DESCRIPTIONS AND BOTANICAL AFFINITIES OF *Tubulifloridites* Cookson 1947 ex Potonié 1960 POLLEN GRAINS FROM THE SAN GREGORIO FORMATION, BAJA CALIFORNIA SUR, MEXICO

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ABSTRACT

From the San Gregorio Formation (Upper Oligocene-Lower Miocene), Baja California Sur, Mexico, 105.4 meter-deep borehole "B4" was analyzed. Among the continental palynomorphs, four *Tubulifloridites* taxa, whose botanic affinity is Asteraceae family (Astereae, Eupatorieae and Heliantheae tribes), were recovered and described. The four *Tubulifloridites* types were classified into three groups according to morphological measures, using k-means cluster analysis. Scanning electron microscope and light photomicrographs were taken. Descriptions complement the contributions made by other authors to this genus, pertaining to the Baja California peninsula during the Paleogene and Neogene and contribute to the geological history of the family.

Keywords: Asteraceae*, Tubulifloridites,* fossil-pollen, systematic-descriptions.

DESCRIPCIONES Y AFINIDADES BOTÁNICAS DEL POLEN DE *Tubulifloridites* Cookson 1947 ex Potonié 1960 DE LA FORMACIÓN SAN GREGORIO, BAJA CALIFORNIA SUR, MÉXICO

RESUMEN

El barreno "B4" con una profundidad de 105.4 m, de la Formación San Gregorio (Oligoceno Superior-Mioceno inferior) fue analizado. Entre los palinomorfos continentales, se registran y describen cuatro taxa de *Tubulifloridites*, cuya afinidad botánica con plantas actuales corresponde a la familia Asteraceae (tribus Astereae, Eupatorieae y Heliantheae). Los cuatro tipos de *Tubulifloridites* se clasificaron en tres grupos de acuerdo a sus medidas morfológicas, usando un análisis de agrupación por el método k-medias. Se tomaron fotomicrografías en el microscopio electrónico de barrido y óptico. Las descripciones complementan las contribuciones previas hechas por otros autores para este género durante el Paleógeno y Neógeno de la península de Baja California y contribuyen a la historia geológica de la familia.

Palabras Clave: Asteraceae*, Tubulifloridites,* polen fósil, descripciones sistemáticas.

INTRODUCTION

During the Paleogene and Neogene, the state of Baja California Sur (BCS), was covered by a shallow sea in which more than 4000 m of sediments were deposited [1]. In central BCS state, in the La Purísima region (Comondú), the stratigraphic sequence of these deposits is formed by the Tepetate Formation (Paleocene-Eocene), the San Gregorio Formation (Upper Oligocene-Lower Miocene), the San Isidro Formation (Lower or Middle Miocene), the Comondú Formation (Upper Oligocene-Miocene) and the La Salada Formation (Pliocene) [1, 2, 3, 4, 5]) (Figure 1).

The San Gregorio Formation (SGF) consists of interbedded phosphatic shale, silicified shale, diatomite, phosphatic pelotoidal sandstone, rhyolite tuff, and diatomaceous shale with a high content of fish remains [2, 6, 7, 8].

System	Period	Epoch	Age	Picks (Ma)	La Purísima (Hausback, 1984)
Tertiary	Neogene	Pliocene	Placenzian	3.6	La Salada
			Zanclean	5.3	
		Miocene	Messinian	7.2	
			Tortonian	11.6	
			Serravalian	13.8	Comondú
			Langhian	16.0	
			Burdigalian	20.4	Isidro
			Aquitanian	23.0	San Gregorio
	Paleogene	Oligocene	Chattian	28.1	
			Rupclian	33.9	
		Eocene	Priabonian	37.8	Tepetate
			Bartonian	41.2	
			Lutetian	47.8	
			Ypresian	56.0	
		Paleocene	Thanctian	59.2	
			Selandian	61.6	
			Danian	66.0	

Fig. 1. Stratigraphy sequence of the Paleogene and Neogene sediments in central Baja California Sur, Mexico.

The radiometric K-Ar ages [2], as well as studies of diatoms and foraminifera from the SGF [8], have established a Late Oligocene-Early Miocene age (27.2-22.5 Ma).

A borehole for mineral exploration from the SGF was analyzed in order to study continental and marine palynomorphs. Among the continental palynomorphs, pollen and spores were found, as well as marine elements, for instance dinoflagellate cysts, algae, acritarchs, copepod eggs and microforaminiferal lining.

Among the fossil pollen taxa recorded in borehole B4, one of the most abundant taxon is *Tubulifloridites* Cookson 1947 ex Potonié 1960. The morphology of these pollen grains has affinity with present genus of the Asteraceae family, which is one of the most important plants in Mexico due to of its great diversity and wide distribution throughout the country [9].

The aim of this paper is to present the records and systematic descriptions of four pollen types of *Tubulifloridites*, which were found at different depths in borehole B4 of the SGF (Late Oligocene-Early Miocene) and establish its botanical affinities at tribe level.

MATERIALS AND METHODS

Borehole B4, which reaches a depth of 105.40 meters, was obtained in the town of Comondú at coordinates 26 º 19'03 "N and 112 ° 06'08" W, central BCS (Figure 2).

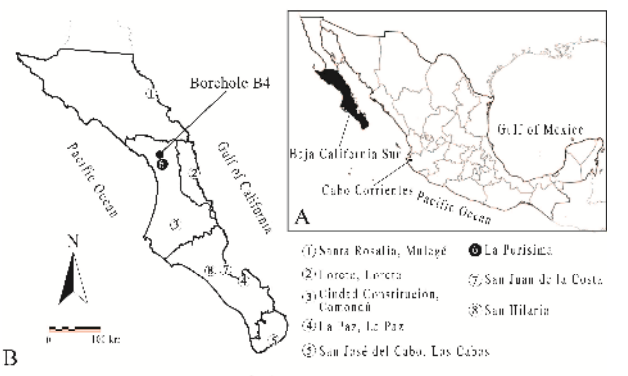

Fig 2. A) Geographic location of Baja California Sur state; **B)** Borehole B4 extraction point, town of Comondú.

A total of 40 samples (Figure 3) were collected and processed through standard methods for the extraction of palynomorphs. Permanent slides were prepared with hydroxyl-acetyl-cellulose and Canada balsam, and were deposited in the IGLUNAM palynological collection of the UNAM (Universidad Nacional Autónoma de México), Geology Institute.

A slide from each sample was reviewed with an Axiolab Zeiss light microscope (LM), using x1000 objective and phase contrast. In each slide, all palynomorphs were counted. Photomicrographs were taken with an ICc1-Zeiss AxioCam and using AxioVision software, version 4.8.2.

Additionally, the positive samples were prepared for the scanning electron microscope (SEM) observation. The samples were dehydrated in an alcohol series; a few drops of the pollen suspension were added on the prepared stubs and then dried whit a lamp and sputter coated with gold-palladium and carbon. Specimens were examined and photographed, using a JEOL 6300 SEM at an accelerating voltage of 20 kV, at the UNAM, Geology Institute.

The pollen diagram was plotted with Tilia Graph version 1.7.16 [10], and includes only the samples where *Tubulifloridites* is found.

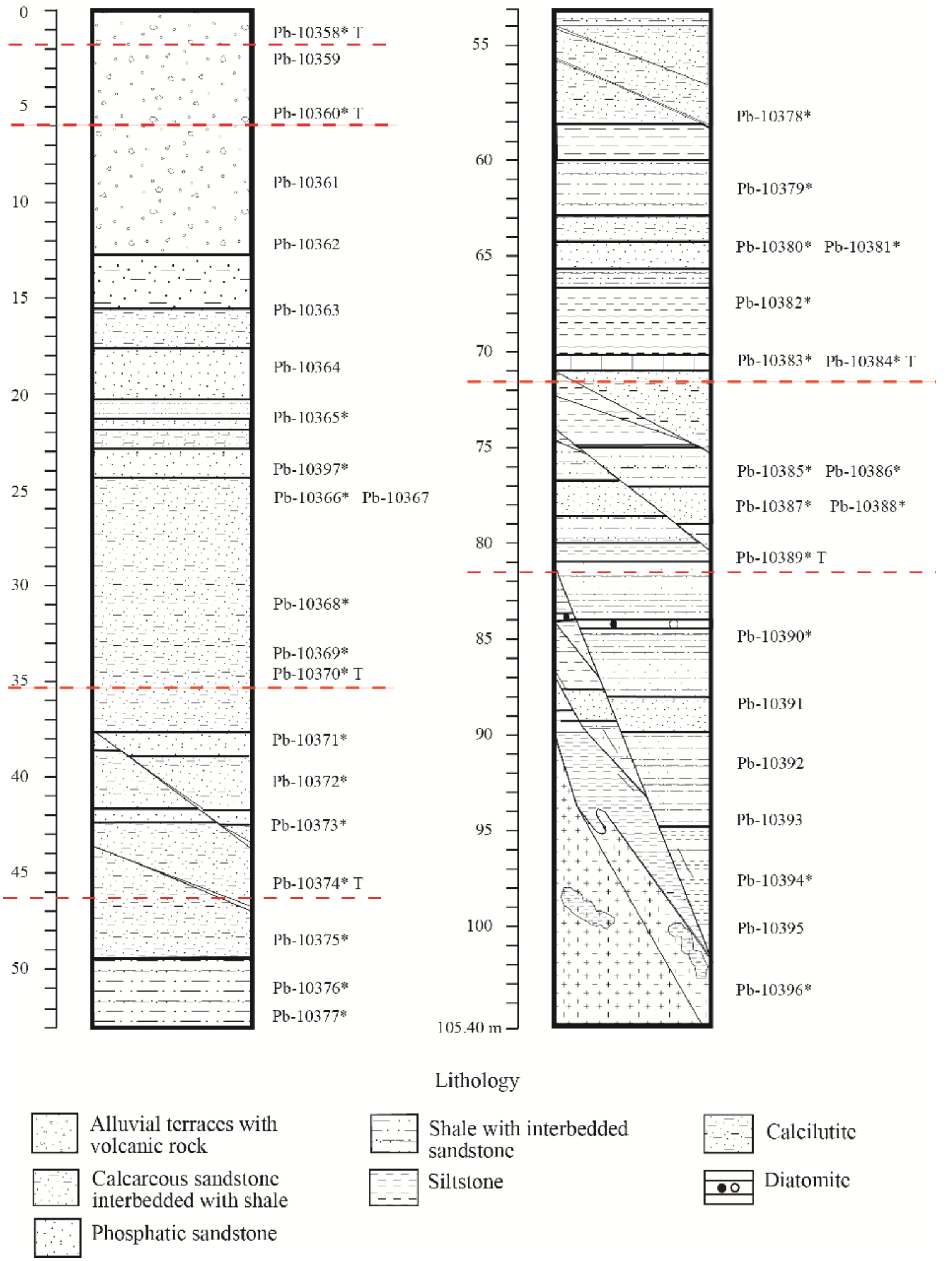

Fig. 3. Borehole B4 stratigraphic column, San Gregorio Formation, Comondú, Baja California Sur, Mexico. Pb Numbers indicate the sample number and depth. (*) = Presence of palynomorphs. T = samples in which pollen *Tubulifloridites* was recovered.

The morphological descriptions of the *Tubulifloridites* taxa were made following the Erdtman [11] and Punt *et al.* [12] terminologies. Considering the morphological measures, we defined the morphological pollen types and classified them into groups using K-means cluster analysis, through statistical program R Commander version 3.0.2.

RESULTS AND DISCUSSION

Although the *Tubulifloridites* genus was recorded in only six of the 40 samples from borehole B4 (Figure 3), this is one of the most abundant taxa in positive samples. Its presence varies from 1 to 27 specimens (Figure 4), and represents between 3 and 47% of the total pollen count registered per sample.

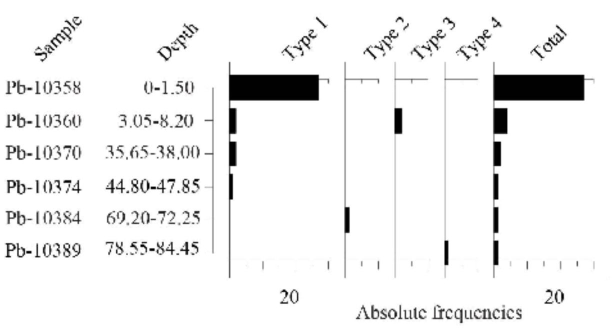

Fig. 4. Absolute frequencies of the four pollen types of *Tubulifloridites* quantified in six samples from borehole B4, San Gregorio Formation, Comondú, Baja California Sur, Mexico.

Systematic descriptions:

Genus: ***Tubulifloridites*** Cookson 1947 ex Potonié 1960

Type species: ***Tubulifloridites antipodicus*** Cookson 1947

***Tubulifloridites* type 1**

(Figures 5a-d, 9a)

Description: Monade, isopolar, radial symmetry, prolate-spheroidal to prolate. Tricolporate or tetracolporate. Endoaperture lolongate from 1.9 µm wide to 4.3 µm high. Large polar area. Exine tectate, columellate, supraequinate, without cavea. Exine 0.8-1.8 µm thick. Spines 0.5-0.8 µm long and 1.0-1.5 µm wide at the base, distance between the spines of 2-2.8 µm. Sexine/ nexine relationship 4:1.

Dimensions: Polar axis = 20.7 µm (15.5-25.4 µm), equatorial axis = 20.3 µm (12.8-23.4 µm): seven specimens measured.

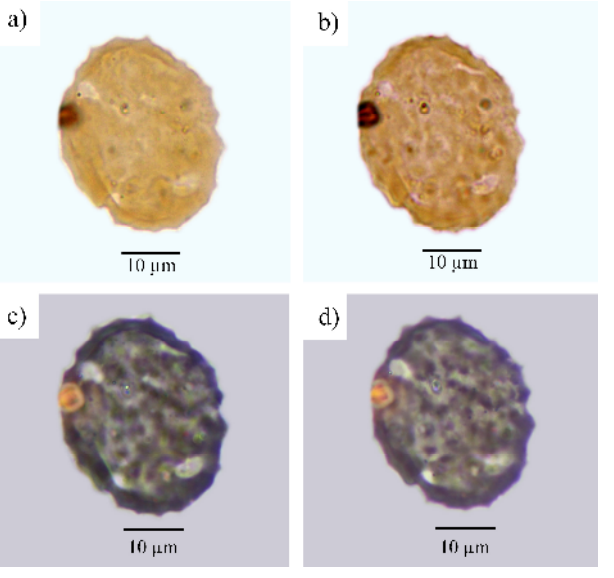

Fig. 5. LM photomicrographs, *Tubulifloridites* type 1, Pb-10358 (1): 90.7/5.6, 97.8/5. a) and b) normal light photomicrographs; c) and d) phase contrast photomicrographs; a) and c) optical section; b) and d) supraoptic section**.**

***Tubulifloridites* type 2**

(Figure 6a-d)

Description: Monade, isopolar, radial symmetry. Tricolporate. Large polar area. Exine tectate, columellate, supraequinate, without cavea. Exine 1.7 µm thick. Spines 6.7 µm long by 5.7 µm wide at the base, distance between the spines of 6.4 µm. The apex of the spines is solid. Sexine/nexine relationship 3:1.

Dimensions: Equatorial axis = 24.1 µm (23.6- 24.6 µm): one specimen measured.

***Tubulifloridites* type 3**

(Figures 7a-d)

Description: Monade, isopolar, radial symmetry, prolate. Tricolporate. Exine tectate, columellate, supraequinate, without cavea. Exine 1.8 µm thick. Spines 3.5 µm long by 2.4 µm wide at the base, distance between the spines of 4.6 µm. The spines have columellae at the base. Sexine/nexine relationship 3:1.

Dimensions: Polar axis = 27.6 µm, equatorial axis = 20.3 µm: one specimen measured.

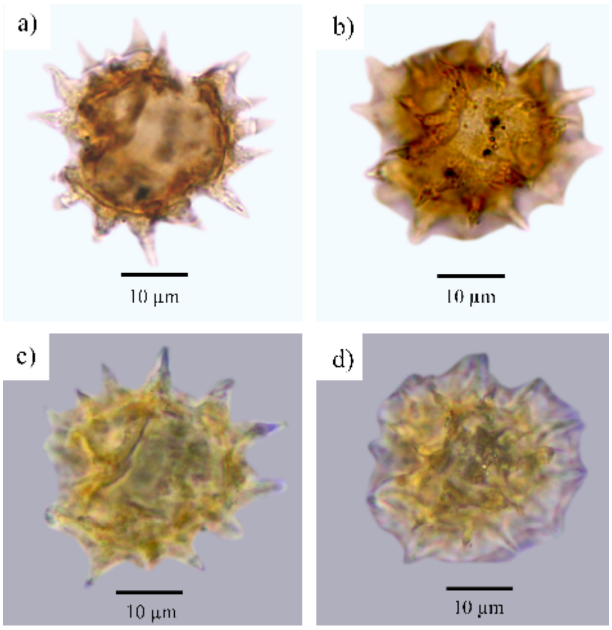

Fig. 6. LM photomicrographs, *Tubulifloridites* type 2, Pb-10384 (6): 99.0/18.8; a) and b) normal light photomicrographs; c) and d) phase contrast photomicrographs; a) and c) optical section; b) and d) supraoptic section**.**

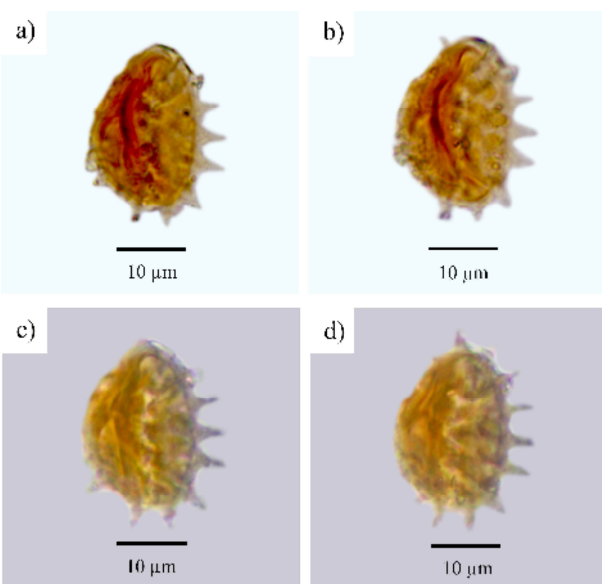

Fig. 7. LM photomicrographs, *Tubulifloridites* type 3, Pb-10360 (4): 99.3/12.9; a) and b) normal light photomicrographs; c) and d) phase contrast photomicrographs; a) and c) optical section; b) and d) supraoptic section**.**

Tubulifloridites type 4

(Figures 8a-d, 9b)

Description: Monade, isopolar, radial symmetry, subprolate. Tricolporate. Exine tectate, columellate, supraequinate, without cavea. Exine 1.5 µm thick. Spines 3.8 µm long by 4.1 µm wide at the base. Distance between the spines of 5.4 µm. Sexine/nexine relationship 4:1.

Dimensions: Polar axis = 34.6 µm, equatorial axis = 29.2 µm: one specimen measured.

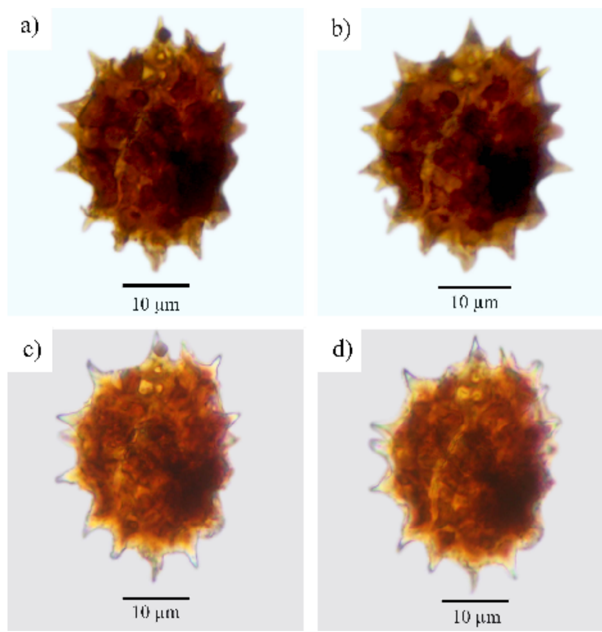

Fig. 8. LM photomicrographs; *Tubulifloridites* type 4, Pb-10389 (9): 99.4/13.0; a) and b) normal light photomicrographs; c) and d) phase contrast photomicrographs; a) and c) optical section; b) and d) supraoptic section**.**

Using K-means cluster analysis, the four types of *Tubulifloridites* pollen were classified into three groups according to spine size (length and width) and the distance between spines (Table 1). The first group is pollen Type 1, characterized by small and abundant spines; the second group, Types 3 and 4, have large spines. The last group is Type 2 pollen, which has the largest spines.

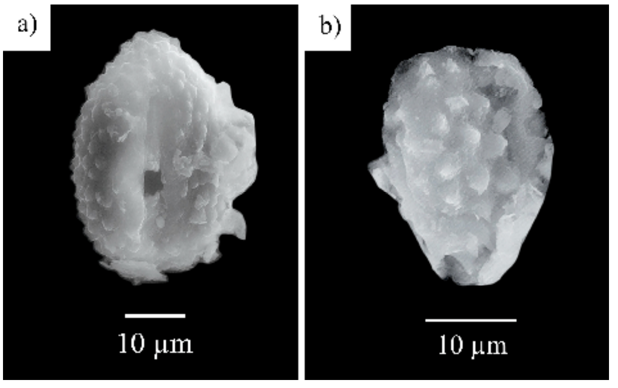

Fig. 9. SEM photomicrographs. **a)** *Tubulifloridites* Type 1; overview of the pollen grain x1,700; **b)** *Tubulifloridites* Type 4; overview of the pollen grain x2,500.

Table 1. Classification of the four types of *Tubulifloridites* into three groups, using K-means cluster analysis, according to spine size. SL = Spine Length, SW = Spine Width, DS = Distance between Spines.

Pollen type	Specimen	SL	SW	DS	K-means cluster
1	1	0.7	1.2	2.8	1
1	2	0.8	1.0	2.6	1
1	3	0.5	1.3	2.2	1
1	4	0.5	1.2	2.6	1
1	5	0.6	1.1	2.1	1
1	6	0.8	1.5	2.2	1
1	7	0.5	0.9	2.0	1
2	1	6.7	5.7	6.4	2
3	1	3.5	2.4	4.6	3
4	1	3.8	4.14	5.4	3

According to the Bremer [13] classification, the three groups of *Tubulifloridites,* exhibit morphological features that are similar to some modern genera belonging to tribes Astereae, Eupatorieae and Heliantheae (AEH), which besides include the largest number of genera and species recorded in Mexico [9,14]. Funk *et al.* [15] propose an Asteraceae family classification based on morphological and molecular data. In that classification the tribes AEH are at the highest level of the cladogram.

The records for fossil pollen related to Asteraceae family in Mexico range from the Eocene in Baja California [16], Late Eocene-Early Oligocene, Pie de Vaca Formation, Tepexi de Rodríguez, Puebla [17]; Late Eocene-Early Oligocene, Cuayuca Formation, Puebla [18, 19]; Middle Miocene, Tehuacán Formation, Puebla [20]; Early-Middle Miocene, Méndez Formation, Chiapas [21] and Upper Miocene, Paraje Solo Formation, Veracruz [22].

One of the palynological surveys covering the Paleogene age in Mexico, which included systematic descriptions of fossil pollen, was carried out by Ramírez–Arriga [18] in the Cuayuca Formation, Puebla (Upper Eocene-Oligocene). In this work one pollen type of *Tubulifloridites* is described, which has a tectate exine with cavea. This is a notable difference to those recorded in the SGF.

Fossil pollen with Asteraceae affinity has been found in other zones of the world: in the Paleogene Rio Leona Formation, South Argentina [23]; Paleocene-Eocene South Africa [24]; Late Oligocene from Patagonia Argentina [25]; Late Oligocene?-Miocene of Southern Argentina [26, 27]; and Miocene of Nebraska, United States [28] and Argentina [29, 30, 31].

Graham [32] makes an interesting review of macrofossils and microfossils (pollen) records, related to Asteraceae, for defining the geological history of this family and trying to establish their origin and diversification. As the author mentions, macrofossil records are almost absent, therefore the geological history of the family has been based on paleopalynological records.

In their review, Graham [32] refers to the Asteraceae fossil pollen type as AHH *et al.* type, which includes similar pollen to Astereae, Heliantheae, Helenieae and other tribes. Global records of AHH *et al*. type, are mainly registered during Lower-Middle Miocene. There are some Mutisieae and AHH *et al.* pollen records during Eocene in Central and South America, and one record during Upper Eocene-Lower Oligocene in Montana, USA, which if confirmed, would be the oldest to the Asteraceae family.

CONCLUSIONS

Systematic descriptions of the four *Tubulifloridites* taxa show morphology similar to typical present-day pollen from the Asteraceae family (Astereae, Eupatorieae and Heliantheae tribes). Given that in Mexico there are approximately 2,400 species belonging to this family [33], it is difficult to establish botanical affinity with living genera.

The three *Tubulifloridites* pollen groups shown in this study, are the first to be registered for the Upper Oligocene-Lower Miocene in the La Purísima region, BCS.

These *Tubulifloridites* records and descriptions contribute to the information previously submitted by Cross and Martínez-Hernández [16] pertaining to the Eocene of Baja California. Both records add to knowledge of the early history of this family and its distribution throughout Mexico, providing useful information about its presence on the peninsula of Baja California during the Paleogene and Neogene.

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