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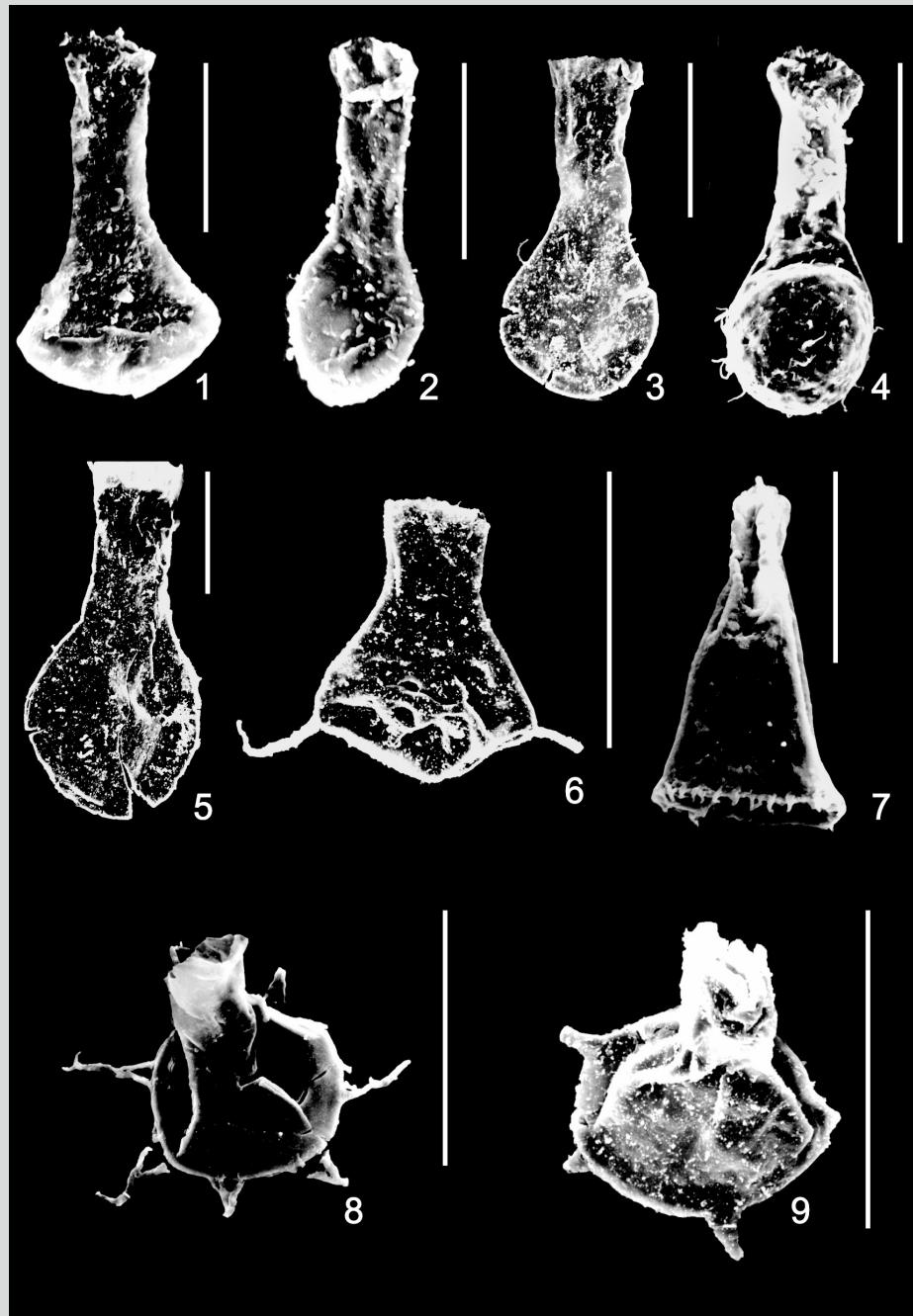
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INTEGRATED CHITINOZOAN AND MIOSPORE ZONATION OF THE SERRA GRANDE GROUP (SILURIAN-LOWER DEVONIAN), PARNAÍBA BASIN, NORTHEAST BRAZIL

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Abstract

Silurian and Early Devonian chitinozoans and miospores have been identified from samples of the Serra Grande Group, Parnaíba Basin, northeast Brazil. The chitinozoans indicate a Llandovery (late Aeronian-early Telychian) age for the uppermost Ipu, Tianguá and lowermost Jaicós formations. The upper part of the Jaicós Formation yielded chitinozoan species similar to those from the latest Pragian age strata in Bohemia. The miospore age determinations agree with those based on chitinozoans. The *Laevolancis divellomedia* Subzone is recognized from the Early Silurian interval, and the Su (*Dictyotriletes subgranifer*) Interval Zone (latest Pragian-earliest Emsian) in the uppermost Jaicós Formation. The overlying Itaim Formation is separated from the Serra Grande Group by a hiatus comprising a yet undetermined amount of Emsian time. Therefore the total age range of palyniferous parts of the Serra Grande Group is Early Silurian (Llandovery) through possibly earliest Emsian. Three chitinozoan species, *Angochitina gurupiense*, *Pogonochitina tianguaense* and *Sphaerochitina palestinaense*, are newly described. Two chitinozoan biozones are defined: the Interval Zone of *Pogonochitina tianguaense* n. sp. (late middle-early late Llandovery, equivalent to the upper part of the *L. divellomedia* Subzone) and the Assemblage Zone of *Ramochitina* sp. A and *Ramochitina* sp. B (latest Pragian or possibly earliest Emsian, equivalent to the older part of the Su Interval Zone).

Key words: Silurian, Lower Devonian, Chitinozoa, Miospores, Parnaíba Basin, Brazil.

Resumen

Se han identificado quitinizoos y miosporas del Silúrico y Devónico inferior del Grupo Serra Grande, Cuenca de Parnaíba, nordeste de Brasil. Los quitinizoos indican una edad Llandovery (Aeroniense tardío-Telychiense temprano) para la parte más alta de la Formación Ipu, la Formación Tianguá y la parte más baja de la Formación Jaicós. La parte alta de la Formación Jaicós contiene especies de quitinizoos similares a las de las capas de edad Pragiense terminal en Bohemia. Las determinaciones de edad con miosporas coinciden con las que se basan en quitinizoos. La Subzona de *Laevolancis divellomedia* se reconoce en el intervalo del Silúrico inferior, y la Zona de Intervalo de Su (*Dictyotriletes subgranifer*) (Pragiense terminal-Emsiense basal) en la parte más alta de la Formación Jaicós. La Formación Itaim suprayacente se separa del Grupo Serra Grande por un hiato de edad Emsiense y duración todavía no determinada. Por lo tanto, el rango total de edad de los intervalos con palinomorfos del Grupo Serra Grande es Silúrico temprano (Llandovery) hasta posiblemente Emsiense más temprano. Se describen por primera vez tres especies de quitinizoos: *Angochitina gurupiense*, *Pogonochitina tianguaense* y

Sphaerochitina palestinaense. Se definen dos biozonas de quitinozoos: la Zona de Intervalo de *Pogonochitina tianguaense* n.sp. (Llandovery medio tardío-tardío temprano, equivalente a la parte superior de la Subzona de *L. divellomedia*) y la Zona de Asociación de *Ramochitina* sp. A y *Ramochitina* sp. B (Praguiense más tardío o posiblemente Emsiense más temprano, equivalente a parte de la Zona de Intervalo de Su).

Palabras clave: Silúrico, Devónico inferior, Quitinozoos, Miosporas, Cuenca de Parnaíba, Brasil.

INTRODUCTION

Paleozoic sedimentation in the Parnaíba Basin began with deposition of the Serra Grande Group, a siliciclastic rock stratigraphic unit, which consists of the Ipu, Tianguá, and Jaicós formations (Caputo and Lima, 1984; Góes and Feijó, 1994). An unconformity supposedly separates the Serra Grande Group from the Canindé Group (late Emsian-Mississippian), which succeeds it. The term Serra Grande Series was introduced in the Brazilian geological literature by Small (1914). Ever since that time it was regarded as a formation until Carozzi *et al.* (1975) elevated it to Group rank, and included the Itaim Formation (nowadays the base of the Canindé Group) in its upper part. The total age span of the Itaim Formation, as indicated by miospores, is late Emsian to late Eifelian AP-AD (*Acinosporites apiculatus-Grandispora protea* and *Acinosporites acanthomammillatus-Densosporites devonicus*) zones after Melo and Loboziak, (2003), but no chitinozoans older than Eifelian are present in its upper part (Grahn *et al.*, 2001; Grahn and Melo, submitted). Chitinozoans and/or miospores from the Serra Grande Group were discussed earlier by Müller (1962), Daemon (1964), Quadros (1982), Grahn (1992), Quadros *et al.* (2000), Grahn and Steemans in Le Hérisse *et al.* (2001), and Grahn *et al.* (2001). The aim of the present study is to evaluate the stratigraphic value of chitinozoans and miospores in Silurian and Early Devonian beds of the Parnaíba Basin, and to define and document the age of the Serra Grande Group.

MATERIAL AND METHODS

The locations of wells investigated for this paper are shown on Figure 1. Altogether 85 rock samples have been obtained from the Ipu, Tianguá and Jaicós formations (Serra Grande Group) of the Parnaíba Basin. In

addition several slides with palynomorphs from the Tianguá and Jaicós formations were analyzed during 2000 and 2003. The residues were studied for chitinozoans using a stereoscopic binocular microscope, and representative chitinozoan specimens were picked for scanning electron microscope (SEM) illustration in cooperation with the Applied Biostratigraphy and Paleoecology Management (BPA) at PETROBRAS Research and Development Center (CENPES) in Rio de Janeiro. Sample processing and SEM-preparations were completed at the Geological Laboratory (LGPA) of the Geological Faculty at Universidade do Estado do Rio de Janeiro following the techniques described by Laufeld (1974). Photographed chitinozoans are stored at the Department of Stratigraphy and Paleontology at Universidade do Estado do Rio de Janeiro and the Institut de Géologie de Rennes (IGR), and the miospores at the Applied Biostratigraphy and Paleoecology Management of PETROBRAS Research and Development Center, Rio de Janeiro.

GEOLOGICAL SETTING AND CHITINOZOAN BIOSTRATIGRAPHY

The Serra Grande Group is distributed over an extensive part of the Parnaíba Basin, an intracratonic sedimentary basin that covers ca. 600,000 km² in northeast and north-central Brazil (Fig. 1). The basin is delimited by the Tocantins and Ferrer/Urbano Santos structural highs in the north, and by the São Francisco Structural High in the south. Erosional remnants of Silurian and Devonian rocks from a former westward extension of the Parnaíba Basin are present in the Marajó Basin, which is a down-faulted Cretaceous rift basin. The Early Silurian and Early Devonian rock units investigated are briefly described below. For additional details, see Caputo (1984), Grahn (1992), and Góes and Feijó (1994).

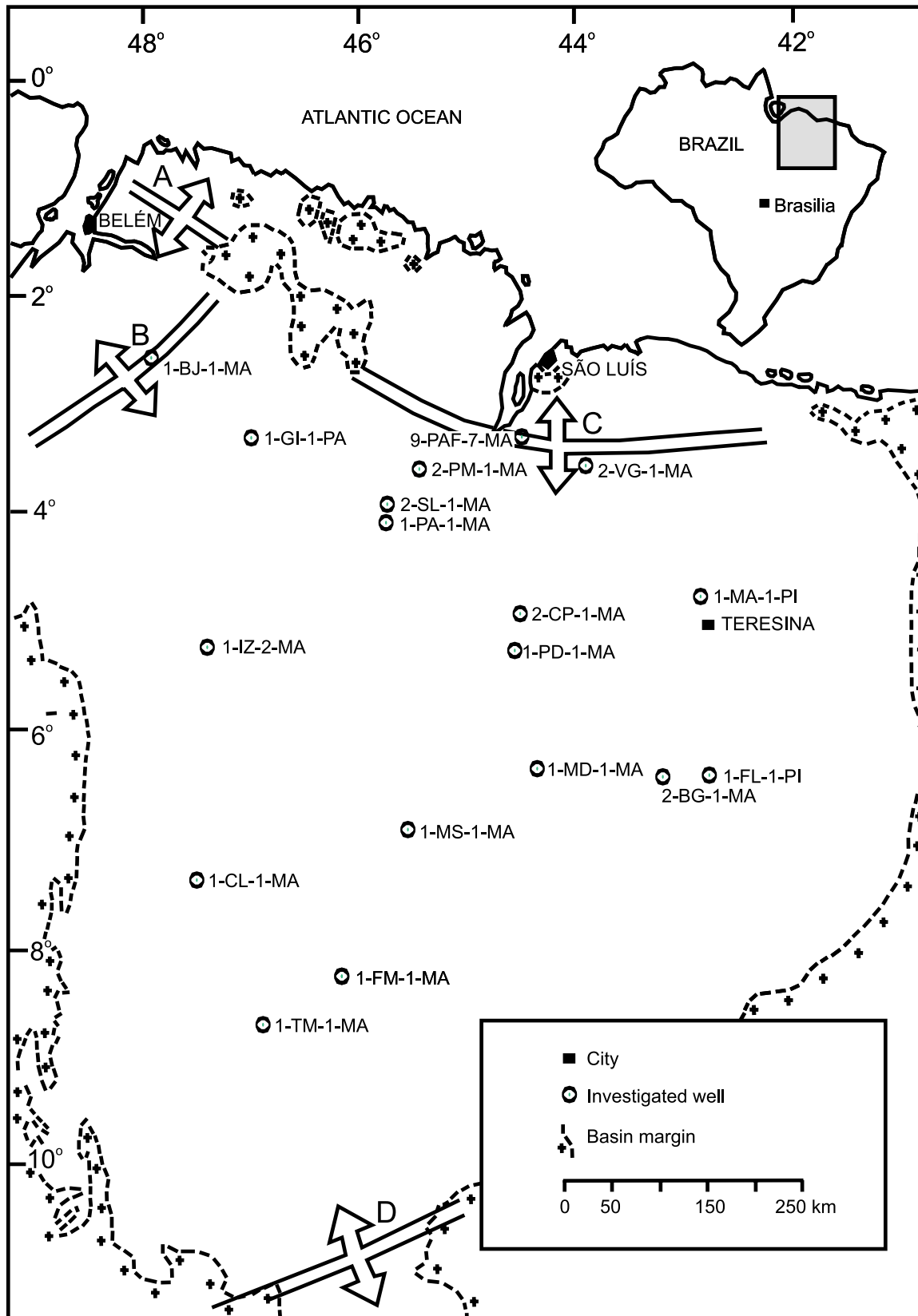


FIGURE 1—Location map of the Parnaíba Basin wells investigated in this study. Structural Highs: A – Guamá. B – Tocantins. C – Ferrer/Urbano Santos. D – São Francisco.

Ipu Formation

Campbell (1949) proposed the Ipu Member of the then defined Serra Grande Formation for the thick, basal sandstone section exposed along the Serra Grande escarpment. Caputo (1984) raised the Ipu Member to formation rank and defined it as the basal unit of the Serra Grande Group. Lithologically the Ipu Formation includes conglomerates and sandstones yielding glaciogenic beds in the upper part. These latter beds are currently correlated with Llandovery glacial strata already recorded in several parts of Western Gondwana (e. g., Pitinga, Vila Maria, Zapla, and Cancañiri formations) Grahn and Caputo (1992) and Grahn and Gutiérrez (2001). The uppermost part of the Ipu Formation is developed as an interbedded sandstone and shale facies laterally equivalent with the Tianguá Formation shales. The shaly intervals yield the following chitinozoan species: *Ancyrochitina erichseni* Sommer and van Boekel, 1963 (Plate 2, Fig. 7), *Cingulochitina bouniensis* Verniers, 1999 (Plate 1, Fig. 1), *Pogonochitina tianguaense* n. sp. (Plate 1, Figs. 7-8) and *Sphaerochitina palestinaense* n. sp. (Plate 1, Figs. 10-11). The chitinozoans indicate that the Ipu Formation is of the same age as that of the Tianguá Formation. Moore (1963) tentatively identified *Arthropycus* sp. in beds assigned by him to the Ipu Formation in the southwestern corner of the basin. Nowadays *Arthropycus* is no longer considered a reliable age indicator (although it was often used as a Lower Silurian index in the older paleontological literature). It is more significant paleoecologically, and Boucot *et al.* (1999) relates *Arthropycus* occurrences to Boucot's Benthic Assemblage 1, i. e., the shallowest water conditions adjacent to transitional or non-marine conditions in a marine basin. The Ipu Formation attains an estimated maximum thickness of about 300 m in the northeastern sector of the basin. Carozzi *et al.* (1975) used the name Mirador Formation instead of the Ipu Formation. However, the Mirador Formation, as originally defined by Rodrigues (1967), is now considered a distinct, much older unit of the pre-Silurian basement (Caputo, 1984).

Tianguá Formation

The Tianguá Member of the then Serra Grande Formation was proposed by Rodrigues (1967) for shales and sandstones that are best developed in the subsurface of the Parnaíba Basin. Carozzi *et al.* (1975) elevated the Tianguá Member to the rank of formation. The Tianguá Formation is subdivided into three informal members (Caputo and Lima, 1984).

The lower member includes carbonaceous mudstones with shale and siltstone intercalations. The middle member consists of sandstones, and the upper member of shales with siltstone intercalations. The unit's maximum thickness is estimated to be about 270 m in the subsurface of the northwestern sector of the basin. Müller (1962) considered the age of the Tianguá Formation as Early Devonian. Mesner and Wooldridge (1964) assigned a Late Silurian age to sections of the Serra Grande Group now considered to belong to the Tianguá Formation. According to Carozzi *et al.* (1975) the Tianguá palynomorphs resemble those in the Pitinga Formation (Amazonas Basin), which corresponds to interval III sensu Daemon and Contreiras (1971). The Silurian age was subsequently confirmed by Daemon (1976). Based on acritarchs, Brito (1979) also suggested a Silurian age, whereas Quadros (1982) supported a Lochkovian age. Grahn (1992) and Grahn *et al.* (2001) concluded that the Tianguá Formation was Llandovery in age, and this was also the opinion of Le Hérisse *et al.* (2001) based on microphytoplankton data. The chitinozoan species present in the Tianguá Formation are: *Cingulochitina bouniensis* Verniers, 1999, *Conochitina edjelensis* (Taugourdeau, 1963) (Plate 1, Fig. 3), *Conochitina elongata* (Taugourdeau, 1963) (Plate 1, Fig. 4), *Conochitina proboscifera* Eisenack, 1937 (Plate 1, Fig. 5), *Conochitina* aff. *C. acuminata* Eisenack, 1959 (Plate 1, Fig. 6), *Pogonochitina tianguaense* n.sp. (Plate 1, Fig. 2), *Sphaerochitina solutidina* Paris, 1988 (Plate 1, Fig. 9), *Sphaerochitina palestinaense* n. sp. (Plate 1, Figs. 10-11), *Lagenochitina* n. sp. aff. *L. navicula* (Taugourdeau and Jekhowsky, 1960) (Plate 1, Fig. 12), *Fungochitina* sp. A (Plate 2, Fig. 1), *Angochitina longicollis* Eisenack, 1959 (Plate 2, Fig. 2), *Angochitina gurupiense* n. sp. (Plate 2, Figs. 3-4), *Angochitina* sp. A. (Plate 2, Fig. 5), *Ancyrochitina ancyrea* (Eisenack, 1931) (Plate 2, Fig. 6), and *Ancyrochitina* sp. (Plate 2, Figs. 8-9). Chitinozoan occurrences in each well are listed in Tables 1-4. The cryptospores and miospores from the Tianguá Formation were described by Steemans (in Le Hérisse *et al.*, 2001). In addition to the palynomorphs, graptolites (*Climacograptus* cf. *scalaris scalaris*) and ichnofossils are also known in the Tianguá Formation (see Grahn, 1992 and Le Hérisse *et al.*, 2001).

Jaicós Formation

The "Jaicós" Formation was originally proposed by Plummer (1948) for sandstone beds exposed along the

WELL	FORMATION	SAMPLE	DEPTH (in meters)	Barren of chitinozoans	Ancyrochitina spp.	Angochitina spp.	Cingulochitina bouinensis	Pogonochitina tianguaense n.sp.	Angochitina gurupiense n.sp.	Conochitina elongata	Fungochitina sp.A	Conochitina aff. C. acuminata	Sphaerochitina palestinaense n.sp.	Angochitina longicollis	Lagenochitina n.sp. aff. L. navicula	Conochitina proboscifera	Sphaerochitina solutidina	Ancyrochitina erichseni	Ancyrochitina ancyrea	Ancyrochitina sp.	Angochitina sp.A	Conochitina edjelensis	Ramochitina sp.A	Ramochitina sp.B		
2-BG-1-MA	Jaicós	Core 35 cuttings	1719.3-1720.5 1812	X X																						
1-BJ-1-PA	Jaicós Tianguá	Core 49 cuttings	1689.9-1692.2 1743				X	X																		
		Core 51 cuttings	1804.4-1805.9	X																						
		Core 52 cuttings	1832.1-1835.2 1837					X	X	X																
		cuttings	1859	X							X															
		cuttings	1866					X					X													
		cuttings	1886					X			X		X													
		cuttings	1909					X					X	X												
		cuttings	1915		X			X			X		X	X	X											
		cuttings	1941								X		X	X	X	X										
		cuttings	1990								X		X	X		X		X								
		cuttings	2124									X	X	X				X								
		1-CL-1-MA	Tianguá	Core 40 Core 41	1097.5-1103.6 1142.4-1148.5	X X																				
		2-CP-1-MA	Jaicós	cuttings	2628	X																				
cuttings	2634			X																						
cuttings	2721			X																						
cuttings	2745			X																						
cuttings	2763			X																						
cuttings	2775			X	X																					
cuttings	2793			X																						
cuttings	2817			X																						
cuttings	2823			X																						
cuttings	2833			X																						

TABLE 1—Chitinozoan distribution in the well samples investigated.

Serra Grande escarpments. Although the term Serra Grande (Small, 1914) has priority over Jaicós, Rodrigues (1967) revalidated the name Jaicós as a member of the Serra Grande Formation. Subsequently Carozzi *et al.*

(1975) reinstated the Jaicós at formation rank. The maximum thickness of the Jaicós Formation is about 500 m. The lower part of the formation is developed as a sandy facies laterally equivalent to the Tianguá shales, and it

contains an impoverished assemblage of chitinozoans and miospores that is representative of the Tianguá Formation. The chitinozoan species recorded in the lower Jaicós Formation include: *Cingulochitina bouiniensis*, *Pogonochitina tianguaense* n. sp., *Sphaerochitina pales-*

tinaense n. sp., *Lagenochitina* n. sp. aff. *L. navicula*, *Ancyrochitina* spp., and *Angochitina* sp. A.

The age of the upper part of the Jaicós Formation, briefly discussed as possibly Pragian in Grahn *et al.* (2001), is definitively established in the present study

WELL	FORMATION	SAMPLE	DEPTH (in meters)	Barren of chitinozoans	<i>Ancyrochitina</i> spp.	<i>Angochitina</i> spp.	<i>Cingulochitina bouiniensis</i>	<i>Pogonochitina tianguaense</i> n.sp.	<i>Angochitina gुरुpiense</i> n.sp.	<i>Conochitina elongata</i>	<i>Fungochitina</i> sp.A	<i>Conochitina</i> aff. <i>C. acuminata</i>	<i>Sphaerochitina palestinaense</i> n.sp	<i>Angochitina longicollis</i>	<i>Lagenochitina</i> n.sp. aff. <i>L. navicula</i>	<i>Conochitina proboscifera</i>	<i>Sphaerochitina solitudina</i>	<i>Ancyrochitina erichseni</i>	<i>Ancyrochitina ancyrea</i>	<i>Ancyrochitina</i> sp.	<i>Angochitina</i> sp.A	<i>Conochitina edjelensis</i>	<i>Ramochitina</i> sp.A	<i>Ramochitina</i> sp.B	
2-CP-1-MA	Tianguá Ipu	cuttings	2859	X																					
		cuttings	2865	X																					
		cuttings	3087																X						
		cuttings	3090		X																				
		cuttings	3096		X																				
		cuttings	3099		X																				
		cuttings	3150		X																				
1-FL-1-PI	Tianguá	cuttings	2250	X																					
1-FM-1-MA	Jaicós	cuttings	1551	X																					
		cuttings	1560	X																					
	Tianguá	cuttings	1650	X																					
		cuttings	1719									X	X												
1-GI-1-PA	Tianguá	cuttings	2175	X																					
		cuttings	2181	X																					
		Core 3	2257.0-2266.0					X	X	X						X				X	X	X	X	X	X
		cuttings	2313		X									X									X		
1-IZ-2-MA	Jaicós	cuttings	2202	X																					
		cuttings	2253	X																					
		cuttings	2262	X																					
1-MA-1-PI	Tianguá	Core 104	1386.1-1341.6	X																					
		Core 113	1862.3-1864.7					X																	
		cuttings	1837			X																			
1-MD-1-MA	Tianguá	Core 41	2674.1-2676.1		X																				
1-MS-1-MA	Tianguá	Core 25	2285.2-2287.7				X																		

TABLE 2—Chitinozoan distribution in the well samples investigated.

as latest Pragian-earliest Emsian. Two chitinozoan species, *Ramochitina* sp. A (Plate 3, Fig. 1) and *Ramochitina* sp. B (Plate 3, Fig. 2), occur in the uppermost part of the formation. The same species are probably also present in the upper Pragian of Bohemia (Florentin Paris, personal communication 2002, 2003). The miospore study herein confirms for the first time the presence of the Su (*Dictyotriletes subgranifer*) Interval Zone (latest Pragian-earliest Emsian) in the uppermost Jaicós Formation.

SYSTEMATIC PALEONTOLOGY

Twenty chitinozoan species were identified in the present study. Those left in open nomenclature and the new species are commented upon below. Most of the specimens recovered are compressed, and a correction factor of 0.8 (Paris, 1981; Jaglin, 1986) was used to calculate their uncompressed dimensions (values given within brackets). The taxonomy follows that proposed by Paris *et al.* (1999).

Group CHITINOZOA Eisenack, 1931
Order PROSOMATIFERA Eisenack, 1972
Family CONOCHITINIDAE Paris, 1981
Subfamily CONOCHITININAE Paris, 1981
Genus *Conochitina* Eisenack, 1931 emend. Paris,
Grah, Nestor and Lakova, 1999
Conochitina aff. *C. acuminata* Eisenack, 1959
Plate 1, Fig. 6

Description.—For descriptions of *Conochitina acuminata* see Eisenack (1959) and Laufeld (1974). *C.* aff. *C. acuminata* differs in its insignificant flexure, more slender vesicle, rounded margins, and much smaller mucron.

Dimensions (6 specimens measured).—Total length 145-214 μm ; maximum width 70 (56)-90 (72) μm ; apertural width: 50 (40)-61 (49) μm ; length of mucron: < 6 μm ; neck ca. 1/3 total length.

Occurrence.—Tianguá Formation (see Tables 1-2).

Subfamily POGONCHITININAE Paris, Grah,
Nestor and Lakova, 1999
Genus *Pogonochitina* Taugourdeau, 1963
Pogonochitina tianguaense n. sp.
Plate 1, Figs. 7-8.

Derivation of name.—Latin, *tianguaense*, referring to the Tianguá Formation, from which the species is described.

Diagnosis.—A *Pogonochitina* species with a conical to subcylindrical body and a short cylindrical neck. The vesicle is ornamented by tubercles, and a crown of simple appendices at the margin. The base is rounded with an apical pit. *P. djalmi* is similar but differs in having long simple spines at the aperture, a feature not observed in *P. tianguaense*.

Holotype.—Plate 1, Fig. 7. IGR 54536 (O37/4).

Type locality.—Well 1-GI-1-PA, core 3 (2.257-2.266 m).

Description.—This *Pogonochitina* species is characterized by its conical to almost cylindrical vesicle, short cylindrical neck with denticulated aperture, and a crown of simple short appendices. The flexure is insignificant. The vesicle is covered by tubercles. The rounded base, that extends anteaperturally of the margin, is also characteristic. The base has an apical pit.

Dimensions (20 specimens measured).—Total length: 190-585 μm . Most specimens are 193-296 μm , holotype: 268 μm ; maximum width: 62 (50)-136 (104) μm , holotype: 96 (77) μm ; apertural width: 37 (30)-91 (73) μm , holotype: 68 (54) μm ; length of spines \leq 3 μm , holotype: 3 μm ; neck 1/4-1/2 total length. Holotype neck 2/5 of total length.

Occurrence.—Parnaíba Basin. Upper Ipu, Tianguá and lower Jaicós formations (see Tables 1-4). *P. tianguaense* n. sp. is also known from the lower Pitinga Formation in the Amazonas Basin (Grah, unpublished data).

Family LAGENOCHITINIDAE Eisenack, 1931 emended
Paris, 1981
Subfamily LAGENOCHITININAE Paris, 1981
Genus *Sphaerochitina* Eisenack, 1955 emended Paris,
Grah, Nestor and Lakova, 1999
Sphaerochitina palestinaense n. sp.
Plate 1, Figs. 10-11

1985 *Sphaerochitina* sp. B – Paris (in Hill *et al.*, 1985), Pl. 14, Figs., 11 a-b.

2000 *Sphaerochitina* sp. B – Grah (in Grah *et al.*, 2000), Pl. 3, Fig. 10.

2001 *Sphaerochitina* sp. B – Grah (in Le Hérisse *et al.*, 2001), Pl. 3, Fig. 9.

Derivation of name.—Latin, *palestinaense*, referring to the well Palestina n.° 1 (1-PA-1-MA), from which the holotype is described.

Diagnosis.—A *Sphaerochitina* species with a spherical to ovoid body and a long cylindrical neck widening into a collarete. The vesicle is provided with tubercles.

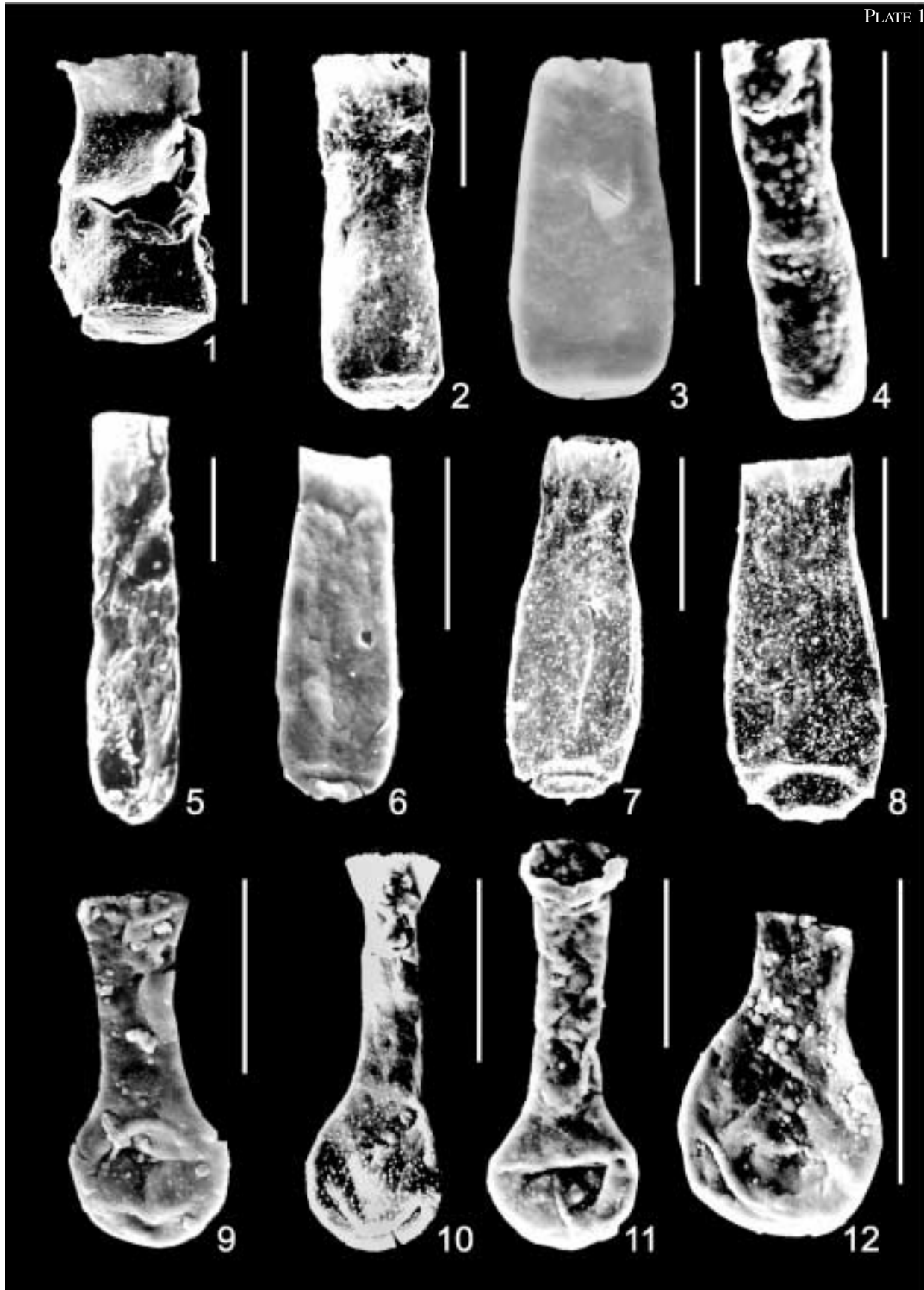
WELL	FORMATION	SAMPLE	DEPTH (in meters)	Barren of chitinozoans	Ancyrochitina spp.	Angochitina spp.	Cingulochitina bouinensis	Pogonochitina tianguaense n.sp.	Angochitina gurupiense n.sp.	Conochitina elongata	Fungochitina sp.A	Conochitina aff. C. acuminata	Sphaerochitina palestinaense n.sp.	Angochitina longicollis	Lagenochitina n.sp. aff. L. navicula	Conochitina proboscifera	Sphaerochitina solitudina	Ancyrochitina erichseni	Ancyrochitina ancyrea	Ancyrochitina sp.	Angochitina sp.A	Conochitina edjelensis	Ramochitina sp.A	Ramochitina sp.B		
1-PA-1-MA	Jaicós	cuttings	2538																							
		cuttings	2574	X									X													
	Tianguá Ipu	cuttings	2583	X																						
		cuttings	2727			X							X													
		cuttings	2841		X				X																	
9-PAF-7-MA	Tianguá	cuttings	1202																							
		cuttings	1212		X								X													
		cuttings	1215	X																						
		cuttings	1278						X					X												
		cuttings	1284					X						X												
		cuttings	1293										X													
		cuttings	1322										X													
1-PD-1-MA	Jaicós	cuttings	2604					X																		
		cuttings	2691					X																		
	Tianguá	Core 37	2768.5-2769.1					X	X				X		X								X			
cuttings		2808	X																							
2-PM-1-MA	Tianguá	Core 53	1985.8-1987.6				X						X													
		Core 54	2033.5-2034.5																			X				
2-SL-1-MA	Jaicós	Core 68	2136.0-2136.5	X																						
		Core 69	2191.3-2193.3	X																						
		Core 70	2243.3-2244.8	X																						
		Core 71	2244.8-2245.3	X																						
		Core 72	2245.4-2248.0	X																						
		Core 73	2248.0-2249.3	X																						
		Core 74	2290.5-2296.1	X																						
		Core 75	2353.0-2354.1	X																						

TABLE 3—Chitinozoan distribution in the well samples investigated.

→

PLATE 1—Llandovery chitinozoans from the Serra Grande Group. The scale bars represent 100 μm . 1, *Cingulochitina bouinensis* Verniers, 1999. Lower Jaicós Formation, well 1-BJ-1-PA, core 49 (1689.90-1692.20 m). 2, *Pogonochitina tianguaense* n. sp. Tianguá Formation, well 1-BJ-1-PA, core 52 (1832.10-1835.20 m). 3, *Conochitina edjelensis* (Taugourdeau, 1963). Tianguá Formation, well 1-GI-1-PA, core 3 (2257.0-2266.0 m). 4, *Conochitina elongata* (Taugourdeau, 1963). Tianguá Formation, well 1-BJ-1-PA, cuttings 1886 m. 5, *Conochitina proboscifera* Eisenack, 1937. Tianguá Formation, well 1-BJ-1-PA, cuttings 1915 m. 6, *Conochitina* aff. *C. acuminata* Eisenack, 1959. Tianguá Formation, well 1-BJ-1-PA, cuttings 2124 m. 7, *Pogonochitina tianguaense* n. sp. Holotype. IGR 54536 (O37/4). Tianguá Formation, well 1-GI-1-PA, core 3 (2257-2266 m). 8, *Pogonochitina tianguaense* n. sp. Tianguá Formation, well 2-SL-1-MA, core 77 (2246.5-2451.3 m). 9, *Sphaerochitina solitudina* Paris, 1988. Tianguá Formation, well 1-BJ-1-PA, cuttings 1990 m. 10, *Sphaerochitina palestinaense* n. sp. Holotype. IGR 54595 (N42/2). Upper Ipu Formation, well 1-PA-1-MA, cuttings 2727 m. 11, *Sphaerochitina palestinaense* n. sp. Tianguá Formation, well 1-BJ-1-PA, cuttings 1865 m. 12, *Lagenochitina* n. sp. aff. *L. navicula* (Taugourdeau and Jekhowsky, 1960). Tianguá Formation, well 1-BJ-1-PA, cuttings 1909 m.

PLATE 1



Holotype.—Plate 1, Figure 10. IGR 54595 (N42/2).

Type locality.—Well 2-SL-1-MA, core 77 (2246.5-2451.3 m).

Description.—Its short ovoid to almost spherical vesicle, and a long cylindrical neck widening into a collarette that may have finely denticulate edges characterizes *Sphaerochitina palestinaense*. The vesicle is covered with tubercles, which are concentrated on the body.

Dimensions (9 specimens measured).—Total length: 223-384 µm, holotype: 234 µm; maximum width: 75 (60)-117 (94) µm, holotype: 55 (63) µm; apertural width: 50 (40)-67 (53) µm, holotype: 55 (44) µm; neck 1/2-3/4 total length. Holotype neck 3/5 the total length.

Occurrence.—Parnaíba Basin. Upper Ipu, Tianguá and lower Jaicós formations (see Tables 1-4 and Grahn in Le Hérisse *et al.*, 2001). *S. palestinaense* was originally illustrated from middle-late Llandovery strata in Libya (Paris in Hill *et al.*, 1985). The species is also known from Llandovery strata (Vargas Peña Formation) in Paraguay (Grahn *et al.*, 2000).

Remarks.—*S. palestinaense* differs from *Sphaerochitina solutidina* in having a longer neck and pronounced collarette.

Genus *Lagenochitina* Eisenack, 1931 emend. Paris, Grahn, Nestor and Lakova, 1999

Lagenochitina n. sp. aff. *L. navicula* (Taugourdeau and Jekhowsky, 1960)

Plate 1, Fig. 12

1992 *Lagenochitina* n. sp. aff. *navicula*-Grahn and Paris, Pl. 1, Fig. 11.

2001 *Lagenochitina* n. sp. aff. *navicula*-Grahn (in Le Hérisse *et al.*, 2001), Pl. 3, Fig. 5.

Description.—A small, typically chain-forming *Lagenochitina* species with an ovoid body, and a short cylindrical neck. The vesicle wall is glabrous.

Dimensions (2 specimens measured).—Total length: 133-151 µm; maximum width: 83 (66) µm; apertural width: 40 (32) µm; neck 1/3-1/4 total length.

WELL	FORMATION	SAMPLE	DEPTH (in meters)	Barren of chitinozoans	Ancyrochitina spp.	Angochitina spp.	Cingulochitina bouinensis	Pogonochitina tianguaense n.sp.	Angochitina gurupiense n.sp.	Conochitina elongata	Fungochitina sp.A	Conochitina aff. C. acuminata	Sphaerochitina palestinaense n.sp.	Angochitina longicollis	Lagenochitina n.sp. aff. L. navicula	Conochitina proboscifera	Sphaerochitina solutidina	Ancyrochitina erichseni	Ancyrochitina ancyrea	Ancyrochitina sp.	Angochitina sp.A	Conochitina edjelensis	Ramochitina sp.A	Ramochitina sp.B	
2-SL-1-MA	Tianguá	cuttings	2364										X												
		cuttings	2370													X									
		Core 76	2393.5-2394.5					X																	
		Core 77	2246.5-2451.3					X					X								X	X			
1-TM-1-MA	Jaicós (top)	Core 67	1313.4-1313.7																			X	X		
2-VG-1-MA	Tianguá	Core 33	1379.0-1380.8							X															
		Core 37	1441.1-1442.6					X																	

TABLE 4—Chitinozoan distribution in the well samples investigated.

Occurrence.—Parnaíba Basin. Tianguá and lower Jaicós formations (see Tables 1-4). Grahn and Paris (1992) reported this species from the lower Pitinga Formation in the Amazonas Basin.

Subfamily ANGOCHITININAE Paris, 1981

Genus *Fungochitina* Taugourdeau, 1966

Fungochitina sp. A

Plate 2, Fig. 1

2000 *Fungochitina* sp. A – Grahn (in Grahn *et al.*, 2000), Pl. 2, Fig. 7.

Diagnosis.—A *Fungochitina* species with a conical body, and a long cylindrical neck that slightly widens at the aperture. The flexure is distinct. Base rounded and margin pronounced. The vesicle wall is covered with randomly distributed, small and simple spines.

Dimensions (3 specimens measured).—Total length: 163-212 μm ; maximum width: 88 (70)-119 (95) μm ; apertural width: 47 (38)-60 (48) μm ; neck 1/2-2/3 total length.

Occurrence.—Parnaíba Basin. Tianguá Formation (see Tables 1, 3-4). Grahn in Grahn *et al.* (2000) reported this species from transitional beds (Telychian) between the Vargas Peña and Cariy formations in Paraguay.

Genus *Angochitina* Eisenack, 1931

Angochitina gurupiense n. sp.

Plate 2, Figs. 3-4

2001 *Angochitina* n. sp. A – Grahn (in Le Hérisse *et al.*, 2001), Pl. 3, Figs. 1-2.

Derivation of name.—Latin, *gurupiense*, referring to the well Gurupi n.º 1 (1-GI-1-PA), from which the holotype is described.

Diagnosis.—An *Angochitina* species with a sphaerical to ovoid body and a cylindrical neck widening into a collarete. The vesicle is provided with simple hair-like spines.

Holotype.—Plate 2, Fig. 3. IGR 54536 (S41/4).

Type locality.—Well 1-GI-1-PA, core 3 (2257.0-2266.0 m).

Description.—*Angochitina gurupiense* has an ovoid vesicle, and a wide cylindrical neck, widening into a collarete. The vesicle is covered with randomly, sparsely distributed simple and hair-like spines. The flexure is distinct.

Dimensions (8 specimens measured).—Total length: 174-260 μm , holotype: 235 μm ; maximum

width 62 (50)-115 (92) μm , holotype: 107 (85) μm ; apertural width: 47 (38)-65 (52) μm , holotype: 65 (52) μm ; neck 2/5-3/5 total length, holotype: 2/5 total length.

Occurrence.—Parnaíba Basin. Tianguá Formation (see Tables 1-3 and Grahn in Le Hérisse *et al.*, 2001).

Remarks.—*Angochitina longicollis* is similar but differs in having a longer neck without any pronounced collar, and a more elongated body.

Angochitina sp. A

Plate 2, Fig. 5

2001 *Angochitina* n. sp. B—Grahn (in Le Hérisse *et al.*, 2001), Pl. 3, Fig. 3.

Description.—This *Angochitina* species has an ovoid body and a cylindrical neck. The flexure is distinct. The vesicle wall is covered with randomly distributed, small and simple spines.

Dimensions (2 specimens measured).—Total length: 157-246 μm ; maximum width: 71 (57)-120 (96) μm ; apertural width: 40 (32)-61 (49) μm ; neck 2/5 total length.

Occurrence.—Parnaíba Basin. Tianguá and lower Jaicós formations (see Tables 2-4).

Genus *Ramochitina* Sommer and van Boekel, 1964

emend. Paris, Grahn, Nestor and Lakova, 1999.

Ramochitina sp. A

Plate 3, Fig. 1

Description.—This *Ramochitina* species has an elongated ovoid body, and a short neck formed as an inverted cone. The aperture is provided with simple spines. The flexure is inconspicuous. The vesicle wall has massive spines, simple or multirooted, which are sparsely distributed in crests.

Dimensions (2 specimens measured).—Total length: 157-246 μm ; maximum width: 71 (57)-120 (96) μm ; apertural width: 40 (32)-61 (49) μm ; neck 1/6 total length; length of spines \leq 16 μm .

Occurrence.—Parnaíba Basin. Uppermost Jaicós Formation (see Table 4).

Ramochitina sp. B

Plate 3, Fig. 2

Description.—A *Ramochitina* species with an ovoid body, and a subcylindrical neck. The aperture is provided with simple spines. The flexure is distinct. The vesicle wall has massive, simple spines distributed in crests.

Dimensions (1 specimen measured).—Total length: 209 µm; maximum width: 88 (70) µm; apertural width: 35 (28) µm; neck 2/5 total length; length of spines ≤ 13 µm.

Occurrence.—Parnaíba Basin. Uppermost Jaicós Formation (see Table 4).

Subfamily ANCYROCHITININAE Paris, 1981

Genus *Ancyrochitina* Eisenack, 1955

Ancyrochitina sp.

Plate 2, Figs. 8-9

2001 *Plectochitina* n. sp. A—Grahn (in Le Hérisse *et al.*, 2001), Pl. 3, Fig. 7.

2001 *Plectochitina* sp.—Grahn (in Le Hérisse *et al.*, 2001), Pl. 3, Fig. 8.

Description.—This small *Ancyrochitina* species has a conical body and a short cylindrical neck. The flexure is distinct. The vesicle wall is glabrous. The margin is provided with seven multirooted appendices which are branching at their tips. A specimen with conical and simple appendices is included (Pl. 2, Fig. 9).

Dimensions (2 specimens measured).—Total length: 96-100 µm; maximum width: 68 (54)-73 (58) µm; apertural width: 18 (14)-35 (28) µm; neck 1/2 total length.

Occurrence.—Parnaíba Basin. Tianguá Formation (see Tables 2, 4).

CHITINOZOAN BIOSTRATIGRAPHY

The Silurian and Lower Devonian chitinozoans from the Parnaíba Basin discussed herein can be

used to recognize two biozones. These are defined below.

Interval Zone of *Pogonochitina tianguaense*

Definition.—This biozone is defined by the occurrence of *Pogonochitina tianguaense* n. sp. in the Parnaíba Basin.

Type Interval and Locality.—The type interval for the zone is defined within the upper Ipu, Tianguá and lower Jaicós formations (late Aeronian-early Telychian). No type locality is designated.

Characteristic chitinozoans.—All chitinozoan species recorded in this study are restricted to this zone except *Ramochitina* sp. A and *Ramochitina* sp. B (see Table 4).

Occurrence.—*Pogonochitina tianguaense* is also known from coeval strata in the lower Pitinga Formation, Amazonas Basin (Grahn, personal observations).

Assemblage Zone of *Ramochitina* sp. A and *Ramochitina* sp. B

Definition.—This biozone is defined by the joint occurrence of *Ramochitina* sp. A and *Ramochitina* sp. B.

Type Interval and Locality.—The type interval for the zone is defined within the uppermost Jaicós Formation (latest Pragian). Type locality is 1-TM-1-MA (core 67, horizon at 1313.38 m).

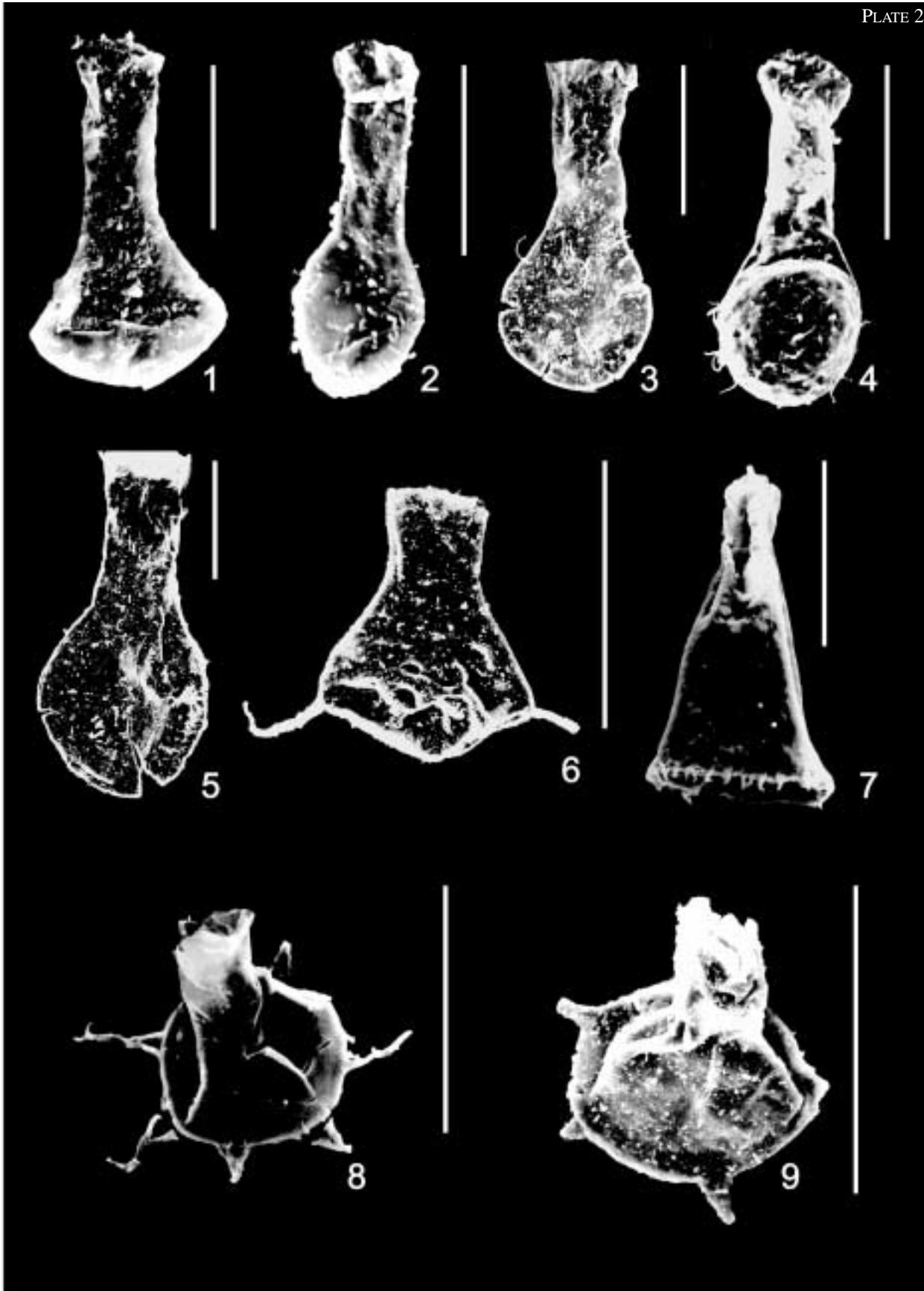
Characteristic chitinozoans.—Only *Ramochitina* sp. A and sp. B have been thus far recognized in the biozone.

Occurrence.—Chitinozoans similar to *Ramochitina* sp. A and sp. B are also known from uppermost Pragian rocks of Bohemia (Florentin Paris, personal communication 2002, 2003).

→

PLATE 2—Llandovery chitinozoans from the Serra Grande Group. The scale bars represent 100 µm. 1, *Fungochitina* sp. A. Tianguá Formation, well 9-PAF-7-MA, cuttings 1202 m. 2, *Angochitina longicollis* (Eisenack, 1959). Tianguá Formation, well 1-BJ-1-PA, cuttings 1909 m. 3, *Angochitina gurupiense* n. sp. Holotype. IGR 54536 (S41/4). Tianguá Formation, well 1-GI-1-PA, core 3 (2257.0-2266.0 m). 4, *Angochitina gurupiense* n. sp. Tianguá Formation, well 2-SL-1-MA, core 77 (2246.5-2451.3 m). 5, *Angochitina* sp. A. Tianguá Formation, well 1-GI-1-PA, core 3 (2257.0-2266.0 m). 6, *Ancyrochitina ancyrea* (Eisenack, 1931). Tianguá Formation, well 1-GI-1-PA, core 3 (2257.0-2266.0 m). 7, *Ancyrochitina erichseni* Sommer and van Boekel, 1963. Upper Ipu Formation, well 2-CP-1-MA, cuttings 3087 m. 8, *Ancyrochitina* sp. Tianguá Formation, well 2-SL-1-MA, core 77 (2246.5-2451.3 m). 9, *Ancyrochitina* sp. Tianguá Formation, well 1-GI-1-PA, core 3 (2257.0-2266.0 m).

PLATE 2



MIOspore BIOSTRATIGRAPHY

Tianguá Formation

Trilete spores and cryptospores from the Tianguá Formation were discussed by Steemans (in Le Hérisse *et al.*, 2001). The earliest trilete spores are rare, and when used in long-distance correlations they seem to have diachronous first occurrences from latest Ordovician through Llandovery. In the intracratonic basins of Brazil they first appear in Aeronian (Steemans and Pereira, 2002). The cryptospores are few and characteristic for a Caradoc through Llandovery age elsewhere. The presence of *Laevolancis divellomedia*, combined with the scarcity of characteristic species of the *chulus-nanus* Zone, together suggest that the Tianguá assemblage belongs to *Laevolancis divellomedia* Subzone, which is dated Rhuddanian-early Telychian in Saudi Arabia (Steemans *et al.*, 2000). Nevertheless, the presence of trilete spores (see comments above) favors a more restricted correlation of the Tianguá palynoflora with the younger, post-Rhuddanian part of that biozone.

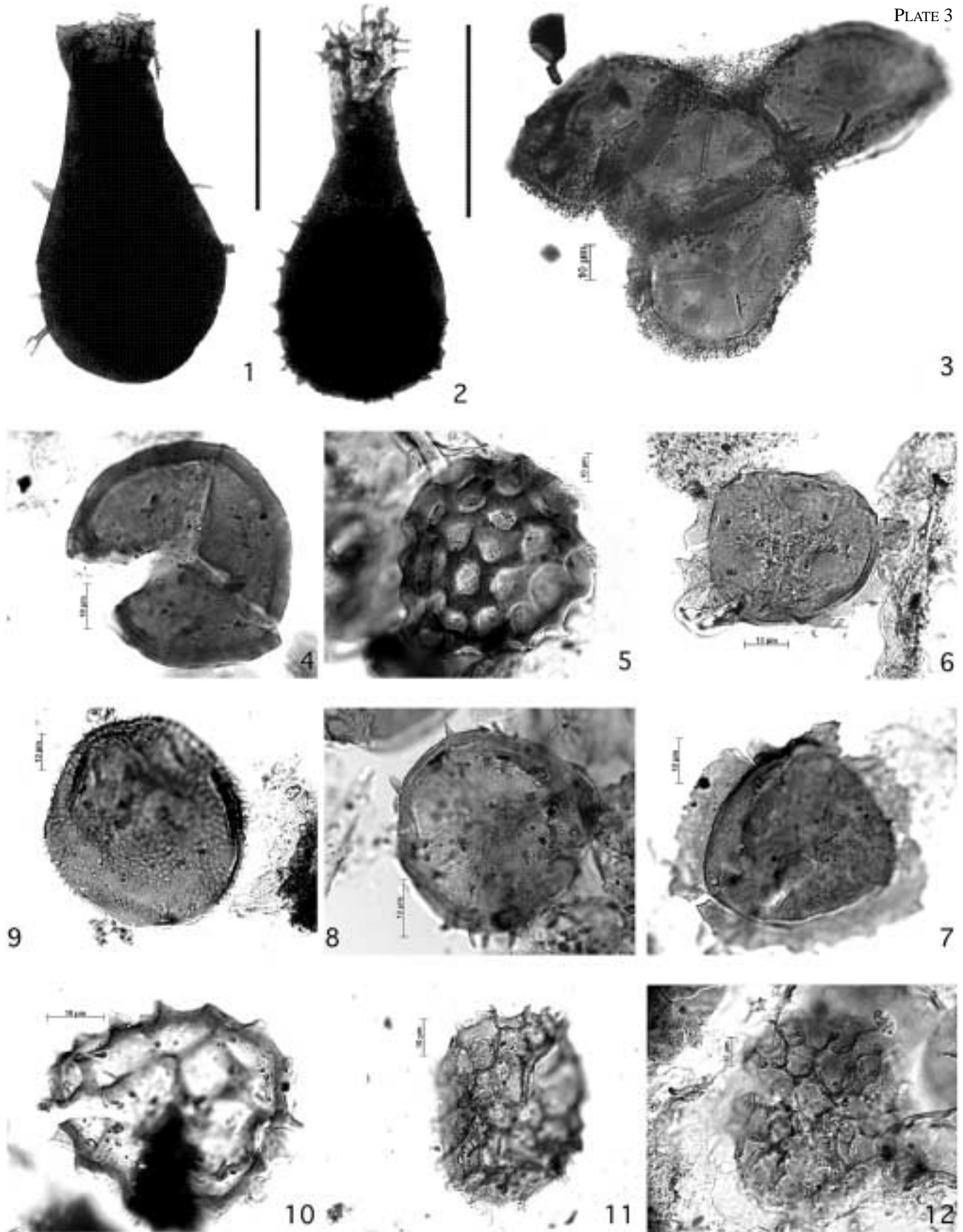
Jaicós Formation

Miospores from seven palynological samples of core 67 of well 1-TM-1-MA (1313.3-1319.3 m, at the top of the Jaicós Formation) have been studied. All the samples are rich in well preserved palynomorphs, yellow to brown in color. The current investigations are limited to the recognition of miospore taxa known in the literature. All seven samples were collected from a 6 m core that was cut a little more than one meter below the Itaim/Jaicós unconformity (1312 m in well 1-TM-1-MA). All samples yielded the same miospore assemblage. In many respects (including several shared miospore species), this uppermost

Jaicós palynoflora resembles a very similar assemblage present in the upper part of the Jatapu Member (Maecuru Formation, Amazonas Basin), of latest Pragian-earliest Emsian age (Melo and Loboziak, 2003). Among the stratigraphically most useful miospores from core 67 (Plate 3, Figs. 3-12, and Plates 4-5) the following species have been identified: Morphon *Dictyotriletes emsiensis* (*D. emsiensis* type McGregor, 1973) sensu Rubinstein *et al.* (in press), *Dictyotriletes subgranifer* McGregor, 1973, and *Verrucosporites polygonalis* Lanninger, 1968. The joint occurrence of these three species ensures that the core samples belong to a stratigraphic interval no older than the Su Interval Zone (Steemans, 1989), latest Pragian to earliest Emsian in age (Streel *et al.*, 2000). Excepting *D. emsiensis*, which is rarely observed in AP (*Acinosporites apiculatus-Grandispora protea*) Zone-equivalent sections of the Amazonas Basin (Melo and Loboziak, 2003), of latest Emsian to early Eifelian age, the two others are not known in biozones younger than the FD (*Emphanisporites foveolatus-Verruciretusispora dubia*) Zone, late (but not latest) Emsian in age. Among the other species, *Knoxisporites? riondae* Cramer and Díez, 1975 is relatively frequent. This latter species is known in the San Pedro Formation, León Province, Spain, Upper Silurian (Cramer and Díez, 1975); in the Montguyon Formation, Brittany, France, within assemblages 2 and 3, upper Pragian and lower Emsian (*Knoxisporites? riondae* and *Knoxisporites? cf. riondae* in Le Hérisse, 1983); in the Illizi Basin, Sahara, Zones VI and VII, "Gedinnian?"-Emsian? (Spore trilète à papilles soudées sp. 3 in Jardiné and Yapaudjan, 1968); in the Acoz Formation, Dinant Synclinorium, Su Interval Zone, upper Pragian or basal Emsian (Steemans, 1989); and in the Emsian from Saudi

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PLATE 3—Lower Devonian chitinozoans and miospores from core 67 of well 1-TM-1-MA (uppermost Jaicós Formation, 1313.3-1319.3 m). The scale bars for figures 1 and 2 represent 100 µm. Locations of specimens on the slides are given in England Finder coordinates. 1, *Ramochitina* sp. A., Slide N.º 95.0202A, 1313.38 m, P34/1. 2, *Ramochitina* sp. B., Slide N.º 95.0202A, 1313.38 m., D36/2. 3, *Ambitisporites tripapillatus* Moreau-Benoit, 1976, Slide N.º 95.0206 (2073), 1317.73 m, X65/1. Open tetrad covered by residual sporangia tissue. 4, *Archaeozonotriletes chulus* Richardson and Lister, 1969, Slide N.º 95.0202 (2069), 1313.38 m, O52. 5, *Brochotriletes foveolatus* Naumova, 1953, Slide N.º 95.0201B, 1312.73 m, T51/3. 6, *Cirratiradites diaphanus* Steemans, 1989, Slide N.º 95.0205A, 1315.13 m, J36. 7, *Cirratiradites diaphanus* Steemans, 1989, Slide N.º 95.0202A, 1313.38 m, R46. 8, *Cymbosporites rarispinosus* Steemans, 1989, Slide N.º 95.0202 (2069), 1313.38, N60/4. 9, *Dibolisporites echinaceus* Richardson, 1965 emend. McGregor, 1973, Slide N.º 95.0203 (2070), 1313.83 m, B43/4. 10, Morphon *Dictyotriletes emsiensis* (*D. emsiensis* type McGregor, 1973) sensu Rubinstein *et al.* (in press), Slide N.º 95.0201 (2068), 1312.73 m, U54/2. 11, *Dictyotriletes subgranifer* McGregor, 1973, Slide N.º 95.0206 (2073), 1317.73 m, M54. 12, *Dictyotriletes subgranifer* McGregor, 1973, Slide N.º 95.0202A, 1313.38 m, K50/2.



Arabia (Stemans, personal observation, unpublished data). Various specimens of *Cirratiradites diaphanus* Stemans, 1989 have been found in almost all samples from core 67. This species occurs in Western Europe from the MN (*Emphanisporites micrornatus-Streelispora newportensis*) Zone, of Lochkovian age, up to the Su Interval Zone (Stemans, 1989). In Brazil (Melo and Loboziak, 2003) the species ranges from the Non-spinose Zonates (NsZ) Interval Zone to the *Dictyotriletes emsiensis* (Ems) Interval Zone, of Lochkovian to earliest Emsian age. Well preserved specimens of *Zonotriletes* sp. 2 and sp. 3 (Jardiné and Yapaudjan, 1968) have also been observed. *Zonotriletes* sp. 2 ranges from Zones V to VII in the Illizi Basin, and has its acme in the upper part of Zone VII, Pragian? (Jardiné and Yapaudjan, 1968). The same species first appears in the upper part of the Ems Interval Zone in Brazil (*Perotriletes* sp. cf. *Zonotriletes* 2 in Melo and Loboziak, 2003). Therefore, its total known range seems to be Lochkovian through the earliest Emsian, but thus far there are still no pre-late Pragian records of the species in Brazil (including the upper Jaicós occurrence). Another interesting feature of the uppermost Jaicós palynoflora is the occurrence of some representatives of a new, micrornamented *Emphanisporites* species, previously recorded from the Rhynie Chert of the UK (Charles Wellman, personal communication 2003), which also belongs to the Su Interval Zone. In the absence of any characteristic species from younger Emsian miospore zones (AB or FD), and in view of the presence of *D. subgranifer*, *C. diaphanus* and *Zonotriletes* sp. 2, it is concluded that the palyniferous

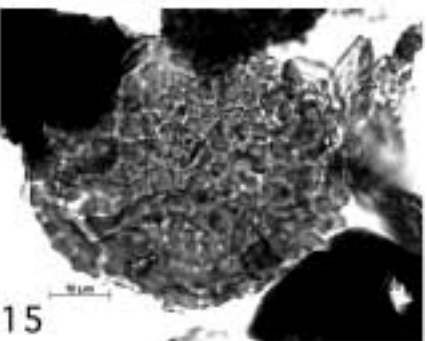
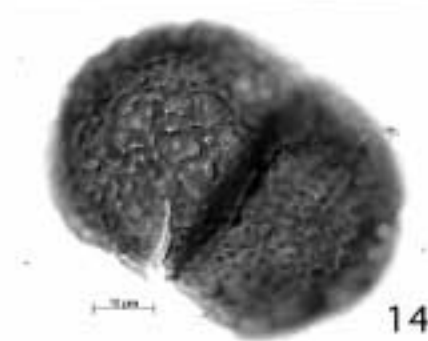
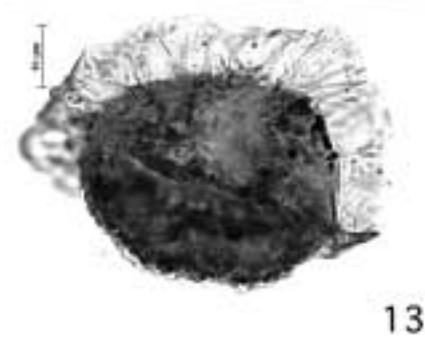
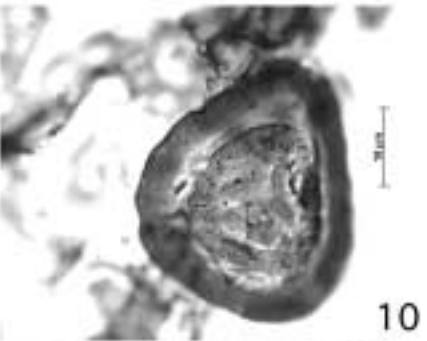
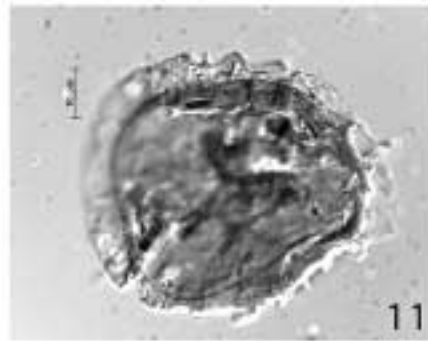
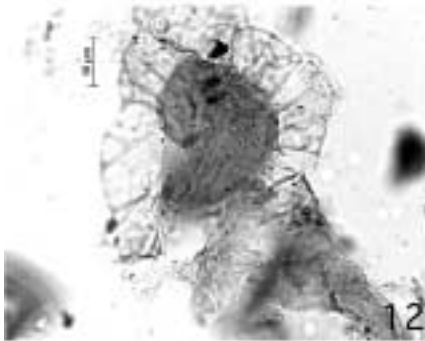
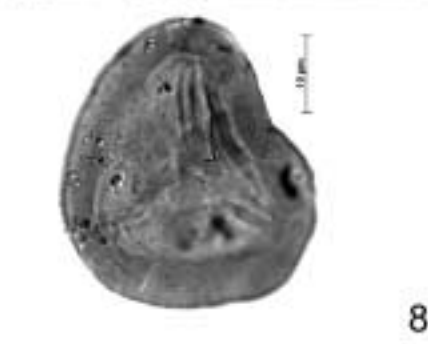
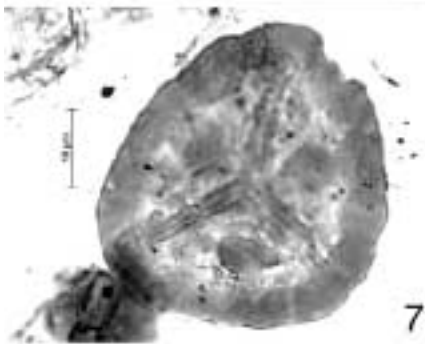
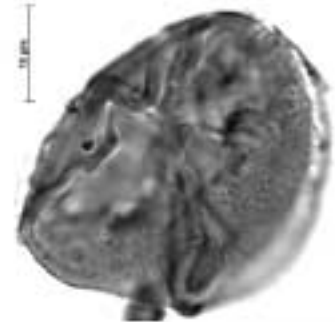
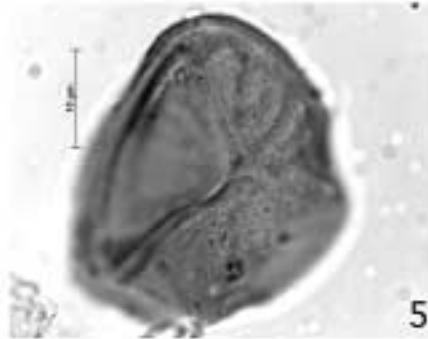
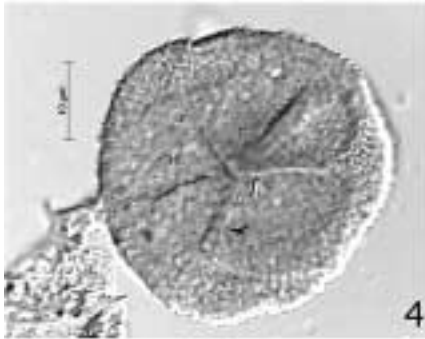
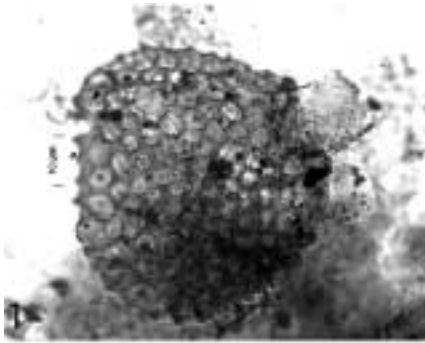
levels from core 67 of well 1-TM-1-AM all belong to the Su Interval Zone, so their age is constrained to that between the latest Pragian and earliest Emsian. The other species observed are consistent with this age interpretation, including: *Dibolisporites echinaceus* Richardson, 1965 emend. McGregor, 1973, *Archaeozonotriletes chulus* Richardson and Lister, 1969, *Emphanisporites rotatus* McGregor, 1961, *Retusotriletes* spp., *Apiculiretusispora* spp., *Perotriletes caperatus* Stemans, 1989, *Cymbosporites rarispinosus* Stemans, 1989, *Brochotriletes foveolatus* Naumova, 1953, *Kraeuselisporites gaspiensis* McGregor, 1973, *Ambitisporites tripapillatus* Moreau-Benoit, 1976, *Dictyotriletes favosus* McGregor and Camfield, 1976, and *Kraeuselisporites gaspiensis* McGregor, 1973.

DISCUSSION OF BIOSTRATIGRAPHIC RESULTS

The stratigraphic relationships of the miospore and chitinozoan zones recognized in this paper for the Serra Grande Group are shown in Figure 2. The age determinations based on the marine and terrestrial fossil groups are in general agreement. The Interval Zone of *Pogonochitina tianguaense* characterizes about the same stratigraphic interval in the lower Serra Grande Group as the *Laevolancis divellomedia* Subzone, which is represented here only by its younger (post-Rhuddanian) part in Brazil. Therefore, the total age span of the upper Ipu, the Tianguá and basal Jaicós sections is Aeronian (probably late Aeronian) to early Telychian.

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PLATE 4—Lower Devonian miospores from core 67 of well 1-TM-1-MA (uppermost Jaicós Formation, 1313.3-1319.3 m). Locations of specimens on the slides are given in England Finder coordinates. 1, *Dictyotriletes favosus* (McGregor) McGregor and Camfield, 1976, Slide N.º 95.0201 (2068), 1312.73 m, T40. 2, *Emphanisporites rotatus* McGregor, 1961, Slide N.º 950205A, 1315.13 m, P54/2. 3, *Emphanisporites* n. sp. (Wellman, personal communication), Slide N.º 95.0201 (2068), 1312.73 m, G41/3. 4, *Emphanisporites* n. sp. (Wellman, personal communication), Slide N.º 95.0200A, 1311.78 m, F50/3. 5, *Emphanisporites* n. sp. (Wellman, personal communication), Slide N.º 95.0201 (2068), 1312.73 m, R54. 6, *Emphanisporites* n. sp. (Wellman, personal communication), Slide N.º 95.0201 (2068), 1312.73 m, M43/2. 7, *Knoxisporites? riondae* Cramer and Díez, 1975, Slide N.º 95.0203B, 1313.83 m, P55. 8, *Knoxisporites? riondae* Cramer and Díez, 1975, Slide N.º 95.0206 (2073), 1317.73 m, K42/3. 9, *Knoxisporites? riondae* Cramer and Díez, 1975, Slide N.º 95.0202 (2069), 1313.38 m, W41/3. 10, *Knoxisporites? riondae* Cramer and Díez, 1975, Slide N.º 95.0201 (2068), 1312.73 m, N60/3. 11, *Kraeuselisporites gaspiensis* McGregor, 1973, Slide N.º 95.0201B, 1312.73 m, Q55/1. 12, *Perotriletes caperatus* (McGregor) Stemans, 1989, Slide N.º 95.0202 (2069), 1313.38 m, N54. 13, *Perotriletes caperatus* (McGregor) Stemans, 1989, Slide N.º 95.0202 (2069), 1313.38 m, D41. 14, *Segestrespora rugosa* (Johnson) Burgess, 1991, Slide N.º 95.0201 (2068), 1312.73 m, U52. 15, *Verrucosisporites polygonalis* Lanninger, 1968, Slide N.º 95.0203B, 1313.83 m, K57/3.

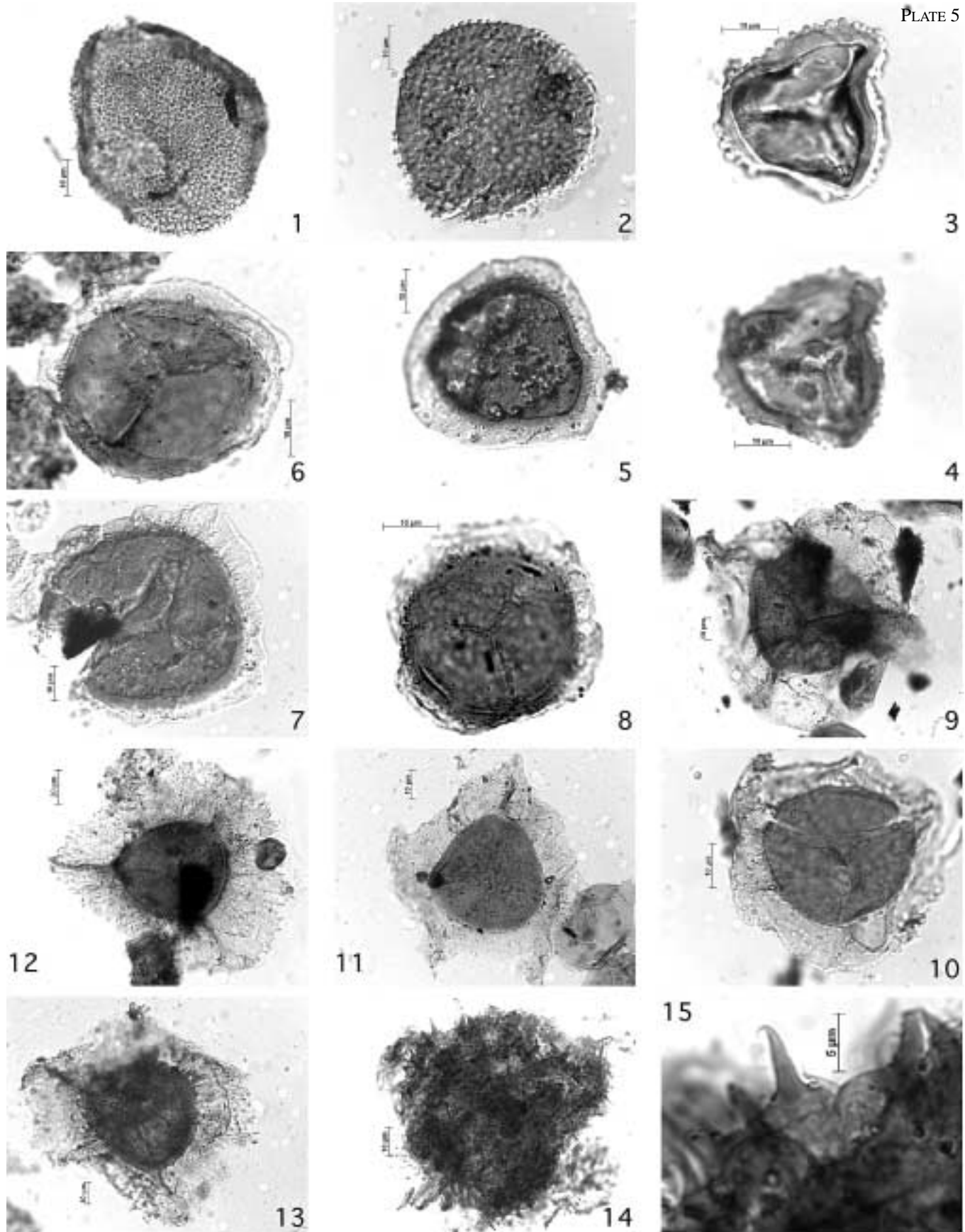


Geological age	Amazonas Basin	Parnaíba Basin		Miospore biozones	Chitinozoan biozones	
Emsian	Maecuru Fm. Lontra Mbr.	Itaim Fm.	Camin- de Grp.	AP	?	
	?	?		?	?	
Pragian	Maecuru Fm. Jatapu Mbr.	Jaicós Fm.	Serra Grande Group	Su	Ramochitina sp. A & sp. B	
	Loch- kovian	Manacapuru Fm.		?	?	
Pridoli	Manacapuru Fm.	↑ Hiatus(es) expected to occur within this interval ↓		?	?	
	Ludlow			Upper Pitinga Fm.	?	?
Wenlock	Lower Pitinga Fm.			Jaicós Fm.	Laevolancis divellomedia	Pogonochitina tianguaense
	Llando- very			Tianguá Fm.	?	?
	Nhamunda Fm.			Ipu Fm.		

FIGURE 2—Biozonation of the Serra Grande Group, Parnaíba Basin, and its correlation with the Amazonas Basin Siluro-Devonian section. Miospore zonation for the Tianguá Fm. after Steemans and Pereira (2002).

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PLATE 5—Lower Devonian miospores from core 67 of well 1-TM-1-MA (uppermost Jaicós Formation, 1313.3-1319.3 m). Locations of specimens on the slides are given in England Finder coordinates. 1, *Verrucosisporites polygonalis* Lanninger, 1968, Slide N.º 95.0201 (2068), 1312.73 m, U42/2. 2, *Verrucosisporites polygonalis* Lanninger, 1968, Slide N.º 95.0206 (2073), 1317.73 m, F52/2. 3-4, *Verrucosisporites* n. sp., Slide N.º 950205A, 1315.13 m, D50. A new species with strong bulbous verrucae, irregularly distributed on the distal face and three papillae on the proximal face. 5, *Zonotriletes* sp. 3 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0202 (2073), 1317.73 m, S54/3. 6, *Zonotriletes* sp. 3 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0205B, 1313.13 m, O40/3. 7, *Zonotriletes* sp. 3 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0200A, 1311.78 m, O52/1. 8, *Zonotriletes* sp. 3 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0202 (2069), 1313.38 m, M56/4. 9, *Zonotriletes* sp. 2 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0206 (2073), 1317.73 m, K50. 10, *Zonotriletes* sp. 2 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0206 (2073), 1317.73 m, Q55/4. 11, *Zonotriletes* sp. 2 in Jardiné and Yapaudjan, 1968, Slide N.º 95.0202 (2069), 1313.38, F47/1. 12, Unknown trilete spore with an ornamented (?) serrated equatorial membranous zona, Slide N.º 95.0201 (2068), 1312.73 m, E47. 13, Unknown trilete spore with an ornamented (?) serrated equatorial membranous zona, Slide N.º 95.0206 (2073), 1317.73 m, M62. 14-15, Unclassified trilete spore with dense, strong, biform ornaments (15: detail of the ornamentation), Slide N.º 95.0201 (2068), 1312.73 m, K41/3. Possibly conspecific forms occur in coeval strata of the uppermost Jatapu Member of the Maecuru Formation, in the subsurface of the Maués area, southern margin of the Amazonas Basin (Melo, personal observations).



In the uppermost Jaicós Formation, the levels corresponding to the Assemblage Zone of *Ramochitina* sp. A and *Ramochitina* sp. B occur within section assignable to the Su Interval Zone, of latest Pragian-earliest Emsian age, as compared to European sections. The chitinozoans suggest a position close to the Pragian-Emsian boundary, i. e., probably within the lower part of the Su Zone.

CONCLUDING REMARKS

Chitinozoans and miospores have been recovered from the Tianguá Formation, and its sandier lateral facies in the upper Ipu and lower Jaicós formations, whereas a second distinct assemblage occurs in the uppermost part of the Jaicós Formation.

The chitinozoan assemblage of the Tianguá Formation (and its lateral equivalents) displays low abundance and diversity comparing to the coeval lower Pitinga Formation assemblage in the adjacent Amazonas Basin (Grahn, personal observations). The palynoflora of the Tianguá Formation is dominated by cryptospores, whereas only few trilete spores are observed. It is representative of the younger (post-Rhuddanian) portion of the *Laevolancis divellomedia* Subzone, i. e., Aeronian-early Telychian (Stemans *et al.*, 2000). The chitinozoans suggest a slightly more restricted late Aeronian-early Telychian age, and the organic-walled microphytoplankton investigated by Le Hérisse *et al.* (2001) an even more restricted age, early-middle Telychian.

Miospores and chitinozoans of latest Pragian or earliest Emsian age are described for the first time from the uppermost Jaicós Formation. They allow an accurate age determination for the top of Serra Grande Group, and an improved estimate of the duration of the hiatus that separates it from the base of the overlying Canindé Group (Itaim Formation, of latest Emsian to early Eifelian age). Furthermore, judging from the present palynological results and the proposed correlation with coeval rock units in the Amazonas Basin (Fig. 2), one or more intraformational hiatuses (probably of Silurian age) are expected to occur within the Jaicós Formation.

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LATE PERMIAN FORAMINIFERAL ASSEMBLAGES FROM THE HAMBAST REGION (CENTRAL IRAN) AND THEIR EXTINCTIONS

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Abstract

The upper-middle, upper Permian and lowermost Triassic of the Hambast region (Iran) are characterized by three principal lithologies: (1) grey limestones of late Midian/Dzhulfian (i. e., Capitanian/Wuchapingian) age, overlain by (2) reddish nodular ammonoid-bearing (*Paratirolites*) deep-water limestones of Dorashamian/Changhsingian, and (3) well exposed, grey thin bedded, limestones of early Triassic age.

The first grey limestones contain a relatively diversified assemblage: *Gymnocodium bellerophon-tis*, *Permocalculus digitatus*, *P. fragilis*, *P. tenellus*, *Epimastoporella* (?) sp., *Palaeotextularia* sp., *Deckerella* cf. *composita*, *Climacammina valvulinoides*, *C. sphaerica*, *Globivalvulina* ex gr. *bulloides*, *Septoglobivalvulina decrouezae*, *Dagmarita chanakchiensis*, *D. shahrezaensis*, *Nankinella minor*, *Reichelina* sp., *Codonofusiella kwangiana*, *C. schubertelloides*, *Pseudodunbarula arpaensis*, *Hemigordiellina* spp., *Hemigordius schlumbergeri*, *Neohemigordius* aff. *zaninettiae*, *Neodiscus* aff. *orbicus*, *Nodosinelloides* spp., *Geinitzina* spp., *Pseudolangella fragilis*, *Calvezina* sp. and *Fron-dina permica*. Other important foraminifera are *Neoendothyra reicheli*, *Cyclogyra* sp., *Orthovertella shalshalensis*, *Reitlingeria* sp., recorded respectively at the base and at the top of the sequences.

The representative section of Shareza can be subdivided into seven biozones: (1) the early Midian with *Yabeina* (not represented in our samples); (2) the late Midian (= late Abadehian) with *Reitlingeria*; (3) the latest Midian (= top of Abadeh Formation) with the local appearance of *Reichelina*, *Codonofusiella*, *Pseudodunbarula* and *Neohemigordius*; (4) the early Dzhulfian with the possible FAD of *Dagmarita shahrezaensis* and *Fron-dina permica*; (5) the late Dzhulfian with rare *Reichelina*; (6) the last biozone of Permian foraminifera (accurately subdivided by ammonoids), probably entirely Dorashamian in age; *Neoendothyra* is only known at the top of this zone; (7) the Triassic beds, with rare foraminifera, for instance *Orthovertella shalshalensis*, from the base.

Key words: Foraminifera, Late Permian, Early Triassic, Taxonomy, Biostratigraphy, Iran.

Resumen

La parte superior del Pérmico medio, el Pérmico superior, y el Triásico más inferior de la región de Hambast (Irán) se distinguen por tres principales litologías: las calizas grises del Midiense superior/Dzhulfense están cubiertas por calizas de mar profundo, rojizas y nodulosas, con *Paratirolites* del Dorahamiense; el Triásico basal, con calizas grises en capas finas, está bien expuesto.

Las primeras calizas grises contienen una microflora de algas calcáreas y una microfauna bastante diversificada de pequeños foraminíferos asociados con varios pequeños fusulinidos. Casi treinta taxa se encuentran: *Gymnocodium bellerophon-tis*, *Permocalculus digitatus*, *P. fragilis*, *P. tenellus*, *Epimastoporella* (?) sp., *Palaeotextularia* sp., *Deckerella* cf. *composita*, *Climacammina valvulinoides*, *C. sphaerica*, *Globivalvulina* ex gr. *bulloides*, *Septoglobivalvulina decrouezae*, *Dagmarita cha-*

nakchiensis, *D. shahrezaensis*, *Nankinella minor*, *Codonofusiella kwangsiana*, *C. schubertelloides*, *Pseudodunbarula arpaensis*, *Hemigordiellina* spp., *Hemigordius schlumbergeri*, *Neohemigordius* aff. *zaninettiae*, *Neodiscus* aff. *orbicus*, *Nodosinelloides* spp., *Geinitzina* spp., *Pseudolangella fragilis*, *Calvezina* sp. and *Froncina permica*. Otros importantes foraminíferos, *Neoendothyra reicheli*, *Cyclogyra* sp., *Orthovertella shalshalensis*, *Reitlingeria* sp., se añaden respectivamente en la base de la serie, en la cima de las calizas rojas nodulares, y en la base del Triásico.

En la sección más característica de Shahreza, siete biozonas se encuentran desde la cima del Abadehense hasta la base del Triásico. Se trata del Midiense inferior con la biozona 1 con *Yabeina*; (2) Midiense superior (= Abadehense superior) con *Reitlingeria*; (3) Midiense terminal (= cima de la Formación Abadeh) con la aparición local de *Reichelina*, *Codonofusiella*, *Pseudodunbarula* y *Neohemigordius*; (4) Dzhulfiense inferior con la probable FAD (aparición más antigua) de *Dagmarita shahrezaensis* and *Froncina permica*; (5) Dzhulfiense superior con raros *Reichelina*; (6) última biozona con foraminíferos pérmicos (con una zonación más fina por amonoideos); probablemente enteramente de edad Dorashamiense; *Neoendothyra* se encuentra sólo en la cima de esta zona; (7) la pobreza de las capas triásicas, pero que presentan el pequeño foraminífero característico *Orthovertella shalshalensis*, desde la base.

Palabras clave: Foraminíferos, Pérmico superior, Triásico inferior, Taxonomía, Bioestratigrafía, Irán.

INTRODUCTION

Although conodonts and ammonoids are of prime importance in stratigraphy, foraminifera are one of the most important index microfossils due to their worldwide distributions and accurate stratigraphic ranges. They are in particular, an excellent tool for testing biological crises. They have been utilized for the K/T crisis, but can also be interesting for the P/T crisis.

This remarkable event is the largest of the five major extinctions, and denominated by Erwin (1993) "the mother of mass extinctions" affected the composition and subsequent evolution of earth biota. According to Sepkoski (1989, 1990), during the P/T crisis, perhaps as many as 90% of all the species from the late Permian disappeared. Post-extinction recovery of plant and marine ecosystems has been very slow, occurring over 4-5 million years (e. g., Looy *et al.*, 1999; Erwin, 2001).

Important P/T boundary sections are located in Iran (NW, NE and Central Iran; Alborz region, belonging to Iranian Plate and Zagros fold belt, belonging to Arabian Plate), Oman, Southern China, Japan, Pakistan, Afghanistan, Turkey, Greenland, Austria, Italy, South Africa and Antarctica.

In this paper, the marine latest middle Permian, late Permian and Permian-Triassic boundary of Central Iran between Esfahan and Shiraz (Shahreza/Hambast

range) were studied with respect to microfacies, paleogeography and biostratigraphy. For detailed micropaleontological investigations, more than 200 samples have been collected from the Shahreza/Abadeh area.

The recommended, but somewhat controversial, chronostratigraphical Permian scale is summarized here, according to Jin *et al.* (1997) and Wardlaw (1999), but correlated with the alternative classification of Leven (e. g., Leven, 1992; Kotlyar and Pronina, 1995). For instance we prefer, concerning the stratigraphy of Iran, the names Midian (eventually Abadehian), for Capitanian, Dzhulfian for Wuchiapingian, and Dorashamian for Changhsingian (Fig. 1).

The purpose of this article is to complete the knowledge of the late Midian (latest middle Permian) to earliest Triassic foraminifera of Iran. This paper attempts also to characterize new markers of the Dzhulfian. The Dorashamian (= Changhsingian) biomarkers *Palaeofusulina* and *Colaniella*, which commonly occur in shallower water environment, have not been recognized, probably due to a deeper depositional (i. e., basin) environment. It also allows a characterization of one of the best-known areas of the Permo-Triassic boundary. Theoretically, its corresponds to the geographically transitional area between the Palaeotethys, and the Neotethys, considered here as narrow seaways and not as extended oceans.

Systems	Series	STAGES		
		Names	Base	Duration
Triassic	Early Triassic	Scythian	251.4 Mya	-
Permian	Lopingian	Changhsingian (=Dorashamian)	253.4	2.0
		Wuchiapingian (=Dzhulfian = Longtanian)	260	6.6
	Guadalupian	Capitanian (=Midian)	265.0	5.0
		Wordian (=Murgabian)	267.0	2.0
		Roadian (=Ufimian = Kubergandian)	269.0	2.0
	Cisuralian	Kungurian (=Bolorian)	277	8.0
		Artinskian (=Yakhtashian)	283	6.0
		Sakmarian	288.5	5.5
		Asselian	291.5	3.0
	Carboniferous	Late Pennsylvanian	Gzhelian	-

FIGURE 1—Chronostratigraphical subdivisions of the Permian (according to Jin *et al.*, 1997; and Wardlaw, 1999). Correspondance of the stage names.

GEOLOGICAL SETTING

Iran essentially comprises eight different geological provinces (Fig. 2A). One of the most important, for the Permian paleobiogeography and biostratigraphy, is the Sanandaj-Sirjan thrust belt located in the central part of Iran, where the sections from the Shahreza and Abadeh areas are situated. This belt was formed by the coalescence of several blocks or microplates and was located near to the equator during late Permian and early Triassic time (e. g., Scotese and Langford, 1995).

According to the most classical geodynamic hypotheses, the architecture of the Sanandaj Sirjan basin was controlled during the late Permian by the opening of the Neotethys from Australia to the east Mediterranean area (e. g., Sharland *et al.*, 2001). This opening corresponds to the drifting of the Cimmerian

superterrane and the final closing of Paleotethys northward in the middle Triassic times.

The Shahreza/Abadeh region belongs to the Shahreza-Abadeh-Hambast belt, which covers an area about 25 km wide and 220 km long. The major part of this belt consists of Permian and Triassic deposits.

The continuous Permian-Triassic sections of Shahreza-Abadeh are located in a NW-SE trending range south of Esfahan, in the Central Iranian province, Lat. 30°-32°N and Long. 51°-54°E along the main road from Esfahan to Shiraz (Fig. 2 B-C).

In previous studies (Taraz *et al.*, 1981), seven lithologic units (units 1-7) in the Permian and five units (units A-E) in the early Triassic are recognized in this area, but only units 5-7 in the Permian are studied in this paper. In fact, the investigated part (50 m in Shahreza; Fig. 3) consists of the upper part of the

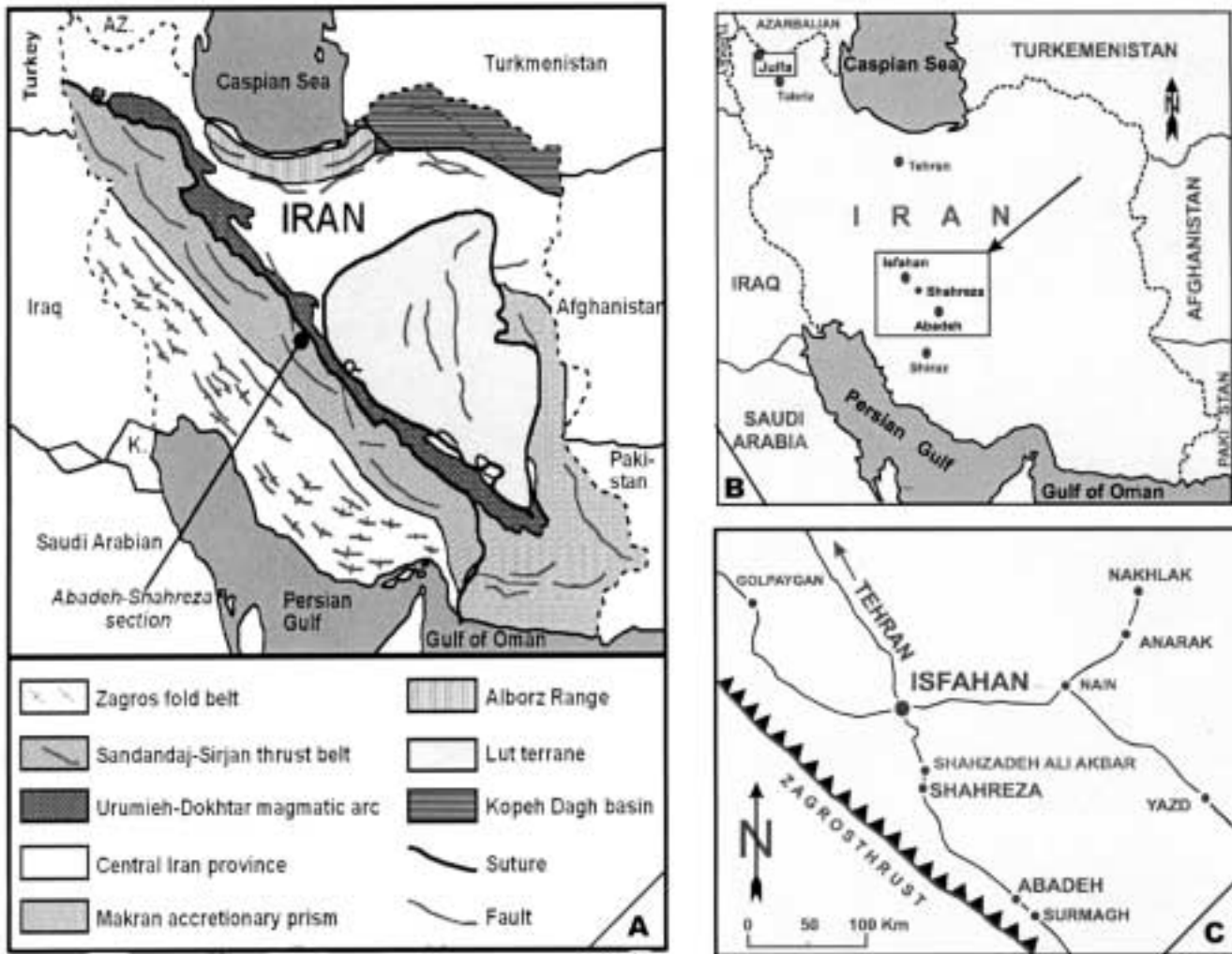


FIGURE 2—Location maps. A. General geological map of Iran showing the eight geological provinces, B. Location of the area Esfahan-Shahreza and Abadeh in central Iran, and C. Locality map of Shahreza.

Abadeh Formation (i. e., the last 8 m of unit 5, whose total thickness is 58 m), the Hambast Formation (units 6-7), and the base of the Elika Formation (unit A).

The Abadeh Formation is composed of dark grey, thin-bedded, bioclastic, bioturbated marly wackestones and packstones. The lower part of unit 6 is represented by about 10 m of thin-bedded, light grey, bioclastic, bioturbated packstones and wackestones. This unit overlies the Abadeh Formation with a sharp boundary. The upper part of unit 6 is represented by light olive-green wackestones and mudstones containing a few foraminifera.

Prior to the P/T boundary, a major sea-level rise is documented by a change in litho- and biofacies from a shelf to a basinal environment. The uppermost Permian limestones grade into 15 m of reddish nodu-

lar ammonoid-bearing (*Paratirolites*) deep-water limestones of the Dorashamian. They contain mainly conodonts, ostracods, fish remains and ammonoids and are poor in foraminifera. These red beds (unit 7 of Taraz *et al.*, 1981) are correlated with the Dzhulfa (*sensu lato*) beds in Iranian Julfa and the Dorasham beds in Armenian Dzhulfa (Taraz *et al.*, 1981, p. 89). The lowermost Triassic sharply overlies the unit 7. The first beds consist of yellow calcareous shale and marl followed by a stromatolitic limestone with thrombolitic (non-laminated stromatolites) mounds (1 m thick) in Abadeh and considerably thinly developed in Shahreza (Taraz *et al.*, 1981; Heydari *et al.*, 2000, 2003; Sharland *et al.*, 2001). The stromatolitic limestone is followed by red, paper-thin bedded, silty limestone, which yielded rare ammonoids and ostracods.

PREVIOUS WORK

Large fusulinids of the Iranian middle Permian were first described by Kahler (1933) and later by Douglas (1936, 1950), Kahler (1974), and Kahler and Kahler (1979). Other biostratigraphical studies began systematically with the middle/late Permian brachiopods and ammonoids, principally in Armenia and across the border in Iran (Ruzhentsev and Sarytcheva, 1965, Stepanov *et al.*, 1969, Waterhouse, 1976). The Abadehian stage was created by Taraz (1971, 1973, 1974). The microfauna of Armenia were subsequently studied by Kotlyar *et al.* (1984, 1989), and those of Iran by Bozorgnia (1973), Teichert *et al.* (1973), Zaninetti *et al.* (1978), Altiner *et al.* (1980), Taraz *et al.* (1981), Jenny-Deshusses (1983), Kalandari (1986), Baghbani (1993, 1997, 2000), Partoazar (1995, 2002), Sweet and Mei (1999), Taraz (1999a-b).

A historical review of the Permian-Triassic in Iran was compiled by Taraz *et al.* (= Iranian Japanese Research Group) (1981). These authors, (a) examined accurately the sections of the Abadeh region, described with three stages: Abadehian, Dzhulfian and Dorashamian; (b) contributed to a detailed investigation of the Dzhulfian stratotype; (c) concluded that the first Triassic biozone (i. e., *Otoceras woodwardi* zone) is probably missing in Abadeh. More exactly, this zone was correlated with the thrombolite limestones of unit A (Nakazawa, 1992); see also the discussion about the *Otoceras woodwardi* zone in Wignall and Hallam (1993, p. 218).

According to the complete study of Baghbani (1993), the Permian system, in the Abadeh region, begins with the Vazhnan Formation, which contains *Occidentoschwagerina* sp. (sic: *Pseudoschwagerina*, Baghbani, 1993, Pl. 1, Fig. 1), *Pseudofusulinoides* (sic: *Pseudofusulina*, Baghbani, 1993, Pl. 1, Fig. 3) "*Schwagerina*" sp., *Triticites* sp. and *Zellia* sp. (sic: *Robustoschwagerina*, Baghbani, 1993, Pl. 1, Fig. 4). Great affinity exists between the Vazhnan Formation and the lower Permian of the Hadim Nappe (central Turkey), studied by Okuyucu (1999). The Vazhnan Formation is separated from the Surmaq Formation by an unconformity (Leven, 1994). The Surmaq Formation exhibits all the zones of the late early Permian to middle Permian: *Darvasites*, *Misellina*, *Cancellina*, *Maklaya*, *Afghanella*, *Neoschwagerina*, *Skinnerella*, *Paraskinnerella*, *Eopolydiexodina* (Baghbani, 1993; Leven, 1998; Kobayashi and Ishii, 2003). The Abadeh Formation is characterized by *Yabeina* and *Metadoliolina*, i. e., Midian/Capitanian

fossils. The lower Hambast Formation is characterized by *Codonofusiella* (Taraz *et al.*, 1981; Baghbani, 1993). An indication of a middle Dzhulfian foraminifera is given in the lower part of the Hambast Formation with *Reichelina* and *Pseudodunbarula* (interpreted as *Nanlingella* by Baghbani, 1993). The comparisons between Armenia (and Transcaucasia in general) and Iran were newly compiled by Leven (1998).

Sequence stratigraphy of the Hambast Mountains was established by Sharland *et al.* (2001). Among maximum flooding surfaces defined in Saudi Arabia, the MFS P20 and TR 10 can be precisely located respectively at the base of Taraz's unit 5 and unit A. The MFS P30 and P40 are only approximately located within the unit 7 (Sharland *et al.*, 2001, Fig. 4. 26, p. 175). The Permo-Triassic boundary in the Abadeh region was recently investigated by Heydari *et al.* (2000, 2003), who demonstrated the continuity with the Permian and investigated accurately the two first beds: (a) thrombolites (resembling to bothryoid cements); (b) ooidal or peloidal grainstone.

The geodynamic analysis rapidly progressed with many works, e. g., Braud and Ricou (1975); Stöcklin (1977); Sengör (1984); Sengör *et al.* (1984); Wensink (1991); Dercourt *et al.* (1993); Scotese and Langford (1995); Sengör and Natalin (1996); Besse *et al.* (1998); Lemaire *et al.* (1998); Jenny-Deshusses and Stampfli (2000). Carboniferous-earliest Permian rifting of the Cimmerian plates, including Lut, Qiantang, and Sibumasu from Gondwana, turned into drifting during the Permian, marking the start of the opening of the Neotethys Ocean. Rifting and the subsequent opening of oceanic basin probably occurred also in the Eastern Mediterranean areas, which is represented by the deep-water sediments of Sicily, Lago Negro (southern Appennines, Italy) and Creta (Greece). However, these hemipelagic accumulations are most probably Triassic in age (Vachard *et al.*, 2001), and at least locally contain reworked Dorashamian *Colaniella* (Jenny-Deshusses *et al.*, 2000).

The idea of Lemaire *et al.* (1998) is interesting, but completely opposed to Besse *et al.* (1998) with respect to the senses of migration of Iranian plates. It is mechanically complicated, since it considers strong lateral displacements associated with the evolution of a Pangea B (Irving, 1977) to a Pangea A2 (van der Voo and French, 1974) during the Permian, and finally to a Pangea A (Bullard *et al.*, 1965) during the Jurassic. The models of Tethys as a vast ocean that disappeared in later subduction are too

simple for understanding the Permian paleogeographic evolution.

As generally admitted, the continued northward drift of the Cimmerian continent corresponds with the closing and progressive consumption of the Paleotethys oceanic crust and the opening of the Neotethys Ocean. Active subduction existed along northern Paleotethys convergent margins (e. g. Dercourt *et al.*, 1993; Baud *et al.*, 1993; Stampfli and Pillevert, 1993; Nairn *et al.*, 1996; Ueno, 2003). At this time, the Neotethys Ocean could be already fully opened. This ocean is bordered on one side by Arabia, Greater India and Australia, and Lut-Qiantang-Southeast Asia on the other side. These reconstructions are controversial, and are opposite to the absence of evidence of Permian oceanic deposits in Iran or in Afghanistan (Vachard, 1980; Argyriadis and Vachard, 2003), a hypothesis which begins to be accepted (Yin, 1999; see also the palaeocontinental reconstructions of Erwin, 1992, and Wilde, 2002).

Concerning the problem of the respective dating of the Dzhulfian-Dorashamian deposits in Iran, data are often contradictory; e. g., Kozur *et al.* (1975), Mostler and Rahimi-Yazd (1976), Taraz *et al.* (1981), Jenny-Deshusses and Baud (1989), Iranian-Chinese Research Group (1995), Baghbani (1997, 2000), Leven (1998), Sweet and Mei (1999), Taraz (1999 a-b). The Dorashamian is often considered to be lacking, for instance in Alborz, because of the absence of *Colaniella* and *Palaeofusulina*. (Gaillot, comm. pers.). The question of the systematic correlation of the *Palaeofusulina sinensis-Colaniella parva* zone, in the late Dzhulfian/Dorashamian is clearly demonstrated by Reitlinger (1965), Leven (1975), Altiner *et al.* (1980), Altiner (1981, 1984), Köylüoğlu and Altiner (1989), and Vachard *et al.* (2002). We agree with Altiner (1981, Fig. 25, p. 92) for the order of appearance of the principal biostratigraphical markers, but we attribute other periods to these appearances (see also Vachard *et al.*, 2002).

BIOSTRATIGRAPHY

The late Permian (or post-keriotheca phase) is characterized by the absence of fusulinids schwagerinoids and neoschwagerinoids, which disappeared in the middle and/or late part of the Midian/Capitanian (e. g., Sheng, 1992, Jin *et al.*, 1994). Large fusulinid species (with a shell width of more than 6 mm) and species with distinctive keriotheca in the wall structure became extinct during the Midian/Capitanian mass

extinction. Survivors were small species with simple wall structures (see discussion in Wilde, 2002).

Many global explanations were suggested, e. g., (a) the Guadalupian supersequence represents a time when the relative sea level is near its Phanerozoic minimum (Ross and Ross, 1988, 1994, 1995); or (b) the warming that followed the Gondwanian glaciation seems, according to Crowell (1995) to correspond closely with the extinction event at the Permian-Triassic boundary (Sepkoski, 1989). This climatic change and biological extinction is perhaps related to the plate reorganization mentioned above.

The last giant fusulinids from Iran are *Yabeina* sp. reported from the Abadeh Formation of the Abadeh region (Baghbani, 1993, Pl. 4, Fig. 3, Pl. 5, Fig. 1-2). The species identified by Baghbani (1993) is *Yabeina syrtalis* (Douville 1934), and this species is of early Midian age in Jebel Tebaga of Tunisia (Vachard and Razgallah, 1993). The late Midian, in our samples, is only characterized by the probably endemic nodosarioid *Reitlingeria* sp. This late Midian and the early Dzhulfian contains a relatively rich and diverse foraminiferal assemblages (Fig. 3). The schubertelloids *Codonofusiella* are index fossils previously reported by Taraz *et al.* (1981), but without illustration. Here, we confirm the importance of the other schubertelloid *Pseudodunbarula*, considered as characteristic of the Dzhulfian by Kotlyar *et al.* (1984). The smaller foraminifera absent in the late Midian and present in the early Dzhulfian are *Dagmarita chanakchiensis* Reitlinger, 1965; *D. sharezaensis* Mohtat-Aghai and Vachard, 2003 and *Fronidina permica* Sellier de Civrieux and Dessauvage, 1965 (Fig. 3). *D. chanakchiensis* appears in the early Wordian, and is still common in the late Wordian = late Murgabian (Vachard, 1980), but the early Dzhulfian is probably the FAD of *Fronidina permica* and *Dagmarita shahrezaensis* (Fig. 3).

The LAD of *Fronidina permica* is in Dorashamian (e. g., Lys *et al.*, 1980, Pl. 4, Figs. 2-3, Altiner, 1981, Köylüoğlu and Altiner, 1989), often documented under different taxonomic names: i. e., *Lunucammia* cf. *palmata* (Wang) sensu Kobayashi (2002), or *Pseudoglandulina conicula* Wang in Zhao *et al.* (1981, Pl. 3, Figs. 10-11). The possible LAD of *Dagmarita shahrezaensis* is late Dzhulfian in Koh-e Surmeh (Zagros) (Gaillot, unpublished).

The Midian to Triassic section of Shareza can be subdivided into seven biozones, at the Permian-Triassic boundary (Figs. 3-5):

(1) the early Midian (= early/middle Abadehian; Taraz's zone 4b) with *Yabeina* (2) the late Midian

(= late Abadehian; Taraz's zone 5) with *Reitlingeria*; (3) the earliest Dzhulfian (= base of Hambast Formation; lower part of Taraz's zone 6) with the

appearance of *Reichelina*, *Codonofusiella*, *Pseudodunbarula* and *Neohemigordius*. This age, at the base of Dzhulfian, is confirmed by the presence of the

FORMATIONS		AGES	BIOZONES - EXTINCTIONS		
A	ELIKA	earliest TRIASSIC	7	<i>Orthovertella shalshalensis</i>	
				← (E4) Permo-Triassic crisis	
7	HAMBAST	DORASHAMIAN (=Changhsingian)	6	rare resedimented <i>Neoendothyra</i>	
				← (E3) Offshore passing to basin	
		late	5	rare <i>Reichelina</i>	
6		DZHULFIAN (=Wuchiapingian)	4	← (E2) Local extinction poorly explained (late Dzhulfian crisis ?)	
				<i>D. sharezaensis</i> - <i>F. permica</i>	
				- continuity (lithological change, no extinction)	
		earliest	3	<i>Codonofusiella</i> - <i>Reichelina</i> - <i>Neohemigordius</i>	
				- continuity	
5	ABADEH	late MIDIAN	2	<i>Reitlingeria</i>	
				← (E1) Local disappearance of giant fusulinids	
4 b		early MIDIAN	1	<i>Yabeina</i>	

FIGURE 4—Biostratigraphical subdivisions of the Abadehian (Midian/Capitanian), Dzhulfian, Dorashamian and early Triassic of Hambast area. Abbreviations: 4a to A: Taraz's lithological zones; 1 to 7 = foraminiferal biozones (this work, explanations in the text).

conodont species *Clarkina dukouensis* (Iranian-Chinese Research Group, 1995; Taraz, 1999b; Sweet and Mei, 1999). This biozone (3) occurs only locally, because *Codonofusiella* appears earlier in other areas, for instance it is late Midian in Salt Range, Pakistan (Douglass, 1970 up-dated by Vachard *et al.*, 2002), early Midian in the Tethys (Leven, 1993) or early Capitanian in Texas (Wilde, 2002); the “late Murgabian” beds with *Codonofusiella* (Vachard and Ferrière, 1991) results from a misinterpretation of the biostratigraphy of associated *Neoschwagerina margaritae* Deprat, considered before the revision of Leven (1992, 1993) as late Murgabian/Wordian in age; (4) the early Dzhulfian (upper part of Taraz’s zone 6) from the local appearance of *Dagmarita shahrezaensis* (more or less coeval of that of *Fronidina permica*) to the local disappearance of *Pseudodunbarula arpaensis* (5) the late Dzhulfian (= upper part of Taraz’s zone 6) is poor in foraminifera and reveals only rare *Codonofusiella*; no local ecologic explanation has been discovered, and consequently the phenomenon might be more general and correspond to a early/late Dzhulfian crisis, characterized herein for the first time among the foraminifera, but corresponding eventually to the “Wuchiapingian-warming” revealed by conodonts (Mei *et al.*, 1999); (6) the Dorashamian, i.e. the last biozone of Permian foraminifera (= Taraz’s zone 7) is accurately subdivided by ammonoids; the foraminifera almost disappeared with the fluctuation of ecology and facies from a shelf to a basinal environment. In Iran, the Dorashamian markers *Paradagmarita* and *Colaniella* are limited to Zagros and Alborz-Shotori Range, respectively, during Dzhulfian and Dorashamian (Partoazar, 1995; Baghbani, 1997); only *Neoendothyra reicheli* was discovered up to the top of this zone; (7) the paucity of the Triassic beds, with rare foraminifera, for instance *Orthovertella shalshalensis*, since the base.

The seven biozones are in continuity, or separated by four extinction events, E1 to E4 (Fig. 4). Extinction events E1 and E4 are very significant regional (or global datums). In contrast, events E2 and E3 probably are local phenomena best explained by local paleoenvironmental controls.

Parallelized with the boundaries of sequential stratigraphy defined by Sharland *et al.* (2001), E1 correspond to P 20 of Sharland *et al.* (2001), E4 to Tr 10; consequently E2 and E3 can correspond respectively to P 30 and P 40, which correspond to the early/late Dzhulfian and Dzhulfian/Dorashamian. These locations are conform with the dating of Vaslet *et al.* (in press) in Saudi Arabia. For the rela-

tions between bioevents and sequence boundaries or maximum flooding surfaces, see for instance Brett (1998).

A hypothetical correlation of these foraminiferal zones, with the other marker zones (conodont, ammonoid, brachiopod) is proposed (Fig. 5) The main result is the correlation between the zones of *dukouensis*, *Araxilevis* and the probable LAD of *Pseudodunbarula* (Fig. 5).

MICROPALAEONTOLOGY

1. Taxonomic list

The illustrated taxa are as follows: *Gymnocodium bellerophontis* (Rothpletz, 1894) Pia, 1937, *Permocalculus digitatus* Elliott, 1955, *P. fragilis* (Pia, 1937), *P. tenellus* (Pia, 1937), *Epimastoporella* (?) sp., *Neoendothyra reicheli* Reitlinger, 1965, *Palaeotextularia* sp., *Deckerella* cf. *composita* Reitlinger, 1950, *Climacammina valvulinoides* Lange, 1925, *C. sphaerica* Potievskaya, 1962, *Globivalvulina* ex gr. *bulloides* Brady, 1876, *Septoglobivalvulina decrouezae* (Köylioglu and Altiner, 1989), *Dagmarita chanaekchiensis* Reitlinger, 1965, *D. shahrezaensis* Mohtat-Aghaï and Vachard, 2003, *Nankinella minor* Sheng, 1955, *Codonofusiella kwangsiana* Sheng 1963, *C. schubertelloides* Sheng, 1956, *Pseudodunbarula arpaensis* Chediya in Kotlyar *et al.*, 1984, *Cyclogyra* sp., *Hemigordiellina* spp., *Orthovertella shalshalensis* Kristan-Tollmann, 1984, *Hemigordius schlumbergeri* (Howchin, 1995), *Neohemigordius* aff. *zaninettiae* (Altiner, 1978), *Neodiscus* aff. *orbicus* Lin 1984, *Nodosinelloides* spp., *Geinitzina* spp., *Reitlingeria* sp., *Pseudolangella fragilis* Sellier de Civrieux and Dessauvague, 1965, *Calvezina* sp., and *Fronidina permica* Sellier de Civrieux and Dessauvague, 1965.

2. Algae

Gymnocodiacean red algae similar to the Recent red algae Galaxauraceae, are abundant and diversified (Pl. 1, Figs. 1-2, 4-6). The assemblage of *Gymnocodium* and *Permocalculus* is characteristic of a shallow marine unconfined offshore (Vachard *et al.*, 2003). Classical fertile specimens of *Permocalculus fragilis* are present (Pl. 1, Figs. 4, 6), but also more rare fertile *P. tenellus* (Pl. 1, Fig. 2).

Dasycladales are very rare. No *Mizzia* has been observed. An unique thallus of *Epimastoporella* (?) sp. indicates the presence of the group (Pl. 1, Fig. 3).

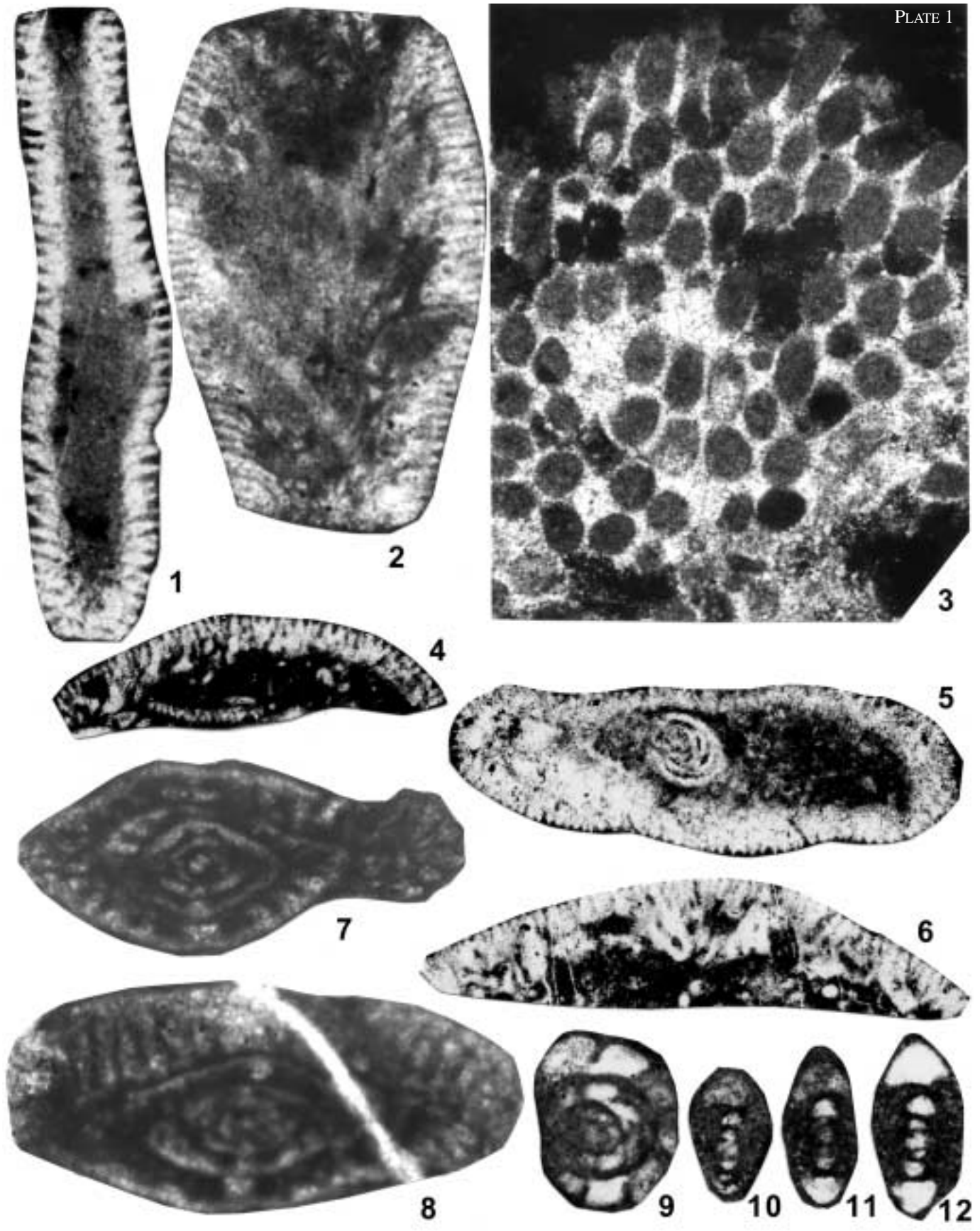
	CONODONTS (1)	AMMONOIDS (Brachiopods)(2)	FORAMINIFERA (3)	
DORAS- HAMIAN	changxingensis	Paratirolites Shevyrites- Iranites Phisonites	last <i>Neoendothyra</i>	6
	subcarinata		↘	
DZHUL- FIAN	wangi	Vedioceras- Haydenella	last local <i>Codonofusiella</i>	5
	orientalis			
	transcaucasica			
	guangyuanensis	Araxoceras- Oldhamina	last local <i>Pseudodunbarula</i>	4
	leveni			
	asymmetrica		acme <i>Codonofusiella- Pseudodunbarula</i>	
			<i>Dagmarita chanakchiensis</i> ↑ <i>Froncina permica</i> ↑	
dukouensis	Araxilevis	<i>Neohemigordius</i> ↑ <i>Codonofusiella</i> ↑ <i>Reichelina</i> ↑ <i>Pseudodunbarula</i> ↑	3	
MIDIAN	altudaensis	Eoaraxoceras	<i>Reitlingeria</i> ↘ ↑	2
	postserrata	Stacheoceras Waagenoceras	<i>Yabeina</i> ↘	1

FIGURE 5—Composite table showing the different biozones (1) according to Wardlaw, 1999; (2) Ruzhentsev and Sarycheva, 1965; Waterhouse, 1976; Taraz *et al.*, 1981; Taraz, 1999b; and (3) this study. Abbreviations: 1 to 6 = biozones introduced in this work.

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PLATE 1–1, *Gymnocodium bellerophontis* (Rothpletz, 1894) Pia, 1937. Subtransverse section, sample A20, x 30. 2, *Permocalculus tenellus* (Pia, 1937). Longitudinal section, sample A18/1, x 28. 3, *Dasycladale indeterminatae* (cf. *Epimastoporella* sp.). Subtangential section, sample A13, x 24. 4, 6, *Permocalculus fragilis* (Pia, 1937). Two fragmentary longitudinal sections. 4, sample S12, x 25. 6, sample S4, x 30. 5, *Permocalculus digitatus* Elliott, 1955. Longitudinal section, sample S15, x 24. 7, *Pseudodunbarula arpaensis* Chediya in Kotlyar *et al.*, 1984. Axial section, sample SA19b/1, x 110. 8, *Codonofusiella kwangiana* Sheng, 1963. Axial section, sample SA19b/1, x 105. 9–12, *Neoendothyra reicheli* Reitlinger, 1965. 9, transverse section, sample S49, x 77. 10–12, axial sections, samples S50, x 65; S64, x 62, and S50, x 80.

PLATE 1



3. Endothyrida (*Neoendothyra*, Palaeotextulariidae, Biseriamminidae)

Neoendothyra is generally absent, but sporadically found at the top of the red nodular limestones (Pl. 1, Figs. 9-12). They are associated with *Cyclogyra* sp. (Pl. 2, Fig. 14). They were probably derived from a shallower environment. These foraminifera excepted, the microfacies are similar to that of the ammonitico-rosso (compare with Mamet and Pr at, 2003) or griottes (see Perret *et al.*, 1994) of the literature, i. e., a ferruginous bioclastic wackestone with ammonoids, sponge spicules, gastropods, ostracodes and thallophyta perforations, whose recent equivalents are situated at 300-800 m water depth on the slope of the Bahamian Platform (e. g., Mullins *et al.*, 1980).

Palaeotextulariidae are sporadically common. They are represented by rather primitive specimens (Pl. 2, Fig. 20; Pl. 3, Figs. 1-4). Only *Climacammina valvulinoides* (Pl. 3, Figs. 1-2) is relatively characteristic of the middle/late Permian (Lange, 1925; Bozorgnia, 1973; Kobayashi, 1997).

Biseriamminids sensu Loeblich and Tappan (1988) (i. e., globivalvulinids) are poorly diversified and only represented by *Globivalvulina* ex gr. *bulloides* Brady, 1876, *Septoglobivalvulina decrouezae* (K ylyo glu and Altiner, 1989) (Pl. 2, Fig. 17), *Dagmarita chankiensis* Reitlinger, 1965 (Pl. 3, Fig. 6), *D. shahrezaensis* Mohtat-Aghai and Vachard, 2003 (Pl. 2, Figs. 21-22; Pl. 3, Fig. 5). Neither *Paraglobivalvulina mira* Reitlinger, 1965, nor *Paradagmarita* spp. were discovered. The absences of these species are significantly important, since *Paradagmarita* is considered to be Dorashamian by Vachard *et al.* (2002), or late Dzhulfian to Dorashamian according to Zaninetti *et al.* (1981).

4. Fusulinida

Nankinella minor Sheng, 1955, a small species of the genus, is rarely abraded (Pl. 2, Figs. 8-9), contrary to the taphonomical morphotypes called *Hayasakina* Fujimoto and Kawada, 1953, frequent in Zagros Mountains of southern Iran (Gaillot, comm. pers.).

Pseudodunbarula arpaensis Chediya in Kotlyar *et al.*, 1984 (Pl. 1, Fig. 7; Pl. 2, Fig. 1) is rather frequent in the zones 3 and 4 (Fig. 3). It is generally considered as characteristic of the zone with *Codonofusiella* and *Araxilevis* (Kotlyar *et al.*, 1984), i. e., the early Dzhulfian (Kotlyar *et al.*, 1991, Kotlyar and Pronina, 1995). This species is sometimes difficult to distinguish from the juveniles of some *Codonofusiella* species. *Pseudodunbarula* has been previously mentioned under the name *Nanlingella* spp., by Baghbani (1993, Pl. 6, Figs. 10-12) in the Abadeh area.

Codonofusiella kwangsiana Sheng 1963 (= *C. laxa* Douglass, 1970; = *C. extensa* Skinner and Wilde, 1955 sensu Leppig, 1995) is characterized by 3-4 internal, fusiform volutions with rather regular septa, and a larger uncoiled last whorl, trapezoid in shape and irregularly folded (Pl. 1, Fig. 8; Pl. 2, Figs. 2-4). *C. schubertelloides* Sheng, 1956, is a minute species, with a relatively large and narrow uncoiled part (Pl. 2, Figs. 5-7).

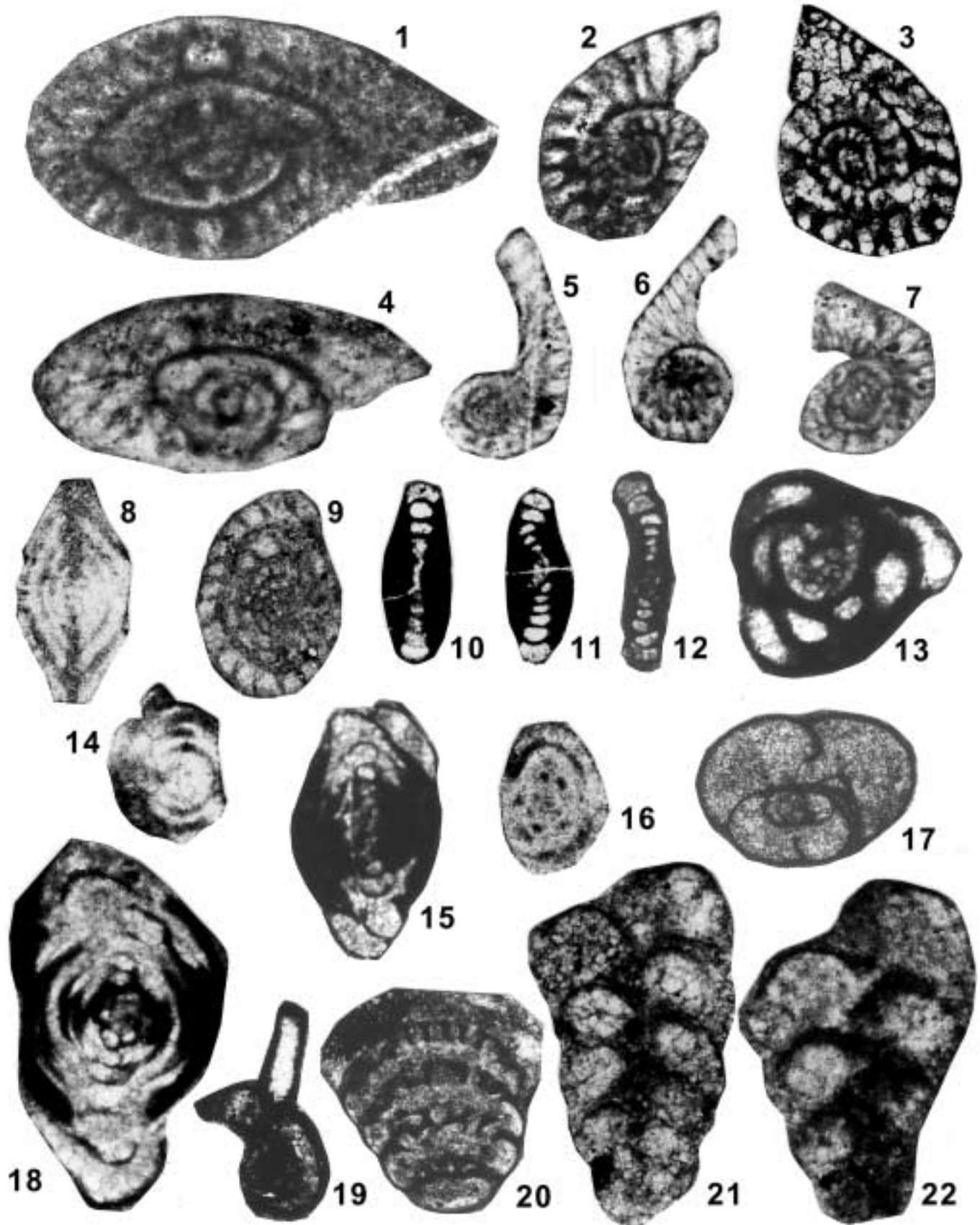
Reichelina, often associated with *Codonofusiella* is surprisingly very rare here.

5. Miliolida

Miliolids are relatively poorly diversified in the Shahreza section. The hemigordiids are represented by *Neohemigordius* aff. *zaninettiae* (Altiner, 1978) sensu Vachard and Ferri re, 1991 (Pl. 2, Figs. 10-11) (= *H. discoides* Lin, Li and Sun, 1990 sensu Pronina

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PLATE 2-1, *Pseudodunbarula arpaensis* Chediya in Kotlyar *et al.*, 1984. 1, Axial section, sample SA19b/1, x 120. 2-4, *Codonofusiella kwangsiana* Sheng, 1963. 2, transverse section, sample S11, x 85. 3, transverse section, sample S7, x 83. 4, subaxial section, sample A20, x 115. 5-7, *Codonofusiella schubertelloides* Sheng, 1956. Three axial sections, sample S20, x 80. 8-9, *Nankinella minor* Sheng, 1955. 8, axial section, sample S5/1, x 28. 9, transverse section, sample A24, x 40. 10-11, *Neohemigordius* aff. *zaninettiae* (Altiner, 1978). Two axial sections, sample S5, x 70 and x 80. 12, *Hemigordius schlumbergeri* (Howchin, 1895). Axial section, sample SA19b, x 100. 13, *Hemigordiellina* ("Glomospira") sp. 2. Axial section, sample A20, x 100. 14, *Cyclogyra* sp. Oblique section, sample S34, x 75. 15, 18, *Neodiscus* aff. *orbicus* Lin, 1984. Two subaxial sections, sample SA19b, x 100 and x 90. 16, *Hemigordiellina* ("Glomospira") sp. 1. Transverse section, sample S10, x 100. 17, *Septoglobivalvulina decrouezae* (K ylyo glu and Altiner, 1989). Subtransverse section, sample S8, x 70. 19, *Orthovertella shalshalensis* Kristan-Tollmann, 1984. Subaxial section, sample S70, x 80. 20, *Climacammina sphaerica* Potievskaya, 1962. Oblique axial section, sample S8, x 26. 21-22, *Dagmarita shahrezaensis* Mohtat-Aghai and Vachard, 2003. Two oblique axial sections, sample SA19b, x 80 and x 130.



Nestell and Nestell, 2001, Pl. 1, Figs. 4-5; ? = *H. admirabilis* Pronina, 1999, Pl. 6-7, Figs. 3-5; = *H. sp.* Kotlyar *et al.*, 1984, Pl. 6, Fig. 2-4) and its probable ancestor, *Hemigordius schlumbergeri* (Howchin, 1895) (Pl. 2, Fig. 12), a species which appeared in the late Pennsylvanian, and often called *Discospirella* or *Okimuraites* during the Permian (Vdovenko *et al.*, 1993; Baghbani, 1993, Pl. 6, Figs. 3-4), or also denominated *Hemigordius discoides* Lin, Li and Sun, 1990; *Hemigordius nikitinensis* Pronina-Nestell and Nestell, 2001; or *Pseudovidalina* spp. (Kobayashi, 2002, Fig. 9. 1-5). Another interesting taxon is *Neodiscus* aff. *orbicus* Lin, 1984 (Pl. 2, Figs. 15, 18), whose specimens differ from the figured types of this species from the early Permian of China (Lin, Li and Sun, 1990, p. 89), by the shape of the volutions. The inventory is completed by *Cyclogyra* sp. (Pl. 2, Fig. 14), resedimented in the red nodular limestones with *Neoendothyra reicheli*. The taxa *Hemigordiellina* spp. (Pl. 2, Figs. 13, 16) correspond to the false porcelaneous “*Glomospira*” of the authors (see emendation in Vachard and Beckary, 1991). *Orthovertella shalshalensis* Kristan-Tollmann, 1984 (Pl. 2, Fig. 19), is locally characteristic, as in the Himalayas, of the first beds of the Triassic, while *Cornuspira* (?) *mahajeri* Brönnimann, Zaninetti and Bozorgnia, *Rectocornuspira kalhori* Brönnimann, Zaninetti and Bozorgnia, and *Aeolisaccus tintinniformis* Misik from the central and eastern Alborz (northern Iran), western and eastern Taurus (Turkey), and Dolomites, Italy (Brönnimann *et al.*, 1972; Zaninetti *et al.*, 1972; Stampfli *et al.*, 1976; Altiner and Zaninetti, 1980; Altiner, 1981; Crasquin-Soleau *et al.*, 2002) were not found in the investigated area.

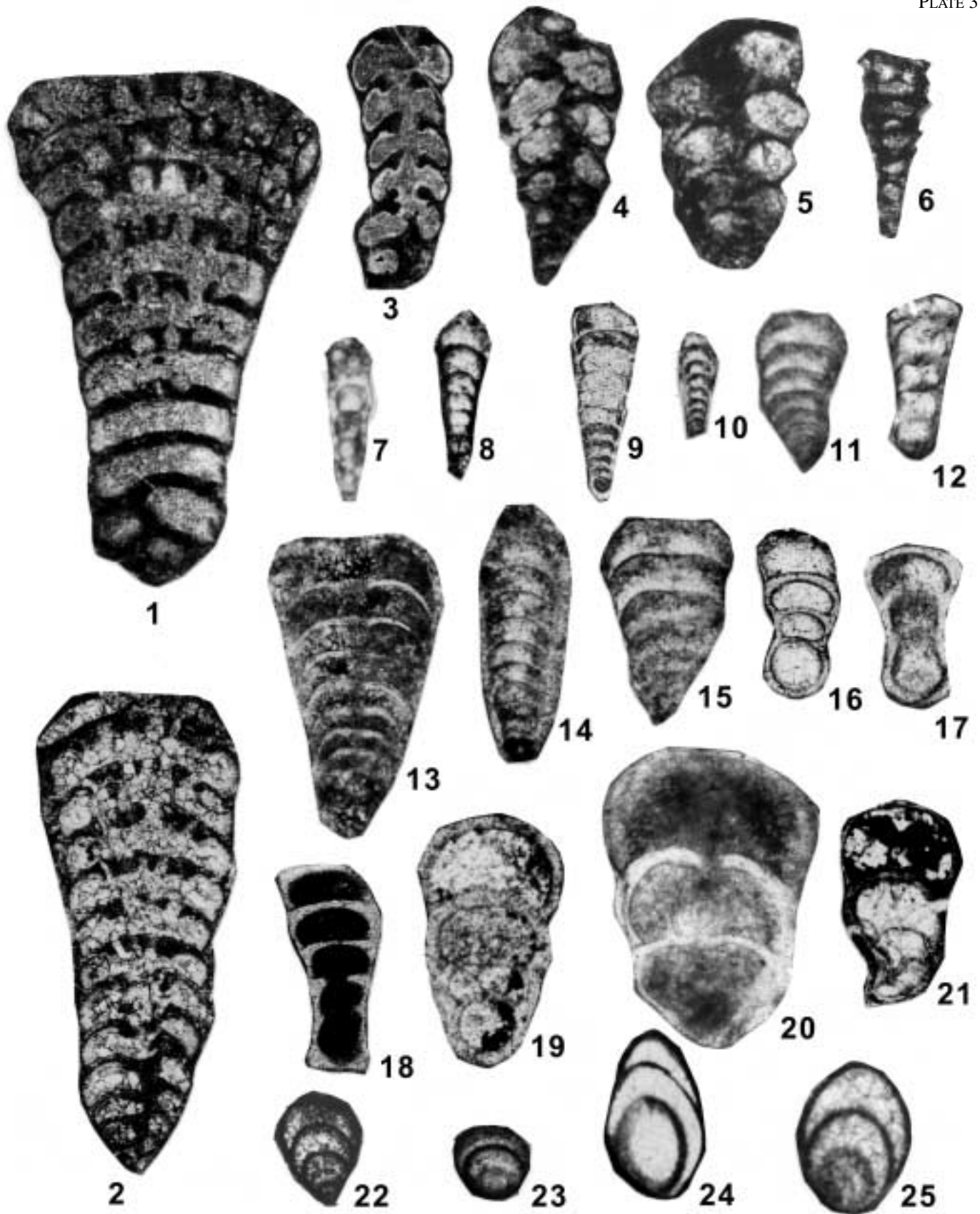
6. Lagenida

Primitive, i. e., late Carboniferous/early Permian, species of *Nodosinelloides* spp. and *Geinitzina* spp. remain common in the middle and late Permian (Pl. 3, Figs. 7-15). *Reitlingeria* (Pl. 3, Figs. 16-18) was described in the Midian (= Capitanian) of Transcaucasia (Kotlyar *et al.*, 1989). The middle/late Permian representatives are three: *Pseudolangella fragilis*, *Calvezina* sp. and *Fronidina permica* (Pl. 3, Figs. 19-25). Although controversial, because it is mentioned in the Midian by Kotlyar *et al.* (1989), *Fronidina permica* sensu stricto is proposed here as a marker of the Dzhulfian-Dorashamian. The Midian forms are most probably species of *Ichtyofronidina* Vachard (in Vachard and Ferrière, 1991).

Colaniella are completely lacking. No favourable facies, i. e., with other nodosarioids or *Rectostipulina*, were encountered in our samples, although *Rectostipulina* are mentioned in the area by Baghbani (1993, Pl. 6, Figs. 6-7). Contrary to Jenny-Deshusses et Baud (1989), or Vachard *et al.* (2002, 2003), the FAD of *Colaniella* is probably not late Midian or late Dzhulfian in age, but only Dorashamian in age. The citation of *Colaniella* in the late Midian (Chediya and Davydov, 1982; Jenny-Deshusses and Baud, 1989) was probably caused by associated *Shindella*, which are previously considered as indicating late Midian (Kotlyar *et al.*, 1984). This *Shindella* is probably assigned to *Palaeofusulina nana* Likharev by Pronina-Nestell and Nestell (2001), and to *Shindella shindensis* Chediya by Skourtsos *et al.* (2002) and Vachard *et al.* (2003). We consider here, as Lin *et al.* (1990), the genus *Colaniella* is restricted to the Changhsingian/Dorashamian.

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PLATE 3-1-2, *Climacammina valvulinoides* Lange, 1925. Two subaxial sections. 1, sample SA19b, x 23. 2, sample S6, x 23. 3, *Deckerella* cf. *composita* Reitlinger, 1950. Subaxial section, sample S8, x 25. 4, *Palaeotextularia* sp. Subaxial section, sample A16, x 37. 5, *Dagmarita shahrezaensis* Mohtat-Aghaï and Vachard, 2003. Oblique axial section, sample SA19b, x 90. 6, *Dagmarita chanakchiensis* Reitlinger, 1965. Sagittal section, sample S8, x 37. 7-10, 12, *Nodosinelloides* spp. Five oblique sections. 7, sample S8, x 70. 8, sample S5, x 50. 9, sample S64, x 60. 10, sample S8, x 100. 12, sample SA19b, x 80. 11, 13-15, *Geinitzina* spp. Four oblique sections. 11, sample A22, x 85. 13, sample S8, x 78. 14, sample S10, x 75. 15, sample A22, x 100. 16-18, *Reitlingeria* sp. 16, axial section, sample S5, x 100. 17, transverse section, sample S29, x 55. 18, oblique section, sample S29, x 66. 19-20, *Pseudolangella fragilis* Sellier de Civrieux and Dessauvague, 1965. Two axial sections, sample A22, x 78 and x 90. 21, *Calvezina* sp. Oblique axial section, sample S5, x 88. 22-25, *Fronidina permica* Sellier de Civrieux and Dessauvague, 1965. 22, axial section, sample S8, x 100. 23, subtransverse section, sample S8, x 140. 24, oblique axial section, sample S5, x 60. 25, oblique axial section, sample SA19b, x 70.



NATURE OF THE EXTINCTIONS

In the boundary sections of Shahreza and Abadeh, large numbers of species disappear a few meters above the Dzhulfian sediments. Systematic paleontological data worldwide compiled by Sepkoski (1992) show that the end-Permian extinction affected many taxa, including all the remaining trilobites, all the fusulinid and 94% of the non-fusulinid foraminiferal genera (Fig. 6), graptolites, all the blastoids, acanthoidians, rugose and tabulate corals, pelycosaur, 98% of the crinozoans (including all the inadunates and camerates), 96% of the anthozoans, virtually all the radiolaria, 96% of the brachiopod genera (including all the orthids and productids), 85% of the gastropods, 59% of the bivalves, 79% of the bryozoans (including all the fenestrates), 8 families of ostracods, and 97% of the ammonoids. Over 33 genera of ammonoids disappear near the P/T boundary. Tetrapod faunas were strongly affected by the P/T

extinction event. 21 tetrapod families (63%) disappeared at or near the P/T boundary (e. g., Benton, 1989).

Radiolaria extinction was almost complete (Fig. 6). Racki (1999) notes that recent studies of deep-water successions in Japan, Canada, China and Turkey document a crash in biosiliceous productivity, spectacularly recorded in a radiolarite gap across the P/T boundary. Except spherical spumellarian, radiolarians disappeared from the record at the P/T boundary event. Only three radiolarian species are known from the early Triassic.

Proposed mechanisms for the P/T mass extinction include principally (e. g., Heydari *et al.*, 2003): sea level fall, meteoric impact, severe cooling, global marine anoxia associated with a sea-level rise, Siberian trap volcanism, a combination of a sea-level fall, volcanism and anoxia. The important sea-level fall and change of environments (passing from basinal nodular limestones to intertidal microbialites) seems to be the most docu-

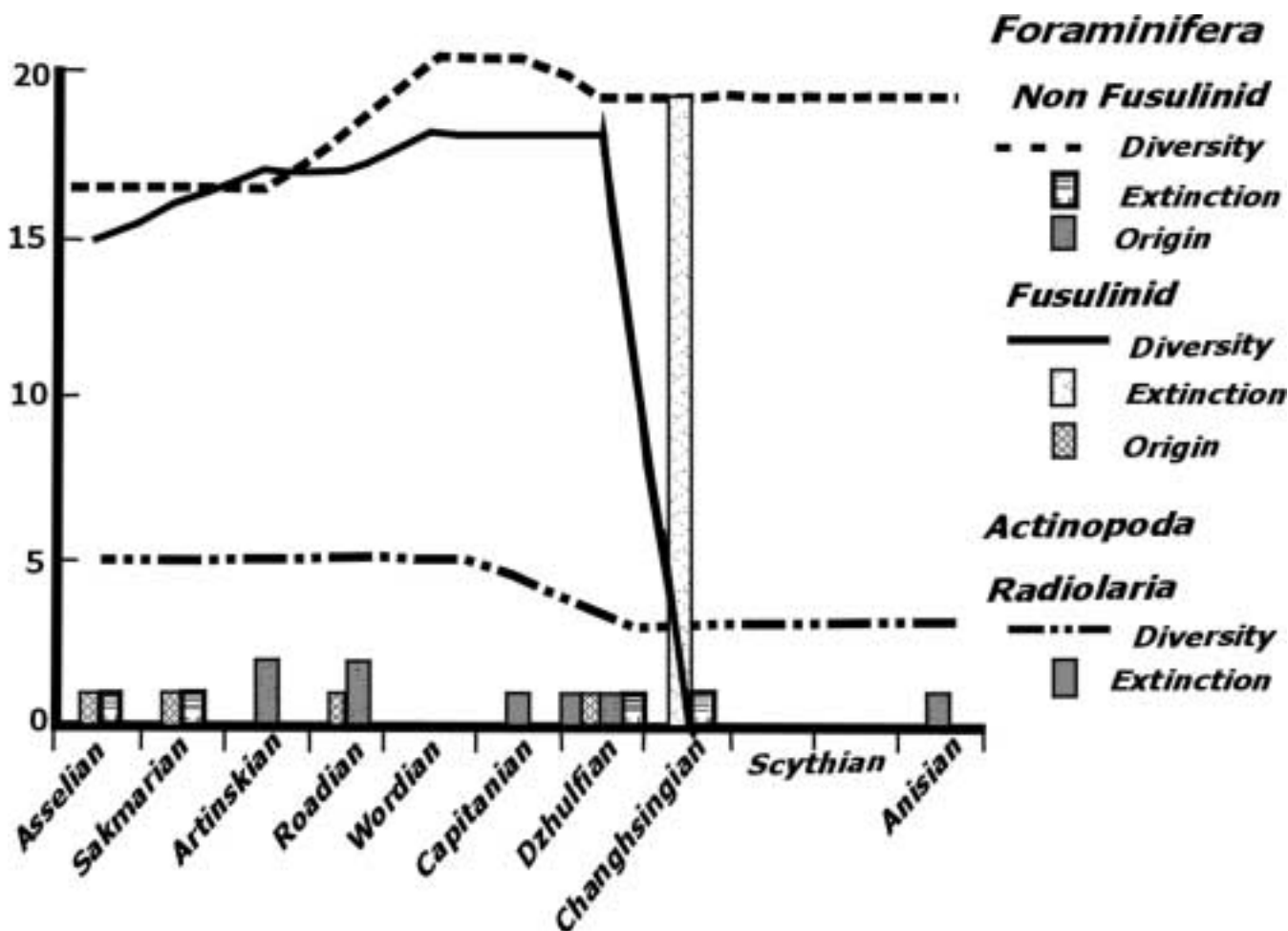


FIGURE 6—Patterns of foraminifera and radiolaria extinctions, from Sepkoski (1992).

mented phenomenon in the investigated Hambast area (Heydari *et al.*, 2003).

Recovery of marine ecosystems following the P/T boundary event progressed very slowly. Reefs disappeared near the boundary and did not recover until the middle Triassic (Flügel, 1994). The lack of reefs in the low latitudes during the latest Permian and the beginning of the Triassic is more logically connected to O₂ deficit both in the atmosphere and the hydrosphere as a consequence of the anoxic event across the P/T boundary (e. g., Baud *et al.*, 1989).

At the same time, microbes spread into many “normal” marine environments during the early Triassic, for the first time since the Ordovician, and formed various kinds of microbialites including stromatolites. Microbes constitute an important source of nutrients for benthic marine grazers, and their presence in early Triassic normal marine deposits was probably facilitated by the extinction of shallow-marine fauna that would normally consume them.

The subject of many studies about the P/T boundary is the development of foraminiferal faunas in relation to major disturbance of the marine environment during the late Permian time. These latter studies provided insight in the relationship between the nature and degree of stress in the marine environment, and the effects on associations of benthic foraminifera. The environmental factors, nature and duration of P/T boundary event and their importance are not always clear from foraminifera studies alone. Therefore, foraminifera data gathering went hand in hand with field and different laboratory experimental studies on some other biogene groups to develop an understanding and interpretation of such high extinction patterns.

In fact, late Permian faunas experienced a double mass extinction (e. g., Jin *et al.*, 1994). Extinction patterns of fusulinid foraminifera reveal that heavy extinction was at or near the end of the middle Permian/Guadalupian (265 million years). Foraminifera appear to have two major crises in the younger Permian: one, in Midian/Captain, which wiped the larger fusulinids out, and other one in the late Dorashamian, which mainly affected the small foraminifera. Micropaleontological studies of the Shahreza sections reveal that fusulinid larger foraminifera abruptly disappeared in the latest Midian/Capitanian.

A first relative absence of smaller foraminifera and small fusulinids exists from the late Dzhulfian (Fig. 3). Family diversity dropped from 40 during the middle Permian to near 20; generic diversity declined from over 100 to about 25 mostly among the fusulinids in the earliest Triassic (e.g., Loeblich

and Tappan, 1988). According to Sepkoski (1992) all the 19 families of the fusulinida disappeared during the Changhsingian/Dorashamian stage.

The non-fusulinid Permian foraminifera have also suffered some extinction. The five non-fusulinid orders, that originated in the Paleozoic and continued in the Mesozoic, are Allogromiida, Textulariida, Miliolida, Lagenida, and Involutinida. About 30 percent of the genera belonging to the order Textulariida became extinct and 50 percent of the Miliolida genera disappeared. Only the Lagenida and Involutinida showed a significant increase in the early Triassic (Loeblich and Tappan 1988). Comparison between the diversity of fusulinida and lagenida is clearly summarized by Groves and Boardman (1999, Fig. 5) and Groves (2002, Fig. 1).

The different extinction patterns of the foraminifera reflect two factors: (a) fusulinids were generally confined to shallow-water (less than 20 m), while non-fusulinid foraminifera lived in deeper waters. Their spreading pattern reveals that P/T extinction event hit higher in shallow environments than in deeper environments; (b) architecturally more complex forms on tropical shelves were heavily affected. In fact, these events can be more precisely related to a crisis of endosymbiotic microfaunas of the giant fusulinids (Vachard and Gaillot, unpublished data), more or less related to the continental “fungal event” (e. g., Visscher *et al.*, 1996; Cirilli *et al.*, 1998).

In Central Iran, the small foraminifera were relatively abundant during the early Dzhulfian, but were less numerous in the late Dzhulfian and Dorashamian and then in the early Triassic.

CONCLUSIONS

1. The passage between the Midian and the Dzhulfian is continuous in the Shahreza area (central Iran).
2. The giant fusulinids disappeared in the early Midian with *Yabeina*.
3. The index fossil of the late Midian is a small probably endemic nodosarioid: *Reitlingeria*.
4. Other well-known late Midian marker such as *Shanita* or *Lepidolina* are absent, probably because of the facies and the paleogeography (*Shanita* is an intertidal genus, *Lepidolina* is westernly limited to Tibet, and is mainly a Cathaysian and western Panthalassan genus; its presence in Turkey announced briefly by Kobayashi and Ishii, 2003, p. 163, must be documented and illustrated).

5. The local appearance of *Codonofusiella*, *Reichelina* and *Dagmarita chanakchiensis* is not a FAD, but due to an undetermined paleoecological factor.

6. The possible FAD, characteristic of the base of the Dzhulfian, are those of *Pseudodunbarula* and *Neohemigordius*.

7. The existence of a late Dzhulfian crisis is suggested.

8. The apparent extinction of the Dorashamian is due to the changing facies, from offshore to basin.

9. The locally observed extinctions E1, E2, E3, E4 are hypothetically correlated with the MFS of the Khuff Formation in Saudi Arabia: P20, P30, P40, and Tr10

10. The productivity on the shelf is probably higher at the end of the Dorashamian and permits the redeposit of *Neoendothyra* coming from the offshore.

11. The earliest Trias is characterized by stromatolites (or thrombolites) accompanied by the first Triassic microfauna, here as in the Himalayas with *Orthovertella shalshalensis*, and not with *Rectocornusupra kahlori* as in Alborz.

12. The Permian-Triassic boundary, as a crisis, is locally controlled by a drastic fall of sea level, with a sedimentation evolving from an "ammonitico-rosso" facies to microbialitic beds.

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BIOSTRATIGRAPHIE ET ASPECTS DU RENOUVELLEMENT DES FORAMINIFÈRES PLANCTONIQUES AU DANIEN BASAL DANS LA COUPE D'OULED HADDOU (RIF EXTERNE ORIENTAL, MAROC)

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Résumé

Dans le Rif externe oriental, les premiers stades de renouvellement des Foraminifères planctoniques au Danien basal se retrouvent dans de la coupe d'Ouled Haddou. La succession des étapes de renouvellement et des stades quantitatifs est établie avec précision, elle permet un découpage biochronologique détaillé de ces dépôts, et des corrélations avec d'autres régions. Au début du Danien, l'évolution des Foraminifères planctoniques s'effectue en trois étapes: au sein de la zone à *G. cretacea*, à la base de la zone à *P. eugubina* et au début de la zone à *P. pseudobulloides*. Plusieurs stades, dominés par des morphologies simples (appartenant aux genres *Guembelitra*, *Parvularugoglobigerina*, *Woodringina* et *Chiloguembelina*), se sont succédés dans un court intervalle qui précède l'expression des morphologies spécialisées, à paroi complexe, qui indiquent le passage aux associations classiques du Paléocène (à *Parasubbotina*, *Praemurica* et *Subbotina*).

Mots clé: Foraminifères planctoniques, Danien basal, Coupe d'Ouled Haddou, Rif externe, Maroc.

Resumen

En el Rif externo oriental, las primeras fases de renovación de foraminíferos planctónicos en los depósitos del Daniense basal se han reconocido en el corte de Ouled Haddou. La sucesión de las etapas de renovación y de las fases cuantitativas se ha establecido con precisión, permitiendo una subdivisión biocronológica detallada de los depósitos y su correlación con otras regiones. Al principio del Daniense, se reconocen tres etapas en la evolución de los foraminíferos planctónicos: una etapa dentro de la zona de *G. cretacea*, una etapa en la base de la zona de *P. eugubina* y, finalmente, una etapa en la parte baja de la zona de *P. pseudobulloides*. Varias fases dominadas por las morfologías simples de los géneros *Guembelitra*, *Parvularugoglobigerina*, *Woodringina* y *Chiloguembelina* se suceden en un intervalo corto. Este intervalo precede a la expresión de morfologías especializadas de pared compleja, que indican el paso a las asociaciones clásicas del Paleoceno (con géneros como *Parasubbotina*, *Praemurica* y *Subbotina*).

Palabras clave: Foraminíferos planctónicos, Daniense basal, Corte de Ouled Haddou, Rif externo, Marruecos.

Abstract

In the oriental external Rif, the first stages of planktonic foraminiferal renewal are recognized in the lower Danian deposits of the Ouled Haddou section. The succession of the renewal and quantitative stages is precisely established, it permits a detailed biochronologic subdivision of these deposits and the correlations with other regions. In the beginning of the Danian, three steps in the evolution of

planktonic foraminifera are recognized: within the *G. cretacea* zone, at the basis of the *P. eugubina* zone and in the lower part *P. pseudobulloides* zone. Several stages dominated by the simple morphologies (of the *Guembelitra*, *Parvularugoglobigerina*, *Woodringina* and *Chiloguembelina* genera) followed each other in a short interval that precedes the expression of specialized morphologies, with complex wall, that indicates the passage to the classic associations of the Paleocene (with *Parasubbotina*, *Praemurica* and *Subbotina*).

Key words: Planktonic Foraminifera, Lower Danian, Ouled Haddou Section, External Rif, Morocco.

INTRODUCTION

Les associations de Foraminifères planctoniques du début du Tertiaire montrent de nettes différences avec celles du Crétacé terminal. Ces différences ont été révélées dès les premières études, à des régions de diverses latitudes et particulièrement dans le domaine téthysien (Drooger, 1952; Reichel, 1952; Berggren 1962; Luterbacher & Premoli Silva, 1964; Bolli, 1966). Après les extinctions fini-crétacées, un renouvellement complet des Foraminifères planctoniques a été observé dans les toutes premières associations daniennes. Il s'agit de l'étape de renouvellement la plus importante dans l'histoire de ce groupe, elle résulte d'un changement majeur dans les paléoenvironnements marins à la transition Crétacé-Paléogène.

Plusieurs études ont accordé un intérêt particulier aux successions de générations de Foraminifères planctoniques au Danien basal, à leur signification biochronologique et dans les interprétations des paléoenvironnements (Luterbacher & Premoli Silva, 1964; Smit, 1982; Keller, 1988; D'Hondt & Keller, 1991; Olsson & Liu, 1993; Arenillas *et al.*, 2004). Parallèlement, d'autres études donnent un intérêt particulier à l'origine et aux radiations des premières morphologies du Danien, les plus récentes utilisent des critères à la fois morphologiques et de texture des parois (Blow, 1979; D'Hondt, 1991; MacLeod, 1993; Liu & Olsson, 1992, 1994; Olsson *et al.*, 1992, 1999).

Les séries pélagiques les plus complètes du Danien basal affleurent dans plusieurs sites en Méditerranée occidentale et sur les côtes atlantiques pyrénéennes. Les Foraminifères planctoniques constituent l'outil principal d'analyses biochronologiques détaillées de ces séries. Dans ce cadre, plusieurs travaux ont été effectués dans l'Atlas tunisien (Keller *et al.*, 1995; Arenillas *et al.*, 2000; Dupuis *et al.*, 2001; Luciani, 2002), en Espagne: dans les Cordillères Bétiques (Smit, 1982; Canudo *et al.*, 1991; Molina *et al.*, 1996) et au Pays Basque (Apellaniz *et al.*, 1997;

Arenillas *et al.*, 1998) et dans la coupe d'Ouled Haddou (Rif externe, Maroc), récemment découverte (Toufiq *et al.*, 2002). Dans cette coupe, les dépôts du Danien basal reposent directement sur le Crétacé terminal, en faciès pélagique assez monotone. La présente étude, basée sur un échantillonnage assez détaillé des premiers niveaux daniens, va constituer une contribution à la compréhension des étapes de renouvellement des Foraminifères planctoniques à l'aube du Cénozoïque. La chronologie des associations et des stades quantitatifs, en relation avec des changements des paléoenvironnements au Danien basal, sera ainsi discutée.

LOCALISATION, MATÉRIEL ET MÉTHODES

La coupe d'Ouled Haddou est localisée dans le Rif externe oriental, à 48 km au Nord de Taza. Elle affleure sur la route reliant Aknoul à Mezguitem (Fig. 1), dans le flanc nord du Jbel Bou Izerzene, qui est un élément de la nappe de Bou-Haddoud (Leblanc, 1979). Dans cette coupe, les dépôts du Danien surmontent le Maastrichtien terminal et affleurent largement dans des ravins assez profonds qui les recoupent (Toufiq *et al.*, 2002). Ces dépôts sont disposés en strates subverticales de direction E-W. Aux marnes grises assez argileuses et friables du Maastrichtien sommital, succèdent quelques décimètres de marnes argileuses du Danien basal, surmontées de 2 mètres de marnes massives, puis de marnes à intercalations calcaires décimétriques (Fig. 2). Le reste du Danien correspond à des marnes assez compactes, avec des intercalations calcaires dépassant parfois 1 mètre de puissance. L'étude des Foraminifères planctoniques est basée sur un échantillonnage assez détaillé (tous les 5 à 10 centimètres dans la partie basale du Danien), 25 échantillons ont été étudiés dans les 9 premiers mètres du Danien. Les échantillons, séchés à l'étuve puis trem-

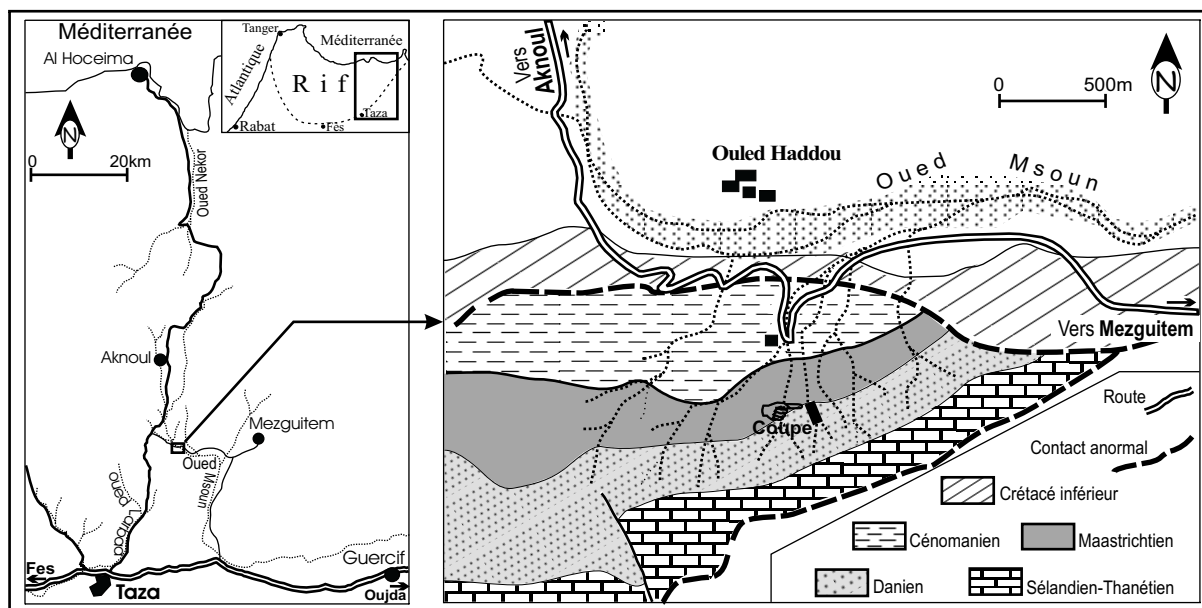


FIGURE 1—Localisation et contexte géologique de la coupe d'Ouled Haddou ($x = 3^{\circ}51'$, $y = 34^{\circ}28'$).
 FIGURE 1—Geological setting and location the Ouled Haddou section ($x = 3^{\circ}51'$, $y = 34^{\circ}28'$).

pés dans l'eau pendant quelques heures, ont été soumis au lavage sur une colonne de tamis sous jet d'eau. Les Foraminifères sont récupérés dans trois fractions de résidus: respectivement dans les tamis de mailles 250 μm , 160 μm et 63 μm . Ces résidus sont très riches en Foraminifères planctoniques, leur état de conservation est généralement bon. Les Foraminifères sont triés à partir des résidus de lavage, sous une loupe binoculaire permettant des grossissements allant jusqu'à 80x. L'étude au microscope électronique à balayage permet l'observation des détails morphologiques et des parois (particulièrement pour les petites espèces du début du Danien) ainsi que les illustrations d'espèces index. Les espèces ont été identifiées suivant les nomenclatures standards et les illustrations fournies dans des travaux originaux et de synthèses (Luterbacher & Premoli Silva, 1964; Blow, 1979; Toumarkine & Luterbacher, 1985; Loeblich & Tappan, 1988; Olsson *et al.*, 1992, 1999). L'étude quantitative, basée sur des proportions relatives de genres ou de groupes à affinités morphologiques, est effectuée pour onze échantillons choisis dans les huit premiers mètres du Danien. Pour chacune des trois fractions (250, 160 et 63 μm), nous avons compté le nombre de Foraminifères dans 0,1 g de résidu. Les effectifs globaux (des différents groupes ou genres) seront calculés en fonction du poids, d'abord pour chaque fraction, puis pour le résidu entier. Cette procédure permet également d'estimer les proportions

absolues de Foraminifères par gramme de sédiment, sachant la masse de l'échantillon lavé (après déshydratation). Elle rend compte également des différences importantes des effectifs des populations entre les différentes fractions de résidu (la majeure partie de la population se retrouve dans la fraction comprise entre 63 μm et 160 μm).

BIOSTRATIGRAPHIE DU DANIEN BASAL DANS LA COUPE D'OULED HADDOU

Comparée aux coupes classiques, particulièrement du domaine méditerranéen, la coupe d'Ouled Haddou peut être divisée, au début du Danien, en zones basées sur les apparitions successives des principaux marqueurs de Foraminifères planctoniques (Fig. 3). Les dépôts compris entre l'extinction en masse de la fin du Crétacé (des Globotruncanidés et des grands Heterohelicidés) et l'apparition de *Parvularugoglobigerina eugubina* sont attribués à la zone à *Guembelitra cretacea*. Cette zone couvre un peu moins de 50 cm de dépôts de marnes argileuses, qui constituent les premiers niveaux du Danien dans la coupe d'Ouled Haddou. Dès le premier échantillon de cet intervalle (K-P + 3-5 cm), on retrouve en proportions assez importantes les toutes premières espèces daniennes (très petites), appartenant au genre *Parvularugoglobigerina* (*P. longiapertura*, *P. minutula*). L'intervalle compris entre l'extinction en masse de la fin

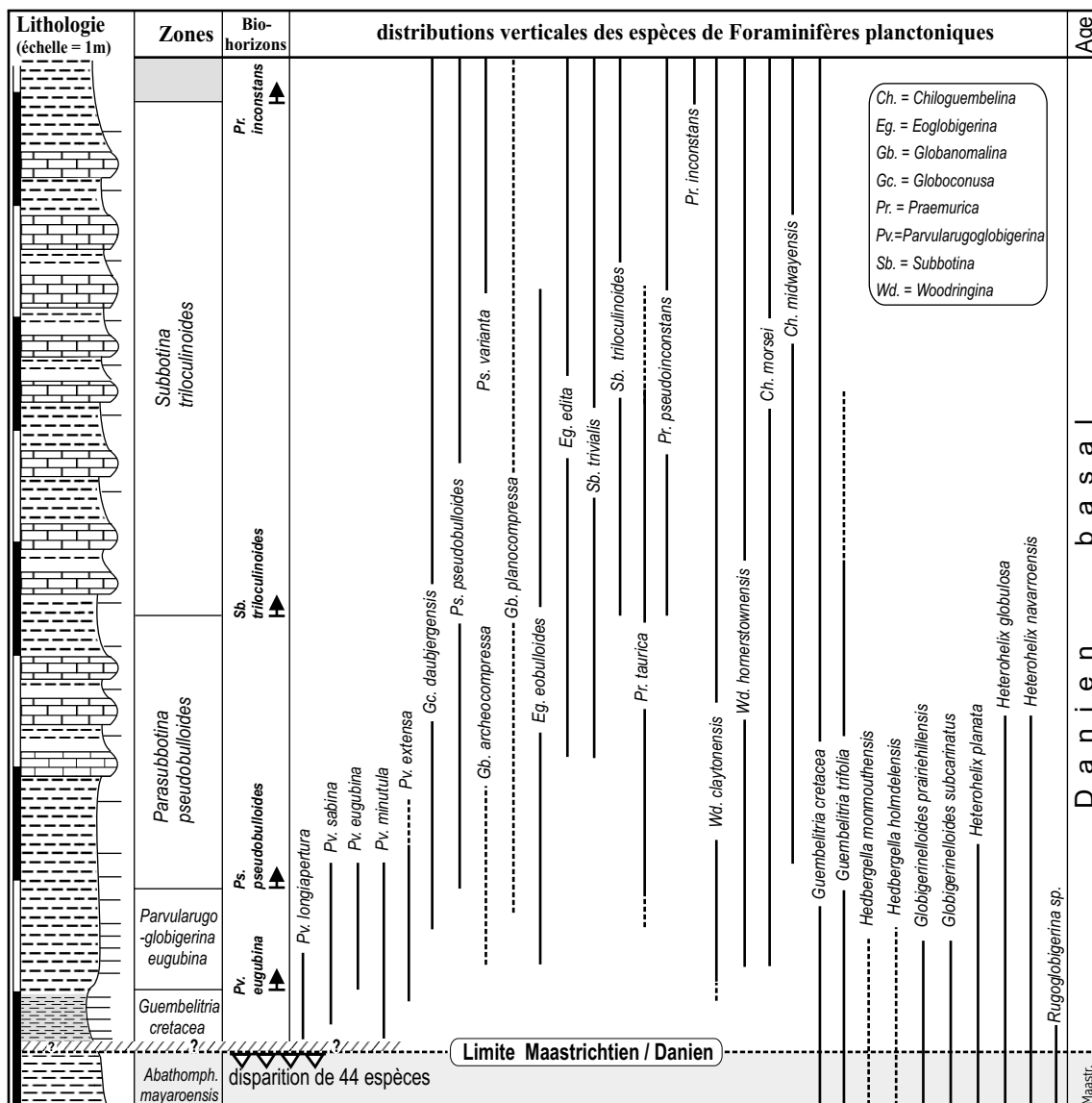


FIGURE 2—Lithologie, biozonation et distribution des Foraminifères planctoniques dans le Danien basal de la coupe d'Ouled Haddou.

FIGURE 2—Lithology, biozonation and distribution of planktonic foraminifera in the lowermost Danian of the Ouled Haddou section.

du Crétacé et l'apparition de ces premières espèces daniennes (sous-zone à *Hedbergella holmdelensis* "sensu" Arenillas *et al.*, 2004) semble très réduit dans la coupe d'Ouled Haddou, indiquant une sédimentation condensée ou la présence d'un petit hiatus. Dans cette zone se retrouvent d'assez rares formes issues du Crétacé dont le marqueur *G. cretacea*, qui semble être le moins affecté par la crise fini-crétacée (bien qu'il montre une nette réduction sur le plan quantitatif). Les Foraminifères planctoniques de cette zone sont de petite taille, seules quelques formes issues du Crétacé se retrouvent dans la fraction de résidu supérieure à 160 μ m.

La zone à *Parvularugoglobigerina eugubina* correspond à l'intervalle compris entre l'apparition du marqueur et l'apparition de *Parasubbotina pseudobulloides*. Elle couvre environ 1 mètre de dépôts marneux dans lesquels les associations sont encore dominées par des petites morphologies. Cette étape dans la diversification du genre *Parvularugoglobigerina* s'accompagne de l'apparition des genres *Woodringina* et *Chiloguembelina*. Dans la partie supérieure de cette zone apparaissent ensuite les premières espèces des genres *Eoglobigerina* (*E. ebulloides*), *Globanomalina* (*G. archeocompressa*) et *Praemurica* (*P. taurica*).

Biohorizons (coupe d'Ouled Haddou)	Différentes zonations utilisées								
	Cette étude	Arenillas <i>et al.</i> (2004)		Olsson <i>et al.</i> , 1999	Apellaniz <i>et al.</i> , 1997	Keller <i>et al.</i> , 1995	Smit, 1982	Blow, 1979	Bolli, 1966; Toumarkine <i>et al.</i> , 1985
<i>Pr. inconstans</i> ↑		Parasubbotina triloculinoides	Subbotina triloculinoides	P1c	Subbotina triloculinoides	P1c	P1d	P.1b	<i>Morozovella</i> <i>trinidadensis</i>
<i>Sb. triloculi- noides</i> ↑				P1b					
<i>Pv. eugubina</i> ↓		Parasubbotina pseudobulloides	<i>Eoglobigerina</i> <i>trivialis</i>	P1a	Parasubbotina pseudobulloides	P1b	P1a(2)	P.1a <i>Globorotalia</i> (<i>Turborotalia</i>) <i>pseudobulloides</i> / <i>Globorotalia</i> (<i>T</i>) <i>archo-</i> <i>compressa</i>	<i>Morozovella</i> <i>pseudobulloides</i>
<i>Ps. pseudo- bulloides</i> ↑									
<i>Eg. eobulloides</i> ↑	Parvularugo- globigerina eugubina	Parvularugo- globigerina eugubina	<i>Eoglobigerina</i> <i>simplicissima</i>	Pα	Parvularugo- globigerina <i>longiapertura</i>	P1a(1)	P1a	P.α <i>Globorotalia</i> (<i>Turborotalia</i>) <i>longiapertura</i>	<i>Globigerina</i> <i>eugubina</i>
<i>Pv. eugubina</i> ↑			<i>Parvularugo- globigerina</i> <i>sabina</i>						
<i>Pv. extensa</i> ↑	<i>Guembelitra</i> <i>cretacea</i>	Guembelitra cretacea	<i>Parvularugo- globigerina</i> <i>longiapertura</i>	PO	<i>Gu. cretacea</i>	PO	PO	M.18	
<i>Pv. longi- apertura</i> ↑			<i>Hd. holmdelensis</i>						
<i>Ab. mayaro- ensis</i> ↓	<i>Abathomphalus</i> <i>mayaroensis</i>				<i>Abathomphalus</i> <i>mayaroensis</i>	<i>Ptx.</i> <i>deformis</i>	M3	M.17	

FIGURE 3—Principaux biohorizons et zonation à l'aide des Foraminifères planctoniques du Danien basal dans la coupe d'Ouled Haddou, et comparaison avec d'autres zonations.

FIGURE 3—Main biohorizons and planktonic foraminiferal zonation of the lowermost Danian of the Ouled Haddou section, and comparison with other zonations.

ca). Ces espèces sont de petite taille et ne représentent encore que des proportions faibles dans les associations. Au cours de cette zone, on assiste également à la disparition des (petites) espèces des genres *Globigerinelloides* et *Hedbergella*, issues du Crétacé.

La zone à *Parasubbotina pseudobulloides*, d'une épaisseur avoisinant 2,5 mètres, couvre l'intervalle compris entre l'apparition du marqueur et l'apparition de *Subbotina triloculinoides*. A la base de cet intervalle, l'association *eugubina-pseudobulloides* est très brève et précède la disparition complète du genre *Parvularugoglobigerina*. La partie inférieure de cette zone se caractérise par l'association *P. pseudobulloides-E. eobulloides-P. taurica* et sa partie supérieure par l'association *P. pseudobulloides-S. trivialis-E. edita*. C'est donc à partir de cette zone que s'observent les assemblages de Globigerinacés classiques du Danien; des espèces appartenant aux genres *Chiloguembelina* et *Woodringina* y sont également bien représentées. À l'exception des espèces du genre *Guembelitra*, le reste des espèces issues du Crétacé (petits Heterohelicidés) disparaissent dans cette zone.

L'intervalle compris entre l'apparition de *Subbotina triloculinoides* et l'apparition de *Praemurica inconstans* (d'une épaisseur voisine de 4,5 mètres) est attribué à la zone à *Subbotina triloculinoides*. La base de cet intervalle montre également l'apparition de *Praemurica pseudoinconstans* et coïncide donc avec une diversification des genres *Praemurica* et *Subbotina*. A partir de cette zone, les grandes espèces typiques du Danien, s'expriment nettement dans les associations. Ces morphologies variées résultent des radiations des genres *Eoglobigerina*, *Parasubbotina*, *Praemurica* et *Subbotina*.

EVOLUTION QUANTITATIVE DES ASSOCIATIONS

Le renouvellement des Foraminifères planctoniques débute très tôt au Danien basal; la figure 2 montre les étapes de diversifications générique et spécifique au cours de la partie inférieure de cet étage. Dès la zone à *G. cretacea*, on note les premières morpholo-

gies du genre *Parvularugoglobigerina*, qui se diversifient rapidement en cinq espèces. A la base de la zone à *P. eugubina* une importante étape de diversification aboutit à l'association du marqueur aux premières espèces des genres *Eoglobigerina*, *Globanomalina*, *Chiloguembelina* et *Woodringina*. Au total, 4 genres, renfermant 9 espèces, apparaissent dans l'intervalle attribué à cette zone. Les associations de la zone à *Parasubbotina pseudobulloides* montrent, à côté du marqueur, la présence des premières espèces des genres *Praemurica* (*P. taurica*) et *Subbotina* (*S. trivialis*). En même temps, on assiste à une spéciation chez les genres *Eoglobigerina* et *Globanomalina*. Ce stade dans le renouvellement des Foraminifères planctoniques succède à la disparition complète du genre *Parvularugoglobigerina*. Le passage aux associations de la zone à *P. pseudobulloides* se caractérise donc par une diversification chez les morphologies assez évoluées, accompagnée d'un déclin chez les morphologies simples du Danien basal. L'extinction affecte 4 espèces appartenant au genre *Parvularugoglobigerina* et la diversification conduit à l'apparition de 5 espèces chez les genres en radiation. Il s'agit là de l'installation des premières associations typiques du Danien, dont l'évolution va conduire à des morphologies de plus en plus grandes (particulièrement chez le genre *Praemurica*), qui deviendront en proportions importantes à partir de la zone à *Subbotina triloculinoides*.

La figure 4 montre les principaux stades quantitatifs de l'évolution des associations de Foraminifères planctoniques (>63 µm) dans la partie inférieure du Danien. De petites formes issues du Crétacé, appartenant aux Heterohellicidés et aux genres *Hedbergella* et

Globigerinelloides, sont présentes dans les associations de la partie basale du Danien. Ces formes sont en proportions importantes dans les premiers centimètres du Danien, où se retrouvent également des morphologies naines de Globotruncanidés (Rugoglobigerines en particulier). Dans ces premiers niveaux, 50% environ de la population se compose de formes issues du Crétacé (exceptée *G. cretacea*), 25% appartient au genre *Guembelitra* et 25% restant au genre *Parvularugoglobigerina*. Ce dernier devient immédiatement dominant dans le reste de la zone à *G. cretacea*, où ses proportions varient entre 70 et 78% de la population, alors que les formes issues du Crétacé se ramènent à des proportions comprises entre 5 et 18%. L'abondance de *Guembelitra cretacea* diminue légèrement, mais reste à des proportions comprises entre 12 et 20%.

Les associations de la zone à *Parvularugoglobigerina eugubina* montrent une présence en proportions assez importantes des *Woodringina* (15 à 18%) et une nette réduction quantitative chez les espèces issues du Crétacé, ainsi que chez le genre *Guembelitra*. Les (petites) espèces du genre *Parvularugoglobigerina* restent aux alentours de 70% de la population. *P. eugubina* et *P. sabina* dominent dans la partie inférieure de cette zone, dans sa partie supérieure dominent les espèces *P. eugubina*, *P. extensa* et *Woodringina claytonensis*.

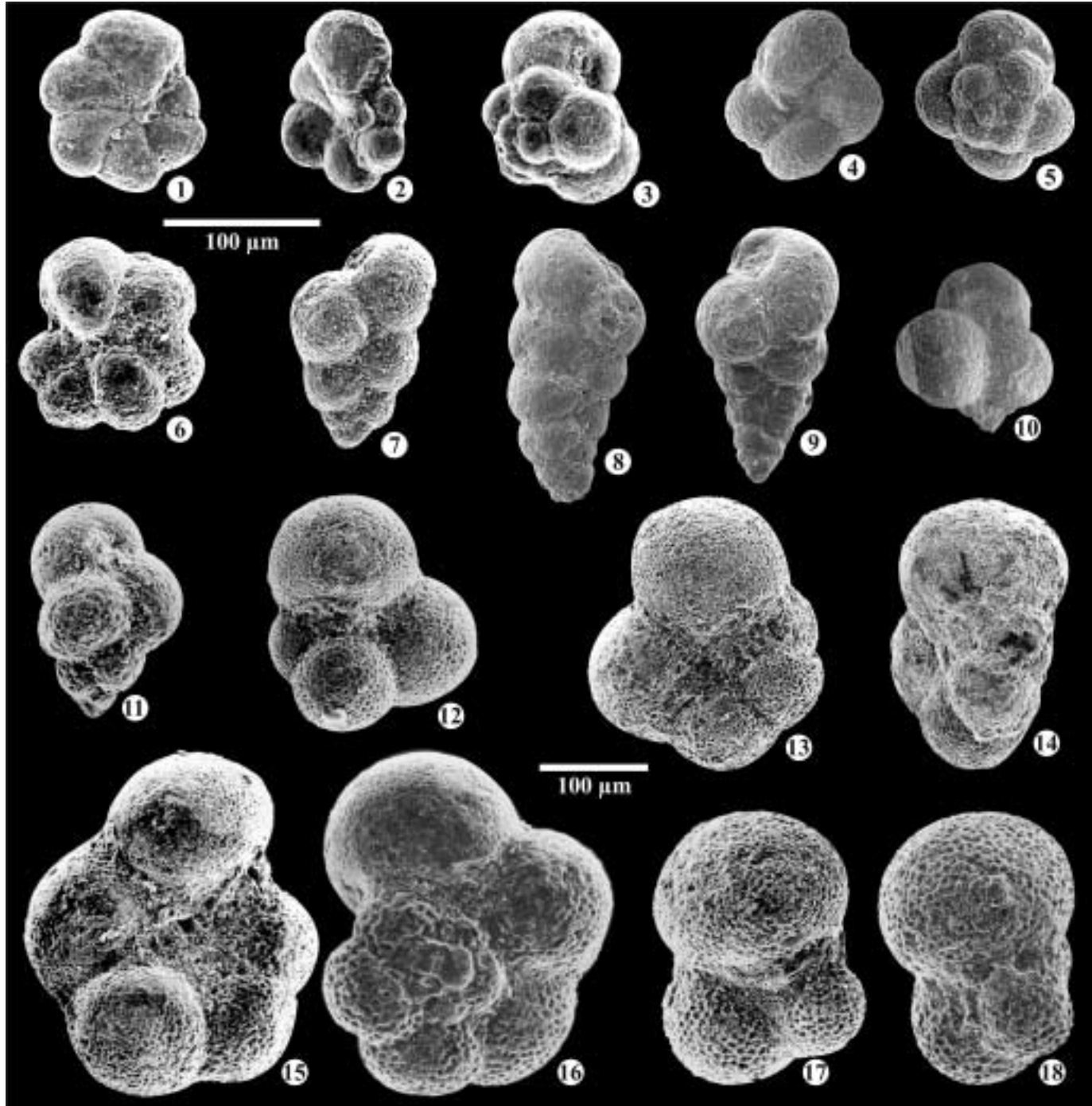
A la base de la zone à *Parasubbotina pseudobulloides* disparaissent assez brutalement les espèces du genre *Parvularugoglobigerina*. A ce stade de l'évolution des associations, on note à nouveau une rapide augmentation de fréquence de *Guembelitra cretacea*

→

PLANCHE 1–1, 2, *Parvularugoglobigerina longiapertura* (Blow), zone à *G. cretacea*. 3, *Parvularugoglobigerina extensa* (Blow), zone à *P. eugubina*. 4, 5, *Parvularugoglobigerina sabina* (Luterbacher et Premoli Silva), zone à *G. cretacea*. 6, *Parvularugoglobigerina eugubina* (Luterbacher et Premoli Silva), zone à *P. eugubina*. 7, *Woodringina claytonensis* Loeblich et Tappan, zone à *P. eugubina*. 8, *Woodringina hornerstownensis* Olsson, zone à *P. eugubina*. 9, *Chiloguembelina morsei* (Kline), zone à *P. pseudobulloides*. 10, *Guembelitra trifolia* (Morozova), zone à *G. cretacea*. 11, *Guembelitra cretacea* Cushman, zone à *G. cretacea*. 12, *Eoglobigerina eobulloides* Morozova, zone à *P. pseudobulloides*. 13–14, *Parasubbotina pseudobulloides* (Plummer), zone à *P. pseudobulloides*. 15–16, *Praemurica pseudoconstans* (Blow), zone à *S. triloculinoides*. 17–18, *Subbotina triloculinoides* (Plummer), zone à *S. triloculinoides*. (Barre d'échelle: en haut, valable pour les Figs. 1 à 11; en bas pour les Figs. 12 à 18).

PLATE 1–1, 2, *Parvularugoglobigerina longiapertura* (Blow), *G. cretacea* zone. 3, *Parvularugoglobigerina extensa* (Blow), *P. eugubina* zone. 4, 5, *Parvularugoglobigerina sabina* (Luterbacher et Premoli Silva), *G. cretacea* zone. 6, *Parvularugoglobigerina eugubina* (Luterbacher et Premoli Silva), *P. eugubina* zone. 7, *Woodringina claytonensis* Loeblich et Tappan, *P. eugubina* zone. 8, *Woodringina hornerstownensis* Olsson, *P. eugubina* zone. 9, *Chiloguembelina morsei* (Kline), *P. pseudobulloides* zone. 10, *Guembelitra trifolia* (Morozova), *G. cretacea* zone. 11, *Guembelitra cretacea* Cushman, *G. cretacea* zone. 12, *Eoglobigerina eobulloides* Morozova, *P. pseudobulloides* zone. 13–14, *Parasubbotina pseudobulloides* (Plummer), *P. pseudobulloides* zone. 15–16, *Praemurica pseudoconstans* (Blow), *S. triloculinoides* zone. 17–18, *Subbotina triloculinoides* (Plummer), *S. triloculinoides* zone. (Upper scale bar for Figs. 1 to 11; lower scale bar for Figs. 12 to 18).

PLANCHE I



(qui passe brièvement de 1 à 37%). Les proportions des genres *Chiloguembelina* et *Woodringina* avoisinent également 37%, alors que la totalité des premières espèces des genres *Eoglobigerina*, *Globanomalina*, *Parasubbotina* et *Praemurica* ne dépasse pas 7% de la population. Ces derniers genres augmentent légèrement proportions (13%) dans la partie supérieure de la zone à *P. pseudobulloides*. A ces niveaux la fréquence de *G. cretacea* rechute rapidement à 8%, alors que les proportions des genres *Chiloguembelina* et *Woodringina* montent à 68%. Le reste de la population se compose du genre *Globoconusa* (6%) et des derniers Heterohelicidés issus du Maastrichtien (5%).

A la base de la zone à *Subbotina triloculinoides* les espèces “classiques” du Paléocène (appartenant aux genres *Eoglobigerina*, *Globanomalina*, *Parasubbotina* et *Praemurica*) montrent des proportions importantes. Celles-ci atteignent (assez rapidement) 42% et deviennent ainsi identiques à celles représentées par les espèces des genres *Chiloguembelina* et *Woodringina* (réduites à 43%). Les grandes espèces franchement paléocènes ne deviennent en proportions dominantes qu’à la partie supérieure de la zone à *Subbotina triloculinoides*. A partir de ces niveaux, leurs proportions dépassent la moitié de la population (57%), une réduction ayant affecté notamment le genre *Woodringina* et ramène les proportions des espèces bisériées (des genres *Chiloguembelina* et *Woodringina*) à 28,5%. Le reste de la population est composé de *Guembelitra cretacea* (11,5%) et de *Globoconusa daubjergensis* (3%).

DISCUSSION

Le début du Tertiaire coïncide avec un changement majeur dans les morphologies chez les Foraminifères planctoniques. Les premières associations du Danien succèdent assez rapidement à une “crise soudaine”, ayant conduit au déclin de la majorité des espèces du Maastrichtien terminal. Dans la coupe d’Ouled Haddou, la fin du Crétacé (et donc le début du Paléocène) est nettement indiquée par la disparition massive des Globotruncanidés et des grands Heterohelicidés (Toufiq *et al.*, 2002).

Le renouvellement des Foraminifères planctoniques s’effectue ainsi progressivement dans la partie basale du Paléocène. 19 espèces apparaissent dans les huit premiers mètres de dépôts du Danien, dont 7 y voient aussi leurs disparitions et se limitent ainsi au Danien basal. Les premières tentatives de renouvellement se produisent en 3 étapes: au sein de la zone à *G. cretacea*, à la base de la zone à *P. eugubina* et à la base

de la zone à *P. pseudobulloides*. La dernière étape conduit à une radiation des morphologies typiques du Tertiaire, qui s’accompagne de la disparition des premières morphologies simples du début du Danien et des rares petites espèces issues du Maastrichtien.

La Chronologie des associations et des stades quantitatifs des Foraminifères au Danien basal est contrôlée par les environnements de dépôt. Plusieurs auteurs rapportent que les espèces du genre *Guembelitra* dominent aux premiers niveaux daniens, immédiatement après la limite K/P. A ces niveaux, *Guembelitra* représente 40 à 80% de la population dans les coupes de l’Atlas tunisien (D’Hondt & Keller, 1991; Keller *et al.*, 1995; Arz *et al.*, 1999a; Arenillas *et al.*, 2000; Luciani, 2002), du Danemark (Nye Klov) (Keller, 1996) et d’Egypte centrale (Keller, 2002). *Guembelitra* est ainsi considéré comme opportuniste, profitant de l’hostilité des environnements marins après une “crise” qui a conduit à l’extinction de la quasi-totalité des Foraminifères planctoniques du Crétacé. Dans la première zone du Danien de la coupe d’Ouled Haddou, les proportions de *Guembelitra* ne dépassent guère 25% de la population. Ces proportions sont comparables à celles observées dans les coupes de la Cordillère Bétique (Canudo *et al.*, 1991; Molina *et al.*, 1996), au désert du Negev et dans les sites ODP 528 et 577 (D’Hondt & Keller, 1991). Dans les dépôts d’environnement bathyal du Pays basque espagnol, les proportions de *Guembelitra* sont plutôt faibles dans les premiers niveaux daniens, qui précèdent l’apparition de *Parvularugoglobigerina eugubina* (Apellaniz *et al.*, 1997; Arenillas *et al.*, 1998; Arz *et al.*, 1999b). Dans les régions antarctiques (ODP Site 738C), la fréquence de *Guembelitra* est “masquée” par une prolifération de l’espèce *Chiloguembelina waiparaensis* (Keller & Perch-Nielsen, 1995). De grandes variations s’observent ainsi quand on compare les proportions relatives de *Guembelitra* dans les premiers niveaux du Danien des différents sites. Par ailleurs, la dominance de ce genre, particulièrement dans les environnements de plate-forme, ne serait que relative dans des mers nettement appauvries en Foraminifères planctoniques par rapport à celles du Crétacé terminal. Dans la coupe d’Ouled Haddou, bien que son abondance relative soit doublée par rapport au Maastrichtien terminal, le genre *Guembelitra* montre une nette réduction d’effectifs absolus au delà de la limite Crétacé/Paléogène. Une population importante de petits Heterohelicidés se retrouve également aux premiers horizons daniens de plusieurs sites: c’est le cas des coupes de la Cordillère Bétique, où des proportions importantes d’*Heterohelix globulosa* précèdent l’apparition des premières espè-

ces daniennes (Canudo *et al.*, 1991; Molina *et al.*, 1996). Des conditions géologiques et géographiques locales ou régionales, ainsi que des phénomènes de dissolution et de remaniements, interviendraient dans les variations des proportions des différentes morphologies à la base du Danien.

Le premier échantillon de la zone à *cretacea* nous livre une population qui contient en proportions voisines les petits Heterohelicidés, le genre *Guembeltria*, le genre *Parvularugoglobigerina* (premières morphologies daniennes) et, en proportion moindres, les genres *Globigerinelloides* et *Hedbergella*, ainsi que de très rares naines Rugoglobigerines. Une diversification rapide conduit à la dominance des (petites) espèces du genre *Parvularugoglobigerina*, observée depuis la partie supérieure de la zone à *G. cretacea* jusqu'à la partie supérieure de la zone à *P. eugubina* (Fig. 4). Dans la zone à

G. cretacea et dans la partie inférieure de la zone à *P. eugubina*, aucune espèce danienne ne se retrouve dans la fraction de résidu supérieure à 160 μ . Les premières espèces daniennes, ainsi que les autres espèces issues du Crétacé, sont des formes simples et cosmopolites, qui supporterait des conditions d'instabilité et de faible productivité océaniques. Au début du Danien, les nouvelles morphologies envahissent plus rapidement les milieux océaniques que les milieux de plate-forme (Liu & Olsson, 1992). Au cours de la zone à *Pv. eugubina*, on note une augmentation des effectifs de Foraminifères planctoniques (rapide augmentation du rapport Planctoniques/Benthiques), accompagné d'une augmentation du taux de CaCO_3 (Toufiq *et al.*, 2002). La dominance des formes simples s'accroît à la fois par une diversification du genre *Parvularugoglobigerina* et par l'apparition des genres *Woodringina* et

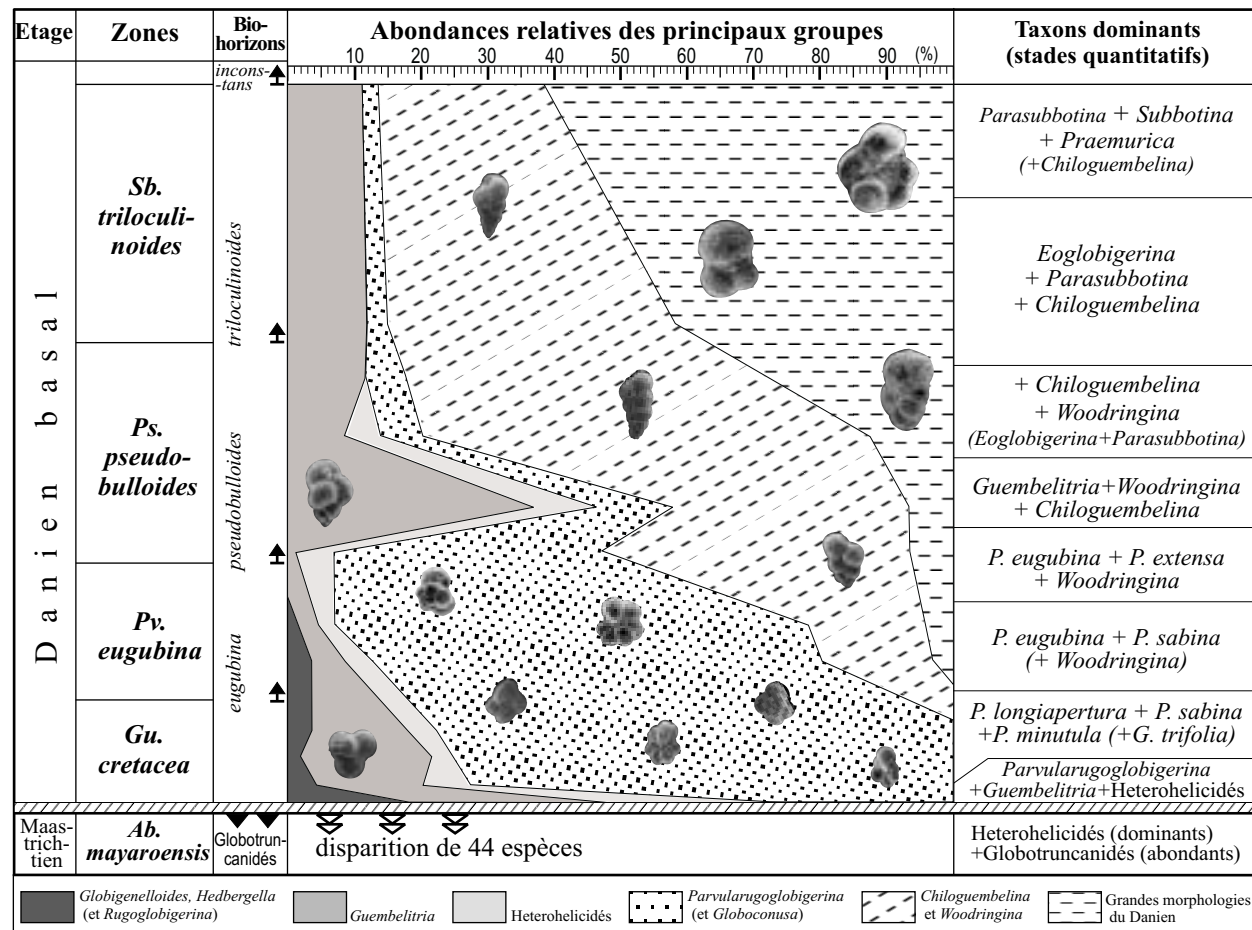


FIGURE 4—Zones, abondances relatives et principaux stades quantitatifs de Foraminifères planctoniques au Danien basal dans la coupe d'Ouled Haddou.

FIGURE 4—Zones, relative abundances and main quantitative stages of planktonic foraminifera in the lowermost Danian of the Ouled Haddou section.

Chiloguembelina. La diversité de ces genres conduit à une nette réduction des proportions de *Guembelitra* (considéré comme leur ancêtre). Ces changements, auxquels s'associe l'apparition des premières morphologies à paroi réticulée, indiquent une relative amélioration des conditions océanographiques par rapport celles de la zone à *G. cretacea*. Les genres *Parvularugoglobigerina* et *Woodringina* dominent nettement (jusqu'à 87%, avec des proportions voisines) à la base de la zone à *P. pseudobulloides*. La disparition assez brutale des espèces du genre *Parvularugoglobigerina* appauvrit ensuite les populations, celles-ci deviennent alors dominées par les espèces des genres *Guembelitra*, *Chiloguembelina* et *Woodringina* (75%). C'est à ces niveaux qu'on observe les plus grandes proportions (37%) du genre *Guembelitra*, elles ne résultent pas uniquement de la réduction affectant le reste de la population (disparition complète du genre *Parvularugoglobigerina*), mais aussi d'une remarquable augmentation des effectifs absolus de ce genre. Ces observations indiquent le caractère opportuniste des espèces du genre *Guembelitra*, celles-ci profiteraient de la compétition entre les genres *Chiloguembelina* et *Woodringina* d'une part, et le genre *Parvularugoglobigerina* d'autre part, dans des conditions océanographiques encore instables. Contrairement à leur disparité d'une région à l'autre au sein de la zone à *G. cretacea*, des proportions importantes de *Guembelitra* ont été observées dans la partie inférieure de la zone à *P. pseudobulloides* dans différents sites (Canudo *et al.*, 1991; D'Hondt & Keller, 1991; Molina *et al.*, 1996; Arenillas *et al.*, 2000; Keller, 2002). Dans le reste de la zone à *P. pseudobulloides*, les proportions des grandes morphologies augmente sensiblement, mais ce sont les petites morphologies bisériées (des genres *Chiloguembelina* et *Woodringina*) qui dominent. Entre la disparition du genre *Parvularugoglobigerina* et la prolifération des grandes morphologies classiques du Danien, la zone à *P. pseudobulloides* (exceptée sa base) montre donc une succession de 2 stades quantitatifs: un stade où dominent les espèces des genres *Guembelitra*, *Chiloguembelina* et *Woodringina*, suivi d'un stade où dominant seulement des morphologies bisériées des genres *Woodringina* et (surtout) *Chiloguembelina*. La succession de ces deux stades à morphologies simples indique la persistance d'un certain "déséquilibre" dans les environnements pélagiques jusqu'à la partie supérieure de la zone *P. pseudobulloides*.

Ce n'est qu'à partir de la zone à *S. triloculinoides* que les grandes morphologies (>160 µm), classiques du Danien, deviennent en proportions importantes. Couvrant rapidement 42% de la population à la base de cette zone, elles avoisinent 57% vers son sommet,

alors que les morphologies bisériées régressent progressivement. Bien que les genres *Praemurica* et *Subbotina* montrent une certaine diversification, les effectifs globaux des populations subissent une sensible diminution (due au recul des genres *Chiloguembelina* et *Woodringina*). Ce comportement des Foraminifères planctoniques indique une certaine tendance vers un équilibre dans les conditions océanographiques, qui s'accompagne d'une différenciation des écosystèmes pélagiques. Ce n'est donc qu'assez tard au Danien basal que s'exprime une diversification écologique, des eaux superficielles vers des tranches de plus en plus profondes du domaine pélagique; cette différenciation caractérise les grandes étapes d'évolution des Foraminifères planctoniques (Hart, 1980; D'Hondt & Zachos, 1993).

CONCLUSIONS

Dans la coupe d'Ouled Haddou, les premières espèces daniennes apparaissent immédiatement après une extinction massive chez les Foraminifères planctoniques à la fin du Maastrichtien. Les étapes de renouvellement et la succession des stades quantitatifs permet un découpage biochronologique détaillé des dépôts du Danien basal. Les premières formes du Tertiaire appartiennent au genre *Parvularugoglobigerina*, elles s'associent aux espèces du genre *Guembelitra* et à des morphologies naines issues du Crétacé (Heterohellicidés en particulier) dès les premiers horizons du Danien (zone à *G. cretacea*). Une importante diversité générique s'effectue dans la partie inférieure de la zone à *P. eugubina*, où l'apparition de morphologies bisériées (genres *Woodringina* et *Chiloguembelina*) est suivie de celle des premières morphologies à paroi réticulée (genre *Eoglobigerina*), ces dernières restent cependant rares et peu diversifiées dans cette zone. La diversification des grandes morphologies à paroi complexe s'exprime, après la disparition des espèces de *Parvularugoglobigerina* (et des formes issues du Crétacé), à partir de la zone à *P. pseudobulloides* et s'accroît à la base de la zone à *S. triloculinoides*.

Dans la partie inférieure de la zone à *G. cretacea*, à côté des espèces issues du Crétacé (du genre *Guembelitra* et d'Heterohellicidés en particulier), les premières espèces du genre *Parvularugoglobigerina* sont assez bien représentées. *Parvularugoglobigerina longiapertura* et *P. minutula* représentent 25% de la population dès le premier échantillon du Danien, ce qui indique vraisemblablement un petit hiatus à la base de la

zone à *G. cretacea*. Le genre *Parvularugoglobigerina*, se diversifiant rapidement, domine ensuite le long de l'intervalle couvrant la partie supérieure de la zone à *G. cretacea* et la zone à *P. eugubina*. C'est à la base de la zone à *P. pseudobulloides* que s'observent instantanément les plus grandes proportions de *Guembelitra* qui, profitant de la disparition des espèces de *Parvularugoglobigerina*, domine avec les genres *Woodringina* et *Chiloguembelina*. Ces derniers augmentent ensuite de proportions et dominent nettement les populations dans le reste de la zone à *P. pseudobulloides*. Les proportions des morphologies grandes et complexes ne s'expriment nettement qu'à partir de la zone *S. triloculinoides*.

L'intervalle compris entre la disparition en masse de la fin du Crétacé et l'installation des associations spécialisées, typiques du Paléocène (à *Parasubbotina*, *Subbotina*, et *Praemurica*), correspond à une période d'instabilité et de faible productivité océaniques. Dans cet intervalle, des morphologies simples d'opportunistes ou généralistes (appartenant aux genres *Guembelitra*, *Parvularugoglobigerina* et *Chiloguembelina*) se sont succédées dans les milieux marins, indiquant les premières tentatives de renouvellement des Foraminifères.

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ANÁLISIS PALINOFACIAL DE LA FORMACIÓN CHALLACÓ, JURÁSICO MEDIO DE LA CUENCA NEUQUINA, ARGENTINA

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Resumen

El estudio interdisciplinario, estratigráfico-secuencial y palinoestratigráfico/palinofacial llevado a cabo en afloramientos del Jurásico Medio del centro-oeste de la Cuenca Neuquina permite interpretar que la Formación Challacó se integraría por dos unidades genéticamente distintas, una perteneciente al Grupo Cuyo (Formación Challacó *sensu stricto*) y otra ubicada en la base del Grupo Lotena (Formación “Challacó”), separadas por la discordancia Intracaloviana. La Formación Challacó *ss.* se caracteriza por la presencia de las asociaciones de palinofacies I, II, IV y V, las que, en general, presentan como rasgo notorio la esterilidad en palinomorfos o presencia de esporas de hongos, *Botryococcus*, y otros palinomorfos de origen continental. Estas palinofacies podrían vincularse a ambientes continentales, desde llanuras de inundación de flujos encauzados hasta lacustres. La Formación “Challacó”, en cambio, estaría caracterizada por las palinofacies IIIa y IIIb, vinculadas a un ambiente marino marginal, por la presencia de acritarcos y quistes de dinoflagelados en sus asociaciones microflorísticas. La presencia de *Ephedripites menendezii* Volkheimer y *Klukisporites variegatus* Couper, no registrados anteriormente en depósitos precaloconvianos de la Cuenca Neuquina, así como la gran similitud con microfloras previamente publicadas de un carbón caloviano, permiten sugerir que las asociaciones aquí descritas no serían más antiguas que el Caloviano. Una edad similar fue propuesta para la Formación “Challacó” en el área de Quebrada del Sapo por otros autores basados en estudios de estratigrafía secuencial. Se infieren condiciones de clima cálido (subtropical), relativamente árido (aridez estacional) y localmente húmedo (en torno a cuerpos de agua dulce a salobre). El tipo de querógeno identificado (tipo III/IV) y el estado de preservación del mismo permiten determinar para las palinofacies estudiadas un escaso a nulo potencial de generación de hidrocarburos líquidos.

Palabras clave: Palinofacies, Formación Challacó, Jurásico Medio, Cuenca Neuquina, Argentina.

Abstract

[*Palynofacial analysis of the Challacó Formation, Middle Jurassic of the Neuquén Basin, Argentina*]. An interdisciplinary sequence-stratigraphic and palynostratigraphical/palynofacial analysis of Middle Jurassic outcrops samples (central-west Neuquén Basin) allow to recognize that the Challacó Formation is composed by two different genetic units. One corresponding to Cuyo Group (Challacó *sensu stricto* Formation) and the other, in the lower part of Lotena Group (“Challacó” Formation). Both are separated by the Intracallovian discontinuity. The Challacó *ss.* Formation is characterized by the Palynofacies I, II, IV and V. In general they are sterile in palynomorphs or present Fungi, *Botryococcus* and others palynomorphs of continental origin. These palynofacies are related to continental environment (alluvial plains to lakes). The “Challacó” Formation is characterized by Palynofacies IIIa and IIIb, they are related with nearshore marine environment due to the presence of acritarchs and dinoflagellates. Due to the presence of *Ephedripites menendezii* Volkheimer and *Klukisporites variegatus* Couper a Callovian Age is suggested for the deposits. These species are not mentioned in deposits older than Callovian in the Neuquén Basin.

This age was also proposed by other authors for the Quebrada del Sapo area using sequence-stratigraphic criteria. Subtropical warm and relatively arid (seasonally drought), locally humid conditions, were inferred for the study area.

The quali/cuantitative studies of the palynological organic matter and the thermal alteration index (TAI) allowed to determinate a scarce oleogenetic potential (kerogen type III/IV) for the studied stratigraphical units.

Key words: Palynofacies, Challacó Formation, Middle Jurassic, Neuquén Basin, Argentina.

INTRODUCCIÓN

El presente trabajo comprende el estudio palinológico llevado a cabo con muestras de afloramientos del Jurásico Medio en el ámbito centro-occidental de la Cuenca Neuquina (Argentina) dentro de un contexto estratigráfico-secuencial. Específicamente, se plantea el análisis palinoestratigráfico y palinofacial de sedimentitas pertenecientes a la Formación Challacó tomando como base las nuevas interpretaciones paleoambientales surgidas del análisis secuencial. Dado que esta formación, hasta el presente, ha resultado prácticamente estéril en el contenido de palinomorfos, los muestreos y estudios palinológicos han sido muy escasos. En años recientes, a partir de convenios realizados con la empresa Total Austral para el estudio de campo y palinológico de secuencias jurásico-cretácicas, se pudo disponer de un mayor número de secciones y muestras pertenecientes al área de estudio.

En esta contribución se presenta por primera vez la palinoestratigrafía de la Formación Challacó en el ámbito neuquino. Enfoques más recientes dentro de la disciplina palinológica han abierto líneas de estudio más diversificadas. En este sentido, el análisis palinofacial (estudio de la materia orgánica palinológica total) en conjunción con las litofacies ha probado ser una herramienta de gran utilidad para efectuar determinaciones paleoambientales y paleoclimáticas. Asimismo, la determinación del tipo y calidad de la materia orgánica palinológica utilizando microscopía de luz transmitida y fluorescencia y del índice de alteración térmica han permitido evaluar el potencial oleogenético de la Formación Challacó para este sector de la cuenca.

Constituye éste un primer aporte más extensivo y formal en el que se reúnen aspectos relativos a la palinoestratigrafía, paleoclima, paleoambientes y potencial de generación de hidrocarburos, y se presenta el estado de conocimiento actual de la Formación Challacó a partir de estudios litofaciales y análisis secuencial.

ÁREA DE ESTUDIO, ESTRATIGRAFÍA Y ANTECEDENTES

La Cuenca Neuquina es una cuenca de retroarco localizada en el sector centro-occidental de Argentina. Se originó durante el Triásico tardío y constituyó una importante área de sedimentación durante el Jurásico y Cretácico temprano. El Grupo Cuyo o "Cuyano" de Groeber (1946) (Jurásico Inferior a Medio) constituye el primer episodio de sedimentación importante después de la configuración de la Cuenca Neuquina (Fig. 1). Representa una sección clástica progradante constituida por las formaciones Los Molles (Weaver, 1931), Lajas (Weaver, 1931) y Challacó (De Ferrariis, 1947; Gulisano *et al.*, 1984). La Formación Challacó comprende una unidad de pelitas rojas con algunas intercalaciones de areniscas y conglomerados que tradicionalmente ha sido interpretada como las facies continentales de niveles marinos equivalentes (Formación Lajas), siendo denominada por algunos autores en el área del arroyo Picún Leufú como "Capas Rojas de la Formación Lajas" (Dellapé *et al.*, 1979a; Volkheimer y Quattrocchio, 1981).

El área de estudio se localiza en el sector centro-occidental de la cuenca y comprende diez secciones estratigráficas denominadas Quebrada del Sapo 1 y 2, Estancia María Juana, Picún Leufú, Puesto Bascuñán, Chacaico, Estancia Charahuilla, Rincón del Águila, Bosque Petrificado y Puesto Policía (Fig. 2).

Existen numerosas contribuciones referidas a la sedimentología y evolución estratigráfica de la Cuenca Neuquina, entre las cuales se destacan los trabajos de síntesis de Gulisano *et al.*, 1984; Legarreta y Gulisano, 1989, y Gulisano y Gutiérrez Pleimling, 1995. En Zavala, 1993, 1996a,b se presenta la estratigrafía y análisis secuencial del Grupo Cuyo en el área de estudio. Más recientemente, Zavala y González (2001) realizan un nuevo esquema estratigráfico secuencial para el Grupo Cuyo, en

EDAD		ESTRATIGRAFÍA	LITOLOGÍA	UNIDADES SECUENCIALES	Difc.	
JURÁSICO	M A L M	TITHONIANO	Formación Quintuco	I		
			Formación Vaca Muerta	H	d.8	
		KIMMER.	GRUPO MENDOZA	Formación Tordillo	G	d.7
					F	d.6
	DOGGER	CALOVIANO	GRUPO LOTENA	Formación Lotena / "Challacó"	E	d.5
					D	d.4
		BATHONIANO	GRUPO CUYO	Formación Challacó	D	d.3
					C	
				Formación Lajas	B	d.2
					A	d.1
BAJOCIANO	GRUPO CUYO					
		Formación Los Molles	A			
ALÉN.						

FIGURA 1—Columna estratigráfica válida para el Jurásico Medio a Superior de la Cuenca Neuquina.

FIGURE 1—Stratigraphy of the Upper-Middle Jurassic of the Neuquén Basin.

el área de la Sierra de la Vaca Muerta, donde discuten la posición estratigráfica y significado de la Fm. Challacó. Zavala (2002) reinterpreta el contacto entre los Grupos Cuyo y Lotena en la Sierra de la Vaca Muerta. Freije *et al.* (2002) presentan un nuevo esquema estratigráfico para el área de Quebrada del Sapo y Picún Leufú, poniendo énfasis en la relación entre tectónica y sedimentación válido para el intervalo Bajociano temprano-Tithoniano tardío.

Prácticamente no existen datos publicados referidos a la palinología de esta formación, probablemente como consecuencia del elevado número de muestras estériles, o sólo con presencia de palinomorfos, que la caracteriza. En años recientes, nuevos enfoques en los

estudios palinológicos (análisis palinofacial) han permitido abrir líneas de investigación más diversificadas al respecto. Desde esta perspectiva, las tesis doctorales de García (1998) y Martínez (1999), y los aportes de Zavala *et al.* (1999) y Martínez *et al.*, (2004) han contribuido a un mayor conocimiento de la Formación Challacó.

METODOLOGÍA

Los resultados derivados del levantamiento de las distintas secciones estratigráficas (aquí analizadas palinofacialmente), sus características litofaciales e interpretaciones secuenciales han sido dados a conocer en diversas contribuciones (Zavala, 1993, 1996a y b; Zavala *et al.*, 1999; Zavala y González, 2001, y Freije *et al.*, 2002). Dichas secciones fueron medidas banco a banco mediante el uso de báculo de Jacob y muestreadas para su estudio palinológico. Durante el relevamiento de las mismas se puso especial atención a la descripción de estructuras sedimentarias primarias, tipos de contacto, geometría, contenido fosilífero, y otras características primarias de los cuerpos de roca, relevantes para el análisis de facies y evaluación paleoambiental; el lector interesado en estos aspectos deberá remitirse a las contribuciones antes mencionadas.

La extracción físico química de las muestras palinológicas (22 niveles) se efectuó sometiendo el material al ataque con ácido clorhídrico y fluorhídrico. A partir de este residuo se realizaron preparados para estudiar el contenido orgánico palinológico total. Batten (1981) y Batten y Morrison (1983) aconsejan un breve tratamiento del residuo orgánico (2 minutos) con oxidación y/o ultrasonido para determinar el origen de la materia orgánica amorfa. El material amorfo derivado de plantas vasculares es más fácilmente removido que el de origen algal tras la oxidación y/o ultrasonido.

Los preparados definitivos se montaron en glicerina gelatina, y el residuo palinológico fue preservado agregando solución de formol. Para el estudio de las palinofacies, el medio de montaje utilizado fue NOA 61 (Norland Products Incorporated, USA), el cual al ser observado con luz fluorescente provee un fondo de color verde oscuro. Las muestras están depositadas en el Laboratorio de Palinología de la Universidad Nacional del Sur, con las siglas UNSP, seguido de las vocales identificatorias de cada muestra (según este trabajo) y su denominación equivalente de laboratorio entre paréntesis. Las coordenadas corresponden a la regilla England Finder.

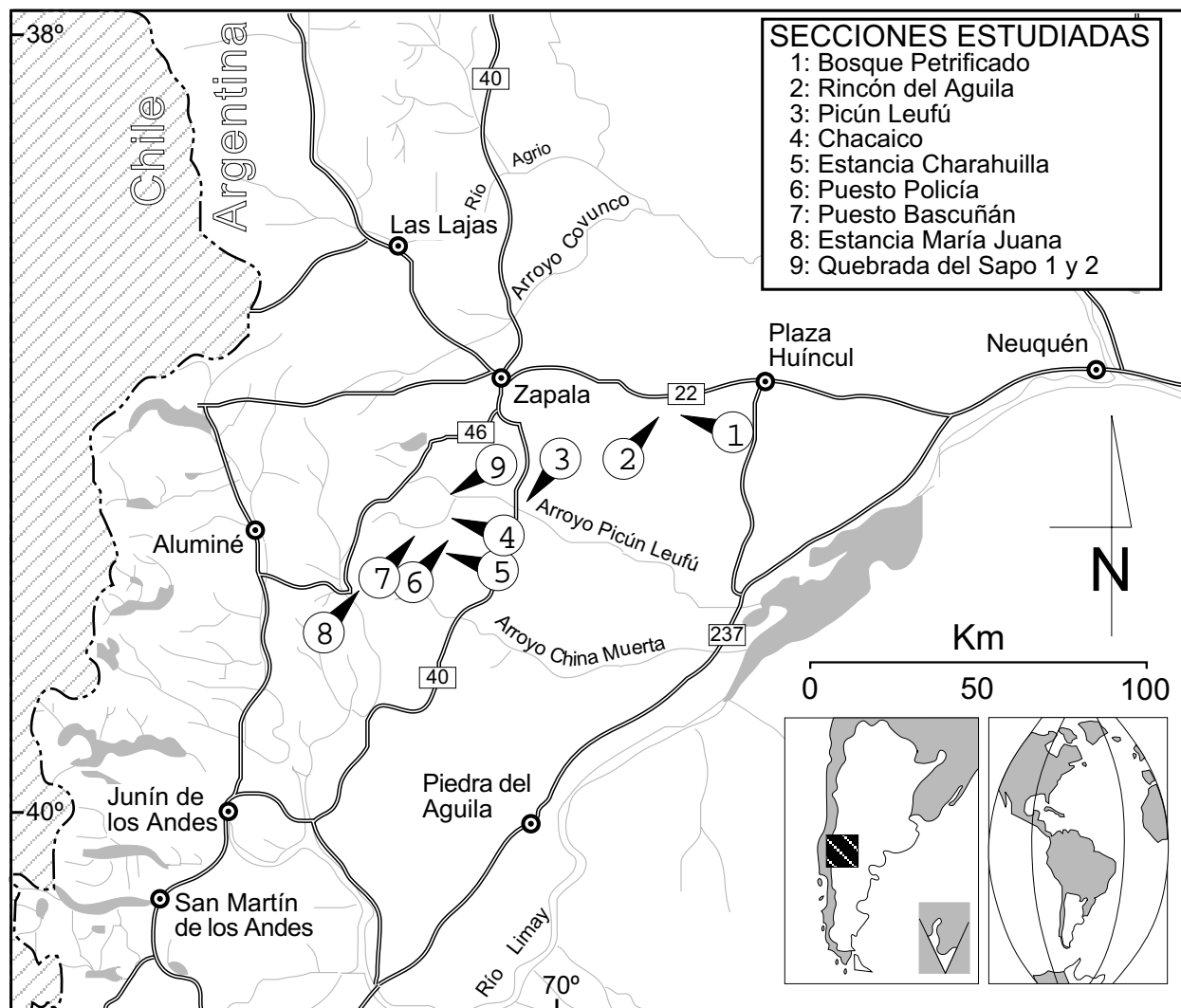


FIGURA 2—Mapa de ubicación de las localidades de estudio.
 FIGURE 2—Location map of the studied localities.

El estudio de las muestras se realizó mediante técnicas de microscopía de luz transmitida, utilizando un microscopio Olympus BH 2 N.º 100786, y microscopía de fluorescencia UV con filtro de excitación azul.

El análisis palinofacial se realizó sobre la base del reconocimiento de cuatro tipos de materia orgánica palinológica, según Tyson (1995): palinomorfos, fitoclastos translúcidos, fitoclastos opacos y amorfo. Cada palinofacies se caracterizó cuali y cuantitativamente determinando las proporciones relativas de estos tipos de materia orgánica mediante valoraciones visuales realizadas en cinco puntos del preparado con un objetivo x 40 bajo luz transmitida, según

Batten (1987) (Fig. 3). La microscopía de luz incidente azul fluorescente permitió, mediante la observación del color e intensidad de los constituyentes orgánicos, determinar su naturaleza y estado de preservación (Tabla 1).

El estado de conservación del contenido orgánico (corrosión, degradación, daño mecánico y cristalización de pirita dentro de la exina) se determinó siguiendo a Delcourt y Delcourt (1980) (Fig. 3).

En las muestras que resultaron fértiles en palinomorfos, el registro de los distintos taxones como frecuencias relativas se realizó independientemente (Tabla 2).

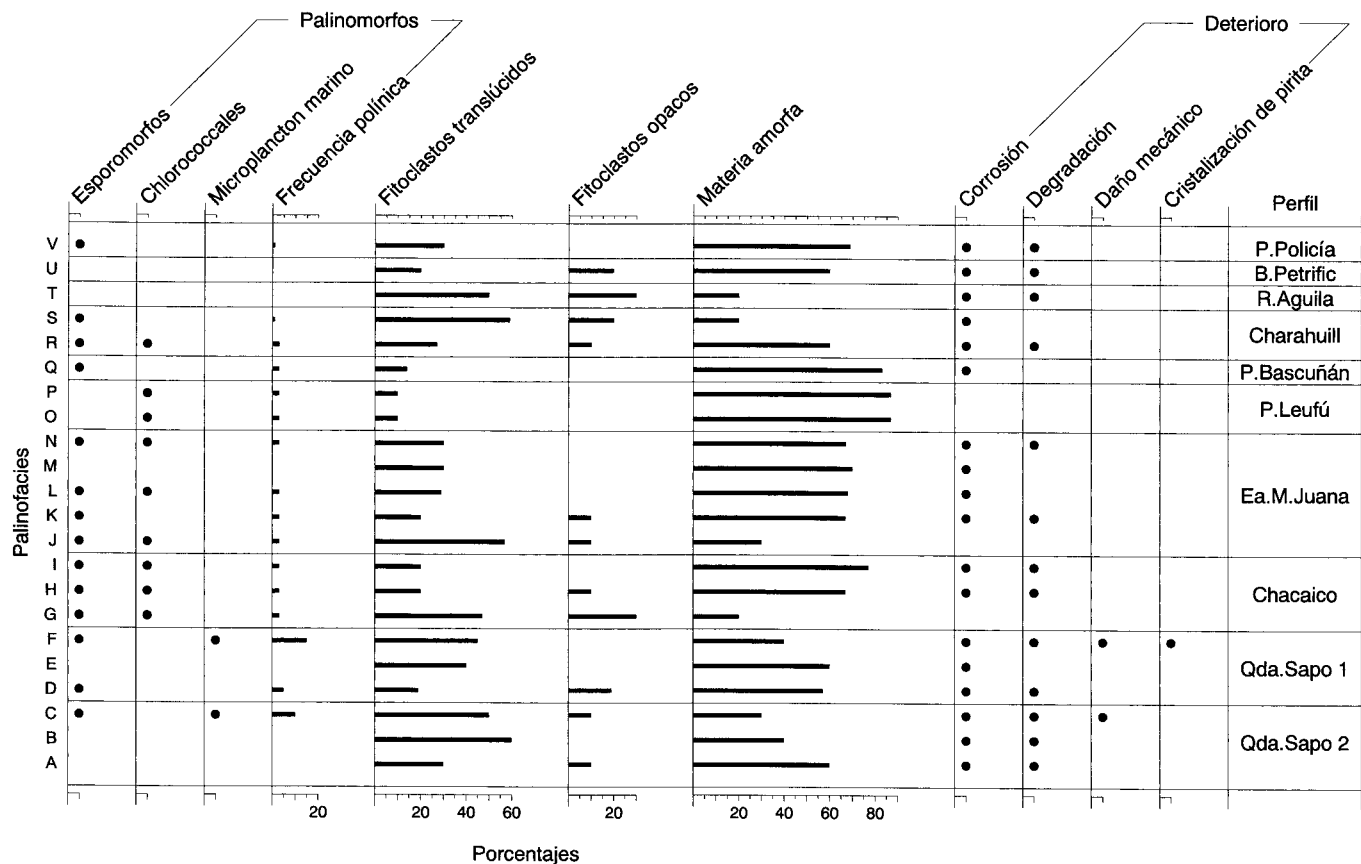


FIGURA 3—Representación de las palinofacies según frecuencias relativas de materia orgánica palinológica y tipo de alteración de los palinomorfos.

FIGURE 3—Palynofacies representation according to relative frequencies of palynological organic matter and type of damage of the palynomorphs.

ANÁLISIS SECUENCIAL

En el sector sur de la Cuenca Neuquina, la Formación Challacó se dispone en contacto neto sobre la Formación Lajas (Bajociano tardío) y en algunos sectores es cubierta por la Formación Lotena (Caloviano medio). Nuevos estudios de campo (Zavala *et al.*, 1999; Zavala y González, 2001) indican la existencia de una importante discordancia (en sectores angular) entre las formaciones Lajas y Challacó. A partir de evidencias sedimentológicas y estratigráficas, Zavala y González (2001) sugieren que la Formación Challacó se integraría por dos unidades distintas, separadas por una importante discordancia (discordancia Intracaloviana), una perteneciente al Grupo Cuyo, denominada como Challacó *ss.* (o secuencia JC6 de Zavala, 1993) y otra ubicada en la base del Grupo Lotena, denominada tentativamente como “Challacó” (o secuencia JC7 de Zavala, 1993). La Formación

Challacó *ss.* comprendería un sistema fluvio-lacustre endorreico desarrollado al sur de la dorsal de Huincul, el que sería tiempo equivalente, pero genéticamente independiente de las facies gruesas de la Formación Lajas aflorantes en la zona norte de la Sierra de la Vaca Muerta (Zavala y González, 2001; Zavala, 2002). La Formación “Challacó”, por su parte, correspondería a un sistema lacustre que evoluciona en la vertical a pelitas rojas relacionadas lateralmente con llanuras de mareas, teniendo como equivalentes laterales a la Formación Tábanos (Stipanovic, 1966; Dellapé *et al.*, 1979b) y pelitas marinas de la Formación Lotena (Weaver, 1931). Tanto las secuencias JC6 como JC7 carecen de control bioestratigráfico y sus edades fueron tentativamente establecidas como Bajociano tardío-Bathoniano temprano y Bathoniano medio por correlación con la curva de cambios eustáticos del nivel de mar de Haq *et al.* (1987) (en Zavala, 1996b) (Figura 4).

Materia orgánica		Qda. del Sapo 2			Qda. del Sapo 1			Chacaico			Estancia María Juana			P. Leufú		P. Bas	Charahulla		R. Aguilá	B. Petri	P. Polic.		
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Palinomorfos	color	amarillo		x																			
		castaño				x				x						x							
		castaño medio																	x				
	Intensidad	castaño oscuro								x	x	x	x			x	x	x		x			x
		gris					x	x	x	x	x	x	x			x	x	x	x	x			x
		nula						x		x	x	x	x			x	x	x	x	x			x
Fitociastos	color	débil		x	x		x		x						x			x					
		moderada			x			x															
		amarillo																x	x				x
	Intensidad	anaranjado																					
		castaño anaranjado						x															
		castaño oscuro				x	x			x	x		x	x	x	x	x		x	x	x		
Materia amorfa	color	gris	x	x	x			x		x	x	x	x	x	x	x		x				x	x
		negro		x				x				x							x	x	x	x	x
		nula	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
		débil							x	x	x							x					
		amarillo claro	x																				
		amarillo				x										x						x	x
	Intensidad	amarillo verdoso																					
		anaranjado				x																x	x
		castaño				x				x						x			x	x			
		castaño anaranjado								x							x						
		castaño oscuro					x									x							x
		gris claro			x			x															
gris					x		x					x	x	x	x		x	x	x			x	
gris verdoso																						x	
gris oscuro			x	x						x	x					x							
negro		x																					
nula		x	x			x	x	x		x	x	x	x	x	x	x	x	x	x			x	
débil	x				x	x	x		x	x					x			x	x	x	x	x	

Tabla 1—Intensidad y color de fluorescencia de la materia orgánica palinológica identificada en cada palinofacies.
 TABLE 1—Fluorescence (intensity and colour) of the palynological organic matter identified in each palynofacies.

GRUPOS SUPRAGEN.	TAXA	PERFILES		Qda. del Sapo 2			Qda. del Sapo 1			Chacaico			Estancia María Juana			P. Leufú		P. Bas	Charahulla		R. Aguilá	B. Petri	P. Polic.
		MUESTRAS	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
ESPORAS de inófitas y pteridófitas	<i>Deltoidospora neddeni</i> Pflug, 1953																						
	<i>Deltoidospora minor</i> (Couper) Pocock, 1970																						
	<i>Granulatisporites</i> spp.																						
	<i>Rukisporites labiatus</i> (Volkheimer) Baldoni y Archangelsky, 1983																						
	<i>Rukisporites variegatus</i> Couper, 1958																						
	<i>Rukisporites</i> spp.																						
	<i>Nevesisporites cf. radiatus</i> (Chlonova) Srivastava, 1972 (en Martínez et al., 2001)																						
	<i>Osmundacidites díazi</i> Volkheimer, 1972																						
	<i>Osmundacidites</i> spp.																						
	<i>Rugulatisporites neuquenensis</i> Volkheimer, 1972																						
	<i>Todisporites minor</i> Couper, 1958																						
	<i>Todisporites</i> spp.																						
	<i>Verrucosporites varians</i> Volkheimer, 1972																						
	<i>Functatosporites scabratus</i> (Couper) Norris, 1965																						
	esporas trilete indeterminadas																						
	Esporas de hongos																						
	<i>Vitreisporites pallidus</i> (Reissinger) Nilsson, 1958	2,9																					
	<i>Alisporites</i> sp. A (en Volkheimer, 1968)	2,9																					
	<i>Alisporites cf. similis</i> (Balme) Dettmann, 1963																						
	<i>Callialasporites dampieri</i> (Balme) Dev, 1961																						
<i>Callialasporites segmentatus</i> (Balme) Srivastava, 1963																							
<i>Callialasporites trilobatus</i> (Balme) Dev, 1961	1,4																						
<i>Callialasporites turbatus</i> (Balme) Schulz, 1967	5,7																						
<i>Callialasporites</i> spp.																							
<i>Podocarpidites cf. ellipticus</i> Cookson, 1947 (en Volkheimer, 1968)	1,4																						
<i>Podocarpidites</i> spp.																							
? <i>Dacrycarpites</i> spp.	1,4																						
<i>Microcachrydites castellanosi</i> Menéndez, 1968																							
<i>Inaperturopollenites microgranulatus</i> Volkheimer, 1972																							
<i>Araucariacites australis</i> Cookson, 1947	11,4																						
<i>Araucariacites fissus</i> Reiser y Williams, 1969	4,3																						
<i>Araucariacites pergranulatus</i> Volkheimer, 1968	1,4																						
<i>Araucariacites</i> spp.	2,9																						
Inaperturados indeterminados	8,6																						
<i>Classopollis cf. classoides</i> (Pflug) Pocock y Jansonius, 1961 (en Volkheimer, 1968)	20,0																						
<i>Classopollis simplex</i> (Danzé-Corsin y Laveine) Reiser y Williams, 1969	4,3																						
<i>Classopollis intrareticulatus</i> Volkheimer, 1972																							
<i>Classopollis</i> spp.	18,6																						
<i>Cycadobennettia adjectus</i> (De Jersey) Volkheimer y Quattrocchio, 1975	4,3																						
<i>Perinopollenites elatoides</i> Couper, 1958	1,4																						
<i>Equisetosporites calchiquensis</i> Volkheimer y Quattrocchio, 1975																							
<i>Ephedripites menendezii</i> Volkheimer, 1972																							
<i>Chlorococcales</i>																							
<i>Botryococcus</i> spp.																							
<i>Micrhystridium</i> spp.	1,4																						
<i>Micrhystridium cf. nannacanthum</i> Deflandre, 1945																							
<i>Micrhystridium stimulierum</i> (Deflandre) Sarjeant y Stanciliffe, 1994	1,4																						
<i>Escharisphaeridia pocockii</i> (Sarjeant) Erkmén y Sarjeant, 1980																							

Tabla 2—Distribución de los palinomorfos según frecuencias relativas y/o presencias.
 TABLE 2—Palynomorphs distribution taking into account its relative frequencies and/or presences.

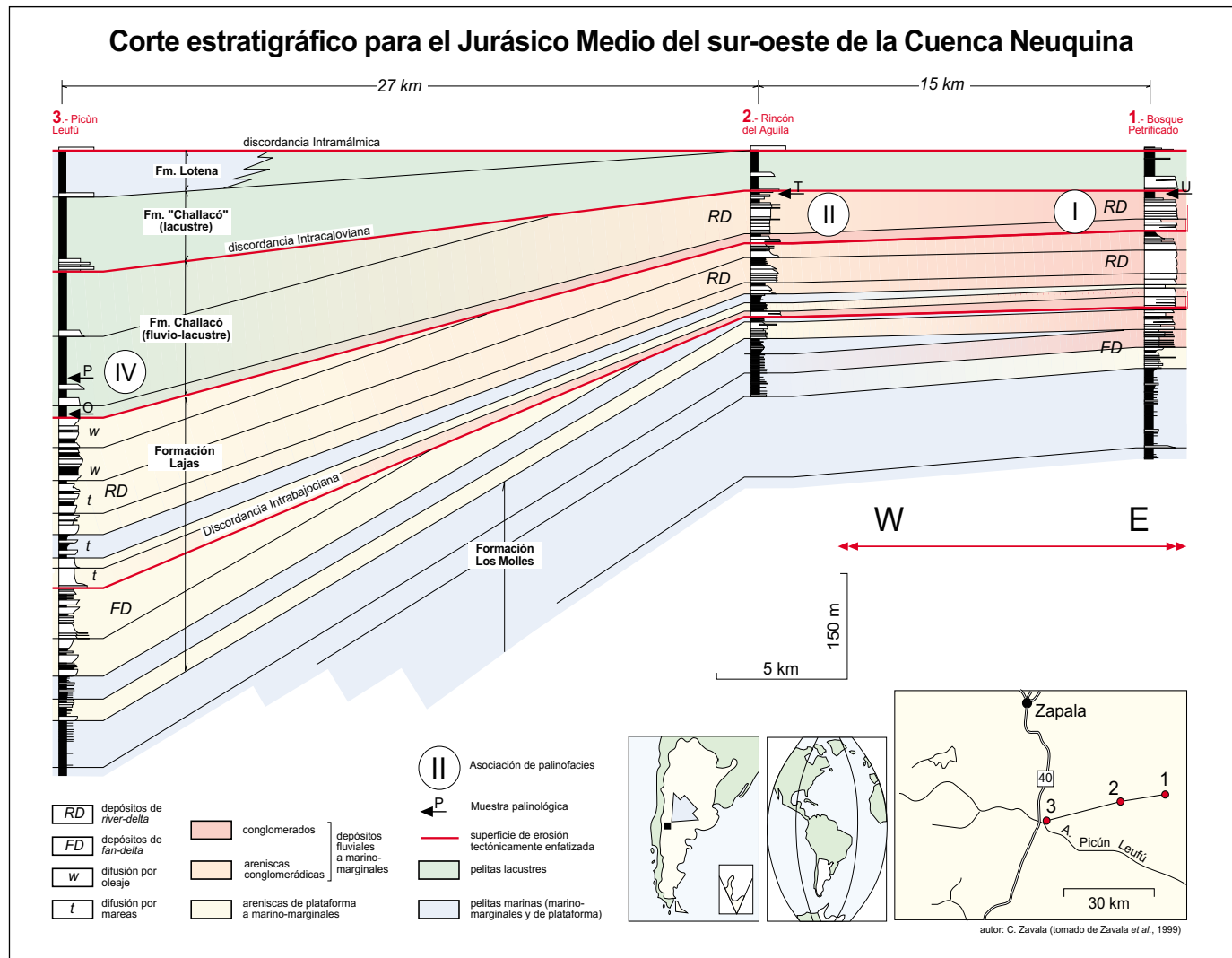


FIGURA 4—Corte estratigráfico para el Jurásico Medio de la Cuenca Neuquina entre Bosque Petrificado y Picún Leufú.

FIGURE 4—Stratigraphic section from the Middle Jurassic of the Neuquén Basin, between Bosque Petrificado and Picún Leufú.

Freije *et al.* (2002) identifican en el área de Quebrada del Sapo y la zona ubicada al sur del Arroyo Picún Leufú nueve secuencias depositacionales denominadas de manera informal con letras desde la "A" hasta la "I" para el intervalo Bajociano temprano-Tithoniano tardío (Fig. 1). La unidad D (? Bathoniano), compuesta por niveles pelíticos grises a morados con abundantes restos vegetales y bancos arenosos, con algunas evidencias de difusión mareal, se correspondería con la Formación Challacó *ss.*, la cual es interpretada como un ambiente lacustre salobre y sugiere una cierta conexión con el medio marino, a partir de la observación de estructuras

relacionadas a mareas (*wave bedding* y *lenticular bedding*). La unidad E se integraría por la Formación Lotena portadora de fauna de amonites con una edad caloviana media. Los niveles basales de la unidad E corresponden a pelitas de color gris verdoso y lentes arenosas que gradan lateralmente a niveles rojizos asignados a la Formación "Challacó" de Zavala y González (2001). Estos cuerpos psamo-pelíticos han sido interpretados como depósitos fluvio-deltaicos de relleno de canales lenticulares subácuos dentro de una cuenca marina somera hasta salobre, la que transita lateralmente a pelitas rojas (? llanura de marea).

PALINOESTRATIGRAFÍA

Hasta el presente, el análisis palinoestratigráfico de la Formación Challacó arrojó resultados negativos, dado el alto porcentaje de esterilidad de las muestras colectadas. En este trabajo pudieron recuperarse dos microfloras en buen estado de conservación que permiten por primera vez realizar una determinación de edad a partir del estudio de los palinomorfos.

Las asociaciones microflorísticas C y F (palinofacies homónimas) han sido identificadas en las secciones Quebrada del Sapo 2 y 1, respectivamente. Dentro del paleomicroplancton se identificaron quistes de dinoflagelados asignados a *Escharisphaeridia pocockii* y acritarcos del género *Micrhystridium*. Esta asociación, indicativa de ambientes marino marginales, carece de valor bioestratigráfico. Las microfloras continentales (esporas + granos de polen) resultaron más diversas en ambas palinofacies. Del estudio de las mismas surge una marcada afinidad con la microflora proveniente de un carbón caloviano localizado en cercanías de Estancia Charahuilla, en la Cuenca Neuquina, cuyos resultados fueron publicados por Volkheimer (1972).

Del total de especies continentales identificadas en cada asociación un alto porcentaje de especies son comunes al carbón caloviano (50% en la asociación C y 73% en la asociación F). Del total de las 12 especies nuevas descritas por Volkheimer (1972), seis de ellas han sido identificadas en este trabajo: *Rugulatisporites neuquensis*, *Verrucosporites varians*, *Osmundacidites diazii*, *Inaperturopollenites microgranulatus*, *Classopollis intrareticulatus* y *Ephedripites menendezii*. Si bien la gran mayoría de los taxones continentales aquí identificados poseen biocrones muy amplios, merecen especial atención *Ephedripites menendezii* Volkheimer y *Klukisporites variegatus* Couper, ya que hasta el presente no han sido identificados en depósitos precalovianos de la Cuenca Neuquina.

Estas consideraciones y la gran similitud con la microflora del mencionado carbón permiten sugerir que las asociaciones aquí descritas no serían más antiguas que el Caloviano. Cabe destacarse que una edad similar fue propuesta por Freije *et al.* (2002) para la Formación "Challacó" en el área de Quebrada del Sapo.

ASOCIACIONES DE PALINOFACIES

En el presente trabajo se utiliza el término palinofacies, en el sentido de Tyson (1995), como "el cuerpo

roca sedimentaria que contiene asociaciones diferenciadas de materia orgánica palinológica que reflejan el conjunto de condiciones ambientales y su potencial como generador de hidrocarburos". Según Traverse (1994), representaría un análisis de tipo palinolitofacial tendiente a determinar características propias de la roca sedimentaria portadora del contenido orgánico (ambiente depositacional). La escasez de palinomorfos recuperados hace dificultosa la realización de estudios más integradores de tipo palinobiofacial o palinobiofilitofacial.

El estudio de las 22 palinofacies ha permitido distinguir seis tipos bien diferenciados de asociaciones de materia orgánica palinológica total denominadas aquí asociaciones de palinofacies I, II, III (a y b), IV y V. Cada una de ellas es el resultado del agrupamiento, según la observación de características comunes de los distintos constituyentes orgánicos de las palinofacies estudiadas (Fig. 3 y Tablas 1 y 2).

Asociación de palinofacies I

Esta asociación está constituida por las palinofacies A (Quebrada del Sapo 2), E (Quebrada del Sapo 1), M (Estancia María Juana), U (Bosque Petrificado) (Fig. 4) y V (Puesto Policía). Se caracteriza por ser estéril en palinomorfos o con presencia de esporas de hongos (palinofacies V). La materia orgánica amorfa es predominante (60% a 70%), siendo de tipo membranosa y esponjosa (colores castaño a anaranjado) y finamente diseminada, predominantemente gris a negra. Los fitoclastos translúcidos varían entre 20% y 40%, siendo los más abundantes los fitoclastos translúcidos no-bioestructurados, de color castaño oscuro a negro con bordes corroídos. Los fitoclastos opacos (predominantemente equidimensionales de pequeñas dimensiones) alcanzan el 20%.

La observación con luz incidente azul fluorescente (denominado UV) muestra colores predominantes que varían desde castaño a gris y, en menor proporción, amarillo anaranjado. La intensidad es débil a nula.

El tipo de deterioro más comúnmente observado es corrosión (oxidación bioquímica) y degradación (oxidación química).

Asociación de palinofacies II

Constituida por las palinofacies B (Quebrada del Sapo 2), T (Rincón del Águila) (Fig. 4) y S (Estancia Charahuilla). Al igual que la asociación anterior, es estéril en palinomorfos o con presencia de esporas de hongos (palinofacies S). Los fitoclastos son los constituyentes orgánicos dominantes, con porcentajes que varían entre 60% y 80%, siendo los más abundantes

los fitoclastos translúcidos no-bioestructurados (hasta un 60%) de color castaño oscuro a negro, cuyas dimensiones varían entre 20 y 30 μm , con bordes corroídos muy irregulares. Los fitoclastos translúcidos bioestructurados se presentan en forma subordinada (tejidos leñosos). Con UV, los fitoclastos translúcidos muestran colores gris oscuro a negro e intensidad nula. Los fitoclastos opacos de tipo equidimensional alcanzan un 30%.

La materia amorfa se presenta en forma subordinada con valores que varían entre 20% y 40%. Domina el tipo finamente dividido (de color castaño a gris) y, en menor proporción, membranoso (de color amarillo pálido a castaño medio). Con UV se observan colores grises a castaños y, en forma muy subordinada, color amarillo. La intensidad es débil a nula.

El tipo de deterioro más comúnmente observado es corrosión y degradación.

Asociación de palinofacies III

La asociación de palinofacies III está formada por las palinofacies C (Quebrada del Sapo 2) y F (Quebrada del Sapo 1).

Esta asociación muestra los contenidos de palinomorfos más elevados (10-15%), con proporciones de microplancton marino que varía entre 3% y 26% (Fig. 5). Los fitoclastos dominan con respecto a la materia orgánica amorfa. Dentro de esta asociación pueden diferenciarse dos palinofacies: IIIa y IIIb.

Palinofacies IIIa

Esta palinofacies (C) se caracteriza por el predominio de fitoclastos (60%), siendo los de tipo translúcidos los dominantes (50%), de color castaño oscuro a negro con translucencia en los bordes, predominantemente de tamaño pequeño (menor de 20 micrones) con bordes corroídos muy irregulares. Escasos fitoclastos bioestructurados (traqueidas), de color castaño oscuro, corroídos y degradados. Con luz incidente azul fluorescente presentan color gris oscuro. Los fitoclastos opacos, de tamaño pequeño, con aristas redondeadas equidimensionales y subangulosos, se presentan de forma subordinada (10%).

La materia orgánica amorfa (30%) es de tipo finamente diseminado, hialino a gris amarillento. La observación con UV presenta color gris oscuro a negro. Los palinomorfos se presentan con un 10%, siendo la asociación microflorística predominantemente continental, caracterizada por Cheirolepidiaceae (43%) y, en menor proporción, Araucariaceae (20%). El microplancton marino está escasamente representado por acritarcos (3%) (Figs. 3 y 5).

Los palinomorfos se presentan afectados por fenómenos de corrosión, degradación y daño mecánico. Bajo fluorescencia presentan color amarillo pálido.

Palinofacies IIIb

Esta palinofacies (F) presenta el más alto contenido de palinomorfos (15%). Del recuento total, el 26% corresponde a microplancton marino (predominantemente acritarcos). El espectro continental está dominado por Pteridospermopsida (34%) y esporas de briofitas y pteridofitas (19%) (Fig. 5).

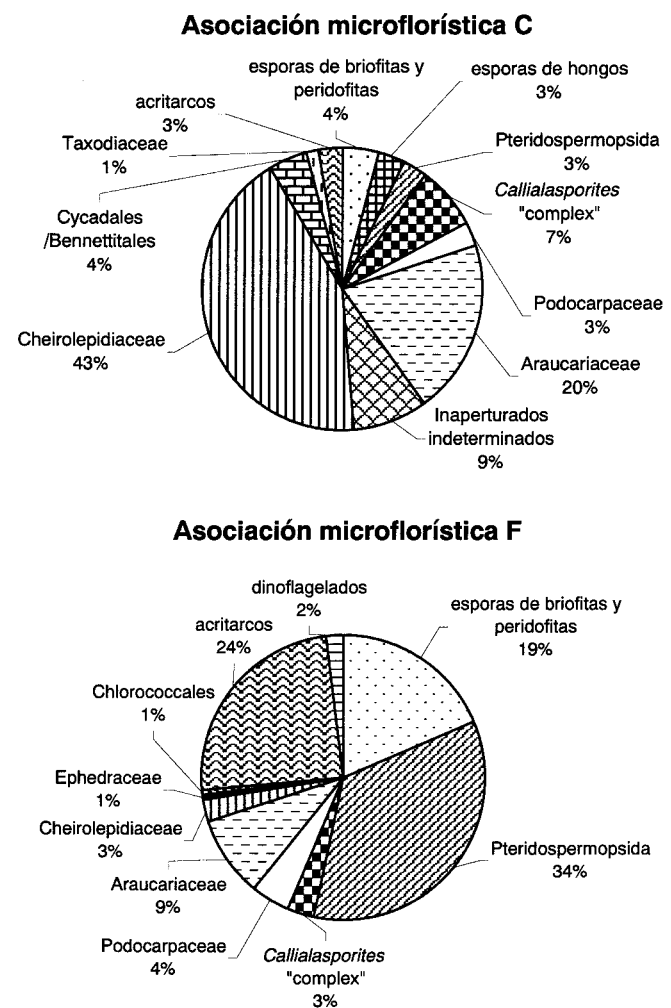


FIGURA 5—Representación de las asociaciones microflorísticas identificadas en el área de Quebrada del Sapo.

FIGURE 5—Microfloristic associations representation identified at the Quebrada del Sapo locality.

Similares proporciones de fitoclastos (45%) y amorfo (40%) son observadas en esta palinofacies. Los fitoclastos son exclusivamente translúcidos, de color ámbar y amarillento, pequeños, con bordes redondeados. Se observa abundante presencia de cutículas y tejidos de color amarillo a ámbar, los que bajo fluorescencia exhiben color anaranjado.

La materia orgánica amorfa es de tipo finamente dividido (castaño) y membranoso (ámbar a amarillento). La observación con UV muestra colores amarillo pálido a amarillo verdoso para el amorfo diseminado, y color amarillo anaranjado y gris oscuro a negro para las masas amorfas.

El tipo de alteración presente en los palinomorfos es corrosión, degradación, daño mecánico y cristalización de piritita dentro de la exina. Se observaron colores de alteración térmica (TAI) de 2- a 2.

Asociación de palinofacies IV

La asociación IV está integrada por las palinofacies D (Quebrada del Sapo 1), H e I (Chacaico), K, L y N (Estancia María Juana), O y P (Picún Leufú) (Fig. 4), Q (Puesto Bascuñán) y R (Estancia Charahuilla). Los palinomorfos varían entre el 3% y 5%, con asociaciones microflorísticas netamente continentales caracterizadas por la presencia de *Botryococcus* spp., cheirolepidiáceas (*Classopollis*

cf. *classoides* y *Classopollis* spp.), efedráceas (*Equisetosporites caichigüensis*), esporas trilete (*Deltoidospora minor*, *Granulatisporites* spp. y *Nevesisporites* cf. *radiatus*) y de hongos. Bajo luz fluorescente los palinomorfos muestran colores de la gama del castaño y gris. La materia orgánica amorfa es predominante, con frecuencias que varían entre 57% y 87%, identificándose mayoritariamente amorfo finamente dividido, membranoso y esponjoso, de color predominante castaño medio y, en menor proporción, amarillo y gris. Bajo luz fluorescente se observan colores entre castaño y gris con intensidad débil a nula.

Los fitoclastos varían entre 10% y 38%, siendo dominantes los fitoclastos translúcidos con frecuencias de hasta 30%. Los fitoclastos translúcidos no-bioestructurados son los más abundantes, de color castaño oscuro. Bajo fluorescencia muestran colores castaño oscuro a gris e intensidad nula. Los fitoclastos translúcidos bioestructurados (tejidos y cutículas) se presentan en forma subordinada con coloraciones que varían entre amarillo y castaño claro, y fluorescencia de color castaño, amarillo y gris e intensidad débil. Los fitoclastos opacos son muy escasos, principalmente de tipo equidimensional.

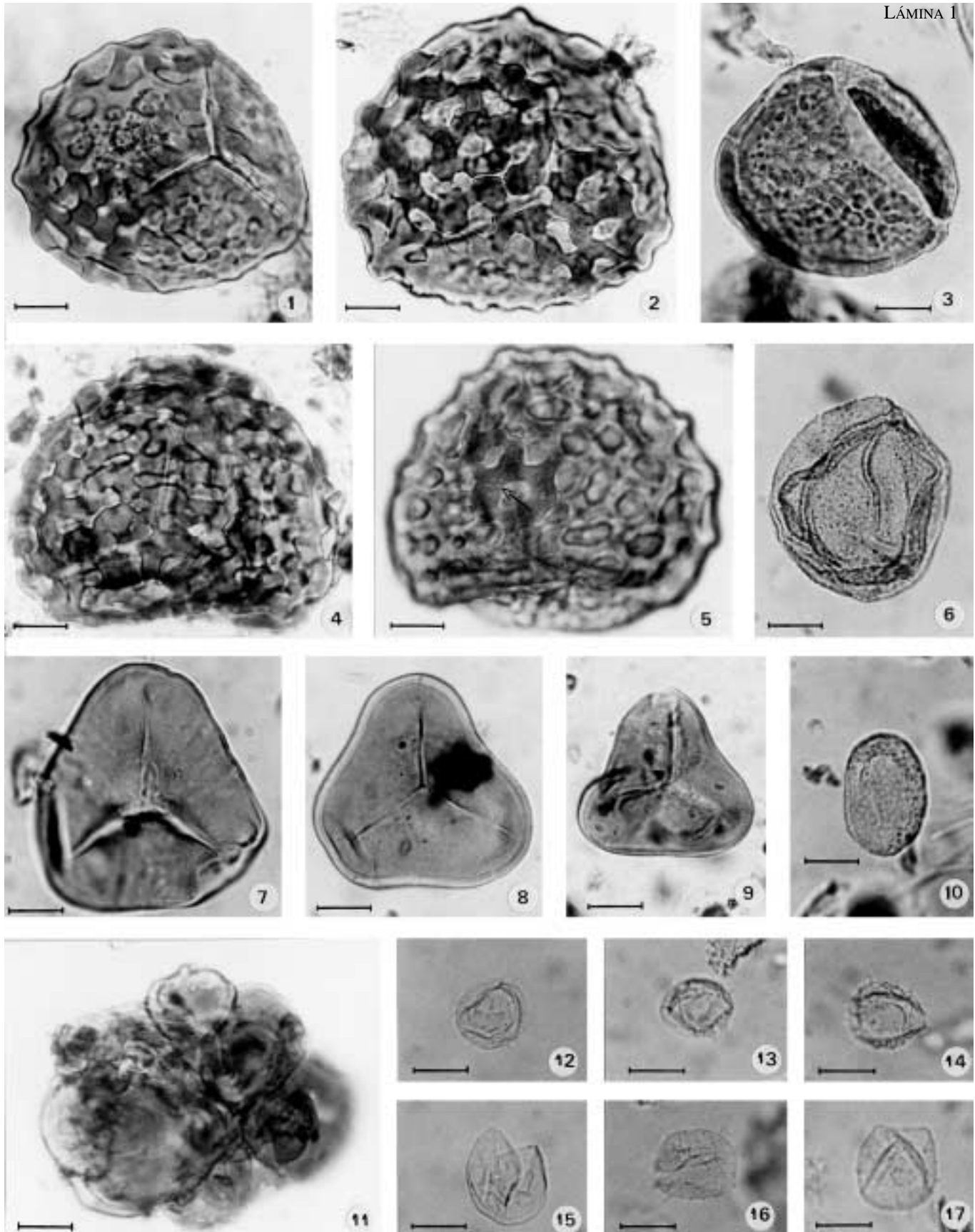
El tipo de deterioro más comúnmente observado es corrosión y degradación.

→

LÁMINA 1—(Escala gráfica = 10 µm). 1-2, 5, *Klukisporites variegatus* Couper, 1958; 1, UNSP F (QS9d): C48. Cara proximal; 2, UNSP F (QS9d): D40. Cara distal; 5, UNSP F (QS9d): X21/3. Cara distal con efectos de corrosión (flecha). 3, *Nevesisporites* cf. *radiatus* (Chlonova) Srivastava, 1972 (en Martínez *et al.*, 2001). UNSP F (QS9d): C32. Cara proximal. 4, *Klukisporites labiatus* (Volkheimer) Baldoni y Archangelsky, 1983. UNSP F (QS9a): Y32. Corte óptico. 6, *Osmundacidites diazii* Volkheimer, 1972. UNSP F (QS9b): Z36. Corte óptico. 7-8, *Deltoidospora neddeni* Pflug, 1953; 7, UNSP F (QS9d): S27/1. Cara proximal; 8, UNSP C (QS1a): C30/3. Cara proximal. 9, *Deltoidospora minor* (Couper) Pocock, 1970. UNSP C (QS1a): M8/2. Cara proximal. 10, *Punctatosporites scabratus* (Couper) Norris, 1965. UNSP F (QS9d): D18/4. 11, *Botryococcus* spp. 12-14, 16-17, *Micrhystridium* cf. *nannacanthum* Deflandre, 1945; 12, UNSP F (QS9d): Y21/1; 13, UNSP F (QS9d): Q24/3; 14, UNSP F (QS9d): C52/4; 16, UNSP F (QS9b): Z37; 17, UNSP F (QS9d): D43/4. 15, *Micrhystridium* spp. UNSP F (QS9b): Z45/4.

PLATE 1—(Scale bar equals 10 µm). 1-2, 5, *Klukisporites variegatus* Couper, 1958; 1, UNSP F (QS9d): C48. Proximal surface; 2, UNSP F (QS9d): D40. Distal surface; 5, UNSP F (QS9d): X21/3. Distal surface with corrosion effect (arrow). 3, *Nevesisporites* cf. *radiatus* (Chlonova) Srivastava, 1972 (in Martínez *et al.*, 2001). UNSP F (QS9d): C32. Proximal surface. 4, *Klukisporites labiatus* (Volkheimer) Baldoni y Archangelsky, 1983. UNSP F (QS9a): Y32. Optical section. 6, *Osmundacidites diazii* Volkheimer, 1972. UNSP F (QS9b): Z36. Optical section. 7-8, *Deltoidospora neddeni* Pflug, 1953; 7, UNSP F (QS9d): S27/1. Proximal surface; 8, UNSP C (QS1a): C30/3. Proximal surface. 9, *Deltoidospora minor* (Couper) Pocock, 1970. UNSP C (QS1a): M8/2. Proximal surface. 10, *Punctatosporites scabratus* (Couper) Norris, 1965. UNSP F (QS9d): D18/4. 11, *Botryococcus* spp. 12-14, 16-17, *Micrhystridium* cf. *nannacanthum* Deflandre, 1945; 12, UNSP F (QS9d): Y21/1; 13, UNSP F (QS9d): Q24/3; 14, UNSP F (QS9d): C52/4; 16, UNSP F (QS9b): Z37; 17, UNSP F (QS9d): D43/4. 15, *Micrhystridium* spp. UNSP F (QS9b): Z45/4.

LÁMINA I



Asociación de palinofacies V

Representada por las palinofacies G (Chacaico) y J (Estancia María Juana).

Los palinomorfos se presentan con un 3% caracterizados por *Botryococcus* spp. y esporas de hongos. Bajo luz fluorescente exhiben colores castaño oscuro a gris e intensidad nula.

Los fitoclastos son predominantes con frecuencias que varían entre 67% y 77%. Los fitoclastos translúcidos no-bioestructurados castaño oscuro a negros con translucencia en los bordes son dominantes, alcanzando valores de hasta 57%. Los fitoclastos translúcidos bioestructurados (tejidos y cutículas) de color castaño se presentan en forma subordinada. Bajo fluorescencia, los fitoclastos muestran colores castaño anaranjado a gris e intensidad nula a débil. Los fitoclastos opacos alcanzan hasta un 30% de tipo equidimensional y tablillas.

La materia amorfa de tipo finamente dividido y membranoso varía entre 20% y 30%. Bajo luz fluorescente se observa de color gris a negro e intensidad nula.

INTERPRETACIÓN PALEOAMBIENTAL Y PALEOCLIMÁTICA EN BASE A PALINOFACIES

El análisis conjunto de las litofacies y las palinofacies ha probado ser una poderosa herramienta en la determinación de paleoambientes y paleoclima, así como también del potencial oleogénico.

Cambios en las asociaciones de palinofacies y composición de las microfloras pueden proveer de información respecto a las condiciones climáticas y ambientes de depositación de una unidad estudiada. La variabilidad de cada palinofacies es interpretada en términos de posiciones relativas al área de aporte terrígeno (proximal/distal al área de aporte) y condiciones del ambiente depositacional. En aquellas asociaciones de palinofacies (palinofacies III a y b) en las que el contenido de palinomorfos permitió realizar recuentos polínicos, el estudio de sus asociaciones microflorísticas (en términos de porcentajes relativos) posibilitó inferir condiciones paleoclimáticas, por comparación de las familias vegetales reconocidas con los análogos modernos.

El presente análisis palinofacial, efectuado a muestras de superficie de la Formación Challacó, revela un predominio de muestras estériles o sólo con presencia de palinomorfos y/o esporas de hongos. A continuación se presentan las interpretaciones paleoclimáticas y paleoambientales que surgen del análisis palinofacial:

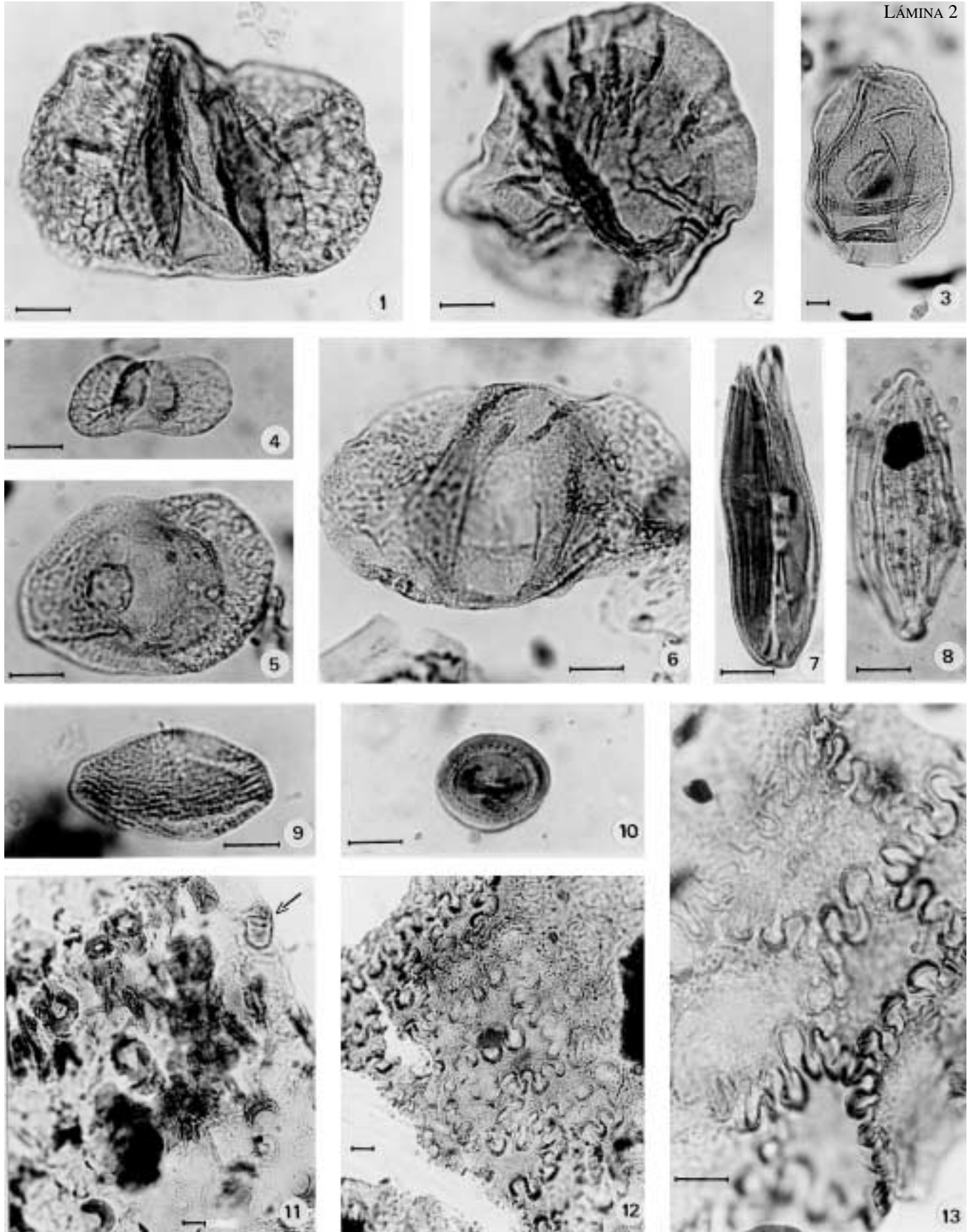
- La asociación de palinofacies I sugiere condiciones de baja energía (predominio de decantación sobre tracción) y ambiente reductor, debido a la abundancia de materia orgánica amorfa con respecto al contenido de fitoclastos. Sin embargo, el mal estado de preservación de dicha materia orgánica indicaría que no siempre prevalecieron estas condiciones, ya sea porque el material pudo en parte ser reelaborado y depositado, o bien por condiciones oxidantes por exposición.

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LÁMINA 2—(Escala gráfica = 10 µm). 1, *Podocarpidites* cf. *ellipticus* Cookson, 1947 (en Volkheimer, 1968). UNSP F (QS9d): T26/1. 2, *Callialasporites dampieri* (Balme) Dev, 1961. UNSP F (QS9d): L48/2. 3, *Araucariacites australis* Cookson, 1947. UNSP F (QS9d): D19. 4, *Vitreisporites pallidus* (Reissinger) Nilsson, 1958. UNSP F (QS9d): D43. 5, *Alisporites* sp. A (en Volkheimer, 1968). UNSP F (QS9d): C45. 6, *Alisporites* cf. *similis* (Balme) Dettmann, 1963. UNSP F (QS9d): D23/3. 7, *Ephedripites menendezii* Volkheimer, 1972. UNSP F (QS9d): C38/3. 8, *Equisetosporites caichigüensis* Volkheimer y Quattrocchio, 1975. UNSP Q (PB1470a): D39/1. 9, *Classopollis intrareticulatus* Volkheimer, 1972. UNSP F (QS9d): 33/4. Vista ecuatorial. 10, *Classopollis simplex* (Danzé-Corsin y Laveine) Reiser y Williams, 1969. UNSP C (QS1a): Y15/1. Vista polar. 11-13, Cutículas de Bennettitales; 11, UNSP F (QS9b): R31/4. Papilas (flecha) en la epidermis abaxial; 12, UNSP F (QS9b): W31. Vista general de la epidermis adaxial; 13, UNSP F (QS9b): Q28. Detalle de la epidermis adaxial.

PLATE 2—(Scale bar equals 10 µm). 1, *Podocarpidites* cf. *ellipticus* Cookson, 1947 (in Volkheimer, 1968). UNSP F (QS9d): T26/1. 2, *Callialasporites dampieri* (Balme) Dev, 1961. UNSP F (QS9d): L48/2. 3, *Araucariacites australis* Cookson, 1947. UNSP F (QS9d): D19. 4, *Vitreisporites pallidus* (Reissinger) Nilsson, 1958. UNSP F (QS9d): D43. 5, *Alisporites* sp. A (en Volkheimer, 1968). UNSP F (QS9d): C45. 6, *Alisporites* cf. *similis* (Balme) Dettmann, 1963. UNSP F (QS9d): D23/3. 7, *Ephedripites menendezii* Volkheimer, 1972. UNSP F (QS9d): C38/3. 8, *Equisetosporites caichigüensis* Volkheimer y Quattrocchio, 1975. UNSP Q (PB1470a): D39/1. 9, *Classopollis intrareticulatus* Volkheimer, 1972. UNSP F (QS9d): 33/4. Equatorial view. 10, *Classopollis simplex* (Danzé-Corsin y Laveine) Reiser y Williams, 1969. UNSP C (QS1a): Y15/1. Polar view. 11-13, Cuticles of Bennettitales; 11, UNSP F (QS9b): R31/4. Papillae (arrow) on the abaxial epidermis; 12, UNSP F (QS9b): W31. General view of the adaxial epidermis; 13, UNSP F (QS9b): Q28. Detail of the adaxial epidermis.

LÁMINA 2



• La asociación de palinofacies II sugiere condiciones ambientales de mayor energía con relación a la asociación de palinofacies I, debido al predominio de fitoclastos sobre el amorfo (con predominio de tracción sobre decantación). Dentro de la materia orgánica amorfa, la abundancia del tipo finamente dividido refleja condiciones moderadamente oxidantes con escasa preservación de otros tipos de amorfo (Tyson, 1995, p.170).

En las palinofacies I y II, la presencia exclusiva de esporas de hongos indica ambientes de tipo continental, con bajo potencial de preservación de otros tipos de palinomorfos. Varios autores sugieren que, bajo condiciones de clima templado húmedo, los sedimentos fluviales son ideales para generar una muy intensa actividad microbiológica de hongos y bacterias (Birks y Birks, 1980; Dimpleby, 1985, etc.). La oxidación bioquímica o corrosión podría haber sido quizá la responsable de la descomposición de los palinomorfos y, a través del tiempo, la causante de su desaparición (Grill, 1993).

• La palinofacies IIIa muestra una asociación microflorística dominante de Cheirolepidiaceae-Araucariaceae, indicativa de condiciones cálidas y relativamente húmedas, asociada a ambientes costeros y suelos bien drenados (predominio de Cheiro-

lepidiaceae), Martínez *et al.*, 1996. Se sugiere para esta palinofacies un ambiente marino marginal (presencia de acritarcos) de moderada energía y oxidación (facies deltaicas distales?).

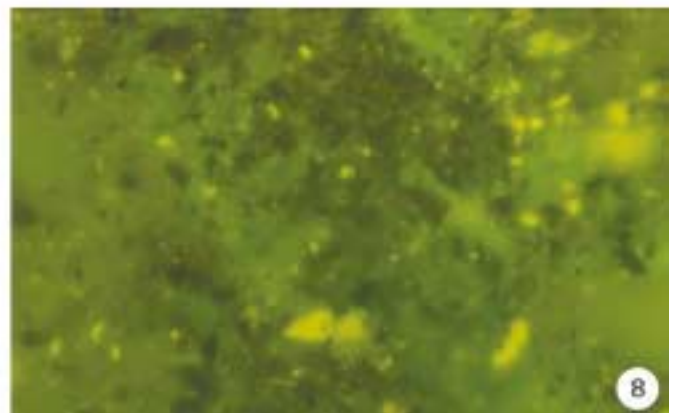
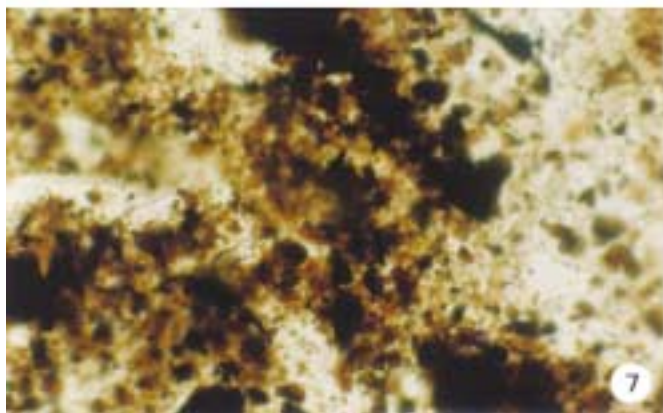
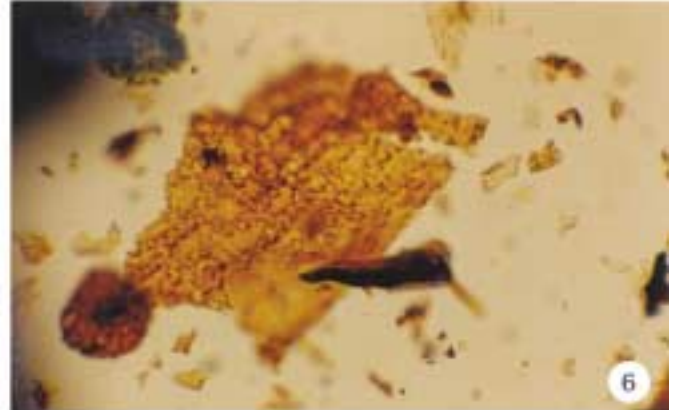
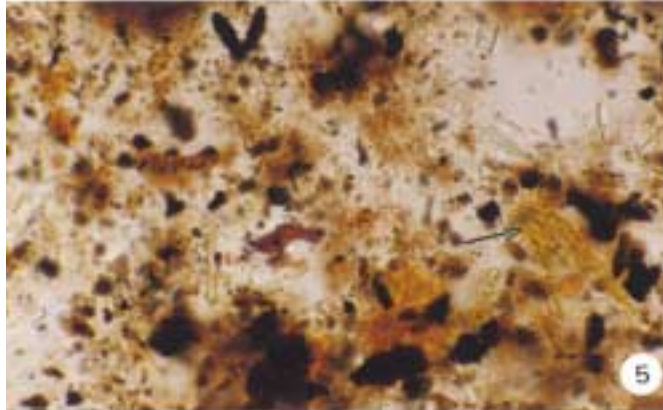
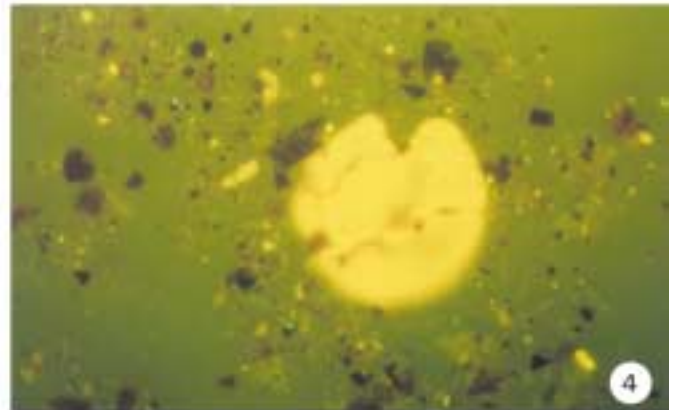
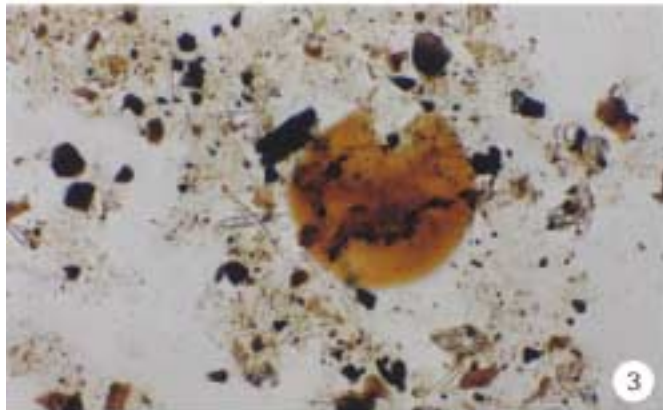
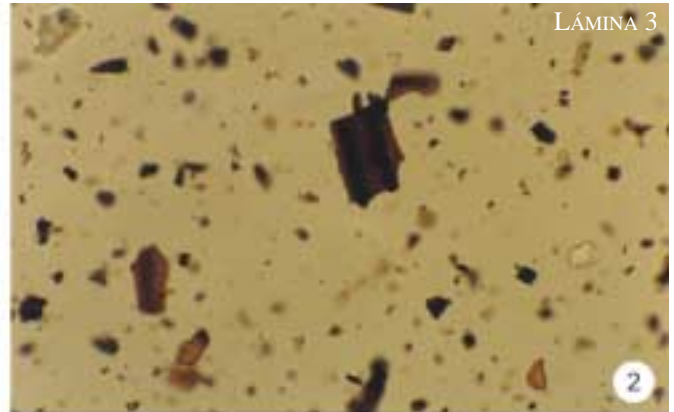
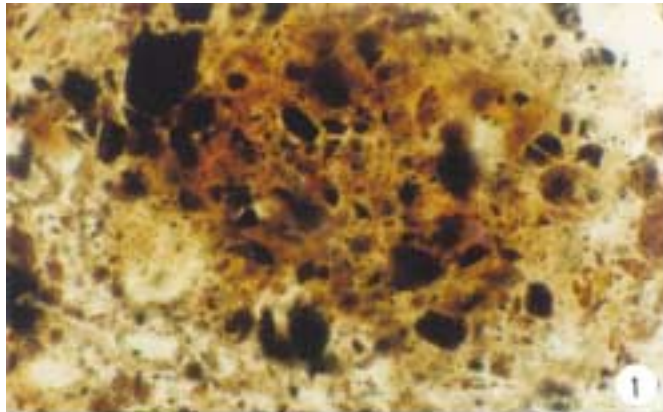
• En la palinofacies IIIb, el predominio de Pteridospermopsida y esporas de briofitas y pteridofitas sugiere condiciones ambientales localmente húmedas en torno a cuerpos de agua dulce a salobre (por el registro de algas asignadas a *Botryococcus* spp.). La presencia de importantes cantidades de cutículas de Bennettitales con rasgos epidérmicos de carácter xeromórfico (pelos y papilas) sugieren, regionalmente, condiciones cálidas, de baja humedad y suelos áridos (Villar de Seoane, 1999, 2001). Según Vakhrameev (1991), tanto las Bennettitales como las Cycadales mesozoicas se desarrollaron principalmente en cinturones subtropicales bajo clima cálido y libre de hielo. Las gruesas cutículas de las Bennettitales con estomas protegidos indican que estuvieron adaptadas a períodos estacionalmente áridos o influencia salina (Abbink, 1998). Estas condiciones estarían corroboradas por la presencia de granos de polen poliplicados correspondientes a efedráceas. En esta palinofacies es de destacar la ausencia de otro tipo de granos colpados que pudieran asignarse a Bennettitales, en contraposición a la

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LÁMINA 3—(Todas las figuras están ampliadas x 400, excepto 6, x 200. Todas fueron tomadas en luz transmitida, excepto 4 y 8, en luz fluorescente). 1, 7-8, Vistas generales de la palinofacies J (Estancia María Juana, 13), perteneciente a la asociación de palinofacies V; 1, 7, Se observa importante participación de fitoclastos translúcidos no-bioestructurados castaño muy oscuro y materia orgánica amorfa de tipo finamente dividido y membranoso; 8, Se observa una matriz débilmente fluorescente. 2, Vista general de la palinofacies T (Rincón del Águila, 985), perteneciente a la asociación de palinofacies II, con predominio de fitoclastos translúcidos no-bioestructurados de color castaño medio a oscuro y, de manera muy subordinada, fitoclastos opacos equidimensionales de pequeñas dimensiones. 3-4, Vistas generales de la palinofacies C (IIIa), con predominio de fitoclastos translúcidos no-bioestructurados castaño muy oscuro a negro, sólo translúcidos en los bordes y opacos equidimensionales, la materia orgánica amorfa finamente dividida, con matriz débilmente fluorescente, se presenta de manera subordinada. En el centro de la figura se observa un palinomorfo indet., con fluorescencia color amarillo de moderada intensidad. 5, Vista general de la palinofacies R (Estancia Charahuilla, 1299), perteneciente a la asociación de palinofacies IV, la materia orgánica amorfa es predominante, también se observan fitoclastos translúcidos, algunos bioestructurados (tejidos) de color castaño anaranjado (flecha). 6, Vista general de la palinofacies F (IIIb), donde se aprecia una resto cuticular de Bennettital y una espora foveolada.

LÁMINA 3—(All figures x 400, except 6, x 200. All taken using transmitted light except 4 and 8 using fluorescence light). 1, 7-8, General views of the palynofacies J (Estancia María Juana, 13), belonging to the palynofacies association V; 1, 7, Important participation of dark brown non-biostructured translucent phytoclasts and finely divided and membranous amorphous organic matter can be observed. 8, Palynofacies with weakly fluorescent matrix. 2, General view of the palynofacies T (Rincón del Águila, 985), belonging to the palynofacies association II, with predominance of medium to dark brown non-biostructured translucent phytoclasts and scarce small particles of equidimensional opaque phytoclasts. 3-4, General views of the palynofacies C (IIIa), with predominance of dark brown to black non-biostructured translucent phytoclasts (only translucent at edge of the particle) and opaques equidimensional phytoclasts. The finely divided amorphous organic matter with weakly fluorescent matrix is scarce. In the middle of the figure a palynomorph indet. with moderate yellow fluorescence can be observed. 5, General view of the palynofacies R (Estancia Charahuilla, 1299), belonging to palynofacies association IV. The amorphous organic matter is predominant. The arrow show orange brown biostructured translucent phytoclast (tissue). 6, General view of the palynofacies F (IIIb), a foveolate spore and a bennettitalean cuticle can be observed.

LÁMINA 3



abundancia de sus cutículas; esto constituye una evidencia más de la baja productividad polínica de esta familia, tal como fuera expuesto en Volkheimer, 1969 y Baldoni y Archangelsky, 1983. El contexto ambiental antes mencionado habría constituido el área de aporte terrígeno a un ambiente marino marginal (presencia de acritarcos y quistes de dinoflagelados) relativamente restringido, bajo condiciones anóxico-disóxicas (cristalización de pirita, como indicativo de condiciones reductoras), las cuales podrían asociarse, probablemente, a ambientes mareales. La presencia de la asociación de *Escharisphaeridia pocockii-Michrystridium* spp. es considerada como indicativa de ambientes marinos marginales (Zavala *et al.*, 1992; García *et al.*, 1994; García, 1998; Martínez *et al.*, 2002).

- La asociación de palinofacies IV sugiere condiciones de baja energía (predominio de decantación sobre tracción), debido al predominio de materia orgánica amorfa con respecto al contenido de fitoclastos. Estas condiciones serían similares a las observadas en la palinofacies I. La presencia de algas de agua dulce/salobre asociadas a esporas de briofitas y otros palinomorfos de origen continental sugieren la presencia de cuerpos de agua más estables. Sin embargo, el mal estado de conservación de dicha materia orgánica, sumado a la escasez de palinomorfos, indicaría condiciones desfavorables para una óptima preservación de la misma (levemente oxidantes y/o alcalinas).

- En la asociación de palinofacies V, la presencia exclusiva de algas de agua dulce y esporas de hongos sugiere un ambiente ácuo continental (pantano/lago) en conexión con corrientes fluviales (predominio de fitoclastos). Condiciones oxidantes y de moderada energía habrían contribuido al escaso potencial de preservación de estos depósitos.

- Las muestras correspondientes a las palinofacies H, I, G, O, P, Q, R, S, T, U y V han sido interpretadas por Zavala (1993) como pertenecientes a un ambiente de llanura aluvial.

POTENCIAL OLEOGENÉTICO DE LA FORMACIÓN CHALLACÓ

Como fuera expresado anteriormente, las palinofacies no sólo pueden ser utilizadas para establecer el ambiente depositacional, sino también para evaluar el potencial como fuente de hidrocarburos de una unidad determinada (Batten, 1981; Tyson, 1995).

Para determinar el potencial oleogenético a partir de las palinofacies, se tuvieron en cuenta los siguientes parámetros de observación:

- El tipo de deterioro predominante (corrosión y degradación) sugiere que la presencia de oxígeno disuelto en agua fue el principal factor de alteración.

- La naturaleza del material amorfo predominante (finamente diseminado) con intensidad de fluorescencia nula a débil.

- Predominio de palinomorfos de origen continental (polen y esporas) en todas las asociaciones microfóricas con color de fluorescencia predominante castaño oscuro a gris e intensidad nula.

- Índices de alteración térmica (2- a 2) correspondientes a un estadio inmaduro de generación de hidrocarburos.

Todas las palinofacies sugieren ambientes depositacionales con escasa preservación del contenido orgánico, por oxidación subaérea durante el transporte y/o deposición, o bien retrabajo de depósitos más antiguos.

Se propone para estas palinofacies un querógeno de tipo III/IV (Tissot y Welte, 1984; Tyson, 1995), con un escaso a nulo potencial de generación de hidrocarburos líquidos.

CONCLUSIONES

- El estado del conocimiento actual, derivado de los aportes multidisciplinarios de la estratigrafía-secuencial y la palinología (palinoestratigrafía y palinofacies), permite interpretar que la Formación Challacó se integraría por dos unidades genéticamente distintas, separadas por una importante discordancia (discordancia Intracalo-viana), una perteneciente al Grupo Cuyo, denominada como Challacó ss., y otra ubicada en la base del Grupo Lotena, "Challacó" de Zavala y González, 2001.

- La Formación Challacó ss. se caracteriza por la presencia de las asociaciones de palinofacies I, II, IV y V, las que, en general, presentan como rasgo notorio la esterilidad en palinomorfos o presencia de esporas de hongos, *Botryococcus*, y otros palinomorfos de origen continental. En aquellos ambientes donde predominaron corrientes tractivas sobre la decantación, los fitoclastos superan a la materia orgánica amorfa, tal sería el caso de las asociaciones de palinofacies II y IV, que podrían vincularse, probablemente, a llanuras de inundación de flujos encauzados bajo condiciones de moderada energía y oxidación. En cambio, en aquellos ambientes de menor energía y condiciones menos oxidantes, donde se da predominio de decantación sobre tracción, la materia orgánica amorfa alcanza los mayores porcentajes, asociada a ambientes lacustres (asociación de palinofacies I y IV).

- Las palinofacies IIIa y IIIb serían características de la Formación “Challacó”, dado que son las únicas que se vincularían a un ambiente depositacional marino marginal, por la presencia de acritarcos y quistes de dinoflagelados en sus asociaciones microfiorísticas.

- La presencia de *Ephedripites menendezii* Volkheimer y *Klukisporites variegatus* Couper en las asociaciones C y F (Quebrada del Sapo 2 y 1, respectivamente), no registrados anteriormente en depósitos precalovianos de la Cuenca Neuquina, así como la gran similitud con la microflora del carbón caloviano (Volkheimer, 1972), permite sugerir que las asociaciones aquí descritas no serían más antiguas que el Caloviano. Una edad similar fue propuesta por Freije *et al.* (2002) para la Formación “Challacó” en el área de Quebrada del Sapo.

- El estudio de las escasas asociaciones microfiorísticas presentes permite determinar condiciones de clima cálido (subtropical), relativamente árido (aridez estacional) y localmente húmedo (en torno a cuerpos de agua dulce a salobre).

- El tipo de querógeno identificado (tipo III/IV, Tissot y Welte, 1984; Tyson, 1995), y el estado de preservación del mismo permite determinar para las palinofacies estudiadas un escaso a nulo potencial de generación de hidrocarburos líquidos.

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PALYNOSTRATIGRAPHY, PALAEOBIOGEOGRAPHY AND EVOLUTIONARY SIGNIFICANCE OF THE LATE SENONIAN AND EARLY PALAEOGENE PALYNOFLORAS OF THE SALTA GROUP, NORTHERN ARGENTINA

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Abstract

A Late Senonian palynoflora from the Salta Basin, northern Argentina (first Cretaceous palynologic record in this basin) is analyzed. It contains typical Mesozoic taxa like *Classopollis* spp., *Callialasporites* spp. and *Todisporites major*. But it contains also some angiospermous taxa which correspond to species previously observed only in younger (Palaeogene) sediments and at lower geographic latitudes of tropical South America and tropical Africa (*Retitrescolpites saturum*, *Retistephanocolpites regularis*, *Spinetricolpites jennerclarkei* and others). Of evolutionary importance is the conclusion that the parent plants of these tropical taxa specialized in subtropical areas of South America during the Late Cretaceous, when Africa and South America were still more closely together. Of paleoclimatologic and paleobiogeographic significance is the evidence that due to a Palaeocene-Eocene climate change (cooling), the parent plants of these formspecies migrated into tropical regions of equatorial South America and Africa and consequently appear in the Palaeogene tropical palynologic record in strata whose temporal equivalents in southern South America are lacking these taxa. The striking palaeofloristic contrast between the Late Senonian and the Palaeogene in the Salta Basin can be appreciated comparing the taxa cited on the taxonomic list of the Vilches locality with those on the quali- and quantitative range chart of palynomorphs from the Palaeogene.

Key words: Palynostratigraphy, Palaeobiogeography, Evolution, Paleoclimate, Late Senonian, Palaeogene, Salta Group, Argentina.

Resumen

Se analiza una palinoflora del Senoniano Tardío de la Cuenca de Salta, norte de la Argentina (primer registro palinológico de edad cretácica en esta cuenca). Aparte de taxones típicamente mesozoicos como *Classopollis* spp., *Callialasporites* spp. y *Todisporites major*, algunos taxones de polen de angiospermas (*Retitrescolpites saturum*, *Retistephanocolpites regularis*, *Spinetricolpites jennerclarkei* y otros) corresponden a especies que se observaron previamente sólo en sedimentos más jóvenes (del Paleógeno) y de paleolatitudes más bajas de Sudamérica tropical y África tropical. De importancia evolutiva es la conclusión que estos taxones tropicales se especializaron en áreas más australes (actualmente de clima subtropical) de América del Sur durante el Cretácico Tardío, cuando África y América del Sur se encontraban más próximas. De importancia paleoclimatológica y paleobiogeográfica es la evidencia de que debido a un cambio climático (enfriamiento) del Paleoceno-Eoceno, las plantas productoras de estas morfoespecies, adaptadas a un clima cálido, migraron a regiones tropicales de América del Sur ecuatorial y África y, por consiguiente, su polen ocurre en el registro fósil tropical del Paleógeno en estratos cuyos equivalentes temporales en América del Sur austral carecen de estas especies. El contraste paleoflorístico entre el Senoniano Tardío y el Paleógeno de la Cuenca

de Salta se percibe comparando los taxones citados en la lista taxonómica de la localidad de Vilches con el cuadro cualitativo y cuantitativo de distribución (*range chart*) de palinomorfos del Paleógeno.

Palabras clave: Palinoestratigrafía, Paleobiogeografía, Evolución, Paleoclima, Senoniano Tardío, Paleógeno, Grupo Salta, Argentina.

INTRODUCTION AND GEOLOGIC SETTING

This paper presents the first record of a Late Senonian palynologic assemblage from the Salta Basin (Fig. 1) of northwestern Argentina. The palynoflora was found at Quebrada de Vilches area, near the southwestern border of the Cretaceous-Palaeogene basin, in the passage beds between the Los Blanquitos Formation (top of the Pirgua Subgroup) and the Lecho Formation (base of the Balbuena Subgroup) of the Salta Group (Fig. 2).

The Salta rift comprises a complex suite of extensional troughs that characterize the Cretaceous to Palaeogene palaeogeography of northern Argentina. There were two main episodes in the basin development. First, a synrift stage (Neocomian-Campanian) represented by red beds and basalts of the Pirgua Subgroup. Second, a postrift stage represented by the Balbuena (sandstones, limestones and pelites of fluvio-eolian, shallow marine and lacustrine postrift transgressive environment; Maastricht to Palaeogene) and Santa Bárbara (lacustrine mudstones and sandstones; final stage of postrift, Palaeogene) subgroups. The western part of the rifts was inverted during the Andean deformation in the Neogene and has since then been involved in a complex fold and thrust belt (Salfity and Marquillas, 1994, 2000).

In the southern portion of the basin, the basal part of the Balbuena Subgroup (Lecho Formation) contains dinosaurs of late Senonian age, being conformably and transitional with the uppermost part of the Pirgua Subgroup (Los Blanquitos Formation). From the contact zone of Los Blanquitos and Lecho formations have been obtained the palynomorphs. Most of the taxa represent first records for the basin; only a few continue into deposits younger than the Lecho Formation.

The Late Cretaceous-Palaeocene-Early Eocene transition in the Salta Basin was characterized by a remarkable temporal variability of palaeoclimate (temperature and humidity) and relief. Whether these phenomena reflect hemisphere-wide or local processes,

will be the subject of further studies. The threefold subdivision of the Palaeocene of the Salta Basin is based on: 1) the presence of three different lithostrati-

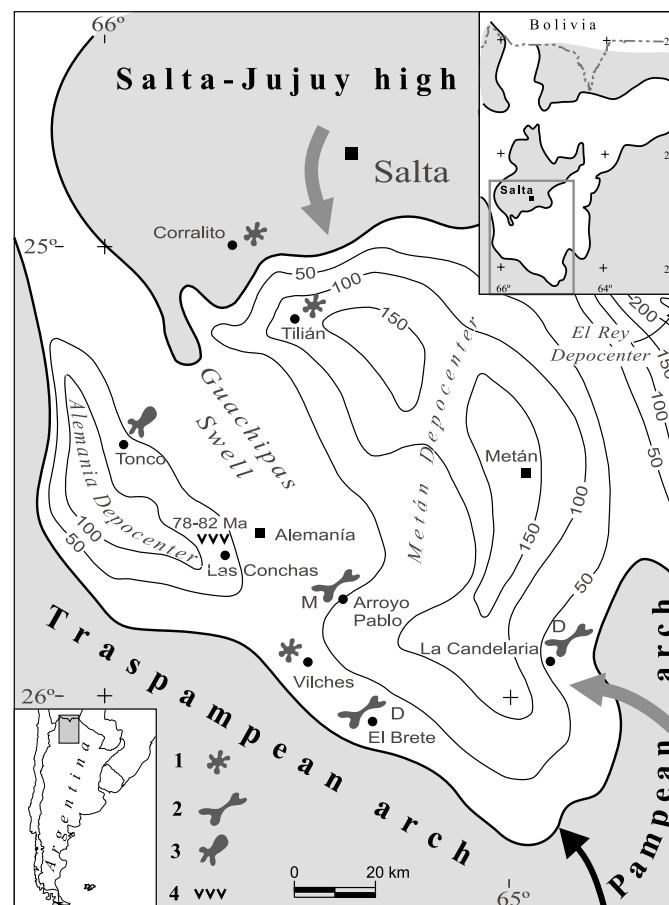


FIGURE 1—Isopach map of Lecho Formation at the southern end of the Salta Group basin (after Salfity 1980). Thickness in metres. Dots indicate localities where diagnostic fossils and radiometric data are given (see Figs. 2 and 3). Arrows mean probable source direction of Ordovician (grey) and Permian (black) redeposited palynofloras into Cretaceous Vilches section. The basal outline (inset) corresponds to the Lecho Formation. 1. Palynoflora, 2. Vertebrates (D Late Senonian dinosaur, M Late Palaeocene-Middle Eocene terrestrial mammal-fauna), 3. Late Senonian dinosaur footprints, 4. Volcanic and radiometric data.

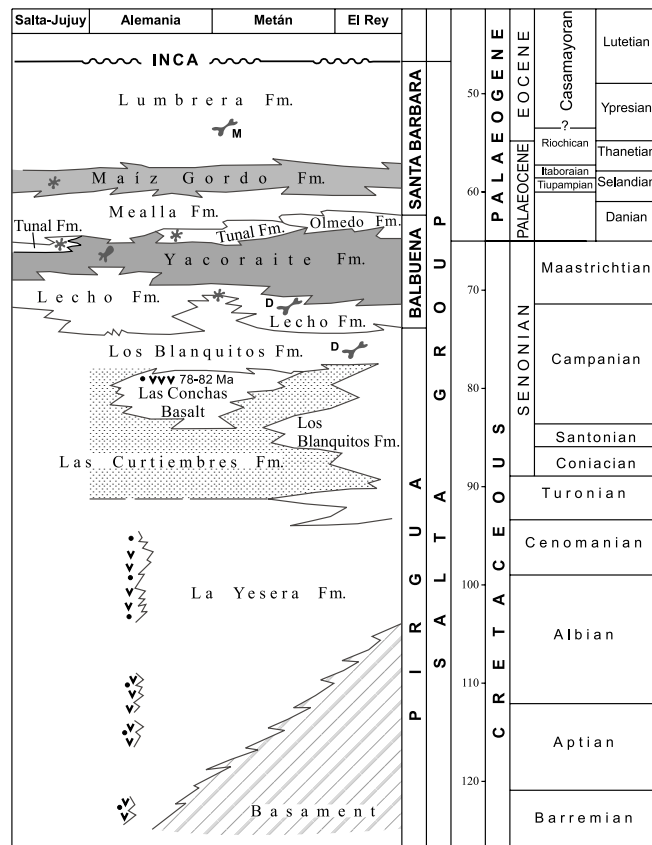


FIGURE 2—Chronostratigraphic column of the Salta Group in Metán, Alemania and El Rey depocenters and in Salta-Jujuy high (based on and adapted from Salfity and Marquillas, 1994). Dots indicate stratigraphic location of radiometric data. Other references: see Figure 1.

graphic units; 2) palaeofloristic changes through bio-events, expressed by first and last appearances of certain species of palynomorphs; 3) palynologic and sedimentary climatic indicators, suggesting:

- a) Warm-humid conditions during the Danian (lacustrine deposits of the Tunal Formation), even if these conditions may not have been general or permanent (for example, the saline to hypersaline lake of the Olmedo Formation and in several parts of the Tunal Formation lake);
- b) Lower humidity during the Selandian (“Franja Gris” of the Mealla Formation, representing a calcareous mudplain);
- c) Dry conditions during the Thanetian and lower Ypresian: alkaline lake of the Maíz Gordo Formation.

The most reliable chronologic information available for defining the relative age of the levels bearing palynomorphs are the vertebrate palaeontologic record and some radiometric data (Figs. 2 and 3). In the land-mammal fossil record, at the family level, the differences between the Late Senonian and Palaeocene assemblages are remarkable, specially concerning the marked turnover in land-mammal communities, between the Campanian and Danian. Two distinct Mesozoic Gondwanan and Cenozoic South American isolation stages are indicated by the South American land-mammal record, both stages being separated by a long interval of time (Pascual, 1988).

In the study area, Bonaparte and Bossi (1967) discovered Campanian dinosaurs in the upper part of the Los Blanquitos Formation approximately 60 km east of the Vilches locality. Near the section we studied, 25 km to the southeast, the El Brete fossiliferous locality is located where Bonaparte found within the Lecho Formation an extraordinary fauna of Campanian-Early Maastrichtian dinosaurs, associated with birds (Bonaparte *et al.*, 1977). *Noasaurus leali* Bonaparte and Powell, 1980 and *Unquillosaurus ceibali* Powell, 1979, are biogeographically and phylogenetically important members of this fauna, due to their differences from related forms of the northern hemisphere.

Stratigraphical, sedimentological and geochemical evidences allow to deduce that the K/T boundary would be located at the upper section of the Yacoraite Formation (Fig. 2); (Marquillas *et al.*, 2002, 2003).

MATERIAL AND METHODS

From the sixteen palynologic samples processed from the Vilches locality, four yielded palynomorphs. The palynologic material was extracted in the Laboratorio de Paleopalinología of IANIGLA (Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales), Mendoza, by A. Moschetti. For the extraction, hydrochloric acid (10%) and hydrofluoric acid (70%) were used to remove carbonates and silicates, respectively. The extracted organic matter was sieved (10 µm mesh) with sodium hexametaphosphate (0,3%). Part of the residue was oxidized with nitric acid (30%).

The microscope slides were mounted in glycerine jelly and are stored in the palaeopalinologic repository of IANIGLA under the code MPLP (Mendoza-Paleopalinoteca-Laboratorio-Paleopalinología) and the numbers 7120, 7225, 7226, 7227.

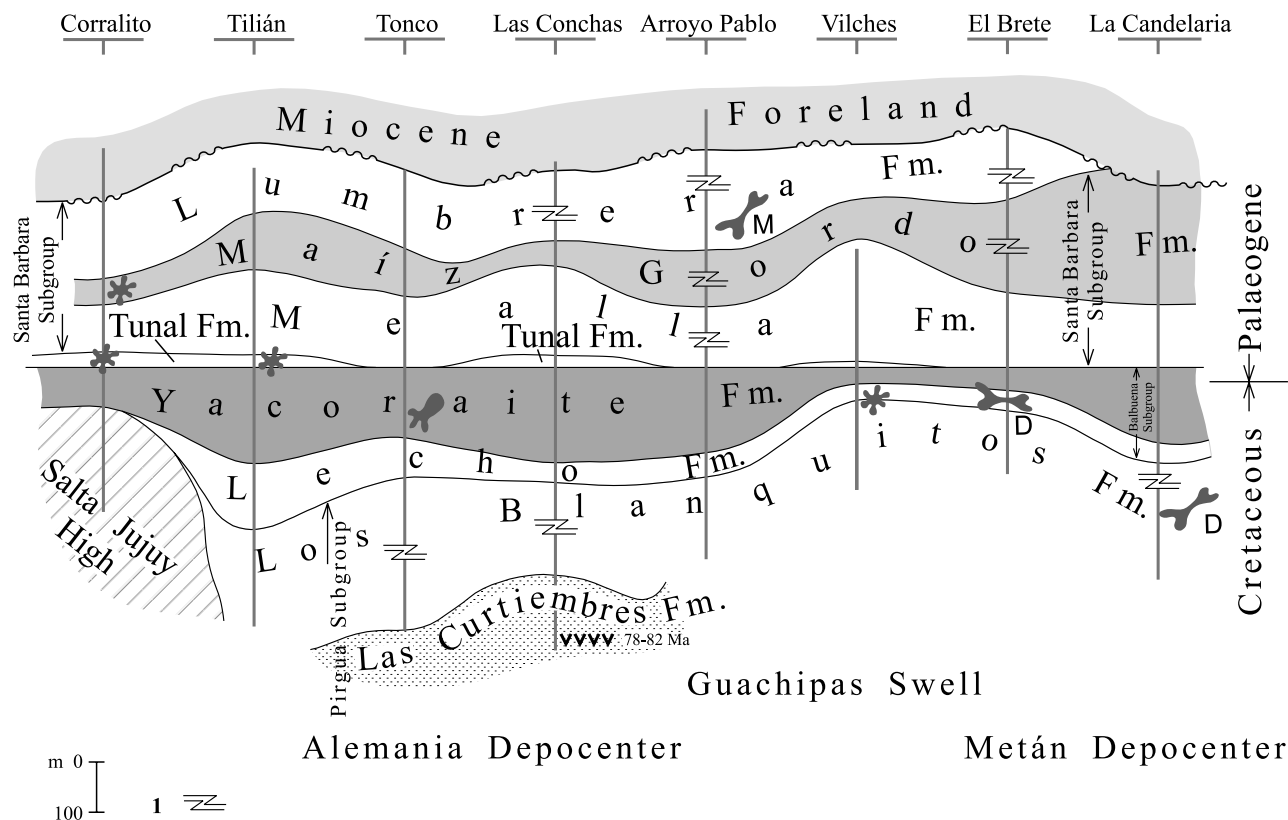


FIGURE 3—Regional cross-section of the Salta Group basin between the Salta-Jujuy high and Metán depocenter. Stratigraphic datum: top of Yacoraite Formation. For position of localities and other references see Figure 1. Horizontal distances between localities are not to scale. Vertical scale refers to thickness of the Balbuena Subgroup (Lecho, Yacoraite, and Tunal formations). Thickness of the Pirgua and Santa Bárbara subgroups are interrupted or not to scale. 1. Interrupted thickness.

The microscopic study was carried out at the Cátedra de Geología Histórica of the Department of Geology of the Universidad Nacional del Sur (UNS), Bahía Blanca, and at the Unidad de Paleopalínología of IANIGLA, Mendoza, using Olympus and Leitz Dialux 20 microscopes, respectively. The position of specimens on slides as determined by an England Finder is given in parenthesis (E24/3) in the plate explanations.

TAXA RECORDED

All taxa identified in the latest Senonian palynoflora from the Vilches locality

The botanical affinity is indicated with an asterisk (*).

Laevigati

Massulae of *Azolla* (Pl. 1; Fig. 1) *Salviniaceae

Todisporites major Couper, 1953 (Pl. 1; Fig. 2)

*Osmundaceae

Biretisporites cf. *B. potoniaei* Delcourt & Sprumont, 1955 (sensu Dettmann, 1963) (Pl. 1; Fig. 3)

*Osmundaceae

Calamospora sp. (Pl. 1; Fig. 4) *Equisetales

Murornati

cf. *Foveasporis* sp. (Pl. 1; Fig. 5)

Zlvisporis sp. C Braman (2001, Upper Santonian, Alberta, Canada) (Pl. 1, Fig. 11) *Bryophyta (Hepaticae)

Zlvisporis sp. 1 (Pl. 1; Fig. 8)

Saccites

Callialasporites dampieri (Balme) Dev, 1961 (Pl. 1; Fig. 7) *Podocarpaceae

Callialasporites trilobatus (Balme) Dev, 1961 *Podocarpaceae

Plicates

Ephedripites spp. (Pl. 1; Fig. 14) *Ephedraceae

?*Bacumorphomonocolpites* sp. (Pl. 1; Fig. 6)

Spinitricolpites jennerclarkei Scholtz ex Jansonius & Hills, 1990 (originally recorded from the Palaeogene(?) of South Africa) (Pl. 1; Fig. 12)

*Valerianaceae?-Verbenaceae

Retistephanocolpites regularis Hoeken-Klinkenberg, 1966 (originally recorded from the Middle Eocene of Nigeria) (Pl. 2; Figs. 3-4)

**Catostemma* (Bombacaceae)

Rhoipites sp. A of Quattrocchio, 1980 (Pl. 2; Fig. 2)

*Rutaceae

Retitrescolpites saturum (González, 1967) Jaramillo and Dilcher, 2001 (originally recorded from the Middle Eocene of Colombia) (Pl. 2; Fig. 1)

Poroses

Classopollis spp. (Pl. 1; Fig. 9) *Cheirolepidiaceae
Gemmapolyporites aegypticus Kedves, 1986, (originally recorded from the Late Eocene of Egypt) (Pl. 1; Fig. 13)

Echiperiporites akanthos van der Hammen and Wijmstra, 1964 (originally recorded from the Oligocene of British Guyana) (Pl. 1; Fig. 10)

Bombacacidites sp. B Muller *et al.* 1987 (originally recorded from the Middle Eocene of Colombia) (Pl. 2; Fig. 6) *Bombacaceae

cf. *Beaupreadites* sp. (Pl. 2 ; Fig. 5) *Proteaceae?

Verrustephanoporites simplex Leidelmeyer, 1966 (originally recorded from the Palaeocene of Guyana) (Pl. 2; Fig. 7) *Ulmaceae (cf. *Phyllostylon*)

Microplankton

Zygnemataceae

Green algae (cysts) (Pl. 2; Fig. 10)

Celyphus sp. (Pl. 2; Fig. 8)

?*Thalassiphora* sp. (Pl. 2; Fig. 9)

Reworked

cf. *Arbusculidium* sp.

cf. *Limbicysta* sp. (Pl. 2; Fig. 11)

All species known to date from the Tunal, Maíz Gordo and Lumbrera formations

Psilamonoleti

Laevigatosporites sp. A of Quattrocchio, 1978b

Laevigati

Azolla sp. of Quattrocchio *et al.*, 1997

Biretisporites sp. of Quattrocchio, 1980

Deltoidospora sp. of Quattrocchio *et al.*, 1997

Murornati

Retitriletes austroclavatidites (Cookson) Doring, Krutzsch, Mai and Schultz, 1963

Ischyosporites spp. of Quattrocchio *et al.*, 1997

Apiculati

Baculatisporites sp. of Quattrocchio, 1980

Apiculatisporis sp. of Volkheimer, 1972

Saccites

Podocarpidites marwickii Couper, 1953

Aletes

Inaperturopollenites sp. D of Quattrocchio, 1980

Inaperturopollenites sp. E of Quattrocchio, 1978b

Smilacipites saltensis Quattrocchio, 1980

Smilacipites sp. of Quattrocchio, 1978b

Plicates

Liliacidites variegatus Couper, 1953

Monosulcites minutiscabratus McIntyre, 1968

Spinizonocolpites sp. of Archangelsky, 1973

Ephedripites cf. *E.* sp. 1 Frederiksen *et al.*, 1983 of Quattrocchio and Volkheimer, 1988

Gemmatricolpites subsphaericus Archangelsky, 1973

Clavatricolpites cf. *gracilis* González Guzmán, 1967

Tricolpites bibaculatus Archangelsky and Zamalóa, 1966

Tricolpites communis Archangelsky, 1973

Tricolpites (Psilatricolpites) lumbrerensis Quattrocchio, 1980

Tricolpites cf. *reticulata* Cookson, 1947, of Quattrocchio and Volkheimer, 1988

Tricolpites sp. cf. *T. reticulata* Cookson, 1947, of Quattrocchio, 1978a

Rousea patagonica Archangelsky, 1973

Psilatricolpites acerbus González Guzmán, 1967

Psilatricolpites simplex González Guzmán, 1967

Rhoipites minusculus Archangelsky, 1973

Rhoipites baculatus Archangelsky, 1973

Rhoipites sp. A of Quattrocchio, 1980

Rhoipites sp. B of Quattrocchio *et al.*, 1988

Rhoipites sp. of Quattrocchio, 1978b

Psilatricolporites salamanquensis Archangelsky and Zamalóa, 1986

Retitricolporites chubutensis Archangelsky, 1973

Retitricolporites medius González Guzmán, 1967

Retitricolporites sp. A of Quattrocchio *et al.*, 1988

Ailanthipites sp. of Quattrocchio *et al.*, 1988

Nothopollenites sp. of Quattrocchio, 1978b

Poroses

Restioniidites spp. of Quattrocchio *et al.*, 1997*Pandaniidites texus* Elsik, 1968*Pandaniidites* sp. of Archangelsky, 1973*Myriophyllumpollenites* sp. 1 of Quattrocchio and Volkheimer, 1988*Myriophyllumpollenites* sp. 2 of Quattrocchio and Volkheimer, 1988*Liquidambarpollenites* cf. *brandonensis* Traverse, 1955 (sensu Quattrocchio, 1978a)*Verrustephanoporites simplex* Leidelmeyer, 1966*Corsinipollenites menendezii* Quattrocchio, 1978b*Echistephanoporites* sp. cf. *E. alfonsi* Leidelmeyer 1966 (sensu Volkheimer *et al.*, 1984)*Cricotriporites* cf. *guianensis* Leidelmeyer, 1966 (sensu Volkheimer *et al.*, 1984)*Cricotriporites* sp. A of Volkheimer *et al.*, 1984*Triorites* sp. of Quattrocchio *et al.*, 1984

Incertae sedis

Mtchedlishvilia saltenia Moroni, 1984

Megaspore

Grapnelispora evansii Stover and Partridge, 1984

Fungi

Inapertisporites sp. A of Quattrocchio, 1978b*Inapertisporites ovalis* Sheffy & Dilcher, 1971*Multicellaesporites* sp. of Volkheimer *et al.*, 1984*Diporisporites elongatus* van der Hammen, 1954*Hypoxylonites* (= *Diporisporites*) sp. of Quattrocchio, 1980*Diporicellaesporites* sp. of Quattrocchio, 1978b*Pluricellaesporites* sp. A of Quattrocchio, 1978b

Algae

Pediastrum sp. of Quattrocchio and Volkheimer, 1988*Catinipollis geiseltalensis* Krutzsch, 1966SIGNIFICANCE OF OCCURRENCES
OF TAXA

Analysis of the stratigraphic distribution of Late Cretaceous-Palaeogene sporomorphs in several basins in Argentina (Ruiz *et al.*, 1996) revealed that *Todisporites major*, *Classopollis* spp. and *Azolla* sp. occur in Late Cretaceous deposits and *Verrustephanoporites simplex*, *Rhoipites* sp. A and *Azolla* sp. are mentioned since the Palaeocene in the Salta Basin. On the other hand, there are also first records for Argentina of other species found: Some of the taxa for the studied levels correspond to species previously documented from younger successions in northern latitudes, i. e., especially from the Palaeogene of Ecuador, Nigeria and Egypt.

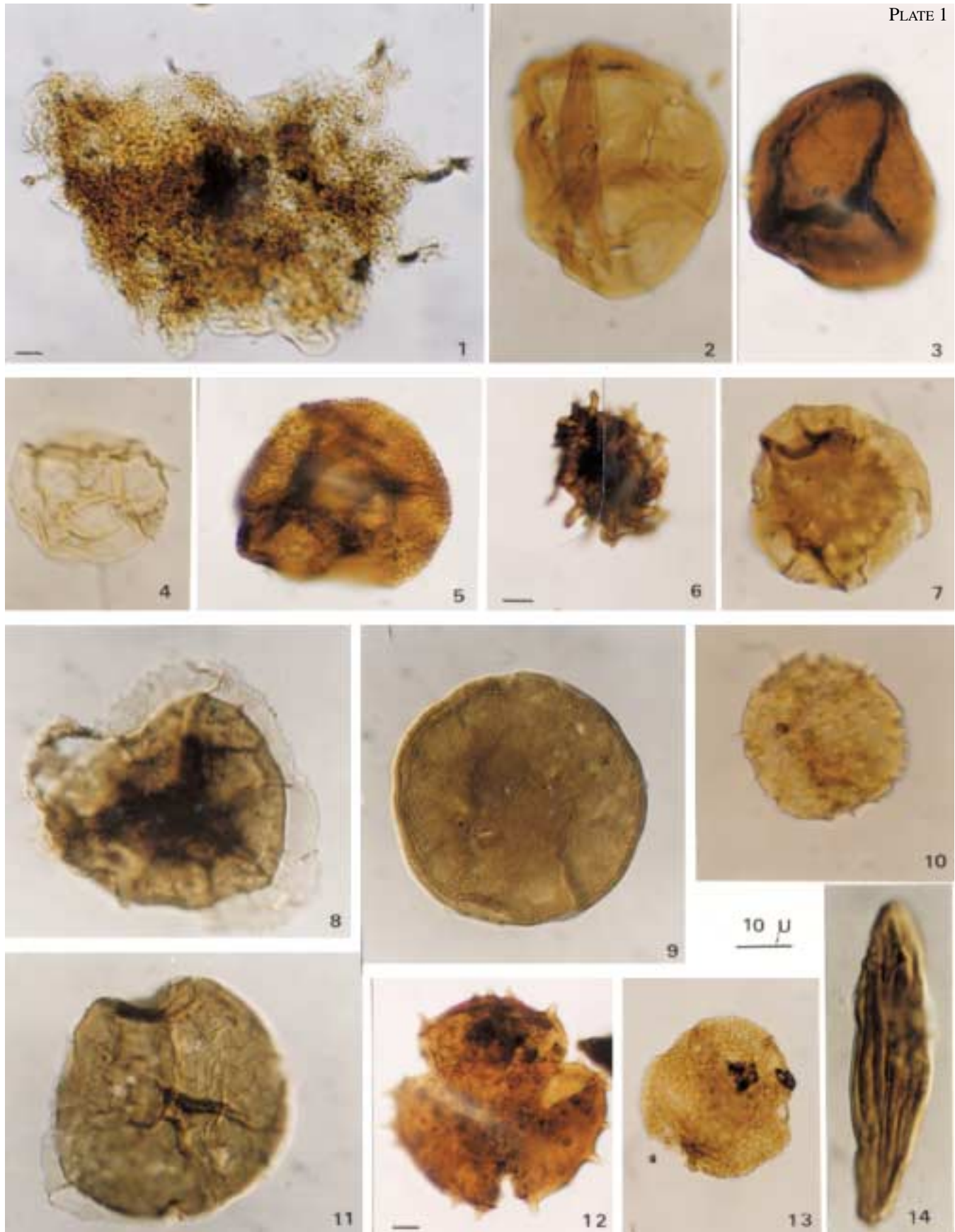
Jaramillo & Dilcher (2001, p. 177) mention: "Pollen and spore biostratigraphers should not expect many widespread synchronous first and last occurrences in the stratigraphic record". Many variables like migration, non-preservation, geographic barriers, and local extinction can truncate the geological range of a taxon (Mann & Lane, 1995).

There is another plausible explanation for those taxa shared with tropical Africa and the Neotropics of Palaeocene and Eocene age. Those taxa could have evolved in subtropical areas (our case) during the Late Cretaceous, when the two continents were still close to each other. Then, as a result of to the Palaeocene-Eocene climatic change, their parent plants migrated into tropical regions and consequently appeared in the tropical fossil record. This hypothesis was postulated by Jaramillo & Dilcher (2001, p. 177). The same authors express: "However, those shared taxa have not been found in subtropical areas during the late Cretaceous. Therefore, at this time, this hypothesis has only weak support". Nevertheless, the Late Senonian assemblage of palynomorphs from the Vilches locality confirms the hypothesis of Jaramillo and Dilcher.

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PLATE 1–I, Massulae of *Azolla*. 7225ñ: 11,4/136(P36) ; (UNS). 2, *Todisporites major* Couper 1953 7225g: 20,2/131,9 (E31/4); (UNS). 3, *Biretisporites* cf. *B. potoniaei* Delcourt & Sprumont 1955 (in Dettmann, 1963). 7225k:8/133 (S33/1); (UNS). 4, *Calamospora* sp. 7225e: 4,9/135,1 (V35); (UNS). 5, cf. *Foveasporis* sp. 7225g: 8,9/130 (R30/1); (UNS). 6, ?*Bacumorphomonocolpites* sp. 7225y: 1,9/142,5 (Y43); (UNS). 7, *Callialasporites dampieri* (Balme) Dev 1961. 7225p: 13,1/127,3 (M27/4); (UNS). 8, *Zlivisporis* sp. 1. 7226 j: 36,2/103,5; (IANIGLA). 9, *Classopollis* spp. 7226j: 44,3/ 11,7; (IANIGLA). 10, *Echiperiporites akanthos* van der Hammen & Wijmstra, 1964. 7225k: 5,4/135 (V35/1); (UNS). 11, *Zlivisporis* sp. C (of Braman 2001). 7226j: 36,2/136,1; (IANIGLA). 12, *Spintricolpites jennerclarkei* Scholtz ex Jansonius & Hills, 1990. 7227g: 14,3/122,7 (L22); (UNS). 13, *Gemmapolyporites aegypticus* Kedves, 1986. 7225g: 13,9/140,9 (M41); (UNS). 14, *Ephedripites* sp. 7226j: 28,5/102,0; (IANIGLA).

PLATE 1



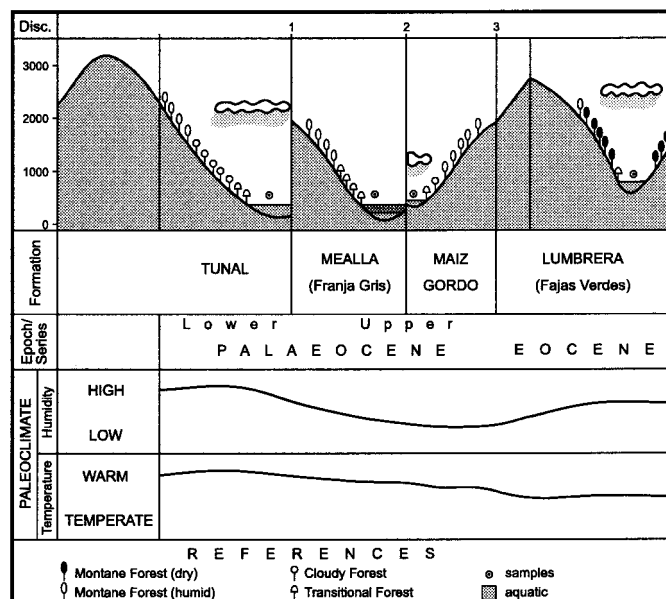


FIGURE 4—Event stratigraphy and environmental reconstruction for the Paleocene and Eocene of the Alemania depocenter (Tunal, Maíz Gordo and Lumbreira formations) and Olmedo Subbasin (Mealla Formation: “Franja Gris”). Note the synchronism of discontinuities (Disc. 1, 2 and 3: basinal events), climatic change and changes in the paleocommunities as expressed by the assemblages of palynomorphs (see also Table 2). The climate curves refer to the overall paleoclimatic development (temperature and humidity/precipitations during the Palaeocene and Lower Eocene. (Adapted and dated from Quattrocchio & Volkheimer, 2000a).

Although the species diversity of Late Cretaceous and Tertiary angiosperm pollen has led to taxonomic difficulties, most pollen forms are well defined and can be easily used to describe a given flora. Within the western Interior of North America, the angiosperm pollen sequence is well understood, especially the Cretaceous-Tertiary transition. They indicate taxonomic and structural similarity to present-day tropical

and subtropical floras (Jarzen, 1982, p. 263). These are the characteristics of the present assemblage.

The presence of indicators for tropical and subtropical forests (Ulmaceae, Bombacaceae), indicates warm and humid areas near the coast, with shallow lacustrine environments (Salviniaceae, Zygnemataceae) and some marine influence (?*Thalassiphora* sp.).

During Late Senonian times the basin was controlled by fluvial processes which accumulated red sandstones under arid climatic conditions (Los Blanquitos Formation) and fluvio-eolian processes (Lecho Formation), but during the Maastrichtian an extensive marine transgression coincided with the end of arid conditions. At the same time a carbonate system (Yacoraita Formation) installed itself in the basin under a warm and humid climate. These conditions were maintained up to the Early Palaeocene. Nevertheless, within the extensive basin, humid and dry conditions alternated up to the middle Eocene. In this moment occurred the inversion of the Salta Basin under a moderately arid climate (Marquillas *et al.*, 1999).

Reworking.—During Late Senonian times, downcutting by rivers in upland regions, exposed progressively older rocks. In consequence, both the palynologic record as the detrital petrographic composition reflect the age and palaeoenvironments of the source areas. Among the reworked palynomorphs are Early Ordovician marine acritarchs (cf. *Arbusculidium* sp.) and latest Palaeozoic monosaccate pollen grains.

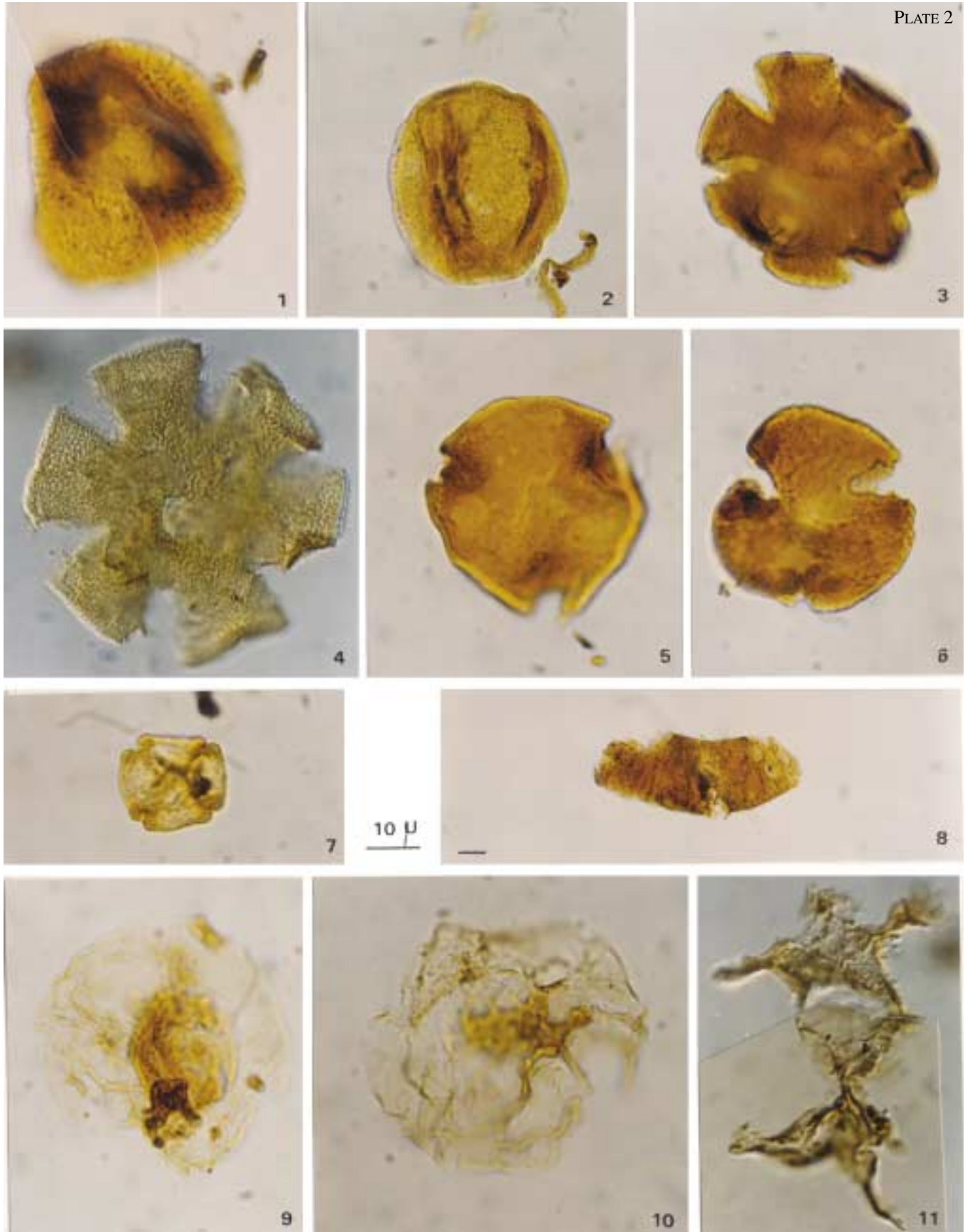
PALYNOSTRATIGRAPHY AND AGE OF THE MICROFLORISTIC ASSEMBLAGES IDENTIFIED IN THE TUNAL, MEALLA, MAÍZ GORDO, AND LUMBRERA FORMATIONS

The pollen assemblage of the Tunal Formation, suggests an Early Palaeocene age (Danian). Quattrocchio *et al.* (2000) defined the Palynozone of *Mtchedlishvilia sal-*

→

PLATE 2—1, *Retitrescolpites saturum* (Gonzalez 1967) Jaramillo & Dilcher 2001.7226ñ: 4,4/137 (W37); (UNS). 2, *Rhoipites* sp. A (of Quattrocchio 1980). 7225g: 19,1/123,4 (F23/2); (UNS). 3-4, *Retistephanocolpites regularis* Hoeken-Klinkenberg 1966. 3.7225g: 18,5/126 (G26/1).(UNS). 4. 7226j: 26,8/93,0; (IANIGLA). 5, cf. *Beaupreadites* sp. 7225i: 4,3/122,9 (V22/4); (UNS). 6, *Bombacacidites* sp. B. Muller *et al.*, 1987.7120j: 15,4/135,2 (K35) ; (UNS). 7, *Verrustephanoporites simplex* Leidelmeier, 1966. 7225i: 17,9/13,7 (H24/1); (UNS). 8, *Celyphus* sp. 7225 o: 3,2/127,5 (W28/4); (UNS). 9, ?*Thalassiphora* sp. 7225i: 20,6/125,1 (F24/4); (UNS). 10, Green algae (cysts). 7225k: 12,2/143,2 (N43/3); (UNS). 11, cf. *Limbicysta* sp. 7226 j: 24,9/109,0; (IANIGLA).

PLATE 2



tenia, an interval zone extending from its first appearance to the incoming of *Rousea patagonica* (Mealla Formation, Salta Basin). The first appearance of *Rousea patagonica* is also observed in the Late Danian Salamanca Formation (San Jorge Basin, Patagonia) and the Pedro Luro Formation (Colorado Basin). The presence of *Simpsonotus* (Mammalia, Henricosborniidae) in the Mealla Formation and the absence of other Casamayoran mammals allowed correlation between the Mealla and the Rio Chico formations of Patagonia (Riochican Age), assigning it a Middle to Late Palaeocene age (Pascual *et al.*, 1981). *Mtchedlishvilia saltenia* Moroni is characteristic of the Danian in NW Argentina and the Colorado Basin, but is not present in the Mealla Formation.

The Maíz Gordo Formation is Late Palaeocene (Riochican Mammal Age) (Pascual *et al.*, 1981) and probably Early Eocene (Casamayoran Mammal Age) (Del Papa, 1999), with *Corydoras revelatus*, Poeciliidae; *Podocnemis*. Pelomedusidae, Crocodylidae, Notoungulata (Henricosborniidae: *Simpsonotus*). The palynoflora from the upper part of the Maíz Gordo Formation contains species restricted to the Paleocene, together with Eocene forms (Quattrocchio and Volkheimer, 1990).

The Lumbrera Formation is of Eocene age (Casamayoran Mammal Age) with Siluriformes, Poeciliidae, *Lepidosiren paradoxa*, Pelomedusidae, Phororhacoidea, Bonaparthedidae (*Bonaparthidium*), Prepidolopidae (*Prepidolops*) and others. Based on radiometric analysis ($^{40}\text{Ar}/^{39}\text{Ar}$), Heizler *et al.* (1998) reported a Late Eocene age for the Casamayorensis of Patagonia. The Lumbrera Formation contains palynomorphs of many biochrons together with endemic species (Quattrocchio and Volkheimer, 1990).

DANIAN PHYTOGEOGRAPHIC PROVINCES IN ARGENTINA

Two major phytogeographic provinces have been recognized for the Danian in Argentina (Quattrocchio and Volkheimer, 2000b), based on the palynologic record at both genus and species levels and at the palaeocommunity level (Fig. 5):

- 1) A northern Ulmaceae province, which includes the Salta or North-West Basin, Neuquén basin, Colorado Basin and San Jorge Basin, characterized by Ulmaceae pollen (*Verrustephanoporites simplex* Leidekmeyer), associated mostly with tropical and subtropical families (Pandanaeae, Palmae, among others). In central and northwes-

tern Argentina a subprovince with “triprojectate” pollen (*Mtchedlishvilia saltenia*) have been distinguished.

- 2) A southern *Nothofagidites* province, which includes southern Patagonia (Austral Basin) and Antarctic (Antarctic Basin): the *Nothofagidites* Phytogeoprovince, where *Nothofagidites*-pollen is mostly associated with temperate families. Warm and humid climatic conditions are indicated for the Ulmaceae Province and more temperate conditions for the *Nothofagidites* Province.

DISCUSSION

Bioevents include all abrupt changes in assemblages of fossils, as a result of palaeogeographic and/or climatic changes, which lead to migration, extinction

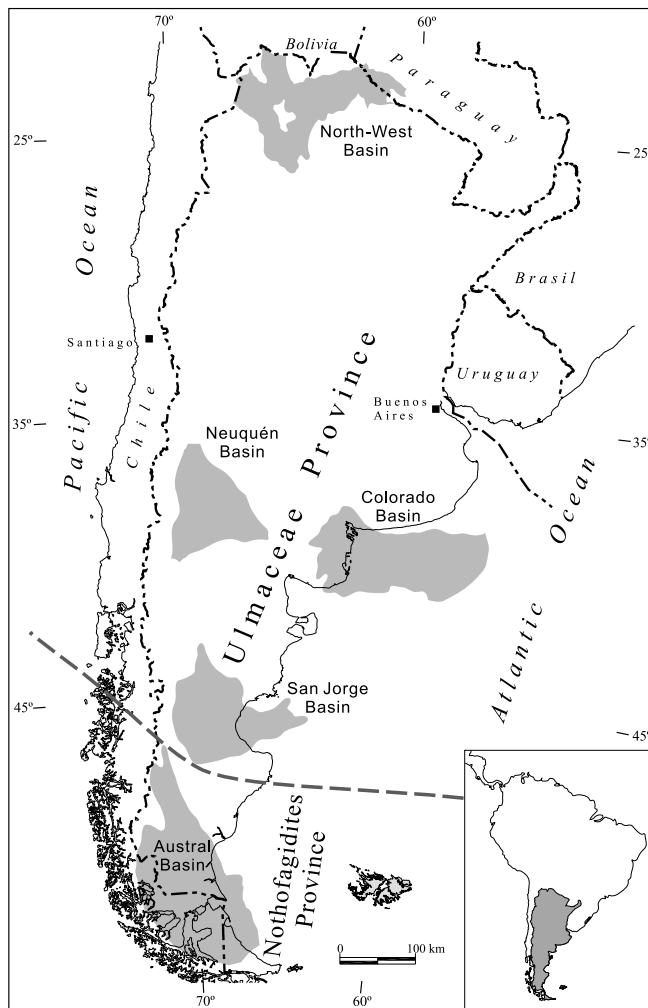


FIGURE 5—Danian phytogeographic provinces in Argentina.

or changes in productivity. Mass extinctions are the most extreme expressions of bioevents.

The characteristic assemblage present in the Tunal Formation is: *Mtchedlishvilia saltenia* Moroni associated with *Verrustephanoporites simplex* Leidelmeyer, *Pandaniidites texus* Elsik, *Gemmatricolpites subsphaericus* Archangelsky and *Clavatricolpites* cf. *gracilis* González Guzmán.

In the Tunal Formation at Tilian locality, both local and inland assemblages are recognized. The grabens and positive structural elements which governed the Salta Group sedimentation, control the characteristics of the palynofloristic assemblages. Due to the assignation of *Verrustephanoporites* cf. *simplex* to *Phyllostylon*, Ulmaceae, (78-88.5%, Quattrocchio *et al.*, 1988), the paleoenvironment of the Tunal Formation could be similar to the present Transitional Forest (350-500 m above sea level) in the Yungas Province, Amazónico Dominion (Cabrera, 1976), where this tree is dominant (Fig. 4).

The presence of Podocarpaceae (*Podocarpidites marwickii* Couper), Anacardiaceae (*Retitricolporites* sp. A) and Rutaceae (*Rhoipites* sp. A) may indicate an association similar to the Montane Forest District, located in the upper part (1200- 2500 m a.s.l.) of the Yungas Province. The interval between both mentioned districts is occupied by the Cloudy Forest District (550-1600 m o.a.s.l.). This district is suggested in our register by the presence of Aquifoliaceae (*Gemmatricolpites subsphaericus* Archangelsky).

The climatic conditions of the Yungas Province are humid and warm with principally summer rain. In consequence these could be the climatic conditions during the deposition of the Tunal Formation. The presence of Haloragaceae (*Myriophyllumpollenites* spp.) and Chlorophyceae (*Pediastrum* sp.) reflect a lake environment for the Tunal Formation. The Transitional Forest would be more impoverished in the “Faja Gris” of the Mealla Formation (Ulmaceae 10-29%) with respect to that of the Tunal Formation. Taking into account the palynological and sedimentological results, the analyzed profile would be located in the “calcareous pelite plain” sub-environment as defined by Gómez Omil *et al.* (1989) for the “Faja Gris”. The latter constitutes a rapid flood and further dessication in an extremely shallow basin (Gomez Omil *et al.*, 1989).

A new palaeogeographic change could be suggested by the dominance of dry and higher montane communities (dominance of Rutaceae, *Rhoipites* sp. A) in the Maíz Gordo Formation with respect to the Mealla Formation (Franja Gris). The lithofacies (litho-

facies 1 and 2 of Gómez Omil *et al.*, 1989) characterize a shallow lake also corroborated by the palynological analysis: presence of Oenotheraceae (*Corsinipollenites menendezii* Quattrocchio) and *Pediastrum* (Volkheimer *et al.*, 1984, Quattrocchio & Del Papa, 2000).

Temperate and humid conditions were inferred for Fajas Verdes I and II, of Lumbrera Formation. The assemblages are dominated by elements characteristic of humid montane paleocommunities (e. g., Gymnospermae, Hamamelidaceae and Lycopodiaceae). Elements from swamps and lakes include Oenotheraceae, Marsileaceae and Combretaceae (Quattrocchio *et al.*, 2000). The variation occurrence of the *Pediastrum-Botryococcus* algae reflects the lake level fluctuations (Del Papa, 2002).

The Palaeocene stages of the Salta Basin are presented in Table 2. Ideally, each stage should represent a period of time on Earth characterized by distinctly different environmental conditions compared to the adjacent stages (Schmitz, 1994).

This was the principle underlying the decision to consider a three-fold division for the Palaeocene of the Salta Basin, on the basis of vertebrate data and palaeofloristic changes (Quattrocchio & Volkheimer, 2000a, Quattrocchio & Del Papa, 2000) observed during this period: warm and humid conditions are suggested during lacustrine deposition of the Tunal/Olmedo Formation during the Danian. Even if the assemblages of palynomorphs of the Tunal Formation from the localities of Tilian and Corralito (Figs. 1 and 3) are indicating warm and humid climate, these conditions did not prevail within the whole extension of the sedimentary basin, given that simultaneously coexisted the saline to hypersaline lacustrine system of the Olmedo Formation (Carlé *et al.*, 1989; Gómez Omil *et al.*, 1989). At other localities of the basin (for example, at the depocenter of Methan, Fig. 1) the Tunal Formation shows evidence of arid climatic conditions in several ways, principally in the presence of evaporites and red beds (Novara, 2003), thus demonstrating that the climatic change that occurred during the Maastrichtian and ended the previous arid conditions, was neither permanent nor extended over the whole basin (Marquillas *et al.*, 1999). Less humid conditions are inferred for the “Faja Gris” of the Mealla Formation (“calcareous pelite plain”) in the Selandian. The Maíz Gordo Formation represents a lacustrine environment with alternating periods of flooding and shallowing and a higher altitude montane palaeocommunity during the Thanetian and earliest Ypresian.

Only three species of the Late Senonian register of palynomorphs from the Vilches locality (*Rhoipites* sp.

A. Verrustephanoporites simplex and *Azolla* sp.) pass, within the Salta Basin, the K/T boundary and appear in the Palaeogene assemblages (Table 1).

CONCLUSIONS

- 1) The age of the palynoflora from the Vilches locality is Campanian to Early Maastrichtian. The first record of Salviniaceae in the biostratigraphic record is from the Campanian (Papú *et al.*, 1988). The Campanian to ?pre-Middle Maastrichtian age of the palynoflora is also indicated by dinosaur remains (Campanian-Early Maastrichtian from the upper part of the Los Blanquitos Formation) and by radiometric data (between 76 and 63 Ma).
- 2) On the southwestern side of the Salta Basin, the presence of indicators of tropical and subtropical forests associated with low numbers of marine dinoflagellates indicates warm and humid areas near the coast, with shallow lacustrine environments and some marine influence.
- 3) The palynologic assemblage from the Vilches locality cannot be placed in any of the defined palynofloristic provinces for the Late Cretaceous. On Traverse's map of Cretaceous palynofloral provinces (1988) it would (geographically) be placed near the boundary between the Palmae Province and the *Nothofagidites* Province.
- 4) Several tropical taxa present in the Vilches palynoflora, such as *Retistephanocolpites regularis* Hecken-Klinkenberg and *Retitrescolpites saturum* (González, 1967) Jaramillo & Dilcher, 2001, evolved in subtropical areas of South America (our case) during the Late Cretaceous, when both continents (Africa and South America) were closer together. Then, owing to the Palaeocene-Eocene climatic change, their parent plants migrated into tropical regions and consequently the pollen appears in the Palaeogene tropical fossil record in strata whose temporal equivalents in southern South America lack these taxa.

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TAXA	Tunal		Mealla		Maíz Gordo		Lumbrera 4	
	1	2	3	5	2	a	b	
<i>Ephedripites</i> cf. <i>E.</i> sp. 1								
<i>Gemmatricolpites subopaeus</i>								
<i>Cleavaticolpites</i> cf. <i>gracilis</i>								
<i>Athripites</i> sp. B								
<i>Arenicolporites</i> sp. A								
<i>Alanthipites</i> sp.								
<i>Pandanidites toxus</i>								
<i>Pandanidites</i> sp.								
<i>Micledonites salensis</i>								
<i>Myriophytumpollenites</i> sp. 1								
<i>Myriophytumpollenites</i> sp. 2								
<i>Athripites minusculus</i>								
<i>Athripites</i> sp. A								
<i>Verrustephanoporites</i> cf. <i>simplex</i>								
<i>Podocarpoides marcolii</i>								
<i>Pediastrum</i> sp.								
<i>Coccolporites gesetianensis</i>								
<i>Azolla</i> sp.								
<i>Biretisporites</i> sp.								
<i>Baculatisporites</i> sp.								
<i>Achysporites</i> sp.								
<i>Apiculatisporis</i> sp.								
<i>Monosuloides minuscebratus</i>								
<i>Spinizonocolpites</i> sp.								
<i>Tricolpites communis</i>								
<i>Lilioides variegatus</i>								
<i>Polatricolporites salamarquensis</i>								
<i>Athripites aculeatus</i>								
<i>Athripites</i> sp.								
<i>Arenicolporites crubutensis</i>								
<i>Arenoidites</i> sp.								
<i>Coccolporites merandzi</i>								
<i>Myriophytumpollenites</i> sp.								
<i>Tricolpites biculatus</i>								
<i>T.</i> sp. cf. <i>T. reticulata</i>								
<i>Tricolpites</i> cf. <i>reticulata</i>								
<i>Roussei patagonica</i>								
<i>Polatricolporites acerbus</i>								
<i>Polatricolporites inapertus</i>								
<i>Polatricolporites simplex</i>								
<i>Polatricolporites</i> sp.								
<i>Dicopphyllidites</i> sp.								
<i>Arenicolporites medius</i>								
<i>Echinosporites</i> sp. cf. <i>E. alfonsoi</i>								
<i>Coccolporites</i> cf. <i>guianensis</i>								
<i>Tricolpites</i> sp.								
<i>Coccolporites</i> sp. A								
<i>Laevigatosporites</i> sp. A								
<i>Retimietes austrocalifornides</i>								
<i>Laevigatosporites</i> sp. A								
<i>Smilacipites salensis</i>								
<i>Smilacipites</i> sp.								
<i>Gaboniporites ugandensis</i>								
<i>Inapertipollenites</i> sp. D								
<i>Inapertipollenites</i> sp. E								
<i>T. (Pedia) lumbreraensis</i>								
<i>Tricolpites</i> sp. A								
<i>Athripollenites</i> sp.								
<i>Liquidambarpollenites</i> cf. <i>bradfordensis</i>								
<i>Inapertipollenites</i> sp. A								
<i>Inapertipollenites curvif</i>								
<i>Mulicollaeosporites</i> sp.								
<i>Diporites</i> sp.								
<i>Diporites elongatus</i>								
<i>Diporites</i> sp.								
<i>Phurcolaeosporites</i> sp. A								
<i>Dinoflagellate cysts</i>								
<i>Acetarsos</i>								

TABLE 1—Stratigraphic distribution of palynomorphs in the continental Danian (Tunal Fm.), Selandian (Mealla Fm.), Thanetian (Maíz Gordo Fm.) and the Eocene (Lumbrera Fm.). Observe the relatively low specific biodiversity in the Tunal Fm. and Maíz Gordo Fm. and the higher diversity in the Mealla Fm. and Lumbrera Fm.

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INSIGHTS ON THE AGE, CLIMATE AND DEPOSITIONAL ENVIRONMENTS OF THE RUDEIS AND KAREEM FORMATIONS, GS-78-1 WELL, GULF OF SUEZ, EGYPT: A PALYNOLOGICAL APPROACH

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Abstract

The pollen palynoflora of the mid-Tertiary Rudeis and Kareem formations encountered in the GS-78-1 well complements the previous dinoflagellate cyst results established in 2002 by El Beialy and Ali. Numerous pollen taxa are recorded from the regional palynoflora that allow a fuller reconstruction of the Miocene vegetation, climate, environment and age. By comparison with modern analogs, the Rudeis and Kareem palynofloras represent mixed vegetation that inhabited a variety of environments. Such seemingly anomalous composition may have resulted from depositional mixing of pollen from several vegetational units or from less distinct ecological zonation of vegetation in the Tertiary. A subtropical to warm temperate climate is inferred, although the palynoflora also includes taxa that today are tropical to subtropical (Mimosaceae, Caesalpiniaceae). The palynoflora might suggest terrestrial climatic cooling as deduced from the dominance of Gramineae and Chenopodiaceae. Gramineae and Chenopodiaceae are probably locally indicative of cooler and drier (arid) climate (?Glacial phase). Chenopodiaceae, on the other hand, also indicate salt marsh (sabkha) conditions. The palynomorphs suggest that there was at least four significant marine/non-marine incursions into the Gulf of Suez area during the Miocene. An interesting association of typical Eocene (*Striatopollis*, *Margocolporites*, *Perforicolpites*) and Oligocene-Miocene taxa (Compositae, Malvaceae, Chenopodiaceae, Gramineae) occurs in both formations. However, Eocene taxa are absent in the Kareem Formation. Most of these types are not restricted stratigraphically. The stratigraphic ranges of taxa and the diversity of herbs suggest that the age of the Rudeis and Kareem formations is early Miocene to early middle Miocene respectively.

Key words: Silurian, Rudeis, Kareem, Gulf of Suez, Pollen, Palaeoclimate, Palaeoenvironment, Miocene, Egypt.

Resumen

La palinoflora de las formaciones Rudeis y Kareem del Terciario medio descritas en el sondeo GS-78-1 complementa los resultados previos basados en el estudio de las asociaciones de dinoflagelados previamente publicados en el 2002 por El Beialy y Ali. Numerosos taxones polínicos han sido registrados de la palinoflora regional, lo que ha permitido realizar una reconstrucción completa de la vegetación, clima y ambiente que caracterizó al Mioceno. Por comparación con representantes actuales, las palinofloras de Rudeis y Kareem representan una vegetación mixta que habitaba una amplia variedad de ambientes. La anómala composición de tales asociaciones podría ser un resultado de un proceso de mezcla durante su deposición de varias unidades vegetales o de diferentes zonaciones vegetales ecológicas terciarias. Como resultado se infiere un clima entre subtropical a templado-cálido, aunque la palinoflora incluye taxones que actualmente son tropicales a subtropicales (Mimosaceae,

Caesalpiniaceae). La palinoflora podría sugerir condiciones climáticas frías terrestres, como indicaría el dominio de Gramineae y Chenopodiaceae. Gramineae y Chenopodiaceae son probablemente indicativas de condiciones climáticas locales frías y secas (áridas) (?fase glacial). Chenopodiaceae, por otra parte, son indicativas de medios mareales (sabkha). Los palinomorfos sugieren que hubo al menos cuatro incursiones significativas marinas/no marinas en el Golfo de Suez durante el Mioceno. Una asociación interesante de taxones típicos eocenos (*Striatopollis*, *Margocolporites*, *Perforicolpites*) y oligocenos-miocenos (Compositae, Malvaceae, Chenopodiaceae, Gramineae) se presentan en ambas formaciones. Sin embargo, ciertos taxones eocenos están ausentes en la Formación Kareem, la mayoría de los cuales no tienen rangos estratigráficos restringidos. Los rangos estratigráficos de los taxones y la diversidad de las hierbas sugieren que la edad de las formaciones Rudeis y Kareem es Mioceno inferior y Mioceno inferior-medio, respectivamente.

Palabras clave: Rudeis, Kareem, Golfo de Suez, polen, paleoclima, paleoambientes, Mioceno, Egipto.

INTRODUCTION

The lack of knowledge on the Tertiary spores and pollen in Egypt has made it inordinately difficult to establish a miospore-pollen chronology that can be applied to important projects which had an exploration focus as in the Miocene deposits of the Gulf of Suez area.

Although very brief palynological results have been recorded from the Neogene in the Gulf of Suez area (Mahmoud, 1993; Ahmed and Pocknall, 1994; Pocknall *et al.*, 1999; El Beialy and Ali, 2002) this is the only study in detail that has been made on pollen and spores. The previously published palynological information was mainly on the dinoflagellate cysts, but in the present work, the authors have taken a new step, that is a deviation from the purely dinoflagellate cyst studies to miospore and pollen investigations.

The aim of this work is two-fold: firstly to present data of our analysis of pollen and spores from the Miocene Rudeis and Kareem formations, penetrated in the GS-78-1 well (Lat. 29° 22' 50.14" N; Long. 32° 36' 45.09" E, Fig. 1) which we know so little about their geographical distribution and their botanical affinities, and secondly to present the ranges of some of the more diagnostic pollen and spores. This microfossil recovery is sufficient to permit some preliminary interpretations of Miocene climate and depositional environments in the Gulf of Suez. It is hoped that spores and pollen will provide a reliable dating to the Rudeis and Kareem formations taking into our consideration the dating scheme presented by El Beialy and Ali (2002) for the Miocene deposits of the GS-78-1 well, based on dinoflagellate cysts. This scheme can not be used with confidence as a framework for the

interpretation of age. It is not an easy procedure to achieve due to the difficulty of calibrating the Miocene section in the Gulf of Suez with a global standard, which makes it impossible to precisely determine the age ranges of the Miocene section in the GS-78-1 well. The Rudeis and Kareem formations palynoflora are therefore interpreted within the context of palynofloras representing well dated Miocene deposits from the Nile Delta (Poumot and Bouroulec, 1984; El Beialy, 1988, 1990a, 1992) and the Gulf of Suez (Mahmoud, 1993; Ahmed and Pocknall, 1994; Pocknall *et al.*, 1999; El Beialy and Ali, 2002).

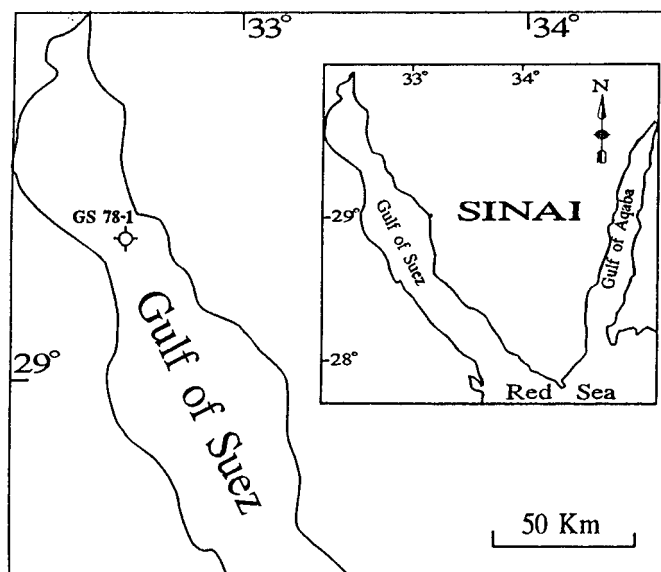


FIGURE 1—Map showing the location of the GS-78-1 well, Gulf of Suez, Egypt.

MATERIAL AND METHODS

Twenty-nine cuttings samples collected from the Rudeis and Kareem formations encountered in the GS-78-1 well, Gulf of Suez, Egypt were processed and analysed for spores and pollen.

Sample positions are shown with the simplified lithostratigraphy (Fig. 2).

A standard processing technique was performed on all samples. This involved cold chemical treatment of 10 gm of sediment with 40% HCl to remove the calca-

reous fraction and with 40% HF to remove the silicates; sieving with a 10 µm nylon mesh. Brief oxidation was applied for each sample and canada balsam was used as the mounting medium. The slides were examined to check for the presence of spores and pollen. Percentages were not used because of the low fossil recovery in some samples which may lead to anomalous values.

Light photomicrographs were taken using an Olympus microscope. For illustrated specimens (Plates 1 and 2) England Finder references are provided.

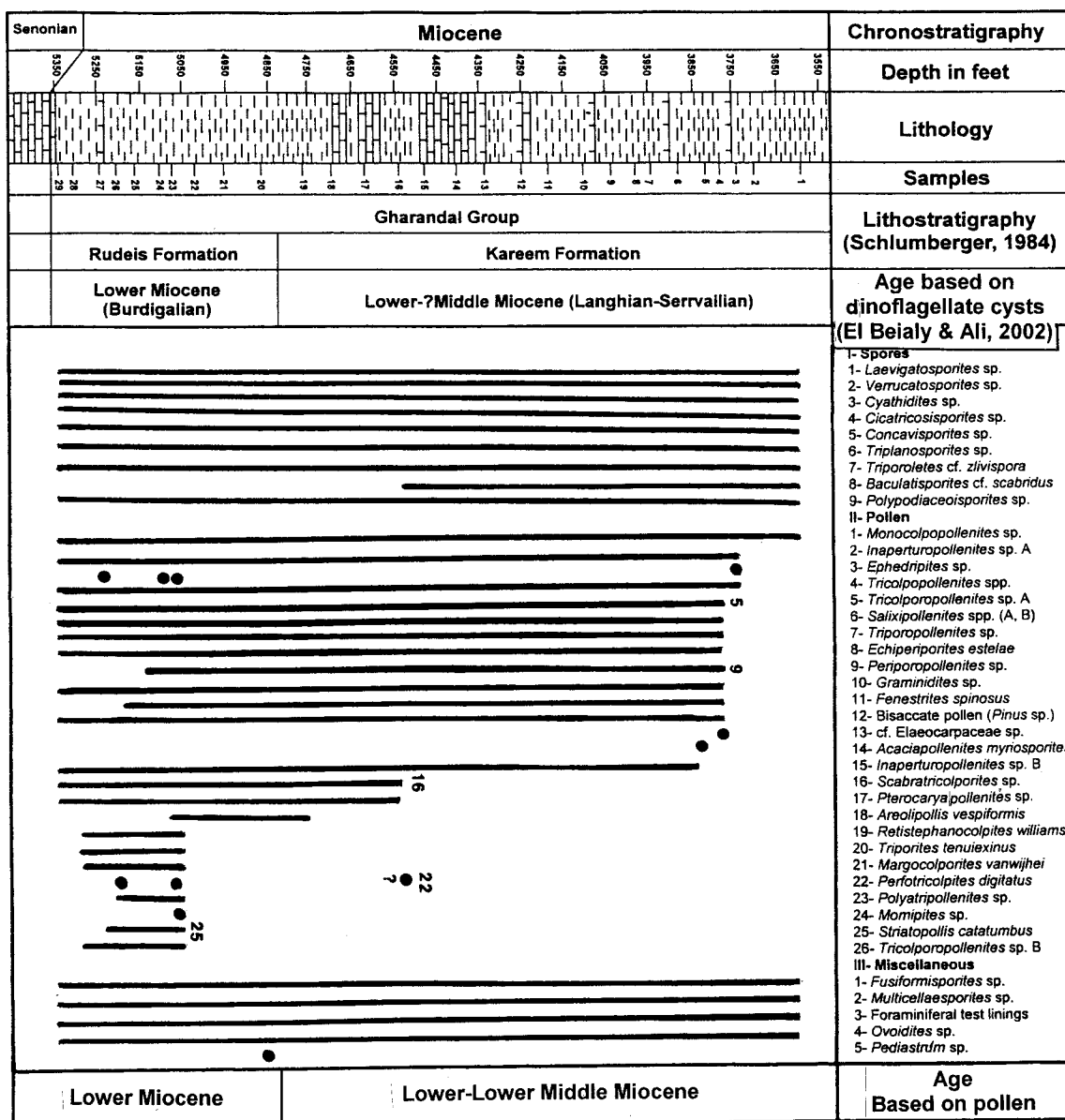


FIGURE 2–Lithological column and total ranges of palynomorphs encountered in the Miocene of the GS-78-1 well, Gulf of Suez, Egypt.

All the preparation slides examined in this study are housed in the palynological collection of the Department of Geology, El Mansoura University, Egypt.

THE TAXONOMIC METHODOLOGY AND SYSTEMATIC PALYNOLOGY

The taxonomic allocation of the Tertiary pollen and spores follows Germeraad *et al.* (1968). They can be identified at the level of form genera in a conventional way within the International Rules of Botanical Nomenclature. In this short systematic section, we discussed the recent affinities, stratigraphic ranges, and sources of some of the less well-known pollen. For consistency all spore-pollen species identified in Fig. 2 are given names of fossil form-genera and species. Even though many can be referred to living species, as will be discussed, they are still retained under a form fossil nomenclature as this procedure avoids the likelihood of the incorrect assignment of the dispersed fossils (Germeraad *et al.*, 1968). For full reference to genera and species see Jansonius & Hills (1976) and Ravn (1998).

Spores

a) Monolete spores

Genus *Verrucatosporites* Pflug & Thomson in Thomson & Pflug, 1953
Verrucatosporites sp.
Pl. 1, Fig. D

b) Trilete spores

Genus *Baculatisporites* Pflug & Thomson in Thomson & Pflug, 1953
Baculatisporites cf. *scabridus* Playford 1982
Pl. 1, Fig. L

Trilete spores bearing spinose processes are here compared to *B. scabridus*, which Playford (1982) des-

cribed from the Neogene of Paupa New Guinea. The Egyptian form differs in having a less dense distribution of spines distally, in having a straight rather than sinuous laesurae. This form is present as a rare element through much of the Rudeis and Kareem samples. Either a fern or a bryophyte may have produced this type.

Genus *Polypodiaceoisporites* Potonié, 1956
Polypodiaceoisporites sp.
Pl. 1, Fig. A

Similar forms are known from the late Tertiary-Quaternary of Egypt (Mahmoud, 2000). These spores are probably produced by fern families.

Genus *Triporoletes* Mchedlishvili 1960
Triporoletes cf. *zlivispora* Pacltova sensu Partridge 1978
Pl. 1, Fig. B

Spores conforming to those from the living bryophyte genus *Riccia* are placed under this form genus. Stratigraphic range observed is late Eocene to Recent (Partridge, 1978). Similar records are known from the upper Tertiary-Quaternary of Egypt (Mahmoud, 1996, as Lycopodiaceae).

Gymnosperm pollen

Genus *Ephedripites* Bolkhovitina, 1953
Ephedripites sp.
Pl. 1, Fig. H

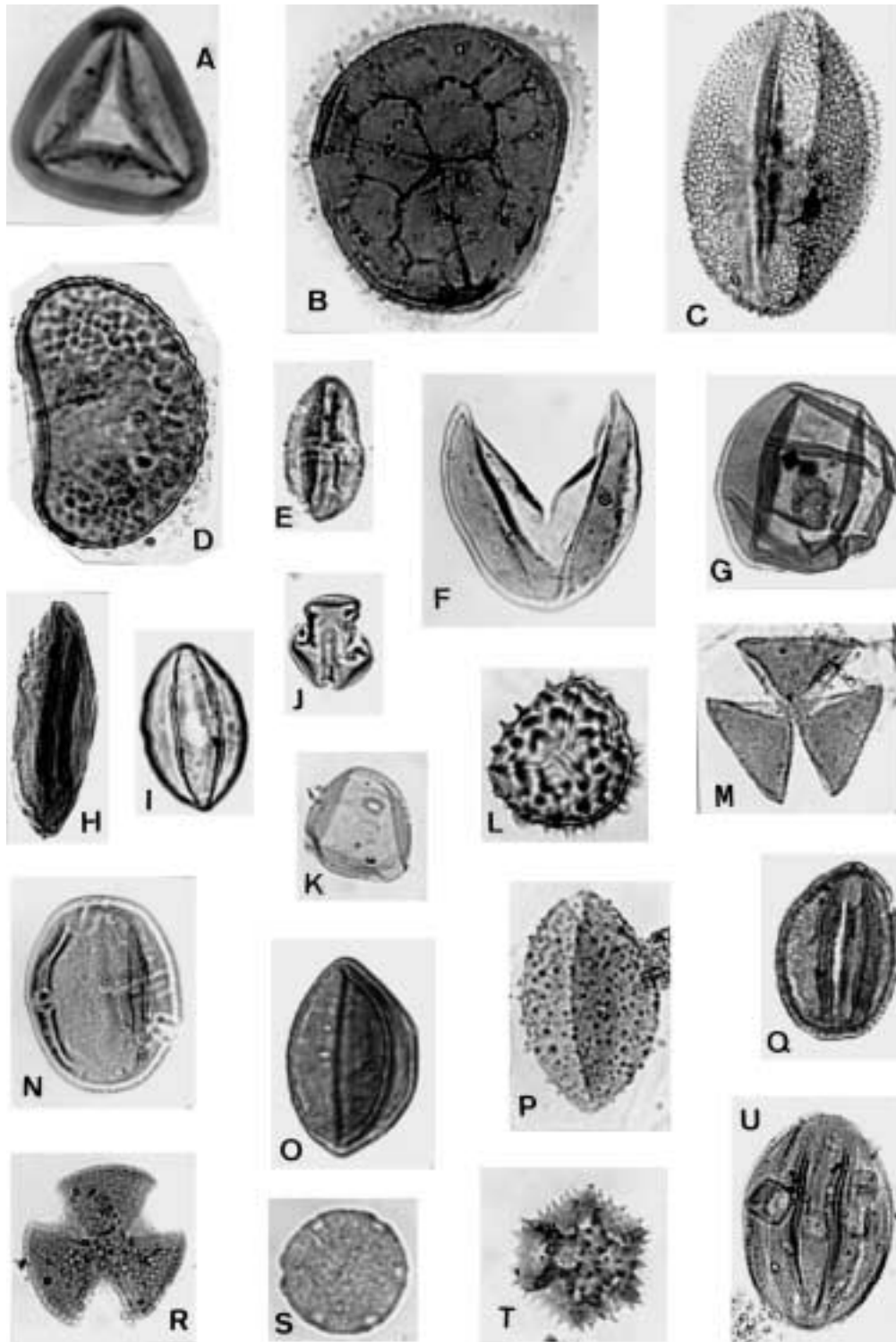
Genus *Inaperturopollenites* Pflug & Thomson in Thomson & Pflug, 1953

Remarks.—This form genus includes all alete pollen which were originally spherical in shape that may or may not tend to split along a symmetry plane through the equator (Thomson and Pflug, 1953).

→

PLATE I—The sample number (e. g., 3), borehole name (GS), slide designation (e. g., B) and England Finder (e.g., G 21) are given sequentially for each illustrated specimen. A Leitz orthoplan microscope was used. All magnifications are X750. A, *Polypodiaceoisporites* sp., 9 GSB, V48. B, *Triporoletes* cf. *zlivispora* Pacltova, 25 GSA, G40. C, *Salixipollenites* sp. A, 29 GSB, Q50. D, *Verrucatosporites* sp., 3 GSB, O27. E, *Tricolporopollenites* sp. A, 12 GSA, L32/33. F, *Inaperturopollenites* sp. A, 3 GSB, G/H21. G, *Inaperturopollenites* sp. B, 18 GSA, H20/21. H, *Ephedripites* sp., 3 GSA, R36. I, M, Q, U, *Tricolporopollenites* spp.; I, 4 GSA, B36; M, 18 GSA, N46; Q, 6 GSA, P24; U, 5 GSA, B/C36. J, Tricolporate pollen (cf. *Elaeocarpaceae*), 4 GSA, J/K38. K, *Graminidites* sp., 2 GSA, L39. L, *Baculatisporites* cf. *scabridus* Playford, 16 GSA, E35/36. N, *Tricolporopollenites* spp. A, 4 GSA, N/O33. O, P, *Monocolpopollenites* sp.; O, 3 GSA, S33; P, 18 GSB, G50. R, *Salixipollenites* sp. B, 5 GSA, M27. S, *Polyatripollenites* sp., 16 GSA, Q28/29. T, *Fenestrites spinosus* Van Der Hammen, 25 GSA, P/Q50.

PLATE 1



Inaperturopollenites sp. A
Pl. 1, Fig. F

Specimens of this species are present as common elements in the two studied formations as circular pollen with a full range split. The ornamentation is smooth. The size measured along the line of gaping hiatus is 20-38 µm. This form is very similar to *I. hiatus* (Potonié) Thomson & Pflug, 1953, and *Cupressacites backwitzensis* Krutzsch, 1971. Forms classified within the form-genus *Taxodiaceapollenites* Kremp, 1949, are invalid since the latter taxon is considered a junior synonym (Wilkinson & Boulter, 1980).

Inaperturopollenites sp. B
Pl. 1, Fig. G

These pollen are similar to those of *Inaperturopollenites* sp. A, but have wider and more distinct folding of the exine. The size ranges from 35-50 µm.

Angiosperm pollen

a) Monocolpates

Genus *Monocolpopollenites* Thomson & Pflug, 1953

Remarks.—Fossil monocolpate pollen identified from the Tertiary of Egypt include *Monocolpopollenites*, *Arecipites* and *Cycadopites*, but the distinction between these is complex. We use *Monocolpopollenites* for all non-reticulate monocolpate pollen, in which the ornament ranges from psilate to scabrate to granulate, and in which the colpus has variable structure (Thomson and Pflug, 1953). *Arecipites*, on the other hand comprises all reticulate pollen (Krutzsch, 1970). The cycads may be absent from the Miocene of Egypt since there is no evidence for their presence within the megafossil record (Lejal-Nicol, 1990).

Monocolpopollenites sp.
Pl. 1, Figs. O, P

This pollen has a generally oval shape with an ornamentation ranging from smooth (Pl. 1, Fig. O) or granulate (Pl. 1, Fig. P). The colpus is straight, slightly open. It usually traverses almost the entire length of the grain. The specimen illustrated in Plate 1, Figure O, is similar to *Cycadopites follicularis* Wilson & Webster, 1964 and the other specimen (Pl. 1, Fig. P) is similar to *Mauritidites* cf. *crassibaculatus* Van Hoeken-Klinkenberg 1964.

b) Tricolpates

Genus *Perfotricolpites* González Guzmán, 1967
Perfotricolpites digitatus González Guzmán, 1967
Pl. 2, Fig. K

Single grain, radially symmetrical, isopolar, prolate and tricolpate. Colpi ectexinous, long, strongly intruding, with straight borders and pointed ends. Columellae digitate. Perforate tectum and psilate-scabrate sculpture. This form was described from the lower-middle Eocene of Colombia (González Guzmán, 1967). Identification of the fossil dispersed pollen with the pollen grains of *Merremia glabra* Hallier in Germeraad *et al.*, 1968 (Convolvulaceae) is rather similar (Germeraad *et al.*, 1968).

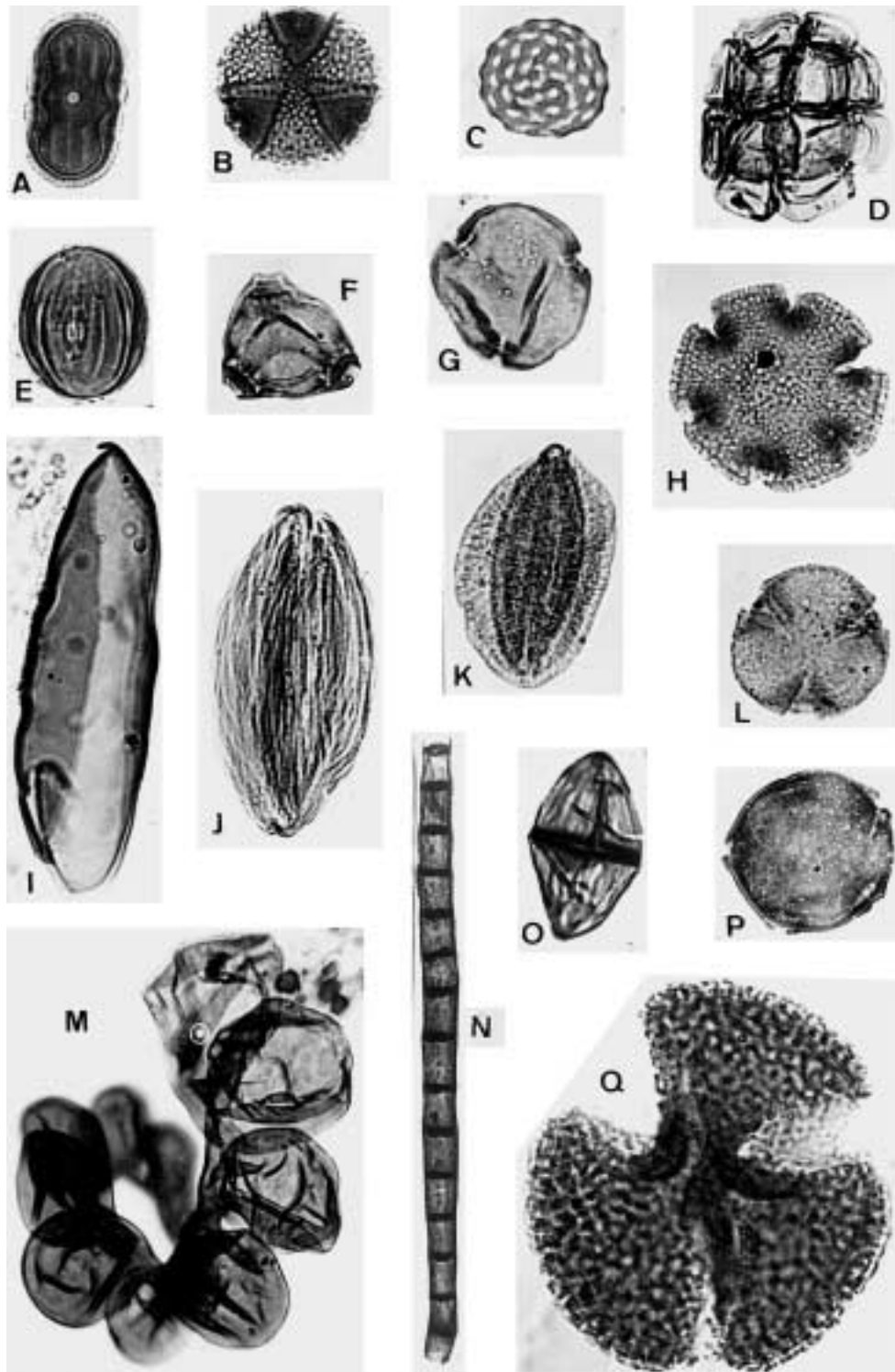
Genus *Salixipollenites* Srivastava, 1966

Remarks.—The form genus is for all tricolpate pollen compressed along the polar or equatorial planes which have a fine to coarse reticulate ornamentation. No distinction need be drawn with *Tricolpopollenites* Pflug & Thomson in Thomson & Pflug, 1953, since the latter doesn't have a reticulate ornamentation (Srivastava, 1966).

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PLATE 2—A, *Areolipollis vespiformis* Clarke & Frederiksen, 19 GSB, T27. B, *Margocolporites vanwijhei* Germeraad *et al.*, 23 GSB, J/K42. C, *Periporopollenites* sp., 16 GSA, T24. D, *Acaciapollenites myriosporites* (Cookson) Mildenhall, 5 GSB, R49. E, *Psilastephanocolporites laevigatus* Salard-Chebodaëff, 24 GSA, G36. F, *Triorites tenuixinus* Muller, 1968, 28 GSA, R39. G, *Momipites* sp., 23 GSB, Z45/46. H, *Retistephanocolpites williamsi* Germeraad *et al.*, 25 GSB, P49. I, *Ovoidites* sp., 2 GSA, Q/R45. J, *Striatopollis catatumbus* (González Guzmán) Ward, 27 GSA, V45. K, *Perfotricolpites digitatus* González Guzmán, 16 GSA, G24/25. L, *Scabratricolporites* sp., 21 GSB, B28. M, Foraminiferal test linings, 6 GSB, V47. N, *Multicellaesporites* sp., 5 GSA, S52/53. O, *Fusiformisporites* sp., 2 GSB, H24. P, *Pterocaryapollenites stellatus* (Potonié) Raatz, 29 GSA, J50. Q, *Tricolpopollenites* sp., 25 GSA, E/F34.

PLATE 2



Salixipollenites sp. A

Pl. 1, Fig. C

This is a prolate tricolpate pollen with a reticulate ornament and lumina measuring 0.6-0.9 µm in diameter. The muri are generally thin. The long axis measures 20-30 µm. This form is similar to *Retitricolpites* (Van der Hammen) Pierce, 1961, recorded from the Miocene of the Gulf of Suez (Ahmed and Pocknall, 1994).

Salixipollenites sp. B

Pl. 1, Fig. R

This species has a characteristic baculo-reticulate ornamentation. The oblate grains are deeply trilobate. This form is present in small numbers in the examined intervals and is similar to *Tricolpites reticulatus* Cookson, 1947, and *T. microreticulatus* Van der Hammen, 1954.

Genus *Striatopollis* Krutzsch, 1959*Striatopollis catatumbus* (González Guzmán) Ward, 1986

Pl. 2, Fig. J

Tricolpate pollen, colpi long, intruding with straight simple borders and pointed ends. Tectum striate, striae 1 µm thick, 1-1.5 µm wide, 1 µm apart, subparallel or slightly anastomosing. The specimen found in the present study agrees in all respects with González' type material. This form was reported from the Eocene of Nigeria and Qatar (Takahashi & Jux, 1989a; El Beialy, 1998). The species is in closest resemblance with pollen of the genus *Crudia*, Fabaceae (Germeraad *et al.*, 1968).

Genus *Tricolpopollenites* Pflug & Thomson in

Thomson & Pflug, 1953

Tricolpopollenites spp.

Pl. 1, Figs. I, M, Q, U & Pl. 2, Fig. Q

The tricolpate pollen have a polar axis which is longer than the equatorial axis. The three colpi are arranged symmetrically about the polar axis, and stretch almost the full length of the body. The ornamentation is scabrate to faintly granulate. These specimens are very common components in the studied samples but have very little stratigraphic or botanical significance. The specimen figured in Plate 2, Figure Q, is similar to the recent pollen grain *Merremia glabra* (Hallier in Germeraad *et al.*, 1968), which has an affinity with the Convolvulaceae.

c) **Tricolporates**Genus *Areolipollis* Clarke & Frederiksen, 1968*Areolipollis vespiformis* Clarke & Frederiksen, 1968

Pl. 2, Fig. A

Prolate pollen grains tricolporate and not dicolporate as described by Clarke and Frederiksen (1968). The modern pollen grains are 3-colporate. This species exhibits areolate ornamentation. The specimens found in the present study constitute the first fossil record of this genus from Egypt. The grains bear affinity possibly with the Acanthaceae and/or Umbelliferae.

Genus *Fenestrites* Van Der Hammen, 1956*Fenestrites spinosus* Van Der Hammen, 1956

Pl. 1, Fig. T

Single grain, radially symmetrical, isopolar, spherical. Colpi and pori indistinct, probably tricolporate. Exine is differentiated into a pattern of intectate lacunae (fenestrae), 8-11 µm wide and tectate-columellate cristae. This species is typical for the liguliflorae pollen type of the Asteraceae (Compositae) which is produced by a large number of genera (Germeraad *et al.*, 1968).

Genus *Margocolporites* Ramanujam, 1966*Margocolporites vanwijhei* Germeraad *et al.*, 1968

Pl. 2, Fig. B

Two specimens of this distinctive pollen type were recorded from the Rudies Formation. They conform closely to the original description given by Germeraad *et al.* (1968) from the Tertiary of Venezuela. The reticulum of the intercolpia is, however, somewhat finer than in the type material, but falls within the range of variation described. Affinity probably with the Caesalpinioidea of the Fabaceae, Germeraad *et al.* (1968) noted a close similarity with two species of *Caesalpinia*.

Genus *Scabratricolporites* Roche & Schuler in

Ramanujam, 1966

Scabratricolporites sp.

Pl. 2, Fig. L

Genus *Tricolporopollenites* Pflug & Thomson in

Thomson & Pflug, 1953

Remarks.—The name *Tricolporopollenites* is very much a convenient name with which to describe commonly occurring pollen which have no known value in palynological interpretation.

Tricolporopollenites sp. A
Pl. 1, Figs. E, N

Prolate tricolpate pollen. The colpi and equatorial pores are distinct. The ornamentation is psilate. The exine is thin. Specimens have been found in the two studied formations. The specimen illustrated (Pl. 1, Fig. E) is similar to *Cupuliferoipollenites pusillus* (Potonié) Potonié 1951 recorded from the Oligocene of Egypt (Kedves, 1985).

cf. Elaeocarpaceae sensu Truswell *et al.*, 1985
Pl. 1, Fig. J

Some tiny, smooth-walled tricolporate pollen grains (Pl. 1J), of diameter 25 µm, are here compared informally to Elaeocarpaceae. They occur sporadically throughout the sampled sequence, in frequencies of up to 1% of the total pollen count.

d) Stephanocolpates

Genus *Retistephanocolpites*
Leidelmeyer, 1966

Remarks.—*Retistephanocolpites* is used here for the radially symmetrical, isopolar, oblate, 6-7 colpate pollen. The ornamentation is reticulate-foveolate, lumina oval to circular, 1-2 µm in diameter. Muri 1.00 µm wide.

Retistephanocolpites williamsi Germeraad *et al.*, 1968
Pl. 2, Fig. H

This species is comparable to the form identified from the Campanian/Maastrichtian of the Red Sea area (El Beialy, 1995), Miocene of the Nile Delta (El Beialy, 1990a, 1992) and the upper Miocene (Tortonian) of the Gulf of Suez (Ahmed and Pocknall, 1994). The combination of 5-6 short apertures, spongy columellate structure and reticulate-foveolate tectum is so far only known from Ctenolophonaceae. It is therefore important to identify the *R. williamsi* with this Indo-Malaesian species (Germeraad *et al.*, 1968).

e) Stephanocolporates

Genus *Psilastephanocolporites*
Leidelmeyer, 1966

Psilastephanocolporites laevigatus
Salard-Cheboldaeff, 1979
Pl. 2, Fig. E

Genus *Pterocaryapollenites* Raatz, 1937

cf. *Pterocaryapollenites* sp.
Pl. 2, Fig. p

The species observed from the Miocene of the Gulf of Suez appears to have a much thicker wall than the form referred to *Pterocaryapollenite stellatus* (Potonié) Raatz, 1937, from the Oligocene of Central British Columbia (Piel, 1971). Affinity probably with the Juglandaceae. This form is similar to *Verrustephanocolporites complanatus* Salard-Cheboldaeff, 1978, and ?*Pterocarya stellatus* (Potonié) Martin & Rouse, 1966.

f) Monoporates

Genus *Graminidites* Cookson, 1947
Graminidites sp.
Pl. 1, Fig. k

Graminidites is thin-walled pollen and reveals an infragranulate structure. They have a smooth to scabrate ornamentation. The pore is well defined and without a distinct annulus. *Graminidites* is better known from the Palaeogene and Neogene of Egypt (Kedves, 1981, 1985; El Beialy and Kora, 1987; El Beialy, 1992). The fossil species closely resembles non-cultivated Poaceae (Gramineae) pollen.

g) Triporates

Genus *Momipites* Wodehouse, 1933
Momipites sp.
Pl. 2, Fig. G

Genus *Polyatriopollenites* Pflug, 1953
Polyatriopollenites sp.
Pl. 1, Fig. S

Genus *Triorites* Muller, 1968
Triorites tenuixinus Muller, 1968
Pl. 2, Fig. F

This is oblate triporate pollen with a triangular amb and convex sides. Pores are situated equatorially and the apertures protrude over the surface, with the surrounding exine slightly thickened.

h) Periporates

Genus *Periporopollenites* Pflug & Thomson in Thomson & Pflug, 1953
Periporopollenites sp.
Pl. 2, Fig. C

The illustrated specimen has a circular amb. The pores are arranged meridionally. The ornamentation is smooth to scabrate. The specimen figured here

resembles those recorded from the Oligocene-Miocene of Egypt (Kedves, 1981, 1985; El Beialy, 1992; Ahmed and Pocknall, 1994). It is also similar to *Polyporina multiporosa* Kars 1985 and *Chenopodipollis multiplex* (Weyland & Pflug) Krutzsch, 1966.

i) Obligate polyads

Genus *Acaciapollenites* Mildenhall, 1972

Acaciapollenites myriosporites (Cookson)
Mildenhall, 1972

Pl. 2, Fig. D

This species occurs as a rare component in some samples, which puts the basal occurrence of *Acaciapollenites* early in the early Eocene of the Western Desert of Egypt (Guinet *et al.*, 1987) and its uppermost occurrence in the Plio-Pleistocene of the Nile Delta (Saad *et al.*, 1987). Similar late Miocene and late Oligocene-early Miocene reports were made by Partridge (1978), Truswell *et al.* (1985) and Torricelli and Biffi (2001) from the Angola Basin off the west Coast of Africa, Australia and Tunisia respectively. This fossil pollen is referable to the subfamily Mimosoideae of the Leguminosae as compared with the species of *Acacia* illustrated by Maley (1972) from the recent pollen spectra of Lake Chad and by Sowunmi (1973) from Nigeria. The earliest occurrence of this pollen in Australia is from the early Miocene (Stover and Partridge, 1973).

Miscellaneous

Foraminiferal test linings

Pl. 2, Fig. M

These occur abundantly in the Rudeis and Kareem formations.

Fusiformisporites sp.

Pl. 2, Fig. O

These fungal spores occur rarely in the investigated samples.

Multicellaesporites sp.

Pl. 2, Fig. N

These fungal spores occur abundantly in the investigated samples of the Rudeis and Kareem formations, with no value in palynological interpretation.

Genus *Ovoidites* Potonié, 1951

Ovoidites sp.

Pl. 2, Fig. I

This form of freshwater algae possesses a furrow, which traverses the entire long axis of the specimen. This microfossil type appears to be similar in its apertural configuration to specimens of *Ovoidites* illustrated by Zippi (1998). *Ovoidites* is known from the Pliocene-Pleistocene of central Egypt (Mahmoud, 2000).

AGE ASSESSMENT

A diverse assemblage of spores and pollen was recovered from the Tertiary subsurface section of the GS-78-1 well (Table 1). Their distribution is illustrated in Fig. 2. and mounted on plates 1 and 2. Not illustrated are *Echiperiporites estelae* Germeraad, Hopping & Muller, 1968, and the bisaccate pollen for which no satisfactory specimens could be located.

Age determination for the Tertiary subsurface section of the GS-78-1 well, based on dinoflagellate cysts (El Beialy & Ali, 2002) has provided an excellent framework against which to describe the distribution of fossil spores and pollen in the well. It should be noted, however, that the apparent lowest occurrences in time of the individual species may be erroneous. There is undoubtedly considerable uphole contamination which tends to artificially extend the ranges downward. It is for this same reason that we rely mostly on highest occurrence data.

Rudeis Formation

Some of the taxa which appear to be confined to, or occur more frequently in the Rudeis Formation include *Perfotricolpites digitatus* González, *Fenestrites spinosus*, *Margocolporites vanwijhei*, *Striatopollis cata-tumbus* and *Areolipollis vespiformis*. *Perfotricolpites digitatus* was firstly described from the early- middle Eocene of Colombia (González Guzmán, 1967). It has, however, been reported from the late Oligocene of New Zealand (Pocknall, 1982). This species has also been reported from the early- middle Oligocene of Australia (Truswell *et al.*, 1985) and the late Eocene/Oligocene of the Sudan (Kaska, 1989). This taxon has also a fossil record extending into the late Neogene off the west Coast of Africa (Partridge, 1978). This species was reported by Germeraad *et al.* (1968) from the Caribbean area and Nigeria occurring for the first time approximately at the base of the

Taxa
<p>Spores <i>Baculatisporites</i> cf. <i>scabridus</i> Playford 1982 <i>Cicatricosporites</i> sp. <i>Concavisporites</i> sp. <i>Cyathidites</i> sp. <i>Laevigatosporites</i> sp. <i>Polypodiaceoisporites</i> sp. <i>Triplanosporites</i> sp. <i>Triporoletes</i> cf. <i>zlivispora</i> Pacltova sensu Partridge 1978 <i>Verrucatosporites</i> sp.</p>
<p>Gymnosperm pollen Bisaccate pollen (<i>Pinuspollenites</i> sp.) <i>Ephedripites</i> sp. <i>Inaperturopollenites</i> sp. A <i>Inaperturopollenites</i> sp. B</p>
<p>Angiosperm pollen <i>Acaciapollenites myriosporites</i> (Cookson) Mildenhall 1972 <i>Areolipollis vespiformis</i> Clarke & Frederiksen 1968 <i>Echiperiporites estelae</i> Germeraad, Hopping & Muller 1968 cf. <i>Elaeocarpaceae</i> sp. <i>Fenestrites spinosus</i> Van Der Hammen 1956 <i>Graminidites</i> sp. <i>Margocolporites vanwijhei</i> Germeraad, Hopping & Muller 19688 <i>Momipites</i> sp. <i>Monocolpopollenites</i> sp. <i>Perfotricolpites digitatus</i> González Guzmán 1967 <i>Periporopollenites</i> sp. <i>Polyatripollenites</i> sp. <i>Pterocaryapollenites</i> sp. <i>Retistephanocolpites williamsi</i> Germeraad, Hopping & Muller 1968 <i>Salixipollenites</i> spp. (A, B) <i>Scabratricolporites</i> sp. <i>Striatopollis catatumbus</i> (González Guzmán) Ward 1986 <i>Tricolpopollenites</i> spp. <i>Tricolporopollenites</i> sp. A <i>Tricolporopollenites</i> sp. B <i>Triporites tenuixinus</i> Muller 1968 <i>Triporopollenites</i> sp.</p>
<p>Miscellaneous Foraminiferal test linings <i>Fusiformisporites</i> sp. <i>Multicellaesporites</i> sp. <i>Ovoidites</i> sp. <i>Pediastrum</i> sp.</p>

TABLE 1—Alphabetical listing of the identified taxa encountered in the Miocene of the Rudeis and Kareem formations, GS-78-1 well, Gulf of Suez, Egypt.

Verrucatosporites usmensis Zone (late middle Eocene-late Eocene), but, while continuously present in the former area up to Recent, in Nigeria disappearing from the record in the upper part of the *Magnastriatites howardi* Zone (early Miocene). In Borneo it is present at least from the base of the *Echitricolporites spinosus* Zone (middle Miocene) upwards. The record of this

species from Venezuela (Rull, 2001) provides a clear indication that *P. digitatus* does extend into the early Miocene.

Fenestrites spinosus was restricted to the middle and upper part of the *F. spinosus* Zone (middle Miocene) onwards (Germeraad *et al.*, 1968) in Nigeria and the Caribbean area. This pollen taxon belongs to the Liguliflore type of the Asteraceae (Compositae). Although this family has a fossil record extending questionably into the Oligocene (Leopold, 1969) it is first reliably recorded on all continents from early to middle Miocene (Germeraad *et al.*, 1968; Stover and Partridge, 1973; Williams, 1975) and generally and consistently and abundantly in late Miocene or younger sediments (Partridge, 1978).

Margocolporites vanwijhei has not previously been reported from Egypt. *M. vanwijhei* was reported by Germeraad *et al.* (1968) as having an Eocene-Recent range in the Caribbean, an Oligocene-Recent range in Borneo, and an Eocene-Oligocene range in West Africa. Extratropical records of the species are those from the late Oligocene in Southland New Zealand (Pocknall, 1982), late Neogene of southern Africa (Partridge, 1978), and the early-middle Oligocene of south Australia (Truswell *et al.*, 1985).

Striatopollis catatumbus first occurs in Lower Eocene deposits in Colombia (González Guzmán, 1967), Nigeria (Takahashi and Jux, 1989a), Venezuela (Colmenares and Teran, 1993) and Qatar (El Beialy, 1998). It also occurs in the Caribbean area and in Nigeria from the base of the *Retibrevitricolpites triangulatus* Zone upwards (late Palaeocene-early Eocene) as suggested by Germeraad *et al.* (1968).

This is the first record of *S. catatumbus* from the Miocene of Egypt; it has, however, been reported from the Upper Eocene to Oligocene strata of the Sudan (Kaska, 1989), the Neogene of southern Africa (Partridge, 1978) and the early Miocene of Venezuela (Rull, 2001).

The GS-78- 1 site has also provided a good fossil record of *Areolipollis vespiformis*, which is present in the Rudeis Formation. This is the first evidence to be published that *A. vespiformis* is present in the Miocene of Egypt. Most previous accounts suggest that it appeared in Upper Tertiary sediments of Nigeria (Clarke and Frederiksen, 1968). The *Umbelliferaepollenites peissenbergensis* Kirchner, 1984, record from the late Oligocene of southern Bavarian pitch coal mine district (Kirchner, 1984) might be conspecific.

Acaciapollenites myriosporites has its earliest occurrence in the early Miocene of Australia (Stover and Partridge, 1973), late Neogene of Africa

(Partridge, 1978). *Polyadopollenites* Pflug & Thomson in Thomson & Pflug, 1953, recorded from the late Oligocene-early Miocene of Tunisia (Torricelli and Biffi, 2001) may be similar and therefore a younger Neogene age may seem plausible to the Rudeis Formation.

It can be concluded that collateral evidence concerning the age of the Rudeis Formation in the GS-78-1 well is available in the form of a few number of fossil pollen discussed above. The pollen assemblage is interpreted to have a general early Neogene range. On the basis of documented stratigraphic ranges, the age can be further restricted to early Miocene. This is based on the overall composition of the Rudeis Formation, which contains a substantial number of taxa that are common in the Miocene palynofloras of Angola (Partridge, 1978) and the Nile Delta which is largely composed of taxa typical of the Miocene (El Bealy, 1990b, 1997), but also includes several taxa more characteristic of the Palaeogene (e. g., *Pistillipollenites* Rouse, 1962, El Bealy, 1988). This mixture of plant types, along with stratigraphic relations is also used to infer an age of early Miocene for the Rudeis Formation palynofloras as supported by other findings based on forams and nannoplankton (El-Heiny & Martini, 1981), nannoplankton (Evans, 1988; Said, 1990) and dinoflagellate cysts (El Bealy and Ali, 2002).

Kareem Formation

The foregoing discussion indicates the marked similarity between the Kareem fossil assemblage and other middle Miocene assemblages from the Nile Delta and the Gulf of Suez. It is sometimes difficult, however, to consistently differentiate early and middle Miocene assemblages in the Gulf of Suez area. The only difference is that in the Rudeis Formation an apparent anomaly exists in the occurrence of Eocene taxa in the GS-78-1 pollen palynoflora. The overlying Kareem Formation, on the other hand contains an abundance of herbs in the pollen palynoflora suggesting that the age is early to early middle Miocene, based on dinoflagellate cysts (El Bealy and Ali, 2002) rather than early Miocene as originally inferred by the Egyptian Stratigraphic Sub-Committee (1974).

The Kareem Formation palynoflora contains a high proportion of taxodiaceous conifers, Schizaeaceae, Polypodiaceae, Gramineae, Compositae, Chenopodiaceae, Malvaceae, Epedraceae and Onagraceae. The chiefly herbaceous families Gramineae, Compositae and Malvaceae though known from older sediments, they first appear consistently in the

Neogene (Leopold, 1969). Pollen referable to the non-cultivated grass (family Gramineae) is common in the productive samples of the Kareem Formation. The rise in the abundance of the grass pollen is a feature characteristic of the Neogene pollen record (Germeraad *et al.*, 1968). The periporate pollen retrieved from the Kareem Formation, and referable to the family Chenopodiaceae/Amaranthaceae have a consistent fossil record back as far as the Oligocene (Stover and Partridge, 1973).

In conclusion, although herbs are abundant in the pollen palynoflora and they have no biostratigraphic importance at that time, they may be locally used to assign the age of the Kareem Formation to early to early middle Miocene, based on comparison with the Weaverville pollen palynoflora, USA (Barnett, 1989).

PALAEOECOLOGICAL AND PALAEOCLIMATOLOGICAL SIGNIFICANCE

The spores and pollen assemblages recovered from the Rudeis and Kareem formations encountered in the GS-78-1 well are preserved through sedimentation in a relatively deep water environment to an outer continental shelf deposits to upper bathyal (distal) environments (El Bealy and Ali, 2002). Observed incursions of terrestrial elements in the Rudeis Formation may have been carried about within the basin of deposition by the waters of the Mediterranean Sea, or that they were displaced into a deep water environment (El Bealy and Ali, 2002). Conditions were dominated floristically by wet-loving plants, which inhabit the flood-plain ecosystem. Evidence comes from the presence of the dispersed pollen *Salixipollenites* in the Miocene of the Gulf, which are similar to pollen from modern plants and the dinoflagellate cyst *Tuberculodinium vancampoae* (Rossignol) Wall, 1967. *Salixipollenites* grows in wet, damp and humid conditions (Wilkinson and Boulter, 1980). *T. vancampoae* may be an indicator of more humid conditions because it is more tolerant of fresh water input than many other dinoflagellates (Morzadec-Kerfourn, 1992). It is obvious that *T. vancampoae* tends to be more common at times of abundant *Pinus* and is seldom common in assemblages dominated by *Polysphaeridium zoharyi* (Rossignol) Bujak *et al.*, 1980, a species more tolerant of high salinity (Pocknall *et al.*, 1999). Wet-loving plants are associated with trees, shrubs and herbs, probably occupying various niches which are preserved in certain levels of the section studied. There is also a

persistent coniferous vegetation or upland palynofloras represented by the bisaccate pollen, which are related to the modern *Pinus*, and the taxodiaceous conifer pollen most like that of a more autochthonous *Taxodium*-like swamp forest element, which remained rather long in the Palaeogene of Egypt (Kedves, 1985; Takahashi and Jux, 1989b). Another confirmatory evidence for humidity also comes from the presence of the fern spore *Polypodiaceasporites* in the Rudeis Formation. It is often regarded as being indicative of damp and humid conditions (Wilkinson & Boulter, 1980).

The Tertiary climate of the Gulf of Suez may also be inferred by comparing the modern and ancient vegetational assemblages and also on the assumption

that present ecological requirements were also similar in the Tertiary (Barnett, 1989). Nearly all the modern taxa represented by the Gulf of Suez palynomorphs are subtropical to warm temperate (e. g., *Taxodium*, Gramineae, Chenopodiaceae, Polypodiaceae). In contrast, Malvaceae are typically tropical to cool temperate (Fig. 3).

The above types of mixed vegetation were found in Egypt near the Nile Delta (El Beialy, 1988; Poumot and Bouroullec, 1984). This mixing can be understood if we assume that ecological requirements have not changed appreciably through time, and palynomorphs from various intervals are mixed at the site of deposition. An alternative interpretation is that some taxa were adapted to different conditions in the Tertiary

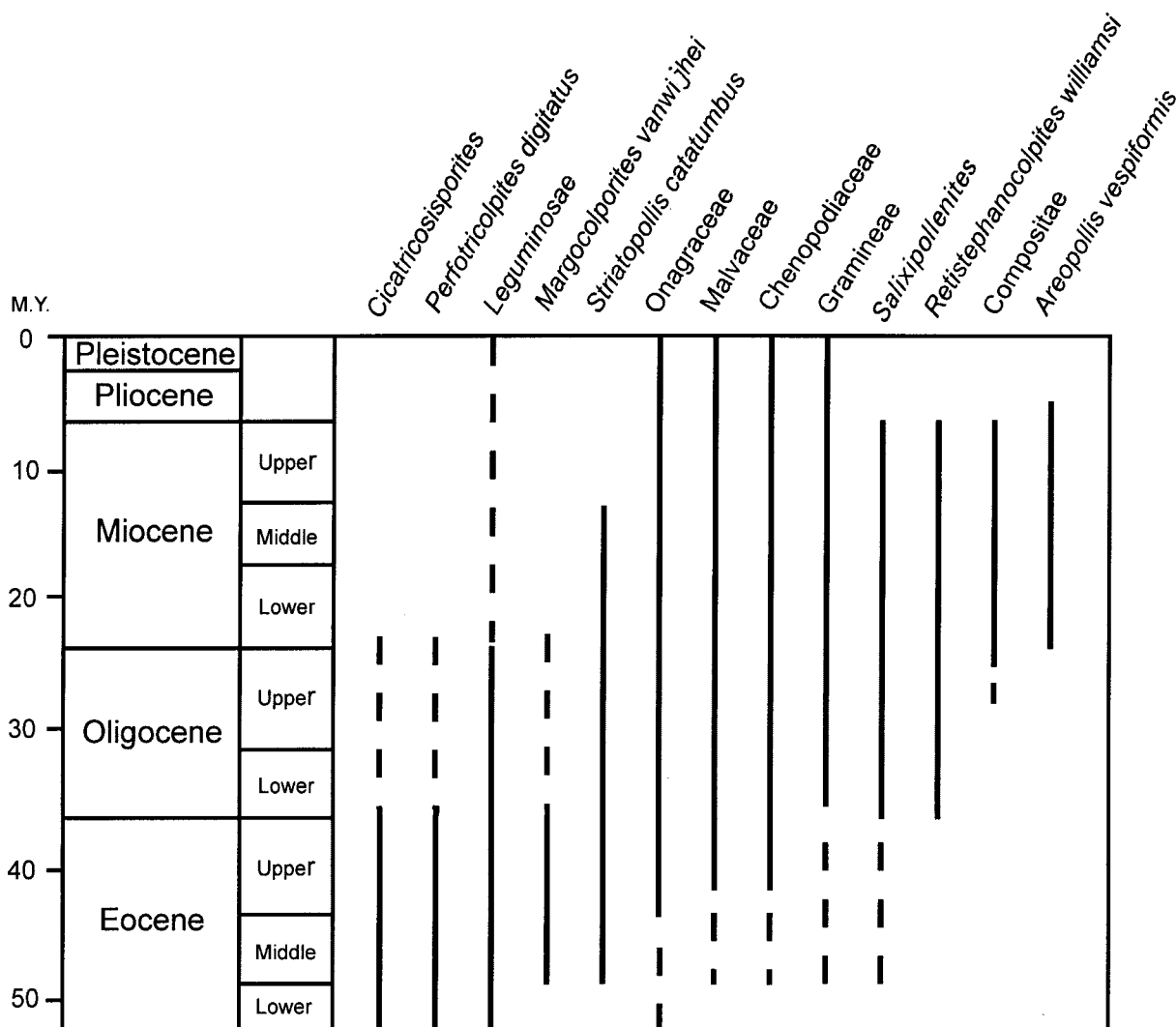


FIGURE 3—Stratigraphic ranges (worldwide) of key palynomorphs that are represented in the Miocene pollen flora of the GS-78-1 well, Gulf of Suez, Egypt.

and/or vegetational zonation in the Gulf of Suez was not pronounced. However, throughout the Tertiary the Earth underwent important climatic changes and the region that now is Egypt was not an exceptional place. Therefore taphonomical processes such as reworking are possibly responsible for this mixing of the Gulf of Suez palynoflora.

Another approach to interpreting palaeoclimate is based on the fluctuations in the Gramineae and *Pinuspollenites* abundance curves (Fig. 4) and the presence of the dinoflagellate cysts *Spiniferites* spp. as reported by Pocknall *et al.* (1999) from the Pliocene of the Gulf of Suez area. The curve indicates that the vegetation of the Gulf of Suez fluctuated from grassland Savanna with very few forest elements (dry phase) to a shrubland forest landscape in which *Pinuspollenites* and other conifers were the common components (humid phase). But, however, the percentage of bisaccate pollen grains in the Kareem Formation could be also be explained by means of change of regional winds. Likewise, the high percentages of Spiniferate cysts, Poaceae and Chenopodiaceae (Fig. 5) may indicate grassland. *Spiniferites* spp. are most common at the same time that Gramineae domi-

nates the assemblages. These cooler water dinoflagellates (Edwards, 1992) together with the dominance of Gramineae are probably indicative of cooler and drier (arid) climate (? Glacial phase). During the last glacial episode when conditions were cool and dry in low latitudes (present day tropics), grassland-Savanna was the most common vegetation type (Van der Hammen, 1974). Chenopodiaceae are generally more common with the grassland Savanna assemblage and indicate dry, arid, salt marsh conditions (sabkha) as deduced from the Pliocene of the Gulf of Suez (Pocknall *et al.*, 1999). This warm and arid episode is supplemented by the presence of *Monocolpopollenites* and the dinoflagellate cyst *Polysphaeridium zoharyi*. The relative frequency of *Monocolpopollenites* is particularly moderate in the two studied formations, and some would interpret this as evidence of a warming of the climate in the early/middle Miocene. The presence of *P. zoharyi*, which is adapted to high salinity waters (Morzadec-Kerfourn, 1992) could possibly be an indicator of arid conditions. In this study, however, *P. zoharyi* is common at times in both the dry (grassland-Savanna) and humid (shrubland forest) phases, suggesting that the oscillation in its abundances is more related to local

CLIMATE TAXON	Tropical	Subtropical	Warm Temperate	Cool Temperate	Boreal
<i>Pediastrum</i>					
<i>Lycopodium</i>					
Polypodiaceae					
Schizaeaceae					
Cupressaceae					
<i>Pinus</i>					
<i>Podocarpus</i>					
<i>Taxodium</i>					
<i>Tsuga</i>					
Gramineae					
<i>Betula</i>					
<i>Caesalpinia</i>					
Chenopodiaceae					
Compositae					
<i>Corylus</i>					
<i>Jussiaea</i>					
Malvaceae					
<i>Pterocarya</i>					

FIGURE 4—Climatic ranges of extant taxa represented by palynomorphs in the Rudies and Kareem formations, GS-78-1 well, Gulf of Suez, Egypt.

environmental changes than to regional climatic changes. The presence of *P. zoharyi* may indicate the prevalence of tropical to subtropical conditions during the sedimentation of the Kareem Formation (El Beialy and Ali, 2002).

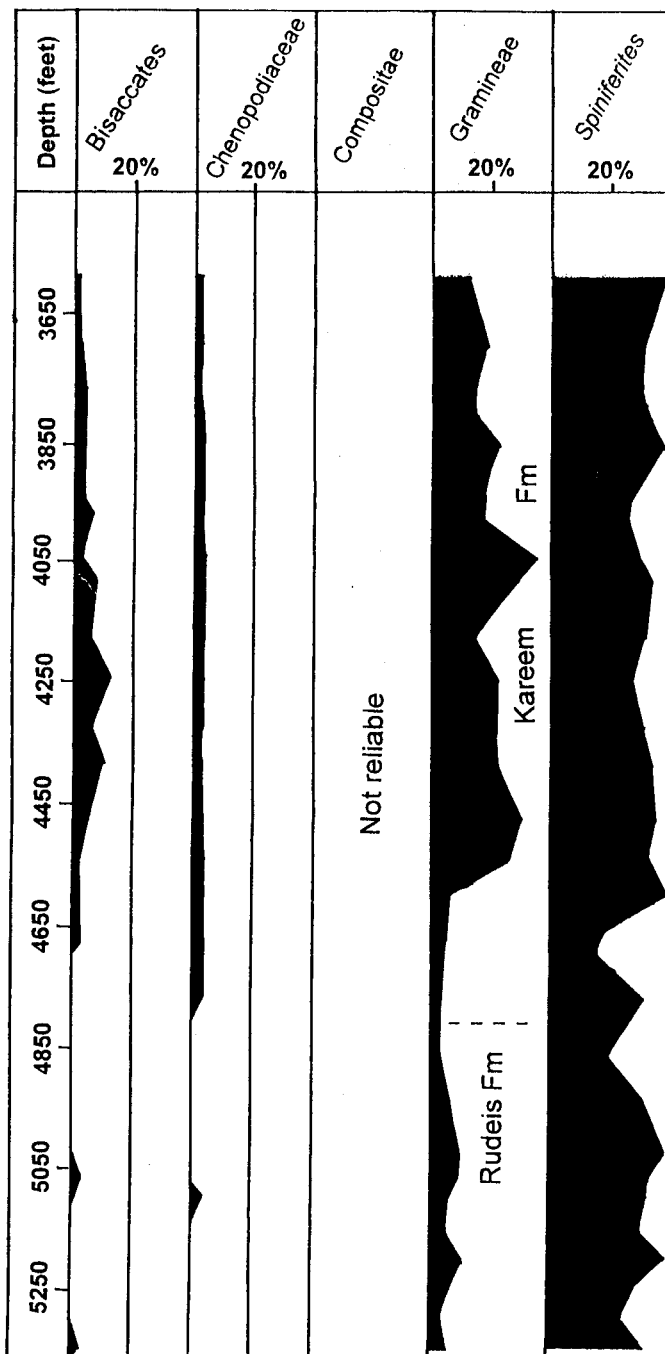


FIGURE 5—Fluctuations in the dinoflagellate cyst *Spiniferites*, major pollen groups and *Pinuspollenites* abundance curves in the Miocene of the Rudeis and Kareem formations, GS-78-1 well, Gulf of Suez, Egypt.

CONCLUSIONS

The Rudeis and Kareem pollen palynoflora recovered from the GS-78-1 well may be especially significant in recording the presence of typically Palaeogene taxa in the early-middle Miocene of the Gulf of Suez. The closest modern analogs for such associations are the palynofloras of southeastern Asia, and North America. Modern vegetation in those regions grows in a fairly warm, mild subtropical climate. A similar climate in the Gulf of Suez area during the mid-Tertiary may have allowed the Palaeogene taxa to exist.

The pollen assemblage examined from the Rudeis Formation is interpreted to have a general early Neogene age range. On the basis of documented stratigraphic ranges, the age can be further restricted to early Miocene based on the presence of a group of pollen that were first recorded from the Tertiary strata in the modern tropics, although in low numbers; these include *Acaciapollenites myriosporites*, *Areolipollis vespiformis*, *Fenestrites spinosus*, *Margocolporites vanwijhei*, *Perforicolpites digitatus* and *Striatopollis catatumbus*.

The samples examined from the Kareem Formation contained long-ranging taxa belonging to the families Gramineae, Compositae, Malvaceae and Chenopodiaceae. The abundance of herbs in the pollen palynoflora was sufficient only to verify early to early middle Miocene age to the Kareem Formation in the GS-78-1 well, based on similar findings from the Weaverville pollen palynoflora, USA (Barnett, 1989).

Vegetation on land during the Miocene fluctuated from dry (cool) grassland-Savanna to humid (warm) shrubland forest dominated by *Pinuspollenites*. The presence of Compositae and Gramineae was taken as an indication of drier habitats and areas of lower rainfall. Their presence also indicates open steppe or grassland conditions during this interval (Piel, 1971). Locally, Chenopodiaceae occupied brackish swampy sites of deposition. In the Kareem Formation conifers together with Gramineae dominate with a more typical Mediterranean climate, which is also established during the Mio-Pliocene of the Nile Delta (Poumot and Bouroullec, 1984) and the Pliocene of the Gulf of Suez (Pocknall *et al.*, 1999).

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RECENT MARINE OSTRACODA FROM THE SOLOMON ISLANDS. PART 2: CYTHERACEA, XESTOLEBERIDAE

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Abstract

Seventeen species of the family Xestoleberidae are included in this contribution. Sixteen belong to the genus *Xestoleberis* Sars and one to *Ornatoleberis* Keij. The strongly endemic nature of the fauna is emphasized by the fact that 9 of the 17 species are new, while 6 species of *Xestoleberis* are left in open nomenclature, all being rather rare. Two species, *X. paraporthedlendensis* Hartmann, 1978 and *X. macrocaticosa* Whatley & Roberts, 1995, have been previously recorded in West Australia and at Pitcairn and Henderson islands respectively. The new species described herein are: *Xestoleberis macrosphaera*, *X. dentamoline*, *X. pseudomargaritea*, *X. maculanitida*, *X. honiaraensis*, *X. intiger*, *X. posterotruncata*, *X. whittakeri* and *Ornatoleberis cordiformis*.

Key words: Xestoleberidae, Ostracoda, marine, Solomon Islands, Pacific, Recent.

Resumen

Se estudian diecisiete especies de la familia Xestoleberidae, dieciséis de ellas pertenecientes al género *Xestoleberis* Sars y una a *Ornatoleberis* Keij. La asociación muestra un fuerte endemismo, manifestado porque nueve de las especies son nuevas, mientras que seis, bastante raras, se dejan en *nomina aperta*. Dos especies, *X. paraporthedlendensis* Hartmann, 1978 y *X. macrocaticosa* Whatley y Roberts, 1995, han sido descritas previamente en el oeste de Australia y en las islas Pitcairn y Henderson, respectivamente. Las nuevas especies que se describen aquí son *Xestoleberis macrosphaera*, *X. dentamoline*, *X. pseudomargaritea*, *X. maculanitida*, *X. honiaraensis*, *X. intiger*, *X. posterotruncata*, *X. whittakeri* y *Ornatoleberis cordiformis*.

Palabras clave: Xestoleberidae, ostrácodos marinos, islas Salomón, Pacífico, Reciente.

INTRODUCTION

The present work is part of a larger study of the Quaternary and Recent Ostracoda of the Solomon Islands. Apart from Harding's (1962) study of species recovered from the gut of freshwater fishes, and two papers by the present authors on marine taxa (Whatley & Titterton, 1981; Titterton & Whatley, 1988), which dealt with two trachyleberidid genera and the large fauna (21 species) of Bairdiinae respectively, the Ostracoda of the Solomon

Islands have been sadly neglected. This is one of a series of publications in which we seek to redress this situation.

The Solomon Islands are situated to the NE of Australia and to the SE of New Guinea between Lat. 5°-12°S and Long. 155°-162°E and enjoy an oceanic tropical climate. The samples on which this study is based were collected off the islands of Guadalcanal and Shortland (Fig. 1). The location of the samples is given in Figs. 2 and 3). All of the samples are of largely bio-detrital sand, ranging from very fine to medium in grain

size. Much of the medium sand originated from coral and were collected with a simple pipe dredge or by diving. Details of the individual samples can be found in Whatley & Titterton, 1981, and Titterton (1984 MS).

The total ostracod fauna comprises some 160 species belonging to 56 genera. The overwhelmingly dominant group are the Cytheracea (63%) the remainder are cyprids (15%), bairdiids (8%) and platycopids/cladocopids (13%). The xestoleberid fauna is very much endemic to the Solomon Islands. Only one species, *X. paraporthendensis* Hartmann, 1978, occurs to the west, in Western Australia, while *X. macrocaticosa* Whatley & Roberts, 1995, also occurs to the east in the Pitcairn Group (Whatley & Roberts, 1995; Whatley *et al.* in press).

There has been something of a resurgence of studies of Ostracoda in the SW Pacific area during the last two decades. Among the important contributions are Behrens (1991a, b, Great Barrier Reef), Cabioch *et al.* (1986, New Caledonia), Dewi (1997, Java Sea), Howe & McKenzie (1989, NW Australia), Jellinek (1993, Kenya), Mostafawi (1992, Malaysia), Whatley *et al.* (1995, 1996, Northern Australia), Whatley & Keeler (1989, Reunion Island), Whatley & Zhao (1987, 1988, Malacca Straits), Whatley *et al.* 2000 (Easter Island), Whatley & Roberts 1995 and Whatley *et al.* in press (Pitcairn Group), Yassini *et al.* (1993, Eastern Australia), Yassini & Jones (1995, Eastern Australia), Zhao & Whatley (1989, Malaysia).

SYSTEMATIC DESCRIPTIONS

The type specimens of all new taxa are housed in the collections of the Natural History Museum, London to which the catalogue numbers prefixed RT/SIR refer. In

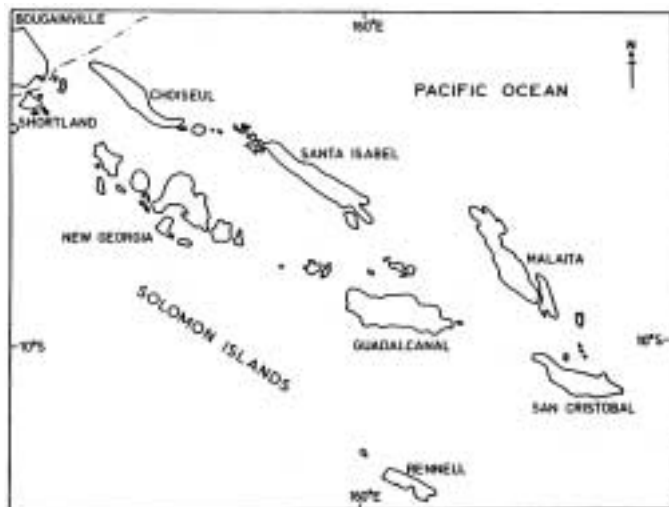


FIGURE 1.

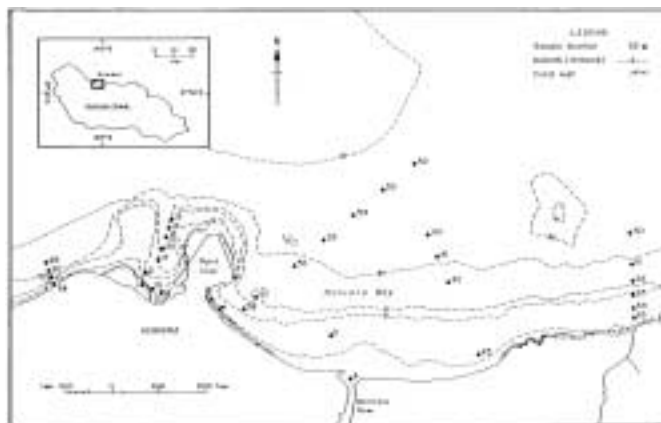


FIGURE 2.

all cases, specimens are of adults unless otherwise stated. All dimensions are given in millimetres, and the size convention for adults, as used by the senior author over many years for podocopid ostracods is as follows: <0.40 very small, 0.40-0.50 small, 0.50-0.70 medium, 0.70-1.00 large, >1.0- very large. Other conventions used throughout are: LV=left valve, RV=right valve, C=carapace, A=adult, rpc=radial pore canal, npc=normal pore canal. All new taxa are fully described.

Class OSTRACODA Latreille, 1806
 Order PODOCOPIDA Müller, 1894
 Suborder PODOCOPINA Sars, 1866
 Superfamily CYTHERACEA Baird, 1850
 Family XESTOLEBERIDIDAE Sars, 1928
 Genus *Xestoleberis* Sars, 1866

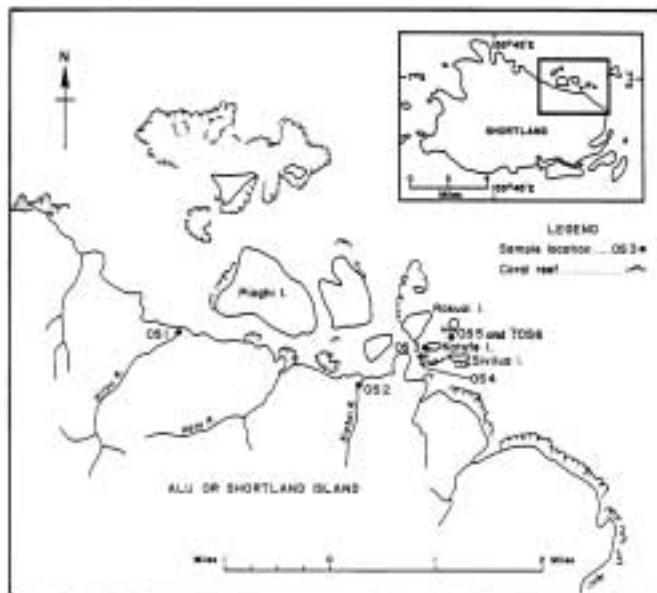


FIGURE 3.

Remarks.—Species of *Xestoleberis* are very common; around 100 species and subspecies, have been described from the Pacific. Their similarity of form, however, makes individual species difficult to identify even within a single assemblage. Problems of comparison with previously described species may be responsible for the fact that most of these species have never been subsequently described outside their type locality or area. This may, however, be due to endemism, as suggested by Kaesler and Waters (1972) in their census of the genus in the Southern Ocean. Of the species described from the Pacific Ocean, the majority are confined to one locality or area. Only some 20 species appear to be more cosmopolitan, but it is difficult to confirm this from the literature, as many of the earlier authors did not realise the importance of illustrating in detail all the characters of these species. The fact that some species could be widely distributed is attested to by the fact that we have identified in the Solomon Islands, two species (*X. paraporthedlandensis* Hartmann, 1978, and *X. dentamonile*) that could be conspecific with species recorded from Madagascar by Maddocks. None of the 6 species of *Xestoleberis* described from Easter Island (Whatley *et al.*, 2000) occur in the present study but one of the 7 species from the Pitcairn Group (Whatley *et al.*, in press), *X. macrocicatricosa*, also occurs in the Solomon Islands.

The 17 species encountered in the Solomon Islands (7 represented by less than 10 specimens) have been placed in 3 morphological groups, principally on shape and the nature of the npc's and selvage. Species are described in the order of their morphological groups.

MORPHOLOGICAL GROUP 1

Similarities in shape of the carapace and development of the selvage primarily distinguish this group. The posterior margin is almost as well rounded as the anterior and the selvage in the LV is strong and peripheral and in the RV, strong and subperipheral, becoming weak and peripheral anteriorly. The close relationship of the 3 described species is also indicated by the similarity in distribution of the npc's, with 4 canals in a similar position along the internal concave side of the conspicuous "Xestoleberis-spot" in all 3 species. All species possess a conspicuous eye-spot and the opaque patches, within the species, are very variable in size, shape and distribution.

Xestoleberis macrosphaerica sp. nov.
(Fig. 4, Nos. 1, 2, Pl. 1, Figs. 1-8)

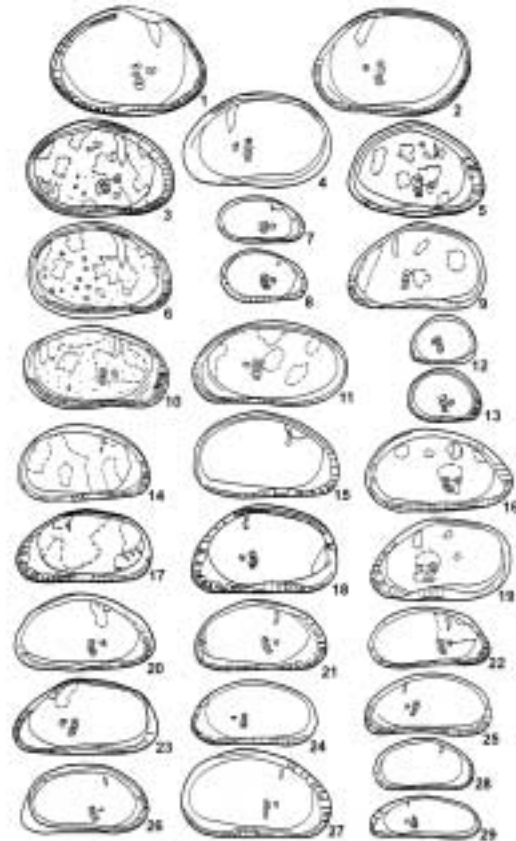


FIGURE 4—Internal lateral views. 1-2, *Xestoleberis macrosphaerica* sp. nov. 1, Paratype, male left valve, RT/SIR/704 x 68.3. 2, Female right valve, RT/SIR/705 x 70.3. 3-4, 6, *Xestoleberis dentamonile* sp. nov. 3, Male left valve, RT/SIR/717 x 81.9. 4, Female right valve, RT/SIR/718 x 73.6. 6, Female left valve, RT/SIR/716 x 67.2. 5, 9, *Xestoleberis paraonslowensis* sp. nov. 5, Male left valve, RT/SIR/741 x 87.8. 9, Female right valve, RT/SIR/740 x 78.2. 7, *Xestoleberis* sp. A. Male left valve, RT/SIR/800 x 74.2. 8, *Xestoleberis* sp. B. Left valve, RT/SIR/807 x 77.6. 10-11, *Xestoleberis pseudomargaritea* sp. nov. 10, Male left valve, RT/SIR/729 x 79.2. 11, Female right valve, RT/SIR/730 x 77.9. 12-13, *Xestoleberis macrocicatricosa* Whatley and Roberts, 1995. 12, Paratype, right valve, RT/SIR/733 x 64.8. 13, Paratype, left valve, RT/SIR/734 x 67.9. 14, 17, *Xestoleberis paraporthedlandensis* Hartmann, 1978. 14, Right valve, RT/SIR/753 x 68.0. 17, Right valve, RT/SIR/754 x 89.0. 15, 18, *Xestoleberis maculanitida* sp. nov. 15, Left valve, RT/SIR/766 x 74.5. 16, 19, *Xestoleberis honiaraensis* sp. nov. 16, Male left valve, RT/SIR/773 x 88.4. 19, Female right valve, RT/SIR/772 x 73.0. 20, 23, *Xestoleberis iniger* sp. nov. 20, Paratype, male left valve, RT/SIR/782 x 71.6. 23, Male right valve, RT/SIR/781 x 74.5. 21, 24, *Xestoleberis* sp. C. 21, Male left valve, RT/SIR/691 x 71.9. 24, Female right valve, RT/SIR/692 x 69.2. 22, 25, *Xestoleberis* sp. D. 22, Left valve, RT/SIR/695 x 73.3. 25, Right valve, RT/SIR/696 x 75.0. 26, *Ornatoleberis cordiformis* sp. nov. Male left valve, RT/SIR/816 x 70.7. 27, *Xestoleberis postero-truncata* sp. nov. Male left valve, RT/SIR/789 x 92.8. 28, *Xestoleberis* sp. F. Left valve, RT/SIR/808 x 74.3. 29, *Xestoleberis* sp. E. Right valve, RT/SIR/803 x 76.3.

Derivatio nominis.—L. From the rather large, spherical carapace of this species.

Holotype.—Female LV, RT/SIR/701.

Type locality and horizon.—Sample 13, 1,800 feet offshore west of Point Cruz, Honiara Bay, 11 fathoms. Unconsolidated, medium-grained coral sand. Recent.

Material.—92 valves and carapaces, A-3 to adult.

Diagnosis.—A medium species of *Xestoleberis*, almost spherical in both dorsal and lateral views. Maximum width medianly, almost equal to maximum height. Selvage peripheral around entire margin of LV and posterior and ventral margins of RV. Hinge antimerodont, terminal and median elements of approximately equal length. Frontal and dorsal adductor muscle scars U-shaped.

Description.—Medium. Thin-shelled. Translucent and shiny. Female conspicuously larger than male. Almost spherical in lateral and dorsal views. Anterior margin asymmetrically and rather narrowly rounded with subventral apex. Dorsal margin broadly rounded with apex at about mid-height. Dorsal margin symmetrically arcuate. Ventral margin with slight oral concavity anterior of mid-length. LV>RV with strong dorsal overlap. Maximum length below mid-height, maximum height and width median, almost equal. Value surface smooth. Npc's sieve-type, flush. Eye-spot inconspicuous. "Xestoleberis-spot" thin, crescentic, extending to one third of height. Inner lamella moderately wide; crescentic anterior and posterior vestibula. Rpc's numerous; approximately 40 anterior and posterior canals, some inflated medianly, some branching, apparently two levels of canals anteriorly. Strong selvage, peripheral around entire margin of LV, in RV around posterior and ventral margins, but not anterior. Hinge antimerodont,

elements of approximately equal length. Central muscle scars a vertical row of 4 adductors, dorsal adductor and frontal scar u-shaped, ventral adductors ovate.

Dimensions.—

Individual specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/701	0.63	0.49	
Paratype			
Female C, RT/SIR/700	0.61	0.48	0.47
Paratype			
Male RV, RT/SIR/702	0.56	0.42	
Paratype			
Female RV, RT/SIR/703	0.62	0.48	
Paratype			
Male LV, RT/SIR/704	0.60	0.43	
Male RV, RT/SIR/705	0.59	0.43	

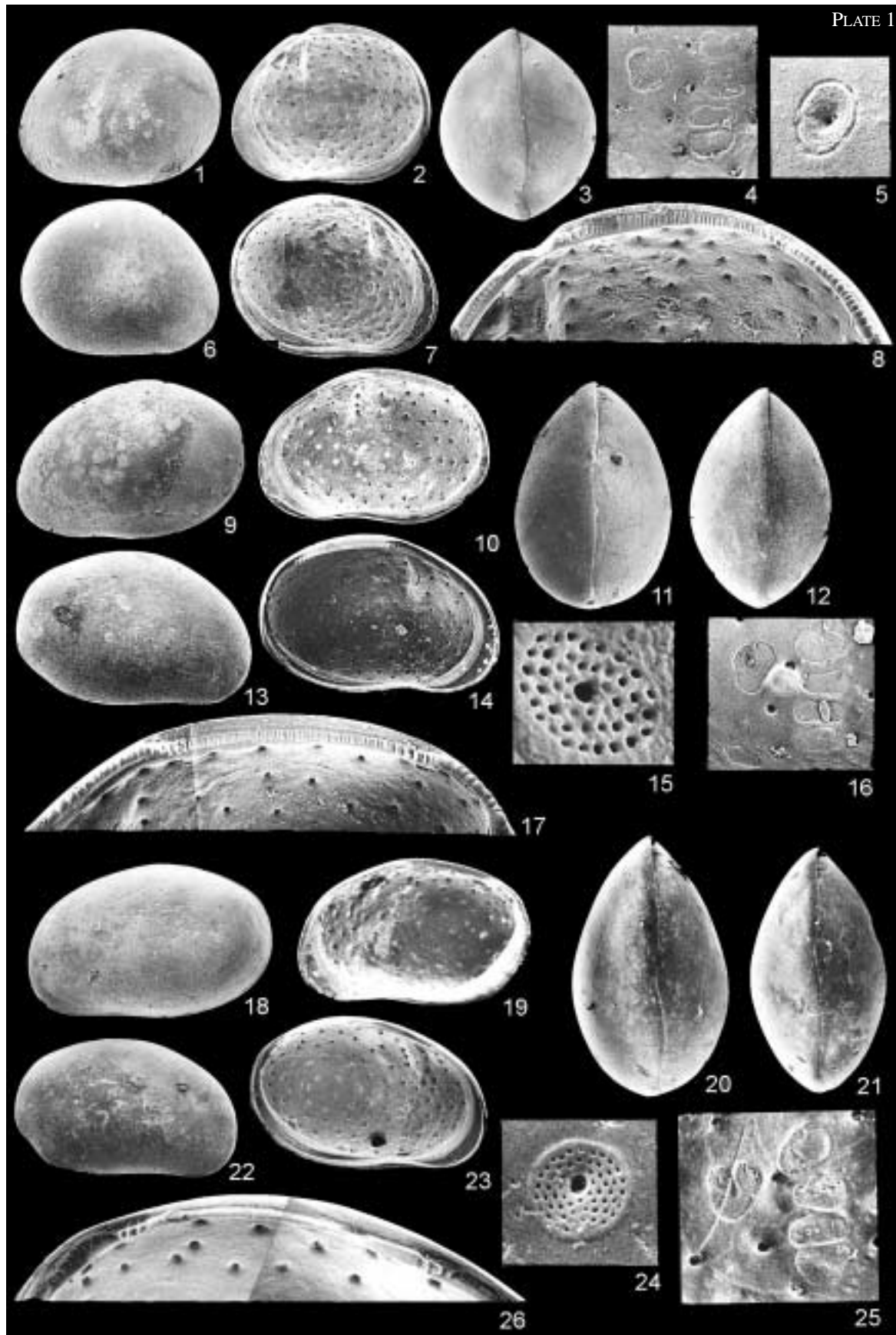
Mean Dimensions

	Length	Height	Width
5 Female	0.62 (0.61-0.63)	0.48 (0.47-0.49)	
8 Male	0.59 (0.56-0.60)	0.43 (0.41-0.44)	
1 A-1 C	0.52	0.44	0.42
19 A-1	0.46 (0.45-0.49)	0.36 (0.34-0.37)	
12 A-2	0.36 (0.34-0.38)	0.27 (0.26-0.28)	
12 A-3	0.28 (0.27-0.29)	0.21 (0.20-0.22)	

Distribution.—Samples: 1, 2, 13-17, 19, 20, 29, 32, 57, OS3-OS6 Guadalcanal and Shortland islands.

→

PLATE 1—1-8, *Xestoleberis macrosphaerica* sp. nov. 1, 7, Holotype, Female left valve, RT/SIR/701. 1, external lateral view x 54.0. 7, internal view x 58.9. 2, 4, 8, Paratype, Female right valve, RT/SIR/703. 2, internal view x 54.0. 4, detail of central muscle scars x 450.2. 8, detail of hinge x 149.0. 3, Paratype, Female carapace, RT/SIR/700, dorsal view x 55.2. 5, 6, Paratype, Male right valve, RT/SIR/702. 5, detail of normal pore canal x 385.0. 6, external lateral view x 58.9. 9-17, *Xestoleberis dentamonile* sp. nov. 9, 15, Holotype, female left valve, RT/SIR/710. 9, external lateral view x 73.4. 15, detail of normal pore canal x 4217.6. 10, Female left valve, RT/SIR/714, internal view x 79.1. 11, Paratype, female carapace, RT/SIR/706, dorsal view x 77.2. 12, Paratype, male carapace, RT/SIR/707, dorsal view x 76.7. 13, Paratype, male right valve, RT/SIR/709, external lateral view x 80.4. 14, Female left valve, RT/SIR/703, internal view x 76.4. 16, 17, Female right valve, RT/SIR/712. 16, detail of central muscle scar x 263.1. 17, detail of hinge x 202.1. 18-26, *Xestoleberis pseudomargaritea* sp. nov. 18, Holotype, female left valve, RT/SIR/721, external lateral view x 83.7. 19, 25, Female left valve, RT/SIR/728, internal view x 81.4. 20, Paratype, female carapace, RT/SIR/719, dorsal view x 77.2. 21, Paratype, male carapace, RT/SIR/720, dorsal view x 76.7. 22, Paratype, male right valve, external lateral view, RT/SIR/724 x 81.0. 23, 26, Female left valve, RT/SIR/727. 23, internal view x 76.9. 26, detail of hinge x 241.8. 24, Male right valve, RT/SIR/724, detail of normal pore canal x 395.2. 25, Male right valve, RT/SIR/726, detail of central muscle scar x 394.9.



Remarks.—The tumidity and spherical shape of this species is very distinctive. *Xestoleberis tumida* Scott, 1905 (Recent, Ceylon) is the only other species described that is as tumid, but differs in shape in that the maximum width is more anterior. *Xestoleberis tumefacta* Brady, 1880 (Recent, New Caledonia) is markedly less spherical.

Xestoleberis dentamonile sp. nov.
(Fig. 4, Nos. 3, 4, 6, Pl. 1, Figs. 9-17)

1966 ? *Xestoleberis* sp. XE Maddocks, p. 70, Fig. 61.

Derivatio nominis.—L. From the fact that the median element of the RV hinge resembles a necklace of teeth.

Holotype.—Female LV, RT/SIR/710.

Type locality and horizon.—Sample 42, 2,000 feet offshore east of the mouth of the Matanikau River, Honiara Bay, Guadalcanal. 15 fathoms. Unconsolidated, medium-grained sand. Recent.

Material.—245 valves and carapaces, A-3 to adult.

Diagnosis.—A medium species of *Xestoleberis* subovate in lateral view; female subelliptical and male drop-shaped in dorsal view. Selvage strong, peripheral around entire margin in LV; in RV subperipheral posteriorly and ventrally with narrow flange; selvage and flange absent anteriorly. Median element of RV hinge a deeply inset locellate groove, the locules resembling a necklace of teeth; terminal elements shorter. Prominent oval fulcral point between dorsomedian and adductor and v-shaped frontal scars.

Description.—Medium, translucent to opaque. Female conspicuously larger than male. Subovate in shape in lateral view; female subelliptical and male drop-shaped in dorsal view. Anterior margin obliquely rounded anteroventrally; extremity well below mid-height. Posterior margin of female well rounded becoming oblique ventrally; posterodorsal of male straight in RV, gently convex in LV, becoming oblique and straight posteroventrally. Maximum length just below mid-height; maximum height just posterior to mid-length; maximum width at posterior third in female, median in male. Valve surface smooth. Npc's sieve-type, flush. Eye-spot inconspicuous. "Xestoleberis-spot" long, one-third of height, narrow. Inner lamella moderately wide; narrow anterior and crescentic posterior vestibula. Rpc's numerous, approximately 40 anterior and 25 posteroventral, simple, straight canals. Selvage strong, in LV peripheral around entire margin; in RV subperipheral posteriorly and ventrally with narrow flange; selvage and flange absent anteriorly. Hinge antimerodont, robust; median element the longest, deeply inset locellate groove, the locules resembling a necklace of teeth; terminal elements shorter. Central muscle scars a vertical row of 4 large, subovate, medianly constricted adductors; prominent ovate fulcral point between dorso-medial adductor and v-shaped frontal scar.

Dimensions.—
Individual specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/710	0.52	0.37	
Paratype			
Female C, RT/SIR/706	0.53	0.34	0.34
Paratype			
Male C, RT/SIR/707	0.50	0.31	0.30
Paratype			
Male RV, RT/SIR/709	0.49	0.31	
Male LV, RT/SIR/708	0.49	0.34	
Female RV, RT/SIR/711	0.51	0.33	
Female LV, RT/SIR/713	0.53	0.35	
Male RV, RT/SIR/714	0.49	0.32	
Male LV, RT/SIR/715	0.48	0.33	
Female LV, RT/SIR/716	0.55	0.38	
Male LV, RT/SIR/717	0.47	0.32	
Female RV, RT/SIR/718	0.53	0.36	

Mean Dimensions

	Length	Height	Width
4 Female C	0.54 (0.52-0.55)	0.36 (0.35-0.37)	0.36 (0.35-0.36)
8 Female LV	0.53 (0.52-0.55)	0.37 (0.35-0.38)	
8 Female RV	0.52 (0.50-0.54)	0.35 (0.33-0.39)	
4 Male C	0.48 (0.47-0.48)	0.33 (0.32-0.34)	0.32
3 Male LV	0.48 (0.47-0.49)	0.33 (0.32-0.34)	
11 Male RV	0.47 (0.45-0.49)	0.31 (0.30-0.32)	
20 A-1 LV	0.40 (0.38-0.43)	0.28 (0.26-0.30)	
20 A-1 RV	0.40 (0.37-0.41)	0.27 (0.25-0.28)	
20 A-2	0.31 (0.28-0.33)	0.22 (0.20-0.24)	
7 A-3	0.27 (0.25-0.28)	0.19 (0.17-0.20)	

Distribution.—Common in shallow water Quaternary sediments, both brackish and marine, Indispensable Reefs and off Guadalcanal (Williams MS, 1980). Recent, Pulau Seribu, Java Sea (Watson MS, 1988). Present study samples: 1, 2, 5, 13-17, 19, 29, 30, 32, 40-42, 53-58, 60, 61, OS6, Guadalcanal and Shortland islands. It is possible that this species has been found at Nosy Bé, Madagascar (Maddocks, 1966) from washings of several types of algae associated with intertidal and reef sands and at 10-15 metres.

Remarks.—Many species of *Xestoleberis* are very similar in shape to the present species and would also be placed in morphological group 1. They possess a similar prominent, peripheral selvage around the entire margin of the LV. Detailed examination of the hinge, muscle scars and pore canals will distinguish these species. *Xestoleberis tantabiddycreekensis* Hartmann, 1978 (Recent, eulittoral Western Australia) is slightly larger and differs in details of the hinge, as the positive elements are more finely denticulate. *Xestoleberis tigrina* (Brady, 1866), as illustrated by McKenzie (1967) from the Recent off Southern Australia, differs only in the pattern and shape of the central muscle scars and distribution of the npc's. *Xestoleberis tumefacta* Brady, 1880, *X. variegata* Brady, 1880, and *X. cautricula* Hartmann, 1978, are also similar in shape but differ in internal characters. *X. malaysiana* Zhao & Whatley (1989) from Malaya is very similar in shape but very much smaller (L=0.32-0.35). Watson's specimens are somewhat smaller (female LV 0.47-0.54, male LV 0.41-0.44). *Xestoleberis* sp. XE Maddocks, 1966, although of the same size and shape lacks opaque patches and is less strongly sexually dimorphic.

Xestoleberis pseudomargaritea sp. nov.
(Fig. 4, Nos. 10, 11, Pl. 1, Figs. 18-26)

Derivatio nominis.—L. From the similarity in overall morphology to the Recent, European species *Xestoleberis margaritea* (Brady, 1866).

Holotype.—Female LV, RT/SIR/721.

Type locality and horizon.—Sample 15, 1,350 feet offshore west of Point Cruz, Honiara Bay, Guadalcanal. 13 fathoms. Unconsolidated, medium-grained coral sand. Recent.

Material.—Over 1,000 valves and carapaces, A-4 to adult.

Diagnosis.—A subrectangular species of *Xestoleberis*, translucent with variable opaque patches. Selvage strong, peripheral around entire margin in LV; in RV subperipheral becoming weaker posteriorly and

peripheral ventrally and anteriorly. Hinge hemimerodont with smooth median element. Frontal muscle scar v-shaped.

Description.—Medium. Moderately thin-shelled. Translucent with variable opaque patches that may cover entire surface. Female conspicuously larger than male, more tumid posteriorly. Subrectangular in lateral view; female drop-shaped in dorsal view, height equal to width; male subelliptical. Anterior margin well rounded, sloping obliquely anterodorsally in male, extremity well below mid-height. Posterior of female well rounded; in male posteroventral margin sloping obliquely to gently concave. Maximum length at mid-height; maximum height at mid-length in LV, just anterior to mid-length in RV; maximum width just posterior to mid-length in female, median in male. Valve surface smooth. Npc's sieve-type, small, ovate, flush. Eye-spot small, glassy. "Xestoleberis-spot" conspicuous, long, narrow. Inner lamella wide, with crecentic anterior and posteroventral vestibula. Rpc's numerous; approximately 40 anterior and 25 posteroventral canals, simple, straight. Selvage strong, peripheral around entire margin in LV; in RV subperipheral posteriorly becoming weaker and more peripheral ventrally, weak and peripheral anteriorly. Hinge hemimerodont, median element the longest, smooth; RV posterior terminal element with about 10 small, ovate teeth; LV with strong anti-slip bars ventral to terminal sockets. Central muscle scars a vertical row of 4 large, subovate adductors and a v-shaped frontal scar.

Dimensions.—
Individual Specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/721	0.49	0.37	
Paratype			
Female C, RT/SIR/719	0.53	0.34	0.34
Paratype			
Male C, RT/SIR/720	0.43	0.31	0.30
Paratype			
Male RV, RT/SIR/724	0.46	0.31	
Male LV, RT/SIR/722	0.48	0.34	
Female RV, RT/SIR/723	0.49	0.33	
Female LV, RT/SIR/725	0.46	0.35	
Male RV, RT/SIR/726	0.47	0.32	
Male LV, RT/SIR/727	0.52	0.33	
Female LV, RT/SIR/728	0.51	0.38	
Male LV, RT/SIR/729	0.48	0.32	
Female RV, RT/SIR/730	0.52	0.36	

Mean Dimensions, Shortland Island, Sample OS6

	Length	Height	Width
5 Female C	0.53 (0.52-0.54)	0.33 (0.32-0.34)	0.32 (0.31-0.34)
10 Female LV	0.54 (0.52-0.56)	0.33 (0.33-0.34)	
10 Female RV	0.53 (0.51-0.55)	0.32 (0.31-0.33)	
5 Male C	0.48 (0.47-0.49)	0.30 (0.29-0.31)	0.27 (0.26-0.27)
10 Male LV	0.48 (0.47-0.49)	0.30 (0.28-0.31)	
10 Male RV	0.46 (0.45-0.48)	0.28 (0.27-0.29)	
10 A-1 LV	0.40 (0.38-0.42)	0.26 (0.24-0.27)	
10 A-1 RV	0.40 (0.37-0.41)	0.23 (0.22-0.24)	
10 A-2	0.31 (0.29-0.32)	0.20 (0.19-0.21)	
5 A-3	0.25 (0.25-0.26)	0.17 (0.16-0.21)	
2 A-4	0.20, 0.21	0.15	

Mean Dimensions, Honiara Bay

	Length	Height	Width
4 Female C	0.48 (0.46-0.50)	0.31 (0.31-0.32)	0.30 (0.29-0.31)
4 Female LV	0.50 (0.48-0.52)	0.32 (0.31-0.33)	
3 Female RV	0.48, 0.29 (0.47-0.49)	0.29, 0.30 (0.29-0.30)	
2 Male LV	0.40, 0.43	0.26, 0.25	
6 Male RV	0.42 (0.39-0.44)	0.26 (0.24-0.27)	
15 A-1 LV	0.38 (0.37-0.40)	0.25 (0.23-0.26)	
17 A-1 RV	0.38 (0.36-0.39)	0.23 (0.22-0.24)	
30 A-2	0.31 (0.29-0.33)	0.20 (0.19-0.21)	
2 A-3	0.25, 0.26	0.17	
1 A-4	0.21	0.15	

Distribution.—Samples: 1, 2, 5, 13-17, 19, 29, 30, 32, 54-58, 60, OS5, OS6 Guadalcanal and Shortland islands.

Remarks.—The present species is very similar to the European species *X. margaritea* (Brady, 1865), but markedly smaller. *Xestoleberis macrosphaerica* sp. nov., *X. dentamonile* sp. nov. and the present species comprise a morphological group as described above. The present species, however, is more elongate and has more anteriorly situated central muscle scars and it possesses a smooth median hinge bar. This species should not be confused with *X. paramargaritea* Howe & McKenzie (1989) from Northern Australia. The two species are of similar size but the latter is only illustrated by a single line drawing, making comparison difficult.

Xestoleberis sp. A

(Fig. 4, No. 7, Pl. 2, Figs. 1-4)

Material.—10 valves and carapaces, A-1 to adult.

Diagnosis.—A very small, subrhomboidal species of *Xestoleberis* with 'downturned' anterior margin with subventral apex. Posterior margin asymmetrically rounded with subdorsal apex. Dorsal margin arched with apex behind mid-length. Ventral margin with only slight oral incurvature.

Dimensions.—

	Length	Height	Width
Female C, RT/SIR/797	0.32	0.17	0.20
Female C, RT/SIR/798	0.34	0.19	0.20
Female LV, RT/SIR/799	0.34	0.18	
Male LV, RT/SIR/800	0.31	0.17	
Male C, RT/SIR/801	0.32	0.17	0.18

Distribution.—Samples: 1, 2, 16, 17, 57, 58, OS3, OS6 Guadalcanal and Shortland Islands.

Remarks.—The present species belongs to morphological group 1 with *X. macrosphaerica* sp. nov. of the present study but is clearly distinguished by its very small size. *Xestoleberis macrociacatricosa* sp. nov. of the present study is also small but is higher and lacks the strong, peripheral selvage in the LV which is so characteristic of morphological group 1.

Xestoleberis sp. B

(Fig. 4, No. 8, Pl. 2, Figs. 5-8)

Material.—3 adult valves and 1 adult carapace.

Diagnosis.—A very small, subovate species of *Xestoleberis* with hemimerodont hinge, rather large adductor scars and a strongly trefoil frontal scar.

Dimensions.—

	Length	Height	Width
LV, RT/SIR/804	0.31	0.19	
C, RT/SIR/805	0.30	0.19	0.19
LV, RT/SIR/806	0.30	0.19	
LV, RT/SIR/807	0.29	0.18	

Distribution.—Samples: 13, 14, 17, 32 Guadalcanal.

Remarks.—This species, like *X. pseudomargari- tea*, also of morphological group 1 possesses a hemimerodont hinge and similar central muscle scar pattern, although the individual scars are relatively larger. The present species, however, differs in being conspicuously smaller and the maximum width of the carapace is more posterior. This species is very similar to *X. darwinensis* Howe & McKenzie, 1989, from Port Darwin, Northern Australia but is smaller.

MORPHOLOGICAL GROUP 2

Species placed in this group possess a strong, peripheral selvage in the RV that weakens around the anteroventral angle. A distinctive convexity of the anteroventral margin is also present in the 2 named species comprising this group.

Xestoleberis macrocaticosa Whatley & Roberts, 1995.

(Fig. 4, Nos. 12, 13, Pl. 2, Figs. 16-18)

1995 *Xestoleberis macrocaticosa* Whatley & Roberts, p. 362, Fig. 1. 27.

In press *Xestoleberis macrocaticosa* Whatley & Roberts. Whatley, Jones & Roberts, Pl. 6, Figs. 12-16.

Material.—14 adult valves and carapaces.

Diagnosis.—A very small, rotund species of *Xestoleberis*. Ventral margin strongly convex anterior of oral concavity; anteroventral angle sharply rounded leading to a beak-like structure. Central muscle scars proportionally very large, dorsal adductor largest, subdividing; v-shaped frontal scar very close to adductors. Terminal elements of hemimerodont hinge short, in RV with 6 ovate teeth; median element smooth, gently arched.

Dimensions.—

	Length	Height
LV, RT/SIR/731	0.28	0.21
RV, RT/SIR/732	0.28	0.20
RV, RT/SIR/733	0.27	0.19
LV, RT/SIR/734	0.28	0.21

Distribution.—Samples: 1, 2, 13, 14, 16, 17, 19, 32, 53 Guadalcanal.

Remarks.—The present species is very distinctive in its small size and proportionally large central muscle scars. The central muscle scar pattern is also unusual in that the frontal scar is adjacent to and almost touching the dorsal two adductor scars. No other species of *Xestoleberis* has been described in the literature of similar size, shape and muscle-scar pattern. Whatley & Roberts (1995) and Whatley *et al.* (in press) record the species from Pitcairn and Henderson islands of the Pitcairn group.

Xestoleberis paraonslowensis sp. nov.

(Fig. 4, Nos. 5, 9, Pl. 2, Figs. 9-13)

Derivatio nominis.—L. From the similarity in overall morphology to *Xestoleberis onslowensis* Hartmann, 1978, from the Recent eulittoral of Western Australia.

Holotype.—Female LV, RT/SIR/735.

Type locality and horizon.—Sample 1,200 feet offshore west of Point Cruz, Honiara Bay, Guadalcanal, Solomon Islands. 1.5 fathoms. Medium-grained coral sand. Recent.

Material.—75 valves, A-2 to adult.

Diagnosis.—A medium species of *Xestoleberis* subtriangular in lateral view. Posterior obliquely rounded; ventral margin with marked convexity anterior of oral concavity. Selvage in LV strong, peripheral but absent anteroventrally; in RV with broad flange antero- and posteroventrally. Hinge antimerodont, elements of equal length; median groove of RV finely locellate, not excavated. Dorsal and ventral adductor muscle scars v-shaped.

Description.—Medium. Moderately thin-shelled. Translucent with variable opaque patches, usually an irregular subcentral and an ovate posteromedian patch. Female conspicuously larger than male and more tumid posteriorly. Subtriangular in lateral view; drop-shaped in dorsal view. Anterior margin with rather pointed apex below mid-height as a beak-like structure. Posterior margin obliquely rounded with apex below mid-height.

Ventral margin with marked convexity anterior to oral concavity. Dorsal margin with central subumbonate apex and straight posterior part sloping posteriorly. Maximum length subventral; maximum height at mid-length; maximum width at posterior third. Valve surface smooth. Npc's sieve-type, flush, small, ovate. "Xestoleberis-spot" small, crescentic. Inner lamella moderately wide with crescentic anterior and narrow posterior vestibula. Rpc's moderately numerous, simple, straight. Selvage in LV strong, peripheral, absent antroventrally; in RV peripheral antero- and posterodorsally and orally, weak, subperipheral with wide flange antero- and posteroventrally. Hinge antimerodont, elements of equal length; RV terminal elements gently arched, dentate ridges with about 12 ovate teeth, median element a gently arched, finely locellate groove. Central muscle scars comprise 4 subovate adductors, dorsal and ventral scars v-shaped; v-shaped frontal scar; fulcral point a strong elevation obscuring posterior part of frontal scar.

Dimensions.—

Individual Specimens

	Length	Height
Holotype		
Female LV, RT/SIR/735	0.43	0.28
Paratype		
Female RV, RT/SIR/736	0.41	0.29
Paratype		
Male LV, RT/SIR/737	0.40	0.27
Paratype		
Male RV, RT/SIR/738	0.42	0.28
Female LV, RT/SIR/739	0.44	0.30
Female RV, RT/SIR/740	0.46	0.30
Male LV, RT/SIR/741	0.41	0.28
Male RV, RT/SIR/742	0.41	0.28

Mean Dimensions

	Length	Height
6 Male LV	0.41 (0.40-0.42)	0.28 (0.28-0.29)
4 Male RV	0.41 (0.40-0.43)	0.27 (0.25-0.28)
17 A-1 LV	0.36 (0.33-0.37)	0.24 (0.22-0.26)
18 A-1 RV	0.35 (0.33-0.37)	0.23 (0.22-0.24)
19 A-2	0.29 (0.28-0.30)	0.19 (0.18-0.21)

Distribution.—Samples: 1, 2, 13-17, 30, 32, 53, 57, 58 Guadalcanal.

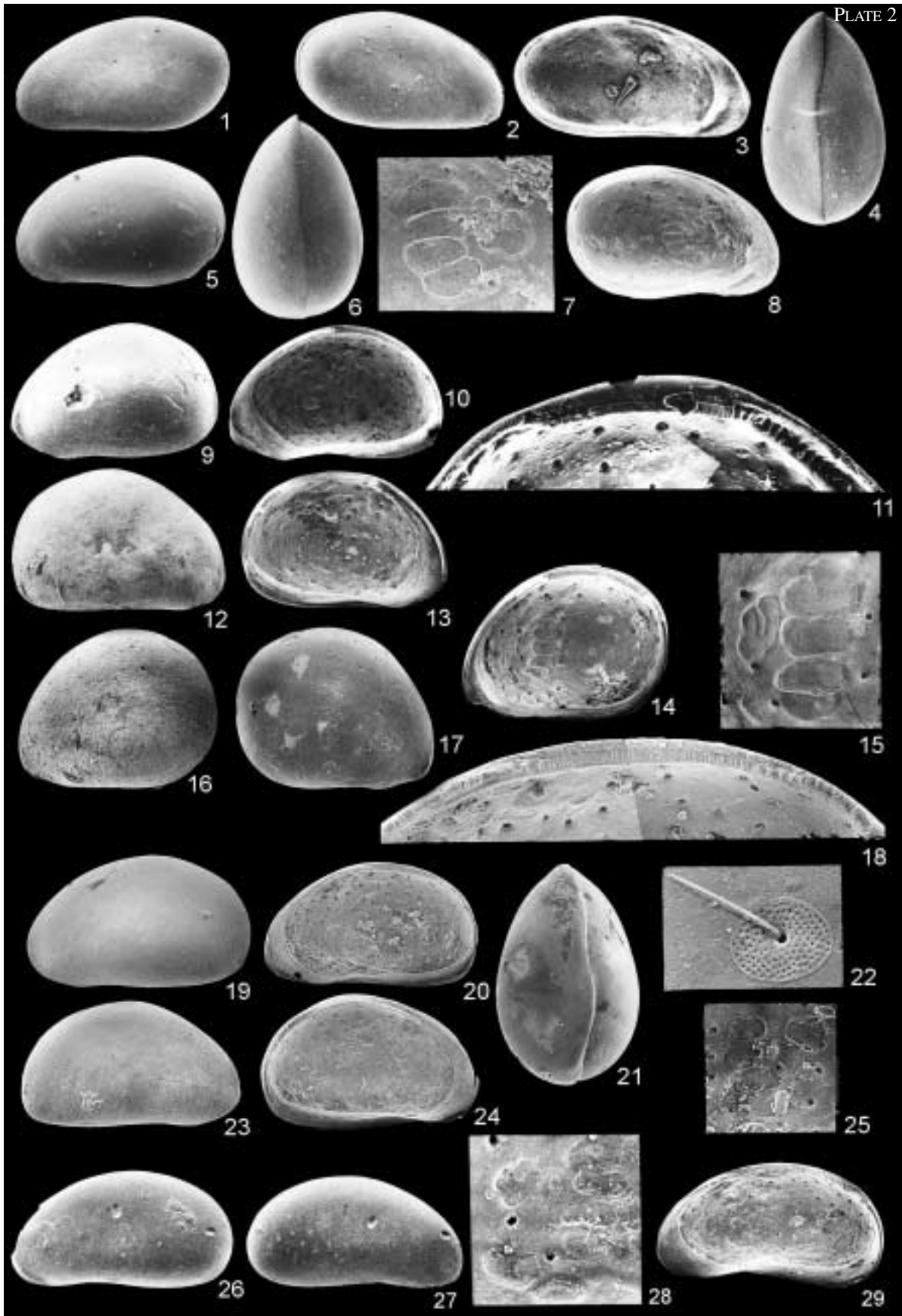
Remarks.—The present species is most similar to *X. onslowensis* Hartmann, 1978, but they differ mainly in the structure of the hinge as the median element of the RV of *X. onslowensis* is deeply excavated. *Xestoleberis ferax* Klie, 1940 (Recent, South-western Africa) is less truncated posteriorly and *X. yambaensis* Hartmann, 1981 (Recent eulittoral, Eastern Australia) is proportionally more elongate. The present species and *X. macrocicatricosa* sp. nov. vary considerably in size but both possess a distinctive convexity of the anteroventral margin and a beak-like anterior structure due to similar selvage in the RV. Only 4 of the adult valves found were females.

MORPHOLOGICAL GROUP 3

The species in this group are similar in shape and size and most easily distinguished by the opaque pat-

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PLATE 2-1-4, *Xestoleberis* sp. A. 1, 3, Female left valve, RT/SIR/799. 1, external lateral view x 105.2. 3, internal view x 117.7. 2, Female carapace, RT/SIR/798, external lateral view of right valve x 103.7. 4, Female carapace, RT/SIR/797, dorsal view x 90.9. 5-8, *Xestoleberis* sp. B. 5, Left valve, RT/SIR/804, external lateral view x 112.9. 6, Carapace, RT/SIR/805, dorsal view x 115.8. 7, Left valve, RT/SIR/806, detail of central muscle scar x 339.6. 8, Left valve, RT/SIR/806, internal view x 119.7. 9-13, *Xestoleberis paraonslowensis* sp. nov. 9, Holotype, female left valve, RT/SIR/735, external lateral view x 80.8. 10, Female right valve, RT/SIR/740, internal view x 77.7. 11, Female right valve, RT/SIR/741, detail of hinge x 264.0. 12, Paratype, male right valve, RT/SIR/738, external lateral view x 85.1. 13, Female left valve, RT/SIR/739, internal view x 78.6. 14-18, *Xestoleberis macrocicatricosa* Whatley and Roberts, 1995. 14, 15, 18, Right valve, RT/SIR/733. 14, internal view x 127.8. 15, detail of muscle scar x 327.4. 18, detail of hinge x 215.0. 16, Left valve, RT/SIR/731, external lateral view x 119.6. 17, Right valve, RT/SIR/732, external lateral view x 117.9. 19-25, *Xestoleberis iniger* sp. nov. 19, Holotype, female left valve, RT/SIR/776, external lateral view x 65.4. 20, Female right valve, RT/SIR/780, internal view x 63.0. 21, 22, Paratype, female carapace, RT/SIR/775. 21, dorsal view x 64.8. 22, detail of normal pore canal x 2377.8. 23, Paratype, male right valve, RT/SIR/778, external lateral view x 75.1. 24, 25, Female left valve, RT/SIR/779. 24, internal view x 66.1. 25, detail of central muscle scar x 219.2. 26-29, *Xestoleberis* sp. D. 26, Left valve, RT/SIR/695, external lateral view x 86.1. 27, Right valve, RT/SIR/694, external lateral view x 86.3. 28, 29, Right valve, RT/SIR/696. 28, detail of central muscle scar x 277.3. 29, internal view, RT/SIR/696 x 86.4.



ches, which are consistent within a species and throughout its ontogeny. All species of this group possess a similarly developed selvage. In the LV it is peripheral becoming weak or absent anteroventrally and in the RV, peripheral becoming subperipheral around the antero- and posteroventral angles and particularly strongly developed orally.

Xestoleberis paraporthedlandensis Hartmann, 1978
(Fig. 4, Nos. 14, 17, Pl. 3, Figs. 1-8)

? 1966 *Xestoleberis* sp. XF Maddocks, p. 68, Fig. 58.

1978 *Xestoleberis paraporthedlandensis* Hartmann, p. 122, Text-figs. 409-422, Pl. 13, Figs. 1, 2.

1984 *Xestoleberis dendritica* Titterton MS, p. 513, Pl. 17, Figs. 1, 2, Pl. 59, Figs. 1-13.

1984 *Xestoleberis paraporthedlandensis* Hartmann, 1978. Hartmann, p. 131, Text-figs. 55-56, Pl. 9, Figs. 4-7.

1988 *Xestoleberis paraporthedlandensis* Hartmann, 1978. Watson MS, p. 251, Pl. 11, Figs. 2, 3, Pl. 46, Figs. 8-14.

Material.—317 valves and carapaces, A-2 to adult.

Dimensions.—

Individual Specimens

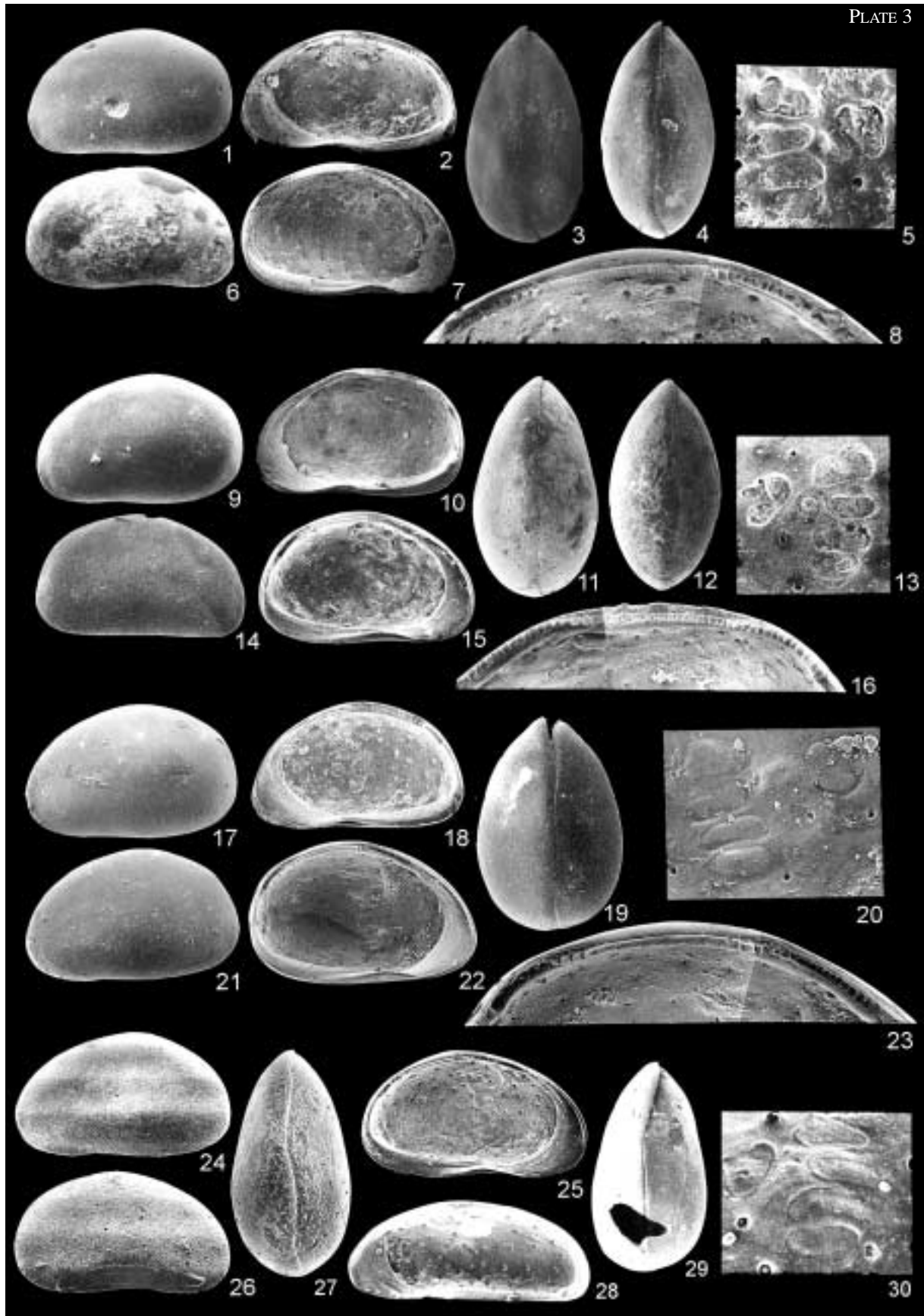
	Length	Height	Width
Male C, RT/SIR/743	0.44	0.26	0.22
Female, RT/SIR/744	0.48	0.29	0.25
Female LV, RT/SIR/745	0.50	0.30	
Female RV, RT/SIR/746	0.51	0.30	
Male LV, RT/SIR/747	0.44	0.25	
Male RV, RT/SIR/748	0.41	0.24	
Female RV, RT/SIR/749	0.51	0.30	
Female LV, RT/SIR/750	0.50	0.30	
Male RV, RT/SIR/751	0.41	0.23	
Male LV, RT/SIR/752	0.42	0.25	
Female LV, RT/SIR/753	0.50	0.30	
Male RV, RT/SIR/754	0.40	0.23	

Mean Dimensions, Shortland Island, Sample OS6

	Length	Height	Width
5 Female C	0.49 (0.48-0.50)	0.30 (0.29-0.31)	0.29 (0.28-0.30)
5 Male C	0.48 (0.42-0.45)	0.26 (0.25-0.27)	0.23 (0.21-0.24)

→

PLATE 3—1-8, *Xestoleberis paraporthedlandensis* Hartmann, 1978. 1, Holotype, female left valve, RT/SIR/745, external lateral view x 68.5. 2, Male right valve, RT/SIR/751, internal view x 87.8. 3, Female carapace, RT/SIR/744, dorsal view x 82.0. 4, Male carapace, RT/SIR/743, dorsal view x 87.5. 5, Male left valve, RT/SIR/752, detail of central muscle scar x 441.1. 6, Male right valve, RT/SIR/748, external lateral view x 85.4. 7, 8, Female left valve, RT/SIR/750. 7, internal view x 72.0. 8, detail of hinge x 198.4. 9-16, *Xestoleberis maculanitida* sp. nov. 9, Holotype, female left valve, RT/SIR/757, external lateral view x 64.9. 10, 16, Female right valve, RT/SIR/761. 10, internal view x 68.2. 16, detail of hinge x 173.7. 11, Paratype, female carapace, RT/SIR/756, dorsal view, x 72.4. 12, Paratype, male carapace, RT/SIR/755, dorsal view x 82.6. 13, Paratype, male right valve, RT/SIR/763, detail of central muscle scar x 347.2. 14, Male right valve, RT/SIR/760, external lateral view x 77.8. 15, Male left valve, RT/SIR/764, internal view x 77.8. 17-23, *Xestoleberis honiaraensis* sp. nov. 17, Holotype, female left valve, RT/SIR/768, external lateral view x 71.6. 18, Paratype, male right valve, RT/SIR/774, internal view x 83.9. 19, Paratype, female left valve, RT/SIR/767, dorsal view x 74.2. 20, 22, 23, Paratype, female left valve, RT/SIR/771. 20, detail of central muscle scar x 379.1. 22, internal view x 76.0. 23, detail of hinge x 194.8. 21, Paratype, male left valve, RT/SIR/770, external lateral view x 80.7. 24-27, *Xestoleberis* sp. C. 24, 25, Male left valve, RT/SIR/691. 24, external lateral view x 80.0. 25, Male left valve, internal view x 84.4. 26, Female right valve, RT/SIR/692, external lateral view x 76.6. 27, Female carapace, RT/SIR/690, dorsal view x 76.9. 28-30, *Xestoleberis* sp. E. 28, 30, Right valve, RT/SIR/803. 28, internal view x 106.6. 30, detail of central muscle scar x 461.4. 29, Carapace, RT/SIR/802, dorsal view x 91.7.



Mean Dimensions, Honiara Bay

	Length	Height	Width
4 Female C	0.49 (0.48-0.50)	0.30 (0.29-0.31)	0.29 (0.28-0.30)
7 Female LV	0.49 (0.47-0.50)	0.30 (0.29-0.31)	
9 Female RV	0.47 (0.45-0.49)	0.28 (0.26-0.29)	
2 Male C	0.42	0.24, 0.25	0.22
13 Male LV	0.41 (0.39-0.43)	0.25 (0.24-0.26)	
5 Male RV	0.41 (0.40-0.42)	0.23 (0.22-0.24)	
20 A-1 LV	0.37 (0.36-0.39)	0.23 (0.22-0.24)	
20 A-1 RV	0.37 (0.35-0.38)	0.22 (0.21-0.23)	
7 A-2	0.30 (0.29-0.32)	0.19 (0.18-0.20)	

Distribution.—Hartmann, 1978 (Recent eulittoral, Western Australian coast). Hartmann, 1984 (Recent eulittoral, Huahine Island and Rangiroa Atoll). Recent, Pulau Seribu, Java Sea (Watson MS, 1988). Present study samples: 1, 2, 5, 13-17, 19, 29, 32, 56-58, 61, OS5, OS6, Guadalcanal and Shortland islands.

Remarks.—Several species of *Xestoleberis* are rather similar to the present species, in particular *X. maculanitida* sp. nov. The shape of the opaque patches is most useful for distinguishing between these species, but there are also differences in hingement, npc's and rpc's and in the muscle scar pattern. *Xestoleberis maculanitida* sp. nov. is distinguished most readily by its single large, almost nacreous opaque patch immediately posterior to the "Xestoleberis-spot". *Xestoleberis capensis* Müller, 1908, illustrated by Benson and Maddocks (1964) from the Recent of the Knysna Estuary, South Africa does not appear to have opaque patches. All these species can be placed in the third morphological group on the character of the selvage, as described above. The present species seems to be conspecific with *Xestoleberis* sp. XF Maddocks, 1966, which was by far the most abundant species in material from Nosy Be, Northern Madagascar, occurring in all reef environments, washings of algae, grasses, sponges, living corals, dead coral accumulations, carbonate reef sands and intertidal quartz sand. The present species is also unique in the nature of its inner lamella posteriorly: posteroventrally the IM and LOC diverge forming a small cres-

centic vestibulum with short simple and bi- or trifurcate rpcs. The IM and LOC then converge to form a very narrow sinus before becoming subparallel to the OM again.

Xestoleberis maculanitida sp. nov.
(Fig. 4, Nos. 15, 18, Pl. 3, Figs. 9-16)

Derivatio nominis.—L. From the very shiny almost nacreous nature of the single opaque patch immediately posterior to the eye-spot.

Holotype.—Female LV, RT/SIR/757.

Type locality and horizon.—Sample 1,200 feet offshore west of Point Cruz, Honiara Bay, Guadalcanal, Solomon Islands. 15 fathoms. Medium-grained coral sand. Recent.

Material.—330 valves and carapaces, A-3 to adult.

Diagnosis.—A small to medium species of *Xestoleberis*, subrectangular in lateral view with a distinctive, almost nacreous opaque patch immediately posterior to the eye-spot. Selvage in LV strong, peripheral but absent anteroventrally; in RV peripheral antero and posterodorsally becoming more proximal ventrally, with well-developed flange. Hinge antimerodont, elements of equal length, median groove in RV finely locellate. Frontal muscle scar irregularly trefoil, anterior arm divided forming a separate scar; dorsal adductor scar almost divided in half.

Description.—Medium. Moderately thin-shelled, opaque with almost nacreous opaque patch immediately posterior to eye-spot. Female conspicuously larger than male, more tumid posteriorly. Subrectangular in lateral view; subelliptical in dorsal view, Anterior obliquely rounded becoming well rounded anteroventrally; ventral margin gently biconvex. Maximum length well below mid-height in female, subventral in male; maximum height at mid-length; maximum width just posterior to mid-length in female, median in male. Valve surface smooth. Npc's sieve-type. Eye-spot conspicuous, large, glassy. "Xestoleberis-spot" crescentic, just posterior to eye-spot, obscured by opaque patch. Inner lamella wide; crescentic anterior and narrow posteroventral vestibula. Rpc's numerous, straight, most simple, some trifurcate anteriorly and orally. Selvage in LV strong, peripheral but absent anteroventrally; in RV peripheral antero- and posterodorsally, becoming more distal ventrally with well-developed flange. Hinge antimerodont, elements of approximately equal length; RV terminal elements dentate ridges with about 13 ovate teeth, median groove finely locellate. Frontal muscle scar irregularly trefoil anterior arm divided forming a separate scar; dor-

sal adductor scar almost divided in half. Fulcral point a shallow depression between frontal and median 2 adductor scars.

Dimensions.—

Individual Specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/757	0.53	0.32	
Paratype			
Male C, RT/SIR/755	0.44	0.27	0.23
Paratype			
Female C, RT/SIR/756	0.52	0.32	0.29
Female RV, RT/SIR/758	0.51	0.30	
Male LV, RT/SIR/759	0.46	0.28	
Male RV, RT/SIR/760	Broken		
Female RV, RT/SIR/761	0.51	0.31	
Paratype			
Female LV, RT/SIR/762	0.50	0.30	
Male RV, RT/SIR/763	0.45	0.27	
Male LV, RT/SIR/764	0.46	0.28	
Male RV, RT/SIR/765	0.45	0.26	
Female LV, RT/SIR/766	0.51	0.31	

Mean Dimensions

	Length	Height	Width
5 Female C	0.50 (0.49-0.52)	0.32 (0.31-0.33)	0.29 (0.27-0.31)
20 Female LV	0.51 (0.48-0.53)	0.32 (0.29-0.33)	
13 Female RV	0.51 (0.48-0.54)	0.31 (0.29-0.33)	
15 Male LV	0.46 (0.44-0.47)	0.29 (0.28-0.30)	
20 Male RV	0.45 (0.44-0.48)	0.27 (0.25-0.29)	
17 A-1 LV	0.41 (0.38-0.42)	0.25 (0.24-0.26)	
20 A-1 RV	0.40 (0.37-0.41)	0.24 (0.22-0.25)	
30 A-2	0.32 (0.30-0.34)	0.20 (0.18-0.21)	
8 A-3	0.27 (0.26-0.29)	0.17 (0.16-0.18)	

Distribution.—Samples: 1, 2, 13-17, 19, 20, 29, 30, 32, 42, 53, 55, 57, 58, 61, 62, OS3, OS5, OS6 Guadalcanal and Shortland islands.

Remarks.—Within morphological group 3, the present species is most similar to *X. paraporthedlandensis* Hartmann, 1978, but the nacreous opaque patch distinguishes it. *Xestoleberis granulosa* Brady, 1880, (Recent, Australia) differs mainly in that the anterior margin is less broadly rounded.

Xestoleberis honiaraensis sp. nov.

(Fig. 4, Nos. 16, 19, Pl. 3, Figs. 17-23)

Derivatio nominis.—L. With reference to the type locality, Honiara Bay.

Holotype.—Female LV, RT/SIR/768.

Type locality and horizon.—Sample 15, 1,350 feet offshore west of Point Cruz, Honiara Bay, Guadalcanal, Solomon Islands. 13 fathoms. Unconsolidated, medium-grained coral sand. Recent.

Material.—109 valves and carapaces, A-2 to adult.

Diagnosis.—A small to medium species of *Xestoleberis* subrectangular in lateral view with distinctive figure 8-shaped opaque patch over muscle scar area. Hinge hemimerodont. Selvage in LV strong, peripheral but absent anteroventrally, where narrow but well developed flange occurs. Frontal muscle scar trefoil in shape, becoming subdivided into 3 scars.

Description.—Small to medium. Moderately thin-shelled. Translucent with characteristic and consistent opaque patches; large figure 8-shaped patch over muscle scars, ovate patch posteromedianly and at anterior extremity with other smaller, variable ovate patches. Female conspicuously larger than male, more tumid posteriorly. Subrectangular in lateral view; female drop-shaped, male subelliptical in dorsal view. Anterior margin narrowly rounded with apex well below mid-height. Maximum length subventral; maximum height at mid-length; maximum width in posterior third. Valve surface smooth. Npc's sieve-type, flush. Eye-spot small, glassy. "Xestoleberis-spot" small, crescentic, just posterior to eye. Inner lamella wide; wide, crescentic anterior and narrow, crescentic posterior vestibula. Rpc's moderately numerous, approximately 40 anterior canals, complex and branching and 30 posterior canals, majority simple, branching particularly near oral region. Selvage in LV strong, peripheral but absent anteroventrally were narrow but well developed flange present; in RV peripheral orally antero- and posterodorsally, absent around antero- and posteroventral angles. Hinge merodont; RV anterior and posterior terminal elements gently arched, dentate ridges, anterior element with 15, posterior element with 10, rounded teeth, extending short way onto median groove which is smooth in LV.

Central muscle scars a vertical row of 4, dorsal scar dividing vertically, frontal scar trefoil, becoming subdivided into 3 separate scars.

Dimensions.—

Individual Specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/768	0.49	0.31	
Paratype			
Female C, RT/SIR/767	0.48	0.30	0.33
Female RV, RT/SIR/769	0.50	0.32	
Paratype			
Male LV, RT/SIR/770	0.44	0.26	
Female LV, RT/SIR/771	0.50	0.31	
Female RV, RT/SIR/772	0.50	0.30	
Male LV, RT/SIR/773	0.43	0.26	
Paratype			
Male RV, RT/SIR/774	0.42	0.26	

Mean Dimensions

	Length	Height	Width
1 Female C	0.51	0.31	0.32
12 Female LV	0.49	0.32	
	(0.48-0.52)	(0.31-0.33)	
5 Female RV	0.48	0.30	
	(0.47-0.50)	(0.29-0.31)	
5 Male C	0.43	0.26	0.26
	(0.41-0.45)	(0.25-0.27)	(0.24-0.27)
6 Male LV	0.43	0.27	
	(0.42-0.43)	(0.26-0.28)	
10 Male RV	0.42	0.26	
	(0.42-0.43)	(0.25-0.26)	
20 A-1 LV	0.37	0.24	
	(0.36-0.39)	(0.23-0.25)	
20 A-1 RV	0.37	0.23	
	(0.36-0.38)	(0.22-0.24)	
20 A-2	0.30	0.19	
	(0.29-0.32)	(0.18-0.21)	

Distribution.—Recent, Pulau Seribu, Java Sea (Watson MS, 1988) Present study samples: 1, 2, 13-17, 20, 29, 30, 32, 57, 58 Guadalcanal.

Remarks.—The present species is distinctive in that the median element of the LV hinge is smooth and the opaque patches form an 8-shape over the muscle scar area. These characters distinguish it from *X. dentamonile* sp. nov. and *X. maculanitida* sp.

nov., which it most closely resembles. It differs from *X. sp. cf. X. nana* Watson (1988 MS) from the Recent of the Java Sea in that the present species is more strongly arched dorsally and possesses opaque patches.

Specimens of this species from the Java Sea, were described by Watson MS, 1988, as possessing an opaque patch over the central muscle scars which was less conspicuously figure 8-shaped than in the present material.

Xestoleberis intiger sp. nov.

(Fig. 4, Nos. 20, 23, Pl. 2, Figs. 19-25)

1986 *Xestoleberis* sp. Cabioch, *et al.*, p. 28, Pl. 10, Figs. 14-16.

Derivatio nominis.—L. With reference to the absence of opaque patches.

Holotype.—Female LV, RT/SIR/776.

Type locality and horizon.—Sample 1,200 feet offshore west of Point Cruz, Honiara Bay. Guadalcanal, Solomon Islands. 1.5 fathoms. Medium-grained coral sand. Recent.

Material.—133 valves and carapaces, A-3 to adult.

Diagnosis.—A medium species of *Xestoleberis* elongate, subrectangular to subovate in lateral view, strongly inflated in posterior 1/3 in dorsal view; ventral margin with gentle convexity just anterior to oral concavity. No opaque patches. Selvage of LV peripheral antero- and posterodorsally and also orally; absent antero- and posteroventrally. Hinge antimerodont, anterior terminal groove of LV with very strong anti-slip bar. Frontal scar v-shaped.

Description.—Medium. Moderately thick-shelled. Opaque. Female conspicuously larger than male, more tumid posteriorly. Subrectangular to subovate in lateral view; drop-shaped and strongly inflated in posterior 1/3 in dorsal view. Anterior margin narrowly rounded below mid-height. Posterior margin subtruncated. Dorsal margin arcuate in anterior part, straight and sloping posteriorly in posterior part. Ventral margin with gentle convexity just anterior to oral concavity. Maximum length subventral; maximum height at mid-length in RV, just posterior to mid-length in LV; maximum width at posterior third. Valve surface smooth. Npc's sieve-type, small, ovate, flush. Eye-spot large, glassy. "Xestoleberis-spot" inconspicuous, small and crescentic. Inner lamella wide, crescentic anterior and posteroventral vestibula. Rpc's numerous, particularly anteriorly and posteroventrally, simple, straight. Selvage of LV peripheral antero- and posterodorsally

and orally, absent antero- and posteroventrally; of RV peripheral antero- and posterodorsally, becoming more proximal with well-developed flange ventrally. Hinge antimerodont, anterior and posterior terminal elements in RV long, gently arched, dentate ridges with 10 rounded teeth extending short way onto finely locellate median groove; LV complementary with strong antislip bars ventral to terminal grooves. Central muscle scars comprise a vertical row of 4 subovate adductors, dorsal scar kidney-shaped, v-shaped frontal scar.

Dimensions.—

Individual Specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/776	0.47	0.33	
Paratype			
Female C, RT/SIR/775	0.57	0.33	0.37
Female RV, RT/SIR/777	0.54	0.31	
Paratype			
Male RV, RT/SIR/778	0.49	0.27	
Female LV, RT/SIR/779	0.56	0.32	
Female RV, RT/SIR/780	0.57	0.32	
Male RV, RT/SIR/781	0.50	0.28	
Paratype			
Male LV, RT/SIR/782	0.51	0.30	

Mean Dimensions

	Length	Height
5 Female LV	0.56 (0.52-0.57)	0.33 (0.32-0.35)
4 Female RV	0.55 (0.53-0.57)	0.31 (0.29-0.32)
5 Male LV	0.50 (0.49-0.52)	0.30 (0.29-0.31)
3 Male RV	0.50 (0.48-0.51)	0.27 (0.27-0.28)
20 A-1 LV	0.42 (0.38-0.45)	0.26 (0.23-0.27)
16 A-1 RV	0.42 (0.38-0.44)	0.24 (0.22-0.25)
20 A-2	0.34 (0.32-0.36)	0.21 (0.19-0.22)
1 A-3 LV	0.28	0.16

Distribution.—Samples: 1, 2, 13-17, 20, 29, 30, 32, 40, 55, 57, 58, OS5, OS6 Guadalcanal and Shortland islands.

Remarks.—The present species is more inflated laterally than *X. granulosa* Brady, 1880 (Recent, Australia). Within morphological group 3 the present species is most similar to *X. maculanitida* sp. nov., but is more elongate and the anterior margin more narrowly rounded.

Xestoleberis posterotruncata sp. nov.

(Fig. 4, No. 27, Pl. 4, Figs. 1-5)

Derivatio nominis.—L. With reference to the somewhat truncated posterior margin of this species.

Holotype.—Female LV, RT/SIR/785.

Type locality and horizon.—Sample 15, 1,350 feet offshore west of Point Cruz, Honiara Bay, Guadalcanal, Solomon Islands. 13 fathoms. Unconsolidated, medium-grained coral sand. Recent.

Material.—17 valves, A-2 to adult.

Diagnosis.—A small species of *Xestoleberis*, subovate to subrectangular in lateral view with almost straight ventral margin and vertical, somewhat truncated, posterior. Hinge antimerodont, median element the longest. Selvage of LV peripheral antero- and posterodorsally and orally, absent antero- and posteroventrally. Dorsal adductor muscle scar becoming subdivided, frontal scar v-shaped.

Description.—Small. Moderately thick-shelled. Translucent. Female conspicuously larger than male, more tumid posteriorly. Subovate to subrectangular in lateral view; narrow drop shaped in dorsal view. Anterior margin asymmetrically and somewhat angularly rounded, with apex well below mid-height. Posterior somewhat truncated, almost vertical, ventral margin almost straight. Maximum length below mid-height; maximum height subcentral, maximum width at posterior third. Smooth. Npc's sieve-type, ovate, flush. Eye-spot large, glassy. "Xestoleberis-spot" inconspicuous, small, crescentic. Inner lamella wide, crescentic anterior and posterior vestibula. Rpc's numerous, approximately 30 anterior canals, some branching and 30 posterior canals, most simple, branching near oval region. Selvage of LV peripheral antero- and posterodorsally and orally, absent antero- and posterodorsally and orally becoming weak and more proximal with flange antero- and posteroventrally. Hinge antimerodont; RV terminal elements gently arched dentate ridges with about 12 ovate teeth, median element longest, finely locellate. Central muscle scars a vertical row of 4 adductors, dorsal scar subdividing, frontal scar v-shaped.

Dimensions.—
Individual Specimens

	Length	Height
Holotype		
Female LV, RT/SIR/785	0.49	0.31
Paratype		
Female RV, RT/SIR/783	0.46	0.28
Paratype Male RV, RT/SIR/784	0.41	0.24
Male RV, RT/SIR/786	0.40	0.24
Male RV, RT/SIR/787	0.43	0.26
Paratype		
Female LV, RT/SIR/788	0.48	0.30
Male LV, RT/SIR/789	0.42	0.25
A-1 RV	0.38	0.21
A-2 LV	0.35	0.20

Distribution.—Samples: 1, 2, 13-15, 19, 32, 58, OS5, OS6 Guadalcanal and Shortland islands.

Remarks.—The present species has been placed in morphological group 3 with *X. paraporthedlandensis* Hartmann, 1978, and *X. maculanitida* sp. nov. It may be distinguished from these species by the posterior margin, which is more truncated and less inflated in dorsal view, particularly anteriorly, and in the detail of its npc's.

Xestoleberis whittakeri sp. nov.
(Pl. 4, Figs. 6-13)

Derivatio nominis.—L. Named for Dr. J. E. Whittaker, in recognition of his sterling contribution to our knowledge of the genus.

Holotype.—Male RV, RT/SIR/794.

Type locality and horizon.—Sample OS5, coral reefs to the east of Rokuai Island which is off the north-east coast of Shortland Island, Solomon Islands. Coarse-grained coral sand. Recent.

Material.—10 adult valves and carapaces.

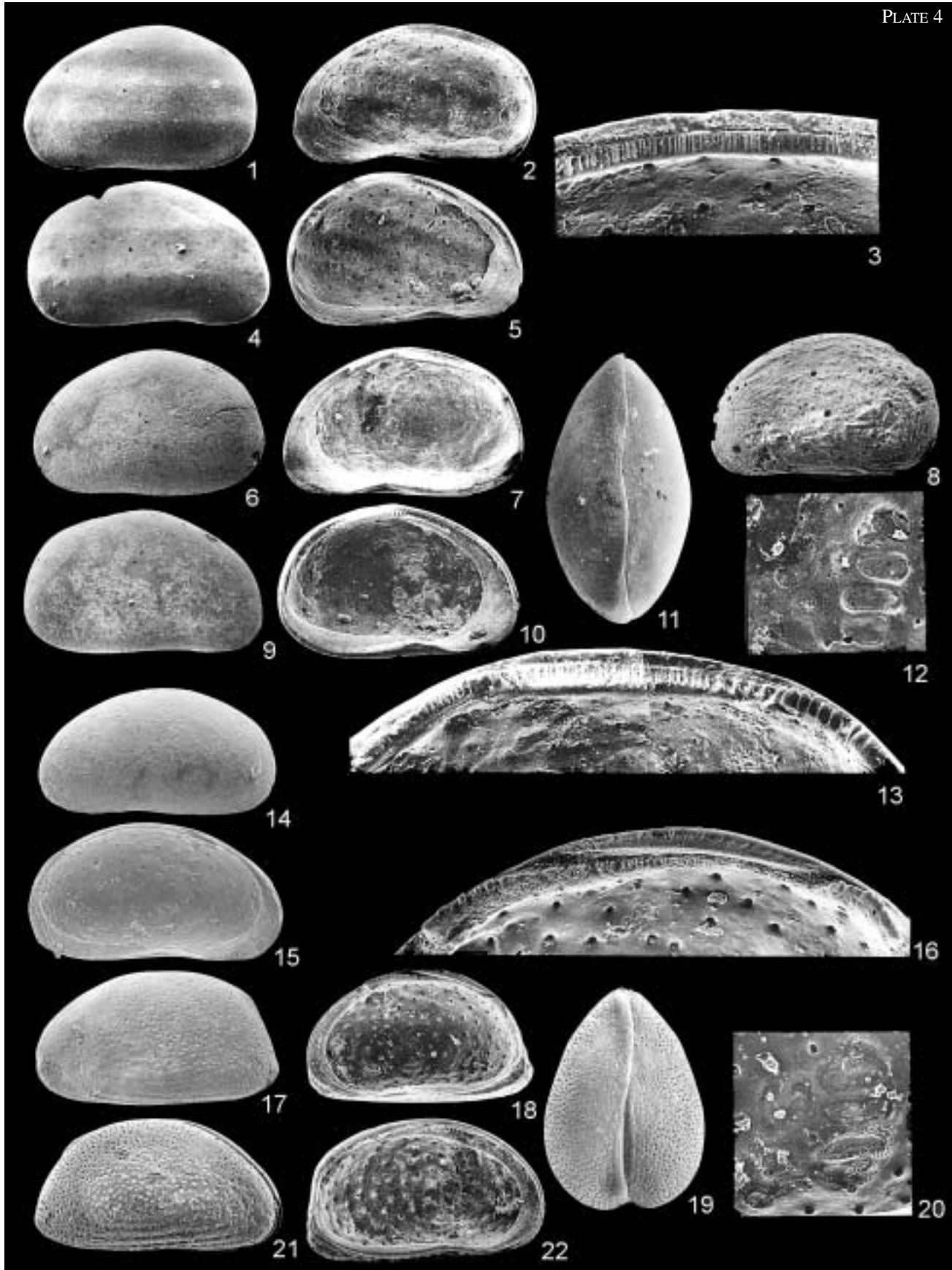
Diagnosis.—A small to medium species of *Xestoleberis*, subovate in lateral view, maximum length subventral. Antimerodont hinge, robust, elements of equal length, median locellate groove of RV deeply etched. Selvage robust, peripheral in LV but absent anteroventrally; subperipheral in RV with a notch present posteroventrally. Dorsal adductor scar trefoil in shape; frontal scar triangular becoming divided dorsally. Fulcral point a large, ovate patch with central depression.

Description.—Small to medium. Moderately thick-shelled. Translucent. Female conspicuously larger, less truncate and tumid posteriorly than male. Subovate in lateral view; female drop-shaped, male elliptical in dorsal view. Anterior and posterior margins similar but posterior slightly more rounded; both with apices below mid-height. Dorsal margin rather strongly arched. Ventral margin biconvex. Maximum length subventral; maximum height at mid-length; maximum width at posterior third in female, subcentral in male. Npc's sieve-type, ovate, flush. Eye-spot

→

PLATE 3—1-5, *Xestoleberis posterotruncata* sp. nov. 1, Holotype, female left valve, RT/SIR/785 external lateral view, x 76.7. 2, 3, Male right valve, RT/SIR/787. 2, internal view x 90.7. 3, detail of hinge x 374.2. 4, Paratype, male carapace, RT/SIR/784, external lateral view x 95.7. 5, Paratype, male left valve, RT/SIR/788, detail of hinge x 79.2. 6-13, *Xestoleberis whittakeri* sp. nov. 6, Male left valve, RT/SIR/792, external lateral view, x 77.1. 7, 12, 13, Holotype, male right valve, RT/SIR/794. 7, internal view x 80.7. 12, detail of central muscle scar x 344.9. 13, detail of hinge x 298.3. 8, Female left valve, RT/SIR/795, external lateral view x 72.5. 9, Paratype, male right valve, RT/SIR/791, external lateral view x 79.9. 10, Male left valve, RT/SIR/793, internal view x 79.6. 11, Paratype, male carapace, RT/SIR/790, dorsal view x 75.8. 14-15, *Xestoleberis* sp. F. 14, Left valve, RT/SIR/808, external lateral view x 109.3. 15, Left valve, RT/SIR/809, detail of hinge x 105.1. 16-22, *Ornatoleberis cordiformis* sp. nov. 16, 18, 20, Holotype, male right valve, RT/SIR/811. 16, detail of hinge x 267.8. 18, internal view x 80.4. 20, detail of central muscle scar x 304.4. 17, Female left valve, RT/SIR/812, external lateral view x 80.1. 19, 21, Paratype, female carapace, RT/SIR/810. 21, dorsal view x 78.8. 21, external lateral view of right valve x 76.9. 22, Male left valve, RT/SIR/814, internal view x 81.9.

PLATE 4



inconspicuous. “*Xestoleberis*-spot” small, crescentic. Inner lamella wide anteriorly, narrower ventrally and posteriorly; large crescentic anterior and narrower posterior vestibula. Rpc’s numerous; approximately 40 anteriorly, anteroventrally complex and polyfurcate, and 25 posterior canals, majority simple, some branching near oral region. Selvage in LV robust, peripheral except anteroventrally where absent; in RV peripheral antero- and posterodorsally and orally, subperipheral and weak antero- and posteroventrally with narrow flange; small notch present just above posteroventral angle in RV only. Hinge antimerodont, elements of approximately equal length; RV terminal elements with 12-14 rounded teeth, median element a deeply etched locellate groove; LV terminal elements bounded ventrally by robust anti-slip bars. Central muscle scars comprise a vertical row of 4 adductors, dorsal scar trefoil; frontal scar triangular, dividing dorsally. Fulcral point a large, ovate patch with central depression, between frontal and median adductors scars.

Dimensions.—
Individual Specimens

	Length	Height	Width
Holotype			
Male RV, RT/SIR/794	0.48	0.28	
Paratype			
Male C, RT/SIR/790	0.49	0.31	0.26
Paratype			
Male RV, RT/SIR/791	0.48	0.28	
Paratype			
Male LV, RT/SIR/792	0.48	0.30	
Male LV, RT/SIR/793	0.49	0.30	
Female LV, RT/SIR/795	0.51	0.31	

Distribution.—Sample: OS5 Shortland Island.

Remarks.—The present species belongs to morphological group 3. It is similar to *X. paraporthedlandensis* Hartmann, 1978. Both species possess similar selvage characters particularly the posteroventral notch in the RV. However, they differ in details of shape and the present species completely lacks opaque patches.

Xestoleberis sp. C

(Fig. 4, Nos. 21, 24, Pl. 3, Figs. 24-27)

Material.—2 valves and 1 carapace.

Diagnosis.—Small. Subovate to subtriangular in lateral view. Anterior margin rather narrowly rounded with apex below mid-height. Posterior subtruncated.

Dorsal margin strongly convex, almost umbonate. Ventral margin markedly biconvex about strong oral incurvature. Selvage as in *X. whittakeri* sp. nov. Hinge hemimerodont.

Dimensions.—

Individual Specimens

	Length	Height	Width
Female C, RT/SIR/690	0.49	0.31	0.26
Male LV, RT/SIR/691	0.45	0.24	
Female RV, RT/SIR/692	0.47	0.27	

Distribution.—Sample: OS6 Shortland Island.

Remarks.—The present species is placed in morphological group 3 with *X. paraporthedlandensis* Hartmann, 1978, and *X. maculanitida* sp. nov. of the present study. This species, however, is distinctive in that the median element of the hinge is smooth, the anterior flange of the RV is very poorly developed and the posterior margin more narrowly rounded.

Xestoleberis sp. D.

(Fig. 4, Nos. 22, 25, Pl. 2, Figs. 26-29)

Material.—5 adult valves.

Diagnosis.—Small. Elongate subovate in lateral view with regularly convex dorsal margin and biconvex ventral margin. Anterior margin tightly rounded with subventral apex. Posterior margin well rounded, especially in LV. Hinge hemimerodont. Frontal scar trefoil; dorsal adductor v-shaped.

Dimensions.—

Individual Specimens

	Length	Height
RV, RT/SIR/694	0.42	0.21
LV, RT/SIR/695	0.43	0.23
RV, RT/SIR/696	0.44	0.23

Distribution.—Samples: 29, 32, OS6, Guadalcanal and Shortland islands.

Remarks.—Like *X. paraporthedlandensis*, the present species belongs to morphological group 3. It differs from the latter species in that the anterior and posteroventral flange is not developed in the RV; the median element of the hinge is smooth and the terminal elements are comparatively short. Additionally, the dorsal margin is strongly and evenly arched in both valves and the anterior and posterior margins more narrowly rounded. This species also occurs in the Java Sea (Watson

MS, 1988). This species differs from *X. polys* Whatley *et al.* (2000) from Easter Island and the Pitcairn Group (Whatley *et al.*, in press) in its slightly smaller size and its rather more rounded posterior margin.

Xestoleberis sp. E

(Fig. 4, No. 29, Pl. 3, Figs. 28-30)

Material.—1 adult carapace and 1 adult RV.

Diagnosis.—A very small to small, very elongate subelliptical species of *Xestoleberis* with strong overlap of LV over RV anteriorly.

Dimensions.—

Individual Specimens

	Length	Height	Width
C, RT/SIR/802	0.40	0.17	0.21
RV, RT/SIR/803	0.38	0.16	

Distribution.—Sample: OS6 Shortland Island.

Remarks.—The present species is distinctive in this study by its very elongate, subelliptical shape in lateral view. In dorsal view the LV appears to strongly overlap the RV on the anterior margin. The present species is similar to *X. briggsi* McKenzie, 1967, from the Recent off southern Australia, but more elongate.

Xestoleberis sp. F

(Fig. 4, No. 28, Pl. 4, Figs. 14, 15)

Material.—3 adult valves.

Diagnosis.—A very small species of *Xestoleberis*, elongate subovate in lateral view and with a microcostate ornament of very fine anastomosing riblets which impart a rough appearance to the valve surface. Hinge hemimerodont.

Dimensions.—

Individual Specimens

	Length	Height
LV, RT/SIR/808	0.35	0.19
LV, RT/SIR/809	0.39	0.22

Distribution.—Samples: 14, 17 Guadalcanal.

Remarks.—The present species is somewhat similar in morphology and shape to *X. paraporthedlandensis* Hartmann, 1978, but is conspicuously smaller by 0.20 mm. It is somewhat unusual in that the median element to the hinge is relatively very long, gently arched and smooth.

Genus *Ornatoleberis* Keij, 1975

Ornatoleberis cordiformis sp. nov.

(Fig. 4, No. 26, Pl. 4, Figs. 16-22)

Derivatio nominis.—L. With reference to the rather heart-shape of the carapace in dorsal view.

Holotype.—Female LV, RT/SIR/814.

Type locality and horizon.—Sample OS5, on coral reefs to the east of Rokuai Island, off the north-east coast of Shortland Island. Coarse-grained coral sand. Recent.

Material.—40 valves and carapaces, A-2 to adult.

Diagnosis.—A species of *Ornatoleberis* distinctively heart-shaped in dorsal view; subpentagonal to subrhomboidal in lateral view. Greatest length well below mid-height. Valve surface ornamented by many small, deep puncta.

Description.—Small to medium. Thick-shelled, opaque. Female conspicuously larger than male. Subpentagonal to subrhomboidal in lateral view; heart-shaped in dorsal view, Anterior well rounded anteroventrally, posterior blunt, straight, gently sloping, overhung posteroventrally by ventrolateral tumidity. Maximum length well below mid-height; maximum height at mid-length; maximum width at posterior third. Valve surface densely covered with many small, deep puncta. Npc's numerous, small, simple. Eye-spot conspicuous, small, glassy. "Xestoleberis-spot" inconspicuous, small. Inner lamella moderately wide, crescentic anterior and narrower posterior vestibula. Rpc's numerous, particularly anteriorly and posteroventrally, simple straight. Strong peripheral selvage in both valves except orally and anteroventrally in RV. Hinge anti-merodont, RV terminal elements dentate ridges, short but high; median element a straight finely locellate, groove. Central muscle scars comprise a vertical row of 4 oblong adductors and v-shaped frontal scar.

Dimensions.—

Individual Specimens

	Length	Height	Width
Holotype			
Female LV, RT/SIR/814	0.54	0.32	
Paratype			
Female C, RT/SIR/810	0.52	0.32	0.33
Male RV, RT/SIR/811	0.46	0.27	
Male RV, RT/SIR/812	0.49	0.28	
Paratype			
RV, RT/SIR/815	0.47	0.27	
Paratype			
LV, RT/SIR/816	0.47	0.26	

Mean Dimensions

	Length	Height
7 Female LV	0.54 (0.51-0.55)	0.33 (0.32-0.34)
13 Male LV	0.47 (0.46-0.50)	0.27 (0.26-0.29)
5 A-1 LV	0.41 (0.39-0.42)	0.24 (0.23-0.25)
3 A-1 RV	0.40 (0.40-0.41)	0.24 (0.23-0.24)
8 A-2	0.34 (0.32-0.36)	0.19 (0.19-0.21)

Distribution.—Samples: 1, 2, 13, 17, 57, OS5, OS6 Guadalcanal and Shortland islands.

Remarks.—The type species *Ornatoleberis morkhoveni* Keij, 1975, is more strongly ornamented and more quadrate in shape. *Ornatoleberis pustulatus* Keij, 1975, although similar in shape in lateral view, is more strongly reticulate with pustulae. Similarly, *O. parva* Hartmann, 1981, is more strongly reticulate than the present species. *Ornatoleberis clanoculata* (Bate *et al.*, 1981) from the Galapagos Islands is not heart-shaped in dorsal view and has narrower end margins, although the ornament is similar.

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OBITUARY

PROFESSOR MIKLOS KEDVES (1933-2003)



With great regret we received at the Paleontology Department of the Geology Faculty of the Complutense University at Madrid the news of the demise of Prof. Miklos Kedves, "Research Councillor" of the Botany Department of the "Josef Attila" University at Szeged (Hungary), city in which he was born on March 1933.

The decease took place the 6th of November 2003, a few days after leaving our Laboratory, where we were carrying on research work on Cretaceous materials, in the context of the research project "Determination of the biodiversity of Cretaceous floras in the Andean Range and the Southern Edge of the Guadarrama Sierra (Madrid)", funded by the Science and Education Ministry of Spain, within the framework of the Programme of Scientific Cooperation with Latin-America, in which he was taking part as a specialist in palynology, although the exact date and circumstances of his death were not known to us till July 2004.

His scientific career was wide and varied, including several fields and spreading out to many countries. He received his Master in Biology-Chemistry in 1955 and his PhD, with the mark of "*summa cum laude*", in 1958 from the University of Szeged, appointed Assistant Professor of Biology in 1963 and member of the Hungarian Academy of Sciences in 1974.

I met Prof. Miklos Kedves for the first time in 1986, with occasion of the IV Symposium on Palynology, held at Salamanca (Spain), to which I had submitted a paper on the finding of *Classopollis classoides* (Pflug) Pocock and Jansonius in Upper Cretaceous levels of the Madrid province. The presence of microcones containing pollen forms was of great interest to him, and through talks held during the Symposium, we agreed on the forms and aspects that we believed should be followed to reach reliable results in Paleobotany.

Since 1989 we exchanged our publications without interruption, and we invited him several times to visit the beds of the Southern Edge of the Guadarrama Sierra. Reciprocally, we received several invitations from the Josef Attila University.

In 1989 Prof. Kedves took part in the II European Conference on Paleobotany organised by the Paleontology Department of the Complutense University at Madrid. Dr. Kedves opened the conference with the lecture "New trends in Micropaleontological researches". During his frequent visits at Madrid he delivered several lectures.

His research papers were published in many countries, his collaborations with scientists of Spain, France and Portugal being very strong.

Dr. Kedves published 474 papers on several fields, being outstanding those related to Ultrastructures, current Botany, Paleobotany and Palynology.

The Hungarian Academy of Sciences and the Spanish Council for Scientific Research funded joint research projects and stays within the framework of the Bilateral Agreements between Spain and Hungary.

As a consequence of our collaboration a total of 8 papers were published in Spanish and Hungarian journals and some results of our joint research were submitted to several Symposia of the APLE (Spanish Speaking Palynologists Association).

Since 1991, until his decease, he was the editor of the journal "Plant Cell Biology and Development", of which 16 volumes were published. Several papers have been published there from members of the Paleobotany and Palynology research Unit of the Geology Faculty at Madrid (G. Almendros, C. Álvarez Ramis, T. Fernández Marrón, P. Clemente, P. Gómez Porter and N. Lamarti), and many of them counted with the collaboration of Dr. Kedves. Some joint research works on Cretaceous materials of the Southern Edge of the Guadarrama Sierra were stopped with his death, being unable of recovering some data and materials.

The close friendly relationship which joined us and his scientific generosity make his loss to be irreparable, although his memory remains indelible with us.

Concepción Álvarez Ramis

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INTERNATIONAL SCHOOL ON PLANKTONIC FORAMINIFERA

5th COURSE

EOCENE PLANKTONIC FORAMINIFERA: AN UPDATE
OF TAXONOMY, BIOSTRATIGRAPHY AND PHYLOGENETIC
RELATIONSHIPS

Perugia, 20-24 February 2006

Prof. Isabella PREMOLI SILVA
University of Milano (Italy)

With the collaboration of Dr. Maria Rose Petrizzo (University of Milano)

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