Sponges from the Wordian (middle Permian) of the Las Delicias Formation, Coahuila, northwestern Mexico

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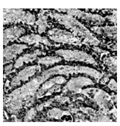

Eleven sponge species from the Las Delicias Formation, Coahuila, northern Mexico, are described. Seven are thalamid sponges: *Amblysiphonella guadalupensis*, *Guadalupia zitteliana*, *Lemonea cylindrica*, *Imbricatocoelia paucipera*, *Discosiphonella mammilosus*, *Girtyocoelia* sp., and *Colospongia americana*. In addition, we report the presence of three poriferan taxa: *Chaunactis* aff. *foliata* and *Heliospongia* sp. sponges related to Demospongia; and the chaetetid *Chaetetes mackrothii*. For the first time in Paleozoic specimens, in the descriptions of *Amblysiphonella guadalupensis*, the presence of siliceous monaxon spicules is reported. The fossils have a high grade of diagenesis and chemical replacement of microstructure, possibly in a context of high tectonic and diagenetic activity. The described species are closely related with others from Grandian localities such as the Guadalupe Mountains from Texas and New Mexico, and Mediterranean localities. Most abundant species in Las Delicias Formation are *Amblysiphonella guadalupensis* and *Lemonea cylindrica*, contrasting with Texas/New Mexico communities where *Guadalupia* species prevailed. • Key words: Porifera, middle Permian, Sphinctozoan, petrography, SEM.

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Previous research in the fields of geology, tectonics, stratigraphy, and paleontology conducted in the Las Delicias Valley, located in the state of Coahuila, northeastern Mexico (Fig. 1, top-center and bottom-left), has highlighted the presence of a highly diverse fauna (King *et* al. 1944, Wardlaw *et al*. 1979, McKee *et al*. 1999), including fusulinids (Dunbar 1944, Téllez-Girón & Nestell 1983) and brachiopods (Cloud 1944, Heredia-Jiménez *et al*. 2019, Torres-Martínez *et al*. 2019, Galeana-Morán *et al*. 2022), mollusks (Miller 1944), conulariids (Quiroz-Barroso *et al*. 2019), trilobites (Sour-Tovar *et al.* 2016), crinoids (Villanueva-Olea *et al.* 2021), corals, and sponges (King *et al.* 1944).

Sponges are characterized by their asconoid, syconoid, and leuconoid body forms (Rigby *et al*. 1993). While some of these body forms exhibit both a rigid calcareous skeleton and a modular structure (Senowbari-Daryan 1991), they are identified here as 'Sphinctozoa' *sensu* Steinmann (1882).

'Sphinctozoa' represents a polyphyletic group of taxonomically diverse sponges (*e.g*., Classes Calcarea Bowerbank, 1864, and Demospongiae Sollas, 1875). Key characteristics of 'sphinctozoans' include a modular arrangement and spherical chamber morphology, a regular pattern of rigid skeleton segmentation, the presence of pores, ostia, or oscula, interwall thickness, and the presence of a siphon or a spongocoel. Most sphinctozoans are extinct, and their skeletons lack preserved organic fibers or spicules; however, not all sponges originally possessed spicules (Bergquist 1998). In Paleozoic sphinctozoans, the skeleton exhibits a spherulitic, irregular, or microgranular microstructure (Senowbari-Daryan & García-Bellido 2002), with a mineralogical composition closely tied to seawater chemistry (Mucci 1983, Sánchez-Beristain *et al.* 2016).

For instance, high magnesium calcite (HMC) and, less frequently, aragonite, were predominant during middle Permian times (Senowbari-Daryan & García-Bellido 2002). During the Paleozoic, reef communities were predominantly composed of sponges from the orders Pisothalamida Senowbari-Daryan & Rigby, 1988 and Guadalupiida Termier & Termier, 1977. The analysis of abundance and diversity in these communities reveals a close similarity between the fauna of Las Delicias and other Permian faunas from Mexico, including El Antimonio,

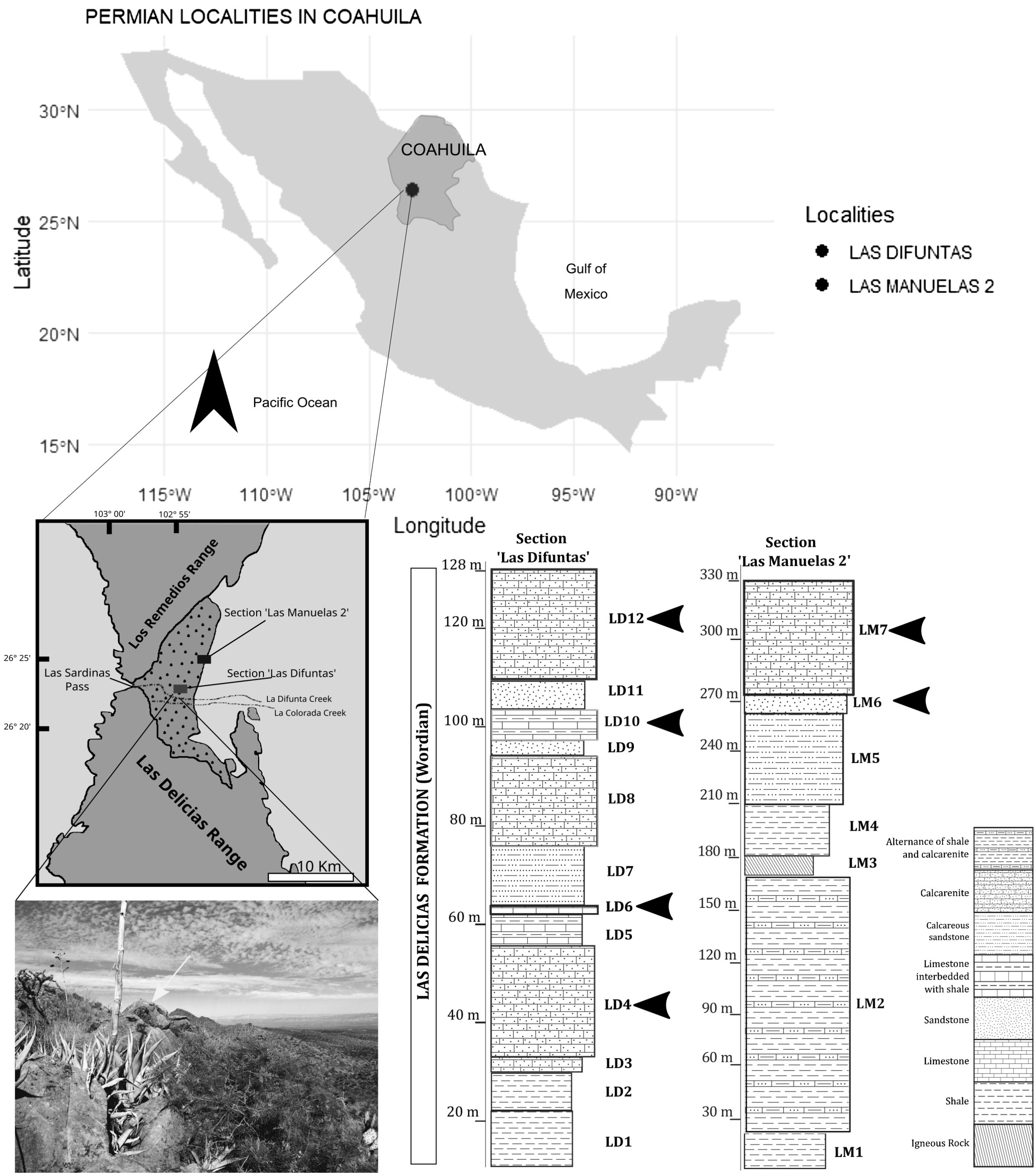

Figure 1. Geographical setting and stratigraphic columns of the two studied sections. Modified from Galeana-Morán *et al*. 2022.

Sonora (Cooper *et al.* 1965); Las Palomas, Chihuahua (Díaz & Navarro 1964); Otlamalacatla-Tianguistengo, Hidalgo (Sour-Tovar *et al.* 2005); Olinalá, Guerrero (Guerrero-Sánchez & Quiroz-Barroso 2013); and the Paso Hondo-Chicomuselo region, Chiapas (Torres-Martínez *et al*. 2016). Similarities are also observed with regions in South America, such as Colombia and Venezuela (Hoover 1981); Central America (Stehli & Grant 1970); and the Guadalupe Mountains in the USA (Shumard 1858; Girty 1908, 1909; Cooper & Grant 1972; Gall 2012). Permian faunas are identified as major components of the Grandian Province (Yancey 1975, Shen & Shi 2004), characterized by tropical to subtropical paleoenvironmental conditions that facilitated the development of extensive euphotic reefs. In these ecosystems, brachiopods, bryozoans, corals, and sponges played a critical role in reef construction (Fagerstrom 1991, Wood *et al*. 1996, Galeana-Morán *et al*. 2022).

In Mexico, the only previously reported sponge genus is *Guadalupia*, identified from the lower Permian (Cisuralian) of the Sierra Plomosa, Chihuahua, in northwestern Mexico (Montgomery 2004). In this context, and considering the occurrence of an abundant but poorly studied and well-preserved fauna in the Las Delicias Formation, Coahuila, in northeastern Mexico, the primary objective of this study is to describe the sponge communities of the Permian Las Delicias Formation using petrography and Scanning Electron Microscopy (SEM).

Geological Setting

The Las Delicias Formation (McKee *et al.* 1999) is an informal stratigraphic unit, by homonymy, composed of alternating siltstone and limestone layers, interspersed with andesitic and dacitic volcaniclastic debris (King *et al*. 1944). Some authors suggest that the Las Delicias Formation was deposited in a basin associated with an active calc-alkaline magmatic arc, bordered by carbonate banks (Coney & Campa-Uranga 1987; McKee *et al.* 1988, 1990; Sedlock *et al.* 1993) although the geological setting is difficult to establish due to poor lateral uniformity and lacking clear contacts between geological units. Fossil sponges were collected from two localities where the Las Delicias Formation outcrops: the 'Las Difuntas' section (Fig. 1, bottom-right), which is divided into 12 rock levels (LD1–LD12), consisting of limestones, calcarenites, shales, and sandstones. The first three levels are unfossiliferous, while levels LD4 to LD12 are fossil-bearing, alternating between levels with high (LD4, LD6, LD8, LD10, and LD12) and low (LD5, LD7, LD9, LD11) fossil content. Fossil groups are well represented by brachiopods, sponges, crinoids, bryozoans, and fusulinids. The 'Las Manuelas 2' section (Fig. 1, lower right) is characterized by seven rock levels, most of which are calcareous, including sandstones, calcarenites, and shales, although siliciclastic rocks are also present (*e.g*., level LM3). In this section, the fossil content is most abundant at levels LM2, LM6 and LM7, including crinoids, brachiopods, sponges, and bryozoans, all of them with a high rate of fragmentation and diagenesis.

Methods

Samples selection for mechanical and chemical cleaning. – The cleaning of specimens involved the use of both chemical (acid bath) and mechanical techniques (*i.e*., ultrasonifier, sandblaster, air scribe). The next step was the preparation of thin sections, beginning with the attachment of samples smaller than 5 cm in length to polished microscope slides using UV resin. The rock samples were then processed in a Buehler PetroThin rock grinding machine until reaching a thickness of 60–70 microns. Additionally, samples larger than 5 cm were polished and clarified with wax to facilitate measurement and photography. The overall process resulted in the preparation of 67 thin sections for microfacies analysis, 37 acetate peels, and 18 polished surfaces.

Alizarin red staining. – In petrography, this technique is used to identify carbonate minerals. To prepare a 200 mL solution, 10 mg of Alizarin Red was added to 200 mL of 1% potassium hydroxide (Rigueur & Lyons 2014). This technique was applied to eight thin sections to identify dolomite crystals.

Microscopy and photography. – Photographs of specimens were taken using a Nikon D5300 DSLR camera with an AF-P DX NIKKOR 18–55mm f/3.5–5.6G VR lens and Newer microlenses (1+, 2+, 4+, 10+). Microstructure analysis was performed with the aid of a Scanning Electron Microscope (SEM) on small samples (0.5 × 0.5 mm) of sponges, including *Amblysiphonella guadalupensis*, *Guadalupia zitteliana*, *Imbricatocoelia paucipora*, *Lemonea cylindrica*, *Colospongia americana*, and *Chaetetes*, due to their good preservation and high abundance. In *Lemonea* and *Colospongia*, the chemical processing of the sedimentary matrix destroyed most of the original fabric, leading to SEM images that differ for these species. Finally, the selected samples were polished using powdered carborundum with a grain size of 1000, attached to microscope slides, and coated with gold to obtain high-resolution images. The overall process resulted in 30 photographs that were used to complement the morphological descriptions of the fossil material studied and to interpret its diagenetic history. Image processing was performed using the free software GIMP 2.10.12 and INKSCAPE.

Systematic paleontology

The sponges described from the Las Delicias Formation belong to five families of the class Demospongiae Sollas, 1875. Eight specimens exhibit a 'sphinctozoan' body form, while one displays an 'inozoan' structure. Additionally, 'chaetetid', 'lithistid', and protomonaxonid sponge forms were identified. The described sponges are housed at the Museo de Paleontología, Facultad de Ciencias, UNAM (FCMP). Additional specimens were collected from the 'San Francisco 2', 'Tordillo 1', 'Las Difuntas 3', 'Cerro Prieto', and 'Cerro San Pedro' localities. Stratigraphic sections for these localities are not yet available, and most of the specimens are housed in the Paleontological Museum of La Laguna, Torreón, Coahuila (MPLL).

Phylum Porifera Grant, 1836
Class Demospongea Sollas, 1875

Genus *Amblysiphonella* Steinmann, 1882

Type species. – *Amblysiphonella barroisi* Steinmann, 1882, Carboniferous of Spain.

Diagnosis. – "Single, rarely branched, porate sponges with one or more central tubes. Chambers are catenulate and ring-shaped. The endo- and exopores may be simple or may branch dichotomously one or more times. Chambers lack filling structures but may contain vesiculae, particularly in early chambers. Skeletons consist of aragonite with a sphaerolitic microstructure. The retrosiphonate central tube may not always be recognizable" (Senowbari-Daryan & Rigby 1988, p. 179).

***Amblysiphonella guadalupensis* Girty, 1909**
Figures 2A, B; 3A–D; 5A, B

Material. – Specimen FCMP 1572, level LD4. Specimens FCMP 1573, FCMP 1574, FCMP 1575 and FCMP 1596 level LD6. Specimens FCMP 1576 and FCMP 1577 level LD8. Specimens FCMP 1578, FCMP 1579, FCMP 1580, FCMP 1581, FCMP 1582, FCMP 1583, FCMP 1584, FCMP 1585 and FCMP 1586 level LD10. Specimens FCMP 1587 and FCMP 1588 level LD12; "Las Difuntas" section. Specimens FCMP 1589 and FCMP 1590 level LM2. Specimens FCMP 1591 and FCMP 1592 level LM6. Specimens FCMP 1593 and FCMP 1594 level LM7; Section "Las Manuelas 2". Specimens FCMP 1595 from "Las Difuntas 3". Specimens MPLL1–MPLL4 from locality "Cerro Prieto". Specimens MPLL5 and MPLL6 from locality "Tordillo". Specimens MPLL7 and MPLL8 from locality "San Francisco 2". Middle Permian of Coahuila, Mexico.

Description. – Multi-chambered sponges are vertically elongated and dichotomously branched. Colonies reach lengths of up to 15 cm and widths of 3 cm. The chambers are semicircular, arranged in a monoserial pattern, catenulated, and intersected at the center by a retrosiphoned spongocoel (Figs 2B, 3B). The external wall of the chambers is perforated by numerous pores, ranging from 0.1 to 0.3 millimeters in diameter. The spongocoel is retrosiphoned, extending from the base of the osculum into the chambers. Both the external and internal walls are thick, reaching up to 0.5 mm. Numerous vesicles, serving as filling material, are present (Fig. 2A), along with monaxon spicules up to 100 microns in length. SEM imaging reveals the presence of rounded spheres, 50 μm thick, scattered across the external wall of the sponge (Fig. 5B), in contrast to other areas, which exhibit an irregular arrangement of calcite crystals.

Discussion. – The morphological features, such as shape and internal structures, as well as the dimensions of the specimens, are consistent with Girty's original description (1909) of *Amblysiphonella guadalupensis* from the Guadalupe Mountains in Texas, USA. Specifically, the catenulated and monoserial chambers, the presence of the retrosiphoned spongocoel, and the small pores in the walls of the chambers are diagnostic characters for this species. It differs from *A. merlai* Parona, 1933 and *A. barroisi* Steinmann, 1882 in its external and internal walls, as well as in the chambers, since in *A. guadalupensis* both walls are slightly thicker, and the number of chambers is greater. The genus *Amblysiphonella* comprises 55 species to date, of which 39 are of Permian age, and no spicules had been previously described. Only Van de Graaff (1969) has reported apparent triradiate spicules for the Carboniferous of Spain, though this was never confirmed. The spicules described here are elongated monaxones with two sharp peaks at both ends of their structure (Fig. 3C, D). These structures had not been previously recognized in this genus, leading to the conclusion that this is the first record of spicules for *Amblysiphonella*. In this regard, we consider it important to systematically address this issue once additional spicule findings are recorded.

Ocurrence. – The genus *Amblysiphonella* has a long and widespread fossil record, ranging from the Late Ordovician of Canada (Rohr 1980) to the Late Triassic of Austria (Senowbari-Daryan 1980, Roniewicz 1989), Iran (Kristan-Tollmann *et al.* 1980; Senowbari-Daryan & Hamadani 1999; Senowbari-Daryan *et al*. 2011; Rashidi & Senowbari-Daryan 2011; Amirhassankhani *et al.* 2014), and Italy (Dieci 1968, Lakew 1990, Sánchez-Beristain & Reitner 2018). During Permian times, the geographical distribution of this genus was restricted to Laurentia (Senowbari-Daryan & García-Bellido 2002).

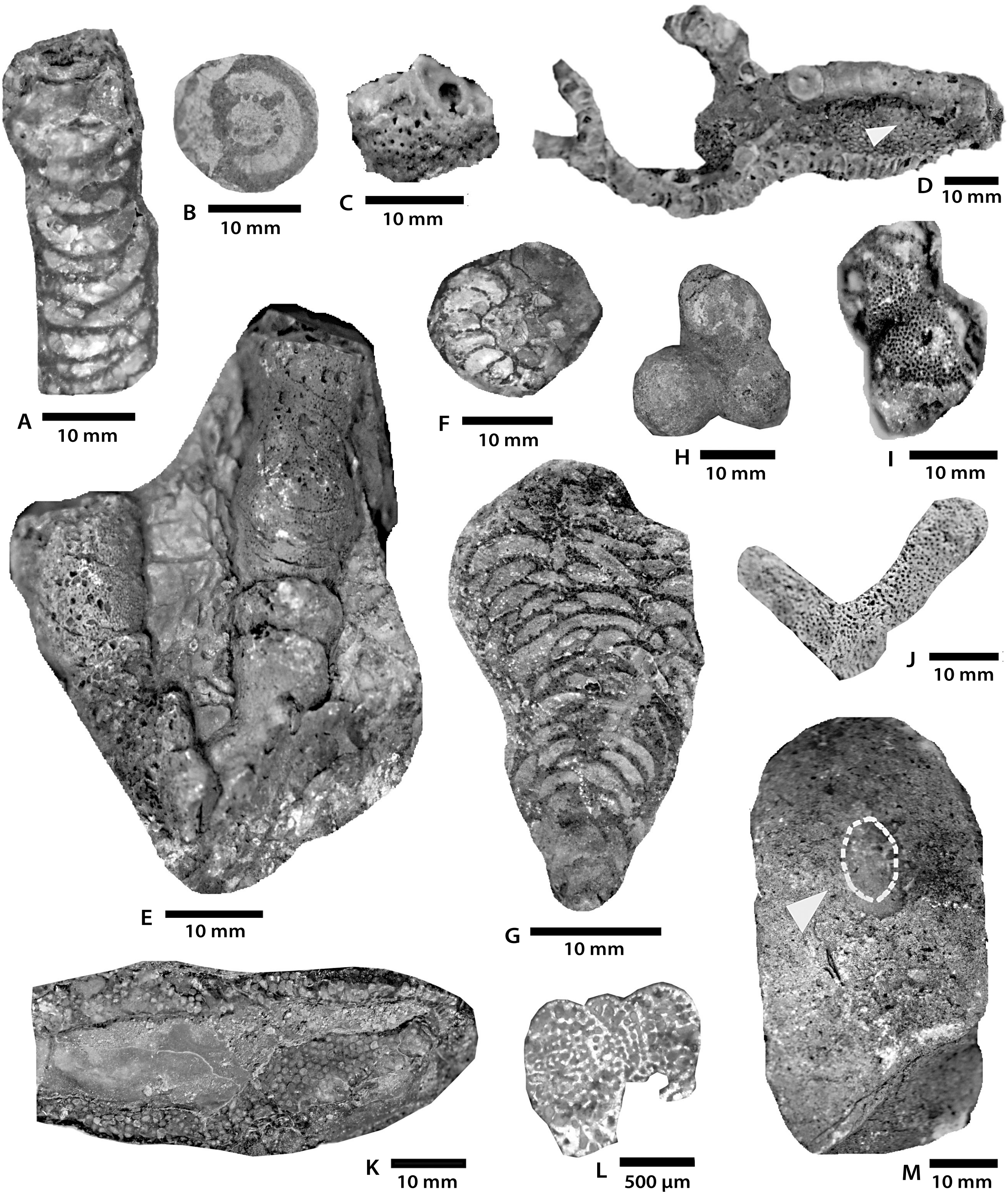

Figure 2. Sphinctozoans described in Las Delicias Formation. • A, B – *Amblysiphonella guadalupensis* Girty, 1909; longitudinal (A) and transversal (B) sections of the cameras; FCMP 1587. • C, D – *Guadalupia zitteliana* Girty, 1909; detail of a camera (C) in a fragmented colony (D), in which the thalamidarium is pointed out with an arrow; FCMP 1600. • E – *Lemonea cylindrica* Girty, 1909; front view of colony with two erect and cylindrical ramifications; FCMP 1614. • F, G – *Imbricatocoelia paucipora* Rigby *et al*., 1989; transversal view of the initial chamber (F) and view of the colony in longitudinal cut (G); FCMP 1619 and 1620. • H – *Gyrtiocoelia* sp.; frontal view of internal mold; FCMP 1623. • I – *Colospongia americana* Weidlich & Senowbari-Daryan, 1996; detail of two cameras where pores and osculi are observed in the outer wall; MPLL25. • J – *Chaetetes mackrotii* Shumard, 1858; fragment of branched colony; FCMP 1630. • K – *Discosiphonella mammilosus* Rigby *et al.*, 1998; polished section of an erect colony; MPLL10. • L – *Chaunactis* aff. *foliata* Finks, 1960; detail of the sponge channel system; FCMP 1635. • M – *Heliospongia* sp.; polished section with spongocoel (circle and arrow) crossing the center of the sponge; FCMP 1633.

Despite many of the species having been described from other localities and ages, these correspond instead to morphological variants of *Amblysiphonella barroisi*. The occurrence of *A. guadalupensis* has been reported in localities in New Mexico (Rigby *et al.* 1998), Italy (Aleotti *et al*. 1986, Flügel *et al*. 1991), Oman (Weidlich & Senowbari-Daryan 1996), Tunisia (Newell *et al*. 1976, Termier *et al*. 1977, Senowbari-Daryan & Rigby 1988, Rigby & Senowbari-Daryan 1996), and China (Rigby *et al*. 1989, Belyaeva 2000).

Family Guadalupiidae Girty, 1909

Genus *Guadalupia* Girty, 1909

Type species. – *Guadalupia zitteliana* Girty, 1909, Permian of Texas, USA.

Diagnosis. – "Platter-like, bowl-like or dendroid sponges composed of tubular oval segments that are arranged next to one another (Finks 1983). Upper surfaces of platters contain astrorhizae, which may be localized on elevations (mamelons) on the upper surface of the sponge (as in stromatoporoids and many sclerosponges). Lower sides of sponges, and the walls between tubes have pierced by numerous pores. Spongocoel rarely developed. Vesiculae may occur. Primary skeletal mineralogy, as well as spicules are unknown. Finks (1983) concluded the microstructure was spherulitic, but our specimens are diagenetically altered, and we cannot confirm that" (Senowbari-Daryan 1990, p. 148).

***Guadalupia zitteliana* Girty, 1909**
Figures 2C, D; 5C, D

Material. – Specimen FCMP 1644 level LD6. Specimen FCMP 1597 and FCMP 1598 level LD8; "Las Difuntas" section. Specimens FCMP 1599, FCMP 1600, 1601 and 1644 level LM2. Specimens FCMP 1602 and FCMP 1603 level LM7; section "Las Manuelas 2". Specimen FCMP 1604 from locality "Tordillo 1". Specimen FCMP 1605 from locality "San Francisco 2". Middle Permian of Coahuila, Mexico.

Description. – Sponges from convex to convoluted-layers shape, and thick up to 3 cm. Absence of spongocoel. Presence of two well-differentiated faces: an inhalant thalamidarium characterized by numerous adjacent spherical chambers, and a trabecularium or exhaling face composed by packed and parallel fibers known as trabeculae. Thalamidarium chambers reach between 1–3 centimeters in diameter, and are perforated by numerous small visible pores with diameters no larger than 1.2 mm. They usually have star-shaped marks (astrorhizae) on the exhaling face, which are part of the channel system. These sponges present vesicles as filling material, and the spicules are absent. Further microstructure analysis reveals the presence of spherules, approximately 50 microns in diameter, scattered in patches over the entire outer wall, similar to *Amblysiphonella*, as well as subrounded bulges (Fig. 5C, D).

Discussion. – The material described as *Guadalupia zitteliana* is characterized by its cup-like shape, although some of these sponges are occasionally branched and display abundant foliations. These features, along with the perforations and the filling material of the chambers, make them similar to sponges from other Permian localities (Girty 1909, King 1943). Some specimens from Coahuila, with convex fronds, are like *Guadalupia ramescens* as reported by Finks (2010), but are remarkably different in their dimensions, as well as in the presence of vesicles inside the chambers and the developed system of astrorhizae. Some authors argue that there are not enough differences, aside from the dimensions of the chambers, to separate *G. zitteliana* from *G. williamsi*, and thus often group them as a single species (Rigby *et al*. 1998). In transverse sections, the original microstructure is not observed, only highly silicified walls.

Ocurrence. – *Guadalupia zitteliana* is considered endemic of the Guadalupe Mountains, Texas in Guadalupian Series, and Glass Mountains, New Mexico in Cisuralian series (Girty 1909, Yochelson 1956, Cooper & Grant 1972, Finks 1995, Rigby *et al*. 1998, Fagerstrom & Weidlich 1999, Rigby & Bell 2006).

Genus *Lemonea* Senowbari-Daryan, 1990

Type species. – *Guadalupia cylindrica* Girty, 1909, Permian of Texas, USA.

Diagnosis. – "Porate, cylindrical, or conical sponges with one or several spongocoels passing essentially through the sponge. Around the spongocoel(s), the tube chambers are radially oriented. Astrorhizal system lacking. Vesiculae may occur but are not abundant. Solitary or colonial forms" (Senowbari-Daryan 1990, p.151).

***Lemonea cylindrica* (Rigby, Senowbari-Daryan & Liu 1998)**
Figures 2E, 4B, 5E

Material. – Specimens FCMP 1606 and FCMP 1607 level LD6. Specimens FCMP 1608, FCMP 1609, FCMP 1610, FCMP 1611 and FCMP 1612 level LD10; section "Las Difuntas". Specimen FCMP 1613 level LM7; section "Las Manuelas 2". Specimens MPLL12-MPLL15 from locality

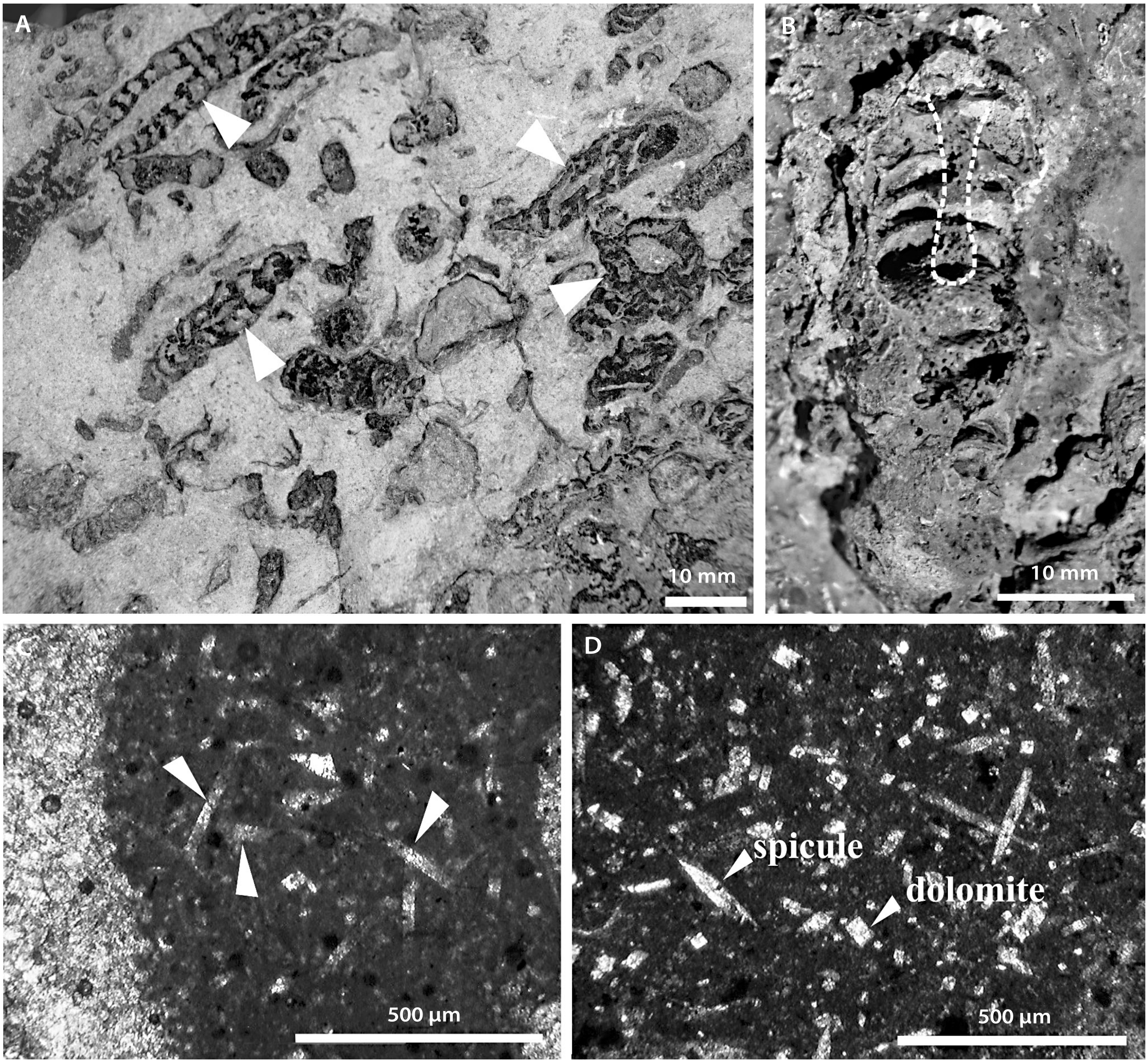

Figure 3. Polished surfaces and thin sheets of *Amblysiphonella guadalupensis* Girty, 1909. A – longitudinal and transverse views of *Amblysiphonella* branches indicated with arrows. B – longitudinal view of *Amblysiphonella*; the spongocoel is highlighted and pointed out; FCMP 1596. C – thin section with presence of monaxon spicules pointed out. D – Alizarin red staining on the sample coloring the sample, except the elongated spicules, as well as rhomboidal crystals of dolomite; FCMP 1590. Scales: 10 mm (A, B), 500 µm (C, D).

"Cerro Prieto". Specimen MPLL16 from locality "San Francisco 2". Specimen FCMP 1614 from locality "Las Delicias 3". Middle Permian of Coahuila, Mexico.

Description. – Sphinctozoans with cylindrical to subconical shape, poorly branched, erect growth but not very high. Presence of spongocoel crossing the entire body of the sponge (Fig. 4B). Many other smaller pores parallel to the main axis of growth are also present. Body size ranges from 8–9 mm wide, between 4–5 cm long, and spongocoel with 3–4 mm diameter. The chambers are small, subrounded on the outer face of the sponge, and tubular on the inner side beside the spongocoel. The arrangement of these chambers is monoglomerate. A poorly developed thalamidarium is present in the inner wall of the spongocoel. Presence of vesicles as filling material. The original texture and the presence of spicules are not well appreciated due to silicification. Microstructure analysis allows only to observe smooth walls because of dissolution, probably due to diagenetic processes (Fig. 5E).

Discussion. – Morphological traits in Coahuila samples that allowed the identification of *Lemonea cylindrica* are the presence of more than one single spongocoel, the cylindrical shape, the development of a thalamidarium, and the monoglomerate arrangement of the chambers surrounding the spongocoel. According to Finks (2010), *L. cylindrica* has a spongocoel more than $^2/_3$ of the diameter of the sponge and presents numerous vesicles as filling material. In contrast, other species like *L. simplex*, possess a smaller spongocoel and walls surrounded by a thalamidarium. This genus differs also from *Guadalupia* in the presence of several small spongocoels parallel to the main spongocoel. Despite both genera develop a thalamidarium, in *Guadalupia* this is much more elaborated.

Occurrence. – Distribution of genus *Lemonea* corresponds to Tethyan and Grandian localities from the Cisuralian, reaching its highest diversity in the Guadalupian. This genus can be found in localities from Croatia (Sremac 1991), Iran (Senowbari-Daryan & Hamedani 2002, Senowbari-Daryan *et al.* 2007), Slovenia (Flügel *et al.* 1984), Italy (Aleotti 1986, Senowbari-Daryan & Di Stefano 1988, Flügel *et al.* 1991), Tunisia (Newell *et al.* 1976, Termier & Termier 1977, Rigby & Senowbari-Daryan 1996) and the USA (Girty 1908, Rigby *et al*. 1998, Fagerstrom & Weidlich 1999, Rigby & Bell 2006).

Genus *Imbricatocoelia* Rigby, Fan & Zhang 1989

Type species. – *Squamella lichatchevi* Belyaeva, 1991 *in* Boiko *et al.* (1991); Permian of Russia.

Diagnosis. – "Cylindrical to club-shaped or spheroidal sponges of overlapping scale-like chambers; chambers walls coarsely perforate, of multiple or single layers, lacks small micromesh outer layer; central tubes may or not be present" (Rigby *et al.* 1989, p. 419).

***Imbricatocoelia paucipora* (Rigby, Fan & Zhang, 1989**
Figures 2F, G; 6A, B

Material. – Specimens FCMP 1615, FCMP 1616 and FCMP 1617 level LD6. Specimens FCMP 1618 and 1619 level LD10; section "Las Difuntas". Specimen FCMP 1620; section "Las Manuelas 2". Specimens MPLL18, MPLL20, MPLL21 and FCMP 1621 from locality "Cerro Prieto". Specimen MPLL21 from locality "Tordillo 1". Middle Permian of Coahuila, Mexico.

Description. – Sponges cylindrical to obconical (inverted cones), vertically elongated, length between 4–8 cm, composed of numerous layers of growing chambers around the axial spongocoel, this last is perforated by numerous endopores. The morphology of the chambers ranges from flat to ellipsoid. In addition, these structures are perforated by several exopores smaller than 1 mm in diameter. The length of the chambers reaches up to 5–11 mm, with a width ranging from 4–5 mm. The wall of the chambers is thick and perforated by numerous interpores up to 0.1–0.25 mm in diameter. The chambers disposed close to the apex of the colony are partially deformed, probably due to the growth of new chambers towards the apical part of the sponge. Some chambers have vesicles as filling material. Spicules absent. The microstructure of these sponges consists of perforations arranged on the external face of the walls. These perforations are rounded, shallow, and reach up to 100 μm in diameter (Fig. 6A, B). Crystals are observed to be packed and aligned parallel to each other between the perforations. No diagenetic spherules were observed.

Discussion. – Morphology of these sponges is similar to that previously described by Rigby *et al.* (1989) for the Middle and Late Permian of China. Typical traits of *Imbricatocoelia paucipora* specie are the obconic to cylindrical external morphology, the flattened shape of the chambers, the increasing arrangement of these structures around the spongocoel and the numerous small interpores on the internal walls. This species differs from *I. obconica* in that exhaling tubes are present between the chambers, and from *I. elongata* in that the central spongocoel and interpores are absent (Rigby *et al*. 1989). The shape of the chambers in *I. paucipora* is distinctly different from that of sponges in the genus *Cystothalamia* (Carboniferous of Spain: García-Bellido *et al*. 2004), particularly in the presence of an axial spongocoel. The segmentation pattern and colony morphology are very similar to those of the genera *Amblysiphonella* Steinmann, 1882 and *Solenolmia* Pomel, 1872; however, these two differ from *Imbricatocoelia* in the flattened, growing morphology of the chambers, which gives the colony a cone-like appearance.

Occurrence. – *Imbricatocoelia* has only been described from localities in south-central China (Rigby *et al.* 1989, Wu 1991), Iran (Senowbari-Daryan *et al*. 2007), and Tunisia (Newell *et al*. 1976). The occurrence of this species in North American localities supports the idea of a trans-Tethyan link between the Grandian and Mediterranean biogeographic provinces during the Late Paleozoic.

Genus *Discosiphonella* Inai, 1936

Type species. – *Discosiphonella manchuriensis*, Inai, 1936; Carboniferous of China.

Diagnosis. – "The specimens consist of straight, bent, or branching cylindrical bodies traversed by a large smooth central cloaca. The body is divided into hollow cysts arranged in regular diagonal rows forming a single layer of cells surrounding the cloaca. All walls are single and are perforated by numerous small pores. The external surface

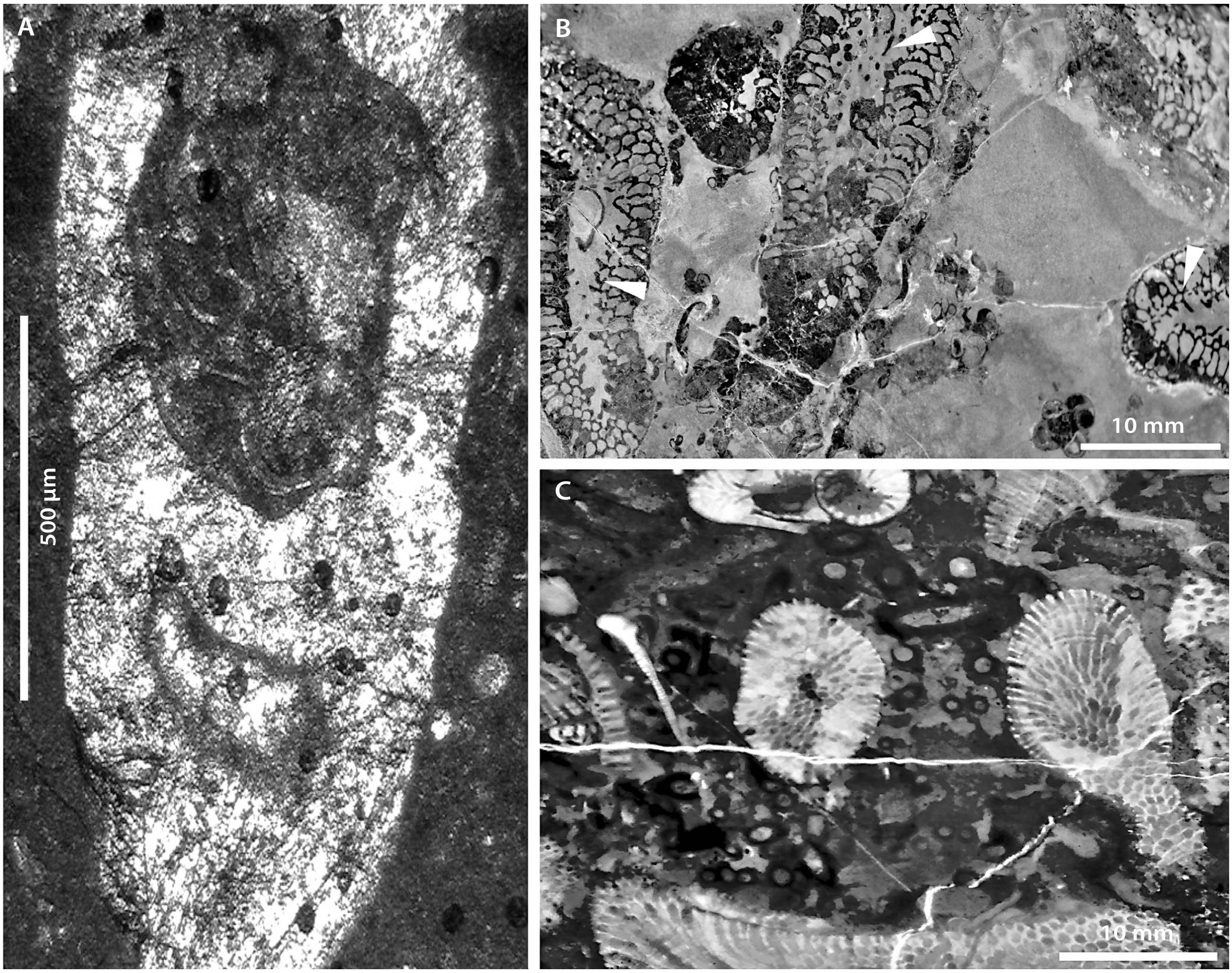

Figure 4. Polished surfaces and thin sections of Las Delicias Formation reef sponges. • A – *Colospongia americana* Weidlich & Senowbari-Daryan, 1996; thin section exhibiting the replacement by silica of the original mineralogy; FCMP 1624. • B – *Lemonea cylindrica* Girty, 1909; *Lemonea* colonies with trabecularium (pointed out) inside the spongocoel; MPLL15. • C – *Chaetetes mackrothii* Shumard, 1859; thin section showing colonies with elongated callicles; FCMP 1626.

is nodular, each node corresponding in position with a cyst in the body. The spicular structure is unknown" (King 1943, p. 31).

***Discosiphonella mammilosus* (Rigby, Senowbari-Daryan & Liu 1998)**
Figure 2K

Localities. – Specimen FCMP 1622 from locality "Tordillo 1". Middle Permian of Coahuila, Mexico.

Description. – Sponges with erect and vertically elongated chambers, most of them branched. Spongocoel with semi conical shape, smooth walls without perforations or trabecularium. Thalamidarium conformed by chambers between 1.5–2.7 cm in diameter, arranged around the spongocoel in a polyglomerate layer. The shape of the chambers is rounded to subrounded towards the base. Chambers with few perforations in the exowalls. Internal and external walls very thin (between 0.2- and 0.4-mm width). Presence of vesicles as filling material in some of the samples. Neither microstructure, nor the presence of spicules can be distinguished.

Discussion. – *Discosiphonella mammilosus* show an erect structure similar to elongated and hollow discs cut in half. Although *D. mammilosus* resemble*s* sponges of genus *Guadalupia*, the former lacks the trabecularium and the characteristic guadalupid astrorhizae system. The exowalls of thalamidarium-chambers are thicker than the endowalls, resembling a false trabecularium. In the specimen MPLL10, the chambers fronds around a hollow spongocoel, as reported in previous literature (Rigby *et al.* 1998).

Occurrence. – The temporal range of the genus *Discosiphonella* extends from the Carboniferous (Muscovian: García-Bellido *et al.* 2004) to the Late Triassic (Norian: Zankl 1969; Stanley 1979; Senowbari-Daryan *et al*. 1982; Senowbari-Daryan & Rigby 2015; Boiko *et al.* 1991; Satterley 1994; Senowbari-Daryan & Link 1998, 2005). Meanwhile, the geographic distribution of *Discosiphonella mammilosus* during Permian times reach from China (Lu 1982; Fan & Zhang 1985; Fan *et al*. 1987, 2002; Reinhardt 1988; Wu 1991; Rigby & Senowbari-Daryan 1995), Greece (Flügel & Reindhart 1989), Iran (Senowbari-Daryan *et al*. 2007), Italy (Aleotti et *al*. 1986, Senowbari-Daryan & Di Stefano 1988, Flügel *et al*. 1991), Russia (Boiko *et al*. 1991), Thailand (Senowbari-Daryan & Ingavat-Helmcke 1994), Tunisia (Newell *et al*. 1976, Termier *et al*. 1977, Rigby & Senowbari-Daryan 1996), and the United States (Rigby *et al*. 1998, Fagerstrom & Weidlich 1999).

Family Girtyocoeliidae Finks, Reid & Rigby 2004
Subfamily Enoplocoeliinae Senowbari-Daryan, 1990

Genus *Girtyocoelia* Cossman, 1909

Type species. – Heterocoelia beedei Girty, 1908, Pennsylvanian of Kansas, USA.

Diagnosis. – "Sponges of the genus *Girtyocoelia* comprise straight, or bent stems composed of a series of spherical chambers slightly overlapping, just in contact, or separated by a space bridged only by the central cloaca, which transverses the entire stem. The outer wall of each chamber is perforated by a few large openings, the margins of which may be extended outward as spouts. There seems to be no communication between cells except through the cloaca; pores open into the cloaca from each chamber. The whole sponge body resembles somewhat a string of beads" (King 1943, p. 33).

***Girtyocoelia* sp.**
Figure 2H

Material. – Specimen FCMP 1623 from locality "Cerro San Pedro". Middle Permian of Coahuila, Mexico.

Description. – Internal cast of three spherical chambers with no pores, osculum or visible spongocoel. Presence of incomplete tubuliform projections in one chamber resembling the characteristic exauli of the genus. Chambers diameter between 10–12 millimeters. No visible spicules or filling material.

Discussion. – This sole specimen presents an external morphology quite similar to the material reported by Girty (1909) from the Guadalupe Mountains, and besides to sponges of the genus *Celyphia* Pomel, 1872 from the Permian of Europe. The poor state of preservation of this material hinders the clear identification of additional diagnostic structures, despite the presence of apparent tubular projections similar to exauli on the external wall of *Gyrtiocoelia*. For this reason, the material could only be determined at the genus level. The arrangement and shape of chambers, displayed as "bead necklace" is shared with many other genera, so more specimens are needed to ensure determination at the genus level.

Occurrence. – This calcareous sponge genus is restricted to paleoequatorial localities (Yancey 1975, Ziegler *et al*. 1981) such as Iran (Senowbari-Daryan & Hamedani 2002; Senowbari-Daryan *et al*. 2005, 2007), Italy (Senowbari-Daryan & Di Stefano 1988), Oman (Weidlich & Senowbari-Daryan 1996), Tajikistan (Boiko *et al*. 1991), Thailand (Senowbari-Daryan & Ingavat-Helmcke 1994), Tunisia (Newell *et al*. 1976, Termier *et al.* 1977), United States (Rigby *et al.* 1998, Rigby & Bell 2006) and Venezuela (Hoover 1981, Rigby 1984).

Order Haplocerida? Topsent, 1928 *sensu* Reitner (1992)
Family Colospongiidae Senowbari-Daryan, 1990
Subfamily Colospongiinae Senowbari-Daryan, 1990

Genus *Colospongia* Senowbari-Daryan, 1990

Type species. – Colospongia dubia Münster, 1841, Triassic of Italy.

Diagnosis. – "Specimens of this genus are catenulate, consisting of spherical or subspheroidal chambers with one superposed above the other. There are numerous pores in the sponge body walls. These pores are simple rather than forked. Central tube is absent. The interior of the chambers is generally empty or filled only with poorly developed vesicular tissue" (Fan & Zhang 1985, p. 9).

***Colospongia americana* (Weidlich & Senowbari-Daryan, 1996)**
Figures 2I, 4A, 5F

Material. – Specimen FCMP 1624 level LM6; Section "Las Manuelas 2".

Description. – Sphinctozoans composed of elongated, erect, very narrow, monoserial stems, with spherical chambers resembling a string of beads. Circular chambers, between 5–16 mm length, covered by two types of exopores, some with a diameter of 0.5 mm, and others known as ostia up to 1 mm. Walls very thick, between 8–10 mm. Chambers increasing in size towards upper portions of the stems, but also lacking of spongocoel or cloaca. Presence of ramifications subparallel to the main axis of the sponge. The spicules and filling material are absent, and the microstructure are not observed in SEM nor petrography.

Discussion. – The traits present in specimens of Coahuila are the stems shape, consecutively vertical-growing chambers, and the presence of two types of exopores of different sizes. This material possesses chambers containing filling material like vesicles, and also presents ostia with

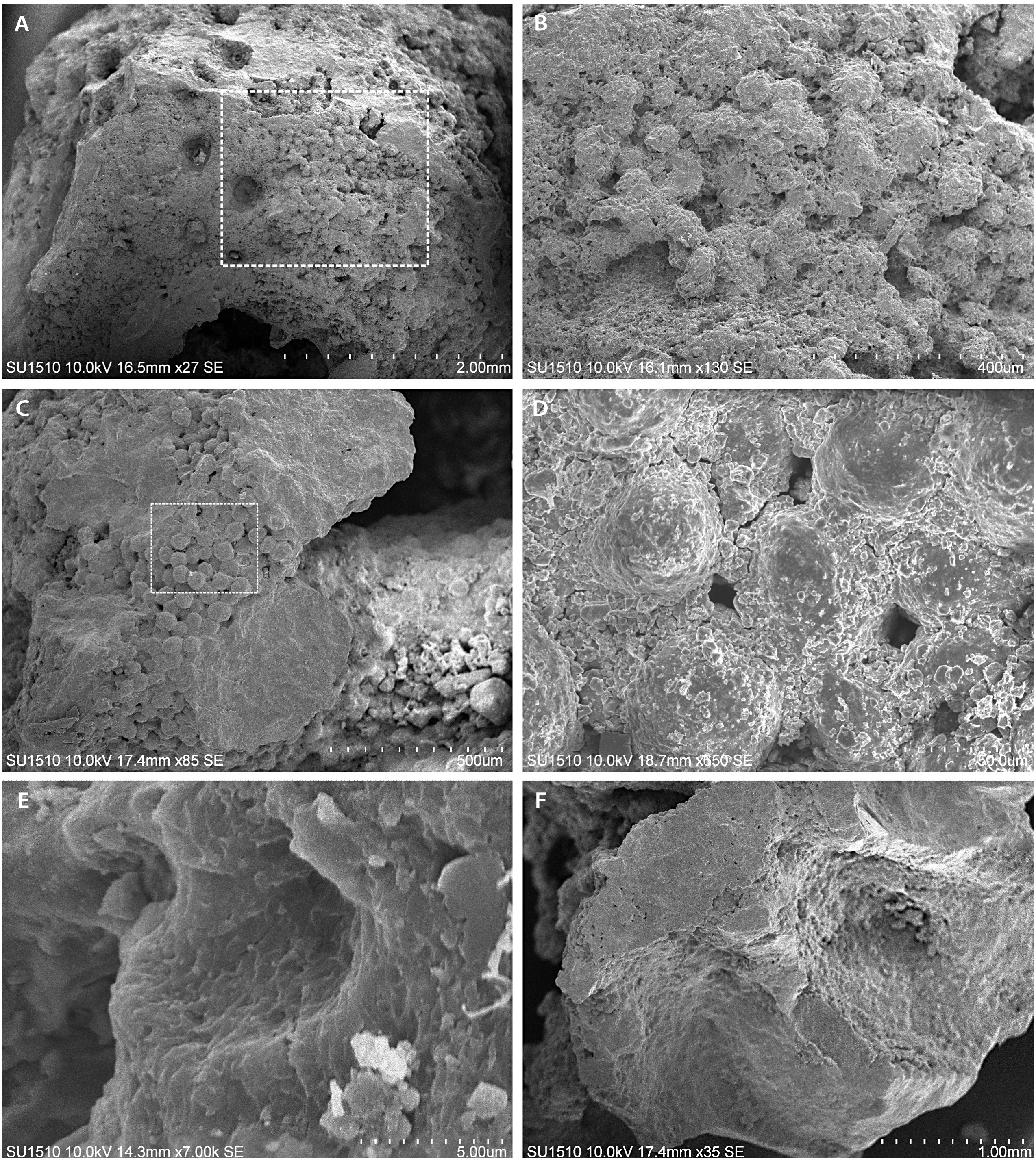

Figure 5. Electron microscopy (SEM) photographs of sponge specimens from Las Delicias Formation (diagenetic specimens). • A, B – *Amblysiphonella*, FCMP 1595; A – sample with diagenetic spherules; B – close-up of the spherules over the wall. • C, D – *Guadalupia*, FCMP 1604; C – outer wall with diagenesis spherules; D – detail of the spherules formed on the wall. • E – *Lemonea* surface showing dissolved calcite crystals; FCMP 1614. • F – detail of the surface of *Colospongia*; MPLL25.

thick edges arranged around the entire surface of chambers, differing in this sense from the genus *Takreamina*? Fontaine, 1962, that lacks previous mentioned traits. According to the description of the genus *Colospongia* made by Laube (1865), the ideal disposition of the exopores should be on the upper portion of the chambers, while in our material they are arranged around the circumference. This feature could be an ecological or regional variant in the character. Unfortunately, the treatment with acids damages part of the original microstructure of the wall, instead, smooth, and dissolved calcite is observed. It is pertinent to mention that authors like Finks *et al.* (2004) include the Family Colospongidae within the Order Vaceletida, along with genus *Colospongia*. However, most representatives of the taxon Vaceletida, such as *Vaceletia* (Jurassic to Recent) and Verticillites (Upper Cretaceous), lack a primary spicular skeleton, as in the case of the specimens referred to in this work. However, later representatives of Vaceletida such as *Stylothalamia* (Middle–Upper Triassic), *Vascothalamia* (Albian, Cretaceous), and species such as *Vaceletia crustans* from the Cretaceous (Upper Campanian) have megasclerae in their basal skeleton (Reitner 1992), which could imply a close phylogenetic relationship of this taxon, and possibly of the genera contained in it, with the order Haplosclerida Topsent, 1928.

Occurrence. – This species is distributed in Oman (Weidlich & Senowbari-Daryan 1996) and New Mexico, USA (Girty 1908).

Order Hadromerida? Topsent, 1928 *sensu* Reitner (1992)
Family *incertae sedis*

Genus *Chaetetes* Fischer von Waldheim, 1829

Type species. – *Chaetetes cylindraceus* Fischer de Waldheim, 1829.

Diagnosis. – "Chaetetidae ne présentant pas de discontinuités dans les parois, dont les zones d'accroissement sont à peine marquées et dont les tubes, bien individualisés se multiplient presque exclusivement par división fissipare (au moyen de pseudoseptes). Genre connu de l'Ordovicien au Portlandien, avec un máximum de development au Carbonifère" (Fischer von Waldheim, 1829).

***Chaetetes mackrothii* Shumard, 1858**
Figures 2J; 4C; 6C, D

Material. – Specimens FCMP 1625, FCMP 1626 and FCMP 1627 level LD6. Specimens FCMP 1628 and FCMP 1629 level LD10; section "Las Difuntas". Specimens FCMP 1630, FCMP 1631 and FCMP 1632 level LM2; section "Las Manuelas 2". Specimen MPLL30 level LM7 from locality "San Francisco 2".

Description. – Colonial sponges presenting elongated, branched, and narrow morphologies. Presence of mamelons on the surfaces of the colonies. Absence of astrorhizae or tubercles on the surface. Tubular calicles up to 4 mm long, with discontinuous growth and up to 0.5 mm in diameter in some specimens. The calicles growth in a meandering pattern, and their walls are imperforate and thin. The spicules are absent. Presence of thin septa, perpendicular to growth direction of the calycles. No filling material is observed. Walls formed by thin, acicular crystals, parallel to each other and closely packed.

Discussion. – General morphology of these colonies, such as the shape of the calicles and discontinuities in growth, allows for the assignment of this material to the genus *Chaetetes*. The distribution of this genus ranges from the Carboniferous of Texas and New Mexico (West 1988, Connolly *et al.* 1989) to the Permian, with *Chaetetes mackrothii* Shumard, 1858 being the only species recorded. According to this author, the presence of *C. mackrothii* constitutes a major component of the Grandian Province faunas, particularly in Texas. As previously mentioned, this record contributes to broadening the information about the geographic distribution of the genus *Chaetetes*. Although no remains of spicules were found in our specimens, the affinity of chaetetids as sponges has long been accepted in various publications (Gray 1980), due to the distinctive bauplan composed of calicles (*e.g.*, Barman *et al.* 2021, Sánchez-Beristain *et al.* 2021). Additionally, we must point out that the Order Chaetetida Okulitch, 1936 is not taxonomically valid, as it refers to Cnidarians. In any case, we prefer to suggest the inclusion of the "chaetetids" described in this work within the order Hadromerida Topsent, *sensu* Reitner (1991, 1992), considering that it includes some poriferans of the genus *Chaetetes* and similar genera based on the presence of bundles of tylostyle-type megascleres as components of their primary skeleton, thus assigning these spongiomorphs a poriferan affinity. Since our specimens lack spicules, however, this classification should remain only a proposal. We will provide a brief discussion on coralline sponges (including chaetetids and sphinctozoans/thalamids) in a subsequent section.

Occurrence. – This genus has a wide temporal distribution, ranging from the Ordovician to the Jurassic. Especially in the Permian, the distribution of *Chaetetes* includes localities from Italy, (Montanaro-Gallitelli 1954), Pakistan (Angiolini 2001), Tunisia (Termier *et al.* 1977) and the United States, particularly in the Guadalupe Mountains, in Texas (Shumard 1858, West 1988, Connolly *et al.* 1989).

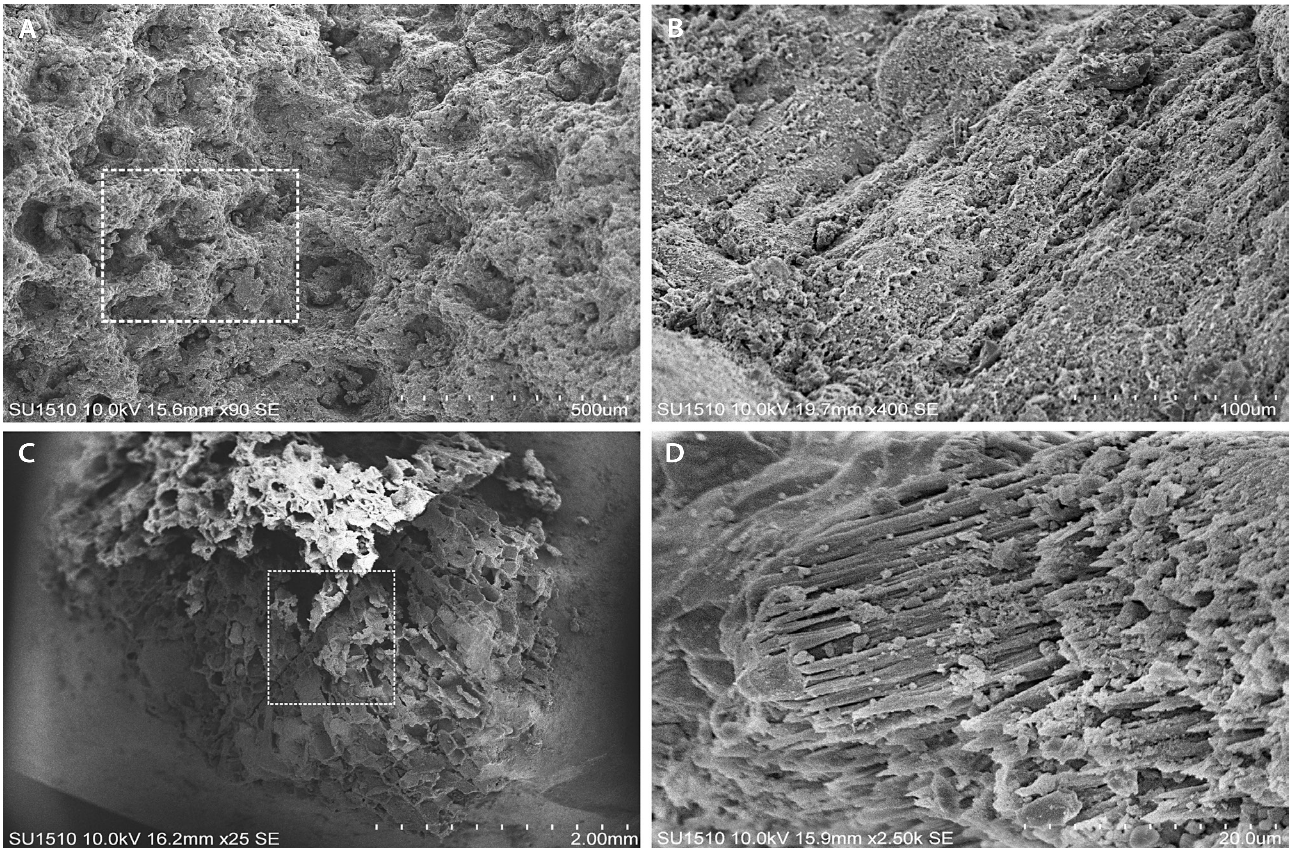

Figure 6. Electron microscopy (SEM) photographs of sphinctozoa specimens from Las Delicias Formation (well-preserved specimens). • A, B – *Imbricatocoelia*, FCMP 1621; A – outer wall with circular perforations; B – wall with crystals arranged close together and parallel to each other. • C, D – *Chaetetes mackrothii*, FCMP 1620; C – tubes or calicles of that preserve original arrangement; D – close-up showing parallel and packed needles constituting the walls of the skeleton.

Subclass Clavaxinellida Lévi, 1956
Order Protomonaxonida Finks, Reid & Rigby 2004
Family Heliospongiidae Finks, 1960

Genus *Heliospongia* Girty, 1908

Type species. – *Heliospongia ramosa* Girty, 1908, Pennsylvanian of Kansas, USA.

Diagnosis. – "Large, cylindrical to flabellate, branching sponge, with thick body wall and relatively narrow cloaca; skeletal net relatively dense and tracts thick; horizontal tract layers strongly downturned about periphery; dermal layer essentially absent; large prosopores frequently stellate; large apopores circular, approximately as large as the prosopores and commonly arranged in vertical and horizontal rows" (Finks 1960, p. 43).

***Heliospongia* sp.**
Figure 2M

Material. – Specimen FCMP 1633 level LM6; section "Las Difuntas". Middle Permian of Coahuila, Mexico.

Description. – The material of *Heliospongia* consists of an elongated and tubular fragment of packed fibers, very large between 12 cm long, 5.2 cm wide, with a 3.1 cm central cloaca. The ventral wall very thick, up to 1.4 cm. Due to the poor preservation, other main traits that could facilitate identification at the species level are not clear, like the internal structure, the channel system, and the presence of pores or spicules.

Discussion. – Considering the poor quality of collected samples, is not possible to observe diagnostic characteristics like radial channels or spicules that allows to assign the material from Coahuila into one of the five known species of this genus. The diameter of the branches and the central tube (> 10 mm) suggest that it could be either *H. ramosa* Girty, 1908 or *H. vokesi* King, 1943. Both species are described from Texas and New Mexico (from the Pennsylvanian and Permian, respectively). More samples are needed to make an accurate taxonomic assignation.

Occurrence. – This genus is well known from the Pennsylvanian of Texas (Rigby *et al.* 2009) to the Permian of China

(Deng 1982a, b), Italy (Flügel *et al.* 1991), Tunisia (Newell *et al*. 1976, Termier *et al*. 1977, Rigby & Senowbari-Daryan 1996) and the United States (Finks 1960, Cooper & Grant 1972, Rigby *et al*. 1998, Fagerstrom & Weidlich 1999).

Order Tetractinellida Marshall, 1876
Suborder Rhizomorina Zittel, 1895
Family Haplistiidae DeLaubenfels, 1955

Genus *Chaunactis* Finks, 1960

Type species. – *Chaunactis foliata* Finks, 1960, Permian of Texas, USA.

Diagnosis. – "Foliate or flabellate sponges with differentiated incurrent and excurrent surfaces; radial tracts originating at base of sponge and dichotomizing upward; tracts loose and open, composed chiefly of irregular rhizoclones in non-parallel orientation, and either hollow or cored with long, smooth monaxons; specialized dermal layer present, which may be composed of a rectangular net of bundles of parallel monaxons; prosochetes and apochetes parallel to horizontal tracts and differentiated from each other by size, shape or spacing" (Fink 1960, p. 93).

***Chaunactis* aff. *foliata* Finks, 1960**
Figure 2L

Localities. – Specimen FCMP 1634 level LD6. Specimens FCMP 1635, FCMP 1636, FCMP 1637, FCMP 1638, FCMP 1639, FCMP 1640, FCMP 1641 level LD10; section "Las Difuntas". Specimen FCMP 1642 level LM2; section "Las Manuelas 2". Specimen MPLL25 from locality "Cerro Prieto". Specimen FCMP 1643 from locality "Cerro San Pedro". Middle Permian of Coahuila, Mexico.

Description. – Sponges with foliate, massive, subrounded shapes. Numerous pores on the outer wall surfaces. Presence of an internal system of leuconoid-type channels. Incurrent and excurrent channels anastomosed. Osculum or atrium are not visible. Monaxon spicules are highly fragmented and scattered inside the tissue of the sponge. The dermal tissues cannot be appreciated.

Discussion. – The subrounded morphology, anastomosed channel system, presence of monaxon spicules, and circular prosopores on the surface are all traits concordant with the original description *Chaunactis* (Finks 1960). The dermal layer cannot be observed on the surface of these sponges. Likewise, a large part of the material is very deteriorated and eroded, thus diagnostic characters are not observed in the same way respect to other Coahuilan sponges. This makes it impossible to accurately assign the material to species level, despite the only species reported for Mexico is *Chaunactis foliata* Finks, 1960.

Occurrence. – This genus is endemic to Grandian Province such as in the Guadalupe Mountains in Texas (King 1931, Finks 1960) and Las Delicias Valley, Coahuila (Finks 1960).

Discussion

"Coralline sponges"

The term "Sclerospongiae", coined by Hartman & Goreau (1970) to describe a group of sponges that produce a solid calcareous matrix, was later subsumed under the classes Calcarea and Demospongiae. Since this term refers to an invalid taxon, we prefer to use "coralline sponges" as defined by Reitner (1992), to designate all sponge species that produce a primary spicular skeleton and a secondary basal calcareous skeleton (predominantly composed of high-magnesium calcite or aragonite). From this perspective, coralline sponges represent a polyphyletic group that primarily includes the following body plans (Baupläne): chaetetid, sphinctozoan (thalamid), and stromatoporoid. The following discussion focuses on the first two, which include some of the taxa described in this work.

"Chaetetids" are marine organisms currently recognized as sponges, characterized by a tubule-based skeleton. They played a significant role as reef builders in the geological past (Fagerstrom 1987; Sánchez-Beristain & Reitner 2012, 2016). Their calcareous skeleton consists of tubules known as calicles, whose shapes vary in response to environmental factors. These calicles may contain structures called pseudosepta, which can disappear as they grow. The primary skeleton of chaetetids is composed of siliceous spicules, while the secondary calcareous skeleton is formed by independent tubules. Although modern chaetetids tend to lose their spicules (Reitner 1992, Sánchez-Beristain *et al.* 2012), the presence of spicules in extinct chaetetids (*e.g.*, Reitner 1991, 1992) supports their classification within the Phylum Porifera, although such findings are not universally accepted.

On the other hand, the term "Sphinctozoa" has historically been applied to chambered sponges with rigid calcareous skeletons, traditionally classified under Calcarea. However, more recent studies (*e.g.*, Senowbari-Daryan 1991, Reitner 1992, Senowbari-Daryan & García-Bellido 2002) have demonstrated that these sponges are polyphyletic, indicating multiple evolutionary origins. Thus, the term "Sphinctozoa" is considered inadequate for systematic classification. The term is now broadly used to refer to all chambered sponges, which independently evolved in various groups throughout Earth's history, including archaeocyathids, calcareans, hexactinellids, and demosponges. Among these, only the genus *Vaceletia* persists to this day. *Vaceletia* features a rigid aragonite skeleton devoid of spicules, and its biological characteristics, such as parenchymella larvae and viviparity, suggest its affiliation with demosponges.

Given that "Sphinctozoa", as introduced by Steinmann (1882), was originally intended to address internal segmentation (Senowbari-Daryan 1991) and likely reflects an understanding of monophyly that has since evolved, we propose the use of the term "thalamid" sponges in future research, as defined by DeLaubenfels (1955) and Reitner (1992). This term highlights the defining traits of most sphinctozoans: their chambered bauplan, regardless of whether they possess spicules. The discovery of coralline sponges in Mexico contributes to a deeper understanding of this polyphyletic group (Sánchez-Beristain *et al*. 2012, 2019, 2021), thus extending their range to the Paleozoic.

Petrography and scanning electron microscopy (SEM)

Petrographic analysis enhances the identification and description of fossil sponges. As outlined in the methodology section, several thin sections and polished surfaces were prepared. Diagenetic features such as abundant fractures, development of orthosparite-type cements, silicification and dolomitization processes are prominent and can be observed in the thin sections. These petrographic features suggest that the specimens were initially deposited in a marine environment, and later buried at greater depths, where they were affected by the regional tectonic activity, as noted in geological reports (Sedlock *et al*. 1993). Given this context, the abundance of fractures can be attributed to the compaction of the fossil-bearing rocks. Furthermore, the exposure of carbonate rocks to the zone where marine and meteoric waters mix facilitate the structural and chemical replacement of the original composition (*e.g.*, dolomitization and silicification), as evident in the thin sections.

Originally, sponge samples were analyzed using Scanning Electron Microscopy (SEM) to examine the microstructure and improve the taxonomic descriptions. Whereas the original arrangement of the crystals can be observed, such as in the genera *Imbricatocoelia* (Fig. 6A, B) and *Chaetetes* (Fig. 6C, D), in other samples the original microstructure is not well appreciated (Fig. 5). In contrast, subrounded spherules with diameters close to 50 microns are displayed on the surface of the sponges. Such structures differ with any previously reported taxonomic characteristic. The presence of such structures can be related to a hydration process of the original crystals. Many of the Permian sponges formed their skeletons of aragonite or high-magnesium calcite "HMC" (Sánchez-Beristain *et al.* 2016), the most chemically unstable form of $CaCO_3$ and very susceptible to constructive diagenetic processes such as hydration. Regarding this, calcite crystals have incorporated hydroxyl ions and recrystallized in rounded shapes (Lippmann 1973, Giraldo & Tobón 2007, Sequeda *et al.* 2012). Hence, despite the abundance and apparent quality of the fossil sponges from Las Delicias, a high degree of diagenesis and irregular replacement in their microstructure and chemical composition are evident.

Paleobiogeography and paleoecology

Sponges described in Las Delicias are closely related with faunas from other Grandian localities such as New Mexico and Texas, United States, as well as with Mediterranean localities (Yancey 1975). For example, the three-sponge species *Lemonea cylindrica* Girty, 1909, *Girtyocoelia* sp. and *Heliospongia* sp. have been reported in New Mexico and Texas, USA (King, 1943), but also in Italy, China, Greece, Slovenia and Tunisia (Newell *et al*. 1976, Rigby & Senowbari-Daryan 1995). In contrast, *Imbricatocoelia paucipera* Rigby, Fan & Zhang 1989 had only been described in Mediterranean localities and China. Likewise, the geographical distribution of the described sponges is like that of other coeval organisms, such as brachiopods (Galeana-Morán & Sour-Tovar 2019, Torres-Martínez *et al*. 2019, Galeana-Morán *et al*. 2022), thus suggesting the existence of an oceanic link within the Paleoequatorial biogeographic Realm.

Furthermore, even if sponge communities in both worked sections keep a great biogeographic affinity with those of Texas and New Mexico (Girty 1909, King 1931), they differ in the structure of the community. While in US localities the genus *Guadalupia* prevails (Finks 2010), in Coahuila *Amblysiphonella* Steinmann, 1882 and *Lemonea* Senowbari-Daryan, 1990 have an abundance up to 60% over the other sponges. A main feature of these two genera is their cylindrical morphology, erect growth direction and dichotomous ramifications, unlike the tapetiform, crawling cup-shaped to flat cone-shaped morphologies of *Guadalupia*. According to the reef-guild model of Fagerstrom (Fagerstrom 1987, 1991; Fagerstrom & Weidlich 1999) vertical morphologies with erect cones, cylinders, and branching shapes are associated with the guild of bio-builders and buffers, and are associated with low energy environmental conditions, contrasting with horizontal-growth sponges associated with the guilds of cementers and unifiers, and with high energy marine environment. This shows a significant difference between USA sponge-reef communities composed mostly of binders, while Las Delicias communities are composed of bio-builders and/or baffler sponges.

Conclusions

The area of Las Delicias in Coahuila, Northwestern Mexico contains a high abundance and diversity of sponges and other groups of marine invertebrates. The present work describes the presence of 10 genera and 8 species of sponges, and sponge-like organisms: *Amblysiphonella guadalupensis* Girty, 1909, *Guadalupia zitteliana* Girty, 1909, *Lemonea cylindrica* Girty, 1909, *Imbricatocoelia paucipera* Rigby, Fan & Zhang, 1989, *Discosiphonella mammilosus* King, 1943, *Girtyocoelia* sp., *Colospongia americana* Weidlich & Senowbari-Daryan, 1996, *Chaetetes mackrothii* Shumard, 1858, *Heliospongia* sp., and *Chaunactis* aff. *Foliata* Finks, 1960. Sponge species described here are closely related to those from other Grandian localities of North America, and Tethyan localities so that a biotic exchange is inferred between eastern and western equatorial fauna during the middle Permian. Dominating sponges in Las Delicias are *Amblysiphonella guadalupensis* and *Lemonea cylindrica*, both belonging to bioconstructors and bafflers reef-guilds (Fagerstrom 1991), characterized by erect-growth and cylindrical shapes. These traits contrast with those sponges from the US Grandian localities, that display a tapetiform body growth (binders) like the genus *Guadalupia*. Petrographic analysis showed the presence of siliceous monaxon spicules in *Amblysiphonella* for the first time in the record of genus, even other features like fractures, high grade of silicification and dolomitization suggest high diagenetic processes as result of tectonic activity.

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