara and Araej formations in Qatar by $^{87}Sr/^{86}Sr$ gives an overall age range of 164.70 Ma (Bathonian/Callovian) to 202.40 Ma (Hettangian). Palynological analysis of these sediments is dominated by marine microplankton. The basal Izhara was found barren of index palynomorphs. Four informal dinoflagellate cyst assemblage biozones embracing the interval from Bajocian to Early Callovian are defined as follows: *Mancodinium semitabulatum-Pareodinia ceratophora* Assemblage Zone I (Early Bajocian), *Gonyaulacysta pectinigera-Escharisphaeridia pocockii* Assemblage Zone II (Late Bajocian), *Ctenidodinium continuum-Dichadogonyaulax sellwoodii* Assemblage Zone III (Bathonian), and *Chlamydophorella ectotabulata-Rhynchodiniopsis cladophora* Assemblage Zone IV (Late Bajocian-Early Callovian). These assemblages resemble those reported from Jurassic deposits elsewhere in the circum-Mediterranean region. The palynofacies and organic matter of these formations are almost exclusively of marine algal origin. The Izhara and Araej formations may have been deposited in shallow marine environment grading from the inner oxic shelf (Izhara) to middle dysoxic shelf (Araej) respectively.

Keywords: Dinoflagellate cysts, Qatar, Jurassic, Paleoenvironment, Izhara, Araej.

Resumen

La datación de las formaciones de Izhara y Araej en Qatar mediante estudios isotópicos ($^{87}Sr/^{86}Sr$) da una edad entre 164,70 Ma (Batoniense/Calloviense) y 202,40 Ma (Hettangiense). El análisis paleontológico de los sedimentos se ha basado en la presencia de microplancton marino. En la Formación Izhara basal no se han encontrado fósiles índices de palinomorfos. Se han definido cuatro biozonas informales de asociación basadas en la presencia de dinoflagelados, que se extienden desde el Bajociense al Calloviense inferior. Estas biozonas son: la Biozona de Asociación I *Mancodinium semitabulatum-Pareodinia ceratophora* (Bajociense inferior), la Biozona de Asociación II *Gonyaulacysta pectinigera-Escharisphaeridia pocockii* (Bajociense superior), la Biozona de Asociación III *Ctenidodinium continuum-Dichadogonyaulax sellwoodii* (Batoniense) y la Biozona de Asociación IV *Chlamydophorella ectotabulata-Rhynchodiniopsis cladophora* (Bajociense superior-Calloviense inferior). Esas asociaciones son semejantes a las registradas en los depósitos jurásicos descritos en toda la región circummediterránea. Las palinofacies y el contenido en materia orgánica de esas formaciones indican exclusivamente un origen algal marino. Las formaciones Izhara y Araej podrían haber sido depositadas en un medio marino somero, que varían desde unas condiciones de una plataforma interna óxica (Izhara) a una plataforma media dióxida (Araej).

Palabras clave: Dinoflagelados, Qatar, Jurásico, Paleoambientes, Izhara, Araej.

INTRODUCTION

Qatar is an arid desert area that covers about 11610 km^2. It constitutes the eastern part of the Arabian Peninsula in the central zone of the Arabian Gulf. Structurally, Qatar is a part of the regional Qatar-South Fars Arch, which trends NNE-SSW. It is a part of the Arabian Interior Platform, over which a thick sequence of sediments has accumulated since the Palaeozoic, the thickness exceeds 10 km. (Alsharhan & Nairn 1997). The Jurassic sedimentary basins in the subsurface of Qatar are regionally important economically. This is because Jurassic formations contain most of the hydrocarbon reservoirs and source rocks. The history of hydrocarbon exploration and production in Qatar, covering both onshore and offshore concessions, was summarized by Domínguez (1965), Sugden & Standring (1975), Owen (1975), Beydoun (1988), and Alsharhan & Nairn (1994, 1997).

This is the first report of Jurassic dinoflagellate cyst of Qatar and Arabia. The present paper describes the palynostratigraphy of Lower-Middle Jurassic rocks, determining the paleoenvironmental conditions which prevailed during the deposition of these sediments and correlating the results with others with special emphasis on the Tethyan Realm.

PREVIOUS BIOSTRATIGRAPHICAL STUDIES

The previous biostratigraphical studies on the Jurassic rocks of Qatar are scarce. Smout & Sugden (1961) gave a description for some species of the genus *Pfenderina* (foraminifera), of the Uwainat Member, of the Araej Formation in Qatar. They introduced the species *Pfenderina trochoidea* and placed it in the family Pfenderinidae. Sugden & Standring (1975) discussed the main stratigraphical and paleontologic characters of the Jurassic and Triassic Araej, Izhara, Hamlah and Gulailah formations in Qatar. They also listed some elements of the faunal contents of these formations of which the Pfenderinidae is the major element of the faunal contents. Al-Saad *et al.* (1992) studied in detail the lithofacies and depositional setting of the Araej Formation in Dukhan Oil Field in Qatar. Based on lithologic and microfacies analysis, they recognized 31 microfacies throughout the Araej Formation, which consist mainly of shallow carbonate facies and suggested its deposition in a subtidal to shoal setting.

Hewaidy & Al-Saad (1993) identified the foraminiferal content of the Areaj Formation in Dukhan Oil Field. They divided the formation into five biostratigraphical zones and assigned the formation to Bathonian/early Callovian times. They also attempted to correlate their zones with those of the Dhruma Formation in Saudi Arabia. Recently, Hewaidy & Al-Saad (2000) studied the foraminiferal content of the Lower-Middle Jurassic exposures around Riyadh City in central Saudi Arabia and in ten wells drilled in the Qatar Peninsula. The Lower Jurassic (Toarcian) Marrat Formation in central Saudi Arabia and the Hamlah Formation in Qatar are found barren of foraminifera. In the Middle Jurassic Dhruma Formation in central Saudi Arabia, 95 foraminiferal species are identified. In the Middle Jurassic Izhara and Araej formations in Qatar, 33 foraminiferal species are identified. Biostratigraphical schemes are proposed for each of the two areas studied. In central Saudi Arabia the Middle Jurassic is divided into eight biostratigraphical zones and in Qatar into seven zones.

MATERIAL AND METHODS

The present investigation is based on the analysis of core samples from two exploration boreholes drilled in west and central Qatar (Fig. 1). A total of 76

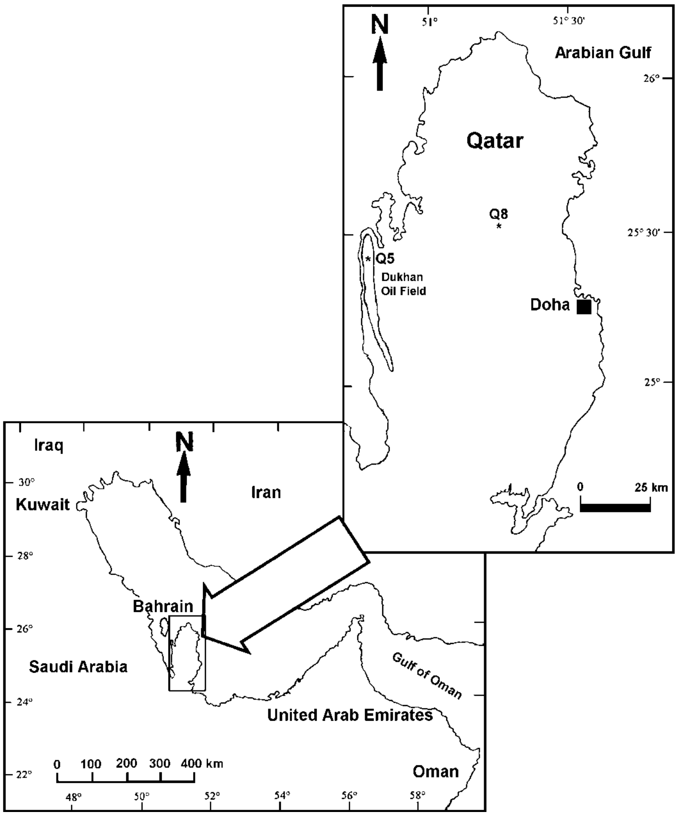

FIGURE 1–Location map of the study wells, Qatar.

core samples taken from well Q5 and Q8, represent the Izhara and Araej formations. The details for each well and the number of samples studied are shown in table 1.

Well No.	No. of Core Samples	Formation	Location
Q5	31	Izhara and Araej	Dukhan anticline, west Qatar
Q8	45	Izhara, Araej and Hanifa	Kharaib, central Qatar

TABLE 1–Number of samples and corresponding formations in the studied wells.

Samples have been processed using the standard palynological techniques. The samples were treated with dilute HCl, HF and concentrated HCl to remove carbonates, silicates and fluorides respectively. The residues were then filtered using wet sieving with 15 µm polyester sieves. At least two slides of each sample were completely examined. The first 200 palynomorphs were counted for statistical analysis. Epoxy resin is used as mounting medium. All slides were microscopically examined with an Olympus microscope. The palynological analysis includes qualitative and quantitative analysis of palynomorphs and determination of the ratio between terrigenous and marine particles.

Selected samples from the base and top of each formation have been analysed for their strontium isotope dating. Detailed chronostratigraphy, palynofacies, source-rock potential and organic thermal maturity of these sediments are beyond the scope of the present study and was published by the present authors (Ibrahim *et al.*, 2002a). All palynological slides are curated in the Department of Environmental Sciences, Faculty of Science, Alexandria University, Egypt.

STRATIGRAPHICAL SETTING

In the study wells, the Lower-Middle Jurassic rock sequence is represented from base to top by the Izhara and Araej formations (Figs. 2, 3) as follows:

Izhara Formation

This formation was introduced by Sugden in an unpublished report and described by Sugden & Standring (1975), and takes its name from a locality near the Kharaib Village in central Qatar. The type section is well Kharaib-1, onshore central Qatar. The thickness of the Izhara Formation in Qatar ranges between 55 to 142 m, while in Dukhan field (Khatiyah sector) it ranges between 122 to 142 m (Al-Saad 1996). Lithologically, the Izhara Formation is formed of dark grey, black argillaceous limestone in its upper and lower parts and dolomitic limestones in its middle part. Generally, the limestone is intercalated with thin lamina of dark grey shale, marl, claystone and anhydrite.

The formation ranges in age from Bajocian to possibly early Bathonian (Sugden & Standring 1975; Al-Husseini 1997; Alsharhan & Nairn 1997; Hewaidy & Al-Saad 2000), where it is regarded as equivalent to the Lower Dhruma Formation in Saudi Arabia. The Izhara Formation rests unconformably over the Gulailah Formation and the Hamlah Formation in

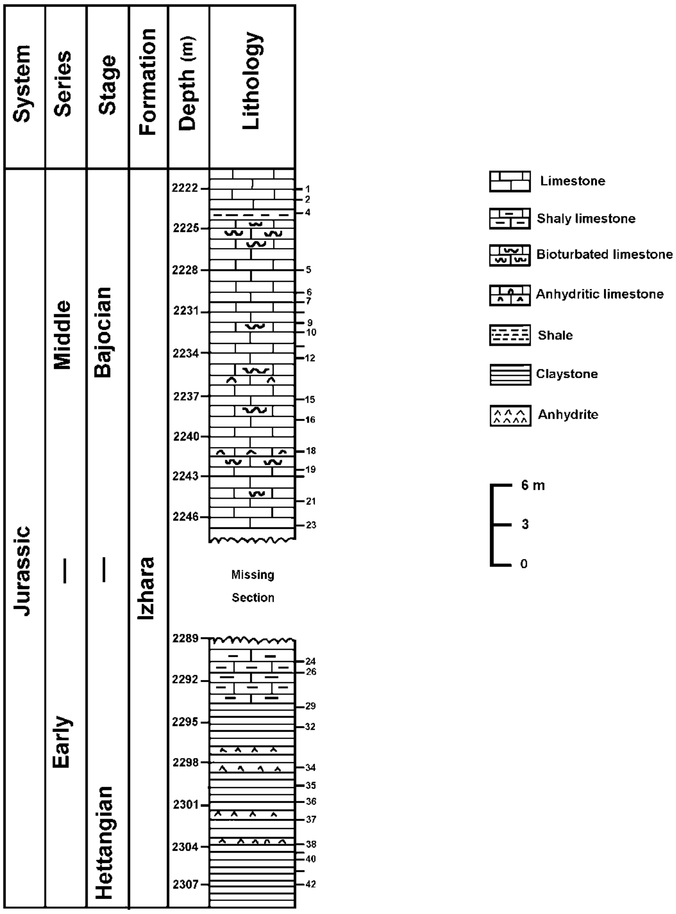

FIGURE 2–Lithostratigraphy and sample position of the Lower Jurassic Izhara Formation in Q5 well.

central and western Qatar respectively. While, it is conformable with the overlying Araej Formation (Fig. 4).

Araej Formation

This formation is introduced by Sugden (cited in Sugden & Standring, 1975) and takes its name from Gebel Araej in central Qatar near the Kharaib Village. The type section was established from well Kharaib-1, between drilled depths 2,137 and 2,316 m, (180 m thick). In other wells, the Araej Formation reaches a thickness of 180 to 200 m, and is divided into three members (Sugden & Standring, 1975; Al-Saad, 1996; Alsharhan & Nairn, 1997) from top to bottom as follows:

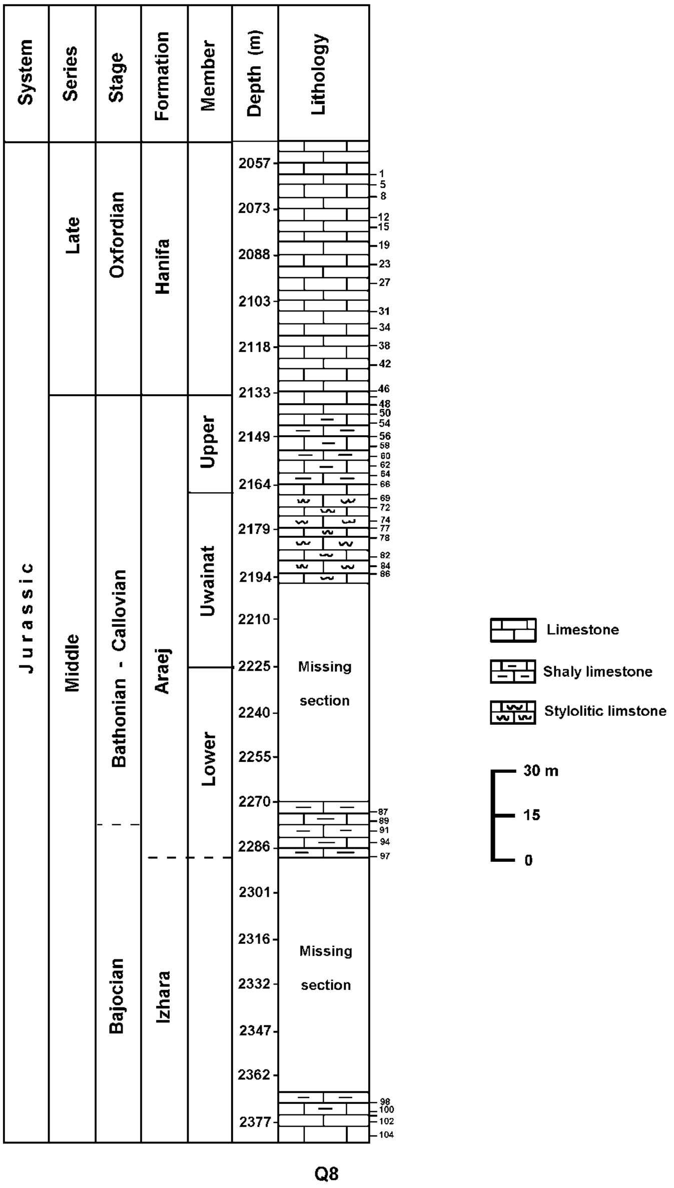

FIGURE 3–Lithostratigraphical correlation and sample position of the Jurassic Izhara, Araej and Hanifa formations in Q8 well.

Upper Araej Member

This unit is composed of dark grey to black, dark reddish pyritic shaly/argillaceous limestone. The upper Araej member is the thinnest member. Its thickness ranges between 29 and 76 m. The contact between the dark to grey shaly limestone of the upper Araej member and the olive limestone of the underlying Uwainat Member is sharp.

Uwainat Member

The Uwainate Member took its name from a locality near Dukhan Oil field. It is the middle member of the Araej Formation and is formed of grey, olive, oil-stained, stylolitic compact limestone. This member is marked by its light coloured sediments when compared with the upper and lower members. The thickness of the Uwainat Member range between 49 and 59 m.

Lower Araej Member

It is the thickest member of the Araej Formation, composed of dark grey, black and dark reddish pyritic, argillaceous limestone. The contact between the lower Araej member and the overlying Uwainat Member is taken between the grey, laminated, bioturbated pyritic argillaceous limestone of the lower Araej member and the olive limestone of the Uwainat Member. The thickness of the lower Araej member ranges between 94 and 117 m.

Generally, Sugden & Standring (1975) assigned the age of the Araej Formation as Bathonian to Oxfordian and, thus claimed the formation was equivalent to the middle and upper parts of the Dhruma Formation (Tuwaiq mountain) in Saudi Arabia (Al-Husseini, 1997). It is overlain disconformably by the Hanifa/Diyab Formation and is conformable with underlying Izhara Formation (Sugden & Standring, 1975; Al-Saad, 1996; Alsharhan & Nairn, 1997).

RADIOGENIC AGE DATING

Strontium isotope stratigraphy is a valuable tool to use either to complement biostratigraphical dating or to use where biostratigraphy is absent or is producing broad biozones. Table 2 gives the Sr results in terms of Stages based on firstly the Gradstein *et al.* (1994, 1995) timescale and secondly the Haq *et al.* (1988) timescale. These ages are based on the Howarth & McArthur (1997) global strontium seawater curve.

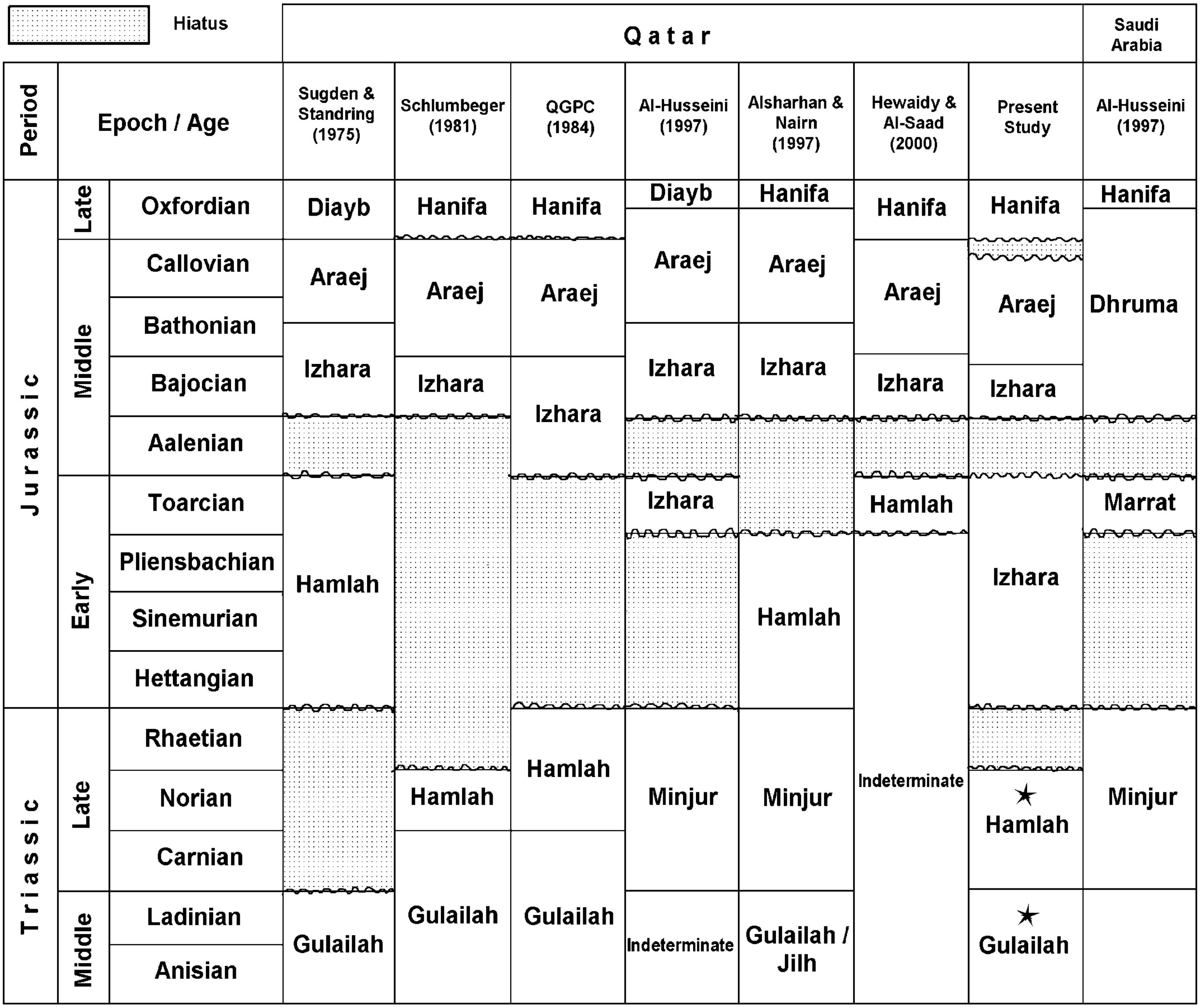

FIGURE 4–Subsurface correlation scheme of the Middle Triassic to Upper Jurassic rock units in Qatar. The asterisk refers to the work of Ibrahim (2003).

DINOFLAGELLATE CYST BIOZONATION

Jurassic palynology has not been studied in Qatar as well as in Arabia. The present investigation represent the first account from the subsurface Izhara and Araej formations encountered in wells Q5 and Q8.

Most of the 76 samples analyzed yielded moderately rich and well preserved but not always diverse dinoflagellate cyst assemblages, especially in the Araej Formation, whilst poor preservation and scarcity of palynomorphs are characteristic features of the upper Izhara in well Q5. The lower part of the Izhara Formation (Hettangian-Sinemurian) in well Q5 is barren of palynomorphs probably due to the destruction of the original matrix by dolomitization, recrystallization and/or bacterial degradation. Spores and pollen have been quantitatively determined to specific level. They occur very rarely in the studied sections. Generally, 58 dinoflagellate cyst species belonging to 29 genera, 4 acritarch taxa, and 17 miospore species related to 13 genera have been identified (see Appendix) and selected taxa are depicted in plates 1-5. The stratigraphical distribution and occurrence of these palynomorphs are depicted in the figures 5 and 6.
]

Sample/ Depth	**Well**	**Formation**	**^{87}Sr/^{86} Sr**	**Age Ma**	**Stage (Gradstein *et al.* 1994) Ages are tops**	**Stage (Haq *et al.* 1988) Ages are tops**	**Epoch**
47/ 2135	Q8	Upper Araej Mm	0.706960	164.70	Bathonian/ Callovian 164.4 Ma	Bathonian 157 Ma	Middle Jurassic
53/ 2142	Q8	Upper Araej Mm	0.706959	165.00	Bathonian 164.4 Ma	Bathonian 157 Ma	Middle Jurassic
65/ 2163	Q8	Upper Araej Mm	0.706964	165.20	Bathonian 164.4 Ma	Bathonian/ Bajocian	Middle Jurassic
86/ 2195	Q8	Mid Araej Uwainat Mm	0.707059	167.70	Bathonian 164.4 Ma	Bajocian 165 Ma	Middle Jurassic
90+89/ 2277-78	Q8	Lower Araej Mm	0.707083	170.10	Bathonian/ Bajocian	Bajocian 165 Ma	Middle Jurassic
99/ 2373	Q8	Top Izhara	0.707268	175.00	Bajocian 169.2 Ma	Aalenian 171 Ma	Middle Jurassic
101/ 2376	Q8	Mid Izhara	0.707426	195.60	Sinemurian 195.3 Ma	Sinemurian 194Ma	Early Jurassic
3/2224	Q5	Top Izhara	0.707185	173.40	Bajocian 169.2 Ma	Bajocian 165 Ma	Middle Jurassic
23/2247	Q5	Mid Izhara	0.707162	185.00	Toarcian 180.10 Ma	Toarcian 179.00 Ma	Middle Jurassic
42/2307	Q5	Base Izhara	0.707682	202.40	Hettangian 201.9 Ma	Hettangian 201 Ma	Early Jurassic

TABLE 2–Sample data and their strontium isotope ratios and age dating according to Gradstein *et al.* (1994, 1995) and Haq *et al.* (1988) timescale.

Four dinoflagellate cyst zones and one barren zone are proposed for the Hettangian-Early Callovian succession of Qatar. Figure 8 shows the correlation between the present dinoflagellate biozones and the Tethyan as well as with the British biozones. The next paragraphs deal with these dinoflagellate biozones in ascending stratigraphical order as follows:

Barren Zone

A barren belt of carbonate rocks representing the basal part of the Izhara Formation in well Q5 (interval between 2,246 to 2,307 m), and well Q8 (from 2,376 to 2,380 m).

Unfortunately, the characteristic Early Jurassic dinoflagellate cysts in this interval are absent. Only microforaminiferal test linings and few numbers of *Inaperturopollenites* are recorded (Figs. 5, 6). Strontium isotopes assigned the age of this barren zone as belonging to the Hettangian-Toarcian (185.0-202.4 Ma).

Zone I: *Mancodinium semitabulatum-Pareodinia ceratophora* Assemblage Zone

This zone contains dinoflagellate cysts from the upper part of the Izhara formation in wells Q5 and Q8 (Figs. 5, 6). The dominant dinoflagellate cysts in well Q5 are *Chytroeisphaeridia chytroeides, Dichadogonyaulax* cf. *sellwoodii, Mancodinium semitabulatum, Mendicodinium microscabratum, M. spinosum, Nannoceratopsis gracilis* and *Rhynchodiniopsis? regalis*. The equivalent interval in well Q8 differs in its dinoflagellate cyst content, where the last mentioned species are absent and other assemblage is present as *Cribroperidinum* spp. (formerly *Acanthaulax*), *Echarisphaeridia* spp., *Pareodinia ceratophora* and *Valensiella* spp.

The age of this zone is assigned to the Early Bajocian as documented by the presence of *Nannoceratopsis gracilis* and *Rhynchodiniopsis*? *regalis*, which appear in Early Bajocian of England (Fenton *et al.* 1980; Riding & Thomas 1992). Dodekova (1990) recorded *R. regalis* from Middle Bajocian of Bulgaria. Also, Davies (1983; Canada) and Below (1987; Germany) recorded *N. gracilis* from the Toarcian-Early Bajocian.

Moreover, the Early Bajocian age is signalized by the occurrence of *Mancodinium semitabulatum*. It was recorded from Early Bajocian of Boreal and Tethyan regions like Arctic Canada (Davies 1983), Germany (Below 1987; Feist-Burkhardt 1990) and France (Rauscher & Schmidt 1990).

The Early Bajocian age is generally indicated in many localities by the FADs of *Pareodinia ceratophora*, e. g., NW Germany (Wilson & Clowes, 1980; Prauss, 1989) and Egypt (Keeley *et al.*, 1990; Ibrahim *et al.*, 2002b). Nevertheless, *Mendicodinium microscabratum* and *M. spinosum* are recorded for the first time from the Bajocian, Bucefalo Palliani *et al.* (1997) firstly recorded these two species from the Early Toarcian of Italy. Finally, the Early Bajocian age is supported by the absence of the Late Bajocian-Bathonian key species as *Ctenidodinium combazii*, *Dichadogonyaulax sellwoodii*, and the *Korystocysta kettonensis*/*gochtii* group.

Correlation

The Bajocian dinoflagellate assemblage described from France by Rauscher & Schmidt (1990) is similar to the studied assemblage zone I based on similar species as *Nannoceratopsis gracilis* and *Mancodinium semitabulatum*. A noticeable similarity is observed between the present assemblage zone I and the *Acanthaulax crispa* Total Range Biozone of Bajocian age in England (Riding & Thomas 1992). Both assemblages are characterized by the presence of *M. semitabulatum*, *N. gracilis* and *P. ceratophora*. However, *A. crispa* is totally absent and *D. sellwoodii* has a younger age (Late Bajocian) in the wells studied. Huault (1999) differentiated the Lower (*Jansonia jurassica* Zone) and Upper Bajocian (*Rhynchodiniopsis? regalis* Zone) strata of the southern margin of Paris Basin by the presence of several species in the lower Bajocian like *Jansonia jurassica*, *R. regalis*, *P. ceratophora* and *Escharisphaeridia* spp. The last species are also recorded herein except *J. jurassica*.

The *Mancodinium semitabulatum-Pareodinia ceratophora* Assemblage Zone is equivalent to the Early Bajocian *Haurania deserta* foraminiferal Zone (Fig. 7) from the Early Bajocian of Qatar (Al-Saad, 1996).

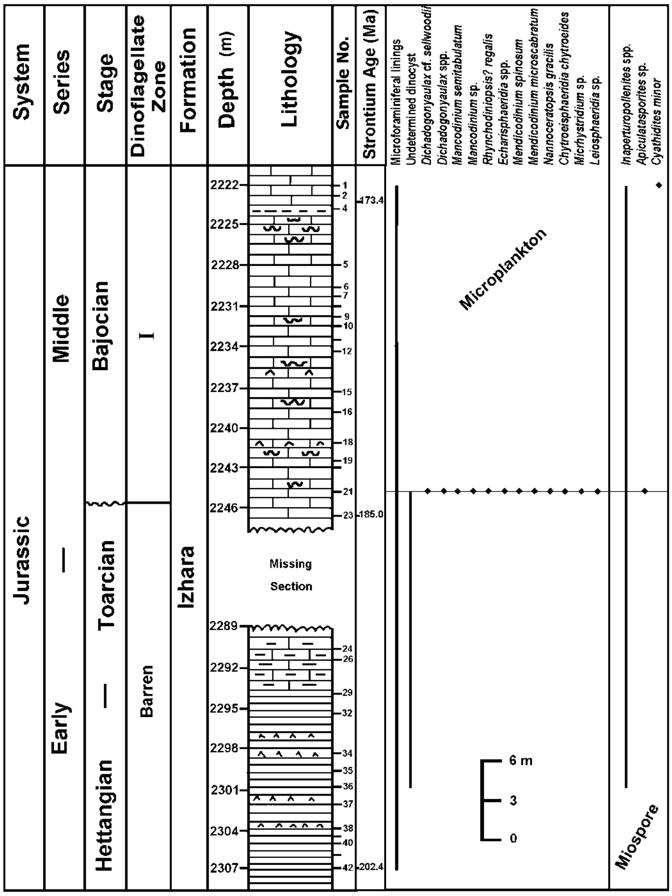

FIGURE 5–Stratigraphical distribution chart of palynomorphs in Q5 well.

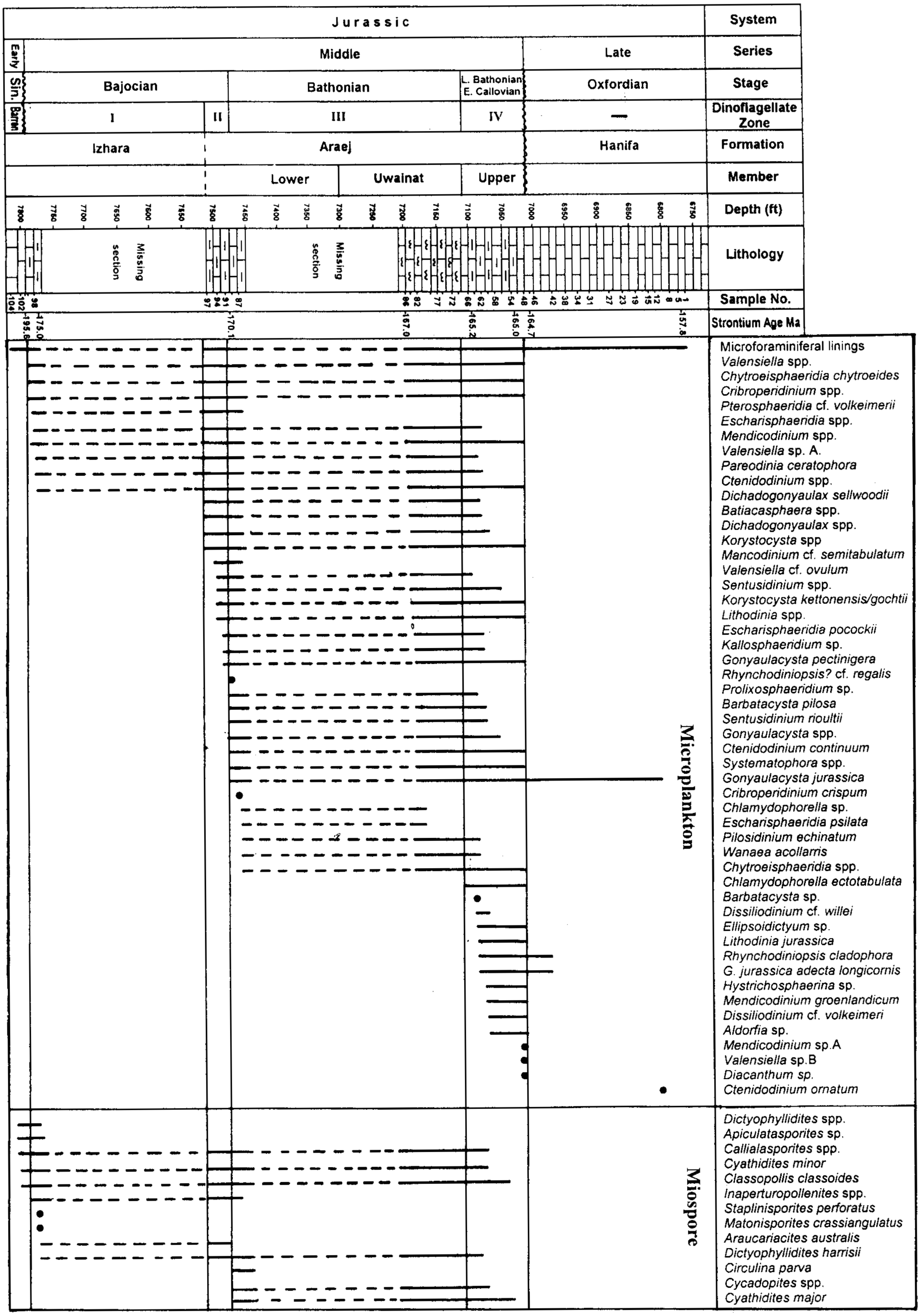

FIGURE 6–Stratigraphical distribution chart of palynomorphs in Q8 well.

Zone II: *Gonyaulacysta pectinigera-Escharisphaeridia pocockii* Assemblage Zone

The *Gonyaulacysta pectinigera-Echarispheridia pocockii* Assemblage Zone is dated Late Bajocian and is represented by the basal part of the Araej Formation in well Q8, interval from 2,277 to 2,288 m.

This zone is characterized by the FADs of *Batiacasphaera* spp., *Dichadogonyaulax sellwoodii, Escharisphaeridia pocockii, Gonyaulacysta pectinigera, Kallosphaeridium* sp., *Korystocysta kettonensis/gochtii*, *Lithodinia* spp., *Mancodinium* cf. *semitabulatum*, and *Sentusidinium* spp., plus the common occurrence of *Pareodinia ceratophora*, which continues from the underlying zone.

The Late Bajocian age assigned to this zone is confirmed by the FADs of *Dichadogonyaulax sellwoodii*, which recorded in the Late Bajocian of England (Fenton *et al.*, 1980; Riding & Wright, 1989; Riding & Thomas, 1992; Gowland & Riding, 1991). *Gonyaulacysta pectinigera* is considered as one of the Late Bajocian marker species in Germany (Fenton, 1981; Feist-Burkhardt & Wille, 1992) and England (Bailey, 1990). The *Korystocysta kettonensis/gochtii* group has FADs in the Late Bajocian of Alberta (Poulton *et al.*, 1990) and Scotland (Riding *et al.*, 1991). On the other hand, the absence of the Bathonian marker species like *Chlamydophorella* spp., *Ctenidodinium combazii, C. continuum* and *Gonyaulacysta jurassica* supports a Late Bajocian age. The upper boundary of the present zone II is located just below the FADs of *C. continuum, G. jurassica, Pilosidinium echinatum* and *Wanaea acollaris.*

Correlation

Woollam & Riding (1983) and Riding & Thomas (1992) differentiated Upper Bajocian rocks in England by several species that occurred in the *Acanthaulax crispa* Zone. The British zone is similar to the studied one by the presence of *D. sellwoodii*, *Kallosphaeridium* sp., *Sentusidinium* spp. and *Pareodinia ceratophora*. However, there are several species that are absent in the studied zone as *Aldorfia aldorfensis, Carpathodinium predae* and *A. crispa* (now *Cribroperidinium crispum*). The latter species has a younger age (Bathonian) in the present material from Qatar. The present assemblage zone II is correlatable with the Late Bajocian zones (*K. kettonensis* and *D. sellwoodii*), which were described by Conway (1990) from Israel. *K. kettonensis, D. sellwoodii* and *Pareodinia ceratophora* are the key markers of the Late Bajocian assemblages in both Qatar and Israel.

The present assemblage zone II is equivalent to the Late Bajocian foraminiferal zone *Trocholina minuta* from Qatar (Al-Saad, 1996) (Fig. 7).

Zone III: *Ctenidodinium continuum-Dichadogonyaulax sellwoodii* Assemblage Zone

The assemblage zone III is comprises the Lower Araej and Uwainat members, interval from 2,169 to 2,277 m in well Q8 and is belongs to the Bathonian Stage.

This assemblage zone is marked by the first incoming of several important species such as *Barbatacysta pilosa*, *Chlamydophorella* sp., *Cribroperidinium* (*Acanthaulax*) *crispum, Ctenidodinium continuum, Escharisphaeridia psilata, Gonyaulacysta jurassica, Pilosidinium echinatum, Prolixosphaeridium* sp., *Sentusidinium rioultii*, and *Wanaea acollaris.* It is also characterized by the abundance of *Dichadogonyaulax sellwoodii* and the *Korystocysta kettonensis/gochtii* group, which persists from the underlying zone. The upper boundary of this zone is located below the FADs of *Gonyaulacysta jurassica* subsp. *adecta longicornis, Lithodinia jurassica* and *Rhynchodiniopsis cladophora.*

The Bathonian age of the present assemblage zone III is supported by the occurrence of *Ctenidodinium continuum* that recorded from Bathonian strata in many localities as Germany (Gocht 1970); England (Riding & Thomas, 1992); Paris Basin (Huault, 1999) and Egypt (Ibrahim *et al.* 2002b). The dominance of *Dichadogonyaulax sellwoodii* and the *Korystocysta kettonensis/gochtii* group have been observed in the Bathonian of England (Woollam & Riding, 1983; Riding & Thomas, 1992); Egypt (Naim *et al.*, 1989; Aboul Ela & Mahrous, 1990; Ibrahim *et al.*, 2002b); NE Spain and Portugal (Smelror *et al.*, 1991); South Germany (Smelror & Dietl, 1994) and South Paris Basin (Huault, 1999).

Other index species of the Bathonian Stage are *Barbatacysta pilosa* (Smelror *et al.*, 1991, Portugal; Smelror & Below 1992, Barents Sea); *Sentusidinium rioultii* (Thusu *et al.* 1988, NE Libya; Huault 1999, Paris Basin); *Pilosidinium echinatum* (Smelror & Leereveld, 1989, southern France; Smelror & Lominadeze, 1989, Caucasus), and *Gonyaulacysta jurassica* (Davies, 1985, Portugal; Huault, 1999, Paris Basin).

Correlation

The Bathonian dinoflagellate assemblage in Europe and circum-Mediterranean regions is dominated by complex chorate cysts like *Adnatosphaeridium* and *Compositosphaeridium* (Riding & Thomas, 1992; Smelror, 1993; Huault, 1999; Ibrahim *et al.*, 2002b).

These genera are completely absent from the Qatar material, which may be due to environmental conditions. The present Bathonian assemblage shows some resemblance with the British assemblage that was recorded by Woollam & Riding (1983), Riding *et al.* (1985) and Riding & Thomas (1992). Generally, they depend on the common occurrence of *Ctenidodinium combazii, C. continuum, C. ornatum, D. sellwoodii* and *Korystocysta* spp. These species are also recorded in the present zone except *C. combazii* and *C. ornatum.*

Taugourdeau-Lantz & Lachkar (1984), Fauconnier (1995) and Huault (1999) recorded dinoflagellate cyst assemblages from the Bathonian of France, which is correlatable with assemblage zone III by the presence of similar species like *Cribroperidinium* (*Acanthaulax*) *crispum, Ctenidodinium continuum, D. sellwoodii, G. jurassica* and *S. rioultii*. Thusu *et al.* (1988) introduced the *Diacanthum filapicatum* Zone for the Bathonian strata of NE Libya. The Libyan dinoflagellate assemblage resembles the present assemblage from Qatar by the occurrence of species as *Chytroeisphaeridia chytroeides, Escharisphaeridia pocockii, Korystocysta kettonensis, Pareodinia ceratophora, Sentusidinium rioultii*, and *Wanaea acollaris*. On the other hand, the *Diacanthum filapicatum* is absent from the present material, whilst *C. continuum, Ctenidodinium* spp., and *D. sellwoodii* are totally absent from the NE Libyan assemblage.

The Bathonian dinoflagellate cyst assemblages recorded from Egypt by Naim *et al.* (1989) and Ibrahim *et al.* (2002b) are comparable with the assemblage under study. The corresponding species are *C. continuum, D. sellwoodii, K. kettonensis/gochtii, Pareodinia ceratophora, Systematophora* spp., and *Wanaea acollaris,* whereas *C. combazii, C. ornatum* and *Compositosphaeridium polonicum* recorded by Ibrahim *et al.* (2002b) are absent from the present assemblage. The correlation between the present assemblage and the Bathonian *Wanaea acollaris* Zone of Israel (Conway, 1990) is valuable. This depends on the abundance of *D. sellwoodii, K. kettonensis,* and the FADs of *Sentusidinium rioultii,* and *Wanaea acollaris,* which is the case as in the present zone III. Hssäida (1990) described the Late Bathonian assemblage (*D. sellwoodii-C. combazii* Zone) in Morocco, which enriched in *Cleistosphaeridium varispinosum, C. combazii, D. sellwoodii* and *Nannoceratopsis pellucida.* The Moroccan assemblage zone is similar to the upper part of studied zone III. Smelror *et al.* (1991) studied the Bathonian dinoflagellate cysts in the Majdal Shams area near the Israel/Syrian border. Their Bathonian assemblage is rich in *Chytroeisphaeridia chytroeides, D. sellwoodii,* and *Systematophora* spp., among other species. The last mentioned species are also recognized here.

The present assemblage zone III is probably equivalent to the foraminiferal *Pfendrina trochoidea* and *Trocholina intermedia* zones from Qatar (Al-Saad, 1996).

Zone IV: *Chlamydophorella ectotabulata-Rhynchodiniopsis cladophora* Assemblage Zone

A Late Bathonian-Early Callovian age is given to the present assemblage zone IV, which includes the Upper Araej Member in well Q8 (interval from 2,131 to 2,164 m).

The present assemblage zone is characterized by the first evolutionary occurrence of several species as *Aldorfia* sp., *Barbatacysts* sp., *Chlamydophorella ectotabulata, Dissiliodinium* cf. *willei, Dissiliodinium* cf. *volkheimeri, Gonyaulacysta jurassica* subsp. *adecta* var. *longicornis, Hystrichosphaerina* sp., *Lithodinia jurassica, Mendicodinium groenlandicum* and *Rhynchodiniopsis cladophora*.

The Late Bathonian-Early Callovian age is determined by the FADs of *Chlamydophorella ectotabulata,* which documented in the Late Bathonian-Early Callovian of East Greenland (Smelror, 1988) and Callovian of Arctic area and Norway (Smelror, 1989; Smelror & Below, 1992). *Rhynchodiniopsis cladophora* was recorded from the Early Callovian of England (Riding, 1982; Porter, 1988; Riding & Thomas, 1992); Late Bathonian-Early Callovian of France (Rauscher & Schmidt, 1990; Huault, 1999) and Egypt (Ibrahim *et al.*, 2002b). The Late Bathonian-Early Callovian age is documented by the first appearance of *Mendicodinium groenlandicum* as in Bulgaria (Dodekova, 1990); Greenland (Smelror & Below, 1992), England (Riding and Thomas, 1992) and Egypt (Ibrahim *et al.*, 2002b). *Lithodinia jurassica* is another marker species recorded from the Late Bathonian-Early Callovian by Bujak & Williams (1977; Canada); Thusu & Vigran (1985; Libya); Williams & Bujak (1985; worldwide); Stover *et al.* (1996; worldwide); and Ibrahim *et al.* (2002b; Egypt).

Correlation

This zone under study shows a resemblance with the Late Bathonian assemblage that described by Fenton & Fisher (1978) from Spain. They concluded that the high percentage of *Ctenidodinium combazii, C. ornatum* and common *Gonyaulacysta jurassica, Escharisphaeridia pocockii, Rhynchodiniopsis cladophora, Lithodinia* sp. and *Atopodinium prostatum* characterize the Late Bathonian stage. *Atopodinium* *prostatum and C. combazii* are absent, while other species are recorded in the studied zone. The Late Bathonian-Early Callovian assemblage zone: *Ctenidodinium combazii-Cleistosphaeridium varispinosum* (Cc-Cv) from France described by Smelror & Leereveld (1989) depends on the occurrence of *C. combazii, C. varispinosum, Compositosphaeridium polonicum* and *Adnatosphaeridium caulleryi*. The last mentioned species are entirely absent in the studied well, which may be due to ecological factors. However, the Cc-Cv Zone includes identical species with the present assemblage zone IV as *Barbatacysta* "*Sentusidinium*" *pilosa, C. continuum, G. jurassica, L. jurassica, M. groenlandicum, Pilosidinium echinatum, R. cladophora* and *Sentusidinium rioultii*. Also, the Late Bathonian-Early Callovian assemblages recorded from England and France by Woollam & Riding (1983); Riding & Thomas (1992); Fauconnier (1995); and Huault (1999) are characterized by the FADs of *C. ornatum, Cleistosphaeridium polonicum, C. varispinosum, Systematophora vesitita* among others, which are absent in the studied zone IV. Whereas, *C. continuum, D. sellwoodii, G. jurassica adecta longicornis, G. jurassica* and *Mendicodinium groenlandicum* are present in the British, French and the Qatar assemblages.

The present assemblage zone IV is equivalent to the foraminiferal *Kurnubia jurassica* and *Trocholina palastiniensis* zones from the Late Bathonian-Early Callovian of Qatar (Al-Saad 1996).

PALEOENVIRONMENTAL INTERPRETATIONS

Palynofacies analysis allows characterizing the depositional environment in terms of salinity, oxygenation, water column stability and paleobathymetry, in addition to preliminary qualitative or semi-quantitative determination of hydrocarbon source rock potential (Batten, 1980; Tyson, 1993).

Izhara Formation

Carbonate sediments of the Izhara Formation (Hettangian-Bajocian) in Q5 and Q8 wells are dominated with opaque fragments "charcoal" (40-65%) and small debris of structured organic matter (cuticle

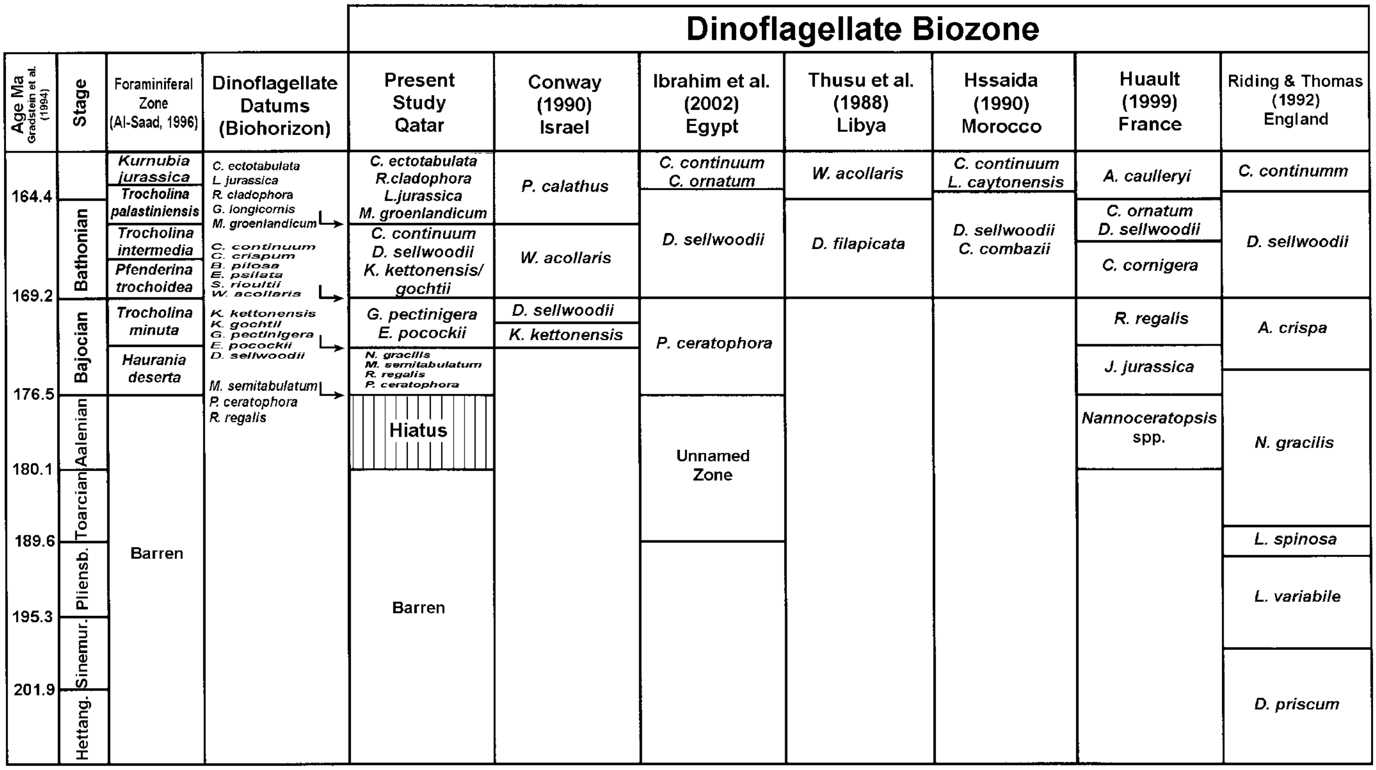

FIGURE 7–Correlation of the proposed dinoflagellate zonations for the Jurassic of Qatar with their equivalents in the Tethyan regions and England.

and tracheid). Palynomorphs are rich in microforaminiferal linings while dinoflagellate cysts and terrestrial miospores are fewer (Figs. 8, 9).

The high abundance of opaque phytoclasts in sediments of the Izhara Formation is mainly derived from the oxidation of woody material during transportation and/or post-depositional alteration. The particle size of the cuticle fragments has been observed to decrease in an offshore direction (Muller, 1959; Batten, 1974; Habib, 1982). The dominance of microforaminiferal linings in the Izhara Formation (Figs. 8, 9) appears indicative of normal marine conditions (Muller, 1959; Courtinat, 1989; Tyson, 1993) of shallow depths as they mainly derived from benthic rather than pelagic foraminifera (Tyson, 1995). Moreover, their high abundance may reflect an oxic water condition. The paucity of dinoflagellate cysts in the Izhara Formation, especially in the lower part, may be due to the increasing salinity of water that evidenced from the evaporite layers (anhydrite) intercalating with the claystone and limestone of the lower Izhara Formation. Tyson (1995) concluded that salinity-stressed biofacies tend to be characterized by blooms of only a limited number of species, hence low diversity and high dominance, which is the case as in most samples of the Izhara Formation.

Accordingly, the high profusion of microforaminiferal linings, opaque phytoclasts and small terrestrial cuticle debris with low frequency of marine dinoflagellate cysts in the carbonate sediments of the Izhara Formation may suggests a deposition in shallow marine environment of the inner oxic (aerobic) shelf condition (20-50 m).

Areaj Formation

The carbonate sediments of the Araej Formation in Q8 well represent the Bathonian-Early Callovian succession of Qatar. The palynomorphs are dominated by marine dinoflagellate cysts and microforaminiferal linings (Fig. 9). While the palynofacies elements (AOM, opaques and vitrinitic particles) are proportionally fluctuating from sample to another with no general trend. The relative abundance of dinoflagellate cysts to miospores is often used as an indicator of proximity to shore and a guide to transgressive and regressive phases (Davies *et al.*, 1982; Habib & Miller, 1989). Dinoflagellate cysts recorded from the Araej Formation belong to gonyaulacoid morphotypes such as *Chytroeisphaeridia, Cribroperidinium, Ctenidodinium, Dichadogonyaulax, Escharisphaeridia, Hystrichosphaerina, Gonyaulacysta, Korystocysta, Lithodinia, Pareodinia, Rhynchodiniopsis, Sentusidinium, Systematophora* and *Valensiella*. Downie *et al.* (1971) mention that gonyaulacoid-dominated assemblages are characteristic of more open marine facies, while peridinioid cavate-dominated cyst assemblages are indicative of lagoonal, estuarine, or brackish water environments.

Moreover, the thick-walled proximate cysts are dominating over the chorate cysts in sediments of the Araej Formation that means shallow neritic environment. Likewise, it has been suggested that near-shore environments tend to be characterized by a greater proportion of thick-walled cysts than open marine environments which typically contain more thin-walled, delicate forms, often also with long, elaborate processes (Scull *et al.*, 1966; Tyson, 1989; Prauss, 1989; Batten, 1996).

In conclusion, the high dominance and diversity of proximate dinoflagellate cysts with microforaminiferal linings suggests that the carbonate succession of the Araej Formation was deposited under shallow normal marine condition, most probably in the middle shelf (depth 40-80 m).

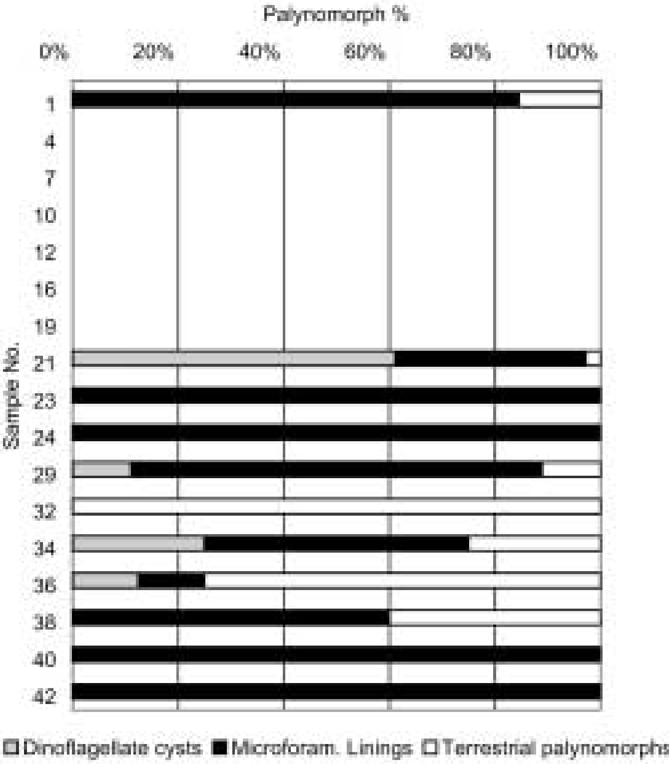

FIGURE 8–Percentage of marine and terrestrial palynomorphs in the Izhara Formation of well Q5.

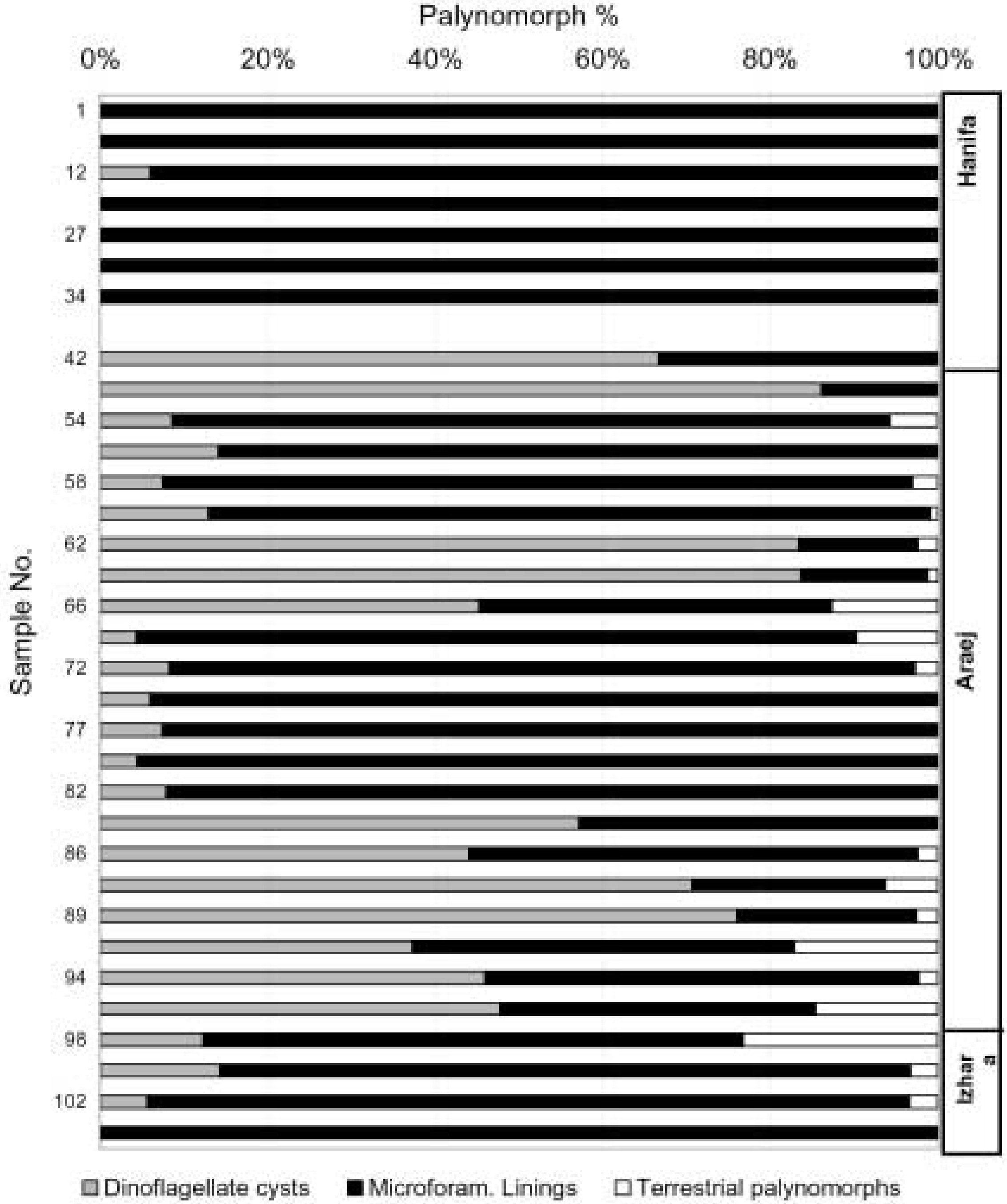

FIGURE 9–Percentage of marine and terrestrial palynomorphs in the Izhara, Araej and Hanifa formations of well Q8.

CONCLUSIONS

Radiogenic age dating proved that the lower Izhara Formation is determined as Hettangian (202.40 Ma) to Sinumerian (195.60 Ma) while its upper part is Bajocian (175.00 Ma). The Araej Formation is dated Middle Jurassic [Late Bajocian/Bathonain to Early Callovian (164.70 Ma-170.00 Ma)]. A hiatus in the middle part of the Izhara Formation due to absence of sediments belonging to Aalenian stage is possible.

Palynological analysis of the Izhara and Araej formations led to the identification of 58 dinoflagellate cyst species, 4 acritarch taxa and 17 miospore species. One barren zone (Hettangian-Toarcian), and four assemblage dinoflagellate biozones are proposed for the Hettangian-Early Callovian succession of the Izhara and Araej formations. Zone I (Early Bajocian), zone II (Late Bajocian), zone III (Bathonian), and zone IV (Late Bathonian-Early Callovian).

The Izhara Formation may have been deposited in shallow marine environment of the inner oxic shelf condition (20-50 m). The carbonate sediments of the Araej Formation were deposited under shallow normal, marine condition, most probably of the middle shelf (depth 40-80 m) in dysoxic condition.

ACKNOWLEDGEMENTS

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PLATE 1–Dinoflagellate cysts of the Izhara Formation. The sample number, slide designation and England Finder reference (EF) are given sequentially for each illustrated specimen. All magnifications X 600. *1, Mendicodinium spinosum* subsp. *spinosum* Bucefalo Palliani, Riding et Torricelli, 1997, Q5, sample 21, slide 3, EF: X30/2. *2-3, Mendicodinium* sp., high and low focus, Q5, sample 21, slide 2, EF: D61/1. *4-6*, Undetermined dinocyst species Q5, sample 21, slide 1, EF: C48, L25. 7. *Leiosphaeridia* sp., Q5, sample 21, slide 1, EF: P 33/3. *8-9, Mendicodinium microscabratum* Bucefalo Palliani, Riding et Torricelli, 1997, high and low focus, Q5, sample 21, slide 2, EF: P 49/4. *10-11,* ?*Mancodinium semitabulatum* Morgenroth, 1970, emend. Below, 1987, high and low focus, Q5, sample 21, slide 1, EF: P56. *12-13, Dichadogonyaulax* cf. *sellwoodii* Sarjeant, 1979, Q5, sample 21, slide 2, EF: M18/2, M24. *14, Escharisphaeridia* sp., Q8, sample 94, slide 1, EF: V 40. *15,* ?*Nannoceratopsis gracilis* Alberti, 1961, emend. Evitt, 1962, emend. Van Helden, 1977, Q5, sample, 21, slide 2, EF: Z 38/3. *16-17, Escharisphaeridia* sp., high and low focus, Q8, sample 97, slide 1, EF: Y68/3. *18, Mancodinium* cf. *semitabulatum* Morgenroth, 1970, emend. Below, 1987, Q8, sample, 97, slide 1, EF: M 561/1. *19, Valensiella* sp., Q8, sample 98, slide 1, EF: H53/3. *20, Escharisphaeridia* sp., Q8, sample 100, slide 1, EF: Y67/2. *21, Batiacasphaera* sp., Q8, sample 97, slide 1, EF: P69.

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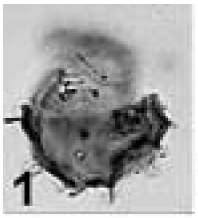
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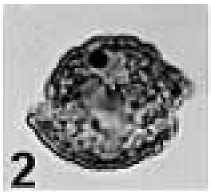
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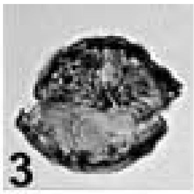
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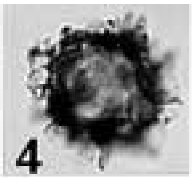
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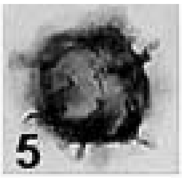
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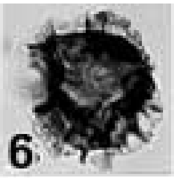
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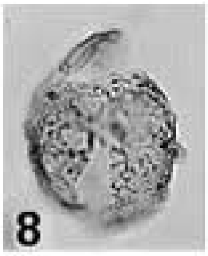
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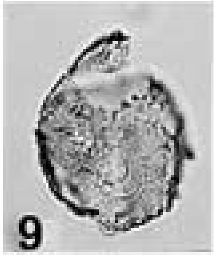
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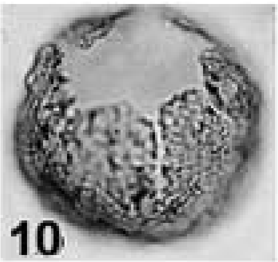
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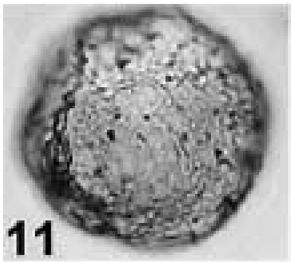
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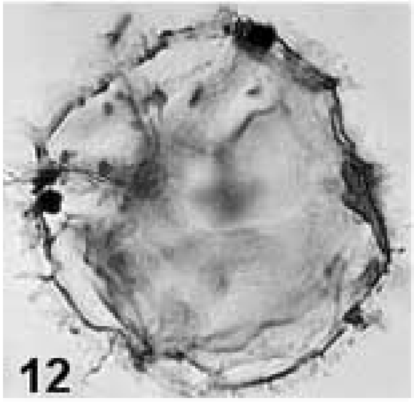
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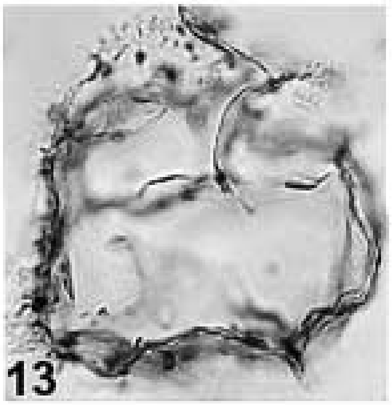
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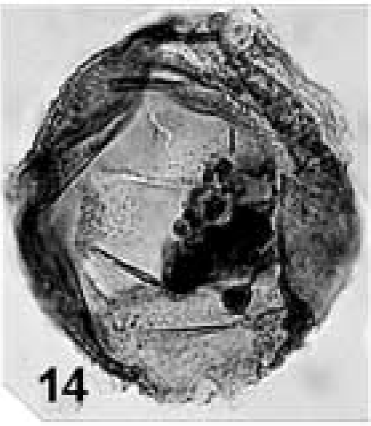
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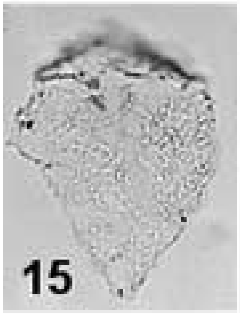
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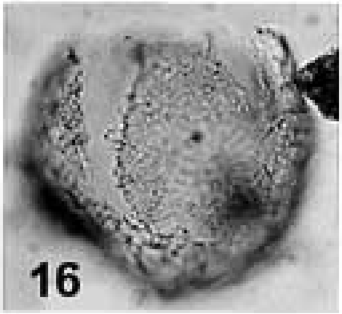
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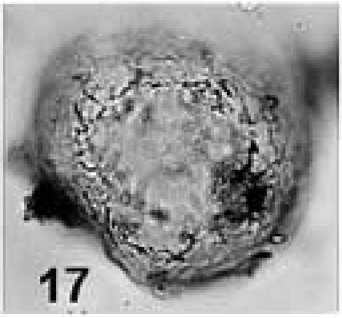
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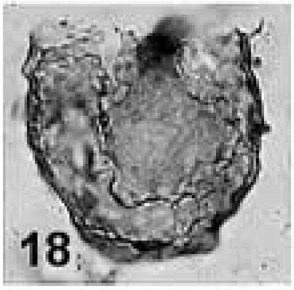
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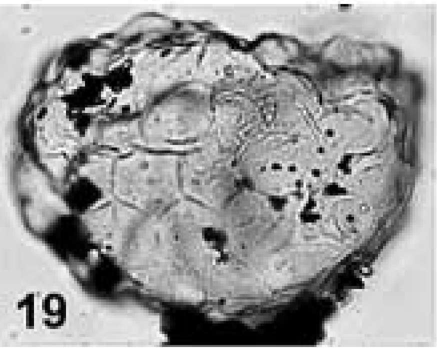
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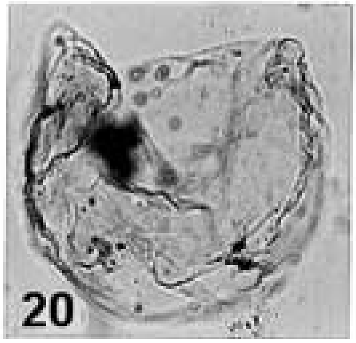
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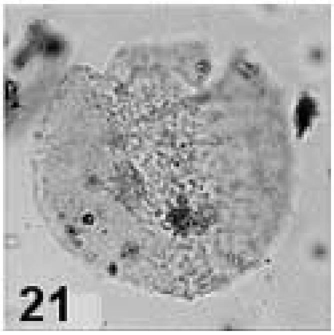
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PLATE 2–Dinoflagellate cysts of the Izhara and Araej formations. The sample number, slide designation and England Finder reference (EF) are given sequentially for each illustrated specimen. All specimens X 600 except Fig. 11 X 400. *1-2, Sentusidinium* sp., high and low focus, Q8, sample 98, slide 1, EF: O27/4. *3-4, Pareodinia ceratophora* Deflandre, 1947, emend. Gocht, 1970, Q8, sample 94, slide 1, EF: B41/4, 9411. *5, Ctenidodinium* sp., Q8, sample 94, slide 1, EF: R 33/4. *6, Mendicodinium* sp., Q8, sample 94, slide 1, EF: J48/3. *7, Lithodinia* sp., Q8, sample 94, slide 1, EF: F 34/2. *8, Pterosphaeridia* cf. *volkheimerie* Quattrocchio, 1980, Q8, sample 100, slide 1, EF: E58/4. *9-10, Gonyaulacysta* sp. sensu Bailey and Partington, 1991, high and low focus, Q8, sample 94, slide 1, EF: W55. *11, Korystocysta kettonensis* (Sarjeant, 1976) Woollam, 1983, Q8, sample 94, slide 1, EF: U30/3. *12-13, Sentusidinium rioultii* (Sarjeant, 1968) Sarjeant & Stover, 1978, emend. Courtinat, 1989, Q8, sample 89, slide 1, EF: J31. *14, Rhynchodiniopsis* cf. *regalis* (Gocht, 1970) Jan du Chêne *et al.*, 1985, Q8, sample 89, slide 1, EF: E27. *15, Prolixosphaeridium* sp., Q8, sample 89, slide 1, EF: X33/1. *16-17, Sentusidinium* sp., high and low focus, Q8, sample 94, slide 1, EF: 40. *18-19, Barbatacysta pilosa* (Ehrenberg, 1854) Courtinat, 1989, high and low focus, Q8, sample 89, slide 1, EF: Q57/1.

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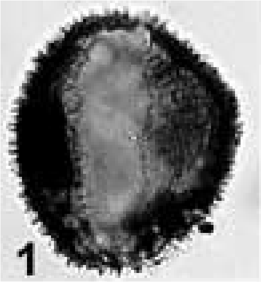
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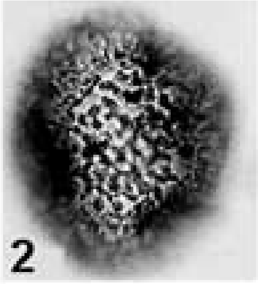
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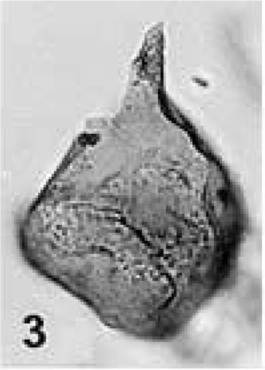
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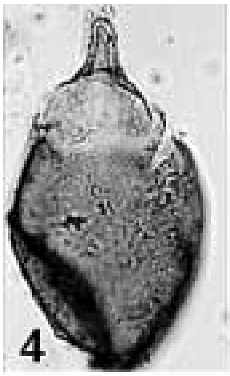
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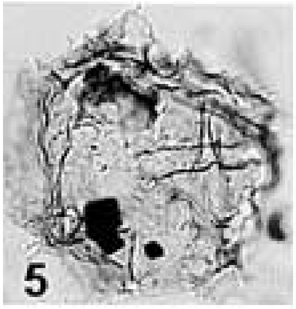
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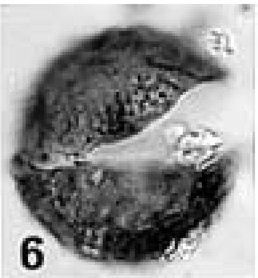
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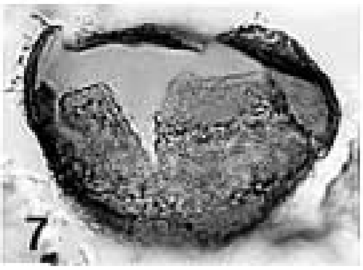
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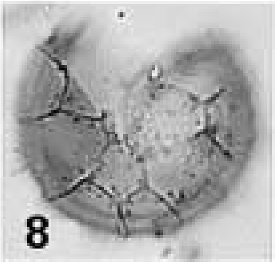
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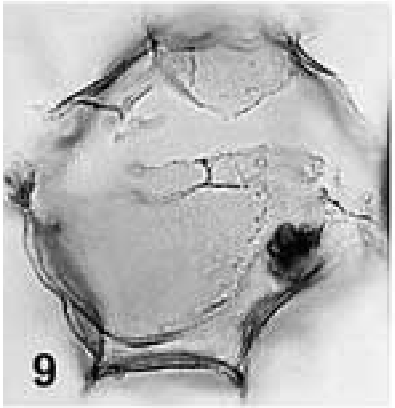
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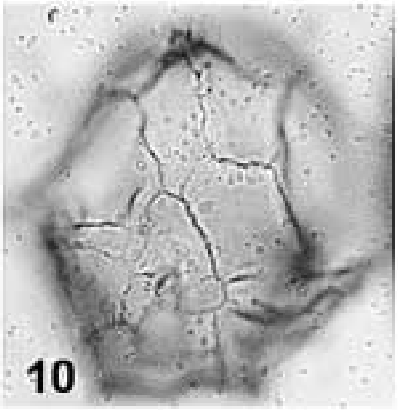
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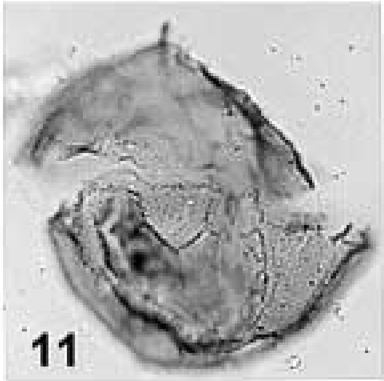
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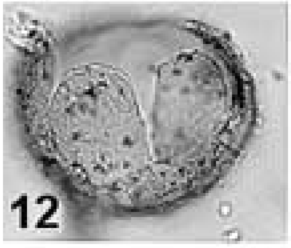
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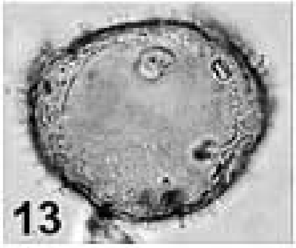
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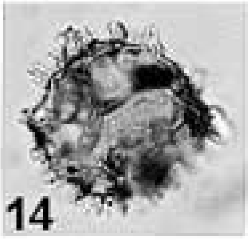
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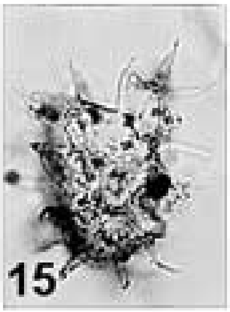
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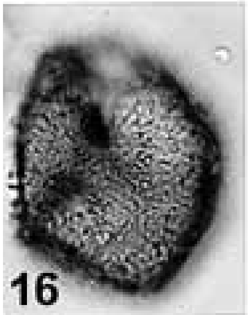
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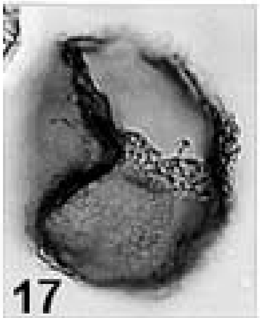
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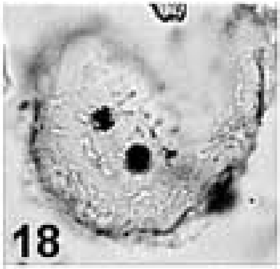
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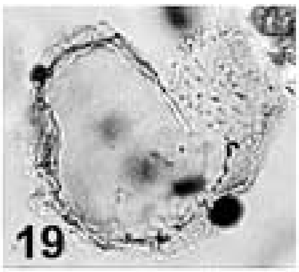
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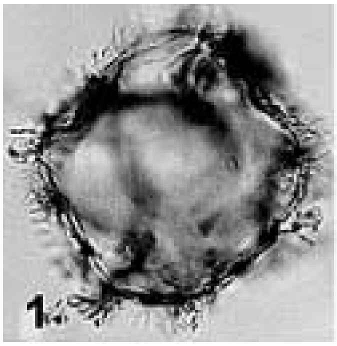
PLATE 3–Dinoflagellate cysts of the Araej Formation. The sample number, slide designation and England Finder reference (EF) are given sequentially for each illustrated specimen. All specimens X 600. *1-2, Gonyaulacysta pectinigera* (Gocht, 1970) Fensome, 1979, high and low focus, Q8, sample 91, slide 1, EF: J47/2. *3, ?Ctenidodinium continuum* Gocht, 1970, Q8, sample 87, slide 1, EF: O30/2. *4, Gonyaulacysta jurassica* (Deflandre, 1938) Norris & Sarjeant, 1965, emend. Sarjeant, 1982, Q8, sample 87, slide 1, EF: E35/1. *5, Rhynchodiniopsis cladophora* (Deflandre, 1938) Below, 1981, Q8, sample 87, slide 1, EF: 62/4. *6, 9, Gonyaulacysta pectinigera* (Gocht, 1970) Fensome, 1979, high and low focus, Q8, sample 87, slide 1, EF: R53/4. *7, Wanaea acollaris* Dodekova, 1975, Q8, sample 87, slide 1, EF: X41/2. *8, Pilosidinium echinatum* (Gitmez & Sarjeant, 1972) Courtinat, 1989, Q8, sample 87, slide 1, EF: P63. *10, Valensiella* cf. *ovulum* (Deflandre, 1947) Eiseanack, 1963, emend. Courtinat, 1989, Q8, sample 87, slide 1, EF: J47/4. *11-12, Cribroperidinium crispum* (W.Wetzel, 1967) Fenton, 1981, high and low focus, Q8, sample 87, slide 1, EF: J23/3.

PLATE 3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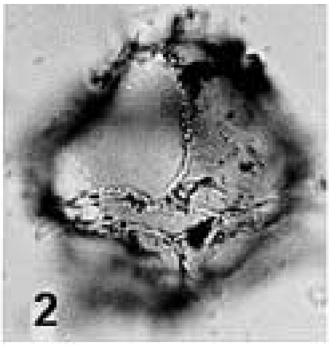
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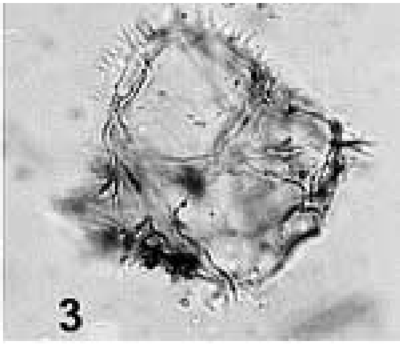
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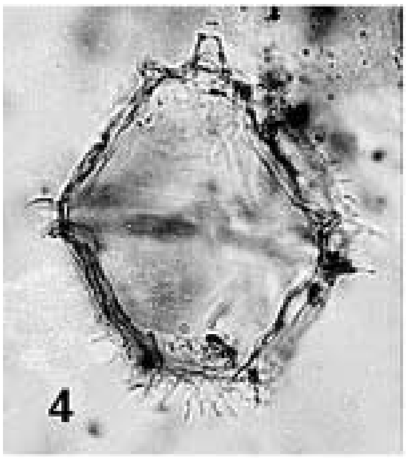
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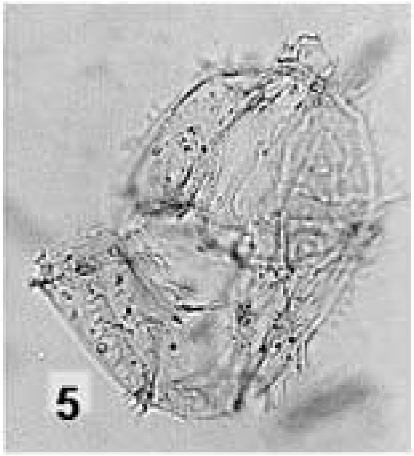
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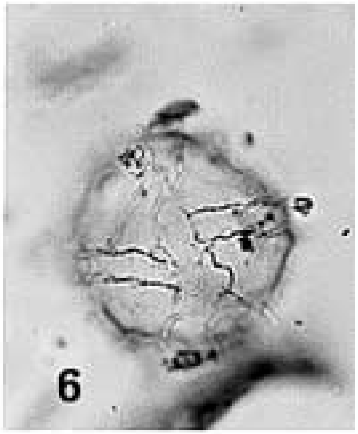
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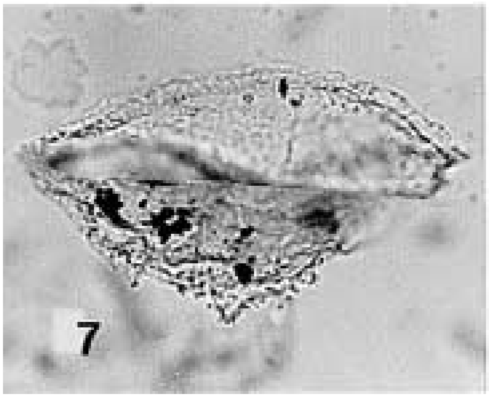
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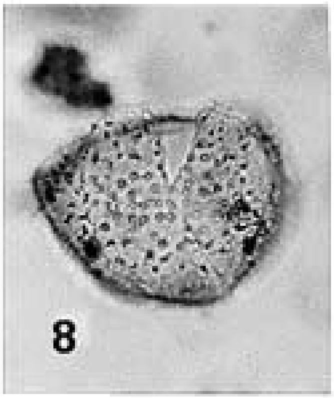
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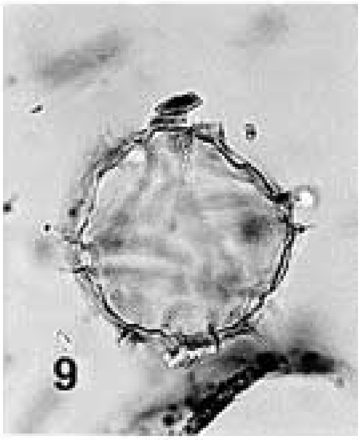
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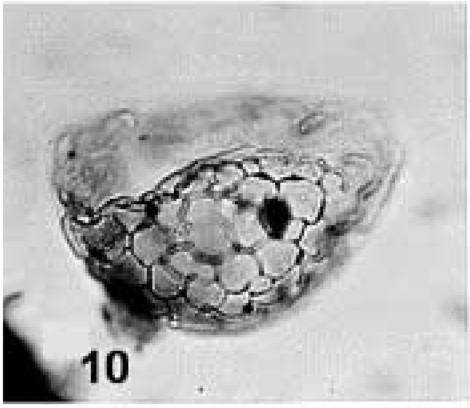
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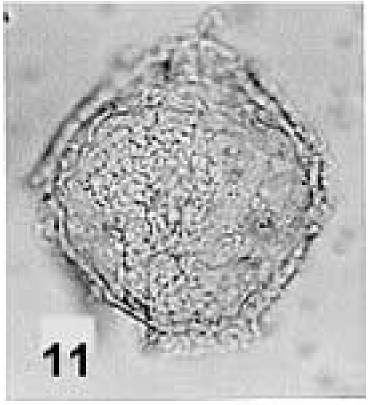
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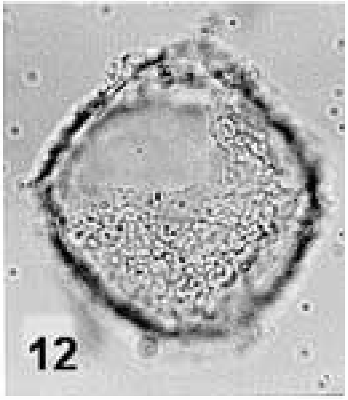
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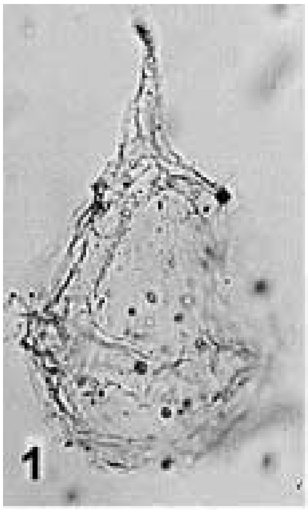
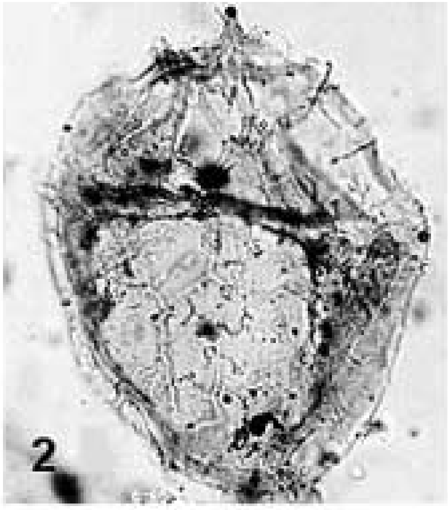
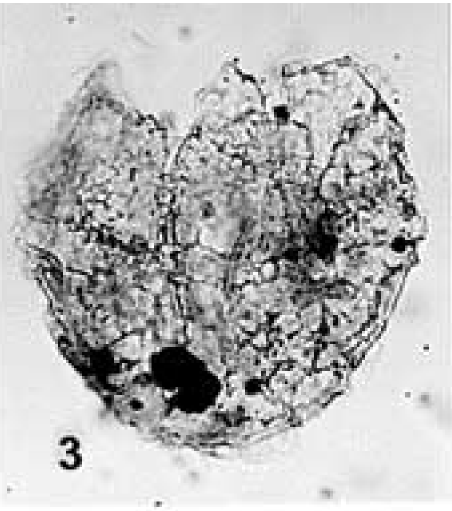
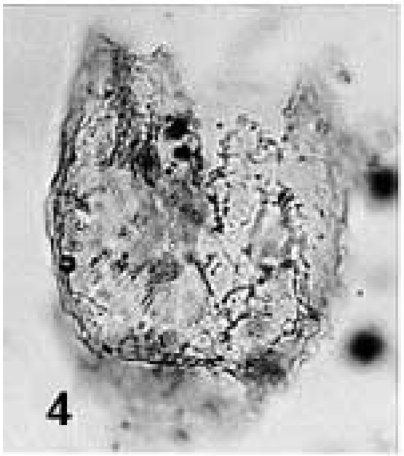
PLATE 4–Dinoflagellate cysts of the Araej Formation. The sample number, slide designation and England Finder reference (EF) are given sequentially for each illustrated specimen. All specimens X 600. *1, Gonyaulacysta jurassica adecta longicornis* (Deflandre, 1938) Downie & Sarjeant, 1965, emend. Sarjeant, 1982, Q8, sample 64, slide 2, EF: V61/2. *2, Korystocysta gochtii* (Sarjeant, 1976) Woollam, 1983, Q8, sample 87, slide 1, EF: O51/2. *3, Lithodinia jurassica* Eisenack, 1935, emend. Gocht, 1975, Q8, sample 64, slide 1, EF: 23/4. *4, Barbatacysta* sp., Q8, sample 64, slide 2, EF: K60. *5, Dichadogonyaulax sellwoodii* Sarjeant, 1975, Q8, sample 64, slide 2, EF: V41/2. *6, Mendicodinium* sp., Q8, sample 86, EF: F57. *7-8, Gonyaulacysta* cf. *pectinigera* (Gocht, 1970) Fensome, 1979, high and low focus, Q8, sample 86, slide 1, EF: K43/2. *9, Chytroeisphaeridia chytroeides* (Sarjeant, 1962) Downie & Sarjeant, 1965, emend. Davey, 1979, Q8, sample 86, slide 1, EF: S45/3. *10-11, Systematophora* spp., Q8, samples 86, 64, slide 1, EF: L36/2, B43. *12, Korystocysta kettonensis* (Sarjeant, 1976) Woollam, 1983, Q8, sample 50, slide 1, EF: P36/4.

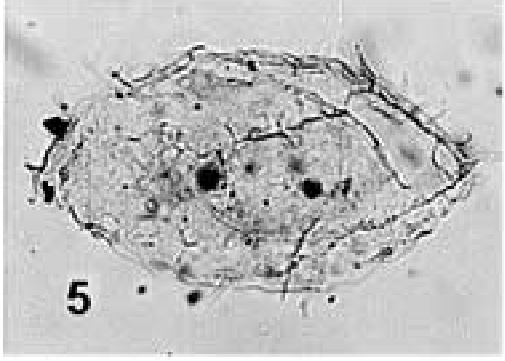
PLATE 4

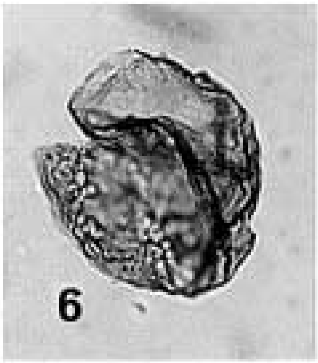


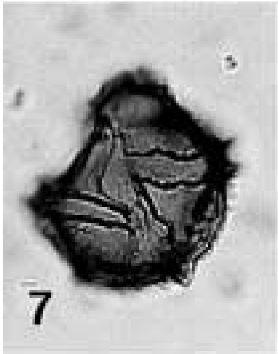


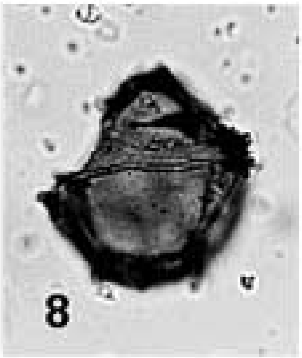


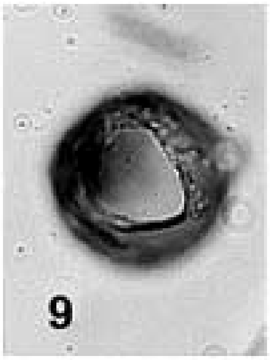


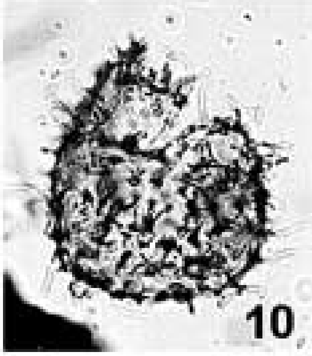


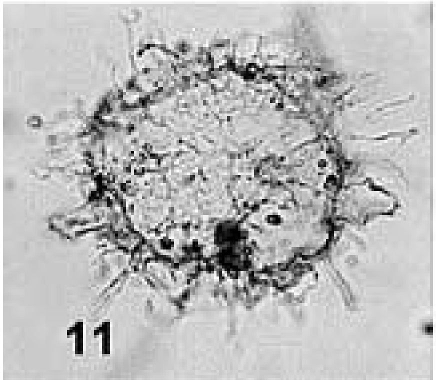


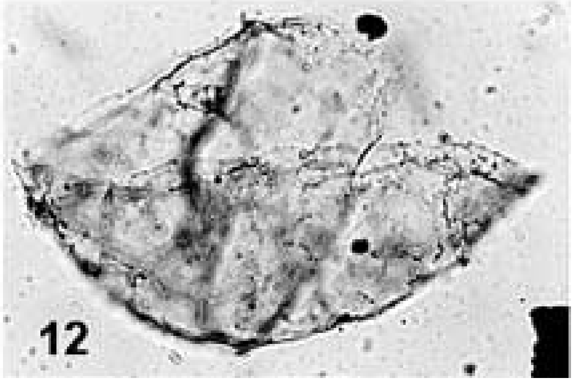












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APPENDIX: TAXONOMIC LIST

The following list includes all the palynomorphs encountered in the present study. The dinoflagellate cysts taxonomy used herein are followed that of Williams *et al*. (1998).

Dinoflagellate cysts

Aldorfia sp.

Barbatacysta pilosa (Ehrenberg, 1854) Courtinat, 1989.

Barbatacysta sp.

Batiacasphaera spp.

Chlamydophorella ectotabulata Smelror, 1989.

Chlamydophorella spp.

Chytroeisphaeridia chytroeides (Sarjeant, 1962) Downie & Sarjeant, 1965, emend. Davey, 1979.

Chytroeisphaeridia spp.

Cribroperidinium crispum (W.Wetzel, 1967) Fenton, 1981.

Cribroperidinium spp.

Ctenidodinium continuum Gocht, 1970.

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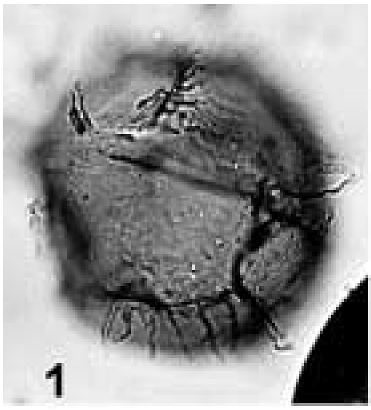
PLATE 5–Dinoflagellate cysts and miospores of the Araej Formation. The sample number, slide designation and England Finder reference (EF) are given sequentially for each illustrated specimen. All specimens X 600. *1, Ctenidodinium ornatum* (Eisenack, 1935) Deflandre, 1939, Q8, sample 77, slide 1, EF: Z23/1. *2, Ctenidodinium continuum* Gocht, 1970, Q8, sample 62, slide 1, EF: B29/4. 3, *Dissiliodinium* cf. *volkheimeri* Quattrocchio & Sarjeant, 1992, Q8, sample 62, slide 1, EF: R22. *4, Rhynchodiniopsis cladophora* (Deflandre, 1938) Below, 1981, Q8, sample 64, slide 2, EF: 30/4. *5, Mendicondinium groenlandicum* (Pocock & Sarjeant, 1972) Davey, 1979, Q8, sample 62, slide 1, EF: O55/1. *6,* Microforaminiferal test linings, Q 8, sample 94, slide 1, EF: B58/2. *7,* cf. *Mendicodinium* sp., Q8, sample 66, slide 1, EF: B52/2. *8, Dictyophyllidites harrisii* Couper, 1958, Q8, sample 98, slide 1, EF: K49/3. *9, Apiculatasporites* sp., Q8, sample 98, slide 1, EF: V26. *10, Dictyophyllidites* sp., Q8, sample 102, slide 1, EF: R40/1. *11, Dictyophyllidites harrisii* Couper, 1958, Q5, sample 38, slide 1, EF: M31/2. *12, Araucariacites australis* Cookson, 1947 ex Couper, 1953, Q8, sample 98, slide 1, EF: F53/1. *13, Staplinisporites perforatus* Dettmann, 1963, Q8, sample 98, slide 1, EF: P18. *14, Matonisporites crassiangulatus* (Balme, 1957) Dettmann, 1963, Q8, sample 98, slide 1, EF: O57.

PLATE 5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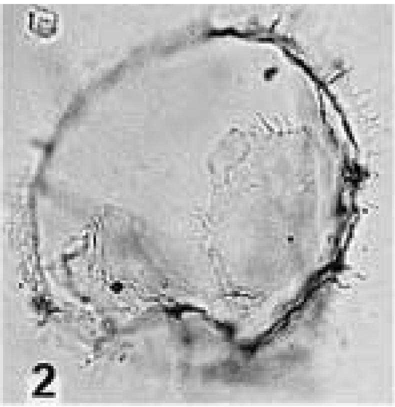
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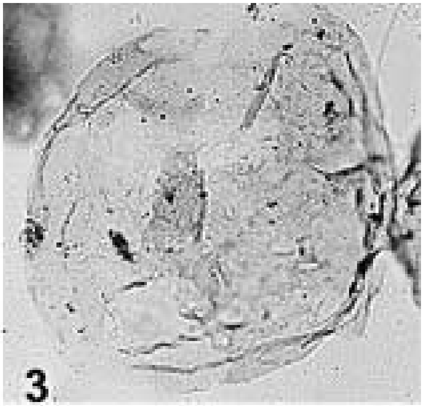
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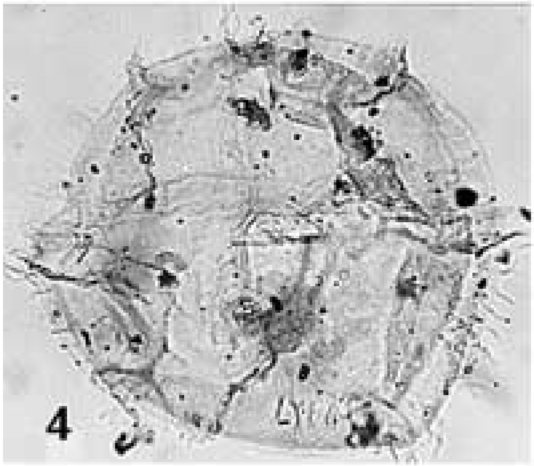
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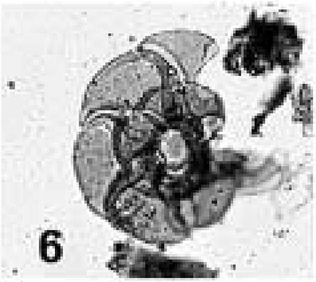
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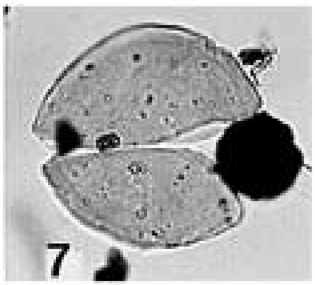
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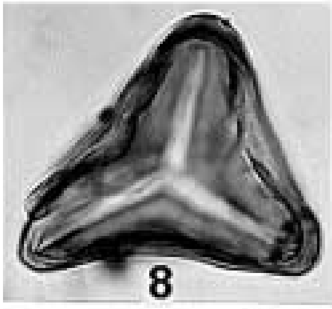
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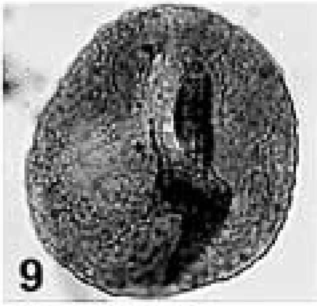
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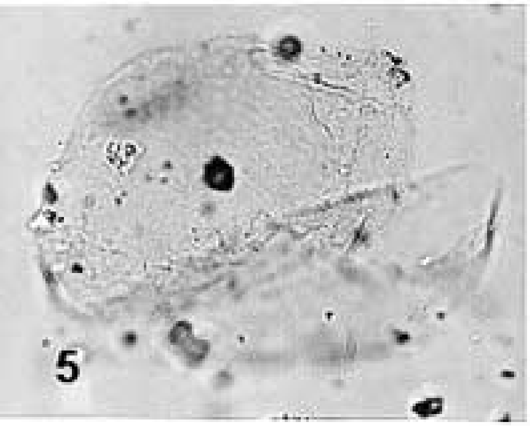
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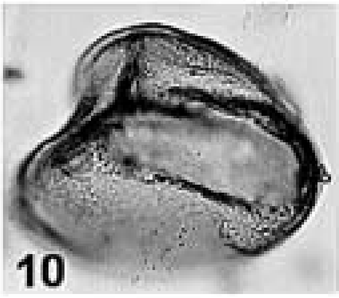
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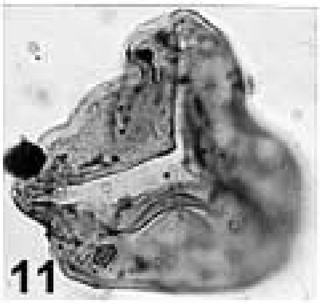
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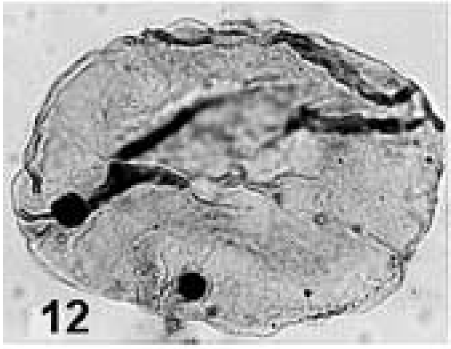
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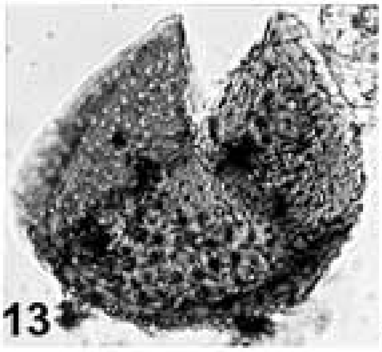
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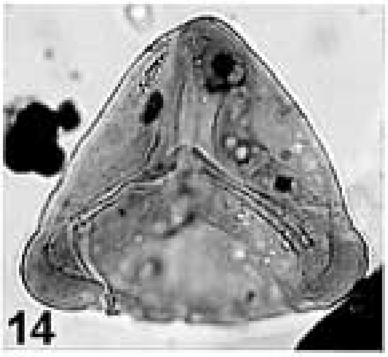
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Ctenidodinium ornatum (Eisenack, 1935) Deflandre, 1939.

Ctenidodinium spp.

Diacanthum sp.

Dichadogonyaulax sellwoodii Sarjeant, 1975.

Dichadogonyaulax spp.

Dissiliodinium cf. *volkheimeri* Quattrocchio & Sarjeant, 1992.

Dissiliodinium cf. *willei* Bailey & Partington, 1991

Dissiliodinium spp.

Ellipsoidictyum sp.

Escharisphaeridia pocockii (Sarjeant, 1968) Erkmen & Sarjeant, 1980.

Escharisphaeridia psilata Kumar, 1986.

Escharisphaeridia spp.

Gonyaulacysta jurassica adecta longicornis (Deflandre, 1938) Downie & Sarjeant, 1965, emend. Sarjeant, 1982.

Gonyaulacysta jurassica (Deflandre, 1938) Norris & Sarjeant, 1965, emend. Sarjeant, 1982.

Gonyaulacysta pectinigera (Gocht, 1970) Fensome, 1979.

Gonyaulacysta spp.

Hystrichosphaerina sp.

Kallosphaeridium sp.

Korystocysta gochtii (Sarjeant, 1976) Woollam, 1983.

Korystocysta kettonensis (Sarjeant, 1976) Woollam, 1983.

Korystocysta spp.

Lithodinia jurassica Eisenack, 1935, emend. Gocht, 1975.

Lithodinia spp.

Mancodinium cf. *semitabulatum* Morgenroth, 1970, emend. Below, 1987.

Mancodinium semitabulatum Morgenroth, 1970, emend. Below, 1987.

Mancodinium sp.

Mendicodinium groenlandicum (Pocock & Sarjeant, 1972) Davey, 1979.

Mendicodinium microscabratum Bucefalo Palliani, Riding et Torricelli, 1997.

Mendicodinium sp. A.

Mendicodinium spinosum subsp. *spinosum* Bucefalo Palliani, Riding et Torricelli, 1997.

Mendicodinium spp.

Nannoceratopsis gracilis Alberti, 1961, emend. Evitt, 1962, emend. Van Helden, 1977.

Pareodinia ceratophora Deflandre, 1947, emend. Gocht, 1970.

Pilosidinium echinatum (Gitmez & Sarjeant, 1972) Courtinat, 1989.

Prolixosphaeridium sp.

Rhynchodiniopsis cladophora (Deflandre, 1938) Below, 1981.

Rhynchodiniopsis? cf. *regalis* (Gocht, 1970) Jan du Chêne *et al.*, 1985.

Rhynchodiniopsis? *regalis* (Gocht, 1970) Jan du Chêne *et al.*, 1985.

Sentusidinium rioultii (Sarjeant, 1968) Sarjeant & Stover, 1978, emend. Courtinat, 1989 .

Sentusidinium spp.

Systematophora spp.

Undetermined dinocyst species.

Valensiella ovulum (Deflandre, 1947) Eisenack, 1963, emend. Courtinat, 1989.

Valensiella sp. A.

Valensiella sp. B.

Valensiella spp.

Wanaea acollaris Dodekova, 1975.

Other microplankton

Cymatiosphaera sp.

Leiosphaeridia sp.

Micrhystridium sp.

Microforaminiferal linings.

Pterosphaeridia cf. *volkheimeri* Quattrocchio, 1980.

Spore and Pollen

Apiculatasporites sp.

Araucariacites australis Cookson, 1947 ex Couper, 1953.

Callialasporites dampieri (Balme) Sukh Dev, 1961.

Callialasporites trilobatus (Balme) Sukh Dev, 1961.

Callialasporites spp.

Cibotiumspora jurienensis (Balme) Filatoff, 1975.

Circulina parva Brenner, 1963.

Classopollis classoides Pflug, 1953.

Cyathidites major Couper, 1953.

Cyathidites minor Couper, 1953.

Cycadopites spp.

Deltoidospora hallii Miner, 1935.

Dictyophyllidites harrisii Couper, 1958.

Dictyophyllidites spp.

Inaperturopollenites spp.

Matonisporites crassiangulatus (Balme) Dettmann, 1963.

Staplinisporites perforatus Dettmann, 1963.

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CONTRIBUTION TO THE STRATIGRAPHY AND PALEOECOLOGY OF THE MIOCENE SEQUENCE AT AL KHUMS AREA, SIRTE BASIN, NW LIBYA

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Abstract

Miocene carbonate-siliciclastic deposits are widely exposed in Al Khums area, Sirte Basin, NW Libya. They overlie unconformably the Late Cretaceous Sidi As Sid Formation and are overlained unconformably by Quaternary clastic deposits. Three stratigraphic sections were investigated, namely from north to south: Qabilat Ash Shurfah, Ras Al Shaqqah and Wadi Zaqlum sections. Lithostratigraphically, the Miocene sequence could be differentiated into two main rock units representing shallow carbonate-siliciclastic deposits with relatively intermittent deep marine incursions. These are from base to top as follows: 1. Al Faidiyah Formation (composed mainly of polymictic conglomerates at base, followed upwards with calcareous sandstone and argillaceous limestones interbedded with sandy to algal limestone at top. 2. Al Khums Formation (represented mainly by sandy limestone, biohermal reefal and argillaceous limestone beds at lower part (An Naggazah Member) followed upwards with thickly bedded coralline limestones and subordinate dolomitic limestone with argillaceous chalky limestones (Ras Al Mannubiyah Member). Detailed foraminiferal investigations led to the recognition of three foraminiferal zones from base to top: *Elphidium macellum / Miogypsina intermedia* and *Globigerinoieds trilobus* zones covering Al Faidiyah Formation and assigned it to Early Miocene (Burdigalian) age and the *Borelis melo melo* zone which includes Al Khums Formation and dated it to Middle Miocene (Langhian to Early Serravallian) age. The careful examination of the coralline red algal (Rhodophyta) association and their growth morphology encountered in both of the studied rock units led also to the recognition of twenty four algal species. On the basis of the stratigraphic distribution of these coralline red algae, the studied Miocene sequence could be subdivided into three local algal zones from base to top: *Sporolithon saipanensis* zone covers the upper part of Al Faidiyah Formation and *Lithophyllum ghorabi* and *Mesophyllum lemoineae* zones include Al Khums Formation. Detailed microfacies analysis of the rock units led to the recognition of eleven microfacies types indicating that the Miocene sequence was deposited in transgressive-regressive cycles ranged from near shore, warm shallow inner to middle shelf marine environments with development of reefal facies with slightly deep marine incursions. Such environments reflect the eustatic sea level changes related to the latter minor tectonic pluses that accompanied the main Upper Cretaceous tectonic event.

Keywords: Al Khums, Al Faidiyah, Foraminifera, Coralline algae, Miocene, Sirte, Libya.

Resumen

Los depósitos carbonáticos-siliciclásticos están ampliamente expuestos en el área de Al Khums, Cuenca de Sirte, noroeste de Libia. Los depósitos descansan en inconformidad sobre la Formacion Sidi As Sid del Cretácico superior, y se encuentran cubiertos por depósitos cuaternarios clásticos en inconformidad. Las tres secciones estratigráficas estudiadas son, de norte a sur: las de Qabilat Ash Shurfah, Ras Al Shaqqah y Wadi Zaqlum. El análisis litoestratigráfico indica que la secuencia miocena incluye dos unidades rocosas, que están representadas por depósitos carbonáticos someros-siliciclásticos, con incursiones relativamente intermitentes de materiales marinos profundos. De base a techo son las siguientes: 1. Formación Al Faidiyah (formada por conglomerados polimícticos en la base, seguidos hacia arriba por areniscas calcáreas y calizas arcillosas intercaladas con calizas algares y arenosas a techo), y 2. Formación Al Khums, representada por unidades de calizas arenosas, calizas arrecifales biohermales y calizas arcillosas en la parte inferior (Miembro Naggazah), que se continúan a techo por calizas coralinas en grandes bancos y con calizas dolomitizadas que muestran de forma subordinada calizas arcillosas margosas (Miembro Ras Al Mannubiyah). Las investigaciones detalladas de las asociaciones de foraminíferos han permitido el reconocimiento de tres zonas, que son, de base a techo: la Zona *Elphidium macellum/Miogypsina intermedia* y la Zona *Globigerinoieds trilobus*, que incluyen la Formación Al Faidiyah de edad Mioceno inferior (Burdigaliense) y la Zona *Borelis melo melo*, que incluye la Formación Al Khums del Mioceno medio (Langhiense al Serravaliense inferior). El examen detallado de la asociación de algas rojas (rodofitas) y su morfología de crecimiento en las secciones estudiadas ha permitido el reconocimiento de veinticuatro especies de algas. La distribución estratigráfica de las algas rojas coralinas de la secuencia miocena estudiada ha permitido reconocer tres zonas algares locales, que desde base a techo son: la Zona *Sporolithon saipanensis*, que cubre la parte superior de la Formación Al Faidiyah, y las zonas *Lithophyllum ghorabi* y *Mesophyllum lemoineae*, que incluyen la Formación Al Khums. El análisis detallado de las microfacies ha permitido el reconocimiento de once tipos de microfacies, que indican que la secuencia miocena fue depositada en un régimen de ciclos transgresivos-regresivos, desde ambientes marinos someros, próximos a la costa, a plataformas someras cálidas y a plataformas de profundidad intermedia con el desarrollo de facies arrecifales con intercalaciones marinas profundas. Tales ambientes reflejan cambios en el nivel eustático relacionados con pulsos tectónicos menores tardíos, que acompañaron al evento tectónico principal del Cretácico superior.

Palabras clave: Al Khums, Al Faidiyah, Foraminifera, algas rojas, Mioceno, Sirte, Libia.

INTRODUCTION

Sirte Basin was tectonically developed in the Late Mesozoic time as a southerly extension of the Tethys geosyncline, by block faulting and subsidence of a part of the Sahara shield (Tibesti-Sirte arch). By the advent of the Miocene period the embayment was largely infilled by carbonate and siliciclastic deposits through marine transgression (Selley, 1971, 1985). The Miocene deposits situated in Al Khums area, NW Sirte basin, are represented basically by transgressive-regressive marine carbonate-siliciclastic sediments and are characterized largely by striking lateral variation in facies and thickness. This variation is controlled mainly by the degree of erosion and topography conditions of the preexisted underlying Upper Cretaceous rocks. The areal extension of the Miocene outcrops is small and occurred as relic, isolated deposits in the form of low lying hills and hillocks disected by several wadis around Al Khums City. Moreover, the Miocene rocks form distinct low lying outcrops surrounding the Upper Cretaceous topographic highs. The deposition is predominantly commenced with a siliciclastic lithofacies of coarse clastic polymictic conglomerates (that marks the unconformable contact with the underlying Late Cretaceous Sidi As Sid Formation), calcareous sandstone and thin beds of argillaceous limestone. This sequence is followed upwards with sandy, argillaceous, chalky limestone in the uppermost part of the studied sections and lasted with coralline algal limestone reflecting environments of shallow to relatively deep marine conditions.

The study area is about 260 km^2 located in the northwestern side of Sirte Basin, nearly about 15 km south of Al Khums City (Fig. 1). The main target of the present work is to study in details the different lithostratigraphic units of the Miocene sequence and their biostratigraphic zones as well as reconstruct the paleoenvironmental conditions prevailed during the deposition. About 120 samples were collected from three main stratigraphic sections, namely Qabilat Ash Shurfah (Lat. 32° 35’ 20 N & Long. 14° 18’ 23” E), Ras Al Shaqqah (Lat. 32° 28’ 18 N & Long. 14° 27’ 10” E) and Wadi Zaqlum (Lat. 32° 35’ 20” N & Long. 14° 18’ 23” E). These sections were subjected to biostratigraphic analysis based on the benthonic and planktonic foraminiferal content as well as examination of the coralline red algal assemblage to recognize the Miocene biozones and determine the age of the encountered rock units. Additionally, the main microfacies types are recognized and evaluated where paleocological interpretation was based on the environ-

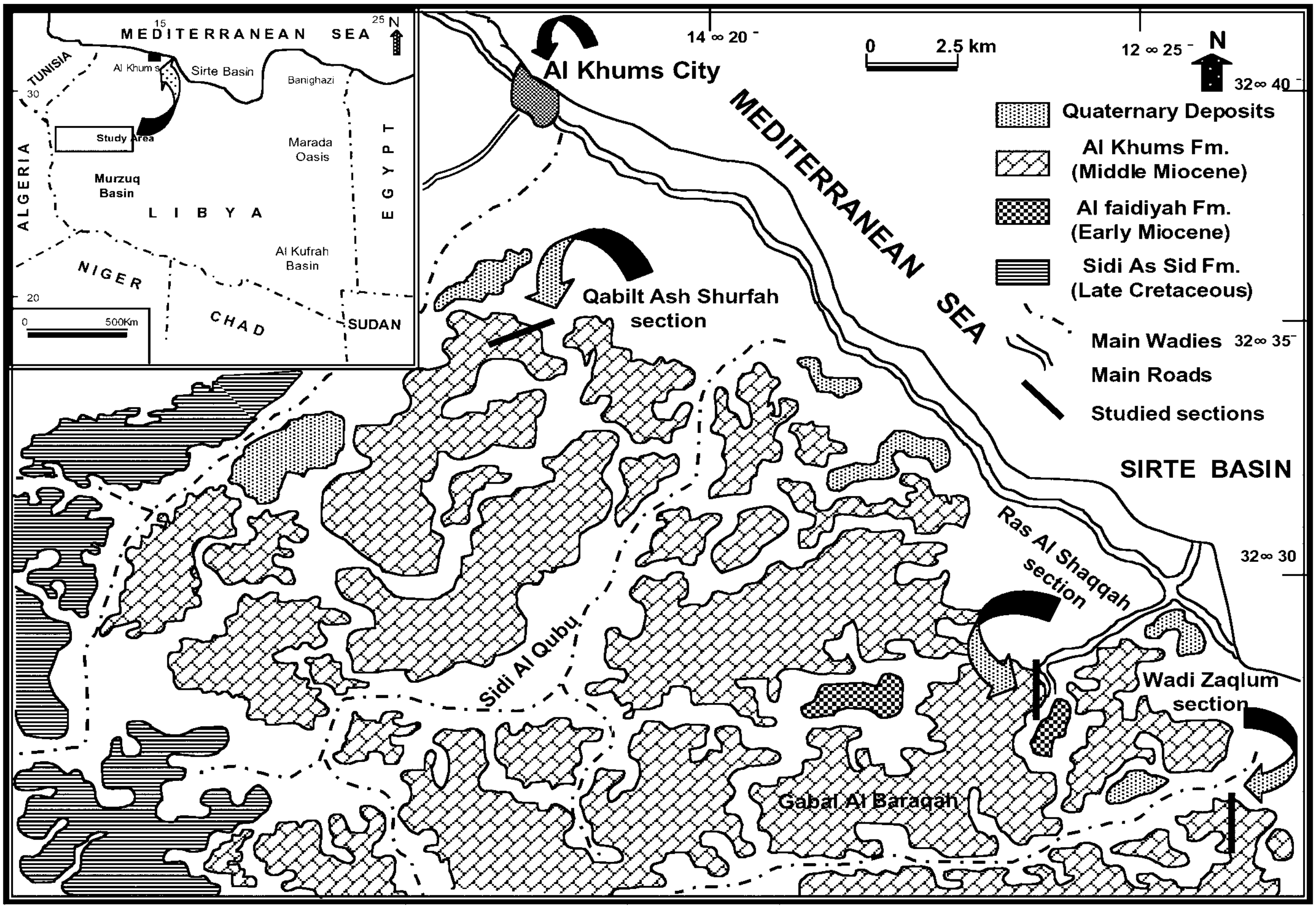
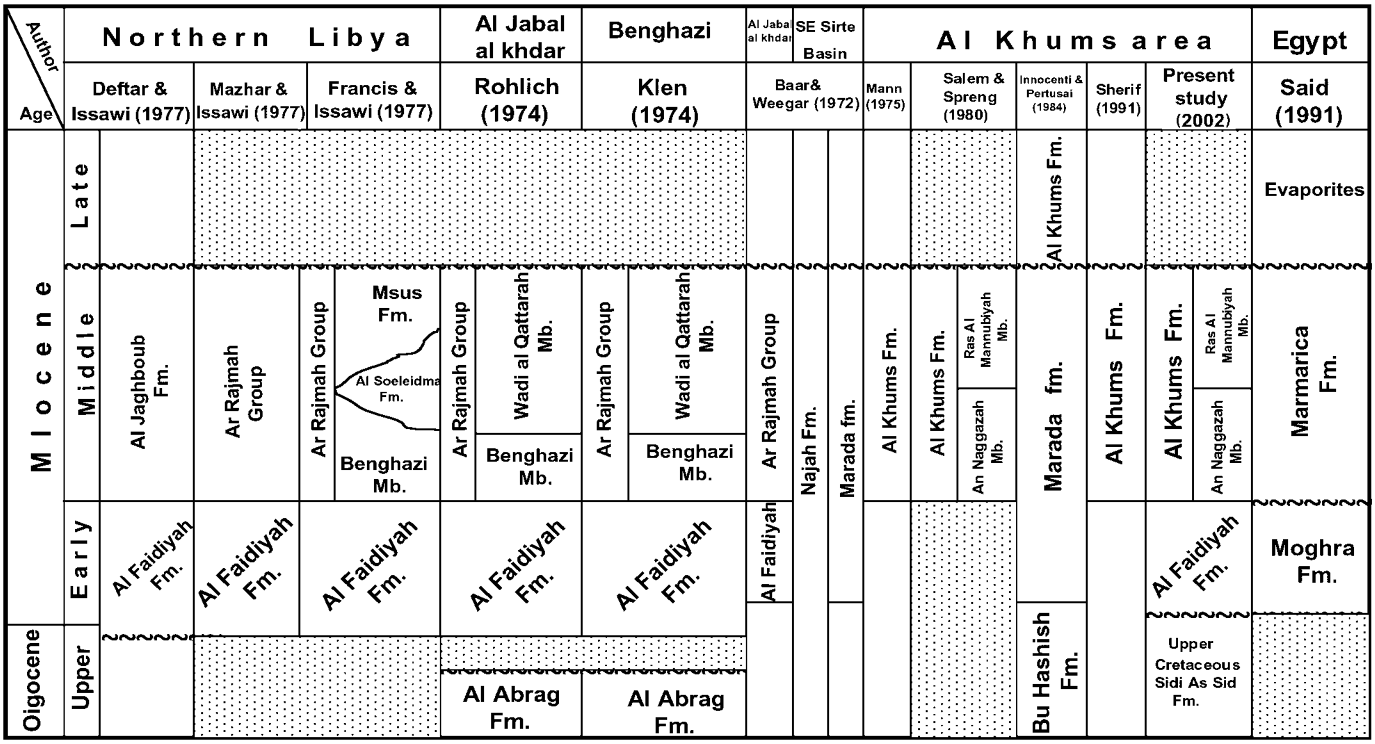


FIGURE 1–Simplified geological map of the Miocene outcrops in Al Khums area, NW Sirte Basin, Libya.

mentally diagnostic foraminiferal and coralline red algal assemblages as well as field observations and primary structures.

LITHOSTRATIGRAPHY

The stratigraphy and to a certain extent, the structural setting of the exposed Miocene successions at Al Khums area have been previously discussed by numerous works of Florida (1939), Desio (1939, 1971), Klen (1974), Hinnawy & Chestitev (1975), Mann (1975), Francis & Issawai (1977), Mazhar & Issawi (1977), Mijalkovic (1977), Zivanovich (1977), Said (1978), Srivastva (1979), Salem & Spreng (1980), Innocenti & Pertusati (1984), Sherif (1984, 1991) and El Waer (1991). Most of these researches concentrated on the startigarphy but little works have been carried out on the micropaleontology of the area. These authors also assigned Al Khums Formation to the Middle Miocene (Langhian) except the work of Innocenti & Pertusati *(op. cit.)* and El Waer (1991) who assigned this Formation to Late Miocene (Torotonian to Messanian). Lithostratigraphically, the Miocene deposits in the study area have been classified and discussed by few authors. The currently used lithostratigraphical subdivision of the Miocene in northeastern Libya is mainly based on the work of Mann (1975). Other significant contributions to the lithostartigraphy of this sequence (Salem & Spreng, 1980; Sherif, 1991) are adopted in the present work. The general stratigraphical subdivision of the studied sequence is correlated to the other Miocene units in northern parts of Libya (Table 1). Two main rock units represent the Miocene succession will be discussed, from base to top as follows:



Author / Age		Northern Libya	Northern Libya	Northern Libya	Al Jabal al khdar	Benghazi	Al Jabal al khdar	SE Sirte Basin	SE Sirte Basin	Al Khums area	Al Khums area	Al Khums area	Al Khums area	Al Khums area	Egypt
		Deftar & Issawi (1977)	Mazhar & Issawi (1977)	Francis & Issawi (1977)	Rohlich (1974)	Klen (1974)	Baar& Weegar (1972)	Baar& Weegar (1972)	Baar& Weegar (1972)	Mann (1975)	Salem & Spreng (1980)	Innocenti & Pertusai (1984)	Sherif (1991)	Present study (2002)	Said (1991)
Miocene	Late											Al Khums Fm.			Evaporites
Miocene	Middle	Al Jaghboub Fm.	Ar Rajmah Group	Ar Rajmah Group: Msus Fm.; Al Soeleidma Fm.; Benghazi Mb.	Ar Rajmah Group: Wadi al Qattarah Mb.; Benghazi Mb.	Ar Rajmah Group: Wadi al Qattarah Mb.; Benghazi Mb.	Ar Rajmah Group	Najah Fm.	Marada fm.	Al Khums Fm.	Al Khums Fm.: Ras Al Mannubiyah Mb.; An Naggazah Mb.	Marada fm.	Al Khums Fm.	Al Khums Fm.: Ras Al Mannubiyah Mb.; An Naggazah Mb.	Marmarica Fm.
Miocene	Early	Al Faidiyah Fm.	Al Faidiyah Fm.	Al Faidiyah Fm.	Al Faidiyah Fm.	Al Faidiyah Fm.	Al Faidiyah							Al Faidiyah Fm.	Moghra Fm.
Oigocene	Upper				Al Abrag Fm.	Al Abrag Fm.						Bu Hashish Fm.		Upper Cretaceous Sidi As Sid Fm.	

TABLE 1–Correlation chart of the Miocene rock units in Northern Libya.

1. Al Faidiyah Formation

It is the oldest Miocene rock unit exposed in the study area and represented the first transgressive marine deposits. It was first described and established by Pietersz (1968) as "Faidia" Formation. According to its type section at Qaryat Al Faidiyah on Al Bayda sheet and later on Barr & Weeger (1972) adopted it. It is subsequently modified by Rohlich (1974) to Al Faidiyah Formation to delineate the clay-carbonate sequence at its type section, Al Faidiyah village. In the studied sections this Formation is of very limited distribution and locally developed only in Ras Al Shaqqah section attaining thickness of 15 m where it overlies unconformably the Late Cretaceous Sidi As Sid Formation (Ain Tobi Member) with polymictic conglomerates marking this boundary and underlies conformably Al Khums Formation (An Naggazah Member). The lower part of the Formation is represented in the field by siliciclastic-dominated facies typified by coarse polymictic conglomerates that onlaps and pinches out on the Upper Cretaceous limestone. These siliciclastic facies consist of 2-3 m thick with reworked Upper Cretaceous clasts represented by subrounded to rounded, moderately sorted, grain-supported polymictic conglomerates, the good roundess of the clasts indicate long period of abrasion before accumulation. The clasts composed of bioclastic carbonate and subordinate chert of pebble to boulder sizes closely packed in matrix of sandy lime mud. This type of polymictic conglomerate could be formed as erosional channel fills and represents the first Miocene marine transgression over the uneven surface of the pre existing Upper Cretaceous rocks. The siliciclastic dominated facies grades upwards to yellowish white, fossiliferous with oyster shells, cross-bedded, coarse to pebbly calcareous sandstones of moderately sorted detrital quartz grains followed by medium to fine calcareous sandstones and calcareous mudstone with thin band of greenish grey, fissile, fossiliferous, silty claystone. The calacreous mudstone is grey, fissile partly sandy and commonly intercalated the cross-bedded sandstone. The upper part of Al Faidiyah Formation is carbonate-dominated facies depicted in the presence of yellowish to whitish grey, massive-bedded, hard, sandy limestone highly fossiliferous with *Pyconodonte virleti* Deshayes, *Ostrea frondosa* Fuchsia, *Pecten jossilingi* Sowerby, *Pecten ziziniae* Blanckenhorn, *Chlamys submalvinae* Blanckenhorn, *Clypeaster intermedius* Desmoulins, *Clypeaster* sp. and *Flablepecten burdigalensis* Lamarck. Coralline red algae, echinoid and other bivalved shells represent the less common faunal assemblage. This carbonate-dominated unit is commonly interbedded with greenish grey, fissile, fossiliferous, argillaceous limestone highly fossiliferous with planktonic and benthonic foraminifers. Thin bands of calcaeeous, grey, fissile, shale (10 to 20 cm in thickness) are commonly observed in this unit.

2. Al Khums Formation

This rock unit was first described and established in its type locality Al Khums area by Mann (1975) for the Middle Miocene carbonate-clay / marl sequence. In the studied sections, this formation overlies conformably the Early Miocene Al Faidiyah Formation as in Ras Al Shaqqah Section but in Qabilt Ash Shurfah and Wadi Zaqlum sections it overlies unconformably the Late Cretaceous Sidi As Sid Formation (Ain Tobi Member). This rock unit sometimes crop out directly and in some places it is overlain unconformably by clastic section of polymictic conglomerates and sandstone of Pliocene-Pleistocene age. Salem & Spreng (1980) locally subdivided Al Khums Formation in Al Khums area into two informal members, from base to top: 1. An Naggazah Member and 2. Ras Al Mannubiyah Member (Table 1). These two members are noticeably recognized in this study. Lithologically, Al Khums Formation is represented mostly by shallow water carbonate-dominated facies usually interrupted by slightly deep marine conditions. In the field the lower part of this formation (An Naggazah Member) is composed medium to coasre grained sandstone forming the base, followed upwards by yellowish grey to brownish yellow, hard, massive-bedded, fossiliferous, reefal limestone beds. These beds overlain by grey to yellowish grey, compact to partly fissile, moderately fossiliferous with coralline algae, argillaceous to sandy limestone interbedded with thin beds of gypsiferous shale. While, the upper part of the formation (Ras Al Mannubiyah Member) is represented predominantly by yellowish grey to whitish yellow, hard, porous, highly fossiliferous with coralline algae, nodular limestones followed by grey to greyish white, irregulary bedded chalky limestone interbedded with sandy to argillaceous and dolomitic limestone beds. Overlying the previous beds, greyish white, thickely bedded, porous cavernous algal limestone beds forming the topmost part of the foramtion. Al Khums Formation attains different thickness where it reaches about 35 m in Ras Al Shaqqah and 50 m in Qabilat Ash Shurfah section and 30 m in Wadi Zaqlum respectively. Regarding the age of Al Khums Formation, Mann (1975), Mijalkovic (1977), Said (1978) and Srivistava (1979) have assigned this rock unit as Middle Miocene (Langhian) on the basis of its stratigraphic position and paleontological evidences. But on the contrary, Innocenti & Pertusati (1984) and El Waer (1991) assigned it to Late Miocene (Tortonian to Early Messinian) on the basis of the ostracod content. In the present study, the mutual relationship of the field investigations, recorded foraminiferal biostratigraphic zones as well as coralline algal assemblage assigned Al Khums Formation to Middle Miocene age as will be explained in the nextcoming paragraphs.

2.1. An Naggazah Member

The An Naggazah Member was first introduced informally by Salem & Spreng (1980) to define the lower part of Al Khums Formation in Al Khums area, NW Libya. It overlies unconformably the Late Cretaceous Sidi As Sid Formation (Ain Tobi Member) in Qabilt Ash Shurfah and Wadi Zaqlum sections and underlies conformably Al Mannubiyah Member. This rock unit conformably overlies Al Faidiyah Formation in Ras Al Shaqqah section. The lowermost part of this member is represented by polymictic conglomerates (clasts are composed predominantly of carbonate with chert embedded in sandy carbonate matrix), this basal bed followed by pebbly to coarse sandstones grading upwards into medium to fine grained, poorly sorted calcareous sandstones, fossiliferous with gastropodes and pelecypods shell fragments. The sandstone is followed upwards to yellow-yellowish brown, irregulary to massive-bedded of ledge-forming, porous to hard, sandy, algal reefal limestone highly fossiliferous with corals, coralline algae, oyster bivalves, bryozoa and echinoide. These oragnic accumulations usually thicken to form coral patch reefs of variable thickness and located in the middle part of this unit. Many branched coral reef builds up are observed along Wadi Zaqlum. This coral patch reef is locally developed above the submarine paleohigh (uneven Late Cretaceous surface). It is massive, richly fossiliferous with diverse faunal assemblage such as bioclasts, calcareous red alge, echinoids, bryozoans, large benthonic foraminifers and bivalved shell fragments and algal rhodoliths. The most prominent organic elements is represented by in situ colonial corals. These faunal content attest to deposition in shallow clear water environments with normal salinity and open circulation. Among the megafossils that observed in this bed are *Pycnodonte virleti* Deshayes, *Ostrea frondosa* Fuchsia, *Pecten cristato-costatus* Sacco, *Pecten ziziniae* Blanckenhorn, *Strombus bonelli* Brongniart, *Chlamys submalvinae* Blanckenhorn, *Clypeaster* sp.

and *Flablepecten burdigalensis* Lamarck. This reefal limestones overlain by another brownish yellow to yellow, partly massive, fossiliferous with bivalved shell fragments and echinoids, argillaceous to sandy algal limestone. Yellow to greyish yellow, partly massive, fossiliferous argillaceous limestone and dolomitic limestone interbedded with green gypsiferous shale beds are recorded in the uppermost part of An Naggazah Member (Figs. 2 & 3).

2.2. Ras Al Mannubiyah Member

This rock unit was first introduced informally by Salem & Spreng (1980) to define the upper part of Al Khums Formation in Al Khums area, in the eastern side of Ras Al Mannubiyah village, about 8 km west-southeast of Al Khums, NW Libya. It overlies conformably An Naggazah Member and underlies unconformably the Quaternary clastic sediments and sometimes capped the topmost part of the section as in Wadi Zaqlum (Fig. 4). This member is essentially composed of highly fossiliferous algal reefal limestone separated by white cream-coloured chalky limestone bed. It is represented in its lowermost part by yellowish white, poorly cemented, fine to medium grained, moderately sorted, polymictic conglomeratic bed (with reefal limestone and subordinate calcareous sandstone lithoclasts), fossiliferous with oyster shell fragments and reworked corals. This bed may be probably developed during regresive phase of shoeline and changed laterally to dolomitic, fine to medium grained, moderately sorted, coarse to pebbly sandstones as in Ras Al Shaqqah section. Upwards this unit graded to light grey to greyish white, massive, ledge-forming, irregularly bedded highly fossiliferous with larger benthonic foraminifera, silty to sandy limestone interbedded with green shale and dolomitic limestone. This unit is conformably overlain by white to greyish white,

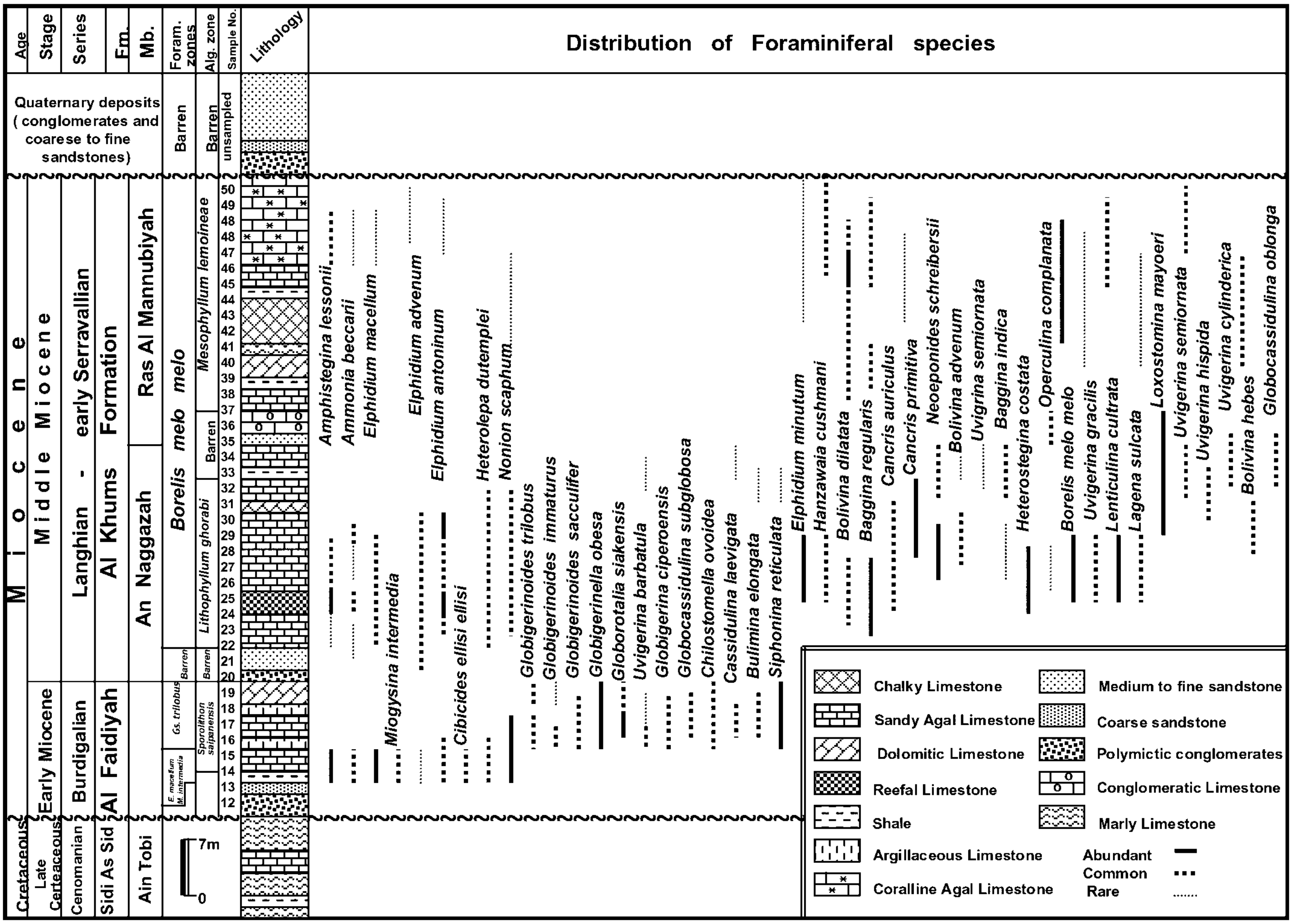


FIGURE 2–Distribution of the Miocene foraminifera in Ras Al Shaqqah.

irregularly bedded, crumbly, slightly fossiliferous with foraminifers and ostracods, slightly argillaceous, chalky limestone. An Naggazah Member terminated with thick bedded, yellowish to greyish white, porous, cavernous, algal reefal limestone, highly fossiliferous with coralline red algae, gastropods and other bivalved shell fragments. This unit has exhibits a characteristic honeycombed structura due to the lweathering process. Among the macrofossils extracted from this bed are *Pecten ziziniae* Blanckenhorn, *Flemingostrea crassissima aegyptiaca* Deshayes, *Chlamys submalvinae* Blanckenhorn, *Lucina multilamellata* Deshayes, *Turritella terebralis* Lamarck, *Echinolampus amplus* Fuchs, *Clypeaster isthmicus* Fuchs and fragmented colonial corals. The algal reefal limestone is usually capped the uppermost part of the Ras Al Mannubiyah Member by grayish yellow, cavernous fossiliferous sandy limestone beds (Figs. 2 & 4).

FORAMINIFERAL BIOSTRATIGRAPHY

About 120 samples were collected at close intervals. Ages were established by biostratigraphic analysis of the foraminiferal assemblages. Paleobathimetric interpretation was also made when possible. The continuous nature of the stratigraphic sections permit development of a detailed foraminiferal biostratigraphic framework. The Miocene foraminiferal biostratigraphy presented in this work based on the ranges and assemblages of the larger and smaller benthonic foraminifers and on the presence and distribution of the planktonic foraminifers. Detailed investigations of the foraminiferal content of the studied Miocene sequence in Al Khums area led to the recongition of three foraminiferal zones from base to top: *Elphidium macellum/ Miogypsina intermedia* zone and *Globigerinoides trilobus* zone (Early Miocene age) covering the lower and upper parts of Al Faidiyah Formation respectively.

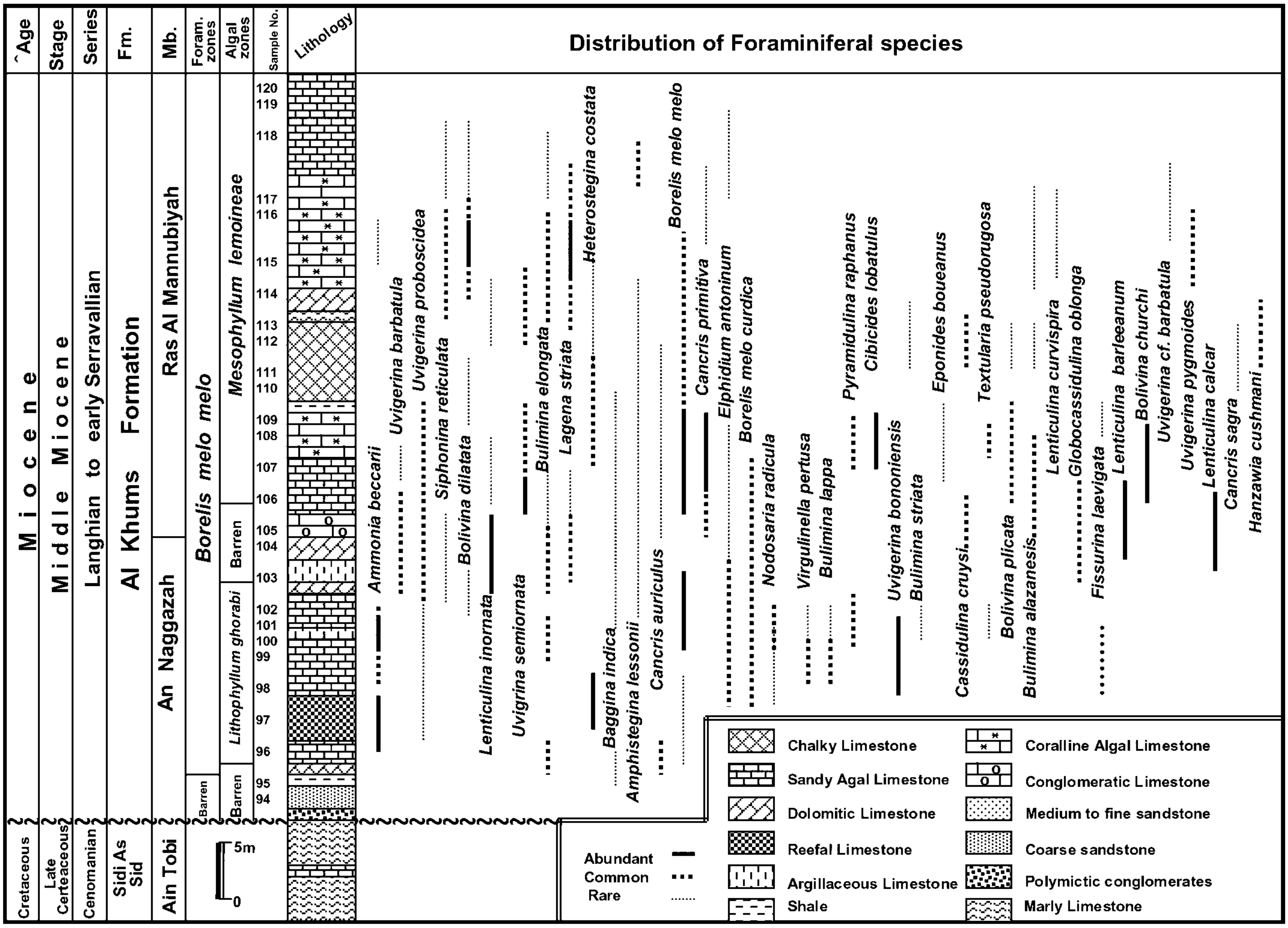


FIGURE 3–Distribution of Miocene foraminiferal species in Wadi Zaqlum.

Whereas the *Borelis melo melo* zone (Middle Miocene age) includes the whole Al Khums Formation.These biozones are discussed whereas the distribution charts of these foraminiferal species are also given in figures 2, 3 and 4, and the most diagnostic foraminiferal species are shown in Plates 1 & 2. In the following are the main foraminiferal zones recognized in the Miocene succession from base to top:

1. *Elphidium macellum / Miogypsina intermedia* Assemblage Zone

This zone is defined on the basis of the great abundance of the two nominal taxa (*Elphidium macellum* Fichtel & Moll and *Miogypsina intermedia* Drooger) and spanned the interval from the first occurrence of shallow marine *Elphidium macellum* Fichtel & Moll and *Miogypsina intermedia* Drooger to the first occurrence of *Globigerinoides trilobus* (Reuss). It occupies the lower part of Al Faidiyah Formation from sample 13 to 16 and recorded only in Ras Al Shaqqah section (Fig. 2). The interval of this zone is characterized by low to moderate diversity of both genera and species, among the most characteristic foraminiferal taxa recorded are: *Miogypsina intermedia* Drooger, *M. cushmani* Cushman, *M. complanata* Schlumberger, *M. mediterranea* Drooger, *Amphistegina lessonii* Brady, *Heterostegina heterostegina* (Silvestri), *Operculina complanata* (Defrance), *Elphidium macellum* Fichtel & Moll, *E. minutum* (Reuss), *E. advenum* Cushman, *E. crispum* Linne', *Nonion boueanum* d'Orbigny, *N. granosus* d'Orbigny, *Bolivina tumida* Reuss, *B. arta* Macfadyen, *Cibicides ellisi* Souaya, *Uvigerina gallowayi* Cushman, *U. cocoaensis hantkeni* Cushman & Edwards. The planktonic foraminifers are very rare and associalted commonly with the clays and marl thin bands, being represented mainly by non-diagnostic minute tests that makes it difficult to delineate its planktonic zone. Among the planktic taxa

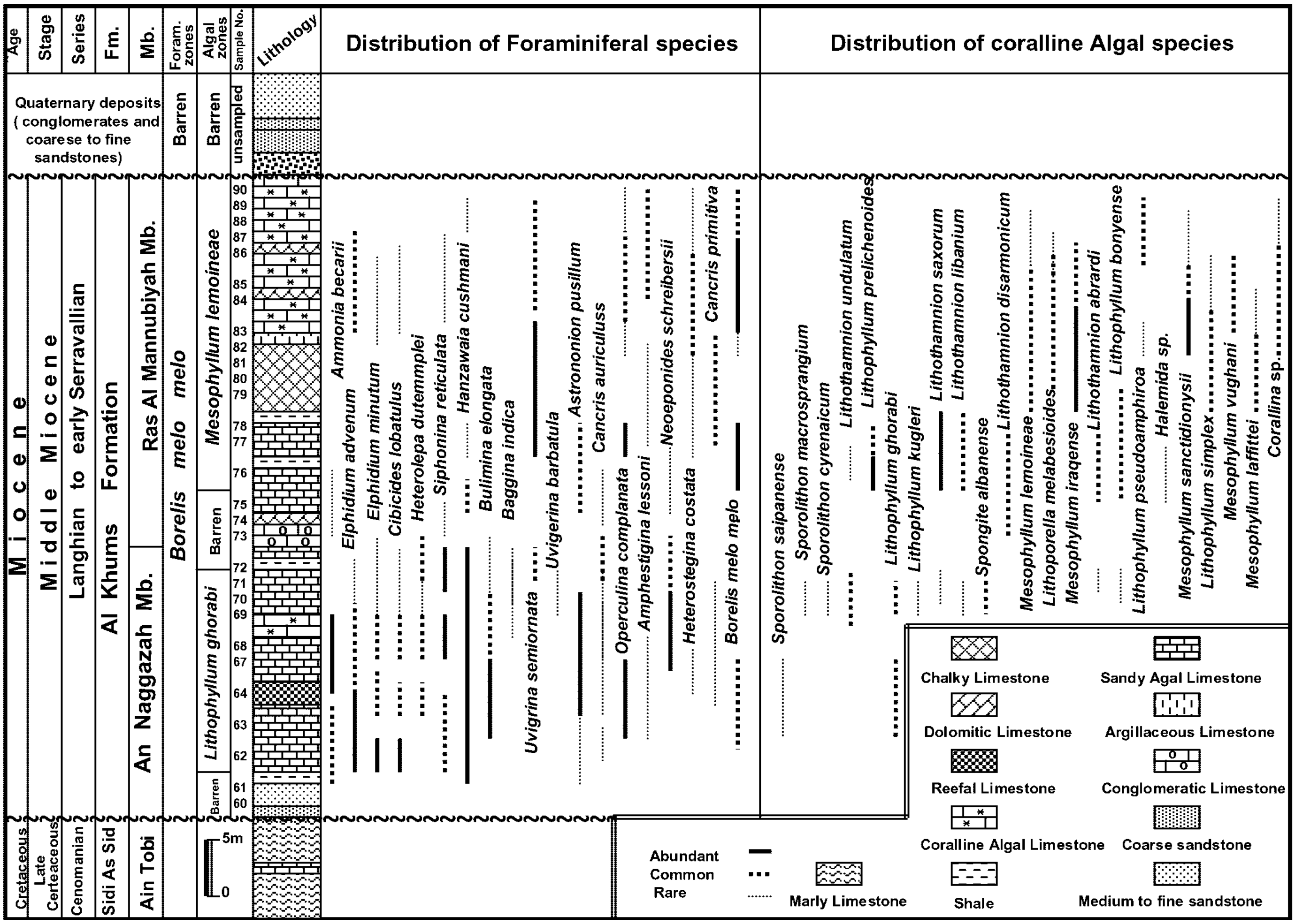


FIGURE 4–Miocene foraminiferal and coralline alga in Qabilt Ash Shurfah.

recorded are *Globigerina ciperoensis* Bolli, *Gg. angustiumbilicata* Bolli, *Gg. praebulloides* Blow, *Cassigerinella chipolensis* (Cushman & Ponton).

It is noteworthy of mention that *Miogypsina* taxa played an important role in the age assignment of this zone. Drooger (1954, 1963, 1993) related the *Miogypsina* group (*M. intermedia* Drooger, *M. cushmani* Cushman, *M. complanata* Schlumberger, *M. globulina* (Drooger) to Burdigalian age and equated to planktonic zone not older to N6. Souaya (1961, 1963) and Cherif (1966, 1980) recorded *Miogypsina intermedia* Drooger associated with *Operculina complanata*, *Heterostegina heterostegina* from the Miocene deposits of Cairo-Suez road of Egypt and assigned the rocks to Early Miocene (Burdigalian) age. Nassif *et al*. (1992) recorded the same assemblage of the nominated zone in the Miocene sequence of Wadi Feiran, southwest Sinai, Egypt and assigned the assemblage to an Early Miocene (Burdigalian) age. Moreover, Abdel Ghany & Piller (1999) recorded *Miogypsina intermedia, M. cushmani* and *M. mediterranea* from the Early Miocene Gharra and Sadat formations in Cairo-Suez district, Egypt and assigned to late Burdigalian age. Imam & Refaat (2000) recorded also this zone from the Early Miocene (Burdigalian) deposits of Wadi Abura and Gabal Hammam Sayidna Musa, southern Sinai, Egypt. More recently, Boudaghar *et al*. (2000, 2001) described some such large benthonic foraminiferal assemblage from Early Miocene (Burdigalian) sections in Boreno and nearby countries. From the foregoing discussion, the lower part of Al Faidiyah Foramtion that encompasses this zone is frankly assigned to Early Miocene (Burdigalian) age on the basis of the *Miogypsina* spp. and the rare occurrence of *Globigerina* spp. Consequently, this zone could be matched with N5 / N6 of Blow (1969) and correlated to the *Globigerinoides altiaperturus* / *Catapsydrax dissimilis*

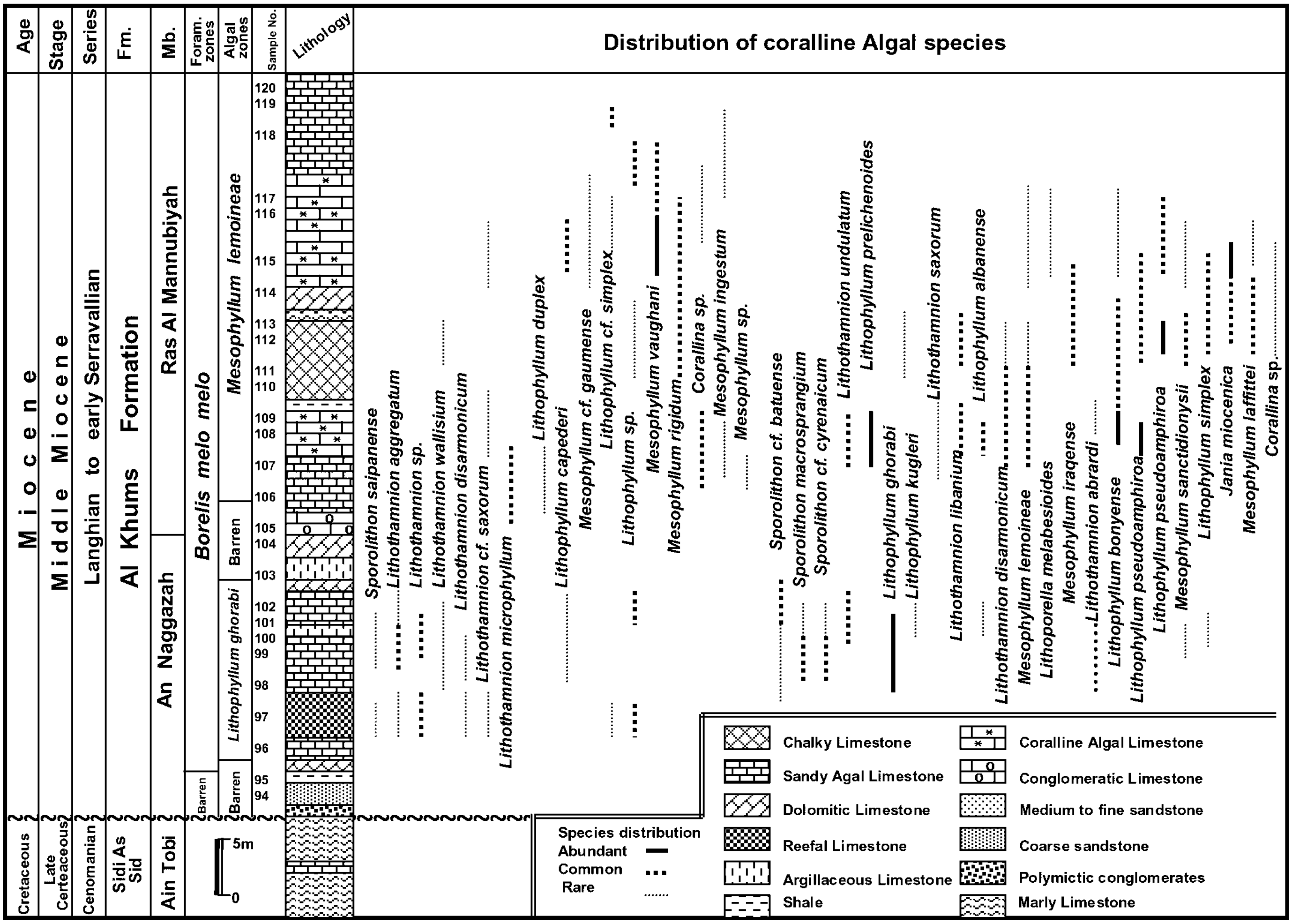


FIGURE 5–Distribution of Miocene coralline algae in Wadi Zaqlum.

zone of Iaccarino (1985) in the Mediterranean region. It is noteworthy of mention that no evidences of Aquitanian deposits were recorded in the studied area, where neither the *Miogypsina tani* Drooger (larger benthonic foraminifera) nor the *Globiquadrina dehiscens dehiscens* (planktonic foraminifera) zones are recorded, denoting that the Miocene transgression started earlier at the Late Burdigalian.

It is interesting to mention that some striking environmental foraminiferal species characterize this zone. The co-occurrence of *Bolivina tumida, Nonion scaphum, Uvigerina gallowayi* and *Miogypsina spp*. and the low P/B ratio indicate shallow marine environments (Douglas, 1979; Van der Zwaan & Jorissen, 1991; Murray 1991). Moreover, the co-occurrence of the *Ammonia beccarii* and the *Elphidium* sp. as well as *Heterolepa dutemplei* are taken as evidence of shallow marine less than 10 m shelf environments (Lipps *et al.* 1979; Boersma, 1985; Jorissen, 1991; Murray, 1991; Abul Nasr & Salama, 1999). Another feature that supports shallow marine shelf environments for the lower part of Al Faidiyah Formation (*Elphidium macellum / Miogypsina intermedia* zone) is the occurrence of oyster and molluscan shell fragments in the lower calcareous sandstone and the polymictic conglomerate beds that indicate near shore environment (Friedman & Sanders, 1978). All these environmental features assert that the *Elphidium macellum / Miogypsina intermedia* zone was deposited in very shallow inner shelf marine environments.

2. *Globigerinoides trilobus* Zone

The lower boundary of *Globigerinoides trilobus* interval zone of Blow (1969) is marked in the studied sections by the last occurrence of *Miogypsina intermedia* Drooger. While its upper boundary is delimited by the first occurrence of *Borelis melo melo* Fichtel & Moll. It occupies the upper part of Al Faidiyah Formation from sample 17 to 20 and are recorded only in Ras Al Shaqqah section (Fig. 2). It is characterized by the abundance of the following planktonic foraminiferal species: *Globigerinoides trilobus* (Reuss), *Gs. immaturus* Le Roy, *Gs. sacculifer* Brady, *Gs. parawoodi* Jenkins, *Gs. subquadratus* Brönnimann, *Globigerina ciperoensis* Bolli, *Gg. angustiumbilicata* Bolli, *Gg. praebulloides* Blow, *Globigerinella obesa* (Bolli), *Cassigerinella chipolensis* (Cushman & Ponton). It contains also some benthonic foraminifers such as *Nonion boueanum* (d'Orbigny), *N. granosus* (d'Orbigny), *N. scaphum* Fichtel & Moll, *Uvigerina barbatula* Macfadyen, *U. graciliformis* Papp & Turnovsky, *U. proboscidea* (Schwager), *Cibicides ellisi ellisi* Souaya, *Siphonina reticulata* Czjzek, *Bolivina dilatata* Reuss, *Cassidulina laevigata* d'Orbigny, *Cancris primitiva* Cushman, *C. auriculus* Fichtel & Moll, *Bulimina alazanensis* (Cushman), *Chilostomella ovoidea* Reuss and other listed in Figure 3. Such benthonic foraminiferal association and the high proportion of the planktonic foraminifera over the benthonic ones as well as its association with argillaceous limestone beds (carbonate dominated facies) indicate that maximum depth of the Miocene transgression occurred during the upper part of Al Faidiyah Formation suggesting deposition in inner to middle shelf marine environments. This is supported also by the absence of *Ammonia* and *Elpidium* and the first appearance of *Uvigerina barbatula* and *Cassidulina laevigata* that lived in deeper marine environments (Murray, 1991). Going upwards, a marked diminution in number and diversity of the planktonic foraminifera occurred over this interval. This sharpest decrease coincides with the relatively rapid shallowing indicated between the *Globigerinoides trilobus* zone and the overlaying *Borelis melo* zone (eustatic fall in sea level). Otherwise, a regressive phase occurred by the beginning of the *Borelis melo* zone and spanned the time of deposition of the uppermost Al Faidiyah Formation. This interval is to great extent comparable with the global eustatic sea level lowering suggested by Haq *et al.* (1987) and combined with localized minor tectonic movement that played a role in the definition and distribution of Al Faidiyah Formation in the area.

Concerning the age of this zone, many authors assigned it to the Early Miocene; among them are El Kerdany (1967), El Heiny & Martini (1981), Imam (1986 & 1991 & 1997), Youssef *et al*. (1988), Rateb (1988), Haggag *et al*. (1990), Imam (1991& 1997), who recorded this zone in the Gulf of Suez region, Egypt. Nassif *et al.* (1992) recorded the same nominated zone in the Miocene sequence of Wadi Feiran, southwest Sinai, Egypt and assigned the assemblage to an Early Miocene (Burdigalian) age. Isamil & Abdel Ghany (1999) recorded also this zone in some Lower Miocene sections in Cairo-Suez road, Eastern Desert, Egypt. Imam & Refaat (2000) recorded also *Globigerinoides trilobus* zone from the Early Miocene deposits of Wadi Abura and Gabal Hammam Sayidna Musa, southern Sinai, Egypt and dated it as Early Miocene (Burdigalian) age. This zone could be safely correlated with the standard planktonic foraminiferal zone N7 of Blow (1969) and also to the *Globigerinoides trilobus* zone of Iaccarino & Slavatorini (1982) and Iaccarino (1985) in the

Mediterranean region. Therefore, it is safely to assigne this zone to Early Miocene (late Burdigalian) age and assumes relatively open deep marine environments.

3. *Borelis melo melo* Zone

The *Borelis melo melo* zone is defined in the present study by the total range of the nominated zonal taxon, where its lower boundary is delineated on the first occurrence of *Borelis melo melo* Fichtel & Moll, while the upper boundary is marked by its extinction where the Miocene-Pliocene unconformity is located. This zone is encountered in the studied sections covering the whole Al Khums Formation. It is characterized by the abundance of larger foraminifera such as *Borelis melo melo* Fichtel & Moll, *B. melo curdica* (Reichel), *Amphistegina lessonii* Brady, *Operculina carpenteri* Silvestri, *Heterostegina costata costata* d'Orbigny, *H. heterostegina heterostegina* Silvestri, *H. heterostegina praecosta* Papp & Kupper. Among the benthonic foraminifera recorded in this zone are: *Ammonia beccarii* Linne', *Elphidium minutum* (Reuss), *E. advena* Cushman, *Eponides repandus* Cushman, *Nonion boueanum* d'Orbigny, *N. scaphum* Fichtel & Moll, *Uvigerina costata* Bieda, *U. semiornata* d'Orbigny, *U. barbatula* Macfadyen, *U. hispida* Schwager, *Siphonina reticulata* d'Orbigny, *Bolivina dilatata* Reuss, *Textularia* sp., *Cancris auriculus*, *Baggina indica*, *Bulimina pupoides*.

The careful investigation of the argillaceous limestone beds and the white cream-coloured chalky limestone beds yielded low diversified planktonic foraminiferal association represented by: *Globigerinoides trilobus* (Reuss), *Gs. immaturus* Le Roy, *Gs. sacculifer*

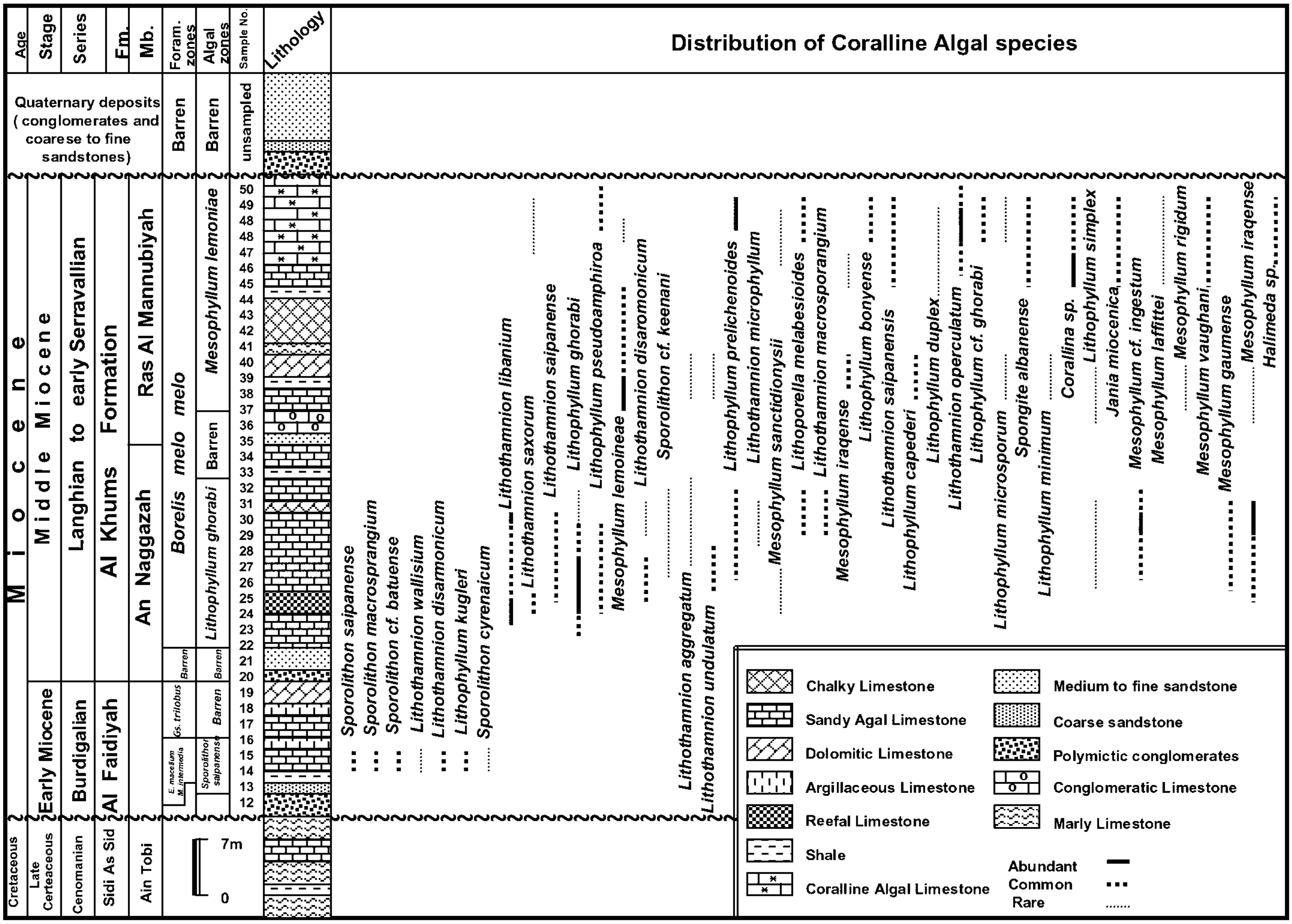


FIGURE 6–Distribution of the Miocene coralline algae in Ras Al Shaqqah.

Brady, *Gs. subquadratus* Bronimmann, *Globigerina ciperoensis* Bolli, *Gg. praebulloides* Blow, *Globogerinella obesa* Bolli, *Gr. siakensis* Le Roy, *Cassigerinella chipolensis* Cushman & Ponton, *Orbulina suturalis* Bronimmann, *Orbulina universa* d'Orbigny. These planktonic foraminiferal assemblages indicate deeper water environment than the *Borelis melo* association (shallow marine environment) and hence suggest progressive deepening of water. This zone could be correlated with the standard planktonic foraminiferal zone N8 and N9 of Blow (1969) and also to the *Praeorbulina glomerosa* zone and *Orbuina suturalis* subzone of Iaccarino (1985) and Fornaciari *et. al.* (1997) as well as Foresi *et al*. (1998) in The Mediterranean region. Consequently, this zone is assigned to Middle Miocene (Langhian to Early Serravallian) time.

It is noteworthy to mention that *Borelis melo melo* (Fichtel & Moll) is the most conspicuous large benthonic foraminiferal species recorded in this zone. Many authors have discussed the biostratigraphic and paleoenvironmental significance of this taxon as Middle Miocene index species. It was first described by Colom (1958), who recorded this taxon as *Orbulina* spp. in the Middle Miocene strata overlying the *Miogypsina mediterranea* beds of Majorca in Spain. Eames *et al*. (1962) recorded it associated with *Globorotalia fohsi fohsi / Orbulina* spp. zone and considered it as index large foraminiferal species marking the beginning of the Middle Miocene boundary. Souaya (1963a) recognized it in the *Miogypsina cushmani* zone in the Middle Miocene of Gabal Gharra, Cairo Suez road, Egypt. Later on, Souaya (1963b) reported it from the Middle Miocene-Pliocene succession in the Red Sea, Egypt. Reiss & Givertzmann (1966) showed that the presence of *Borelis melo* in the Middle to Upper Miocene Ziqlag Formation of Israel and attributed to zone N9 of Blow

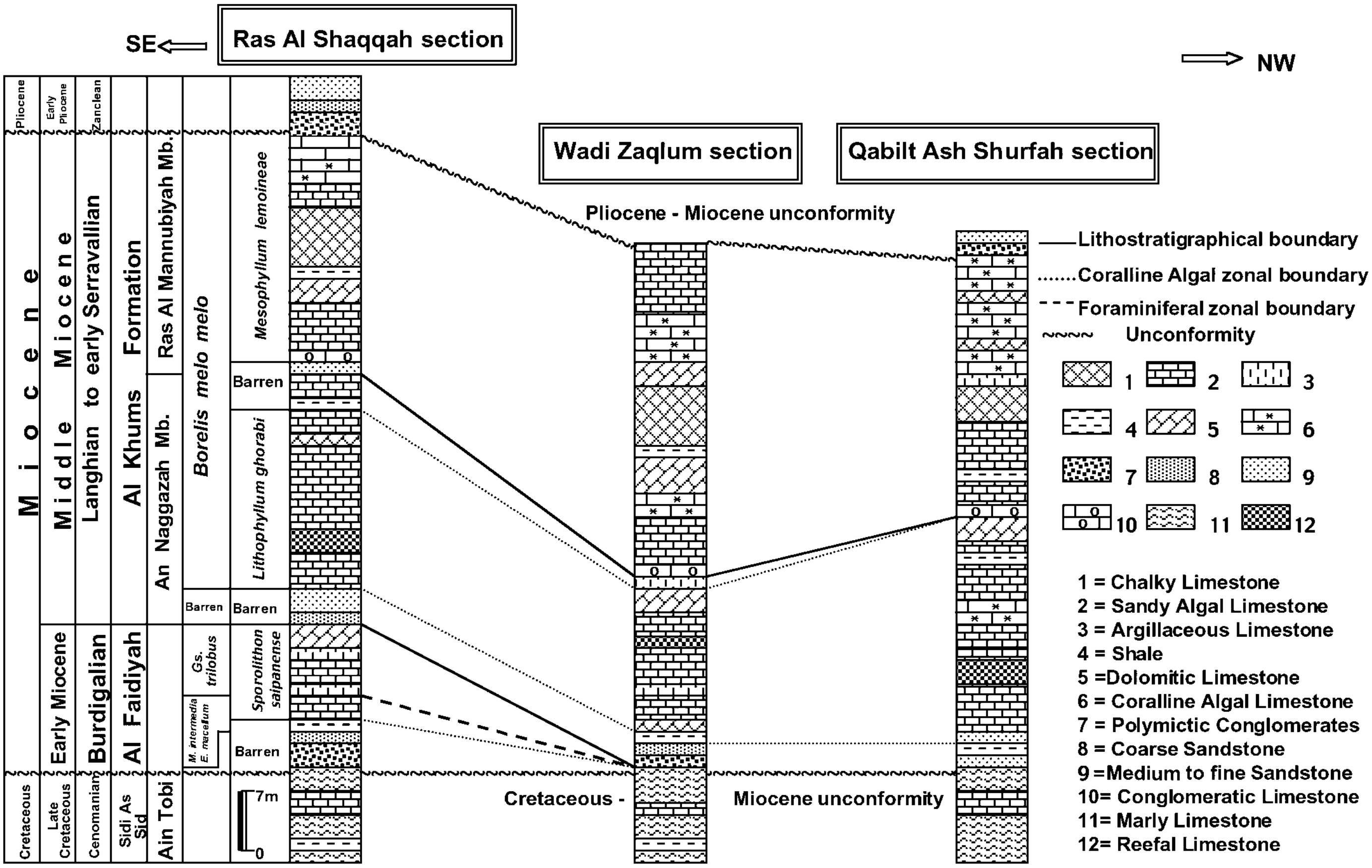


FIGURE 7–Correlation chart of the studied Miocene sections.

(1969). Bizon *et al.* (1968) and Clarke & Blow (1959) reported that *Borelis melo* ranges stratigraphically from base of zone N9 to Recent deposits. Moreover, Imam (1986, 1991,1996 and 1999 a, b) reported this taxon in the algal reefal limestone deposits of the Middle Miocene Sarbut El Gamal Formation in west-central Sinai, Egypt. In Libya, Barr & Weegar (1972) recorded this species in Al Jabal Al Akhdar as a marker for the Middle Miocene beds. Later on, Sherif (1991) recorded this taxon from the middle Miocene deposits of Al Khums Formation. Imam (1997, 1999a, b) also defined this taxon in the Middle Miocene Al Jaghboub Formation in Al Bardia area, NE Libya. Imam & Refaat (2000) recorded also this taxon from the Middle Miocene Hammam Faroun Member of Belayium Formation and gave it a definite zone in Gabal Hammam Sayidna Musa and Wadi Abura, southern Sinai, Egypt. Recently, Imam (2002) recorded the *Borelis melo* zone from the Middle Miocene Marmarica Formation in the Salum area, Western Desert, Egypt. From the above mentioned discussion, the presence of *Borelis melo melo* Fichtel & Moll in the present work associated to representative forms of *Praeorbulina* spp., *Orbulina universa* in the argillaceous limestone interbeds give a strong support for a Middle Miocene age (Langhian to Early Serravallian) to the Al Khums Formation, which could be correlated to zone N8 and N9 of Berggren (1967), Blow (1969) and Iaccarino (1985).

MORPHOLOGY AND MODE OF OCCURRENCE OF THE CORALLINE ALGAE

Coralline algae are important paleoenvironmental indicators. Their associations and growth form types, in combination with petrographic and sedimentological data can be used to determine the environment of

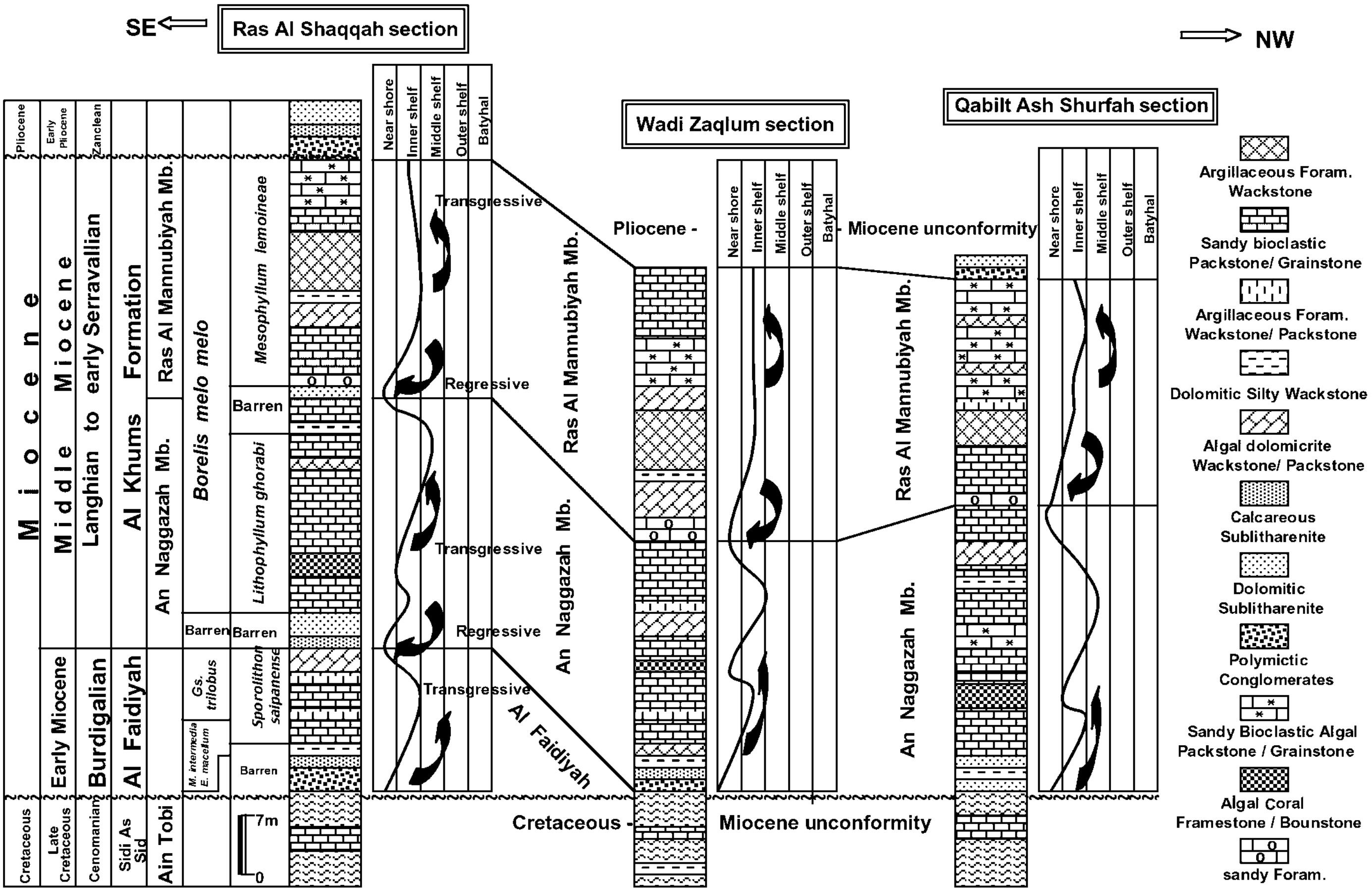


FIGURE 8–Suggested Depositional environments of the studied Miocene sections.

deposition and the genesis of the sediments (Johnson, 1960; Adey, 1979, 1986; Bosence, 1983; Braga & Martin, 1988 and Martin *et al*., 1993). Coralline algae are the most important biota in the carbonate-dominated facies (algal to reefal limestone deposits) of Al Khums Formation, where large number of well preserved coralline algae (mainly Rhodophyta) are very common and appear together with skeletal particles of bryozoans, molluscs, echinoids and larger foraminifera. These coralline algae are sited to family Corallinaceae mostly in situ forming crusts on the corals and other skeletal elements loose branches and rhodoliths. Both of the crustose non-geniculate corallines (subfamily Meloisioideae, forming more than 80% of the coralline thalli) and the (geniculate corallines) articulated coralline algae (subfamily Corallinoideae, 20%) are well represented and abundant, especially in the lower and upper parts of Al Khums Formation. The green alga of Family Codiaceae (Cholorophyta division) is rarely recorded, being represented by only one genus, *Halimeda* sp. The coralline diversity of the studied material is moderately high with twenty-four taxa of coralline algae. The algal association is dominated by shallow water coralline algae of lithophylloids (*Lithophyllum)* intercalated with intervals dominated by melobesoids (*Mesophyllum* and *Lithothamnion*), with minor sporolithaceans (*Sporolithon*) and subordinate mastophoroids (*Spongites* and *Neogoniolithon*) that predominate in algal association of slightly deep sediments. The main growth types observed in the studied materials are 1) Rhodoliths: made up of unattached nodules of non-geniculate laminar, encrusting thalli and foralgaliths in which thin encrusting coralline thalli are intergrown with encrusting larger foraminifera. Two main types of algal nodules are evident, the first one is typical rhododliths with nuclei of fragmented corals or molluscan shell fragments, and dominated with coralline red algae, mostly of melobesioide coralline such as *Lithophyllum* spp., *Lithothamnion* spp., and also *Lithoporella* sp., *Mesophyllum* sp. and rarely *Sporolithon* spp. Serpulids, bryozoans, vermitids and encrusting foraminifers can all be found intergrowthing coralline inside. This type of bioclastic association is typical of shallow water-temperate marine platforms. The second type of rhodolith is serpulids nodules, consists exclusively of nuclei of serpulids worm tubes and encrusting with *Mesophyllum* spp. (mainly of *Mesophyllum sanctidionysi* and *Mesophyllum laffittei*. With *Lithophyllum* spp. and rarely *Lithoporella* sp). The algae were sometimes occurred as individual algal nodules of coarse rhodoliths (3-5 cm) composed mainly of overturned coralline, but this type is very rare. The presence of rhodoliths indicates depth ranges from 50-80 m (Adey & MacIntyres, 1973). 2) Coralline algal branches: that includes unfragmented isolated algal thalli and are extensively developed in the lower and upper parts of Al Khums Formation. 3) Attached coralline crustose forms, dominated by *Lithophyllum* spp. The algal crusts consists mainly of *Lithophyllum prelichenioides* (most abundant species and outnumbering any other *Lithophyllum* spp.), *Lithophyllum ghorabi* (the second abundant species mainly associated with bryozoans and coral colonizes), *Lithophyllum simplex* Johnson and *Lithophyllum pseudoamphiroa* Johnson. These types of coralline red algae occurred commonly in the form of superimposed undulating crusts of 300-500 µm thick and usually alternating with encrusting foraminifers forming short protuberances and short branches. They occurred also as encrusting the large benthonic foraminifers such as *Amphistegina* spp. and *Heterostegina* spp. and rapped also the bryozoans, echinoids plates and the colonial corals. Both the *Lithophyllum prelichenioides* and *Lithophyllum ghorabi* reach more than 30% of the studied coralline algae. The *Lithophyllum* spp. and *Mesophyllum* spp. are the main components of the algal associations. *Lithothamnion* spp. and *Sporolithon* spp. are relatively rare and existed as fragmented specimens. *Lithoporella* spp. occurs as monostromatic crusts that highly exited and commonly encrusting in situ and fragmented corals, large benthonic foraminifers and other coralline red algae. This type of coralline algae is commonly occur as abraded, fragmented grains which may be derived from attached crusts and are either micritized that prevent the taxonomic identification. They usually form free crusts but relatively scarce and mainly associated with isolated coral colonies or form algal bank which pave the solid substrates (Buchbinder, 1977). The other form is as branched thalli, which existed as loosely packed branches.

CORALLINE ALGAL BIOSTRATIGRAPHY

The careful examination of the coralline red algae in the studied sections allowed subdividing the Miocene sequence into a number of local algal zones. Each zone is characterized by its peculiar association of coralline red algal taxa. In the following section, a brief description of each zone is given from base to top:

1. *Sporolithon saipanense* Zone

This interval zone is defined by the total range of the zonal species and characterized by the common occurrence of *Sporolithon saipanense* Johnson, *S. cyrenaicum* Raineri and *S. macrosprangium* Johnson. This zone is recorded in the lower part of the Al Faidiayah Formation (Ras Al Shaqqah section) covering the stratigraphic interval from sample no. 14 to sample no. 19. This zone is distinguished by its low diversity and little frequency of the coralline red algal speciessuch as *Sporolithon saipanense* Johnson, *Lithothamnion saxorum* Johnson, *Ln. alasanii* Maslov, *Ln. aggregatum* Lemoine, *Sporolithon cf. batuense* Lemoine, *S. cyrenaicum* Raineri, *S. cf. keenani* Howe. These species are mostly incoporated in the limestone or sandy algal limestone lithofacies of Al Faidiyah Formation especially in sample nos. 15, 17 and 19.

2. *Lithophyllum ghorabi* Zone

This zone is characterized by the total range of *Lithophyllum ghorabi* Souaya. It is recorded in Al Khums Formation in both of the studied sections, in Qabilt Al Shurfah section covering the stratigraphic interval from sample 53 to 62 and characterized by rare occurrence of algal species such as *Lithophyllum ghorabi* (zonal marker), *Lm. kugleri* Johnson, *Lm. albanense* Lemoine and *Sporolithon batuense* Airlodi. Where in Ras Al Shaqqah section, it includes the interval from sample no. 26 to 36 and distiguished by *Lithophyllum ghorabi* Souaya, *Lm. albanense* Lemoine, *Lm. bonyense* Johnson, *Lm. pseudoamphiora* Johnson, *Lm. kugleri* Johnson, *Lithothamnion abrardi* Lemoine, *Ln. saxorum* Johnson, *Ln. libanium* Edgell & Basson, *Ln. disarmonicum* Conti and *Lithoporella melabesioidea* Foslie and *Mesophyllum guamense* Johnson, *Corallina* sp. (Figs. 2 & 3).

3. *Mesophyllum lemoineae* Zone

This zone is recorded in the upper part of Al Khums Formation covering Ras Al Mannubiyah member at Qabilt Al Shurfah section from sample no. 65 to 80 and are also observed in Ras Al Shaqqah section including the samples from 40 to 50 (Figs. 2, 3, 4). Among the most common recorded coralline algal species are: *Lithothamnion abrardi* Lemoine, *Mesophyllum lemoniae* Souaya, *M. guamense* Johnson, *M. vughanii, M. sancti-dionysii* Lemoine, *M. iraqense* Johnson, *M. laffitte* Lemoine *Lithoporella melabesioidea* Foslie, *Lithophyllum prelichenioides* Lemoine, *Lm. simplex* Johnson, *Lm. bonyense* Johnson *Lm. pseudoamphiora* Johnson, *Corallina prisca* Johnson.

DESCRIPTION OF THE MAIN CORALLINE ALGAL TAXA

The terminology of the taxonomic features of Woelkerling, 1988; Braga & Aguirre 1995 and the different growth forms of Woelkerling *et al*, 1993, Rasser & Piller, 1999, have been adopted in the present work. In the following paragraphs the main characteristic algal species will be discussed from their arrangement and characters of the core filaments and peripheral filaments (shape of cells and their arrangement), shape of the reproductive organs (conceptacles and sporangia) and different growth forms for algal thalli as well as its stratigraphic significance

Division RHODOPHYTA Wettstein, 1901
Class RHODOPHYCEAE Rabenhorst, 1863
Order CORALLINALES Silva & Johansen, 1986
Family CORALLINACEAE Lamouroux, 1816
Subfamily LITHOPHYLLOIDEAE Setchell, 1943
Genus *Lithophyllum* Philippi, 1837

Lithophyllum prelichenioides Lemoine (Pl. 5, Fig. 2): Occurs as thin (0.2-0.5 mm), pale pink rugosa crusts with white growing edges. The crust margins are commonly upturned and free of substrate imparting a leafy shape to this coralline. Crusts frequently bifurcate and rejoin, which combined with the leafy growth, resulting in an open crustose framework. New crusts growing from the previous peripheral filaments produce the majority of birfucation. Columnar peripheral filaments also occur within the framework with diameter of 4 mm and heights of 4-5 mm. Conceptacles are observed and bear usually fertile sporangia.

Lithophyllum ghorabi Souaya (Pl. 4, Fig. 1): Thick undulate crust (2-4 mm), commonly overgrow in cavities and bifurcate. It also overgrows the previous neighboring crust of other coralline algae. The core filaments is thick (180-700 µm thick) composed of regular coaxial rectangular cells 10-27 µm in diameter and 20-45 µm in length where the cells becomes smaller toward the peripheries. The peripheral filaments (300-430 µm) composed also of rectangular cells 25-32 µm in length and 10-19 µm in diameter. Columnar growth zones are commonly and frequently contain multipored conceptacles.

Lithophyllum bonyense Johnson (Pl. 5, Fig. 1): Numerous crusts composed of structurally uniform core filaments and variably thick peripheral filaments. Core filaments are coaxial with cell 23-42 µm in length and 9-12 µm in diameter in the axial part, arranged in regular arched rows. The peripheral filaments are poorly developed with cell measuring 7-15 µm in length and 9-11 µm in diameter taking the shape of a regular grid. Conceptacles are not observed.

Lithophyllum duplex Maslov (Pl. 5, Fig. 6): Regular spine-like branch composed completely of peripheral filaments with strong lenticular growth zones. The peripheral filaments composed of subquadrate cells 7-13 µm in length and 8-11 µm in diameter with no conceptacles.

Lithophyllum simplex Lemoine (Pl. 4, Fig. 10): Numerous fragments of branched thalli represented exclusively by peripheral filaments with strong lenticular growth zones. The peripheral filaments composed of subquadrate cells. These cells have 9-14 µm in length and 7-10µm in diameter with no observed conceptacles.

Lithophyllum pseudoamphiroa Johnson (Pl. 5, Fig. 3): The thallus is composed of regular-branched forms, encrusting the other bioclastic constituents. Well-developed core filaments (250-520 µm thick) and thin peripheral filaments are occurred. The core filaments composed of concentric coaxial arched layers of cells measuring 25-45 µm in length and 16-20 µm in diameter. Cells become thick in the middle part and thin towards the peripheries. Well-developed conceptacles are observed.

Subfamily Mastrophoroideae Setchell, 1943

Genus *Lithoporella* (Foslie) Foslie, 1909

Lithoporella melabesioides (Foslie) Foslie (Pl. 4, Fig. 2 & Pl. 5, Fig. 7): Thick unistratose thallus of multilayered (multiple overgrowth), which represent the basal primigenous filaments with no additional peripheral filaments. Crusts are superimposed on each other, each single layer consisting of large rectangular palisad cell except around the conceptacles where the thalli are thick. Cells are 40-68 µm in length and 15-24 µm in diameter. The conceptacles are circular measuring 70-110 µm in height and 60-110 µm in diameter.

Genus *Spongites* Kützing, 1841

Spongite albanense Johnson (Pl. 5, Fig. 9 & Pl. 4, Fig. 5): Irregular crustose thalli (0.5-1.9 mm thick). Thallus composed of irregular peripheral filaments with rectangular cells measuring 10-19 µm in length and 9-12 µm in diameter and indistinct basal core filaments with cells measuring 13-25 µm in length and 12-17 µm in diameter. Conceptacles are observed measuring 290-430 µm in diameter and 160-180 µm in height with single short thick opening.

Subfamily Melobesioideae Bizzorzero, 1897

Genus *Lithothamnion* Heydrich, 1897

Lithothamnion libanium Lemoine (Pl. 3, Fig. 7): Crustose thalli (210-420 µm thick) of well-developed core filaments and peripheral filaments. The hypothallic cells are measured 12-19 µm in length and 8-14 µm in diameter where the perithallic cells are 7-14 µm in length and 5-11 µm in diameter. Well-developed conceptacles are observed measuring 270-530 µm in diameter and 120-160 µm in height.

Lithothamnion saipanense Johnson (Pl. 3, Fig. 1): This type of algal taxa occurred as crustose thalli of well-developed core filaments and peripheral fila-

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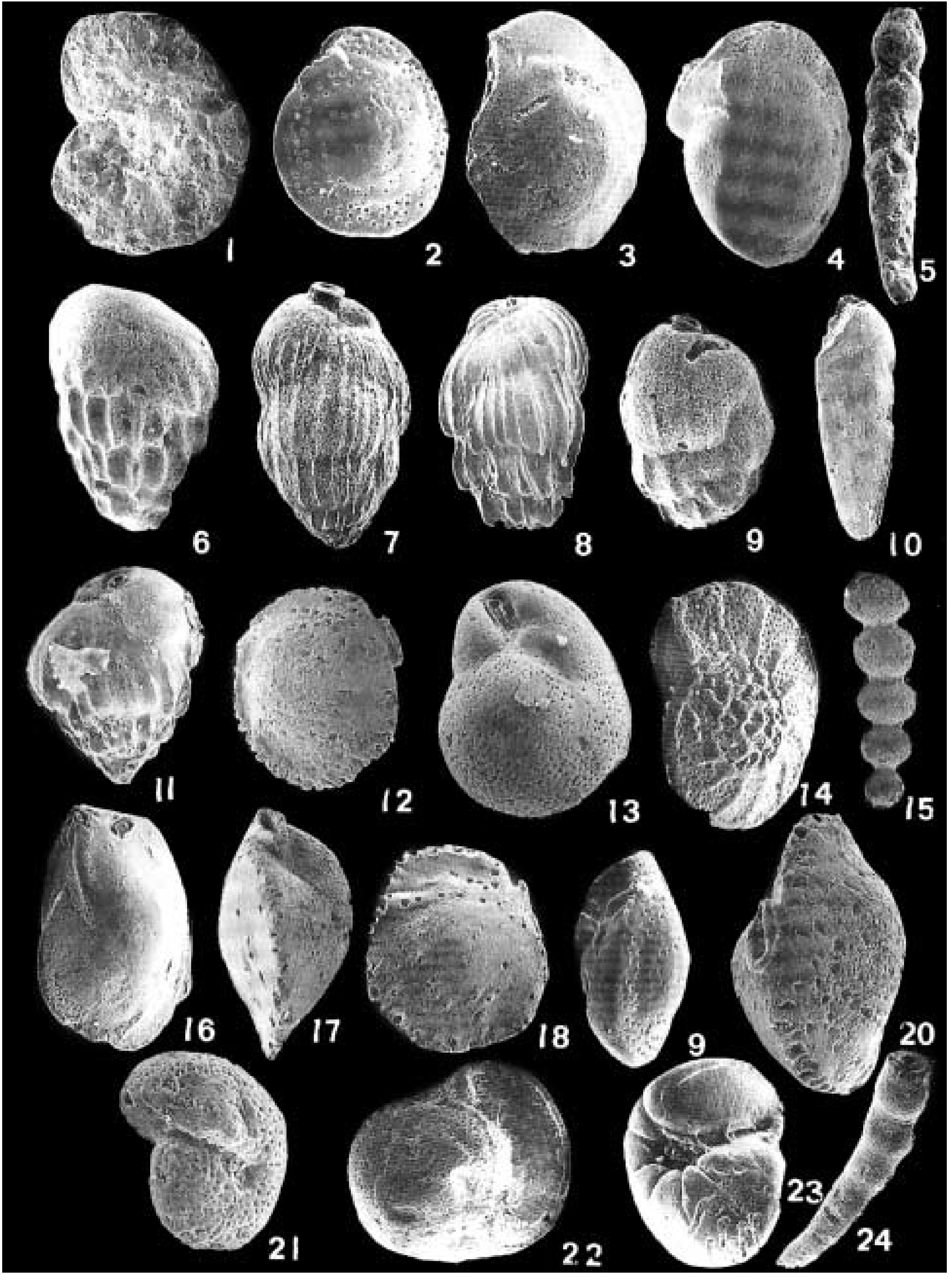
PLATE 1–*1, Cibicides lobulatus* d'Orbigny, venteral view, sample 14, Al Faidiyah Fm., Ras Al Shaqqah section, x 70. *2, Heterolepa dumpelti* d'Orbigny, dorsal view, sample 28, Al Khums Fm., Ras Al Shaqqah section, x 70. *3- 4, Heterolepa dumpelti* d'Orbigny, dorsal view, sample 30, Al Khums Fm., Qabilat Ash Shurfah section. 5, *Stilostomella consobrina* Reuss, side view, sample 98, Al Khums Fm., Wadi Zalqum section, x 50. 6, *Bulimina alazanensis* Cushman, side view, sample 106, Al Khums Fm., Wadi Zalqum section, x 120. *7-8, Uvigerina semiornata* d'Orbigny, side view sample 107, Al Khums Fm., Wadi Zalqum section, x 60. *9, Uvigerina barbatula* Brady, side view, sample 15, Al Faidiyah Fm., Ras Al Shaqqah section, x 90. 10, *Bolivina advenum* d'Orbigny, side view, sample 28, Al Khums Fm., Ras Al Shaqqah section, x 80. *11, Bulimina elongata* d'Orbigny, side view, sample 68, Al Khums Fm., Qabilat Ash Shurfah section, x 170. *12, Siphonina planoconvexa* Silvestri, side view, sample 72, Al Khums Fm., Qabilat Ash Shurfah section, x 110. *13, Globocassidulina subglobosa* BRADY, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *14, Cibicides ellisi ellisi* d'Orbigny, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 90. *15, Stilostomella monilis* Silvestri, sample 32, Al Khums Fm., Ras Al Shaqqah section, x 80. *16, Lenticulina cultrata* (Cushman), sample 47, Al Khums Fm., Ras Al Shaqqah section, x 80. *17-18, Siphonina reticulata* Gzjzek, sample 72, Al Khums Fm., Qabilat Ash Shurfah section, x 130. *19, Heterolepa bellincionii* Giannini, sample 34, Al Khums Fm., Qabilat Ash Shurfah section, x 140. *20, Siphonina planoconvexa* Silvestri, sample 35, Al Khums Fm., Ras Al Shaqqah section, x 110. *21, Melonis pompilioides* (Fitchel & Moll), sample 45, Al Khums Fm., Ras Al Shaqqah section, x 150. *22, Melonis soldania* d'Orbigny, sample 74, Al Khums Fm., Qabilat Ash Shurfah section, x 90. *23, Gyroidinoides girardanus* d'Orbigny, sample 107, Al Khums Fm., Wadi Zalqum section, x 100. 24, *Stilostomella verneuilli* d'Orbigny, sample 104, Al Khums Fm., Wadi Zalqum section, x 50.

PLATE 1



ments. The core filaments are 160-310 µm composed of curved upward rows of cells. The peripheral filaments composed of regular cells with conceptacles of flat or concave base.

Lithothamnion undulatum Capeder: Crustose thalli with warty protuberance of undulating appearance. The basal core filaments are faintly developed consisting of curved rows of regular cells measuring 10-15 µm in length and 11-14 µm in diameter. The peripheral filaments tissue is well developed showing contorted appearance and lenticular growth zones with conceptacles.

Lithothamnion saxorum Capeder (Pl. 3, Fig. 3): Crustose thalli of plumose basal core filaments and well-developed peripheral filaments. The core filaments consist of upward curved cell rows of rectangular shape (12-27 µm in length and 10-15 µm in diameter). The peripheral filaments are composed of regular tissue with pronounced vertical cell threads and growth zones. Cells are 10-18 µm in length and 7-11 µm in diameter). Conceptacles are rare, measuring 260-320 µm in diameter and 140 µm in height.

Lithothamnion wallisium Johnson & Tafur: Crustose form with mammillae. The core filaments are thin, usually absent. The peripheral filaments consist of irregular lenticular growth zones. Cells are 8-11 µm in diameter and 10-12 µm in length. Conceptacles are abundantly occurred measuring 180-360 µm in diameter and 100-130µm in height.

Lithothamnion disarmonicum Conti (Pl. 3, Fig. 9): Thick mammillae crusts composed exclusively of peripheral filaments that consist of irregular lenticular growth zones. Cells are 8-10 µm in diameter and 9-12 µm in length. Conceptacles are abundantly occurred measuring 190-430 µm in diameter and 110-130 µm in height.

Lithothamnion macrosporngicum Mastrorilli (Pl. 3, Fig. 2): Crustose form with mammillae. The core filaments are thin, usually absent. The peripheral filaments consist of irregular lenticular growth zones. Cells are 7-10 µm in diameter and 9-12 µm in length. Conceptacles are abundantly occurred measuring 150-335 µm in diameter and 110-150 µm in height.

Lithothamnion microphyllum Maslov (Pl. 5, Fig. 4): Two fragments of crustose form with distinctly zoned thalli. The core filaments are thin. Cells are 7-11 µm in length and 6-9 µm in diameter. The peripheral filaments consist of irregular lenticular growth zones. Cells are 7-13 µm in diameter and 9-11 µm in length. Conceptacles are abundantly occurred measuring 170-240 µm in diameter and 120-140 µm in height.

Lithothamnion opercultum Conti (Pl. 3, Fig. 5): Crustose form with mammillae. The core filaments are thin, poorly preserved and usually absent. The peripheral filaments consist of irregular lenticular growth zones. Cells are 7-9 µm in diameter and 9-13 µm in length. Conceptacles are abundantly occurred measuring 230-330 µm in diameter and 110-120 µm in height.

Genus *Mesophyllum* Lemoine, 1928

Mesophyllum laffittei Lemoine (Pl. 3, Fig. 6): Crustose to knobby protuberance, The core filaments are basal and zoned with rectangular cells 17-26 µm in

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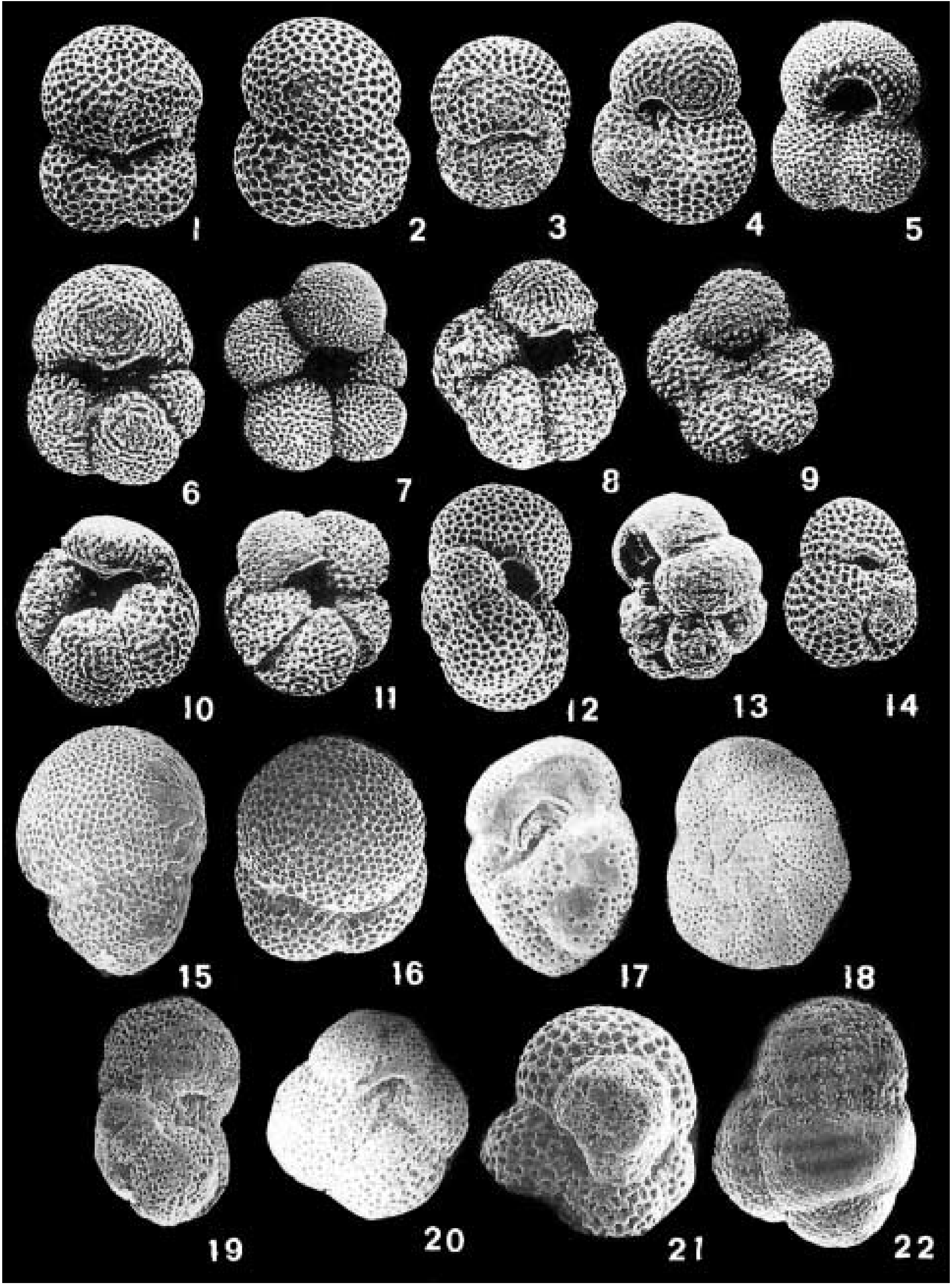
PLATE 2–*1, Globigerinoides trilobus* Reuss, umbilical view, sample 18, Al Faidiyah Fm., Ras Al Shaqqah section, x 80. *2, Globigerinoides immaturus* Le Roy, umbilical view, sample 18, Al Faidiyah Fm., Ras Al Shaqqah section, x 80. *3, Globigerinoides trilobus* Reuss, umbilical view, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section, x 80. *4, Globigerinoides succulifer* Brady, spiral view, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section, x 90. 5, *Globigerinoides subquadratus* Brönnmimann, umbilical view, sample 19, Al Faidiyah Fm., Ras Al Shaqqah section, x 90. 6, *Globigerina bulloides* d' Orbigny, umbilical view, sample 19, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *7, Globigerina ciperoensis* Bolli, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *8, Globigerina angustiumbilicata* Bolli, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *9, Globigerina angulisuturalis* Bolli, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *10, Globoquadrina dehiscens* (Cushman & Collins), umbilical view, sample 19, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *11, Globigerina angulisuturalis* Bolli, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *12, Globigerinnella obesa* Bolli, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 100. *13, Cassigerinella chiploensis* Cushman & Ponton, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section, x 90. *14, Globigerinoides succulifer* Brady, spiral view, sample 18, Al Faidiyah Fm., Ras Al Shaqqah section, x 80. *15, Globigerinoides sicanus* De Stefani, side view, sample 75, Al Khums Fm., Qabilat Ash Shurfah section, x 150. *16, Praeorbulina glomerosa* d' Orbigny, umbilical view, sample 75, Al Khums Fm., Qabilat Ash Shurfah section, x 150. *17, Globorotalia siakensis* Le Roy, umbilical view, sample 85, Al Khums Fm., Qabilat Ash Shurfah section, x 150. *18, Globorotalia siakensis* Le Roy, spiral view, sample 113, Al Khums Fm., Wadi Zaqlum section, x 120. *19, Globigerinella obesa* Bolli, side view sample, sample 115, Al Khums Fm., Wadi Zaqlum section, x 120. *20, Globigerina druryi* Akers, umbilical view, sample 103, Al Khums Fm., Wadi Zaqlum section, x 150. *21-22, Catapsydrax dissimilis,* umbilical view, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section, x 150.

PLATE 2



length & 10-12µm in diameter. Lenticular growth zones characterize the peripheral filaments with cells measuring 12-15 µm in length and 7-9 µm in diameter. Conceptacles are fairly abundant.

Mesophyllum sanctidionysii Lemoine (Pl. 4, Fig. 8): Crustose form with peripheral filaments of numerous conceptacles. The core filaments are usually thick composed of co-axial cell layers. Cells are 8-12 µm in length and 9-10 µm in diameter The peripheral filaments are composed of strong lenticular growth zones and conceptacles embedded in the center of each growth zone.

Mesophyllum lemoinaea Souaya (Pl. 3, Fig. 8): Thick crustose form that usually bifurcates through growth of new crusts of peripheral filaments. Cells are 9-11 µm in length and 7-10 µm in diameter Sometimes grow freely over the other coralline algae with alternative layers of *Lithoporella* spp. and bryozoans. This association results in regularly spaced osculae within the crusts.

Mesophyllum iraqense Johnson (Pl. 3, Fig. 4): Long slender branches that consist of medullary coaxial core filaments with pronounced growth zones. Cells are 9-12 µm in length and 8-10 µm in diameter. The marginal peripheral filaments are sometimes worn with rare conceptacles of minute sizes.

Mesophyllum guamense Johnson (Pl. 4, Fig. 7): Regular spine like branche composed of peripheral filaments with strong lenticular growth zones. The peripheral filaments are composed of subquadrate cells having 7-13 µm in length and 9-10 µm in diameter, with no conceptacles.

Mesophyllum vaughani (Howe) Lemoine (Pl. 4, Fig. 4): Regular spine like branche composed of peripheral filaments with strong lenticular growth zones. The peripheral filaments are composed of subquadrate cells 8-12 µm in length and 10-12 µm in diameter with no conceptacles.

Family Sporolithaceae Verheij, 1993
Genus *Sporolithon* Heydrich, 1897

Sporolithon cyrenicum Raineri: (Pl. 5, Fig. 5 & Pl. 3, Fig. 3 & Pl. 4, Fig. 5): Crustose dorsiventeral and monomerous thalli with rounded protuberance measuring 180 µm in height. The ventral core filaments are commonly thin plumose with cell filaments 14-23 µm in length and 10-12 µm in diameter. The peripheral filaments are usually regular 15-27 µm in length and 10-13 µm in diameter, where cell fusion are scarce. Sporangia are not observed.

Sporolithon saipnense Johnson (Pl. 3, Fig. 1): Thick crusts with mammilliated structure, regular dorsiventeral and monomerous thalli. The core filaments are relatively thin composed of plumose cell filaments with cells measuring 11-15 µm in length and 10-15 µm in diameter. The peripheral filaments are thick, composed of regular rectangular cells measuring 7-15 µm in length and 8-13 µm in diameter with pronounced vertical cell threads. Sporangia are elliptical or ovoid to circular measuring 110-160 µm in height and 60-120 µm in diameter closely packed and arranged in sori.

Corallina sp.: several fragments of segmented stems are observed (300 µm thick) composed exclusively of core filaments, cells are 30-45 µm in length and 8-12 µ in diameter. Peripheral filaments weakly developed on the margins of segments. Conceptacles are not observed in the present specimens.

Phyllum CHLOROPHYTA Pasher, 1914
Class CHOLOROPHYCEAE Kutzing, 1843
Order SIPHONALS Wille, In Warming, 1884
Family CODIACEAE Zanardini, 1843
Genus *Halimeda* Lamouroux, 1812

Halimeda sp. (Pl. 5, Fig. 8): Thallus strongly branched and calcified with elliptically elongated segments

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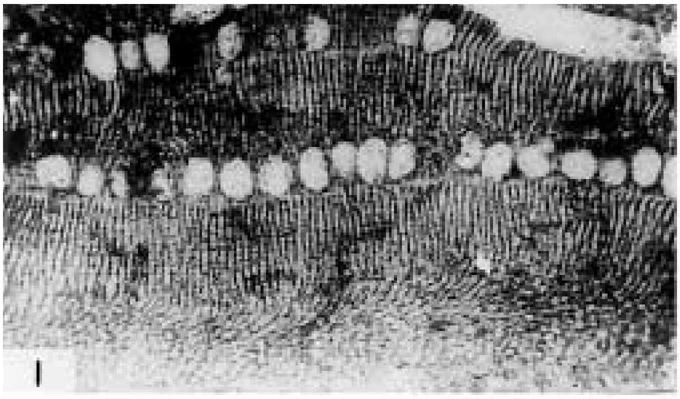
PLATE 3–*1, Sporolithon saipanense* Johnson, noncoaxial core filaments in the lower part and peripheral filaments with sporangial sori, sample 15, Al Faidiyah Fm., Ras Al Shaqqah. *2, Lithothamnion macrosporangium* Mastrorilli, Fragment of protuberance showing postigenous filaments with ovoid conceptacles with no remains of calcified cells, sample 70, Al Khums Fm., Qabilat Ash Shurfah. *3, Sporolithon* sp. postigenous filaments with group of sporangial sori, sample 15, Al Faidiyah Fm., Ras Al Shaqqah. *4, Mesophyllum iraqense* Johnson, warty protuberance of coaxial core filamnets and outer peripheral filaments, sample 31, Al Khums Fm., Ras Al Shaqqah. *5, Lithothamnion operculatum* Conti, protuberance showing postigenous filaments with growth rhythms and ovoid conceptacles, sample 48, Al Khums Fm., Ras Al Shaqqah. *6, Mesophyllum laffittei* Lemoine, Long slender warty protuberance of coaxial core filaments and outer peripheral filaments with conceptacles in outer part, sample 114, Al Khums Fm., Wadi Zaqlum. *7, Lithothamnion libanum* Johnson, postigenous filaments with growth rhythms and ovoid conceptacles, sample 54, Al Khums Fm., Qabilat Ash Shurfah. *8, Mesophyllum lemoineae* Souaya, branch of warty protuberance of coaxial core filamnets with growth zones and outer peripheral filaments sample 108, Al Khums Fm., Wadi Zaqlum.

PLATE 3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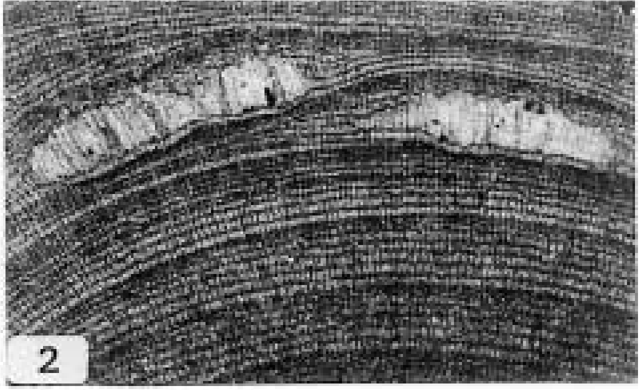
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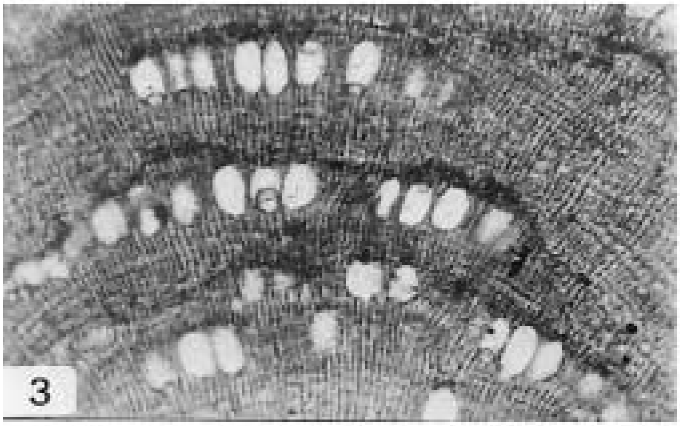
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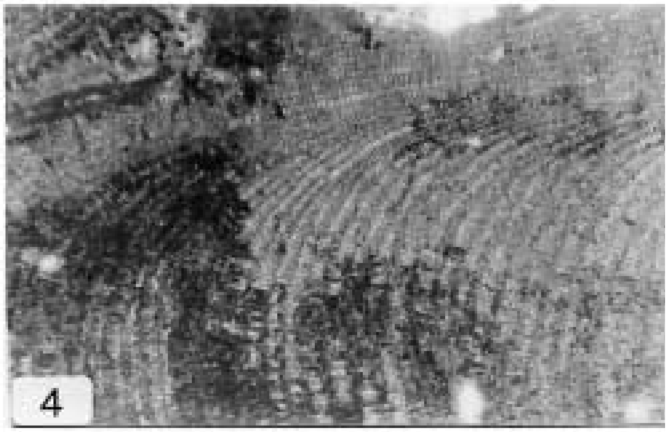
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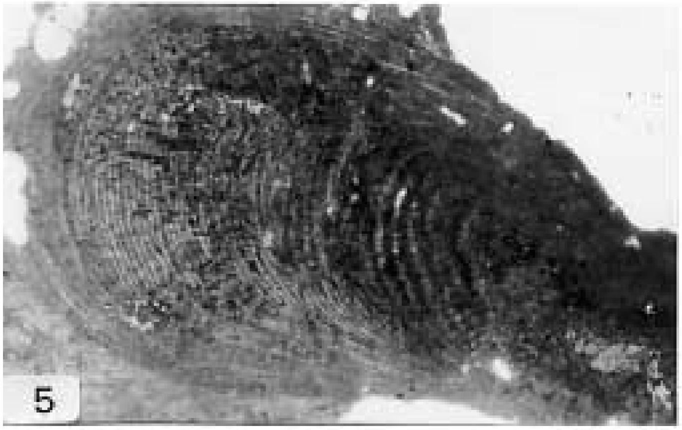
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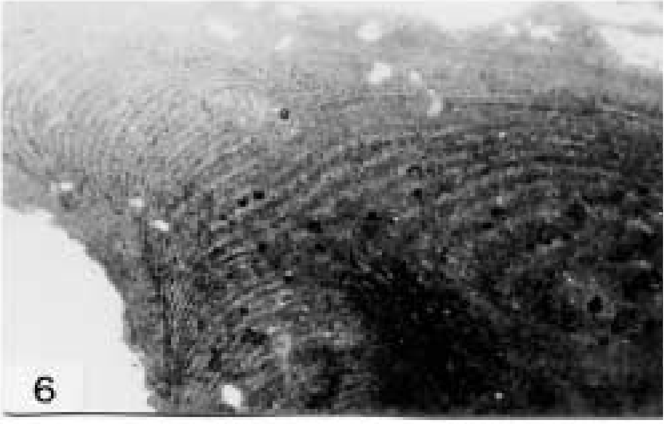
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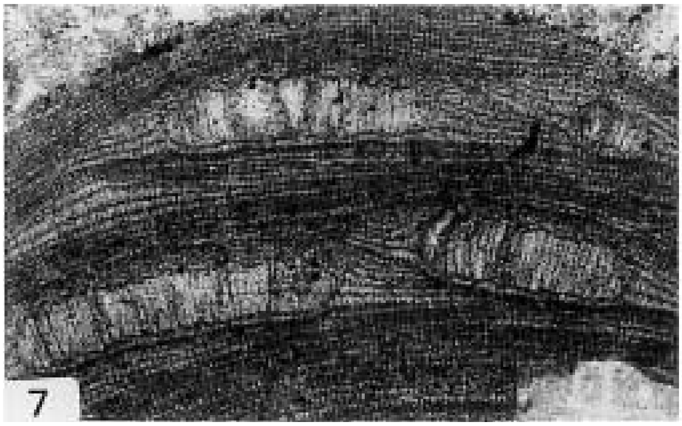
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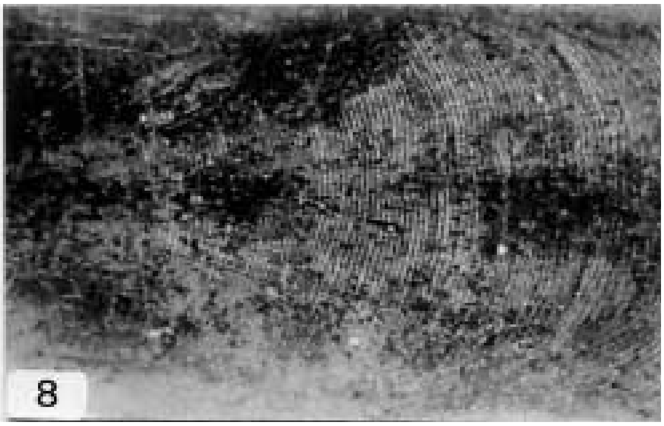
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of about 0.5 to 1.9 mm in diameter and 1.5-2.6 mm in length. Filaments slightly oblique with non-distinctive layers.

DESCRIPTION OF THE MAIN MICROFACIES TYPES

About 40 thin sections representing the studied two rock units and the different localities have been subjected to petrographic, microfacies and diagenetic studies. The carbonate microfacies study is described according to the classification of Dunham (1962), Wilson (1975), Flügel (1982), Tucker (1984) and Tucker & Wright (1990). While for the study of the siliciclastics microfacies, the work of Folk (1974), Pettijohn (1975), Pettijohn *et al*. (1987) are adopted.

1. Microfacies types of Al Faidiyah Formation

In the study area the Al Faidiyah Formation is recorded only in Ras Al Shaqqah section and is represented predominantly in its lower part by siliciclastic dominated facies (polymictic conglomerate, calcareous sandstone, thin laminae of mudstone and claystone), while the upper part is represented by carbonate dominated facies (limestone and dolomite) with carbonate-siliciclastic dominated facies (argillaceous limestone and sandy limestone). In the following are the main microfacies types recorded in Al Faidiyah Formation.

1.1. Polymictic conglomeratic Facies

This microfacies type is well developed in the basal part of Al Faidiyah Formation in Ras Al Shaqqah section (sample No.12) and decrease upward in thickness and size of the clasts. They are dark yellow to brownish yellow, polymictic, hard consolidated, clast-supported, poorly to moderately sorted, mostly of different lithoclasts (carbonates and chert with subordinate quartz). The clasts are in the form of pebble and gravel sizes, rounded to subrounded, disoriented, slightly with imbricate structure especially at the base of the bed and shows also normal graded beds. Petrographically, the matrix is made up of coarse to fine, subangular to subrounded, moderately sorted detrital quartz grains (Pl. 4, Fig. 1) cemented by carbonate (micrite matrix partially recrystallized into pseudospars and minute dolomite rhombs) material. This microfacies association is characterized by slightly diversified bioclastic content such as fragmented oyster shells and corals, bryozoan fragments and echinoids spines as well as reworked large benthonic foraminifers.

1.2. Calcareous Sublitharenite Facies

This microfacies type is recorded overlying the former microfacies type and represents the second dominated siliciclastic facies in the lower part of Al Faidiyah Formation (sample No.13). In the field the sandstones are yellowish white to greenish yellow, medium to fine grained with dense subangular to subrounded detrital quartz grains, highly calcareous with glauconitic grains. Cross-bedded and lamination are the most conspicuous primary structures recorded in this facies. Thin section investigation revealed that this microfacies consists mainly of subangular to subrounded, moderately sorted, detrital quartz grains of monocrystalline type with straight to slightly undulose extinction. These quartz grains form 80% of the total framework (Pl. 4, Fig. 2). Lithic fragments are represented by different types of lithoclasts such as chert, detrital carbonates fragments and glauconitic grains embedded in micrite matrix, usually corroded the quartz grains. It is noteworthy of mention that this matrix is partially recrystallized into sparite (aggra-

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PLATE 4–*1, Lithophyllum ghorabi* Souaya, fragmented crust of coaxial core filaments embedded in micrite matrix, sample 69, Al Khums Fm., Qabilat Ash Shurfah. *2, Lithoporella melabesioideae* (Foslie) Foslie, encrusting dimerous layers of palisads cells with circular conceptacle, sample 83, Al Khums Fm., Qabilat Ash Shurfah. *3, Lithophyllum capederi* Lemoine, warty protuberance of obliquely cut to co-axial core filaments, sample 40, Al Khums Fm., Ras Al Shaqqah. *4, Mesophyllum vaughani* (Howe) Lemoine, branch protuberance of core filaments at base with peripheral filaments and conceptacles, sample 48, Al Khums Fm., Ras Al Shaqqah. *5, Spongites albanensis* (Lemoine), Peripheral filaments showing bean-shaped conceptacles in irregular grid, sample 70, Al Khums Fm., Qabilat Ash Shurfah. *6, Sporolithon cyrenaicum* Raineri, postigenous filaments with group of sporangial sori, sample 69, Al Khums Fm., Qabilat Ash Shurfah. *7, Mesophyllum guamense* Johnson, sample 28, Al Khums Fm., Ras Al Shaqqah. *8, Mesophyllum sancti-dionysi* Lemoine, long branch protuberance with conceptacles, sample 25, Al Khums Fm., Ras Al Shaqqah. *9, Lithothamnion disarmonicum* Conti, peripheral filaments showing number of conceptacles in irregular grid, sample 15, Al Faidiyah Fm., Ras Al Shaqqah. *10, Lithophyllum simplex* Lemoine, core filaments abraded by microbrial sample 37, Al Khums Fm., Qabilat Ash Shurfah.

PLATE 4


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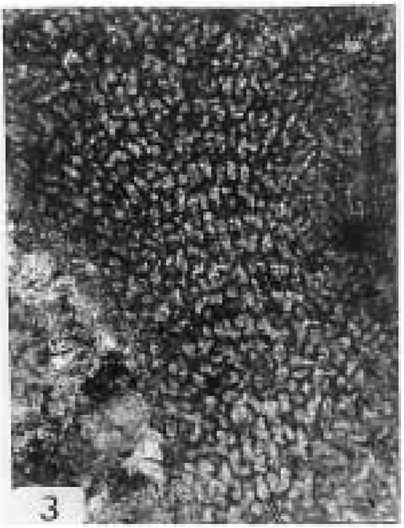
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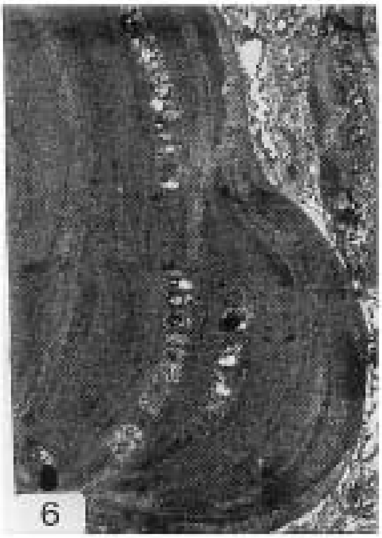
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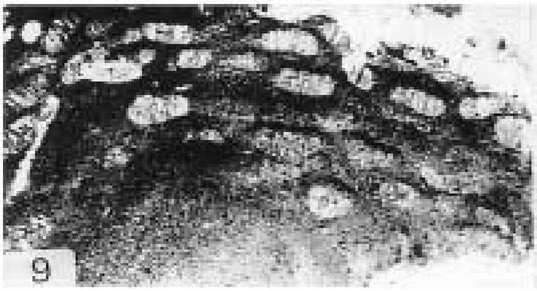
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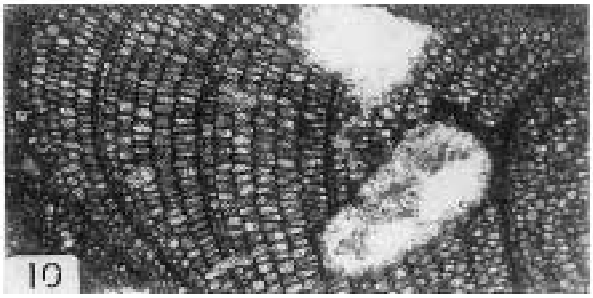
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ding neomorphism) and also slightly fossiliferous with benthonic foraminifera in the form of small tests of *Nonion* spp. and *Bolivina* spp. and reworked skeletal coralline algae (*Sporolithon* spp. and *Lithophyllum* spp.), bryozoans fragments as well as echinoid spines. The matrix also shows some idiotpoic, zoned with dark nucleated core and clear outer peripheries, dolomite rhombs ranging in sizes from 20 to 130 µm.

1.3. Sandy Bioclastic Packstone / Grainstone Facies

This facies type is distinguished at the upper part of Al Faidiyah Formation at Ras Al Shaqqah section covering the samples Nos. 15 and 17. It is composed mainly of skeletal bioclastics forming more than 60% of the total framework, intraclastic particles 20% and detrital quartz grains 20%. Petrographically, the bioclasts are represented commonly by molluscan shell fragments, echinoid spines, fragmented corals and coralline red algae such as *Lithophyllum* spp., *Lithothamnion* spp. and *Lithoporella* spp. Small amount of minute size planktonic foraminifera (mainly of the family *Globigerinoide*s) and large benthonic foraminifers such as reworked *Nummulites* spp., *Operculina* spp., *Miogypsina* spp. and *Amphistegina* spp.). The intraclasts are depicted in the presence of dark micritic clasts, some subangular chert clasts and subangular to subrounded, fine to medium, moderately sorted detrital quartz grains of monocrystalline type as well as glauconitic and argillaceous patches. All these constituents are embedded in micrite matrix that partially recrystallized into microsparite cement.

1.4. Argillaceous foraminiferal Wackestone / Packstone Facies

The rocks of this facies are recorded in the upper part of Al Faidiyah Formation (samples Nos. 16 and 18) and commonly interbedded with the previous sandy bioclastic packstone / grainstone facies. In the field it is composed of grey to dark yellowish grey, hard, partly massive, fossiliferous argillaceous limestone interlayered with thin laminae of whitish grey fossiliferous mudstone. Thin section investigations revealed that this facies consists mainly of more than 80% of the total framework of planktonic foraminifera in the form of *Globigerina* spp., *Globigerinoides* spp. and *Globorotalia* spp. as well as small tests of benthonic foraminifera such as *Bulimina* spp., *Bolivina* spp., and *Cancris* spp. Minor amounts of detrital silt-sized quartz grains, angular chert lithoclasts and dark micritic carbonate pellets (20%) are also existed. These biogenic constituents are embedded in microcrystalline micrite matrix with argillaceous materials.

1.5. Dolomitic silty Wackestone Facies

This facies type is recorded only in the uppermost part of Al Faidiyah Formation at Ras Al Shaqqah section (sample No. 19). In the field it is composed of grey to dark grey, hard, massive, fossiliferous dolomitic limestone. Thin section investigation revealed that consists predominantly of porous clotted micrite with moderately preserved planktonic and benthonic foraminiferal tests. Other bioclastic constituents are echinoid, shell fragments and badly preserved reworked skeletal coralline algae. Glauconitic grains and scattered silt-sized quarts grains are also embedded in the micrite matrix. Dolomitization affected the micritic matrix in the form of fine grained, 4-20 µm in size, dolomite rhombs with cloudy core and clear outer rims This facies type reflects deposition in shallow shelf marine environments representing slightly regressive environment toward the end of Al Faidiyah Fm. depositional time.

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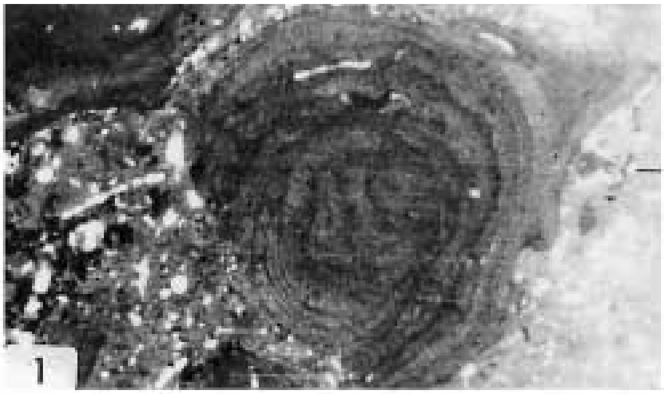
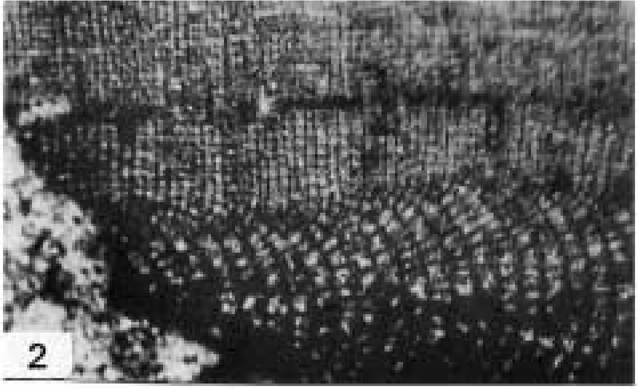
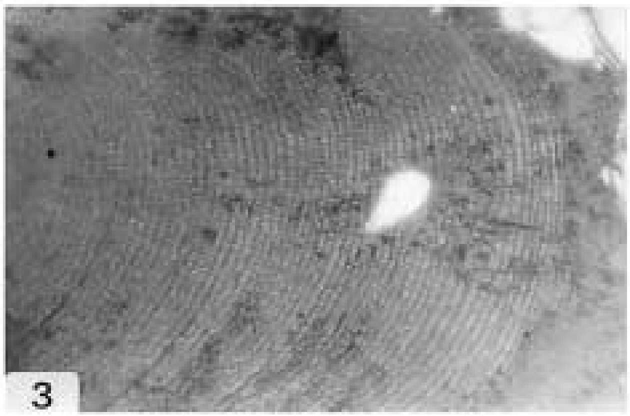
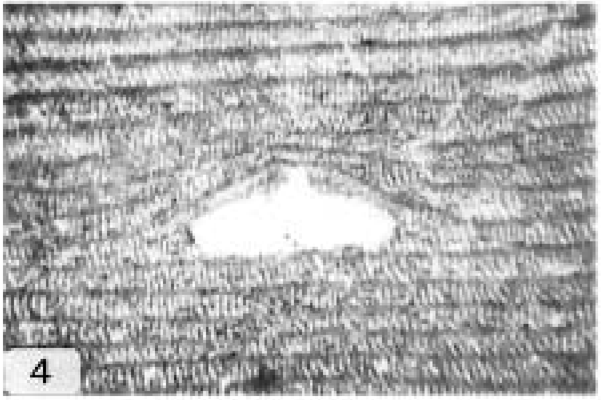
PLATE 5–*1, Lithophyllum bonyense* Johnson, coralline branched protuberance showing thin monomerous thin thalli continuously overgrowing a fracture zone in lower part, distinct growth rhythms in upper part, sample 48, Al Khums Fm., Ras Al Shaqqah section. *2, Lithophyllum prelichenoides* Lemoine, characteristic coaxial core filaments at base with crustose portion of peripheral filaments, sample 102, Al Khums Fm., Wadi Zalqum section. *3, Lithophyllum pseudoamphiroa* Johnson, coaxial core filaments, sample 107, Al Khums Fm., Wadi Zalqum section. *4, Lithophyllum kugleri* Johnson, uniporate conceptacles with filaments arround the conceptacle pore subparallel to the lower conceptacle roof, sample 102, Al Khums Fm., Wadi Zalqum section. *5, Sporolithon cyrenaicum* Raineri, encrusting growth form with basal core filaments and group of sori, sample 70, Al Khums Fm., Qabilat Ash Shurfah section. *6, Lithophyllum duplex* Maslov, postigenous filaments and tetra/bisporangial conceptacles with raised floor (Columella remains) in a protuberance, sample 48, Al Khums Fm., Qabilat Ash Shurfah section. *7, Lithoporella melabesioideae* (Foslie) Foslie, encrusting dimerous layers of large palisads cells with circular conceptacle and postigenous filaments with serpulids nucleus, sample 83, Al Khums Fm., Ras Al Shaqqah section. *8, Halimeda* sp., Halimeda segments with well preserved internal filaments bounded by dense and peloidal micritic crusts, sample 77, Al Khums Fm., Qabilat Ash Shurfah section. *9, Spongite albanense* Johnson, coaxial core filament surounded by postigneous filaments, sample 49, Al Khums Fm., Ras Al Shaqqah section.

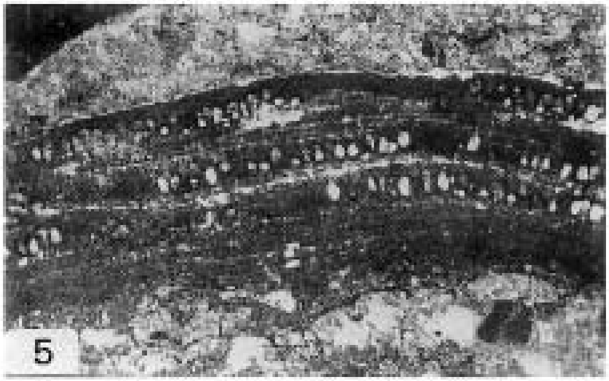
PLATE 5

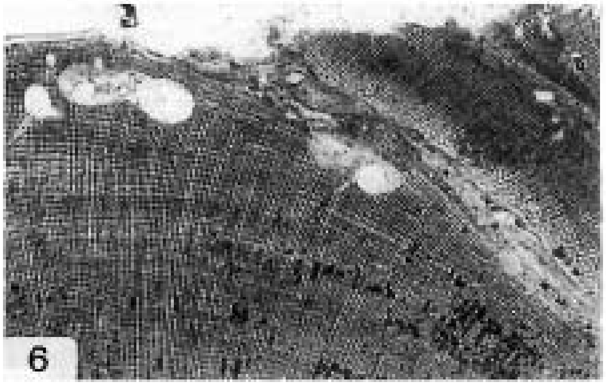


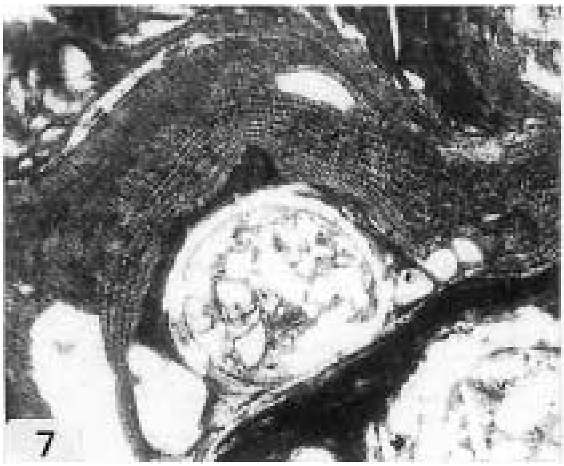


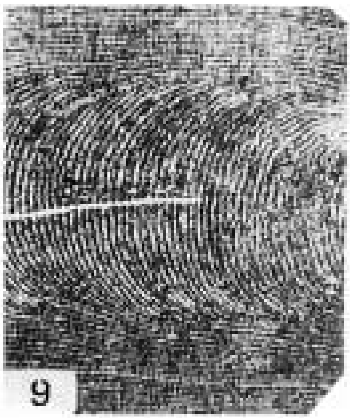












2. Microfacies types of Al Khums Formation

In the study area Al Khums Formation is represented predominantly by carbonate-dominated facies (sandy algal limestone 60% and chalky limestone 30%, dolomitic limestone 10%) and subordinate siliciclastic facies in the form of minor thin laminae of sandstone, mudstone and claystone. The main microfacies types recorded in this unit are.

2.1. Dolomitic Sublitharenite Facies

This microfacies type is recorded in the lower part of Al Khums Formation (An Naggazah Member). It is recorded in Wadi Zaqlum section (sample No. 94), Ras Al Shaqqah (sample Nos. 20 and 21) and Qabilt Ash Shurfah (sample Nos. 60 and 61). In the field the sandstone is cross-bedded, laminated, yellow to yellowish white, medium to fine grained with dense subangular to subrounded detrital quartz grains, moderately sorted, highly calcareous with dolosparry calcite cement. Thin section investigation revealed that it consists predominantly of subangular to subrounded, moderately sorted, detrital quartz grains of monocrystalline type that constitutes more than 80% of the total framework. Few detrital quartz grains of polycrystalline nature with undulose extinction are also observed. The lithoclasts are represented by chert and detrital microcrystalline carbonates fragments embedded in micrite matrix. This facies type shows some fossiliferous thin laminae with benthonic foraminifera in the form of small tests of *Nodeseria* spp. and *Bolivina* spp. and reworked skeletal coralline algae (*Lithoporella* spp. and *Lithophyllum* spp.), bryozoans fragments as well as echinoid spines. The matrix is usually corroded the quartz grains depicted in the presence of engulfed quartz grains. The matrix also shows some idiotpoic, zoned with dark nucleated core and clear outer peripheries, dolomite rhombs ranging in sizes from 10 to 100 µm.

2.2. Algal Coral Framestone / Boundstone Facies

This facies type is represented in the field by coralline patch reef deposits. The geometry of this unbedded facies suggests a biohermal rather than biostromal development that locally developed above the submarine paleohighs. It is located in the lower part of Al Khums Formation (An Naggazah Member) and recorded in Wadi Zaqlum section (sample No. 101), Ras Al Shaqqah (sample Nos. 24 and 30) and Qabilt Ash Shurfah (sample Nos. 63 and 64). This facies is represented by fairly high proportion of thick accumulation of organic organisms that commonly contain scattered in situ hermatypic corals (*Pavona trinitatis* Vaughan, *Orbicella limbata* Vaughan, *Mycetophyllia* sp. and *Stylophora imperatoris* Vaughan), molluscan shell fragments, bryozoans, ostarcods, larger benthonic foraminifers (*Borelis melo melo* Fichtel & Moll, *Amphistegina lessonii* Brady, *Operculina complanata* Defrance, *Miogypsina* sp., *Ammonia beccarii* Linné) and rhodoliths up to 5 cm in diameter (frame builders), bounded by highly diversified coralline red algae in the form of *Lithophyllum* spp., *Lithothamion* spp., *Sporolithon* spp., and *Lithoporella* sp. Petrographic investigation revealed that the ground mass of this microfacies type is composed essentially of bioclastic constituents (70%), coralline red algae (20%) and detrital quartz grains (10%) tightly packed in granular sparry calcite cement. Some corals are partially recrystallized into pseudospar or dolomitized into coarse granular rhombs while the interseptal cavities are filled with micritic matrix.

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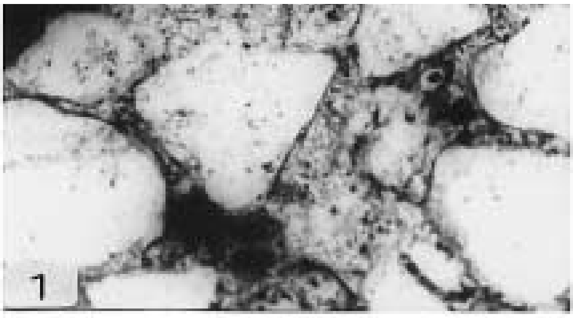
PLATE 6–*1,* Polymictic conglomeratic Facies, subrounded to subangular detrital chert clasts in argillaceous micritic matrix with some dolomites rhombs, Al Faidiyah Fm., Ras Al Shaqqah section. *2,* Calcareous sublitharenite Facies, subrounded to subangular detrital quartz grains with lithic fragments of feldspars and glauconitic grains in microcrystalline calcitic matrix, Al Faidiyah Fm., Ras Al Shaqqah section. *3,* Sandy bioclastic Packstone / Grainstone Facies, subrounded to subangular detrital quartz grains with dark micritic clasts and bivalved shell fragment in sparry calcite cement, Al Faidiyah Fm., Ras Al Shaqqah section. *4,* Sandy bioclastic Packstone / Grainstone Facies, close up of the previous photo showing subrounded to subangular, poorly sorted detrital quartz grains, with corroded boundaries, Al Faidiyah Fm., Ras Al Shaqqah section. *5,* Argillaceous foraminiferal Wackestone / Packstone Facies, benthonic foraminifera, *Heterolepa* sp., with minute planktonic foraminifera in micritic matrix, Al Faidiyah Fm., Ras Al Shaqqah section. *6,* Argillaceous foraminiferal Wackestone / Packstone Facies, planktonic foraminifera *Globigerinoides* spp, filled with sparry calcite cement (Intragranular cementation) associated with other planktonic foraminifera in micritic matrix, Al Faidiyah Fm., Ras Al Shaqqah section. *7,* Dolomitic silty Wackestone Facies, minute dolomitic rhombs with fine to silt sized quartz grains in argillaceous micritic matrix, Al Khums Fm., Qabilt Ash Shurfah section. *8,* Dolomitic sublitharenite Facies, subrounded to subangular detrital quartz grains with lithic fragments of feldspars and dolomitic grains in sparry calcite cement, Al Khums Fm., Qabilt Ash Shurfah section. *9-10,* Sandy bioclastic algal Packstone / Grainstone Facies; *9,* transverse section in corallite showing septa and columella, the cavity filled with coarse sparry calcite; *10,* enlarged section of echinoid spine filled with micritic matrix, Al Khums Fm., Wadi Zalqum section.

PLATE 6



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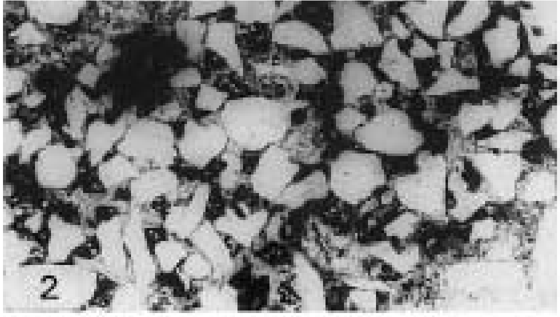

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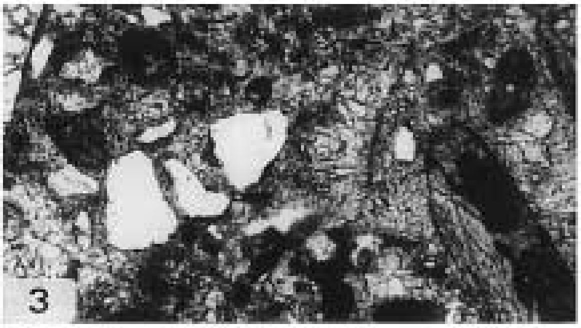

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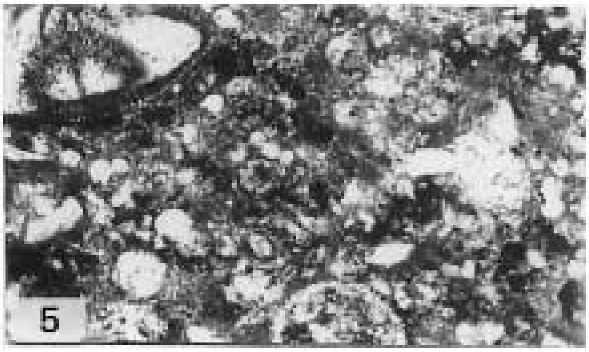

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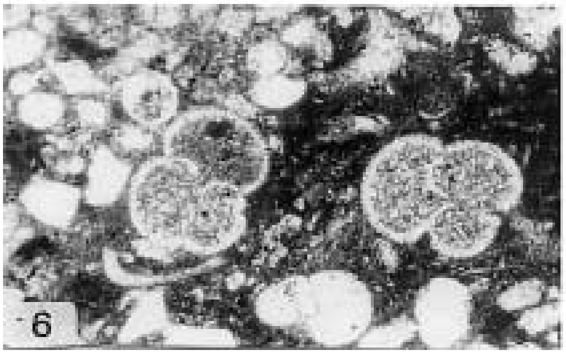

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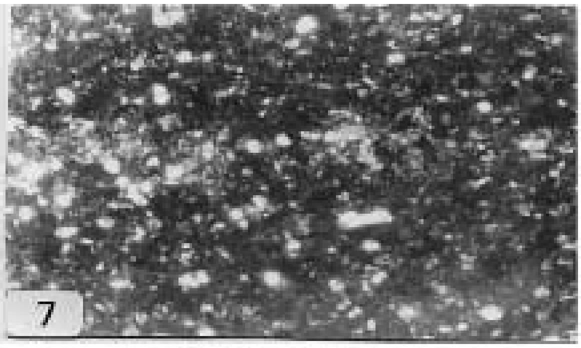

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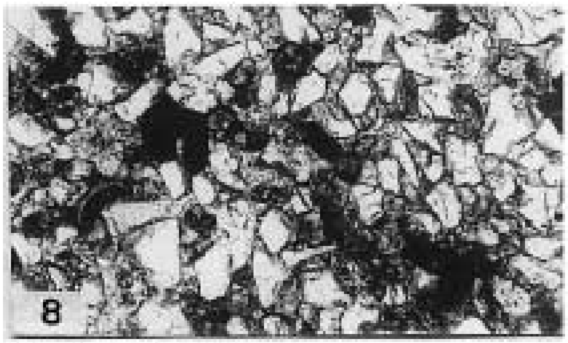

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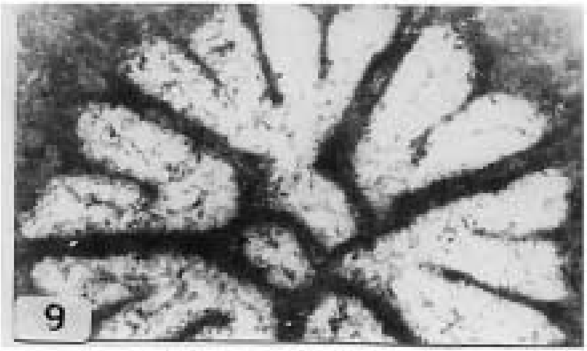

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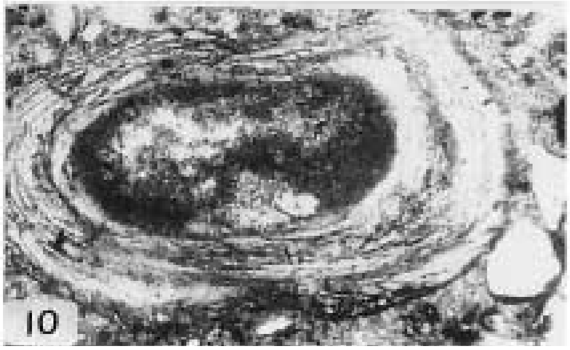

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2.3. Algal dolomicritic Facies (Algal Wackestone / Packstone Facies)

This facies type is recorded in the upper part of Al Khums Formation (Ras Al Mannubiyah Member). It is greyish white, to yellowish grey, massive hard, fossiliferous dolomitic limestone with algae and oyster shell fragments. Petrographically, this facies is composed mainly of abundant crustose coralline red algae such as *Lithophyllum* spp., *Mesophyllum* spp., *Lithoporella* spp. and *Corallina* spp. Other bioclastic components are represented by fragmented corals and molluscan shell fragments, benthonic foraminifera and echinoids spines. The lithoclasts are represented by subangular to subrounded, fine to medium, moderately sorted detrital quartz grains and chert clasts embedded in dolomitized microsparite cement. Dolomitization has also affected the matrix where idiomorphic rhombic dolomite crystals with distinct cloudy zoning (dark nucleated core and clear outer rim) make up about 20% of the matrix.

2.4. Sandy Foraminiferal Wackestone / Packstone Facies

The rocks of this facies are recorded in the middle part of Al Khums Formation (Ras Al Mannubiyah Member). In the field it can be distinguished by its greyish white to grey, crumbly, partly massive, fossiliferous argillaceous chaly limestone that interlayered with thin laminae of whitish grey fossiliferous mudstone. Petrographically, this facies consists mainly of more than 70% of the total framework of small sized planktonic foraminifera in the form of *Globigerina* spp., *Globigerinoides* spp. and Globorotalia spp. as well as small tests of benthonic foraminifera such as *Bulimina* spp., *Bolivina* spp., Minor amounts of detrital silt-sized quartz grains, angular chert lithoclasts and dark micritic carbonate pellets (30%) are also existed. These biogenic constituents are entobdded in microcrystalline micrite matrix with argillaceous materials.

2.5. Sandy Bioclastic Algal Packstone / Grainstone Facies

This facies type generally represents the coralline algal limestone beds in the uppermost part of Al Khums Formation (uppermost part of Ras Al Mannubiyah Member) in the three studied sections, in Ras Al Shaqqah (samples 47-50) and in Wadi Zaqlum (samples 112-117) and in Qabilat Ash Shurfah (samples from 83-90). This facies type forming prominent white to yellowish white, massive to porous, fossiliferous, cavernous (with honeycomb structure) coralline algal limestone. Petrographically, this facies composed mainly of bioclasts and skeletal coralline algae in the form of algal nodules which presents the most conspicuous component of this facies (80% of the total framework), intraclastic grains (15%) and lithoclasts and detrital quartz grains of 5% of the total framework. The bioclasts are represented by molluscan shell fragments, echinoid plates and spines, bryozoan fragments and fragmented corals (20% of the total bioclasts). The other bioclastic types are depicted in the presence of in situ coralline algal nodules (Rhodophyta) represented essentially by crustose and branched taxa such as *Lithophyllum* spp., *Mesophyllum* spp. *Lithothamnion* spp. and *Lithoporella* spp. Other bioclasts are occurred in the form of subordinate amounts of planktonic and benthonic foraminifera e.g. *Borelis melo*, *Heterostegina* spp., *Amphistegina* spp., *Textularia* sp. and miliolides. The intraclasts are showed in the pre-

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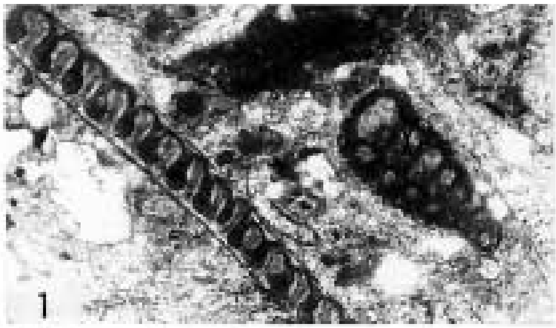
PLATE 7–*1-2,* Algal coral Framestone / Boundstone Facies, (1): benthonic foraminifera, *Texturalia* sp. with dark perepheries and long slender echinoid spine (2): Bryozoan fragment in sparrite cemnet, Al Khums Fm., Wadi Zalqum section. *3-4,* Algal dolomicritic Wackstone /Packstone Facies, (3): foralgalith of peripheral filaments and subangular detrital quartz grains in partially dolomitic sparry calcite cement (4): Close up the matrix showing dark nucleated dolomite rhombs with clear outer peripheries, Al Khums Fm., Qabilt Ash Shurfah section. *5-6,* Sandy bioclastic algal Packstone / Grainstone Facies, subrounded dark micritic intraclast with angular chert lithoclasts associated with foraminiferal tests in sparry calcite cement, and Al Khums Fm., Wadi Zalqum section. *7,* Sandy foraminiferal Wackestone / Packstone Facies, minute sized foraminiferal tests with dark micritic patches and very fine detrital quartz grains in partialy recrystallized micritic matrix, Al Khums Fm., Ras Al Shaqqah section. *8,* Sandy bioclastic algal Packstone / Grainstone Facies, large benthonic foraminifera *Borelis melo* with dark micritic test embedded in sparry calcite cement, Al Khums Fm., Wadi Zalqum section. *9,* Sandy bioclastic Packstone / Grainstone Facies, angular chert lithoclasts associated with subrounded dark micritic intraclasts and foraminiferal tests entobdded in sparry calcite cement Al Khums Fm., Wadi Zalqum section. *10,* Sandy bioclastic Packstone / Grainstone Facies, bivalved shell fragments recrystallised into coarse sparry calcite crystals with seggregated pattern and subrounded to subangular, fine detrital quartz grains in partialy recrystallized micritic matrix, Al Khums Fm., Ras Al Shaqqah section.

PLATE 7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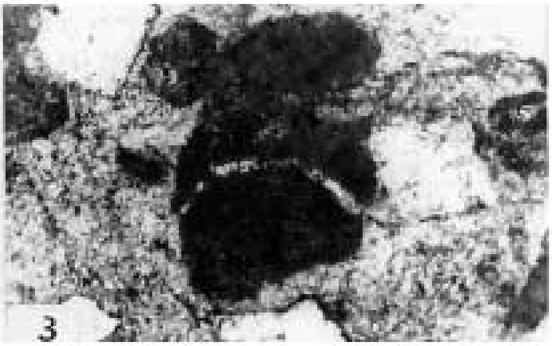
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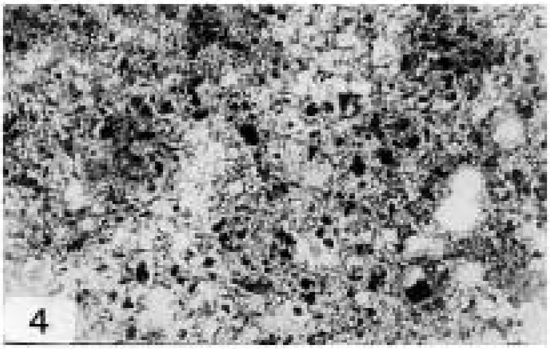
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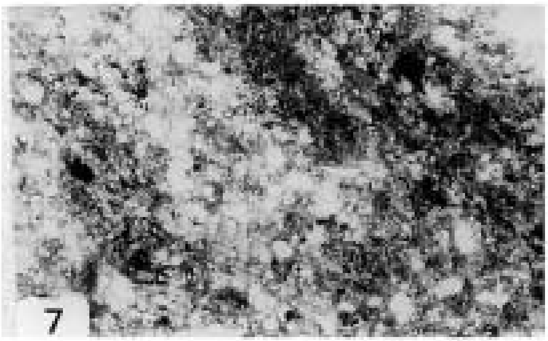
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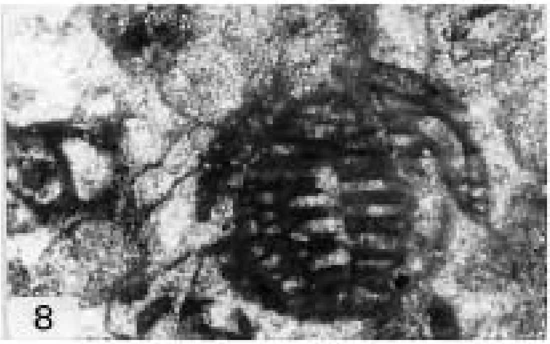
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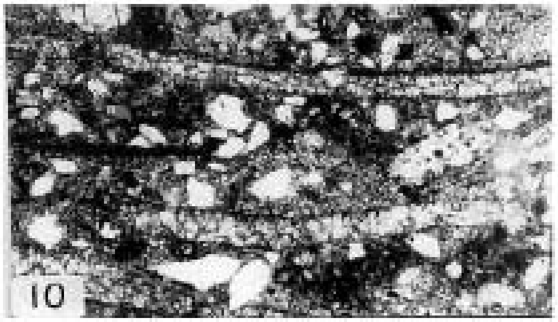
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sence of subangular to subrounded, fine to medium, moderately sorted detrital quartz grains with subordinate chert clasts and reworked carbonate pellets. All these constituents are embedded in sparry calcite cement that indicate deposition under high-energy shallow marine environments favorable for reef growth. Sparry calcitic cement usually blocky and coarse and developed syntaxially around the echinoid spines and fragments. Moreover, some of the bivalved shells are partially leached leaving moulds filled with drusy calcite.

DEPOSITIONAL ENVIRONMENTS OF THE STUDIED MIOCENE SEQUENCE

The paleoecological interpretation (vertical oscillation of the depositional environments) is based essentially on the mutual relationship of the lithofacies, field observations, environmentally diagnostic planktonic and benthonic foraminiferal assemblages, the coralline red algal content, and the different microfacies association types recorded. Ras Al Shaqqah succession is taken as a reference section as it is represented by the two Miocene rock units. Towards the end of the Late Cretaceous an intense tectonic event took place and it resulted in the uplifting of the northern parts of Libya which led to the configuration of the Sirte Basin and resulted in the prevalence of continental regim all over area. The Tethyan sea invaded this faulted trough (Sirte Basin) in the early Miocene times where the oldest Miocene transgression over the area is detected. This marine transgression started nearly in the Burdigalian times depositing of the Al Faidiyah Formation, while it is not recorded in the other two sections and this could be attributed to deposition, uplift and subaerial erosion or non-deposition in these localities. The lower part of Al Faidiyah Formation started with deposition of polymictic conglomerates (siliciclastic-dominated facies) indicating that the lower part of the formation was probably resulted from alluvial fans very near to the coastal plains, and designated also a period of steady clastic influx accompained the beginning of the Early Miocene sea level rise. This bed followed by fossiliferous, calcareous sandstone bed, calcareous shale and sandy limestone representing the proper shallow marine transgression (near shore, tidal to very shallow marine environments). This occurred at the time corresponding to that of the *Elphidium macellum* / *Miogypsina intermedia* zone. This zone was developed in shallow marine inner shelf environments as evidenced be the low planktonic / benthonic ratio, the co-occurrence of *Heterolepa dutemplei* and *Ammonia becarii* with the predominance of *Elphidium* spp., and *Nonoin scaphum* in addition to low diversity of its coralline red algal content together with their microfacies associations, all these characters indicate shallow marine conditions with depth less than 20 m (Douglas, 1979; Boersma, 1985; Murray, 1991). Going upwards, this previous zone is overlain conformably by *Globigerinoides trilobus* Zone (upper part of Al Faidiyah Formation) which has been formed in an environments deeper than the underlying zone (inner to middle shelf environments reflecting increasing in the water depth of the basin). This deepening upward is supported also by high planktonic / benthonic ratio and the presence of deep benthonic foraminiferal species such as *Uvigerina barbatula, Bulimina alazanensis*, and *Cassidulina laevigata* with the low frequency and diversity of the coralline red algal (Sporolithaceans) content that depicted in the presence of *Sporolithon* spp. and *Lithothamnion* spp. and corresponds to *Sporolithon saipanensis* zone. All these evidences indicate inner to middle shelf marine environments. By the beginning of the middle Miocene (Langhian to Early Serravallian) times, tectonic pluses occurred and caused an episoid of relative regression of the sea and reactivation of some of the main faults in the area. This short regressive phase corresponds to the presence of siliciclastics (coarse to medium calcareous sandstones) at the lowermost parts An Naggazah Member of Al Khums Formation (Figs. 7 & 8). Then the water depth increases gradually through the advent of the sea water where shallow marine carbonate facies increases upwards. Biohermal limestones are locally developed as patch reef on the structurally paleohighs. It is abundant with corals, bryozoans, shell fragments, large benthonic foraminifera and well-diversified coralline red algae. This shallow marine condition was prevailed all over the deposition of An Naggazah Member and continued to the lower part of Ras Al Mannubiyah Member. But by the beginning of the deposition of middle part of Ras Al Mannubiyah Member (chalky limestone), the conditions changed to slightly deep marine environments (inner to middle shelf) where the planktonic / benthonic ratio increased accompanied by low diversity of coralline red algae. Then the sea become so shallow (inner shelf) that thick sequence of algal reefal limestones were deposited in the upper part of Ras Al Mannubiyah Member of Al Khums Formation. This lowering of the sea level cannot be interpreted on the basis of the eustacy but some localized uplift should take in consideration, which enhanced the effect of the sea level lowering during the end of the deposition of Ras Al Mannubiyah Member (regressive phase).

SUMMARY & CONCLUSIONS

The study of the transgrssive Miocene deposits in Al Kums area, NW Sirte basin, Libya are focused mainly on three stratigraphic sections; they are Qabilat Ash Shurfah, Wadi Zaqlum and Ras Al Shaqqah sections. The study revealed valuable informations on the lithostratigraphy, biostratigraphy (both of foraminiferal and algal association) and the main different depositional environments. The lithostratigraphic studies allowed to subdivide the Miocene succession into two main rock units, arranged from base to top as follows: 1. Al Faidiyah Formation (early Miocene) and 2. Al Khums Formation (middle Miocene). The Al Faidiyah Formation is locally developed only in Ras Al Shaqqah section (15 m thick) where it overlies unconformably the Late Cretaceous Sidi As Sid Formation and underlies conformably the Al Khums Formation. This unit is differentiated in the field into two main lithofacies types. The lower lithofacies is siliciclastic dominated one (polymictic conglomerates and calcareous sandstone with few shale and argillaceous limestone thin bands) and typified with the *Elphidium macellum / Miogypsina intermedia* assemblage zone. The upper part is carbonate-dominated facies (sandy limestone interbedded with argillaceous limestones) encompasses the *Globigerinoides trilobus* Zone. The field observations, foraminiferal assemblage and coralline algal association as well as the microfacies types indicate that the lower part of the formation was deposited in alluvial fan followed upward with invasion of the shallow marine water environment meanwhile its upper part was deposited under relatively deep maine conditions (middle shelf environments) with fluctuation in the sea level. The Al Faidiyah Formation is assigned to Early Miocene (late Burdigalian) age on the basis of its foraminiferal and coralline algal content. The overlying Al Khums Formation (middle Miocene) is recorded in the three studied sections, attaining a thickness of 35 m, 40 m and 50 m in Ras Al Shaqqah, Wadi Zaqlum and Qabilat Ash Shurfah sections respectively. It commonly outcrops directly and sometimes overlain by Quaternary deposits. Where it overlies unconformably the Late Cretaceous Sidi As Sidi Formation as in Wadi Zaqlum and Qabilat Ash Shurfah sections and overlies conformably the early Miocene Al Faidiayh Formation. In the field, it is represented mostly by shallow carbonate dominated facies ranged from fossiliferous algal sandy limestone and argillaceous limestone beds at the lower part of the formation (An Naggazah Member) to coralline nodular limestone and subordinate dolomitic limestone and argillaceous to chalky limestone interbeds in the upper part (Ras Al Mannubiyah Member). This unit includes the large benthonic foraminiferal *Borelis melo melo* zone. It encompasses also the coralline algal zones; *Lithophyllum ghorabii* and *Mesophyllum lemoineae*. The field observations, foraminiferal and coralline algal content as well as the microfacies types recorded, indicate that this formation was deposited in shallow warm marine environments (inner shelf facies) with relative sea level fluctuations from inner to middle suites. The high diversity of the foraminiferal content with the other macrofaunal one indicates open circulation as well. The presence of the large benthonic foraminifera such as *Borelis melo melo* and *Heterostegina costata costata*, in addition to the rarity of planktonic foraminiferal species *Orbulina universa, O. suturalis* in the argillaceous to chalky limestone strongly asserted that this formation is assgined to middle Miocene (Langhian to early Serravallian) age.

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PALYNOSTRATIGRAPHIC ANALYSIS OF THE RÍO FOYEL FORMATION (LATEST OLIGOCENE-EARLY MIOCENE), NORTHWESTERN PATAGONIA, ARGENTINA

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Abstract

A palynologic and palynofacies analysis of the Río Foyel Formation, from outcrops within the Ñirihuau Basin (Río Negro Province, Argentina) is presented. The recovered organic matter is strongly altered both by bacterial activity and thermally. Although the palynologic assemblages are of low diversity they are integrated by marine (dinoflagellates and microforaminiferal linings) and continental elements (spores, pollen grains, fungal spores, algae, woody particles and cuticles). Among the dinoflagellates *Tuberculodinium vancampoae* (Rossignol) Wall dominates, followed by a subordinate assemblage of protoperidinioids. The spore-pollen assemblage is dominated by ferns belonging to the Lophosoriaceae, Dicksoniaceae and Cyatheaceae. Less frequent are the gymnosperm pollen representing the Podocarpaceae and Araucariaceae. Angiosperms are subrepresented consisting mainly of Fagaceae. The palynologic spectre shows strong affinities with other palynofloras identified in the Late Oligocene and Early Miocene of the San Jorge Gulf Basin and Mazarredo Subbasin, especially the dinoflagellates. Continental elements are comparable with those recognized in the Ñirihuau Formation, through the megafloristic record (Early Miocene of the Ñirihuau Basin). The presence of forms of recognized stratigraphic value, such as *T. vancampoae* and additional forms observed, indicate a latest Oligocene to Early Miocene age for the studied sequence. A restricted marine littoral environment with salinities lower than normal marine and warm-temperate water, rich in nutrients, is indicated. The basin may have been surrounded by a temperate forest, populated by pockets of warm-temperate relict assemblages.

Keywords: Palynology, Late Oligocene-Early Miocene, Río Foyel Formation, Northwestern Patagonia, Argentina.

Resumen

[Análisis palinoestratigráfico de la Formación Río Foyel (Oligoceno Tardío-Mioceno Temprano), Patagonia noroccidental, Argentina]. Se presentan los resultados del análisis palinológico y palinofacial de la Fm. Río Foyel, aflorante en la Cuenca Ñirihuau, provincia de Río Negro. El residuo orgánico recuperado se encuentra muy alterado tanto por actividad bacteriana como por efecto térmico; las asociaciones palinológicas son poco diversas y no muestran variaciones composicionales significativas a lo largo de la secuencia analizada. Están integradas por elementos marinos (dinoflagelados y cubiertas internas de foraminíferos) y continentales (esporas, polen, restos de hongos, algas, leños y cutículas). Entre los dinoflagelados domina la especie *Tuberculodinium vancampoae* (Rossignol) Wall, seguida por un conjunto subordinado de protoperidinioides. La asociación esporopolínica está dominada por helechos de las lofosoriáceas, dicksoniáceas y cyatheáceas. El polen de gimnospermas

es menos frecuente representado por podocarpáceas y araucariáceas. A excepción de las fagáceas, las angiospermas son muy escasas. El espectro palinológico muestra fuertes afinidades con otros identificados en el Oligoceno Tardío y Mioceno Temprano de la Cuenca del Golfo San Jorge y Subcuenca Mazarredo, en especial a partir de los dinoflagelados. Los elementos continentales son comparables con los reconocidos en la Fm. Ñirihuau a partir de la megaflora (Mioceno Temprano de la Cuenca Ñirihuau). La presencia de formas de reconocido valor bioestratigráfico como *T. vancampoae* y las afinidades halladas indican para la secuencia una antigüedad en el entorno del Oligoceno Tardío alto--Mioceno Temprano. Se infiere un ambiente de depositación marino litoral, restringido, con aguas con salinidades inferiores a las marinas normales, templado-cálidas y ricas en nutrientes. Circundaría la cuenca una flora de bosque templado aunque todavía se reconocen algunos elementos de clima cálido, probablemente relícticos.

Palabras clave: Palinología, Oligoceno Tardío-Mioceno Temprano, Formación Río Foyel, Patagonia noroccidental, Argentina.

INTRODUCTION

The Cenozoic volcano-sedimentary complex that outcrops in the North-Patagonian Cordillera has been the object of numerous geologic and paleontologic studies. Traditionally, the lower volcanic part of these deposits has been referred to as “Serie Andesítica” and the upper part, mostly sedimentary, has been referred to as “Postpatagoniano”, “Strata with *Nothofagus*” or “Patagoniense continental” (Feruglio, 1941; González Bonorino, 1944; Volkheimer, 1964; etc.).

In the region of San Carlos de Bariloche, González Bonorino and González Bonorino (1978) formally defined the Nahuel Huapi Group, as consisting of the Ventana and Ñirihuau Formations. The Ventana Formation is Late Paleocene to Eocene (González Díaz, 1979), while the Ñirihuau Formation corresponds to the Late Eocene-Early Miocene interval (Ramos, 1982). However, an Early Miocene age is now generally accepted for this last unit (Malumián, 1999). These deposits have accumulated within an elongated basin which extended from north to south and was filled with fluvial, deltaic and marine sediments (Spalletti, 1981, 1983), which have been named based on the lithologies and geographic areas where they outcrop.

The pelitic sequence of marine origin exposed in the extreme southwestern part of the Río Negro Province, was named Río Foyel Formation and correlated with the Ñirihuau Formation and equivalents (Spalletti, 1983). Earlier names for these sediments have been “Corral Foyel”, “Tertiary of Río Foyel” and “Lutitas de Río Foyel”. A detailed analysis of these previous records has been recently presented by Chiesa and Camacho (2001). The Río Foyel Formation contains an abundant fauna of marine invertebrates, which have been studied since the beginnings of the last century (Ihering, 1904, 1907, 1914; González Bonorino, 1944). Bertels (1980, 1993, 1994a-b) found strong similarities between the assemblages of foraminifera recognized in this basin with those from the Monte León Formation. Based on this relation she postulated an Oligocene age for the Río Foyel Formation. But Malumián *et al.* (1984) consider these foraminiferal assemblages to be Early Miocene, and Chiesa and Camacho (2001), based on the megafauna, propose a Middle Eocene age for the lower part of this unit. The only palynologic studies on the Río Foyel Formation are those of Pöthe de Baldis (1984), who recognizes an assemblage of palynomorphs with the presence of several species of Fagaceae, Podocarpaceae and spores, which she interprets to be of Late Eocene to Early Oligocene age.

The objective of this paper is to provide palynologic evidence from the Río Foyel Formation, for a more precise age dating, a definition of the depositional conditions and to analyze the similarities with and differences from assemblages reported from correlative Cenozoic basins of the southern hemisphere.

The fieldwork was conducted by W. Volkheimer, who sampled two sections: “Río Foyel”, section 1 and “El Foyel”, section 2 (Figure 1). Section 1 is located on the northern margin of the big curve of road N.º 258, immediately north of the Foyel River and consists of dark gray alternating lutites and siltstones. The sediments are more or less marly and bear a fauna of marine invertebrates, integrated by bivalves, corals and echi-

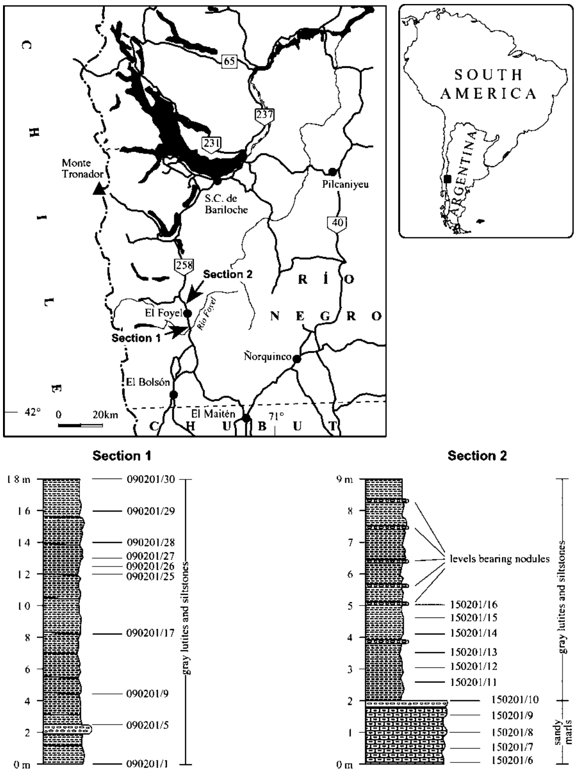

FIGURE 1–Location of the studied area and stratigraphic location of the palynologic samples/*Ubicación geográfica del área estudiada y ubicación estratigráfica de las muestras palinológicas.*

noderms. Thirty palynologic samples were collected with a sampling interval of 50 cm (stratigraphic) or 1 meter. The total thickness of the sampled section is 18 meters. Section 2 is located 1 km north of El Foyel village, on the northern margin of the main road to Bariloche. From this section eleven samples have been extracted, which represent 9 m of the sequence. These two sections represent the lower part of the Río Foyel Formation.

METHODS AND MATERIALS

The physical and chemical extraction of the palynologic samples was done by A. Moschetti in the Paleopalynologic Laboratory of IANIGLA in Mendoza, using standard methods (HCl, HF). For palynofacies studies the samples were analyzed after removing the matrix of the sediments, prior to oxidation and filtering, using slides specifically prepared for this purpose. Additional observations were made with fluorescent light (excitation with blue or blue-UV-light). For identification of the palynofacies with transmitted light the proceeding of Batten (1987) was applied, calculating the relative frequencies through visual evaluation of five areas of the slide, with a magnification of x40. For observations with fluorescence microscopy we followed Tyson (1995), using an objective x20. His classification of the disperse organic material distinguishes the amorphous-phytoclast-palynomorph and zooclast groups.

The palynologic slides are reposited at IANIGLA, as numbers of cathalog 7368-7399 and 7524-7533. All levels analyzed in section 1 have good recovery; in section 2 significant organic residue was obtained only from 4 of the samples (150201/6, 150201/7, 150201/9, 150201/11). Coordinates of specimens are denoted by an England Finder reference.

RESULTS

Organic facies

The palynologic organic matter (OM) analysis from samples of the Río Foyel and El Foyel sections had consistant recoveries of OM. In all levels amorphous organic matter (AOM) is the dominant organic constituent (60-80%). The most prevalent AOM is fine grained and gray in color. In a lower proportion is a membranous-grumose AOM of pale yellow to dark brown. Under incident blue fluorescent light a scarce or nil dark brown and grey fluorescence can be observed. All the organic components exhibit a high degree of degradation. Corroded marine and terrestrial palynomorphs are observed, some intensly biodegraded. The thermal alteration index (TAI) 3-, measured on the spores, indicates moderate maturity. The transparent phytoclasts without structure and those with biostructures (tissues, cuticles) are strongly corroded and degraded and never exceed 40% of the recovered OM.

Through palynofacies analysis a marine depositional paleoenvironment is indicated, which is relatively restricted, as suggested by the abundance of amorphous organic matter and the presence of pyrite. It is relatively proximal as suggested by the presence of phytoclasts (tissues and cuticles) and terrestrial palynomorphs. The presence or absence of pyrite could be related with variations of the REDOX potential and often indicates quiet water deposition where sulfate-reducing bacteria florish.

We recommend a taphonomic study of the marine fauna to determine paleoenvironment and reworking previous to deposition and diagenesis.

Features of the palynologic assemblages

The palynologic assemblages recovered are of fear to poorly preserved. Diversity is low consisting of forms both of marine (dinocysts, foraminiferal linings) and continental origin (spores, pollen, fungi, algae, wood remains and cuticles). The palynomorphs exhibit scaring from pyrite frambuos and degradation due to thermal alteration and other bacterial activity. The assemblages are relatively monotonous; no compositional variations can be observed along the sections, save minor changes in frequency. Thus it is possible to analyze the microflora as a whole. It is dominated by marine elements; the continental palynomorphs are very scarce and of a low diversity. Poor preservation may have caused the assemblages recovered to be selectively biased to the more resistant palynomorphs. Although preservation is poor, assemblages identified in section 1 are dominated by marine elements and contain very scarse continental palynomorphs. In contrast, productive assemblages in section 2 suggest less marine influence due to the low number of dinoflagellate cysts present and the stronger representation of continental elements.

Marine palynomorphs

Among the elements of marine origin can be recognized dinoflagellate cysts and, in some levels, microforaminiferal linings. Section 1 consists of assemblages of very low species diversity with a strong dominance of *Tuberculodinium vancampoae* (65 to 90% of the total number of dinocysts). A secondary component consists of a group of protoperidinioid species previously identified in the “Patagonian” sequences of the San Jorge Gulf Basin and Mazarredo Subbasin: *Lejeunecysta communis, L. globosa, Selenopemphix* sp. (Palamarczuk and Barreda, 1998; Barreda and Palamarczuk, 2000a). Additional forms are *Operculodinium centrocarpum, Spiniferites* spp. and some cysts comparable to those illustrated for the Chenque Formation as gen. et sp. indet. (Palamarczuk and Barreda, 1998; Plate 3, fig. 3). In section 2 the composition of the assemblages does not show significant changes, but the abundance of palynomorphs is much lower.

Continental palynomorphs

Spores with resistant exines are dominant and pollen grains are relatively under represented possibly due to their delicate wall structure. Thus a preservationally biased assemblage remains. Among the fern spores Lophosoriaceae *(Cyatheacidites annulatus)*, Dicksoniaceae *(Ischyosporites areapunctatis, Trilites* spp.), Cyatheaceae (*Cyathidites* spp.) and *Baculatisporites* type are dominant. More subordinate elements are the Pteridaceae *(Muricingulisporis chenquensis)*, Matoniaceae *(Matonisporites ornamentalis, Corrugatisporites argentinus)* and Polypodiaceae (*Polypodiisporites* spp.). Gymnosperms are represented by a low number of specimens of Podocarpaceae *(Podocarpidites* spp., *Phyllocladidites mawsonii, Lygistepollenites florinii)* and Araucariaceae *(Araucariacites australis)*. The angiosperm component of the assemblage is relatively small, consisting of Fagaceae (*Nothofagidites* spp.) and Proteaceae (*Proteacidites* sp.) and, in some levels, Winteraceae *(Pseudowinterapollis couperi)*. Of note is the presence of a polyad of Mimosoideae, similar to the extant genus *Parkia* or *Anadenanthera*. Due to the poor preservation definitive taxonomic determination of this specimen is not possible. Among the algal remains few colonies of green algae of *Pediastrum* and *Botryococcus* were recovered.

The second section is palynologically less productive. In the lower levels (150201/6-150201/10) the recovered organic residue is strongly altered and palynomorphs are rare. However, sample 150201/11 contains a palynologically significant assemblage were continental influence is varied and, in addition to species recognized in section 1, specimens of Myrtaceae are present.

TAXONOMIC LIST OF IDENTIFIED SPECIES

	Botanical affinity
Dinoflagellate Cysts	
Gen. et sp. indet. (Plate 3, fig. 3, in Palamarczuk and Barreda, 1998)	Dinoflagellates
Lejeunecysta communis Biffi and Grignani	Dinoflagellates
Lejeunecysta globosa Biffi and Grignani	Dinoflagellates
Operculodinium centrocarpum (Deflandre and Cookson) Wall	Dinoflagellates
Selenopemphix sp.	Dinoflagellates
Spiniferites spp.	Dinoflagellates
Tuberculodinium vancampoae (Rossignol) Wall	Dinoflagellates

Spores	**Pteridophytes and bryophytes**
Baculatisporites sp.	Uncertain
Baculatisporites turbioensis Archangelsky	Uncertain
Biretisporites sp.	Uncertain
Corrugatisporites argentinus Archangelsky	Matoniaceae?
Cyatheacidites annulatus Cookson	Lophosoriaceae
Cyathidites patagonicus Archangelsky	Cyatheaceae
Ischyosporites areapunctatis (Stuchlik) Barreda	Dicksoniaceae
Matonisporites ornamentalis (Cookson) Partridge	Matoniaceae
Muricingulisporis chenquensis Barreda	Pteridaceae *Pteris semiadnata*
Polypodiisporites inangahuensis (Couper) Potonié	Polypodiaceae
Polypodiisporites radiatus Pocknall and Mildenhall	Polypodiaceae
Retitriletes austroclavatidites (Cookson) Potonié	Lycopodiaceae *Lycopodium*
Trilites spp.	Dicksoniaceae
Verrucosisporites kopukuensis (Couper) Stover	Lycopodiaceae

Pollen	**Gymnosperms**
Araucariacites australis Cookson	Araucariaceae
Lygistepollenites florinii (Cook and Pike) Stover and Evans	Podocarpaceae *Dacrydium*
Phyllocladidites mawsonii Cookson	Podocarpaceae *Lagarostrobos*
Podocarpidites elegans Romero	Podocarpaceae *Podocarpus/Dacrydium*
P. ellipticus Cookson	Podocarpaceae *Podocarpus/Dacrydium*
P. marwickii Couper	Podocarpaceae *Podocarpus/Dacrydium*
P. rugulosus Romero	Podocarpaceae *Podocarpus/Dacrydium*

	Angiosperms
Myrtaceidites sp.	Myrtaceae
Nothofagidites acromegacanthus Menéndez and Caccavari	Fagaceae
N. americanus Zamaloa	Fagaceae
N. dorotensis Romero	Fagaceae
N. saraensis Menéndez and Caccavari	Fagaceae
N. tehuelchesii Zamaloa and Barreda	Fagaceae
Polyadopollenites sp.	Leguminosa Mimosoideae *Parkia* or *Anadenanthera*
Proteacidites obscurus Cookson	Proteaceae
Pseudowinterapollis couperi Krutzsch emend. Mildenhall	Winteraceae *Drymis*
Tricolpites sp.	Uncertain

Freshwater algae	**Green Algae**
Botryococcus spp.	Chlorococcales (Botryococcaceae)
Pediastrum spp.	Chlorococcales (Hydrodictyaceae)

Age and Stratigraphic Correlation

The dinoflagellate assemblage as a whole shows strong similarities with those previously identified in the San Jorge Gulf Basin (Palamarczuk and Barreda, 1998), and especially those from the Mazarredo Subbasin (Barreda and Palamarczuk, 2000a), dated as Early Miocene and Latest Oligocene-Early Miocene, respectively. Although the assemblage of the Río

Foyel Formation is of a much lower diversity and abundance than that recognized in the Mazarredo Subbasin, the assemblage of protoperidinioids is similar. On the other hand, the presence of *Tuberculodinium vancampoae,* a species of recognized stratigraphic value, indicates an age not older than the Latest Oligocene for this sequence. The oldest published occurrence of this species was dated as 26M.Y. (Williams *et al*., 1998).

Most of the continentally derived forms recovered have an extended stratigraphic range. One of the few elements useful for dating is *Polypodiisporites radiatus*, a definitive Late Oligocene and Early Miocene species in New Zealand (Pocknall and Mildenhall, 1984) and recognized in Argentina in the same interval (Barreda, 1996). Fossil polyads such as the Mimosoideae polyad recovered here may be ancestral to *Parkia* or *Anadenanthera*. Fossil polyads ancestral to *Parkia* have been described from the Oligocene and Early Miocene of Brazil and Camerún (Guinet and Salard-Cheboldaeff, 1975; Lima *et al*., 1985), while the genus *Anadenanthera* has an exclusively Neogene distribution and has only been documented from the Early Miocene and Late Pliocene of Argentina (Caccavari and Anzótegui, 1987; Barreda and Caccavari, 1992). There exists a strong similarity between the families identified in these levels and those recognized in the Ñirihuau Formation through the megaflora (Romero and Dibbern, 1984), a unit dated as Early Miocene (Malumian, 1999), with which it is frequently correlated.

Paleobiogeographic inferences

Studying the origin of the marine transgressions in the Bariloche region, Windhausen (1931) proposed, in the context of his paleogeographic reconstruction, a marine connection of these occidental basins with the Pacific Ocean, including a connection with the Atlantic coast. This last connection would have passed through the valley of Río Genoa, the sierra Putrachoique and the area located between the Sierras of Tecka and Tepuel (Ramos, 1982). In the current literature no evidence of marine conditions are documented in the area which would have connected both basins (Franchi and Page, 1980). Spalletti (1983), based on sedimentary facies, postulates a Pacific origin of these transgresions, in agreement with the idea of Feruglio (1941) and Ramos (1982). The strong similarities of the dinoflagellate assemblages with that identified in the “Patagonian” deposits outcropping at the southern side of the San Jorge Gulf (Barreda and Palamarczuk, 2000a), suggest the Atlanctic and Pacific ocean waters were in communication here.

Communities and paleoclimate

These assemblages may have been deposited in a littoral marine environment. The low diversity of the dinoflagellates indicates lower than normal marine salinities. Low salinity assemblages are characterized by blooms of a limited number of species. The unstable environments near the coast are ecologically stressful for most taxa; and as a consequence there is a tendency for colonization by a small number of eutrophic species (Tyson, 1985). The genus *Tuberculodinium* is frequent in estuarine and inner neritic environments, with warm temperate to warm water temperatures (Wall *et al*., 1977; Harland, 1983). The abundance of protoperidinioids is associated with shallow, nutrient-rich waters.

From a paleofloristic point of view, the recovered sporopollinic spectre indicates during deposition of the Río Foyel Formation a flora of forests prevailed consisting of Fagaceae, Podocarpaceae and Araucariaceae, with an abundant lower stratum of

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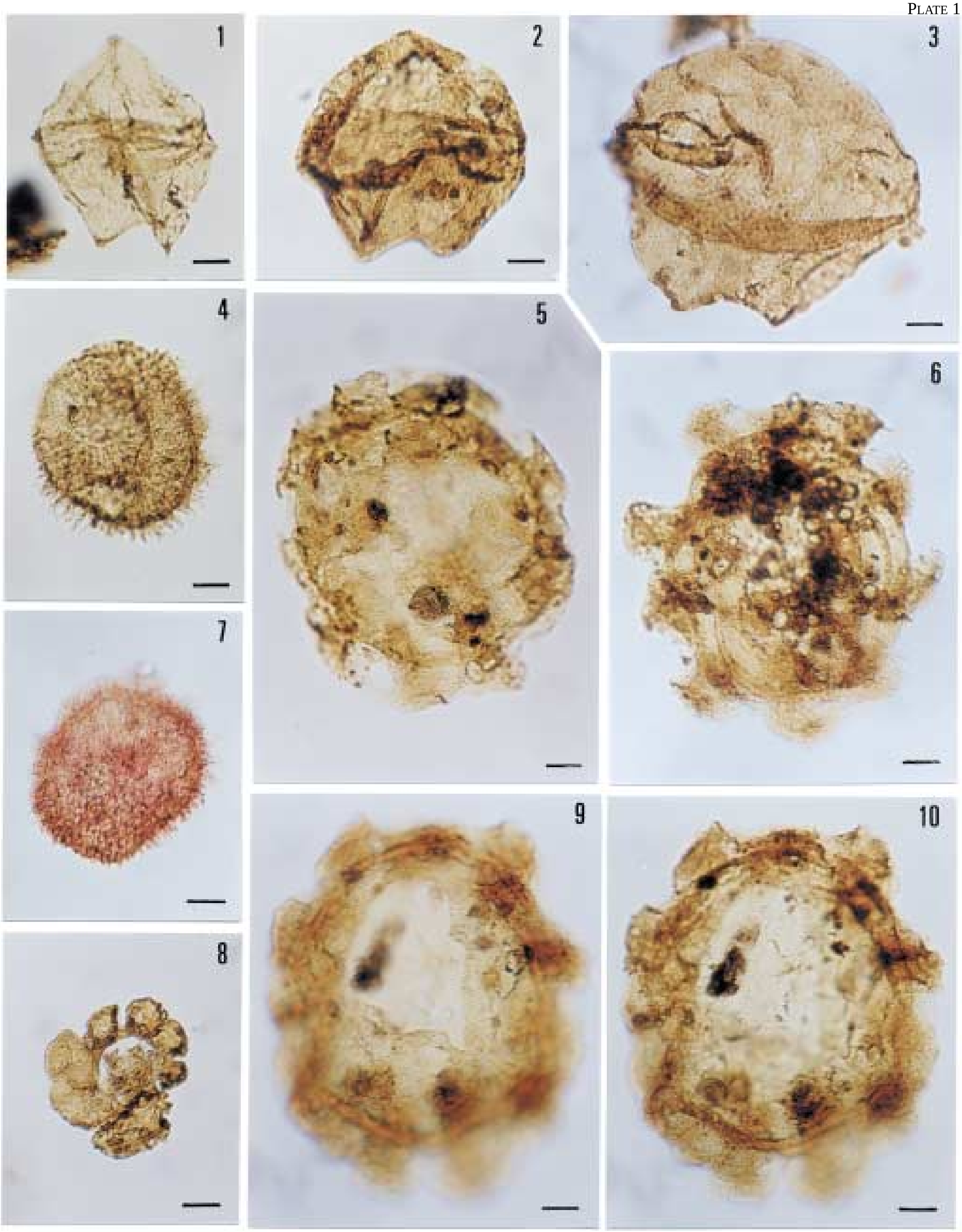
PLATE 1–*1*, *Lejeunecysta communis* Biffi and Grignani IANIGLA 7370H (P35-4/P36-3). *2, 3, Lejeunecysta globosa* Biffi and Grignani. *2,* IANIGLA 7370H (N50-1). *3,* IANIGLA 7369H (S32). *4, 7,* Gen. et sp. indet. (Plate. 3, fig. 3, in Palamarczuk and Barreda, 1998). *4,* IANIGLA 7384 H (E41-4). *7,* IANIGLA 7368E (J48-2/J49-1). *5, 6, 9, 10, Tuberculodinium vancampoae* (Rossignol) Wall. *5,* IANIGLA 7371F (E42-1). *6,* IANIGLA 7384H (N35-1). *9-10,* IANIGLA 7382G (R50-2). *8,* Microforaminiferal lining IANIGLA 7385G (G39-3), Bars in all figures equal 10 µm.

PLATE 1



ferns of Lophosoriaceae, Dicksoniaceae?, Cyatheaceae, Polypodiaceae. The absence of herbaceous and shrubby angiosperms, is not consistent with associations observed in contemporaneous formations of the Atlantic coast, Chenque and Monte León formations, as reported by Barreda, (1996) and Barreda and Palamarczuk (2000b). It is probable that during the latest Oligocene and Early Miocene the paleoclimatic conditions allowed a nearly exclusive development of forests on the western side of Patagonia, while near the Atlanctic coast some areas with open vegetation began to spread. The presence of mimosoid Leguminosae corresponding to living genera of tropical forms such as *Parkia* or *Anadenanthera* could indicate the existence of a possible warm-temperate relict assemblage.

CONCLUSIONS

- — A latest Oligocene to Early Miocene age is suggested for the Río Foyel Formation, based on the known stratigraphic ranges of some of key fossil occurrences and similarities with other Late Oligocene and Early Miocene assemblages previously studied for Argentina.
- — A link between the Ñirihuau Basin and the Atlantic basins is postulated in order to explain the strong similarities found between the palynologic assemblages of both areas.
- — A marine littoral depositional environment with lower than normal marine salinity and warm-temperate water, rich in nutrient, is indicated.
- — The basin may have been surrounded by a humid temperate forest, containing relict pockets of warm-temperate communities.

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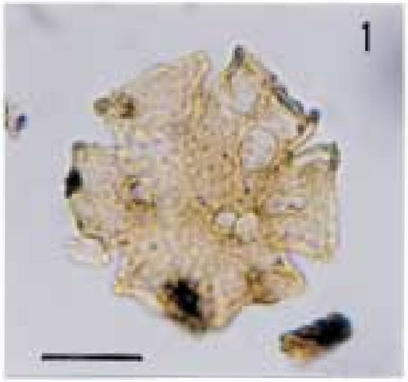
PLATE 2–*1, Nothofagidites acromegacanthus* Menéndez and Caccavari IANIGLA 7533F (M46-2). *2, Proteacidites obscurus* Cookson IANIGLA 7533F (E49). *3, 6, Polyadopollenites* sp. (*Parkia* or *Anadenanthera*) IANIGLA 7369H (U40-2/U41-1). *4, Nothofagidites saraensis* Menéndez and Caccavari IANIGLA 7533F (S40). *5, Araucariacites australis* Cookson IANIGLA 7370H (X50-2). *7, Baculatisporites* sp. IANIGLA 7386G (E42-2/E43-1). *8, Cyatheacidites annulatus* Cookson IANIGLA 7384H (T46). *9, Polypodiisporites radiatus* Pocknall and Mildenhall IANIGLA 7499F (Y38). *10, Muricingulisporis chenquensis* Barreda IANIGLA 7493K (X45-1). *11, Ischyosporites areapunctatis* (Stuchlik) Barreda IANIGLA 7493K (H43-4/H44-3). Bars in all figures equal 10 µm.

Plate 2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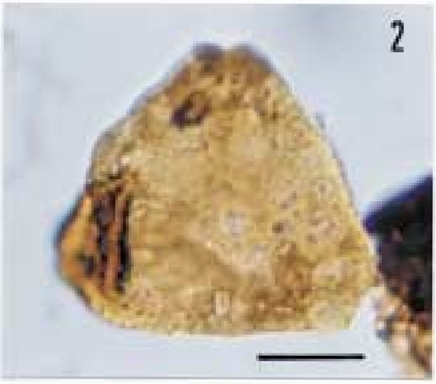
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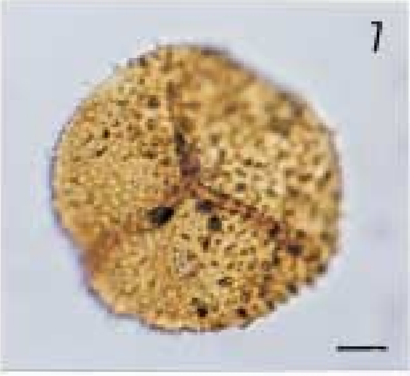
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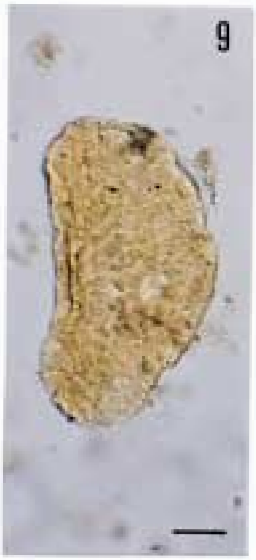
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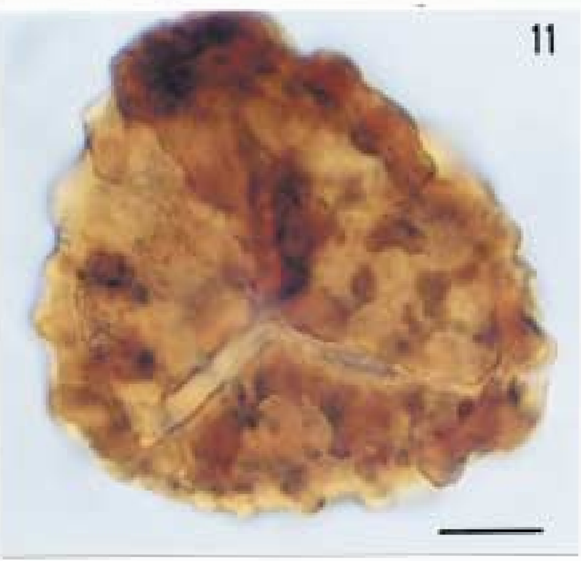
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AN INNER SHELF FORAMINIFERAL FAUNA AND ITS RESPONSE TO ENVIRONMENTAL PROCESSES (ADRIATIC SEA, ITALY)

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Abstract

From February 1991 to January 1995, 25 samples of sea bottom sediment were collected at a depth of 16 m from a station located on the Adriatic inner shelf, to study the temporal changes of benthic foraminifera association. During the sampling, 24-hour recordings of sea bottom hydrological parameters were performed and one water sample was taken to evaluate nutrient, organic carbon and iron content. The inner continental shelf environment studied here is subject to vertical mixing with river waters. The main feature of the hydrological parameters is their marked lack of seasonality. The living assemblage (stained with Rose Bengal) is composed of 64 taxa. The number of living individuals remains yearly constant, although the dynamics are complex, with irregular and discontinuous time behavior for single populations. In confirmation of this, the H values of the Shannon's index of species diversity, calculated on each sampling interval, in spite of their variability, do not show any trend or seasonality. The dead assemblage, composed of 88 species, shows systematic differences with the living assemblage: Rotaliina dominate in the living assemblage and Textulariina and Miliolina dominate in the dead one. To obtain an overall view of the complex system, both univariate and multivariate statistical analyses of living taxa and environmental parameters were used. The results indicate that the occasional availability of phytoplankton is the main factor influencing the productivity of benthic foraminifera in this shallow water basin with deltaic influence. Fluctuations in dominant and subdominant taxa are linked to biotic interactions.

Keywords: Adriatic continental shelf, Benthic foraminifera, Hydrological parameters, Living assemblage, Cluster analysis, Biotic interactions.

Resumen

Entre febrero de 1991 y enero de 1995, desde una estación fija ubicada en la plataforma continental adriática (16 m de profundidad) con influencias del delta, se extrajeron 25 muestras de sedimento para el estudio de la asociación de foraminíferos bentónicos y sus variaciones. Conjuntamente con la extracción se realizó un registro de los parámetros hidrológicos del fondo durante 24 horas y se extrajo una muestra de agua para la evaluación del contenido de nutrientes, carbono orgánico y hierro. El ambiente de plataforma continental interna se encuentra preferentemente sujeto a fenómenos de mezcla vertical con las aguas fluviales. Los parámetros hidrológicos se caracterizan por una ausencia marcada de estacionalidad. La biocenosis (teñida con rosa bengala), representada por 64 taxones, muestra una composición anual constante, pero posee una dinámica compleja con evolución temporal de las poblaciones individuales irregulares e inconstantes; su entropía se mantiene constante. La asociación de individuos muertos, constituida por 88 especies, muestra una gran homogeneidad temporal y espacial, y diferencias sistemáticas con la asociación de individuos vivos. Las relaciones estadísticas entre los taxones vivientes y los parámetros ambientales indican una disponibilidad intermitente de fitoplancton como factor de principal influencia en la productividad de los foraminíferos bentónicos; estas fluctuaciones en los taxones dominantes y subdominantes parecen estar controladas por mecanismos de competitividad interespecífica.

Palabras clave: Plataforma continental adriática, Foraminíferos bentónicos, Parámetros hidrológicos, Asociación de individuos vivos, Correlaciones estadísticas, Interacciones bióticas.

INTRODUCTION

Because foraminifera are widely used to define paleo-environments, great emphasis has been given to the parameters controlling the distribution of living populations.

Recent works on the continental margin compare foraminiferal population fluctuations with organic carbon flux or oxygen content (Silva *et al.,* 1996; Bernhard *et al*., 1997; Patterson *et al.,* 2000). Nutrients are not generally a limiting factor in eutrophic coastal waters and oxygen only becomes a controlling factor when high organic input leads to oxygen depletion (Gooday, 1994). In addition, foraminiferal biotopes are not directly correlated with sediment distribution, although foraminifera and sediments may have similar spatial distributions (Albani *et al*., 1998).

Current data on living foraminiferal faunas indicate that food supply is of prime importance (Loubere, 1994; Schmiedl *et al*., 1997; Smart and Gooday, 1997; De Stigter *et al.*, 1998), but its influence among factors controlling population distribution and productivity is still under debate.

Seasonality of foraminiferal population fluctuations has been the focus of a number of recent studies. Seasonal fluctuations of living foraminifera in deep-sea sediments have been related to phytodetritus and biotic interactions (Gooday, 1986; Gooday and Lambshead, 1989; Lambshead and Gooday, 1990). Much more is known about foraminiferal seasonality in shallow water (Murray, 1983, 1992, 2000; Murray and Alve, 2000) or in paralic environments (Scott and Medioli, 1980a). The results of a recent study in the Lagoon of Venice, Italy (Donnici *et al.*, 1997), indicate that the productivity peaks of dominant species are controlled by available quantities of phytoplankton and by biotic interactions between foraminiferal species: in the lagoon, the dominant paralic taxa were shown to delay the productivity peaks of the marine species.

Our study examines a more open-marine setting in this same region, the inner Adriatic continental shelf off the Venice Lagoon. The purpose of this study is to use this setting to improve our understanding of the effect of environmental processes, especially those related to seasonality, on benthic foraminiferal faunas in shallow-marine environments. The study was based at the oceanographic platform of the Italian National Research Council (CNR), which offered a fixed point from which sediment samples, water samples, and oceanographic probe measurements were obtained. The regular sampling program at this fixed site has enabled us to record benthic foraminifera population dynamics and water properties in marine waters, less trophic than those of the lagoon, thus improving our knowledge of factors controlling living taxa.

STUDY AREA

The investigated area is on the upper northwestern Adriatic inner shelf, where the CNR-Venice oceanographic platform is established. This platform is located 14.8 km off of the coast, 45°18’8” N and 12°30’9” E (Fig. 1), on a sandy bottom belt, at a water depth of about 16 m, where no macroalgae or seagrasses inhabit. The site lies within the photic zone which, in the northwestern Adriatic, extends to a depth of about 40 m (Socal *et al*., 2000). Sedimentation is greatly reduced on the Adriatic inner shelf. The seafloor is characterized by sandy or silty sediments arranged in an elongated pattern of belts parallel with the coastline. They are formed by long-shore currents affecting dispersion of sediments brought by the Po and eastern South-Alpine rivers. Silts are confined to a belt along the Italian coast and are still being deposited by rivers. Sand is sourced from Pleistocene continental deposits reworked by marine processes after the late-Quaternary transgression (Van Straaten, 1965; Correggiari *et al.,* 1996).

River input influences the structure of the water masses in the Adriatic Basin. The River Po is the largest, with more than 8,000 m^3/s at flood periods (Umgiesser *et al*., 1996), and its input causes a density

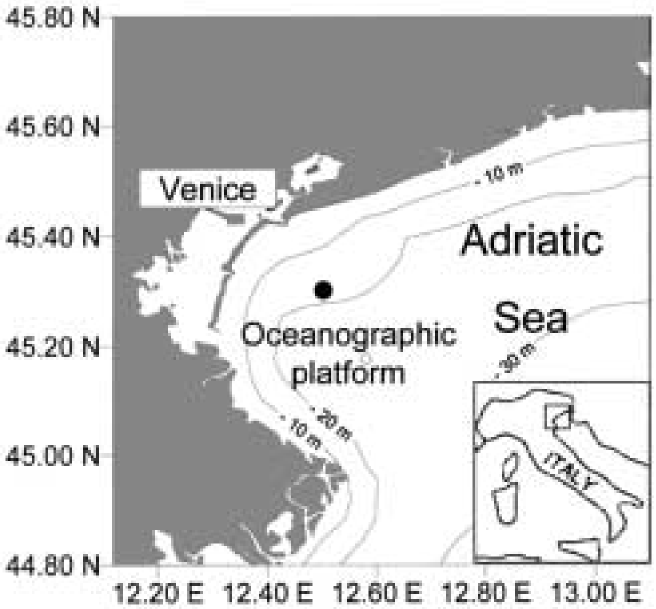

FIGURE 1–Map of the Gulf of Venice showing sampling site at the CNR oceanographic platform (bathymetry in meters).

gradient between the northern and southern parts of the basin. This density gradient gives rise to the upwelling of hyperhaline waters originating from the Mediterranean through the lower Adriatic along the west Balkan coastline and, at the same time, the downwelling of less dense waters from the North Adriatic southwards, along the Italian coastline (Zore-Armanda, 1969). In the northern Adriatic Basin, due to its shallowness and wide annual variations in the thermal cycle, two extreme situations for watermass structure may be distinguished (Franco, 1984). The first is completely unstable, occurring during winter, with a western coastal belt separated by a frontal system from the highly saline offshore waters; the second, occurring in summer, is characterized by a highly stable water column with discontinuous horizontal surfaces and low vertical diffusivity. These two characteristic density fields govern the distribution and flow of substances which interact with photosynthetic processes, e.g., nutrients, particulate and dissolved matter, through different types of advective and turbulent transport. During the winter the vertical mixing leads to a homogeneous distribution of the nutrients, suspended matter, and phytoplankton biomass along the water column; in summer, during the stratification regime, the nutrient distribution depends on the lateral advection of river runoff in the surface layer and on the particulate matter downward flux and mineralization in the deeper layers.

Along the western Adriatic coastline the outflows of rivers produces a 10-40 km wide mixing zone along the coast (Umgiesser *et al.,* 1996). The study area lies within this zone and is thus strongly influenced by the position of the front separating nutrient-laden coastal waters and more nutrient-poor offshore waters.

MATERIAL AND METHODS

1. Sampling

Twenty-five bottom sediment samples were collected every two months from February 1991 to January 1995 at the CNR platform. Sampling was carried out at a depth of 16 m with a Van Veen-type sediment grab. The size of the sampler allowed slabs of about 14 x 24 cm and 10 cm thick to be taken. This thickness was chosen because almost all living foraminifera are concentrated in the upper few centimeters of sediment (Bernhard and Reimers, 1991; Barmawidjaja *et al.,* 1992).

During sampling, temperature, conductivity and salinity in the whole water column (16 m) were measured by means of the “Idronaut Ocean Seven 401” oceanographic probe to check the presence or absence of the pycnocline.

On the sea bottom, salinity, temperature, dissolved oxygen, and pH were measured with the same oceanographic probe for at least two entire tide cycles (24 hours) and their mean values calculated in order to reduce the effects of the tidal phases.

Beginning in March 1991, and thereafter, simultaneously with the collection of bottom sediment, a water sample was taken just above the seafloor in a Niskin sampler bottle for analysis of the following biochemical parameters according to the standard methods (American Public Health Association, 1985): suspended matter, obtained by the gravimetric method (under vacuum weighted fraction held by the 0.45 µm sieve); total organic carbon (TOC), obtained by measuring carbon dioxide after combustion; total iron, measured by atomic absorption spectrometry; sulphates, obtained by chromatographic method; chlorides, obtained by titration; chemical and biological oxygen demands (COD and BOD) measured, respectively, as oxygen required to oxidize reducing substances in water, and oxygen consumed over a period of five days by bacteria; nutrients, composed of nitrogen and phosphorus compounds in dissolved form, obtained by colorimetric method.

2. Sample preparation

A sample volume of 300 cm^3, corresponding to an area of 30 cm^2, was separated and treated. Murray (1991) reports that this is the minimum area required for a sample to be representative of a whole fauna and thus to include both rare and abundant taxa. Samples were stained and fixed following the method of Lutze (1964) and Daniels (1970), with Rose Bengal added directly to denatured alcohol. In spite of criticism (Atkinson, 1971; Boltovskoy and Wright, 1976; Leamon, 1979; Gooday, 1986; Murray and Bowser, 2000), we regard staining with Rose Bengal as still one of the best ways of recognizing living foraminifera.

After staining, samples were washed on a 63 µm sieve, dried at 50 °C and sieved. We chose to analyze the residual > 125 µm to obtain results comparable with those from previous studies on the Adriatic Sea and Venice Lagoon (D'Onofrio, 1969; Jorissen, 1987, referring to samples picked up in 1963; Fregni and Borsetti, 1980; Pranovi and Serandrei-Barbero, 1994; Donnici *et al.*, 1997; Albani *et al.*, 1998). The fraction < 125 µm was stored for further analyses. Because of the low density of living foraminifera, the study of the living assemblage was carried out on the entire sample of 300 cm^3; for the dead assemblage, a microsplitter was used to obtain a fraction of each sample containing about 1000 individuals. The identified taxa were grouped in suborders according to the 1964 classification of Loeblich and Tappan. The more recent classification (Loeblich and Tappan, 1987), with the institution of some new suborders (in particular, for those of our interest, Spirillina and Lagenina) and with a different taxonomic order makes more difficult the comparison of data with previous studies. Many of the species listed here are illustrated and discussed in Albani and Serandrei-Barbero (1990) and Donnici and Serandrei-Barbero (2002); others are discussed in the Appendix. The specimens upon which the descriptions are based, are deposited in the collection of the Istituto per lo Studio della Dinamica delle Grandi Masse.

3. Statistical method

Basic statistic, i.e. mean, standard deviation, etc., were calculated for each environmental data set to synthetically describe the variables. Furthermore, as usually done in ecological studies, the Shannon's entropy index, H, that gives the degree of species diversity (Shannon and Weaver, 1963) was used as a measure of the temporal stability of the living community. It assumes minimum value in the case of absolute dominance (i.e. presence of only one species) and maximum value in the case of zero dominance (i.e. all species with same abundance).

Given the great deal of data, statistical analysis was used, both univariate and multivariate, to obtain a whole vision of the complex system. The Pearson linear correlation coefficent, r, was calculated to examine the existence of significative interrelationships between pairs of species and environmental parameters; correspondence analysis, which is the most suitable method for treating enumerative data (Davis, 1986), was adopted to investigate the interaction between samples and species; the C-mean cluster analysis (Hartigan and Wong, 1979) was finally carried out to better understand the life stategy of the foraminiferal fauna.

DATA

1. Physio-chemical parameters

The coastal environment in this study area is characterized by water column mixing and moderate supplies of nutrients, both caused by river outflows. Temperature and salinity show homogeneous values from the surface to the bottom. A slight stratification of less dense surface waters was observed only during recordings on 23 March 1993, 10 November 1993, and 26 May 1994. These events represent high inputs from the Po River during flood episodes.

Sea-bottom measurements of temperature, salinity and dissolved oxygen measured by oceanographic probe at each sampling interval are plotted in figure 2.

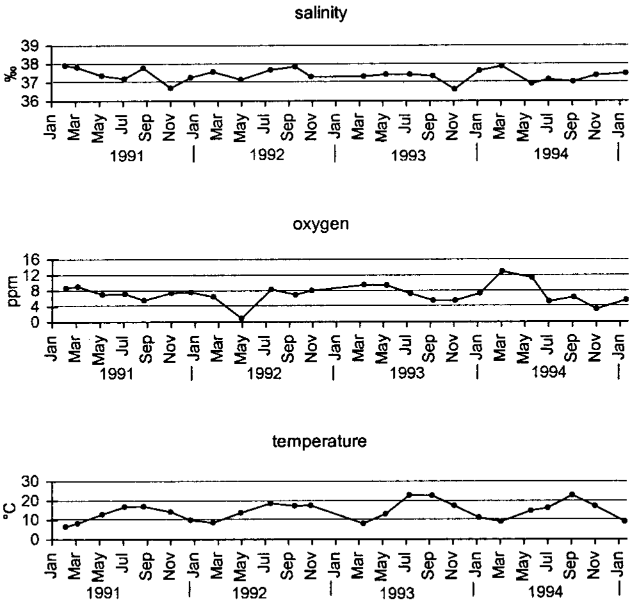

FIGURE 2–Values of physico-chemical properties of the sea bottom water measured with the oceanographic probe from February 1991 through January 1995.

Only temperature (mean value 14.37 °C) shows a marked seasonality. Shifts in salinity (mean value 37.38‰) can be related to variations in fresh water input from the Po. Values of pH are generally stable around 8.0 and appear to be controlled by photosynthesis and decay of organic matter (Zogno and De Boni, 1995). Dissolved oxygen content is also linked to photosynthesis and decay of organic matter. Dissolved oxygen values have a mean of 7.14 ppm (ca. 223 µM O_2 kg^{-1}), only showing hypoxia in May 1992 with a content of 0.90 ppm (ca. 28 µM O_2 kg^{-1}**)**.

The values of the biochemical parameters for the Niskin bottle bottom water samples are listed in table 1 and plotted vs. time in figure 3. Like the salinity and dissolved oxygen measurements obtained with the oceanographic probe, the bottom-water samples generally do not reveal regular seasonal changes. The chemical and biological oxygen demands (COD and BOD) have very irregular maxima; peaks in May 1991, November 1992 and July 1993 occur at the same time as algal blooms described by Bernardi Aubry *et al.* (1995) (see next discussion). The nutrient content as indicated by total nitrogen (TKN), ammonium-nitrogen(N-NH_4), nitric-nitrogen(N-NO_3), nitrous-nitrogen (N-NO_2), orthophosphates (P-PO_4) and total phosphorus (P), show behavior with sharp peaks in spring, summer and winter, reflecting the great variability of the Adriatic regime due to river water outflows, the growth of phytoplankton, and regenerative processes in sediments given by the bacterial activity turning biomass into nutrients. In particular, among the nitrogen compounds, only N-NH_4, as the first product of the remineralization of organic matter, follows the trend of total phosphorus. The irregular behavior of suspended matter, which influences light penetration and thus the extent of the euphotic zone, is due to several factors: particulate matter input from rivers or resuspension by wave motion; organic detritus input; and phytoplankton abundance. The basic statistics for these parameters are summarized in Table 2: the high variability of most of the measurements reflects the general environmental instability in this coastal setting.

2. Living assemblage

In the 25 samples examined, 64 species of living foraminifera were found (Table 3), of which 4 belong to the suborder Textulariina, 12 to Miliolina and 48 to Rotaliina. The size of each living assemblage ranges montly from 57 to 257 indiv. [300 cm^3] $^{-1}$.

sample	date	COD (mg/l)	BOD (mg/l)	chlorides (g/l)	sulphates (g/l)	TOC (mg/l)	iron (mg/l)	susp. matter (mg/l)	T.K.N. (mg/l)	N-NH4 (mg/l)	N-NO3 (mg/l)	N-NO2 (mg/l)	P-PO4 (mg/l)	Total P (mg/l)
1	2/25/1991													
2	3/27/1991	21.3	0.9	15.68	3.11			35	0.22	0.102	0.024	0.015	0.001	0.02
3	5/28/1991	77.8	3	21.624	3.473			20.75	0.768	0.217	0.041	0	0.001	0.006
4	7/24/1991	28	0.9	21	2.476			95	0.312	0.056	0.05	0.001	0.001	0.005
5	9/10/1991	36	1.2	22	3.126	3.5		49.5	0.064	0.057	0.047	0.005	0.001	0.005
6	11/18/1991	42.4	1.5	20.881	2.683	4		195	0.604	0.082	0.045	0.007	0.005	0.005
7	1/7/1992	39.6	1.5	21.788	2.843	1.25		40	0.892	0.12	0.07	0.025	0.005	0.005
8	3/5/1992	63	4.5	21.801	3.048	4.5		85	0.618	0.073	0.095	0.006	0.005	0.005
9	5/14/1992	44.4	3.9	23	2.612	2		35.2	0.544	0.073	0.033	0.005	0.005	0.005
10	7/30/1992	37.6	3.5	22.688	2.79	1.25		34	0.562	0.068	0.018	0.005	0.005	0.005
11	9/30/1992	36	2.9	21.197	2.513	1.24	0.06	23.2	0.59	0.122	0.027	0.005	0.005	0.005
12	11/9/1992	78	8.1	21.8	2.389	2.5	0.07	30.8	0.52	0.052	0.04	0.005	0.005	0.005
13	1/7/1993	30	2.8	21.5	2.986	1	0.075	37.2	0.588	0.063	0.027	0.006	0.005	0.005
14	3/22/1993	34.7	3.2	22.156	3.093	1.15	0.05	29.2	2.6	0.078	0.048	0.005	0.005	0.005
15	5/19/1993	41.5	3.8	22.688	3.847	1.25	0.04	30	0.48	0.054	0.027	0.002	0.005	0.005
16	7/22/1993	66	7.1	23.042	2.955	2.5	0.06	25.2	0.58	0.059	1.3	0.005	0.005	0.005
17	9/17/1993	18.2	2.5	21.444	2.974	0.85	0.24	25.02	0.7	0.045	0	0.024	0.005	0.005
18	11/10/1993	42.4	5.5	19.195	2.931	2	0.5	30	2	0.046	0.026	0.005	0.005	0.005
19	1/12/1994	46.7	6.8	23.042	2.762	1.95	0.3	28	1.18	0.061	0.033	0.022	0.005	0.005
20	3/9/1994	14.2	1.9	23	2.77	0.5	0.38	28.4	2.1	0.044	0.029	0.003	0.005	0.018
21	5/24/1994	61	10.4	22.812	2.266	2.5	0.18	26	0.74	0.12	0.073	0.004	0.02	0.023
22	7/6/1994	51	10	23.397	2.891	2	0.2	35.2	0.58	0.15	0.011	0.005	0.018	0.025
23	9/6/1994	63	10.6	21.979	2.397	2.2	0.49	28.8	0.44	0.24	0.017	0.011	0.005	0.005
24	11/2/1994	65	11.5	22.688	2.995	1.5	0.23	37.2	0.32	0.221	0.04	0.008	0.005	0.01
25	1/16/1995	34	6.1	17.796	2.756	0.8	0.21	29.6	0.65	0.326	0.056	0.011	0.006	0.013

TABLE 1–Values of biochemical water quality variables measured for each sampling interval, from March 1991 to January 1995.

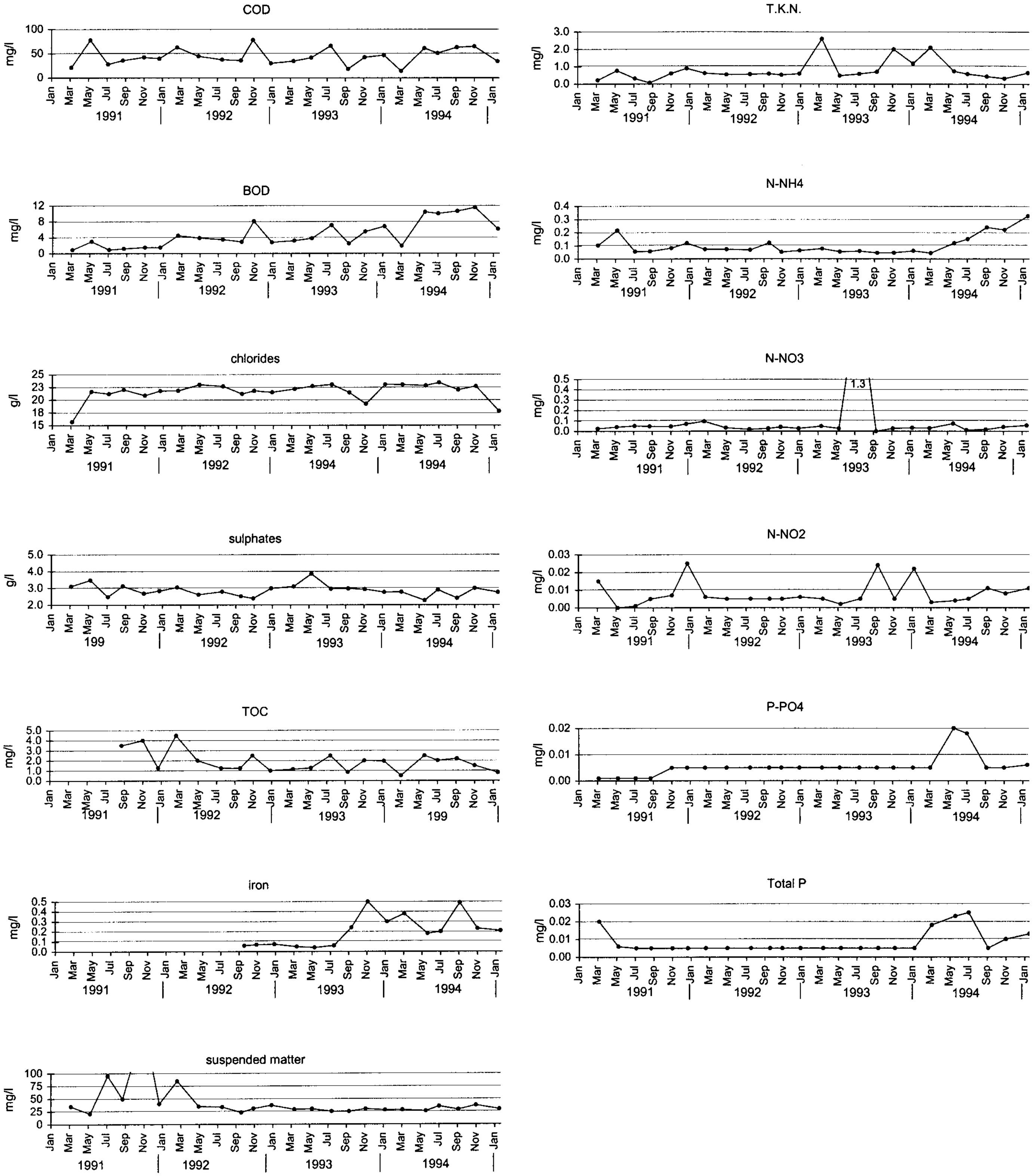

FIGURE 3–Biochemical content vs. time of sampled bottom water from March 1991 through January 1995.

variable	observation number n	mean $\bar{x}$	standard deviation σ	coefficient of variability Cv %
pH	24	8.161	0.309	3.8
susp. matter (mg/l)	24	43.053	36.872	85.6
COD (mg/l)	24	44.658	17.677	39.6
BOD (mg/l)	24	4.754	3.330	70.0
T.K.N. (mg/l)	24	0.777	0.611	78.6
N-NH4 (mg/l)	24	0.105	0.074	70.6
N-NO3 (mg/l)	24	0.091	0.258	283.0
N-NO2 (mg/l)	24	0.008	0.007	87.5
P-PO4 (mg/l)	24	0.005	0.004	80.0
P Tot. (mg/l)	24	0.008	0.006	75.0
Chlorides (g/l)	24	21.600	1.784	8.3
Sulphates (g/l)	24	2.862	0.350	12.2
TOC (mg/l)	21	1.926	1.058	54.9
Iron (mg/l)	15	0.205	0.155	75.6

TABLE 2–Basic statistics of biochemical water quality variables referred to the entire period; the coefficient of variability is expressed as a percentage indipendent of the unit of measure.

Of the total number of living specimens counted throughout the study period, 78% belong to the suborder Rotaliina, 15% to Miliolina, and 7% to Textulariina. Their absolute abundances are shown in figure 4. Peak abundances of living foraminifera occur in samples from March-May-July 1991 and January 1993, and the lowest abundance occurs in the sample from March 1993. The samples are dominated by suborder Rotaliina, which ranges from 61 to 99%.

species and identification number		1991						1992						1993						1994						95	year			
		Feb	Mar	May	Jul	Sep	Nov	Jan	Mar	May	Jul	Sep	Nov	Jan	Mar	May	Jul	Sep	Nov	Jan	Mar	May	Jul	Sep	Nov	Jan	1991	1992	1993	1994
Haplophragmoides canariensis (d'Orbigny, 1839)	1			2												2						1	1				2	0	2	2
Textularia agglutinans d'Orbigny, 1839	2	1		1						3	3	1	2	10	2	5	1	2	1		3	5	5	1	4	5	2	9	21	18
Textularia conica d'Orbigny, 1839	3	1		3	1	2	3			6	6		2	3			4	1	2				2	2		2	10	14	10	4
Eggerella scabra (Williamson, 1858)	4		1	1	11		2		2	4	3	1	2	7	2	6	4	6	3	2	3	3	11	5			15	12	28	24
Quinqueloculina agglutinata Cushman, 1917	5	2	2			2	4	1	1	3	4	4	3					2	4	1	3	2		1	3	3	10	16	6	10
Quinqueloculina candeiana d'Orbigny, 1839	6			4																							4	0	0	0
Quinqueloculina elegans (Williamson, 1858)	7						2				1					1					1						2	1	1	1
Quinqueloculina ferussacii d'Orbigny, 1826	8		1										1														1	1	0	0
Quinqueloculina lamarckiana d'Orbigny, 1839	9															1		1	1			1	1		1		0	0	3	3
Quinqueloculina seminulum (Linnè, 1758)	10	2	6	20	4	7	21	3	7	13	9	8	6	6	4	12	5	10	7	7	9	6	8	3	6	6	60	46	44	39
Quinqueloculina squamosa (Terquem, 1878)	11						1			1		1															1	2	0	0
Quinqueloculina subpolygona Parr, 1945	12		1	2					1		1		1						3								3	3	3	0
Sigmoilina grata (Terquem, 1878)	13			1																							1	0	0	0
Triloculina trigonula (Lamarck, 1804)	14	1	1	27	5	2	2	2	2	4	4	5	1	6	1	7	2	7	5	1	4	5	3	2	1	7	38	18	28	16
Miliolinella suborbicularis (d'Obigny, 1826)	15									1																	0	1	0	0
Miliolinella subrotunda (Montagu, 1803)	16			1					1		1								1			1	1		1		1	2	1	3
Nodosaria perversa Schwager, 1866	17		1																								1	0	0	0
Lagena laevis (Montagu, 1803)	18			1																							1	0	0	0
Lagena striata (d'Orbigny, 1839)	19				1					1																	1	1	0	0
Lagena striata strumosa Reuss, 1858	20								2							1											0	2	1	0
Globulina gibba myristiformis (Williamson, 1858)	21	11	25	8	13	15	5	4	2	9	13	9	9	4	3	4	2	4	14	6	5	5	1	3	5	4	77	46	31	25
Guttulina problema (d'Orbigny, 1826)	22	7	8	5	16	15	3	4	1	4	4	8	3	9		5		1	8	3	4	2	1	1	1	6	54	24	23	12
Fissurina laevigata Reuss, 1850	23				1					1		1						1									1	2	1	0
Fissurina lucida (Williamson, 1848)	24			1																							1	0	0	0
Fissurina orbignyana caribaea (Cushman, 1923)	25		2	2				1											1	2							4	1	1	2
Bolivina pseudoplicata Heron -Allen &Earland, 1930	26	1	1	2	1								1														5	1	0	0
Brizalina spathulata (Williamson, 1858)	27				1		1															1	1	1	2		2	0	0	1
Brizalina striatula (Cushman, 1922)	28					2							1												1		2	1	0	5
Bulimina elongata d'Obigny, 1846	29							1				1						2						1			0	2	2	1
Bulimina gibba Fornasini, 1902	30		1	6	6	1		1	2	1				4		1						2	1	1		1	14	4	5	4
Bulimina marginata d'Orbigny, 1826	31			2						1				1													2	1	1	0
Reussella spinulosa (Reuss, 1850)	32			5		1		1		1	1			2				2	1		2	2			1	2	6	3	5	5
Trifarina angulosa (Williamson, 1858)	33			1						1			1														1	2	0	0
Discorbis mirus (Cushman, 1922)	34		3	1	2		1	2	1	1	4			1		1	4	3	1			1	1	1			7	8	10	3
Buccella frigida granulata (Di Napoli Alliata, 1952)	35	1	5	3	2	3	11	4	3	4	3		4	1			2	1	2	1	1		1				25	18	6	3
Buccella pustulosa Albani e Serandrei Barbero, 1982	36	2	1	3	2	2	2		1		3	2	4	2				10	11	3	2	2	1	4	2	1	12	10	23	14
Discorbinella bertheloti (d'Orbigny, 1839)	37		3	1	1	5	1	1	2	1				4												1	11	4	4	0
Neoconorbina terquemi (Rzehak, 1888)	38		2	3	4	4	3		1	2	2			8			3	3			2	4	2	4		1	16	5	14	12
Rosalina bradyi (Cushman, 1915)	39	4	12	5	11	9	9	7	4	6	1	10	6	15		1	7	7	8	9	9	10	8	8	8	6	50	34	38	52
Rosalina globularis d'Orbigny, 1826	40					1				2		1								1				2	2	3	1	3	0	5
Spirillina vivipara Ehremberg, 1843	41		1			1			1																		2	1	0	0
Asterigerinerata mamilla (Williamson, 1858)	42								1		2	1						2		3	1	1				5	0	4	2	5
Ammonia beccarii (Linnè, 1758)	43		8	2	9	11	37	22	14	10	14	9	6	5	8	5	1	2	7	9	9	5	2	7	8	9	67	75	28	40
Valvulineria perlucida (Heron-Allen & Earland, 1913)	44					1	1			1					1							1		1			2	1	1	2
Elphidium complanatum (d'Orbigny, 1839)	45		1						1		2										1				1	1	1	3	0	2
Elphidium crispum (Linnè, 1758)	46			1																1							1	0	0	1
Elphidium depressulum Cushman, 1933	47										1			1													0	1	1	0
Elphidium macellum (Fichtel e Moll, 1798)	48	3	4	1	4	3	4			1	1		1	1		1		1		2		1	3	6	1	3	19	3	3	13
Elphidium macellum aculeatum (Silvestri, 1901)	49			1	1						1													2	2	3	2	1	0	4
Cellanthus discoidale multiloculum (Cushman e Ellisor, 1945)	50	2	4		1	2				1				2													9	1	2	0
Cribrononion advenum (Cushman, 1922)	51	1	1	2			2		1	1		4						1	3			1	2				6	6	4	3
Cribrononion granosum (d'Orbigny, 1846)	52	7	7	11	13	12	9	8	1	1	9	5	6	18		4	1	10	12	9	7	8	2	11	8	6	59	30	45	45
Cribrononion lagunensis Albani e Serandrei Barbero, 1982	53			1																		1	1				1	0	0	2
Cribrononion simplex (Cushman, 1933)	54											1															0	1	0	0
Cribrononion translucens (Natland, 1938)	55			7		2		1						1			1										9	1	2	0
Cribrononion venetum Albani, Favero e Serandrei Barbero, 1991	56		1	1	3		1		2	1			2	1				1		1		1				1	6	5	2	2
Poroeponides lateralis (Terquem, 1878)	57					3			2	1	1	2		3								1			1		3	6	3	2
Cibicides lobatulus (Walker&Jacob, 1798)	58									1	1	2		3					1		1		1			3	0	4	4	2
Cibicides pachyderma (Rzehak, 1886)	59	5	8	8	21	10	1	4	3	3	6	5	3	28	1		2	4	3	4	5	5	5	12		7	53	24	38	31
Cibicidella variabilis (d'Orbigny, 1826)	60	2	3		4			1	2	1		1	1	1		8	1				1	2			1	1	9	6	10	4
Planorbulina mediterranensis d'Orbigny, 1826	61	4	32	10	42	14	1	13	9	8	5	5	10	106	4	26	21	6	10	12	21	26	46	33	9	12	103	50	173	147
Haynesina paucilocula (Cushman, 1944)	62		1		1						1			1								1					2	1	1	1
Nonion politum (d'Orbigny, 1826)	63		1	3	4		3			1				2		1		1					1		1	2	11	1	4	2
Nonionella opima Cushman, 1947	64			3										1													3	0	1	0
Textulariina		2	1	7	12	2	5	0	2	13	12	2	6	20	4	13	9	9	6	2	6	9	19	8	4	7	29	35	61	48
Miliolina		5	11	55	9	11	30	6	12	22	20	18	12	12	5	21	7	20	21	9	17	15	13	6	12	16	121	90	86	72
Rotaliina		50	136	100	164	117	95	75	56	66	75	67	58	225	17	58	45	62	82	66	71	83	80	98	54	78	662	397	489	452
individuals		57	148	162	185	130	130	81	70	101	107	87	76	257	26	92	61	91	109	77	94	107	112	112	70	101	812	522	636	572
taxa (total)		18	31	39	28	25	25	19	27	35	29	23	23	31	9	19	16	26	23	19	21	30	26	23	23	26	56	53	44	42

TABLE 3–Absolute abundances of living taxa (per 300 cm^3) from February 1991 to January 1995.

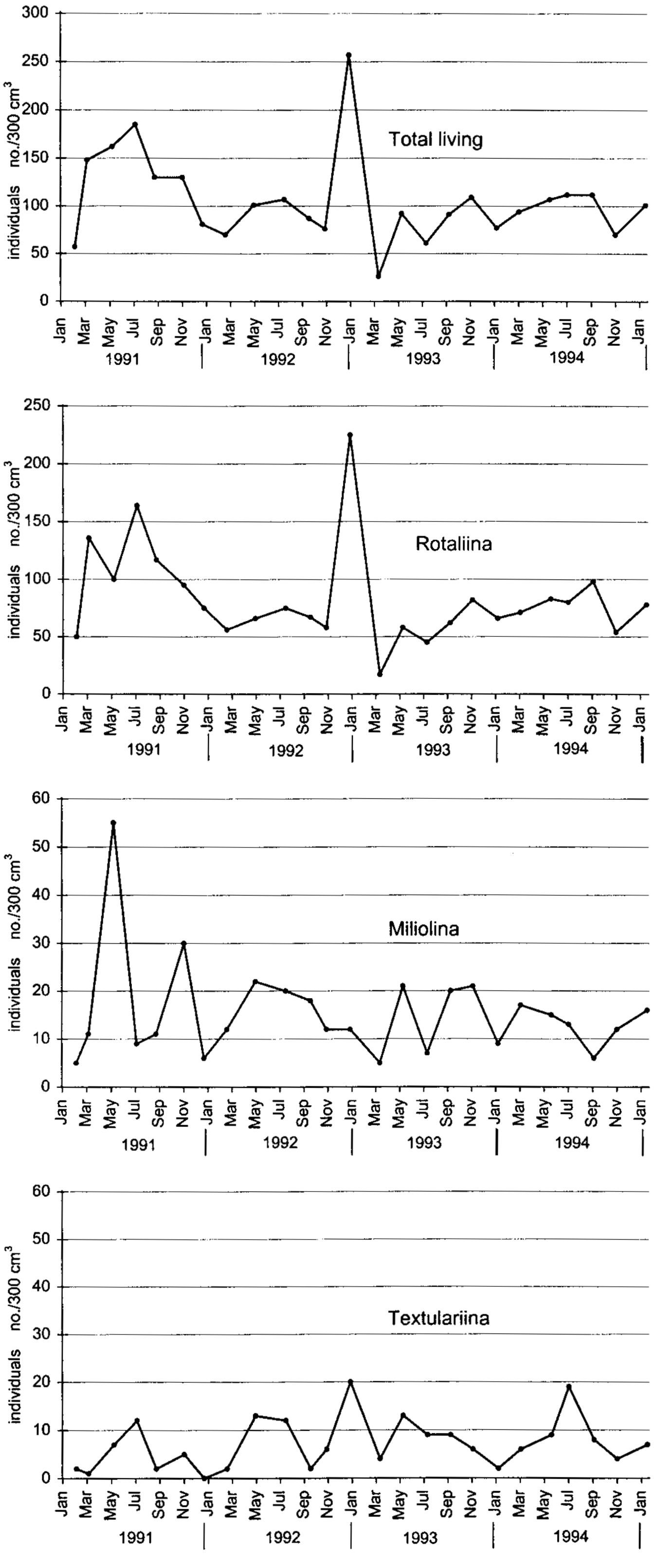

FIGURE 4–Absolute abundances of living foraminifera (no./300 cm^3) vs. time for each sampling interval.

Suborder Miliolina, which ranges from 5 to 34%, is generally the second most abundant group, with peaks in samples from May 1991, where it reaches 34%, and November 1991. Suborder Textulariina is the least abundant.

Of the 64 species recognized in the living foraminifera samples, *Quinqueloculina seminulum*, *Triloculina trigonula*, *Globulina gibba myristiformis* and *Planorbulina mediterranensis* occurred in all 25 samples. *Planorbulina mediterranensis* is the dominant species with a mean abundance of 16.8%. Figure 5 shows the temporal behavior of the 12 species with mean contents ≥ 3% found in at least 18 out of 25 samples; they show a notable variability in dimension and temporal distribution of productivity. In spite of this, the number of living individuals, always composed of a few hundred specimens, remains fairly constant in time showing a substantial stability of the standing stock (Table 3). No anomalies are present in the living assemblage of May 1992, sampled when there was the minimum content of dissolved oxygen.

The Shannon's index of species diversity, H, was calculated, as usual, on percentage composition by species. With our set of data $H_{min} = 0$ and $H_{max} = 4.16$. The H values computed for each sample, plotted vs.time in figure 6, range between 1.9 and 3.1: they do not show any significant variation or temporal tendency.

3. Dead assemblage and comparison with living assemblage

The dead assemblage is composed of 88 species, of which 8 belong to the suborder Textulariina, 25 to Miliolina and 55 to Rotaliina. The dead assemblage is much more abundant than the living assemblage in all samples. Mean relative abundances of the various taxa in dead and living assemblages are compared in Table 4 (see also Fig. 5 showing the data at each sampling interval). Although the living and dead assemblages generally have similar subdominant taxa, Rotaliina dominate in the living assemblage and Textulariina and Miliolina in the dead one, similarly to what had been observed in samples taken south of the oceanographic platform (Pranovi and Serandrei-Barbero, 1994). In particular, the enrichment of Textulariina in the dead assemblage excludes the presence of disaggregation of tests with organic cements. A marked difference between dead and living assemblages is typical of areas with low rate of sedimentation (Murray, 1976). Sedimentation in the study area is dominated by organic calcareous material with a sedimentation rate of less than 1 mm/100 yrs (Van Straaten, 1965). Moreover, occasional effect of strong storm waves on the bottom

(Stefanon, 1984) could induce differential transport of the foraminifera, with the partial removal of the lighter Rotaliina tests and the gradual enrichment in the dead assemblage of the heavier Textulariina and Miliolina; the traction velocity of *Textularia*, in fact, exceeds that of the majority of Rotaliina (Snyder *et al*., 1990). However, in spite of these possible effects, the dead assemblage at this site exhibits similar species richness to the northeast and south areas, that have 85 and 87 species, respectively (Pranovi and Serandrei-Barbero,

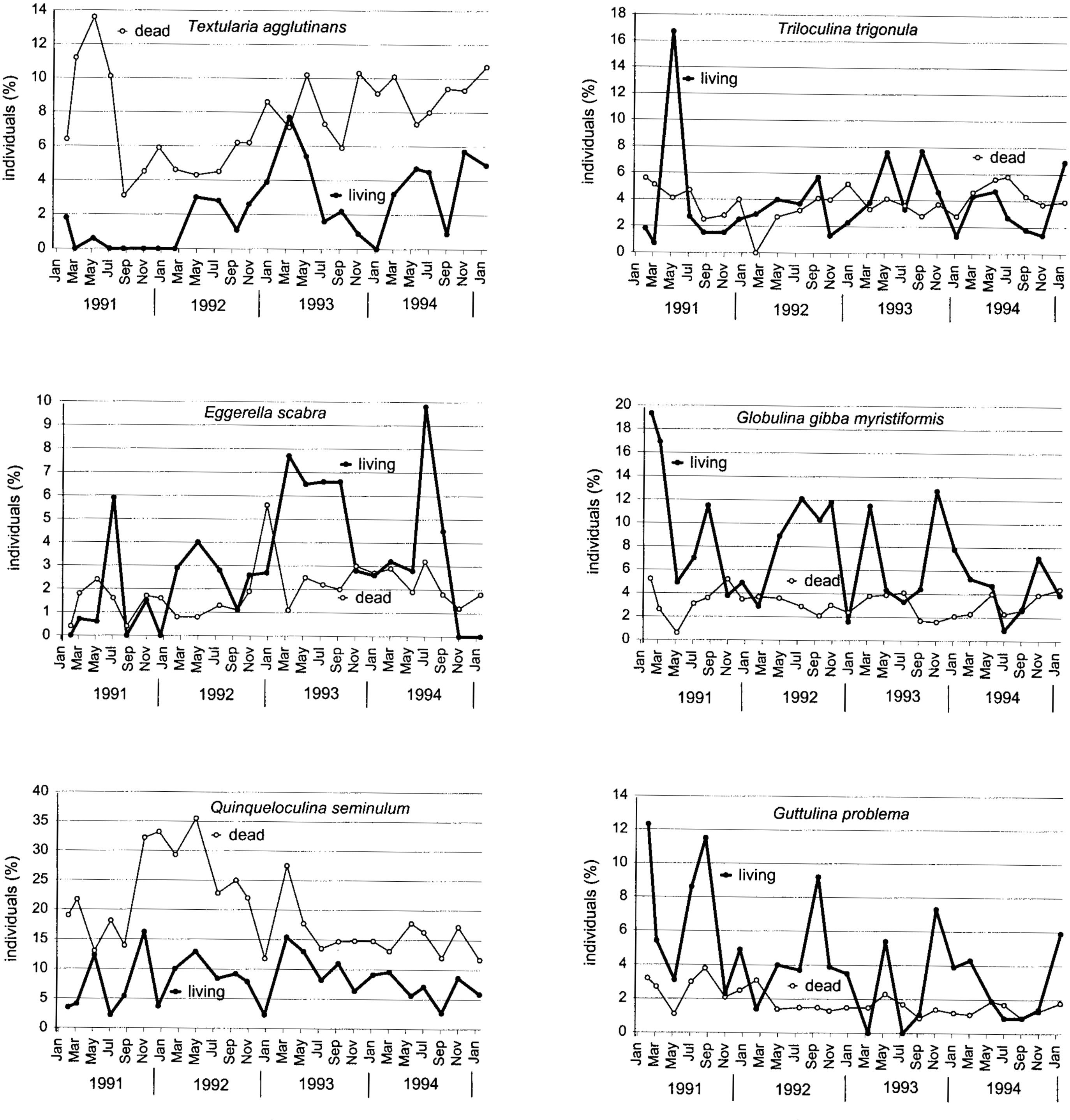

FIGURE 5–Relative abundance of living and dead populations with a relative mean abundance of at least 3%, vs. time.

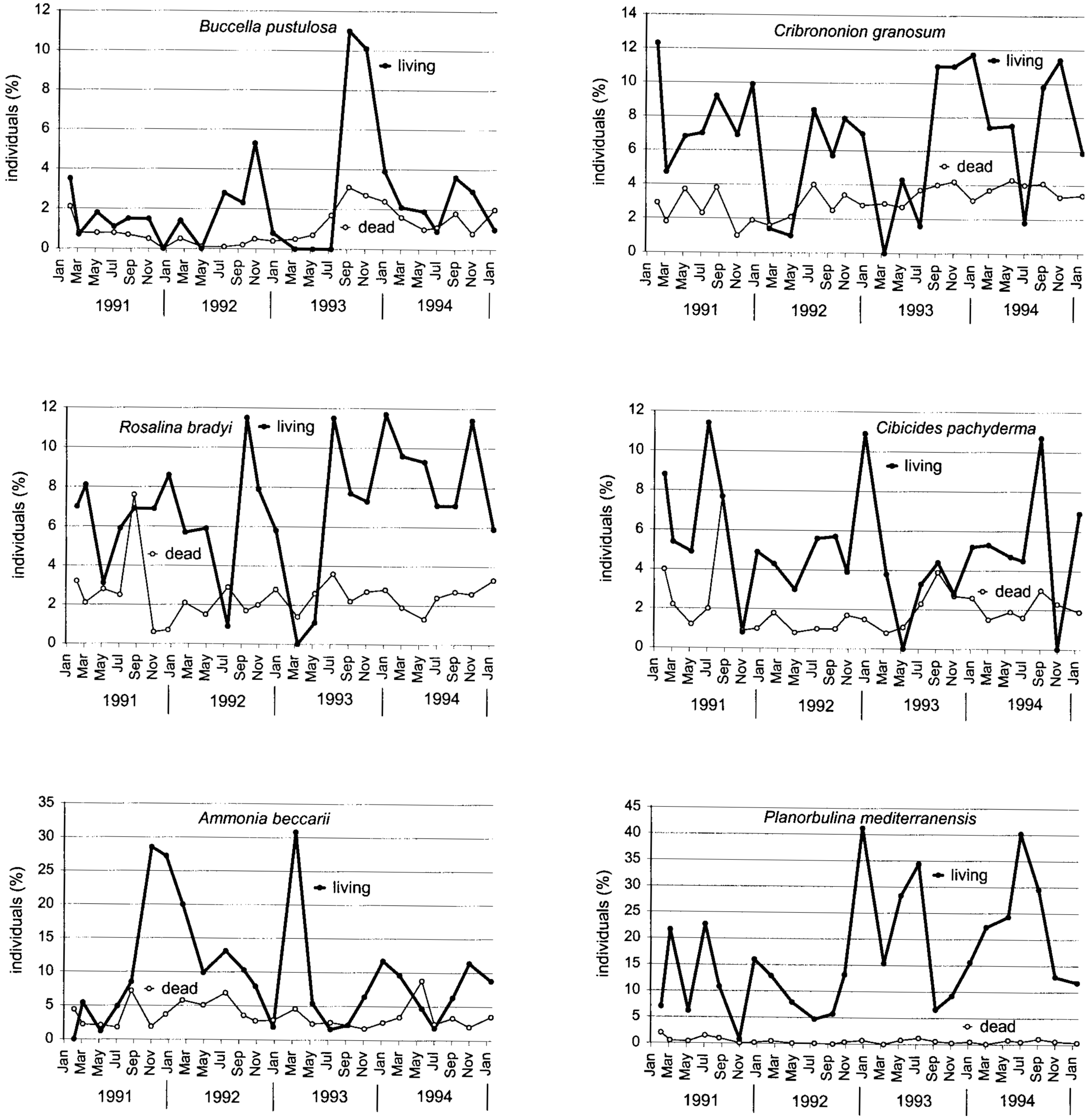

FIGURE 5 (cont.)–Relative abundance of living and dead populations with a relative mean abundance of at least 3%, vs. time.

1994; Albani *et al.*, 1998). The similarity of the foraminiferal faunas suggests similar ecological conditions (Odum, 1971).

As it appears in figure 5, abundances of dead foraminifera generally show less variation through the study interval than the live foraminifera and attenuate sharp short-term variations evident in the live assemblage. This makes the dead assemblage a useful indicator of general sea conditions in present day environments.

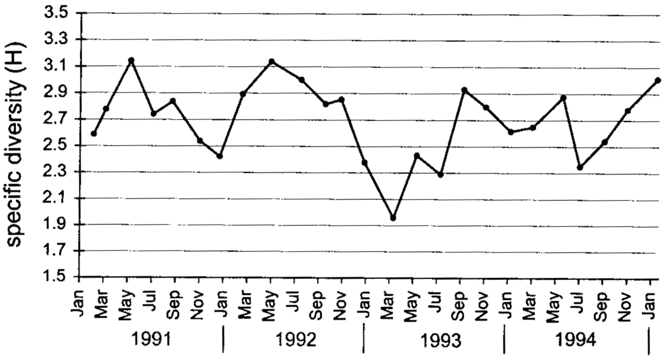

FIGURE 6–Degree of diversity of the living assemblage computed as the H index for each sampling interval.

STATISTICAL ANALYSIS OF DATA AND RESULTS

1. Correlation between living taxa and biochemical variables

To identify dynamic relationships between living taxa and biochemical variables, the Pearson linear correlation coefficient, r, was calculated; the significant values of r at the 5% error probability are reported in table 5. The biochemical variables TKN, N-NH4, N-NO3, N-NO2, total P, sulphates and iron, and pH, are correlated with one or, at most, two taxa. Significant correlations, positive or negative, with a large number of taxa are found for P-PO4, COD and BOD, chlorides, TOC, and suspended matter, which include phytoplankton contents. Metabolic activity involves a significant decrease in phosphorus, accompanied by an increase in dissolved oxygen; the greatly reduced phosphorus in the waters of the northern Adriatic is considered as a factor controlling algal growth (Degobbis, 1990).

2. Dependence of species abundances in the living assemblage from sampling time

To investigate the dependence of taxa to time, correspondence analysis (C. A.) was applied to our data set composed of 25 samples and 64 living species. C. A. clarifies interactions between samples and species projecting both on a Cartesian plane. This analysis supplies the relation of taxa to time because sampling was carried out in the same place. From the graph obtained by plotting the first two linear transformations (Fig. 7) four clusters based on sampling time were identified, grouping taxa that behave in a similar way.

taxa	% living	% dead
Saccamina difflugiformis (Brady, 1879)		0.1
Haplophragmoides canariensis (d'Orbigny, 1839)	1.3	0.2
Ammobaculites agglutinans (d'Orbigny, 1846)		0.2
Textularia agglutinans d'Orbigny, 1839	3.2	7.8
Textularia conica d'Orbigny, 1839	2.6	7.1
Gaudryina sp.		0.1
Trochammina inflata (Montagu, 1808)		0.1
Eggerella scabra (Williamson, 1858)	3.9	1.9
Spiroloculina antillarum d'Orbigny, 1839		0.2
Spiroloculina excavata d'Orbigny, 1846		0.4
Spiroloculina lucida Cushman & Todd, 1944		0.2
Spiroloculina soldanii Fornasini, 1886		0.2
Vertebralina striata d'Orbigny, 1826		0.1
Quinqueloculina agglutinata Cushman, 1917	2.7	13.9
Quinqueloculina anguina var.*arenata* Said, 1949		0.1
Quinqueloculina bicornis (Walker & Jacob, 1798)		0.2
Quinqueloculina candeiana d'Orbigny, 1839	2.5	0.2
Quinqueloculina costata d'Orbigny, 1826		0.2
Quinqueloculina cultrata (Brady, 1881)		0.3
Quinqueloculina elegans (Williamson, 1858)	1.2	4.8
Quinqueloculina ferussacii d'Orbigny, 1826	1.3	0.2
Quinqueloculina laevigata d'Orbigny, 1826		0.2
Quinqueloculina lamarckiana d'Orbigny, 1839	1.1	0.6
Quinqueloculina pseudoreticulata Parr, 1941		0.1
Quinqueloculina seminulum (Linnè, 1758)	8.0	19.5
Quinqueloculina squamosa (Terquem, 1878)	1.0	0.8
Quinqueloculina subpolygona Parr, 1945	1.4	3.1
Quinqueloculina undulata d'Orbigny, 1826		0.1
Massilina disciformis (Wiliiamson, 1858)		0.2
Sigmoilina grata (Terquem, 1878)	0.6	0.3
Triloculina trigonula (Lamarck, 1804)	3.9	4.0
Miliolinella suborbicularis (d'Obigny, 1826)	1.0	0.2
Miliolinella subrotunda (Montagu, 1803)	0.9	0.7
Nodosaria perversa Schwager, 1866	0.7	0.1
Lenticulina limbosa (Reuss, 1863)		0.1
Procerolagena clavata (d'Orbigny, 1846)		0.1
Procerolagena semistriata dorbignyi (Jones, 1984)		0.1
Lagena laevis (Montagu, 1803)	0.6	0.1
Lagena striata (d'Orbigny, 1839)	0.8	0.1
Lagena striata strumosa Reuss, 1858	2.0	0.1
Globulina gibba myristiformis (*W*illiamson, 1858)	7.4	3.1
Guttulina problema (d'Orbigny, 1826)	4.6	1.9
Fissurina laevigata Reuss, 1850	0.9	0.1
Fissurina lucida (Williamson, 1848)	0.6	0.1
Fissurina orbignyana caribaea (Cushman, 1923)	1.5	0.1
Bolivina pseudoplicata Heron -Allen & Earland, 1930	1.1	0.2
Brizalina spathulata (Williamson, 1858)	1.2	0.2
Brizalina striatula (Cushman, 1922)	1.4	0.1
Bulimina elongata d'Obigny, 1846	1.4	0.1
Bulimina gibba Fornasini, 1902	1.6	0.3
Bulimina marginata d'Orbigny, 1826	0.9	0.1
Reussella spinulosa (Reuss, 1850)	1.5	0.5
Trifarina angulosa (Williamson, 1858)	1.0	0.3
Discorbis mirus (Cushman, 1922)	1.8	1.1
Buccella frigida granulata (Di Napoli Alliata, 1952)	2.8	1.2
Buccella pustulosa Albani & Serandrei Barbero, 1982	3.0	1.1
Discorbinella bertheloti (d'Orbigny, 1839)	1.5	0.3
Helenina andersenii (Warren, 1957)		0.1
Neoconorbina terquemi (Rzehak, 1888)	2.5	1.7
Rosalina bradyi (Cushman, 1915)	7.2	2.5
Rosalina globularis d'Orbigny, 1826	1.8	1.1
Spirillina vivipara Ehremberg, 1843	1.0	0.1
Asterigerinerata mamilla (Williamson, 1858)	2.2	1.1
Ammonia beccarii (Linnè, 1758)	10.0	3.6
Valvulineria perlucida (Heron-Allen & Earland, 1913)	1.4	0.4
Elphidium complanatum (d'Orbigny, 1839)	1.3	0.4
Elphidium crispum (Linnè, 1758)	1.0	0.3
Elphidium depressulum Cushman, 1933	0.7	0.3
Elphidium macellum (Fichtel & Moll, 1798)	2.1	0.7
Elphidium macellum aculeatum (Silvestri, 1901)	1.6	0.3
Cellanthus discoidale multiloculum (Cushman & Ellisor, 1945)	1.7	0.6
Cribrononion advenum (Cushman, 1922)	1.7	2.8
Cribrononion granosum (d'Orbigny, 1846)	7.2	3.1
Cribrononion lagunensis Albani & Serandrei Barbero, 1982	0.8	0.2
Cribrononion simplex (Cushman, 1933)	1.1	0.5
Cribrononion translucens (Natland, 1938)	1.8	0.4
Cribrononion venetum Albani, Favero & Serandrei Barbero, 1991	1.2	0.9
Poroeponides lateralis (Terquem, 1878)	1.6	0.3
Cibicides lobatulus (Walker & Jacob, 1798)	1.4	0.7
Cibicides pachyderma (Rzehak, 1886)	5.6	2.1
Cibicidella variabilis (d'Orbigny, 1826)	2.1	0.5
Planorbulina mediterranensis d'Orbigny, 1826	16.8	0.6
Globocassidulina subglobosa (Brady, 1881)		0.1
Haynesina paucilocula (Cushman, 1944)	0.7	0.3
Nonion politum (d'Orbigny, 1826)	1.4	0.7
Nonionella auris (d'Orbigny, 1839)		0.2
Nonionella opima Cushman, 1947	1.1	0.2
Trichohyalus lacunae (Silvestri, 1950)		0.1

TABLE 4–Average abundances of living and dead taxa.

species and identification number		T.K.N.	N-NH4	N-NO3	N-NO2	P-PO4	Total P	COD	BOD	chlorides	sulphates	TOC	iron	pH	susp. matter
Haplophragmoides canariensis	1										0.54				
Textularia agglutinans	2					0.45						-0.47		0.55	
Quinqueloculina elegans	7														0.62
Quinqueloculina ferussacii	8									-0.49					
Quinqueloculina lamarckiana	9					0.55			0.45						
Quinqueloculina seminulum	10														0.43
Quinqueloculina squamosa	11														0.43
Sigmoilina grata	13							0.4							
Triloculina trigonula	14											-0.48			
Miliolinella subrotunda	16					0.43		0.45	0.43						
Nodosaria perversa	17									-0.71					
Lagena striata strumosa	20											0.44			
Globulina gibba myristiformis	21					-0.43			-0.42	-0.60					
Guttulina problema	22					-0.43		-0.42	-0.54						
Brizalina spathulata	27								0.55						
Bulimina elongata	29				0.61										
Reussella spinulosa	32											-0.45			
Trifarina angulosa	33							0.48							
Discorbis mirus	34			0.47											
Buccella frigida granulata	35								-0.42			0.58			0.75
Buccella pustulosa	36												0.59		
Discorbinella bertheloti	37								-0.47						
Rosalina globularis	40		0.68												
Ammonia beccarii	43														0.80
Elphidium macellum	48	-0.47													
Elphidium macellum aculeatum	49		0.84												
Cellanthus discoidale multiloculum	50							-0.40	-0.42	-0.55					
Cribrononion lagunensis	53					0.65	0.58	0.41							
Cribrononion translucens	55										0.42				
Cibicides lobatulus	58											-0.46			
Nonion politum	63														0,50

TABLE 5–Significant values of linear correlation coefficient r between water properties and taxa.

- Cluster I includes *Quinqueloculina agglutinata, Q. elegans, Q. ferussacii, Q. squamosa, Miliolinella suborbicularis, Brizalina striatula, Buccella frigida granulata, Ammonia beccarii, Valvulineria perlucida, Elphidium complanatum* and *Cribrononion simplex.* These species, which generally show autumnal productivity peaks, group close to the sample 6, collected in November.
- Cluster III groups the species *Textularia agglutinans, Eggerella scabra, Quinqueloculina lamarckiana, Neoconorbina terquemi, Elphidium depressulum, Cibicides pachyderma, Cibicidella variabililis* and *Haynesina paucilocula*. These species are almost infralittoral, and with peak abundances in late spring or summer (cf. Table 3); they cluster with samples 4, 15, 16, 21 and 23, collected between May and September;
- Cluster IV isolates *Planorbulina mediterranensis*, which dominates this area of the Adriatic Sea during its maximum peaks of January 1993 (sample 13) and of July 1994 (sample 22);
- Cluster II lies in the middle and groups taxa that are present in all the samples collected throughout the year.

Remaining species, which do not belong to the above clusters showing a behavior independent of the time of sampling, scatter in the upper-middle part of the graph.

Correspondence analysis makes evident some close similarities between species, identifies taxa that are dependent on the season of sampling, and separates those species with no distinct relationship to time of sampling.

3. Dependence of species abundances in the living assemblage on environmental biochemical parameters

To evaluate only the influence of water, eliminating the temporal aspect, a cluster analysis was carried out using the C-means algorithm. To perform this analysis, calculations were made weighting each biochemical variable with the abundance of each taxon characterizing each sample. So, a mean specific value relative to each examined species was obtained for each biochemical variable. Total iron and TOC were discarded because their determination was not made on all samples. Very rare taxa that occurred in only one sample (zero variance) were also excluded. General and specific weighted means so obtained

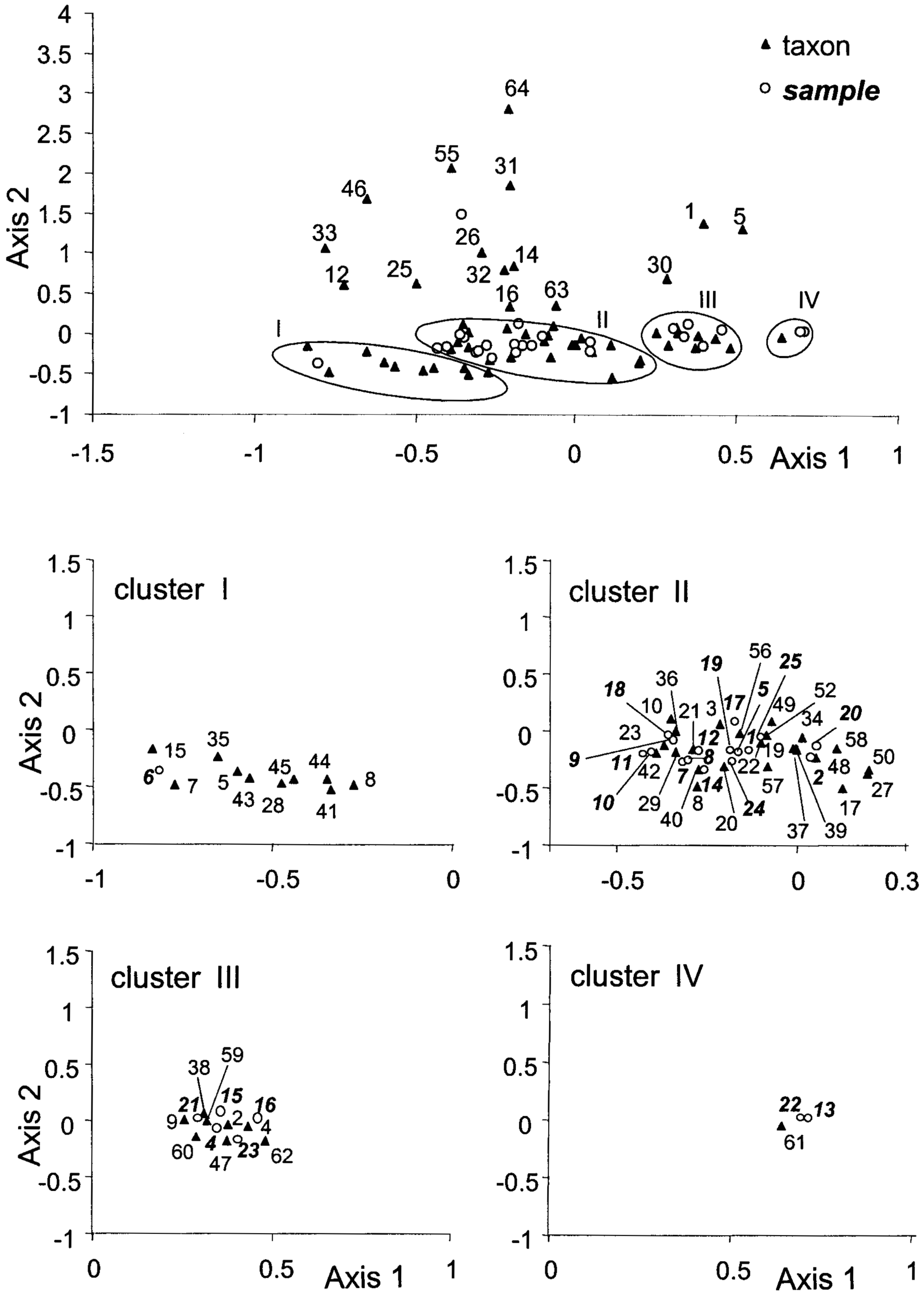

FIGURE 7–Graphical representation of the first two linear transformations of the Correspondence Analysis with the identified clusters. For taxa identification number see Table 3; the 25 samples are progressively ordered numerically from February 1991 to January 1995 (see Table 1).

were used for the C-means analysis. It emerged that in the formation of clusters only biotic variables with a significantly lower mean value than the general mean play an important role, while equal and/or higher mean values are not influential. Only suspended matter, BOD, P and N-NO_3 appear to be significant for grouping taxa. Rather than use a graphical representation, the resulting clusters are given in table 6, making them easier to read. All four significant biotic variables are responsible for grouping taxa in cluster A, while only N-NO_3 and suspended matter are relevant for taxa grouped in cluster B. It is worth observing that all taxa forming cluster A are those scattered in figure 7 since they are independent of the season of sampling. In particular, cluster A groups taxa such as *Bulimina marginata* and *Nonionella opima* (= *N. turgida* in Jorissen, 1987) which, according to Jorissen, tolerate stress well, having an opportunistic life strategy.

Clusters C and D are constituted by the remaining numerous taxa which, on the contrary, live in normal marine condition; in fact, all biochemical variables with their mean close to the general mean value induce cluster formation. This means that all taxa belonging to clusters C and D could be regarded as a unique group, if one considers only their living environment. In particular, cluster C is composed of time-independent taxa (shared in Fig. 7 by cluster II and a few taxa in the "scattered cluster") and Cluster D contains all dominant or subdominant species i.e., practically all those collected in an amount exceeding a mean content of 4.5%, which require normal marine conditions.

cluster	taxa
A	*Haplophragmoides canariensis, Brizalina striatula, Bulimina marginata, Trifarina angulosa, Elphidium crispum, Cribrononion lagunensis, Cribrononion translucens, Nonionella opima*
B	*Textularia agglutinans, Quinqueloculina ferussacii, Quinqueloculina lamarckiana, Cibicides lobatulus*
C	*Quinqueloculina subpolygona, Triloculina trigonula, Miliolinella subrotunda, Fissurina orbignyana caribaea, Bolivina pseudoplicata, Brizalina spathulata, Bulimina gibba, Reussella spinulosa, Rosalina globularis, Valvulineria perlucida, Elphidium macellum, Elphidium macellum aculeatum, Cribrononion advenum, Poroeponides lateralis*
D	*Textularia conica, Eggerella scabra, Quinqueloculina agglutinata, Quinqueloculina seminulum, Globulina gibba myristiformis Guttulina problema, Discorbis mirus, Buccella frigida granulata, Buccella pustulosa, Discorbinella bertheloti, Neoconorbina terquemi, Rosalina bradyi, Spirillina vivipara, Asterigerinerata mamilla, Ammonia beccarii, Elphidium complanatum, Cellanthus discoidale multiloculum, Cribrononion granosum, Cribrononion venetum, Cibicides pachyderma, Cibicidella variabilis, Planorbulina mediterranensis, Haynesina paucilocula*

TABLE 6–Results of C-means cluster analysis: taxa are clustered by biochemical water properties.

The results of these analyses indicate that suspended matter (including phytoplankton) and BOD, both of which are closely connected with algal blooms (Zammattio and Perissinotto, 1995), are the most significant for the benthic community. In fact only these parameters influence both optimal habitat for taxa, as indicated by the results of C-means analysis, and their degree of co-variability with biochemical variables, as expressed by correlation coefficients.

DISCUSSION

According to Odum (1971), more limiting factors cause a decrease in species diversity and an enhancement of the dominance. Slight variations in the values of the Shannon's index of species diversity, H, suggest a generally constant character for the limiting factors that apparently never become close to the threshold for tolerance for a given species.

The lack of a direct correlation between nutrients (nitrogen salts and phosphorus) and productivity in the various populations may be explained by the fact that foraminifera are not primary producers but consumers of primary production and, as such, use nutrients already synthesized by phytoplankton. From this point of view, dissolved oxygen and the presence of organic matter, indicated by Jorissen (1987) as controlling factors, influence the development of the algal blooms which constitute primary production, rather than directly influencing foraminiferal development and productivity. In particular, it has been demonstrated that, in oligotrophic conditions, microhabitat is controlled by the availability of food particles metabolized in sediments (Jorissen *et al*., 1995); and that the availability of oxygen and food are important factors influencing benthic foraminifera (Gooday 1994; Kaiho, 1994; Loubere, 1994; Schmiedl *et al.*, 1997; Smart and Gooday, 1997). It has been also demonstrated (Bernhard and Reimers, 1991) that some foraminifera can withstand very low oxygen content. However, the content of dissolved oxygen throughout the study period does not appear to be a limiting factor. In the study area the minimum oxygen value (0.90 ppm equal to ca 28 µMO$_2$ kg^{-1}) was recorded in May 1992, when the content of living foraminifera was similar to the other samples.

Instead the intermittent scarcity of phytoplankton seems to be a more significant limiting factor.

A phytoplankton sampling program was carried out in the entire coastal area of the Gulf of Venice, which includes our studied area, over a three year interval (February 1991-December 1993) overlapping the present study (Bernardi Aubry *et al.*, 1995). It shows the existence of phytoplankton on the bottom, similar to that in the upper region, with relevant peaks in April 1991 (October, November and December 1991 data were not recorded), in September and November 1992 and in May and July 1993, consistent with the maximum values of COD and BOD (Fig. 3) measured in this study. Diatoms are the dominant taxonomic group in the observed algal blooms, making up 59% of phytoplankton and with the largest number of species of any group. Dinoflagellates are also present and generally represent less than 10% of the specimens. The remainder is constituted by small quantities of coccolithiophoridae, silicoflagellates, and chlorophytes. The high degree of variation evident in the abundance of phytoplankton is due to the varying influence of a number of environmental factors in the northern Adriatic system, such as gusty winds, tidal amplitude, variations in river discharges, and grazing by zooplankton (Socal *et al.*, 1995).

Because they live in the photic zone, the foraminiferal taxa in this study are mainly herbivores. Food sources for herbivores include diatoms, small chlorophytes, and bacteria (Lee, 1980*)*; the abundance of diatoms noted in this part of the coastal Adriatic (Bernardi Aubry *et al.*, 1995) suggests the availability of a plentiful food source.

Landward of this site, in the Venice Lagoon, dominant and subdominant species show spring or summer peaks, following the phytoplankton blooms. This forces species less adapted to the lagoon environment to shift their productivity peaks to autumn (Donnici *et al.*, 1997). In particular, *Ammonia beccarii* (Fig. 8), which is a dominant species in the Venice Lagoon, shows post-bloom summer peaks and reaches lowest abundances in the winter. In contrast, at the site of our study in the Gulf of Venice, where *Planorbulina mediterranensis* is the dominant species, *Ammonia becarii* is most abundant in the winter and least abundant in the summer. This trend is generally opposite to that of *Planorbulina mediterranensis* which may indicate that *Ammonia beccarii* is an opportunist that succeeds when the dominant *Planorbulina mediterranensis* does not (Fig. 9).

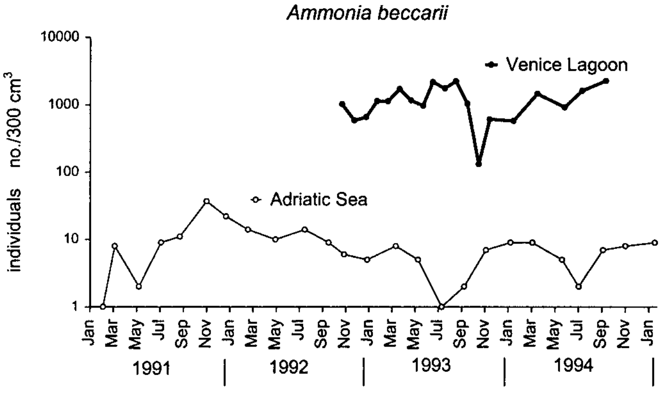

FIGURE 8–Comparison between the absolute abundance of *Ammonia beccarii* (Linné) in the lagoon of Venice (modified after Donnici *et al.,* 1997) and in the Adriatic sampling area (no./300 cm^3).

Even if the competition is minimized by resources portioning (Lee *et al.*, 1977), interspecific competition may also be present, related to symbionts. Murray (1991) has reported that both *Ammonia* and *Planorbulina* host diatoms as symbionts. The biological basis for the adaptation in diatom-bearing hosts is not yet fully understood. But it is known that the most efficient use of food resources, which are sometimes limited, is the re-use of the same resources by the host and its symbiont. Adriatic waters may have unpredictable and irregularly distributed supplies of phytoplankton. In such cases, photosynthesis in the symbionts can supply the host foraminifer with supplementary energy and a greater production of total

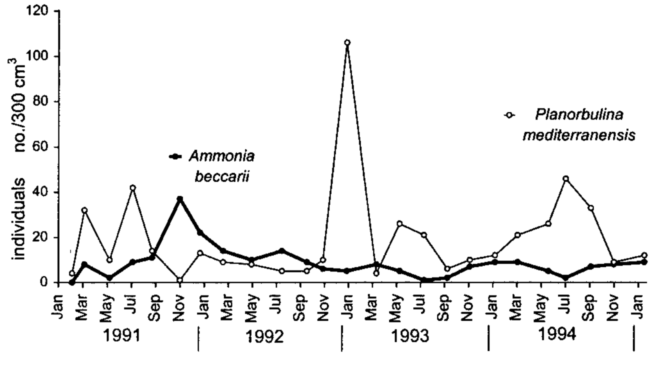

FIGURE 9–Absolute abundances of *Ammonia beccarii* (Linné) and *Planorbulina mediterranensis* d'Orbigny in the Adriatic sampling area (no./300 cm^3).

organic carbon (Hallock, 1988). This is consistent with the results of our study, which showed total organic carbon to be one of the biotic parameters well correlated with living taxa abundances.

CONCLUSIONS

This study on living benthic foraminifera of the Adriatic inner shelf allows the following conclusions to be drawn:

1. The prevailing homogeneity found in the 16-m water column at the oceanographic platform from February 1991 to January 1995 shows that the inner shelf is mainly influenced by run-off patterns. In this shallow-water environment, water properties do not vary seasonally because of the effect of transient forcing events and vertical mixing throughout the year.
2. The dynamics of shallow water living foraminiferal populations do not show outstanding seasonal variations, but a rather marked variability, with irregular fluctuations.
3. Correlation coefficients between taxa abundances and biochemical parameters provide significant results mainly for parameters linked to metabolic activity, such as orthophosphates, chemical and biological oxygen demand, total organic carbon, and suspended matter, including phytoplankton content.
4. Correspondence Analysis and C-means Cluster Analysis show the weak influence of season of sampling and the importance of a few biochemical parameters on living foraminiferal taxa. It happens because the dominant and subdominant species are not influenced by season; they live in “normal” marine conditions, i.e., in waters with environmental parameter values close to the mean general values.
5. Suspended matter, including diatoms, which are the preferred food for foraminifera in the photic zone, and BOD, closely related to productive processes, result to be the most important biochemical parameters. Only suspended matter and BOD, in fact, are connected with the foraminiferal community, considering both the water characteristics in which the various taxa live (C-means Cluster Analysis) and the variation of taxa abundances (correlation coefficients).
6. These results are consistent with those found for the adjacent lagoon of Venice, i.e., that phytoplankton is the main component forcing the productivity of foraminifera whose fluctuations are controlled by interspecific interactions, as shown by the opposite behaviors of *Ammonia beccarii*, dominant in the lagoon, and *Planorbulia mediterranensis*, dominant on the inner shelf.
7. Within this mechanism, both the short-term stability of the living assemblage and the long-term stability of the dead assemblage, are related to the lack of temporal tendency, as expressed by the species diversity index, indicating stable environmental conditions in the northwestern Adriatic continental shelf.

Benthic foraminifera in the photic zone are, therefore, not directly correlated with water quality but rather, by means of complex mechanisms of biotic interactions, with the availability of phytoplankton. As feeders on phytoplankton, these foraminifera can effectively be considered indicators of environmental quality, phytoplankton being linked to the presence of nutrients, conditions of transport, the pycnocline and density that is to those features generally directly correlated with benthic foraminifera.

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APPENDIX

Taxonomic notes

The Appendix refers only to taxa never found before in the northwestern Adriatic or to taxa whose concepts require some clarifications. The original reference and some of the subsequent ones are listed; especially included are the local references.

Saccammina difflugiformis (Brady, 1879)
(Plate 1, Figure 1)

Reophax difflugiformis, Brady, 1879, p. 51, Pl. 4, Figs. 3a,b.

Saccammina difflugiformis (Brady, 1879)-Daniels, 1970, p. 66, Fig. 40, Pl. 1, Fig. 2.

Saccammina difflugiformis (Brady)-Haake, 1977, p. 66, Pl. 2, Fig. 6.

Remarks.–*Saccammina* is a single chamber, while *Reophax* is multiple chambered. Moreover, in *Saccammina*, the agglutinated particles are smaller and very regular with respect to *Reophax*, and the length of the test is shorter.

In the eastern and southern Adriatic, where it has been reported by Daniels (1970) and Haake (1977), it is present at stations located in depths of over 16 meters.

Spiroloculina excavata d'Orbigny, 1846
(Plate 1, Figure 2)

Spiroloculina excavata-d'Orbigny, 1846, p. 271, Pl. 16, Figs. 19-21

Spiroloculina communis-Cushman and Todd, 1944, p. 63, Pl. 9, Figs. 4, 5, 7, 8.

Spiroloculina communis Cushman and Todd, 1944-Albani and Serandrei-Barbero, 1990, p. 294, Pl. 1, Fig. 11.

Remarks.–The species described by Cushman and Todd (1944) seems to have more acute edges than the *S. excavata*. But the concave central part with respect to its peripheral edges, common to both taxa and the presence of intermediate forms whose peripheral edges are more or less thorny and raised suggest to consider *Spiroloculina communis* Cushman and Todd, 1944 synonym of *Spiroloculina excavata* d'Orbigny, 1846.

Quinqueloculina undulata d'Orbigny, 1826
(Plate 1, Figure 3)

Quinqueloculina undulata-d'Orbigny, 1826, p. 302, nº 27.

Quinqueloculina undulata d'Orbigny-Daniels, 1970, p. 75, Pl. 3, Fig. 6.

Remarks.–The original figure by d'Orbigny given by Fornasini (1902, p. 27) shows a very faint keel.

In the past this form (cf. Fornasini, *op. cit.*) has been associated with *Q. bicornis*: but the latter is well-recognizable for its characteristic marked, double keel in its last formed chamber and it does not show an undulated test like in the species discussed here.

It is present in northeastern Adriatic at depths greater than 16 meters.

Miliolinella suborbicularis (d'Orbigny, 1826)
(Plate 1, Figure 4)

Triloculina suborbicularis-d'Orbigny, 1826, nº 12.

Triloculina suborbicularis d'Orbigny-Cushman, 1929, p. 65, Pl. 16, Fig. 5, Pl. 17, Fig. 3.

Remarks.–Our species differs from *Triloculina circularis* Bornemann, var. *sublineata* Brady because the latter has interrupted longitudinal striae (cf. Cushman 1917, p. 68, Pl. 26, Fig. 2). Individuals found in the Adriatic show both types illustrated by Cushman (1929) with the earliest chambers being smooth (Pl. 16, Fig. 5) and with the earliest chambers being costatae (Pl. 17, Fig. 3) like the last formed. Already found by Cushman in the Mediterranean, it is the first time that it has been noted in the Adriatic.

Bolivina pseudoplicata Heron-Allen and Earland, 1930
(Plate 1, Figure 5)

Bolivina pseudoplicata Heron-Allen and Earland, 1930, p. 81, Pl. 3, Figs. 36-40.

Bolivina pseudoplicata Heron-Allen and Earland, 1930-Daniels, 1970, p. 81, Pl. 5, Figs. 2a-c.

Bolivina pseudoplicata Heron-Allen and Earland, 1930-Murray, 1971, p. 107, Pl. 43, Figs. 1-7.

Remarks.–In the northeastern Adriatic it has been reported by Daniels (1970). It is the first time that it has been noted in the Gulf of Venice.

Bulimina elongata d'Orbigny, 1826
(Plate 1, Figure 6)

Bulimina elongata-d'Orbigny, 1826, vol. 7º, p. 269, unpublished drawing.

Bulimina elongata d'Orbigny - d'Orbigny, 1846, p. 187, Pl. XI, Figs. 19-20.

→

PLATE 1–*1, Saccammina difflugiformis* (Brady, 1879); side view, x 87 (slide T1-13). *2, Spiroloculina excavata* d'Orbigny, 1846; side view, x 87 (slide M2-8). *3, Quinqueloculina undulata* d'Orbigny, 1826; side view, x 70 (slide M3-13). *4, Miliolinella suborbicularis* (d'Orbigny, 1826); side view, x 87 (slide M3-12). *5, Bolivina pseudoplicata* Heron-Allen & Earland, 1930; side view , x 174 (slide R6-19). *6, Bulimina elongata* d'Orbigny, 1826; side view, x 98 (slide R3-18). *7, Discorbinella bertheloti* (d'Orbigny, 1839); a) spiral view, x 163; b)umbilical view, x 119 (slide R6-8). *8, Helenina anderseni* (Warren, 1957); a) spiral view, x 136; b) umbilical view, x 163 (slide R6-20).

PLATE 1


1


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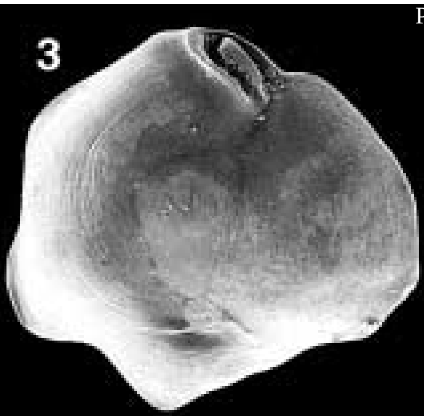
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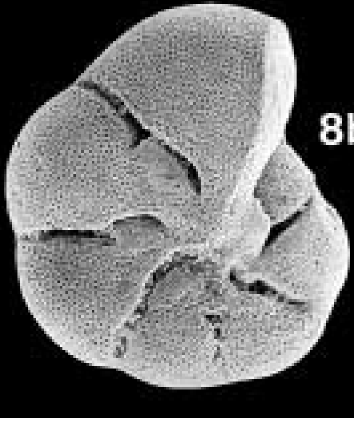

8b

Bulimina elongata d'Orbigny-Fornasini, 1901, p. 376, Pl. 0, Figs. 10, 20.

Bulimina gibba/elongata -Fornasini and d'Orbigny respectively- Murray, 1971, p. 117, Pl. 48, Figs. 1-8.

Remarks.–In the form illustrated by d'Orbigny (in Fornasini, 1901, p. 373), some chambers are more inflated with respect to our examples that are, perhaps, more similar to var. *ariminensis*, that is (d'Orbigny, 1826, 7, p. 269, Fig. 8) a form of *B. elongata* subcylindrical e sub-fusiform.

Murray (1971, p. 117) considers *B. gibba* Fornasini syn. *B. elongata* d'Orbigny and discusses them as extreme forms of a very variable group which is associated also with *B. elegans* d'Orbigny and *B. pupoides* Fornasini.

Also, Haake (1977, p. 66) groups the *Bulimine* found in the Adriatic generically under *Bulimina spp*., in which he describes individuals with more or less elongated, rounded or thorny chambers, and specifically refers to *B. gibba* Fornasini, 1901 and *B. aculeata* d'Orbigny, 1826.

Finally, examples given by Daniels (1970, p. 83, Pl. 5, Fig. 10) as *B. gibba* Fornasini are similar to our *B. elongata* d'Orbigny, while *B. aculeata* d'Orbigny (1826, p. 82, Pl. 5, Fig. 8) seems to be a thorny variety of *B. gibba*.

Therefore, we have rather dilated forms in the last formed chambers of the test and more or less subcylindrical, and both can show a greater or lesser degree of thorniness on the apical part giving a myriad of transition forms.

Discorbinella bertheloti (d'Orbigny, 1839)
(Plate 1, Figures. 7a, b)

Rosalina bertheloti-d'Orbigny, 1839, p. 135, Pl. 1, Figs. 28-30.

Cibicidina boueana (d'Orbigny)-Haake, 1977, p. 65, Pl. 2, Fig. 1.

Planulina sp.-Daniels, 1970, p. 89, Fig. 62; Pl. 8, Fig. 2.

Hanzawaia boneana (d'Orbigny)-Jorissen, 1987, Pl. 3, Fig. 10.

Remarks.–Sgarrella and Moncharmont Zei (1993) consider *D. bertheloti* synonymous with *Hanzawaia boueana* (d'Orbigny). According to these authors, it is a species infra-and circalittoral; it is common in the Adriatic beyond the 16-meter depth.

Helenina anderseni (Warren, 1957)
(Plate 1, Figs. 9a, b)

Pseudoeponides anderseni-Warren, 1957, p. 39, Pl. 4, Figs. 12-15.

Helenina andersoni (Warren)-Scott and Medioli, 1980, p. 40, Pl. 5, Figs. 10-11.

Ammonia beccarii (Linné) 1758-Cann and Gostin, 1985, p. 137, Figs. 10e-g.

Remarks.–In the Venice lagoon subsoil (Serandrei-Barbero *et al*., 1997) this species is found at a depth of –3,20 m.s.l. together with *Trochammina macrescens* in levels indicating ancient tidal marshes.

According to Scott and Medioli (1980) *H. anderseni* is estuarine; its presence in the Adriatic could be due to the presence of residual sands which contain forms typical of intertidal areas (Albani and Serandrei-Barbero, 1990).

In the species illustrated by Cann and Gostin (1985, p. 137, Figs. 10e-g) in coastal sedimentary facies characterized by fresh water influence and reported as *A. beccarii*, the characteristic sutural apertural slits of *H. anderseni* are well recognizable.

Rosalina globularis d'Orbigny, 1826
(Plate 2, Figures 1a, b)

Rosalina globularis-d'Orbigny, Ann. Sc. Nat., vol. 7, 1826, p. 271, Pl. 13, Figs. 1, 2.

Rosalina globularis d'Orbigny-Murray, 1971, p. 135, Pl. 56, Figs. 1-6.

Rosalina globularis d'Orbigny-Donnici, Serandrei-Barbero and Taroni, 1997, p. 450, Pl. 1, Figs. 7-11.

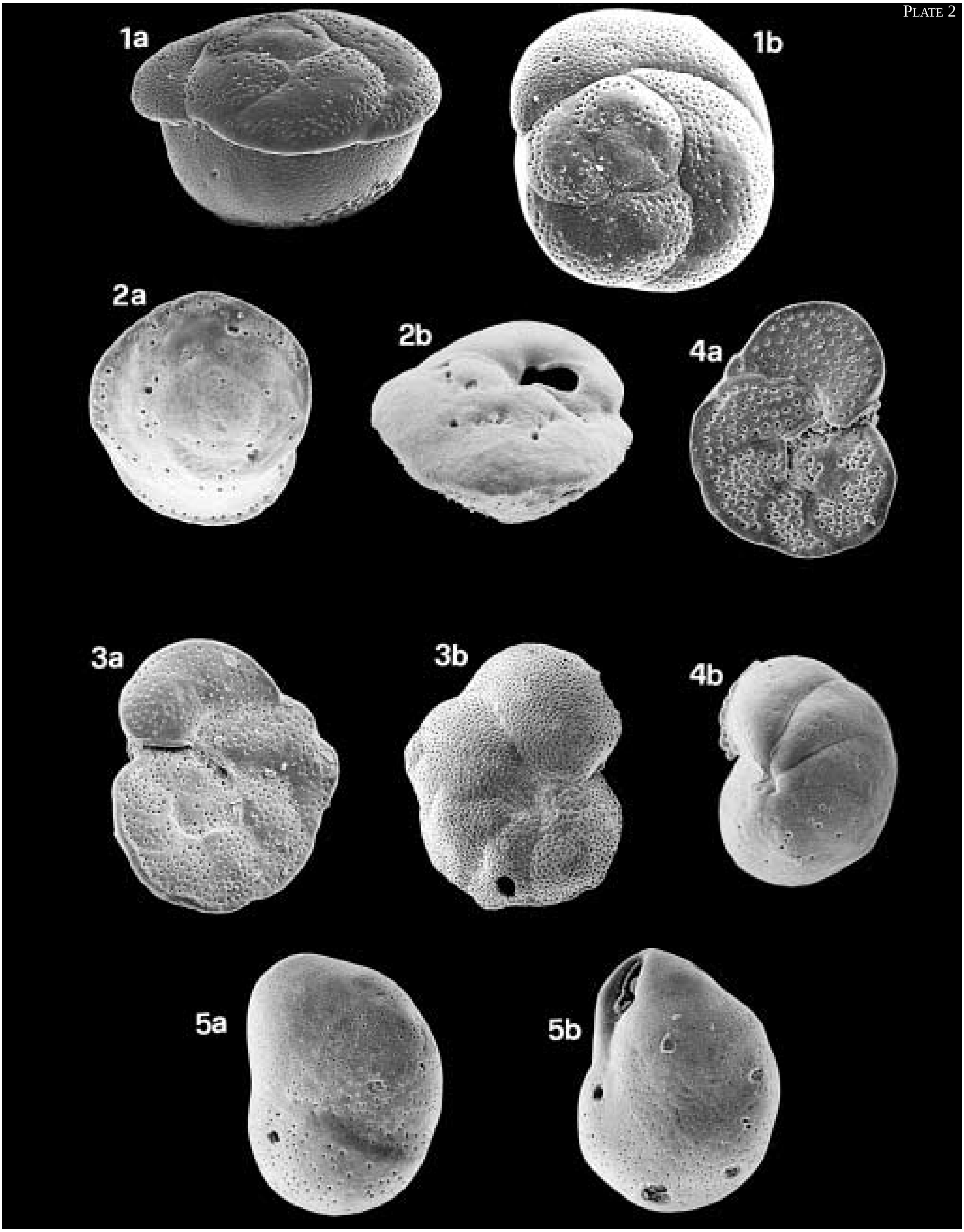
Remarks.–The Adriatic specimens are very similar to the form of d'Orbigny whose figure, modified, is given by Cushman (1915, p. 12), while they differ from those shown by Cushman (1915, Pl. 9, Fig. 4) because the latter have a peripheric keel.

The specimens described by Murray (1971, p. 135) show the umbilical side imperforate and besides they are much more compressed than ours and have an angular periphery rather than rounded. As stated by Cushman (1931, p. 22), instead, the perforation, even if even thinner should be present also on the ventral side. Some specimens have a float chamber (bulla) with several apertures bordered by a lip.

→

PLATE 2–*1, Rosalina globularis* d'Orbigny, 1826; a) side view of form with floating chamber, x 136; b) spiral view of form with floating chamber, x 136 (slide R4-17). *2, Asterigerinata mamilla* (Williamson, 1858); a) spiral view, x 190; b) side view, x 190 (slide R3-17). *3, Cibicides lobatulus* (Walker & Jacob, 1798); a) spiral view, x 89; b) umbilical view, x 62 (slide R5-11). *4, Cibicides pachyderma* (Rzehak, 1886); a) dorsal view, x 119; b) ventral view, x 119 (slide R5-5). *5, Globocassidulina subglobosa* (Brady, 1881); a), b) views of the opposite sides, x 174 (slide R4-20).

PLATE 2



Specimens with float chambers (bulla) are often referred to the species *Tretomphalus* sin. *Rosalina* (Loeblich and Tappan, 1964). This stage has been attributed by Scott et al. (1979) to *Planorbulina mediterranensis*; but in the Venice Lagoon (Donnici *et al.*, 1997) individuals with a float chamber have been found only during the reproductivity peaks of *Rosalina globularis*, in September and October, when they represent about 70% of this taxon. Like in the Adriatic also in the lagoon of Venice, this form has never been found in tanatocenosis, but only in biocenosis, thus confirming it to be a reproductive stage, burst when foraminifer floats out.

Asterigerinata mamilla (Williamson, 1858)
(Plate 2, Figure 2a, b.)

Rotalina mamilla-Williamson, 1858, p. 54, Pl. 4, Figs. 109-111.

Asterigerinata mamilla (Williamson, 1858)-Daniels, 1970, p. 86, Pl. 6 Fig. 11, Pl. 7 Fig. 1.

Asterigerinata mamilla (Williamson)-Murray, 1971, p. 141, Pl. 59, Figs. 1-6.

Remarks.–The dorsal side is similar to that of the species *Discorbis*, while the ventral side shows from 3 to 5 secondary chamberlets that are common to the Asterigerinidae: with respect to the chamberlets of the Asterigerina, those of the species under consideration are smaller and rounder (not forming a stellate pattern). The aperture is shorter and a narrow arch differing from *Discorbis* which also looks very similar in its general form.

Its distribution is given by Parker (1958, p. 264) as common to shallow water and it has already been reported in the Adriatic by Cita and Chierici (1962, p. 350), who note that the inferior chamber border is fringed.

Cibicides lobatulus (Walker and Jacob, 1798)
(Plate 2, Figures 3a, b)

Nautilus lobatulus-Walker and Jacob, 1798, p. 642, Pl. 14, Fig. 36.

Cibicides lobatulus (Walker and Jacob, 1798)-Daniels, 1970, p. 89, Pl. 8, Figs. 3a, b.

Cibicides lobatulus (Walker and Jacob)-Murray, 1971, p. 175, Pl. 73, Figs. 1-7.

Remarks.–This taxon is characterized by a pronounced morphological variation in the form with a spiral side more or less flat, a more or less angular keel, and a more or less inflated final chamber. Also Daniels (1970, p. 89) notes the large morphological variation of this species.

Distribution.–This inner shelf species (0-100 m) (Murray, 1971, p. 175) lives clinging to seaweed or to firm substrates. In the Adriatic, it was found by Haake (1977, p. 64) at the 50 m depth station, by Daniels (1970, p. 89) and by Iaccarino (1967, p. 23) beyond the 22 meter depth. Our specimens come from a depth of 16 meters.

Cibicides pachyderma (Rzehak, 1886)
Plate 2, Figure 4a, b.

Truncatulina pachyderma-Rzehak, 1886, p. 87, Pl. 1, Fig. 5.

Cibicides refulgens De Montfort, 1808-Albani and Serandrei-Barbero, 1990, p. 322, Pl. V, Figs. 10-11.

Distribution.–This species is rather common in the Adriatic where similar specimens with an imperforate calcite filling or boss in the umbilicus are given like *Cibicides pachydermus* (Rzehak, 1886) by Jorissen (1987, p. 47), and like *C. pseudoungerianus* Cushman (1931) by Cita e Chierici (1962, p. 349). Parker (1958, p. 274) reports the form *C.* aff. *floridanus* (Cushman) in the Mediterranean; but *C. floridanus* should have the sutures raised, *C. ungerianus* is from Miocene and is less umbonate, *C. pseudoungerianus* is from the Oligocene and should be less thick (Parker, 1958).

According to Barker (1960) and D'Onofrio (1959, p. 180) *C. pseudoungeriana* Cushman (1931) is synonymous with *C. pachyderma* (Rzehak, 1886) since they are referred to the same form *Truncatulina ungeriana* (Brady 1884, Pl. 94, Figs. 9a-c).

Globocassidulina subglobosa (Brady, 1881)
(Plate 2, Figure 5a, b)

Cassidulina subglobosa-Brady, 1881, 21, p. 60.

Globocassidulina subglobosa (Brady, 1881)-Daniels, 1970, p. 90, Pl. 8, Fig. 6.

Globocassidulina aff. *subglobosa* (Brady)-Murray, 1971, p. 191, Pl. 80, Figs. 1-4.

Remarks.–The longer individuals remind us of *G. oblonga* (Reuss, 1850), but we believe that it is *G. subglobosa* already noted by Daniels (1970) in the north-eastern Adriatic at depths greater than 50 m. According to Murray (1971), it is an outer shelf species.

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Portada: Colonias de *Botryococcus* (Chlorococcales), del Triásico de Argentina. Escala gráfica: 100 µm en las figuras 1, 6, 7, 12; 10 µm en las figuras 2, 4, 8, 9, 10, 11, y 1 µm en las figuras 3 y 5.

Cover: Botryococcus *colonies (Chlorococcales), from the Triassic of Argentina. Scale bar: 100 µm, figures 1, 6, 7, 12; 10 µm, figures 2, 4, 8, 9, 10, 11; 1 µm, figures 3, 5.*

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