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Pantropical palynomorphs in the Eocene of the Malaguides (Betic Range, Southern Spain)

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Resumen

Las arcillas negras situadas en las proximidades de la Factoría Cementos Harania suministraron un conjunto palinológico de edad Cuisiense Superior-Luteciense Inferior. Cuatro muestras presentaron contenido esporopolínico. El conjunto palinológico se caracteriza por la presencia de los géneros *Proxapertites* (Palma), *Leiotriletes* (Schizaeaceae) y *Granulatisporites* (Pteridaceae), junto con *Diporoconia* (Palma) y *Botryococcus* (Algae). En total se han identificado 99 taxones (84 en este estudio, y 15 previamente citados para la misma localidad). El conjunto fósil se diferencia de aquellos encontrados en el NW de Europa y en el NE de España por presentar un elevado número de ejemplares de *Proxapertites* y la ausencia de otros taxones, como el género-forma *Spinizonocolpites* (actual *Nypa,* Palma) y Taxodiaceae. El estado de conservación de *Proxapertites* varía de unas especies a otras, así como en las distintas muestras estudiadas. Las asociaciones palinológicas confirman la existencia de un clima tropical-subtropical cálido y húmedo semejante al que se infiere tras el estudio de otras asociaciones europeas de la misma edad. Los taxones de tipo tropical-subtropical alcanzan un valor máximo de 96%, mientras que los de tipo templado no sobrepasan el 4%. Las características litológicas y palinológicas indican condiciones de sedimentación bajo un clima cálido y húmedo en un medio cenagoso de un pantano litoral dulceacuícola con pequeños canales fluviales, que posiblemente tuvo una conexión esporádica con el mar. Los materiales del afloramiento de Harania se despositaron en una zona litoral del Tethys occidental que presentaba corrientes oceánicas cálidas procedentes del Este. De forma contraria, en las zonas litorales del Noroeste de Europa y de España, ambas localizadas en el litoral Atlántico, las corrientes oceánicas cálidas tenían un origen distinto.

Palabras clave: Palinomorfos pantropicales, *Proxapertites*, Eoceno temprano, complejo Maláguide, Málaga, Sur de España, Tethys occidental

Abstract

A palynological assemblage of Upper Cuisian-Lower Lutetian age was found in black clays near the Harania Cement Factory (Málaga, SE Spain). Four palynological productive samples were obtained. That palynological assemblage is dominated by the fossil form-genus *Proxapertites* (Palm), *Leiotriletes* (Schizaeaceae), *Granulatisporites* (Pteridaceae) joined with *Diporoconia* (Palm), among many others, and with green algae *Botryococcus.* The four samples contained 99 taxa (84 taxa were identified in this paper and additional 15 taxa were cited previously at the same locality). This assemblage differs from that found in NW Europe and NE Spain by the high number of speciments of *Proxapertites* and the absence of other taxa like fossil form-genus *Spinizonocolpites* (actual genus *Nypa,* Palm) and Taxodiaceae. The preservation of *Proxapertites* changes according to the species and samples. The assemblage confirms warm, wet, tropical-subtropical climate as the remainder of Europe in the same age. The tropical-subtropical taxa reach a maximum of 96%, while the temperate taxa does not exceed four percent. The lithological and palynological features confirm deposition under warm and wet climate in a coastal freshwater pond within a marshy environment, in which flowed small fluvial channels, that had possibly a sporadic connection with normal marine environment. The Harania outcrop was located in littoral zones of the Western Tethys

Ocean with warm oceanic circulations coming from Orient, whereas littoral zones of NW Europe and NE Spain, both located in the littoral Atlantic, also had warm oceanic circulations but of different origin.

Keywords: Pantropical palynomorps, *Proxapertites*, Early Eocene, Malaguide complex, Málaga, South Spain, Western Tethys

1. INTRODUCTION

During the stratigraphic study of Meso-Cenozoic rocks of the Malaguide Complex of the Betic Cordillera, southern Spain (Fig. 1), one of us (A.M.A.) collected four samples for palynological analysis in an outcrop at the Harania Cement Factory near Málaga. In 1996, Kedves, *et al.*, registered *Proxapertites* for the first time in Spain, but they published only the sporomorphs of European type. In 2004, the samples were prepared again, and the full palynoflora is presented here. The flora has several taxa of a typical tropical distribution.

Few contributions exist about the Eocene palynology of Spain. Solé de Porta & Porta (1984) published a summary of palynological data concerning the Cenozoic of Spain. Busquets *et al.* (1986), in a paper on the sedimentary environments and micropaleontology of different formations of Early Lower Lutetian age, gave a palynological assemblage that suggested a warm and wet climate. These formations are located between Sant Jaume Frontanyá and Ripoll (Barcelona). Alvarez *et al.* (1993) gave a list of palynomorphs found in the Margas de Vic Formation (Barcelona) of Bartonian age. Cavagnetto & Anadón (1995, 1996) studied a palynological mangrove assemblage that suggests warm climate conditions in the Bartonian of Ebro Basin. All localities that have been studied are placed along the shoreline of a gulf of Atlantic Ocean during the Eocene (Pujalte *et al.*, 2002). Similar palynological assemblages have been found in Western Europe.

2. GEOLOGICAL SETTING

The Betic Cordillera is the westernmost alpine chain, and it outcrops along the southern Iberian peninsula (Fig. 1). It is geologically divided in External, Flysch and Internal Zones. The Internal Zones are made of a tectonic pile of three nappe complexes named, from bottom to top: Nevafilabride, Alpujarride and Malaguide, plus a group of Frontal Units (Figure 1). The area studied is located in the quarries

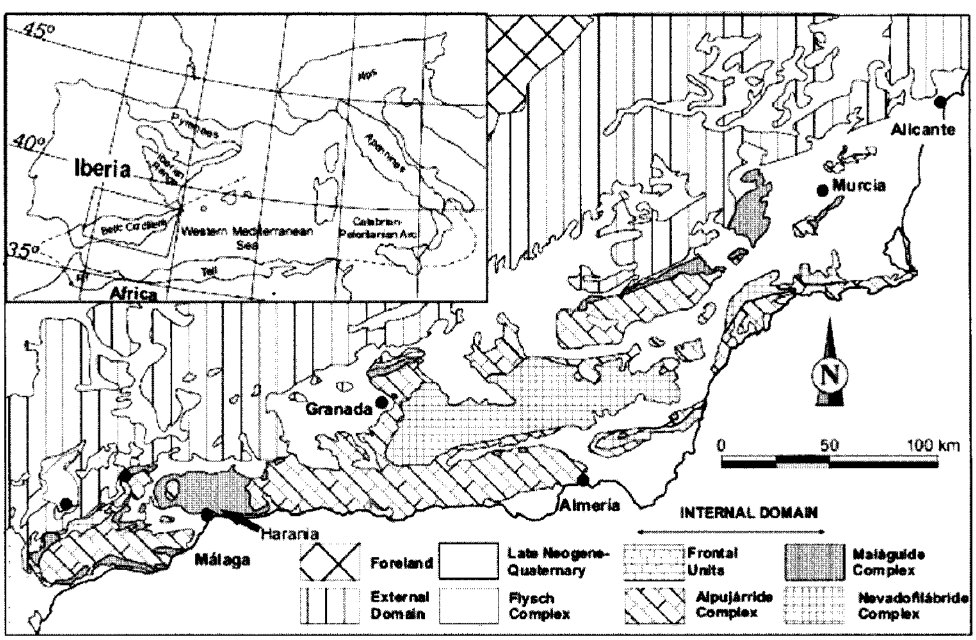


Figure 1. Geological sketch of the Betic Cordillera, with location of the Harania outcrop.

around the Harania Cement Factory near Málaga, and belongs to the Malaguide Complex. This outcrop was first studied by Azema (1961), is structurally very complex (Serrano *et al.*, 1995) and, in several outcrops its Meso-Cenozoic succession is stratigraphically overturned. A more comprehensive description of the stratigraphy of the Malaguide Complex and of the geology of the region can be found in Martín-Algarra (2004) and Serrano *et al.* (1995).

2.1 Stratigraphy of the Harania outcrop and sample location

In spite of the severe structural deformation of the area, which hampers obtaining any continuous complete Paleogene section, correlation of several stratigraphic sections, measured in different outcrops, allows reconstructing the synthetic stratigraphy reproduced in Figure 2. Eocene sediments comprise mainly limestones with *Alveolina* (Azema, 1961: *Alveolina oblonga* d'Orbigny 1826, *Alveolina* sp. aff. *fornasinii* Checchia Rispoli, 1909, *Alveolina sicula* Di Stefani, 1951), overlaid by white marls and micritic limestones with molluscs, charophytes and milliolids, which also include some thin layers of black mudstones. The four palynological samples were collected in these black mudstones, in an outcrop exposed within the main quarry just north of the cement factory, where the stratigraphic succession is overturned. Samples S-65 (stratigraphically lower) and S-66 were taken in the eastern sector, and a limestone bed with *Alveolina* and miliolids lies in between. Samples S-68 and S-67 were collected in higher stratigraphic levels of the western sector, closed to gastropod-rich limestones. Both sectors are about 60 m apart from each other.

3. MATERIALS AND METHODS

Four samples were treated for palynological investigations. All samples were collected in black mudstone sediments in an outcrop exposed in Harania Cement Factory.

The samples were treated with Hidrochloric acid (HCl) and Hydrofluoric acid (HF) without oxidation. Two hun-

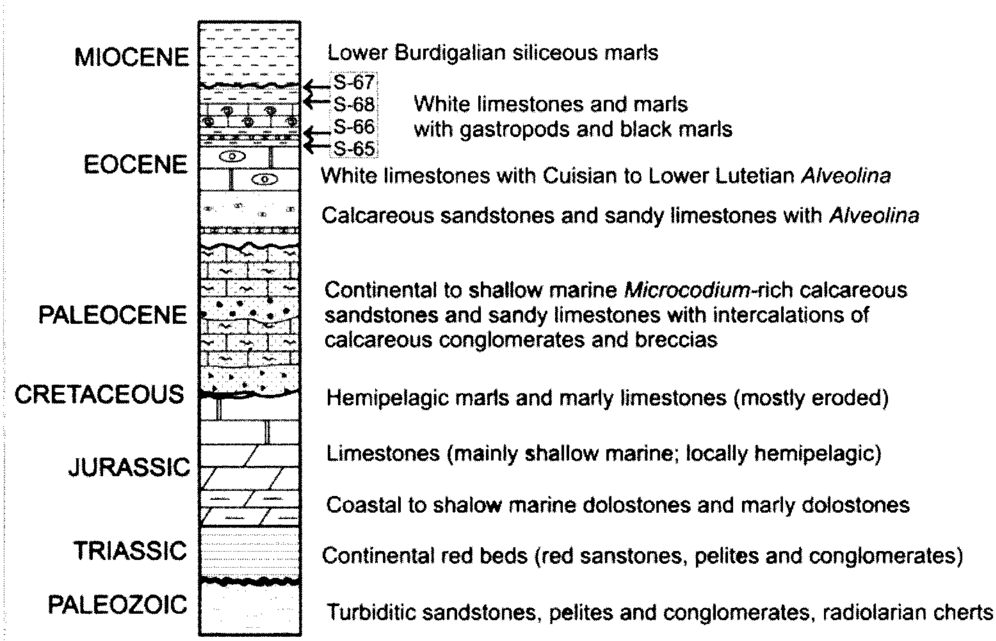


Figure 2. Synthetic stratigraphy of the Malaguide Complex in the Harania Cement Factory area (not to scale), with the approximate stratigraphic position of the studied samples.

dred grains were counted per sample and percentages were then calculated.

4. RESULTS

The Palynological assemblage is characterized by a high number of the tropical-subtropical specimens whereas the temperate specimens are less numerous. The four samples contained 99 identified taxa. In this paper, 84 taxa were identified (Table 1). An additional 15 taxa were cited by Kedves *et al.* (1996) and were not found in this study: *Foveotriletes* sp., *Punctatisporites* sp., *Triplanosporites sinomaxoides* Krutzsch, 1962, *Verrucingulatisporites* sp., *Pinus* sp., *Podocarpidites* sp., *Cupuliferoipollenites quisqualis* Potonié) Potonié, 1960, *Intragranulitricolporites tumescens* (Kedves) Kedves, 1978, *Intragranulitricolporites porasper* (Pflug) Kedves, 1978, *Platycariapollenites shandongensis* Ke and Shi, 1978, *Platycariapollenites miocaenicus* Nagy, 1969, *Plicatopollis* cf. *plicatus* (Potonié) Krutzsch, 1962, *Polycolpites* sp., *Subtriporopollenites sympaticus* (Botscharnikova) Kedves, 1970, *Tetracolporopollenites obscurus* Pflug and Thomson, 1953. Percentages of those species reported by Kedves *et al.* (1996) were not taken into account in this analysis.

The most abundant taxa are *Proxapertites, Leiotriletes, Granulatisporites,* and *Diporoconia.* The remainder of the Angiospermae taxa are diverse but with few specimens, most of them present in the Lower and Middle Eocene of Europe. *Proxapertites* is the most important form-genus of the palynological assemblage.

Up to now, it has been occasionally recorded in Europe but always in low percentage. Kedves (1968) found two grains of *Proxapertites operculatus* in the Ilerdian of the Paris region. The same author in 1988 found this taxon in Hungary. The first record of *Proxapertites* in Austria corresponds to Klaus (1987). Zetter *et al.* (2001) report low percentages (4%-8%) of *P. operculatus* in the Lower Eocene of Austria. Kedves *et al.* (1996) registered high percentages of *Proxapertites* in the Lower-Middle Eocene from Harania (Málaga, Spain). However, the Harania assemblage is distinctive and differs from other known assemblages of the European Eocene by the presence of three species of *Proxapertites (P. operculatus, P. psilatus* and *P. malagensis),* and by their high abundance (4.5% to 58.5%). Figure 3 represents the percentage distribution of Ferns, Gymnosperms, Angiosperms and *Botryococcus* . There is high spore abundance in sample S-65 (Fig. 3).

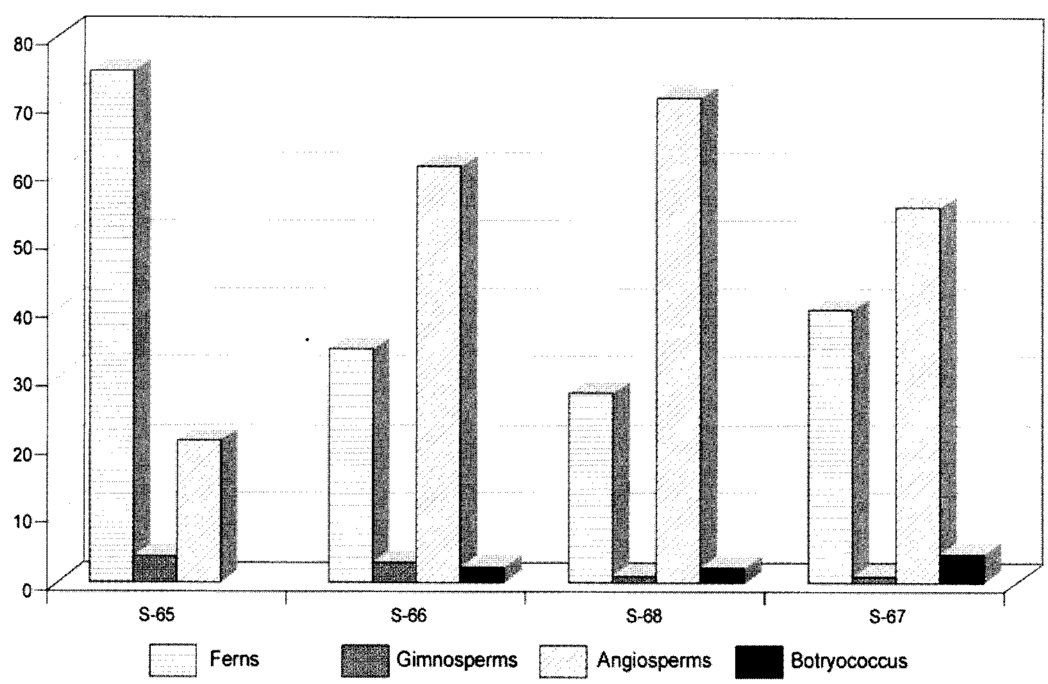


Figure 3. Distribution in percentage of Ferns, Gimnosperms, Angiosperms and *Botryococcus* Groups in every sample.

TAXA	S-65	S-66	S-68	S-67
Leiotriletes adriennis (Potonié and Gelletich 1933) Krutzsch 1959		*	*	*
Leiotriletes microadriennis Krutzsch 1959	*	*	*	*
Leiotriletes maxoides Krutzch 1962		*	*	
Cicatricosisporites cf. *triangulus* Kedves 1973		*		
Monoleiotriletes martinelli Kedves, Solé de Porta and Martín-Algarra, 1996	*	*	*	
Maculatisporites ibericus Kedves, Solé de Porta and Martín-Algarra 1996		*	*	
Maculatisporites eocenicus Kedves, Solé de Porta and Martín-Algarra 1996		*		
Birretisporites elsikii (Frederiksen 1973) Kedves 1995			*	
Birretisporires sp.		*	*	
Granulatisporites luteticus (Krutzsch 1959) Frederiksen 1980	*	*	*	*
Polypodiaceoisporites minor Kedves 1961				*
*Polypodiaceoisporites potoniei (*Potonié and Gelletich 1933) Kedves 1961				*
Polypodiaceoisporites brevisculptatus Kedves 1973		*		
Polypodiaceoisporites bauxitus Kedves and Ráskosy 1965		*		
Polypodiaceoisporites sp. 1	*	*		*
Polypodiaceoisporites sp. 2		*		
Bicingulispora cf. *concentrica* Frederiksen 1983				*
Bicingulispora sp.		*		
Undulozonosporites microundulus Kedves 1974		*		*
Gleicheniidites circinidites (Cookson 1963) Brenner 1963		*		
Gleicheniidites delcourti Doring 1965		*		
Gleicheniidites sp. 1		*		
Gleicheniidites sp. 2		*		
Verrucatosporites saalensis Krutzsch 1959		*		
Reticulosporis cf. *gracilis* Krutzsch 1957		*		
Echinatisporis sp. 1			*	
Echinatisporis sp. 2			*	
cf. *Taurocusporites*		*		
Stereisporites khargaensis Kedves 1986		*		
Stereisporites cf. *divisistereoides* Krutzsch 1959		*		
Stereisporites sp.		*	*	*
Trilete indet.		*	*	*
Equisetosporites multicostatus (Brenner 1963) Norris 1969		*		
Ephedripites sp.		*	*	
Pityosporites labdacus (Potonié 1931) Thomson and Pflug 1953		*		
Pityosporites sp.	*	*		*
Cycadopites cf. *lusaticus* Krutzsch and Sontag 1970		*	*	
Cycadopites cf. *magnus* Herbst 1965		*		
Cycadopites sp. 1		*		
Cycadopites sp. 2		*		
Arecipites sp. 1		*		
Arecipites sp. 2		*		*
Arecipites sp. 3		*		
Monocolpopollenites tranquillus (Potonié 1934) Thomson and Pflug 1953		*		*
Trichotomosulcites granulatus Couper 1953		*		
Proxapertites operculatus (Van der Hammen 1954) Van der Hammen 1956	*	*	*	*

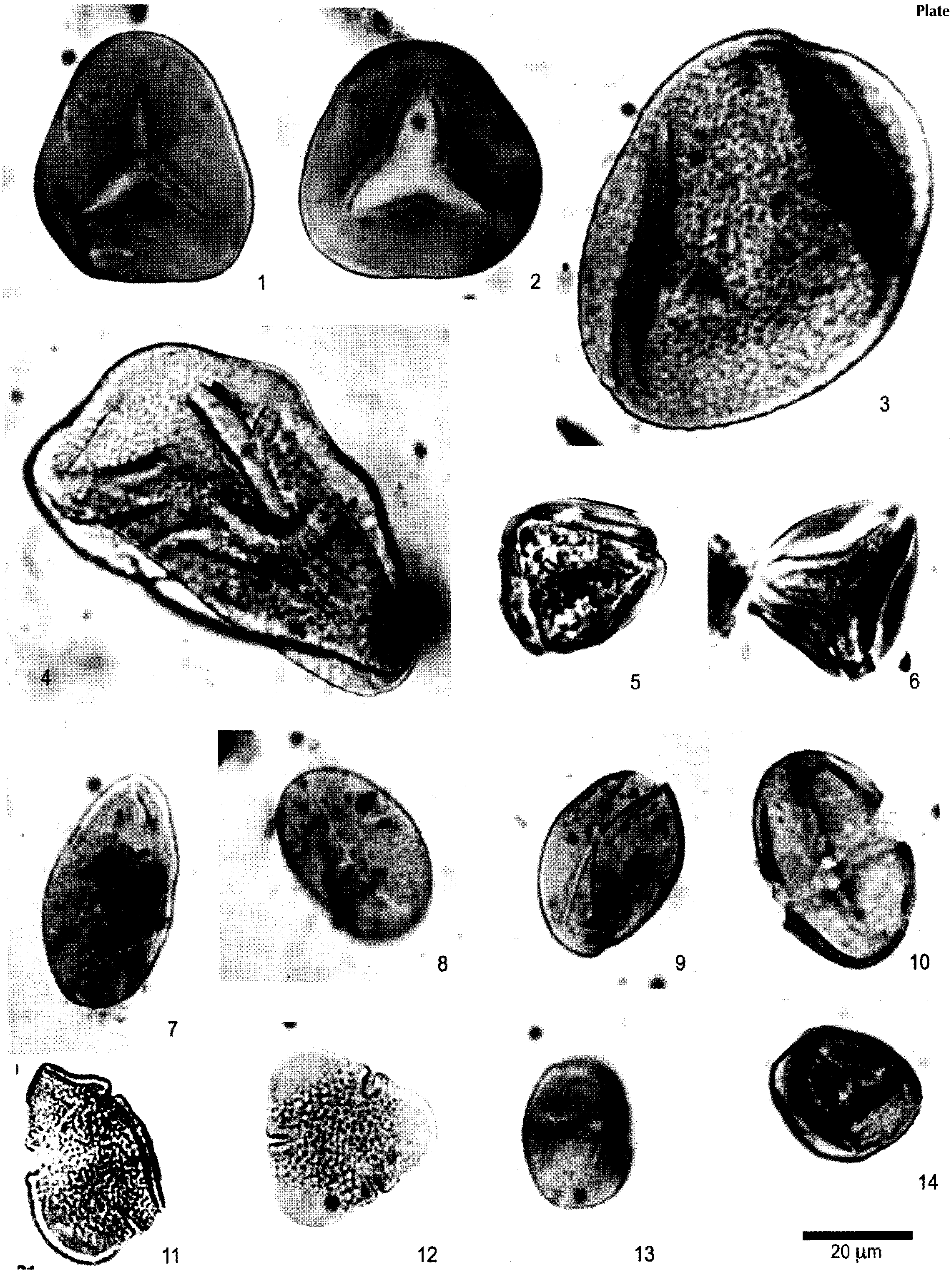
Table 1. Palynomorph distribution in samples from the Harania Cement Factory.

TAXA	S-65	S-66	S-68	S-67
Proxapertites psilatus Sarmiento 1992		*	*	*
Proxapertites malaguensis nov. sp.		*	*	*
Diporoconia iszkaszentgyoergyi (Kedves 1965) Frederiksen, Wiggins, Fergusen, Dransfield and Ager 1985		*	*	*
Liliacidites sp.		*		
Milfordia minima Krutzsch 1970		*		*
Racemonocolpites sp.				*
Retimonocolpites sp.		*		
Ilexpollenites margaritatus (Potonié 1931) Thiergart 1937		*		
Bombacacidites aff. *gonzalezii* Jaramillo and Dilcher 2001	*		*	
Bombacacidites sp.		*		
Triporopollenites robustus Pflug 1953	*	*		*
Triporopollenites constans Takahashi 1961			*	*
Cupuliferoidaepollenites libarensis (Thomson in Potonié, Thomson and Thiergart 1950) Potonié 1960		*	*	
Cupuliferoidaepollenites sp.				*
Compositoipollenites rizophorus (Potonié 1934) Potonié 1960		*		*
Subtriporopollenites subporatus Krutzsch 1961			*	
Subtriporopollenites magnoporatus (Thomson and Pflug 1953) Krutzsch 1961			*	*
Subtriporopollenites facilis (Botscharnikova 1960) Kedves 1970			*	
Subtriporopollenites sp.			*	*
Caryapollenites sp.		*		*
Platycaryapollenites ferreri de Porta, Kedves, Solé de Porta and Civis 1985	*	*		*
Plicatopollis sp.	*			
Labraferoidaepollenites intermedius Gladkova 1965		*	*	
Plicapollis pseudoexcelsus (Krutzsch 1958) Krutzsch 1961		*	*	*
Polycolporopollenites sp. 1			*	
**Polycolporopollenites* sp. 2			*	
Tetracolporopollenites sapotoides Pflug and Thomson 1953			*	
Tetracolporopollenites megadolium (Potonié 1934) Ollivier-Pierre 1980				*
Tetracolporopollenites hungaricus Kedves 1965	*			
Tetracolporopollenites sp. 1		*	*	
Tetracolporopollenites sp. 2			*	
Tetracolporopollenites sp. 3			*	*
Pentapollenites laevigatus Krutzsch 1962	*		*	*
Intratriporopollenites microreticulatus Mai 1961		*	*	
Rhoipites marcodurensis (Pflug and Thiergart 1953) nov. comb.		*		
Botryococcus sp.		*	*	*
Operculodinium sp.		*		*

Table 1. (continued) Palynomorph distribution in samples from the Harania Cement Factory.

Plate 1. *1–2. Leiotriletes microadriennis* Krutzsch, 1959; *3–4. Granulatispories luteticus* (Krutzsch) Frederiksen, 1980; *5. Polypodiaceoisporites minor* Kedves, 1961; 6. *Polypodiaceoisporites brevisculptatus* Kedves, 1973; *7–8. Arecipites* sp.; 9. *Monocolpopollenites tranquillus* (Potonié) Thomson & Pflug, 1953; *10. Tetracolporopollenites megadolium* (Potonié) Ollivier-Pierre, 1980; *11. Bombacacidites* sp.; *12. Bombacacidites* aff. *gonzalezii* Jaramillo & Dilcher, 2001; *13. Tetracolporopollenites sapotoides* Pflug & Thomson, 1953; *14. Polycolporopollenites* sp.

Plate 1



Among the tropical-subtropical species, the following taxa are characterized by high abundances.

Genus *Leiotriletes* Naumova 1939 ex Potonié & Kremp, 1951

Type species.- *Leiotriletes sphaerotriangulus* (Loose) Potoné & Kremp, 1995

Leiotriletes microadriennis Krutzsch, 1959
(Plate 1, Figs. 1-2)

The specimens correspond with the type by their shape, size, sculpturing psilate and a thick exine. This taxon is very abundant and present in all samples. The genus *Leiotriletes* is related to modern genus *Lygodium* (Schizaeaceae). It is a pantropical climbing fern living in dense forest and in tropical and subtropical marsh zones.

Genus *Granulatisporites* Ibrahim, 1933

Type species.- *Granulatisporites granulatus* Ibrahim, 1933

Granulatisporites luteticus (Krutzsch, 1959) Frederiksen, 1980
(Plate 1, Figs. 3-4)

1959 *Punctatisporites luteticus* Krutzsch, p. 68, Pl. IV, Figs. 25-26.

Sculpturing granulate-verrucate is distributed fully over the surface of the spore. The species is related to the modern genus *Acrostichum*, especially with *Acrostichum aureum,* by the ornamentation and size, though by these characteristics it is difficult to separate this genus of *Lygodium*, according to Frederiksen (1980). We compare *G. luteticus* with *A. aureum,* and *Leiotriletes* with *Lygodium,* two modern spores from Colombia. Sporanges were prepared according to the standard acetolysis technique (Erdtman, 1969). The sclerine sculpture in *A. aureum* varies from completely psilate, to lightly granulate to granulate-verrucate, with verrucae up to 3µm. (Solé de Porta & Murillo, 2005). This confirms that it is difficult to separate between *Lygodium* and *Acrostichum* by the sculpturing.

In the present study, the fossil spores with completely psilate sclerine, size and other features are considered to be *Leiotriletes*. The fossil spores with granulate-verrucate sculpturing are assigned to *Granulatisporites luteticus*. They are present in all samples.

The modern genus *Acrostichum* corresponds to one highly shrubby pantropical fern adapted to freshwater and brackish water, from a mangrove zone, river margins up to 200 meters of elevation, in a tropical and wet climate.

Genus *Proxapertites* Van der Hammen, 1956

Proxapertites operculatus Van der Hammen, 1956
(Plate 2, Figs.1-6)

1954 *Monocolpites operculatus* Van der Hammen, p. 89, Pl. 5, Figs. A-B.

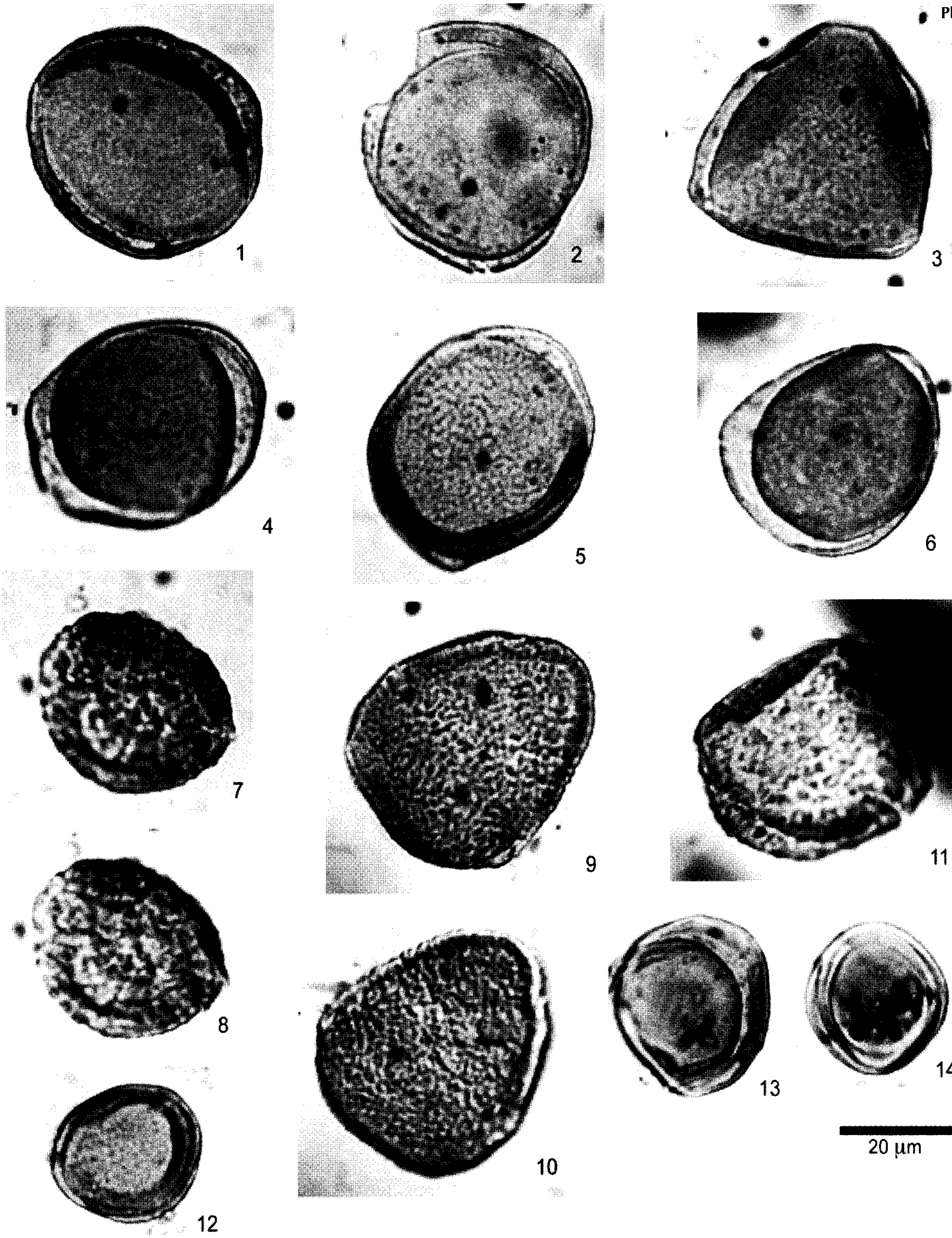
It is a zona-aperturate pollen with equatorial outline, circular to elliptic, with two adhering halves. The diameter of grains is between 27-53 µm. Sculpturing is fine reticulate-perforate with muri lower to 1 µm high. In some specimens the reticulum is slightly rugulate. It was found in all samples, varying from 4.5% to 50.5 % in relative abundance. It is a pantropical Angiospermae known in the Uppermost Cretaceous and Paleogene in the tropical regions of America, Asia, Africa and Europe.

According to Van der Hammen (1956), *Proxapertites* has probable botanical affinity with the modern genus *Astrocaryum* (Palmae). Muller (1968) considered that it probably represents an extinct group of palms, possibly related to *Nypa* (Palmae). Muller (1979) showed that *Proxapertites* had a pantropical and ecologic distribution very similar to that of *Nypa*. Zetter *et al.,* (2001) report a possible botanical affinity to modern Family Araceae. It is a probable evergreen herb life form, living in a coastal environment in a narrow brackish belt along the shores of rivers, channels and lagoons (Zetter & Hoffman, 2001).

Proxapertites psilatus Sarmiento, 1992
(Plate 2, Figs. 12-14)

Plate 2. *1–6. Proxapertites operculatus* (Van der Hammen) Van der Hammen, 1956; *7–11. Proxapertites malaguensis* nov. sp.; *12–14. Proxapertites psilatus* Sarmiento, 1992.

Plate 2



Sculpture psilate to lightly scabrate. The maximum diameter of the grains ranges from 25–40 μm. Up to now, it has only been recorded in Colombia and Venezuela. It is present in samples S-66, S-68 and S-67. There is a possible botanical affinity to Palm.

Proxapertites malaguensis nov. sp.
(Plate 2, Figs. 7-11)

Zona-aperturate pollen, equatorial outline irregular circular to elliptic. The diameter of the grains ranges from 27–56 μm. The pollen halves are not quite symmetric. The exine is 1.5–2 μm thick. Sculpturing reticulate-rugulate with lumina of variable size, sometimes elongated, with a maxim breadth of 1μm, separated by a muri of 1.6–2 μm in heightwith a irregular disposition, generally prolonged, giving rugulate appearance with small verrucae of 1–2 μm large at the upper part of the muri.

Holotype.- Plate 2, Figs. 7-8. Slide: S-66. Deposited in Smithsonian Museum.

Locus typicus.- Harania (Málaga).

Derivatio nominis.- Málaga city.

Proxapertites malaguensis distinguishes from *P. operculatus* in sculpturing, and from *P. verrucatus* Sarmiento (1992), which contains verrucae 2-3 μm broad, irregularly distributed by all surface of the grain, and separated by a micropitted to scabrate sculpturing.

Present in samples S-66, S-68 and S-67, it has only been recorded, until now, in the Harania (Málaga). There is a possible affinity to Palm.

Genus *Diporoconia* Frederiksen, Wiggins, Ferguson, Dransfield & Ager, 1985

Diporoconia iszkaszentgyoergyi (Kedves 1965)
Frederiksen *et al.*,1985
(Plate 3, Figs.1-4)

1965 *Diporites iszkaszentgyoergyi* Kedves, pp. 38-39, Pl. 7, Figs. 15-16.

Grains diporate. The maximum dimension of the grains in the polar view is between 30-52μm, and between 35-45μm in the uppermost occurrence. The exine is 1.5-2μm thick, psilate, and it has two exinal layers. The collumellae may not be clearly observed under transmitted light microscope. The pores are located at the ends of the grain, with an annulus or tumescence present at the pores. The maximum diameter of pores is between 6-10 μm, and between 6-8 μm in the uppermost occurrence. Sometimes one fold extends from pore to pore, giving the impression of a sulcus. The dimensions of the grains and of the pores observed in our specimens are included in the range of the type species without reaching the extreme sizes of 73 and 22 μm (Frederiksen *et al.*, 1985). It is present in samples S-66, S-68 and S-67. It is frequent in the Eocene of Europe, and it has possible botanical affinity to modern genus *Daemonorops*, a pantropical palm living in coastal environments, in freshwater or in brackish water. A similar form has been reported in the upper Paleocene of Colombia, South America (Pardo *et al.*, 2003).

Genus *Rhoipites* Wodehouse, 1933

Rhoipites marcodurensis (Pflug & Thiergart 1953)
nov. comb.
(Plate 3, Figs. 5-6)

1976 *Retitricolporites marcodurensis* (Pflug & Thiergart 1953) Roche & Schuler, p. 28, Pl. XI, Figs. 20-22.

The genus *Retitricolporites* (Van der Hammen 1956) groups together tricolporate pollen grains with a reticulate sculpture (Van der Hammen & Wymstra, 1964). This generic name has been considered invalid (Jansonius and Hills, 1976, card 2402). The genus *Rhoipites* Wodehouse 1933 groups the tricolporate pollen grains with reticulate sculpturing, and prolate shape with costae colpi. *R. marcodurensis* is present in sample S-66. This taxon is related to modern genus *Cissus* (Vitaceae), a pantropical liana characteristic of dense forest.

Plate 3. *1–4. Diporoconia iszkaszentgyoergyi* (Kedves) Frederiksen *et al.*, 1985; *5–6. Rhoipites marcodurensis* (Roche & Schuler, 1976) nov. comb.; *7. Compositoipollenites rizophorus* (Potonié) Potonié, 1960; *8. Cupuliferoidaepollenites liblarensis* (Thomson *et al.*) Potonié, 1960; *9. Intratriporopollenites microreticulatus* Mai, 1961; *10. Subtriporopollenites constans* Pflug, 1953; *11–12. Milfordia minima* Krutzsch, 1970; *13–14. Plicapollis pseudoexcelsus* (Krutzsch) Krutzsch, 1961; *15. Pentapollenites laevigatus* Krutzsch 1962; *16. Botryococcus* sp., algal colony; *17. Cycadopites* cf. *lusaticus* Krutzsch & Sontag, 1970; *18. Cycadopites* sp.

Plate 3

5. CLIMATIC GROUPS

Taxa were classified, according to their temperature affinities, into four major groups: tropical-subtropical, temperate, cosmopolite, and indeterminate. Figure 4 shows the percentages between the four groups. These values are calculated according to the data of Table 2. The Tropical-Subtropical group is dominant in all samples, always with values above 90% and a maximum of 96% in sample S-66. The Temperate group does not exceed four percent. The Cosmopolitan and Indeterminate group also has low values. This confirms a wet tropical-subtropical climate for the Málaga region during the Eocene.

6. TAPHONOMIC EFFECTS

Samples were slightly and slowly stirred during the palynological processing in order to avoid separating the halves of *Proxapertites*. We counted 200 grains of each species of *Proxapertites* to obtain the percentage of specimens with two adhering halves, specimens with an isolated halve, specimens fragmented and specimens degraded. The percentage of these four groups in each sample is very different (Fig. 5).

The samples S-65 and S-67 have a large degree of degradation. Probably these samples were deposited in a freshwater marsh zone with fluvial channels which received fluvial input and fine-grained sediments from nearby emerged land. A short time connection with the marine environment possibly existed because two degraded specimens of dinoflagellate cysts were found.

Sample S-65.- Most of the organic matter is degraded. *Proxapertites* is represented only by *P. operculatus* with all specimens degraded. The remaining taxa are fragmented, with the exception of *Leiotriletes* and *Granulatisporites*, which are not fragmented and are well preserved. This would indicate a short water transport from the source area, not far from the depositional site. *Leiotriletes*, a climbing fern, and *Granulatisporites*, a shrubby fern, dominate the assemblage.

Sample S-66.- Is the richest one in both, taxa and organic matter. The three species of *Proxapertites* have a high proportion of specimens with two adhering halves, *P. opercu-*

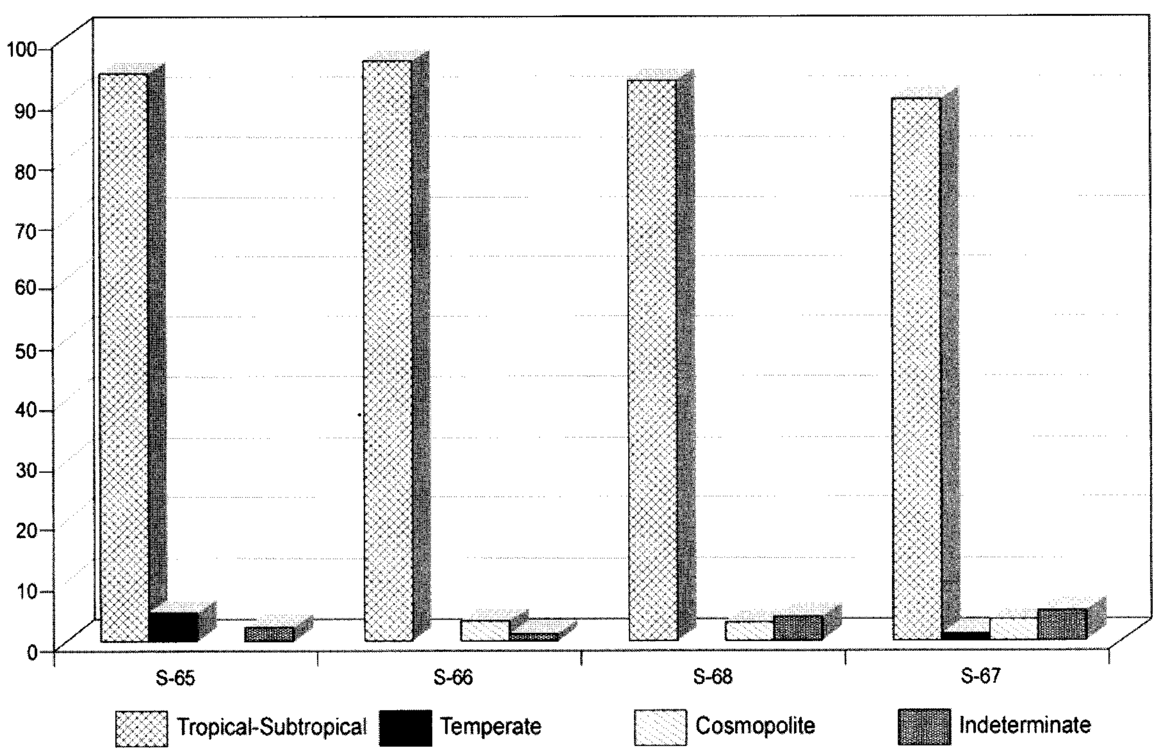


Figure 4. Percentage of tropical-subtropical, temperate, cosmopolite and indeterminate groups in every sample.

TAXA	S-65	S-66	S-67	S-68
Leiotriletes adriennis	—	5%	—	2.5%
Leiotriletes microadriennis	63.8%	22%	6%	16%
Leiotriletes maxoides	—	—	—	0.5%
Granulatisporites luteticus	6.8%	1%	30%	1.5%
Polypodiaceoisporites sp.	2.3%	1.5%	2%	0.5%
Monoleiotriletes martinelli	2.3%	1.5%	—	2.5%
Maculatisporites ibericus	—	—	—	0.5%
Gleicheniidites sp.	—	1%	—	—
Biretisporites sp.	—	0.5%	—	—
Echinatisporis sp.	—	—	—	0.5%
Stereisporites sp.	—	1%	—	0.5%
Trilete indet.	—	0.5%	2%	3.5%
Pityosporites sp.	4.3%	—	1%	—
Cycadopites sp.	—	3.5%	—	0.5%
Monocolpopollenites tranquillus	—	1%	1%	—
Arecipites sp.	—	0.5%	—	—
Proxapertites operculatus	4.5%	50.5%	33%	47%
Proxapertites psilatus	—	3.5%	1%	1%
Proxapertites malaguensis	—	4.5%	1%	2%
Diporoconia iszkaszentgyoergyi	—	—	2%	13%
Compositoipollenites rizophorus	—	—	1%	—
Cupuliferoidaepollenites liblarensis	—	—	—	0.5
Plicatopollis sp.	2.3%	—	—	—
Plicapollis pseudoexcelsus	—	—	—	1.5%
Triporopollenites constans	—	—	2%	0.5%
Subtriporopollenites magnoporatus	—	—	2%	0.5%
Subtriporopollenites constans	4.5%	—	7%	—
Platycaryapollenites ferreri	2.3%	—	—	—
Subtriporopollenites sp.	—	—	1%	0.5%
Tetracolporopollenites megadolium	—	—	1%	—
Tetracolporopollenites sp.	—	—	—	1%
Pentapollenites laevigatus	2.3%	—	—	—
Bombacacidites aff. *gonzalezi*	2.3%	—	—	0.5%
Angiospermae indet.	2.3%	0.5%	3%	1%
Botryococcus sp.	—	2%	4%	2%

Table 2. Percentage of the most relevant Palynomorphs in samples from the Harania Cement Factory area.

latus (58%), *P. psilatus* (100%), and *P. malaguensis* (43%). This suggests that *Proxapertites, Leiotriletes* and algal colonies of *Botryococcus* developed *in-situ*.

Sample S-68.- The dominant tendency in *Proxapertites operculatus* is the presence of specimens with two adhering halves (42%), although the percentage of fragmented grains is high (29%). In *Proxapertites psilatus* all specimens conserve two adhering halves. *Proxapertites malaguensis* has the same proportions of specimens with two and one halves (25%), and many of them are fragmented (50%). The organic matter contains well preserved land plant tissues and abundant woody remains of small size. The fragmented specimens and the woody remains come from areas not far from the depositional site, which was a coastal marsh where abundant *Diporoconia*, a possible palm living in coastal environments, grew either in freshwater or in brackish water, as well as, *Proxapertites*, together with *Leiotriletes* and algal colonies of *Botryococcus*.

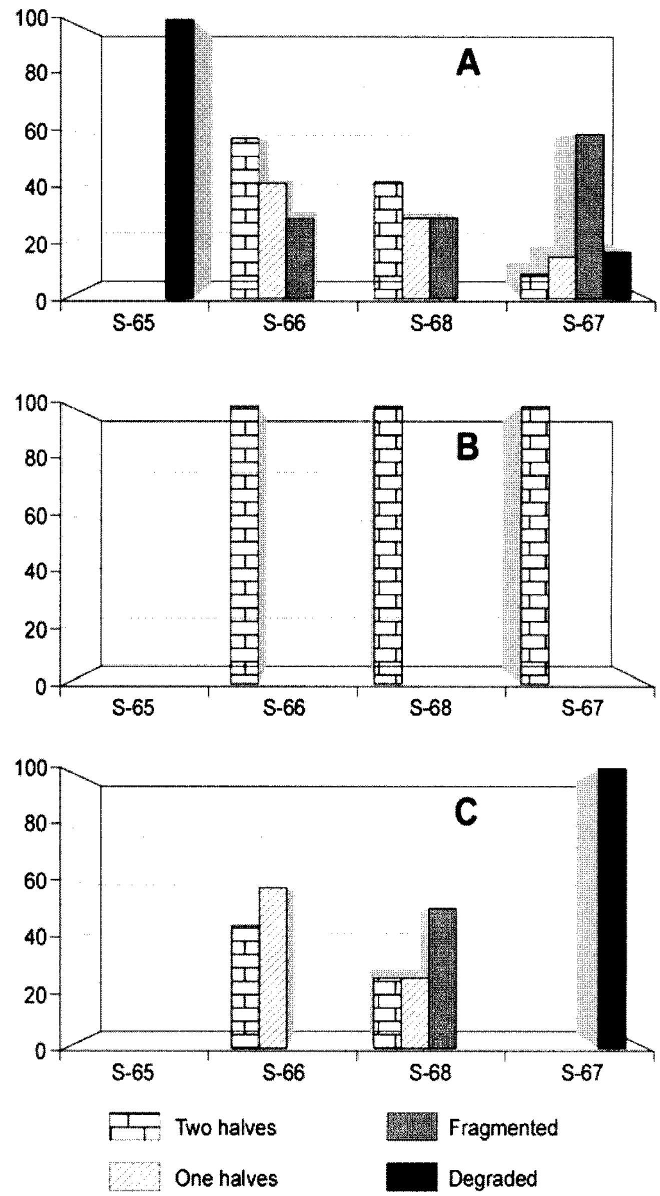
Sample S-67.-Contains fragmented (59%) and degraded (17%) specimens of *Proxapertites operculatus*. *Proxapertites psilatus* presents both adhering halves (100%). All specimens of *Proxapertites malaguensis* are degraded. The organic matter is well preserved. The sample holds numerous *Granulatisporites*, *Leiotriletes* and some Juglandaceae. Most *Proxapertites* grains probably were carried and deposited in a zone inhabited by abundant *Granulatisporites* and algal colonies of *Botryococcus*.

7. PALEOCLIMATE

The Late Paleocene-Early Eocene interval is characterizated by a warm global climate (Wolfe, 1985). Many papers about palynofloras of the Late Paleocene-Eocene in the northwest of Europe confirm this warm and wet climate. During the Lower Cenozoic, the absence of polar ice caps, the attenuated winds and the widespread warm oceanic circulation from the equatorial-tropical areas up to high latitudes of Europe shape this scene.

During the Lower Eocene and Lutetian in the Atlantic coasts of northwest Europe, and Bartonian of northeast Spain mangroves developed. Many families and genera cited from Cuisian and Lower Lutetian today live in tropical regions in warm and wet climates. According to Ollivier-Pierre *et al.* (1987), during the Eocene Juglandaceae, Fagaceae and Myricaceae, today inhabitants of temperate regions, were represented then by early species living in warm climates, that are now extinct.

The palynological assemblage of Harania confirms a wet tropical-subtropical climate. Among archaic forms extinct in the Eocene, Normapolles is registered only by the genus *Plicapollis*. The presence of Bombacaceae, early Juglandaceae, *Diporoconia*, the diversity of Sapotaceae and the amount of Schizaeaceae and Pteridaceae are features found in northwestern Europe at this time. However, the



A. Proxapertites operculatus, **B**. Proxapertites psilatus, **C**. Proxapertite malaguensis.

Figure 5. Taphonomic effects in *Proxapertites operculatus*, *Proxapertites psilatus* and *Proxapertites malaguensis* in every sample (value in percentages).

assemblage from Harania is distinctive by the large amount of *Proxapertites* (4.5%-58.5 %), the low percentage (2%-18%) and low diversity of other Angiospermae, and also the absence of *Nypa*, Taxodiaceae, and Nyssaceae, among many others.

During the Ypresian and Lutetian, the development of a warm marine oceanic circulation from the Atlantic towards northwestern Europe, favoured the development of mangroves characterized by *Spinizonocolpites* (actual genus *Nypa*) together with a vegetation typical of a tropical climate, in England, Belgium, France (Caratini, 1975; Ollivier-Pierre *et al.*, 1987), Austria (Hofmann & Zetter, 2001), and NE Spain (Haseldonckx, 1973; Álvarez-Ramis, 1982; Cavagnetto & Anadón, 1995). The Harania outcrop was located in the Western Tethys Oceanic coastal plain, with warm oceanic circulation coming from the East, probably originating in the Indo-Pacific, allowing the growth of a tropical-subtropical wet vegetation type.

8. AGE

The *Alveolina* present in the limestones of the lower part of the stratigraphic section indicates an Upper Cuisian-Lower Lutetian age. The Harania palynological assemblage is similar to that of another Lower Lutetian locality of northeastern Spain (Boixedat, Huesca) which has, however, a higher proportion of temperate taxa (Solé de Porta & Porta, 1968), and which has been dated with mammals (Crusafont *et al.*, 1968), and larger foraminifera (Busquets *et al.*, 1986).

9. CONCLUSIONS

1) The palynological assemblage from Harania (Málaga) contains 99 taxa (84 taxa were identified in this paper and additional 15 taxa were cited previously at the same locality). The assemblage is dominated by *Proxapertites* (*P. operculatus, P. psilatus* and *P. malaguensis*) together with *Leiotriletes microadriennis* (cf. *Lygodium*) and *Granulatisporites luteticus* (cf. *Acrostichum*).

2) The Harania assemblage is similar to palynological assemblages found in the Krappfeld area (Austria), but it differs because its much higher diversity and high percentage of *Proxapertites*, in the absence of *Nypa,* and in the lower diversity and abundance (4%) of temperate taxa.

3) The Harania outcrop was located in the Western Tethys oceanic litoral which warmed oceanic circulations coming from the east and originated in the Indo-Pacific. 4) The Harania palynological assemblage was dated as Upper Cuisian-Lower Lutetian, corresponds to a vegetation of tropical-subtropical wet climate and is different to that found in northeast Spain and rest of Europe.

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