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Paleoenvironmental significance of a new species of freshwater sponge from the Late Miocene Quillagua Formation (N Chile)

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Abstract

This paper reports the first fossil (Tertiary) occurrence of freshwater sponges of the genus *Ephydatia* in the southern hemisphere. The sponges appear in diatomite lacustrine sediments of Late Miocene Quillagua Formation (Chile, Atacama region). The investigated specimens represent a new species, *Ephydatia chileana* sp. nov., which is close to the Recent cosmopolitan *E. fluviatilis*. On the basis of sedimentological and diatom assemblage data, sponge-bearing diatomites have been interpreted as deposited in open offshore shallow lacustrine conditions with slightly alkaline waters. The sponges show malformations, similar to some diatoms and probably caused by high heavy metal concentrations in a lake water. These concentrations are related to hydrothermal activity, which favored the leaching of volcanic rocks that outcrop extensively in the catchment.

Keywords: Freshwater sponges; Heavy metals and hydrothermal activity; Lacustrine; Malformations; Miocene; Systematics

Resumen

Este artículo informa sobre la primera aparición en el registro fósil (Terciario) del Hemisferio Sur de esponjas de agua dulce del género *Ephydatia*. Los restos fósiles se encuentran en sedimentos diatomíticos lacustres del Mioceno superior de la Fm. Quillagua (Chile, Región de Atacama). Los especímenes estudiados corresponden a la nueva especie *Ephydatia chileana* sp. nov., que es muy parecida a la especie cosmopolita actual *E. fluviatilis*. En base a datos sedimentológicos y a las asociaciones de diatomeas, las diatomitas han sido interpretadas como facies depositadas en zonas lacustres internas, abiertas y someras, con aguas ligeramente alcalinas. Al igual que algunas diatomeas presentes en las capas de diatomitas, las esponjas presentan malformaciones probablemente causadas por altas concentraciones de metales pesados en el agua del lago. Estas concentraciones tienen su origen en la actividad hidrotermal que favorece el lixiviado de las rocas volcánicas que afloran extensamente en las áreas fuente.

Palabras clave: Esponjas; Lacustre; Agua dulce; Sistemática; Mioceno; Malformaciones; Minerales pesados; Hidrotermalísmo

1. Introduction

The majority of sponges are typical marine animals; however, there is a small group of both fossil and Recent siliceous demosponges that occurs in freshwater habitats and is included in the families Spongillidae Gray, Paleospongillidae Volkmer-Ribeiro and Reitner, Potamolepidae Brien, Metaniidae Volkmer-Ribeiro, and Lubomirskiidae Rezvoi. The most common and cosmopolitan Recent genus of freshwater sponges is *Ephydatia* (family Spongillidae), known from several species that occur around the world. Freshwater sponges are rare fossils. Their oldest fossil representative is *Eospongilla morrisonensis* (family Spongillidae), from the Morrison Formation (Upper Jurassic) of the United States (Dunagan, 1999). It is rather poorly known because of its calcareous preservation. Lower Cretaceous (Aptian) freshwater sponges (Paleospongillidae and Spongillidae) from Argentina (Ott and Volkheimer, 1972; Volkmer-Ribeiro and Reitner, 1991) are bodily preserved

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with gemmoscleres with original siliceous spicules. Even the oocytes are fossilised (Volkmer-Ribeiro and Reitner, 1991) and can be compared to Recent forms. The only other reported Mesozoic freshwater sponges are from the Lower Cretaceous of England (Young, 1878). These sponges are more common in Tertiary deposits, where they have been described from the Eocene of Germany (Müller et al., 1982; Gruber, 1994; Richter and Wuttke, 1995, 1999) and Italy (Mallaroda, 1954), the Oligocene of Germany (Martini and Schiller, 1995), and the Miocene of the Baikal region (Siberia) (Martinson, 1940; Mehl-Janussen et al., 2000), and include the only known fossil Lubormiskiidae. Middle Pleistocene freshwater spongillids were also reported from Portugal (Moura, 1958). The only fossil record of Potamolepidae is from the Miocene of Japan (Matsuoka and Masuda, 2000). Among the most interesting occurrences are those in the Eocene oil shales of the famous Messel, from which excellently preserved *Lutetispongilla heili* (Richter and Wuttke, 1999) and *Ephydatia gutenbergiana* (Müller et al., 1982), both Spongillidae, recently were described. The extant species of spongillids may be useful to interpret such physicochemical parameters of a lacustrine paleoenvironment as alkalinity, calcium carbonate and organic matter contents, and turbidity (Harrison, 1988).

The investigated material is housed in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa (ZPAL).

2. Geological setting

The alluvial-lacustrine deposits of the Quillagua Formation (Rieu, 1975) constitute part of the Cenozoic infilling of the Quillagua-Llamara basin, which is a forearc basin located between 21°00′ and 23°00′ in the central Andean region of northern Chile. The basin is located in the Atacama desert and extends in a N–S direction. It is bounded by N–S fault systems, which separate it, on the east, from the Precordillera range and, on the west, from the Coastal range (Fig. 1A).The evolution of the Late Miocene–Pliocene lacustrine sedimentation in the Quillagua-Llamara basin was mainly controlled by a closed hydrological regime; regional variations from arid to

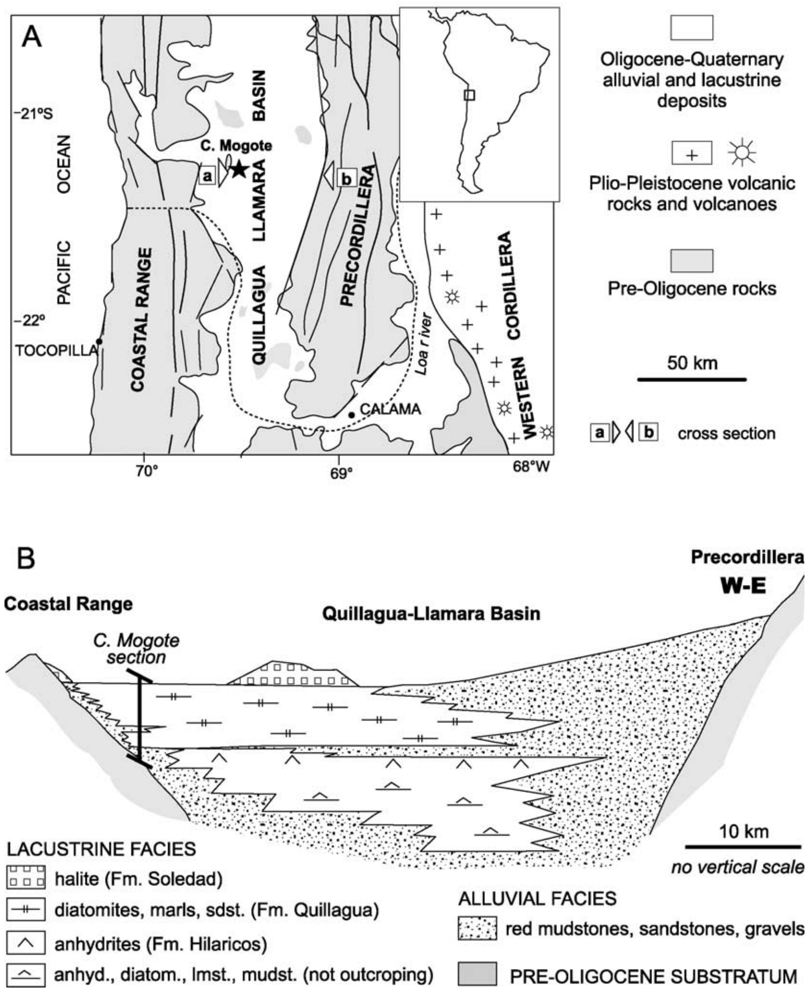

Fig. 1. (A) Geological setting of the Quillagua-Llamara basin in Central Andes, Chile. Note the location of Cerro Mogote site (black star) and the stratigraphic section a–b in B. (B) Stratigraphic transverse cross-section of Cenozoic basin infill of the Quillagua-Llamara basin.

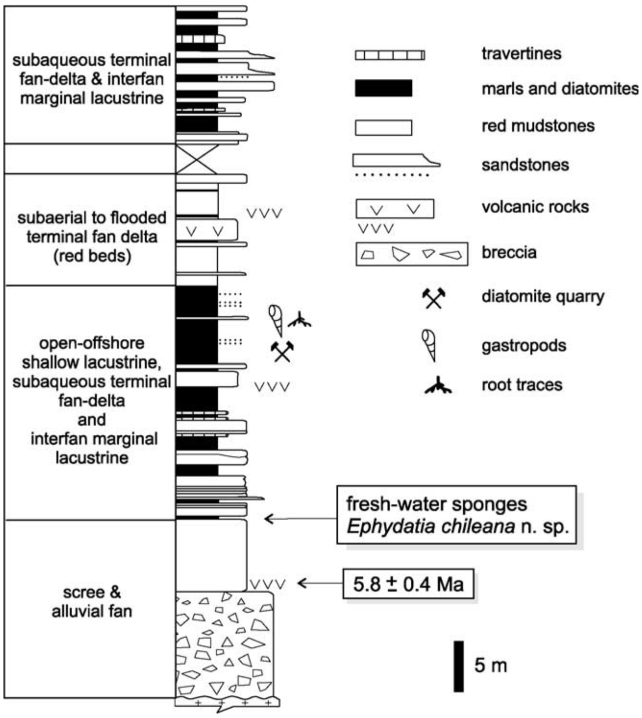

Fig. 2. Stratigraphic and sedimentological log on the Cerro Mogote section showing position of *Ephydatia chileana* sp. nov.

hyperarid palaeoclimate conditions; and the tectonic modifications of watersheds, water divides, and drainage networks in the Precordillera that caused considerable changes in the lacustrine systems budget (Sáez et al., 1999). As a consequence of these changing conditions, perennial lacustrine diatomite successions (i.e. Quillagua) are interbedded with ephemeral evaporite playa-lake-dominated deposits (i.e. Hilaricos Anhydrites and Soledad Formation) (Fig. 1B). High silica content in the Cenozoic lacustrine waters was enhanced by hydrothermal activity and contributions from the western Cordillera volcanic eruptions, which favor the occurrence of sponges and diatom blooms. Also, the high heavy metal concentration in Miocene lacustrine water would be favored by the leaching of Miocene volcanic rocks, which outcrop extensively in the western Cordillera catchment (Fig. 1A).

In the Cerro Mogote section (21°21′S, 69°35′W, 910 m a.s.l.), the Quillagua Formation sequence is 65 m thick. It consists mainly of (1) mudstones and tabular sandstone beds that record terminal fan-delta facies; (2) marls, diatomaceous marls, and travertines of interfan marginal lacustrine facies; and (3) pure diatomites beds that bear the sponge remains and record inner (i.e. open offshore) shallow lacustrine facies. At the base of the Cenozoic Cerro Mogote section, a volcanic bed has been dated by K/Ar as 5.8 ± 0.4 Ma (Sáez et al., 1999). This reference level is 5 m below the pure diatomite bed (less than 3% of carbonate) that contains sponge remains, as discussed herein (Fig. 2).

3. Systematic paleontology

Phyllum Porifera Grant, 1836
Class Demospongiae Sollas, 1875
Order Haplosclerida Topsent, 1928
Family Spongillidae Gray, 1867
Genus *Ephydatia* Gray, 1867
Type species: *Ephydatia fluviatilis* Linnaeus, 1758 Recent, cosmopolitic
Ephydatia chileana sp. nov. (see Figs. 3–5)
Etymology: Chile, where the sponge was found.
Material: Three intact gemmules and many loose megascleres and gemmoscleres preserved in diatomite.
Type locality: Quillagua Formation, Late Miocene, Cerro Mogote section, Atacama region (21°21′S, 69°35′W, 910 m a.s.l.), Chile.
Holotype: ZPAL Pf.12/1
Paratype: ZPAL Pf.12/2
Repository: Institute of Paleobiology, Polish Academy of Sciences, Poland.
Stratigraphic position: Quillagua Formation (Quillagua-Llamara basin).
Age: Tertiary (Late Miocene).
Diagnosis: *Ephydatia* with gemmules 237–250 μm in diameter; rotules (amphidiscs) of the gemmules 39–45 μm long, with spinose shaft and strongly incised discs; megascleres as curved smooth amphioxeas with lengths varying between 240 and 350 μm.
Description: No entire sponge bodies have been found. Only loose megascleres and entire gemmules have been found, and the latter are generally spherical or flattened spherical and 237–250 μm in diameter.
(Figs. 3 and 4) are of one size class and usually measure 39–45 μm long. The shaft, which is 5.5–7.2 μm thick, is supplied with a variable (4–11) number of strong and long conical spines that differ considerably in length. Rotules are irregularly, often deeply incised, and the resulting spines vary greatly in length, reaching approximately 11.0 μm at the longest. In the rotules, 16 to 20–21 spines appear, though some are not in the same plane as the others. The diameter of the rotules is usually between 24.8 and 27.0 μm; on their upper, clear, flat surface, a button-like convexity occurs in the center. In one gemmula, there are many malformed rotules that swell in the middle of the shaft, along with rotules of normal morphology. The spines are reduced to small tubercles on a bulbous-like termination of the rotulae and/or are less numerous and irregularly developed.
Megascleres (Fig. 5) are slightly curved, smooth amphioxeas and measure 240–350 μm long and 8–15 μm thick.

The characters that enable species separation in freshwater sponges are the shape and size of spicules, especially gemmoscleres; however, these may vary widely depending on the chemistry of the water (Poirrier, 1974). Thus, only

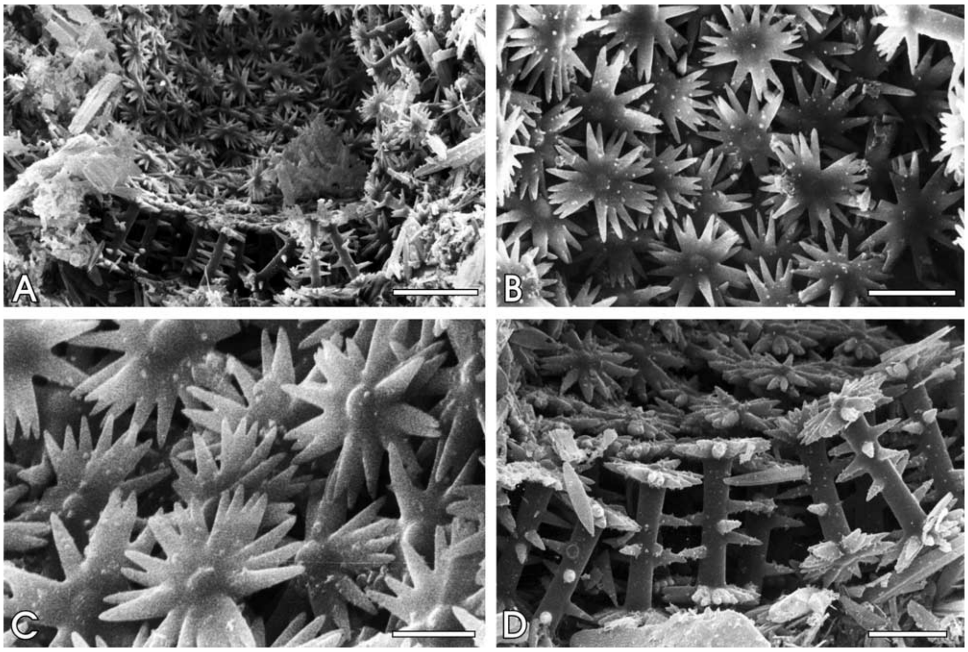

Fig. 3. (A–C) *Ephydatia chileana* sp. nov., holotype, specimen ZPAL Pf.12/1, gemmula. (A) Cross-section of the gemmula showing its internal surface, scale bar 50 μm. (B–C) Details of the internal surface of the gemmula showing details of gemmoscleres discs. (B) Scale bar 20 μm. (C) Scale bar 10 μm. (D) Paratype, specimen ZPAL Pf.12/2, cross-section of the gemmula, showing strong spines on a shaft; scale bar 20 μm.

persistent combinations of characteristics enable species separation. The investigated material resembles the Recent cosmopolitan species *E. fluviatilis* (Linnaeus, 1758) (e.g. Wierzejski, 1935; Penney and Racek, 1968; Pennak, 1989; Ricciardi and Reiswig, 1992) but differs from this species in having smaller diameter gemmules, longer shafts on the gemmoscleres (which are also thicker), and larger diameter rotules. The species described herein also has many long, conical spines on the gemmoscleres shaft; such spines occur very rarely, and in small number, on *E. fluviatilis*. The upper

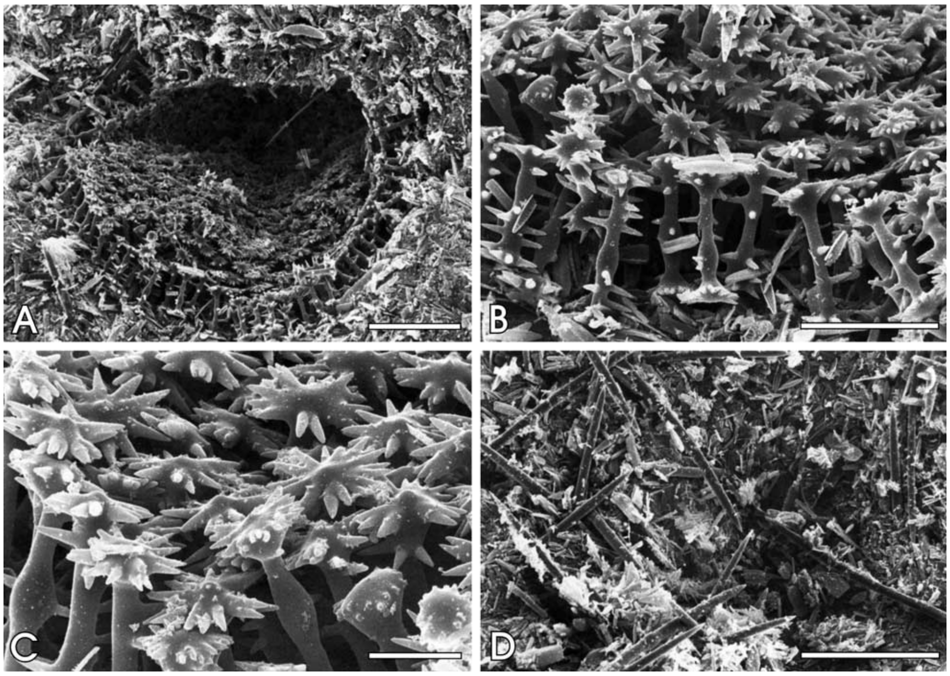

Fig. 4. (A–C) *Ephydatia chileana* sp. nov., specimen ZPAL Pf.12/3. (A) Cross-section of the gemmula, scale bar 100 μm. (B–C) Close up of the gemmula showing malformed gemmoscleres. Note that there are normal rotules among the malformed ones. (B) Scale bar 50 μm. (C) Scale bar 20 μm. (D) Loose amphioxeas in the diatomite, which have been attributed to *E. chileana* sp. nov., specimen ZPAL Pf.12/4, scale bar 200 μm.

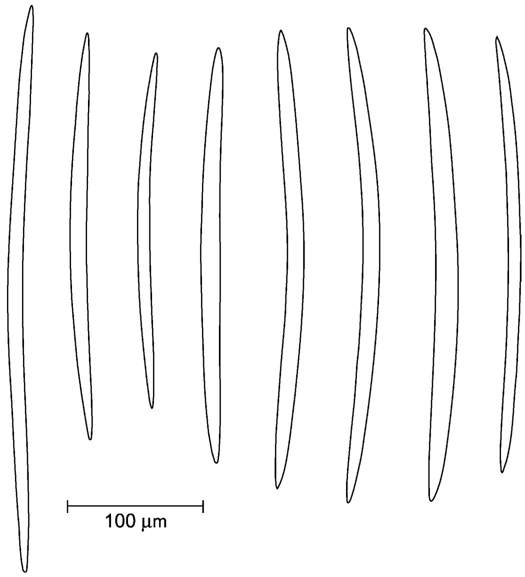

Fig. 5. Loose megascleres in the sample with gemmules and attributed to *Ephydatia chileana* sp. nov.

surface of the rotulae is smooth in the investigated material, whereas in *E. fluviatilis*, it is often spinose to various degrees. Megascleres are of very similar size and smooth in our material, whereas they are often microspinose in *E. fluviatilis*. Atypical gemmoscleres found in one specimen are interpreted as the ecomorphs and/or malformations caused by environmental factors (i.e. the chemistry of the water).

4. Paleoenvironmental interpretation

More than the geological setting and the facies associations that indicate offshore shallow lacustrine conditions for the investigated sponges, the low percentage of fragmented diatoms points to an autochthonous condition for the biogenic material. Diatom assemblage is dominated by *Fragilaria construens* f. *subsalina* [Hustedt] Hustedt (71% of the total diatom assemblage) and *Fragilaria leptostaron* var. *dubia* [Grunow] Hustedt (17%). Diatom data indicate that shallow, oligosaline open waters existed at that time (Bao et al., 1999). *Fragilaria*-dominated sediments are also indicative of slightly alkaline waters (Bradbury, 1989). More specifically, *Fragilaria construens* f. *subsalina* and *Fragilaria leptostaron* var. *dubia* are alkaliphilous species, the former typical of some eastern African sodium chloride-type lakes with pHs of approximately 8 (Gasse, 1986). Both species are typical of meso- to eutrophic waters

According to Harrison (1988) and Ricciardi and Reiswig (1992), *E. fluviatilis*, which is most similar in spiculation to the fossil species described here, occurs in alkaline waters rich in calcium. However, Pennak (1989) states that all common species of Recent freshwater sponges, including *E. fluviatilis*, occur in waters with less than 12.0 ppm of calcium, whereas *E. muelleri* seems restricted to waters with at least 5.6 ppm of calcium. The species *E. fluviatilis* prefers cold to warm climates but can be found in subtropical settings (Penney and Racek, 1968). The requirements of particular species may differ considerably with respect to environmental parameters, so the interpretation of environmental conditions on the basis of *E. chileana* sp. nov. may be misleading, but according to diatom preferences for the same samples, this species preferred very shallow, slightly alkaline, open waters. The malformation of some gemmoscleres observed in our material probably was caused in living forms by pollution, including high contents of heavy metals (Poirrier, 1974; Richelle-Maurer et al., 1994). Teratological morphologies of diatoms observed in some samples from this area have been related to high heavy metal concentrations (Bao et al., 1999). The same factor clearly is responsible for the observed malformation of gemmoscleres.

5. Concluding remarks

The fossil freshwater sponge *Ephydatia chileana* sp. nov. occurs in diatomites of the Quillagua Formation (Late Miocene) and is the first fossil *Ephydatia* species reported from the southern hemisphere. The morphology of its spicules is close to those of the Recent species *E. fluviatilis*, suggesting a direct relationship. Similar to many Recent *Ephydatia* species, *E. chileana* preferred slightly alkaline waters and occurred in shallow water, open offshore lacustrine environments (as suggested by diatom and sedimentological analysis). In contrast to the Recent *E. fluviatilis*, which prefers high calcium carbonate contents, the described new species thrived in an environment poor in $CaCO_3$. High heavy metal concentration caused by hot water leaching volcanic rocks in the catchment was responsible for the malformation of some gemmoscleres.

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