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New findings of Late Jurassic charophyte gyrogonites and gastropods from the San Juan Formation, NW Oaxaca, Mexico

Lourdes Omaña[a,*]; Ismael Ferrusquia-Villafranca[a]; José E. Ruiz-González[a]

[a] Departamento de Paleontología, Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, CDMX, México.

[*] lomanya@geologia.unam.mx

Abstract

Limestone samples were collected from the San Juan Formation, which consists of a mixed marine and non-marine deposit located in the Tlaxiaco Basin, Oaxaca, Mexico. These beds contain a fresh-water assemblage of charophyte gyrogonites and gastropods, and a shallow-water marine association with larger foraminifera *Labyrinthina mirabilis* Weynschenk, 1951, *Everticyclammina* sp. a Rivulariacean-like cyanobacteria and *Cladocoropsis mirabilis* Felix, 1907. An Oxfordian–Kimmeridgian age has been assigned based on the stratigraphic range of the larger foraminifera *Labyrinthina mirabilis* Weynschenk, and *Everticyclammina* sp. The mudstone textured limestone and the fossil association with charophytes and gastropods suggest a continental fresh-water environment. The grainstone-packstone with larger foraminifera *Labyrinthina mirabilis* Weynschenk, Rivulariacean-like cyanobacteria and *Cladocoropsis mirabilis* Felix suggests a shallow-water marine milieu.

Keywords: charophytes, gastropods, larger foraminifera, Late Jurassic, Oaxaca, Tlaxiaco Basin.

Resumen

Se recogieron muestras de caliza de la Formación San Juan, que consiste en una mezcla de depósitos marinos y no marinos situados en la Cuenca de Tlaxiaco, Oaxaca, México. Estos depósitos contienen a un conjunto de agua dulce compuesto por girogonitos de carofitas y gasterópodos y otro de rocas marinas de aguas poco profundas con macroforaminíferos como Labyrinthina mirabilis Weynschenk, 1951, Everticyclammina sp., cianobacterias de tipo Rivulariacea y Cladocoropsis mirabilis Felix, 1907. Se ha asignado una edad de Oxfordiano–Kimmeridgiano basada en rango estratigráfico del macroforaminífero Labyrinthina mirabilis. La textura de tipo "mudstone" de la caliza y la asociación fósil con las carofitas y gasterópodos sugiere un ambiente continental de agua dulce. Las texturas grainstone-packstone sugieren un medio marino de aguas poco profundas con el macroforaminífero Labyrinthina mirabilis, Everticyclammina sp., cianobacterias de tipo Rivulariacea y Cladocoropsis mirabilis.

Palabras clave: carofitas, gasterópodos, Jurásico Tardío, macroforaminíferos, Oaxaca, Cuenca de Tlaxiaco.

1. Introduction

Charophytes are a group of fresh-water green algae that comprise an important part of submerged vegetation in streams, ponds and lakes, estuaries, and swamps; in fact, all sorts of non-marine aquatic habitats. They have a complex morphology composed of a central axis or "stem" made up of long unicellular internodal cells (which in some cases are enclosed by cortex cells), and short multicellular nodes, from which whorls of "branches" originate at more or less regular intervals (Wood, 1965).

Recent charophytes are widely distributed, living in shallow waters of low salinity and an oxygenated bottom at depths of at least 10 m and a maximum of 15–20 m. By studying the charophytes that exist today, we can understand how some limnological conditions of the geological past must have been like (Cohen and Thouin, 1987).

Charophytes can reproduce both vegetatively and sexually. In the latter case, they produce a large number of oospores which, depending on the species and the environmental conditions, develop an ultimate ripening stage involving calcification of the spiral cells surrounding the oospores. The calcified fructifications are termed gyrogonites (Soulié-Märsche and García, 2015). These algae are very well represented in the fossil record from the Jurassic, Cretaceous and Tertiary, where they can be locally abundant, mostly in limestone and marl deposited in freshwater or brackish environments. In these rocks, fossil gyrogonites and parts of the vegetative tallus are often calcified and obviously preserved. They are evidence of the evolution of the charophytes and provide a nearly continuous record of fossil charophytes since the Late Silurian 425 million years ago, constituting the only link between living and fossil charophytes (Mamet *et al*., 1992). During the Devonian and Lower Carboniferous, charophytes were more diverse than in the present (Grambast, 1974).

In some cases, for example in the Purbeck limestone from the lower Upper Jurassic of southern England, the fossil charophytes are so common and diverse that they can be used as zone fossils for biostratigraphy (Feist *et al*., 1995). The preservation of whole plants is not common but may occur and be very striking (Martín-Closas and Diéguez, 1998).

Dufourny de Villiers (1785, in Desmarest, 1812a, b) made the first observations on the gyrogonites and described to the them as "*de petites corps sphériques, couverts de stries très délicates, hélicoïdes, se réunissant aux deux extrémités de l'axe, avaient été signalés, dans les meulières supérieure des environs de Paris associés avec des coquilles lacustres*". Lamarck (1801, p. 401) published a description of these fossils for the first time and established the term gyrogonites for charophycean reproductive organs from the Tertiary (Lower Oligocene, Rupelian) deposits of France. Taking them to be mollusk shells, he named them *Gyrogonites medicaginulus* but it was Léman (1812) who recognized their true plant origin, demonstrating that Lamarck's fossils were calcified charophycean reproductive structures that compared with seeds of aquatic plants of the genus *Chara*.

The first gastropods were exclusively marine. The group initially appeared in the early Cambrian. Gastropod fossils from lower Paleozoic rocks are too poorly preserved for an accurate identification. It was during the Mesozoic era that the ancestors of many of the living forms evolved. The fossil record of freshwater gastropods is irregular at best and likely to considerably underestimate the age and diversity of freshwater lineages (Strong *et al*., 2008). Despite these difficulties, most modern groups appear to make their first appearance during the Jurassic or Cretaceous (Tracey *et al*., 1993). In rocks from the Mesozoic, the gastropods are more common as fossils and their shells are often well preserved. Their fossils are found in freshwater and marine environment strata for example in Jurassic Purbeck marble and early Cretaceous Sussex marble in the south of England, limestone containing the remains of freshwater snail and brackish water gastropods are more common (West, 2013).

In Mexico, there are few mentions of the presence of charophytes. We found references from the Burgos Basin in the Oligocene Non-Marine Frio Formation (Meneses de Gyves, 1950) and another one from the Parras Basin in the Late Cretaceous Cerro Huerta Formation (Weide, 1961; Weide and Murray, 1967); Aguillón-Martínez (2010) reported two taxa of charophytes (*Platychara* and *Porochara gildemeisteri*) from the Campanian Cerro del Pueblo Formation in Rincón Colorado, Coahuila.

From the Difunta Group about 96 km north of Saltillo, Coahuila, *Platychara perlata* and *Porochara* sp. were collected and identified by Peck and Forester (1979).

Also, in the Parras basin, the Mayrán Formation (late Neogene) presents a bedded limestone of mostly wackestone to packstone texture containing usually freshwater components such as charophyte reproductive structures (gyrogonites), gastropods, fish remains, and ostracods (Amezcua Torres, 2012).

In Chiapas in the Limestone Member of the Sierra Madre Formation (Cenomanian) from the Piedra Parada section, Cros *et al*. (1998, p. 314) recognized the mudstone of a hyposaline lagoonal environment with ostracods and charophytes.

Daily and Durham (1966) described three species of charophytes of Miocene age from non-marine strata in the vicinity of Ixtapa, Chiapas, Mexico.

The goal of this paper is to document the presence of the gyrogonites and gastropod assemblage recovered from San Juan Formation beds collected in the northwest of the state of Oaxaca; as well as the dating of these samples containing charophyte fructifications using the occurrence of the larger foraminifera *Labyrinthina mirabilis* Weynschenk which lies adjacent to the beds containing the gyrogonites. In addition, to interpret the paleoenvironment based on paleoecological information of the cahrophytes and larger foraminifera as well as the microfacies study.

2. Geological setting

The study area geographically belongs to the Tlaxiaco Basin (Figure 1), which includes part of the states of Oaxaca, Guerrero and Puebla, within the Sierra Madre del Sur Province, characterized by a tectonic evolution with folding, normal and thrust faults, and intrusive and volcanic events, all of which are included within a complex structure.

According to López Ticha (1985) the Tlaxiaco Basin was developed during the Mesozoic upon the old schist basement (Acatlán-Oaxaca Complex) covered by the Paleozoic continental and/or marine series. In the middle

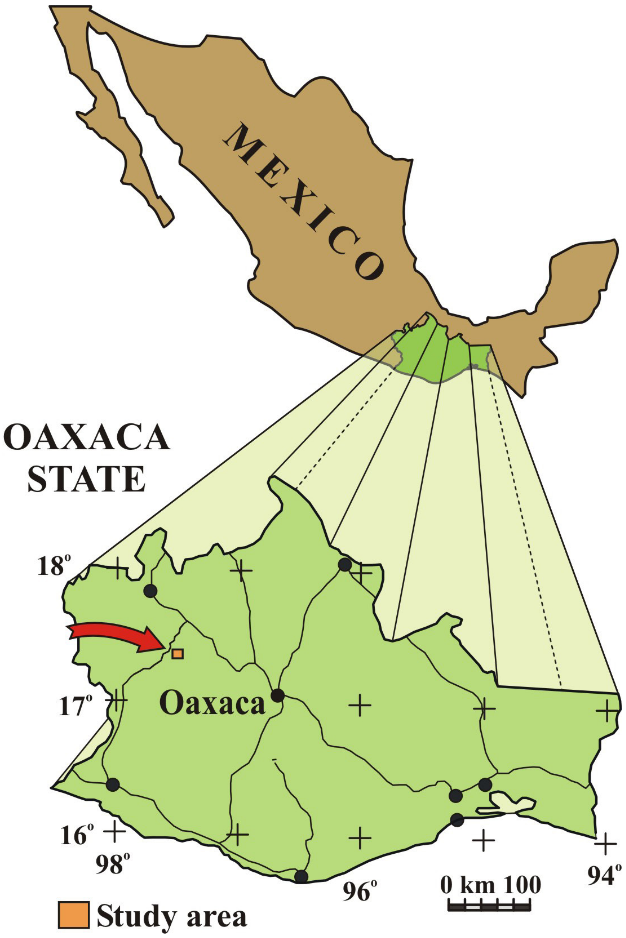

Figure 1. Location of the study area, northwestern Oaxaca State, South Mexico (modified from Ferrusquía-Villafranca *et al*., 2016).

and Late Jurassic continental and shallow-water marine sediments were deposited inside the basin. However, at the end of the Jurassic, the sedimentation was interrupted, and the basin was closed, elevated and partially eroded, before the great Cretaceous transgression, which also flooded the Oaxacan Complex and the Guerrero-Morelos Province. Uplift and folding of the Mesozoic sedimentary infill, about 6,000 meters thick, took place in the Paleocene–Eocene as a result of Laramide Orogeny (Meneses Rocha *et al*., 1994).

The San Juan Formation is a dark gray to black, highly indurate limestone, with micrite texture set in thick bedded and massive strata (Figure 2). The majority of these sedimentary units deposited in the Tlaxiaco Basin are still under informal nomenclature thus the Upper Jurassic deposits are known as Chimeco and Sabinal formations (López-Ticha, 1985; Meneses Rocha *et al*., 1994), due to the very different lithostratigraphic characterization presented by these authors.

3. Material and methods

The samples were collected from the San Juan Formation (informal lithostratigraphic unit). It is located in the Tlaxiaco Basin within the Mixteca Region, northwestern Oaxaca State, in southern Mexico, and its geographical coordinates are 17°20'–17°25' N and 97°28'–97°34' W (Figure 1). For micropaleontological and microfacies analysis, the samples were prepared in thin sections 50 μm thick. The gyrogonites and gastropods are well preserved, as are the larger foraminifera (Figures 3, 4).

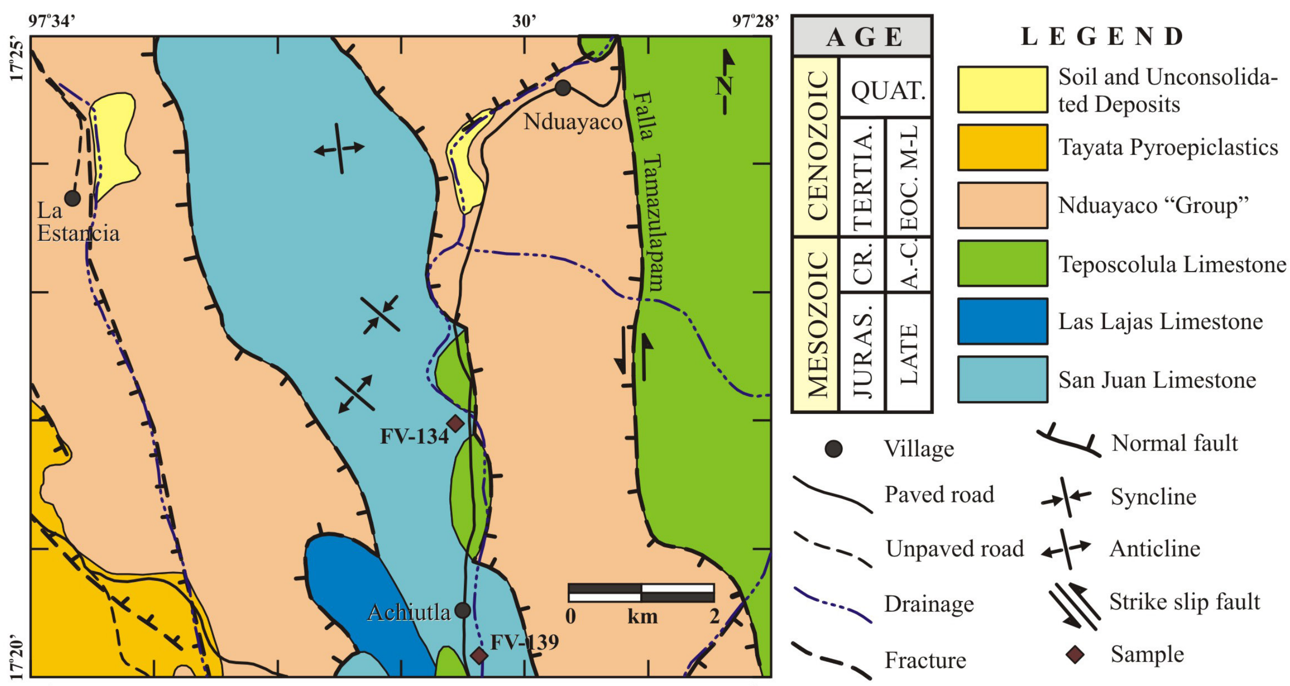

Figure 2. Geologic map of the study area, Oaxaca (modified from Ferrusquía-Villafranca *et al*., 2016).

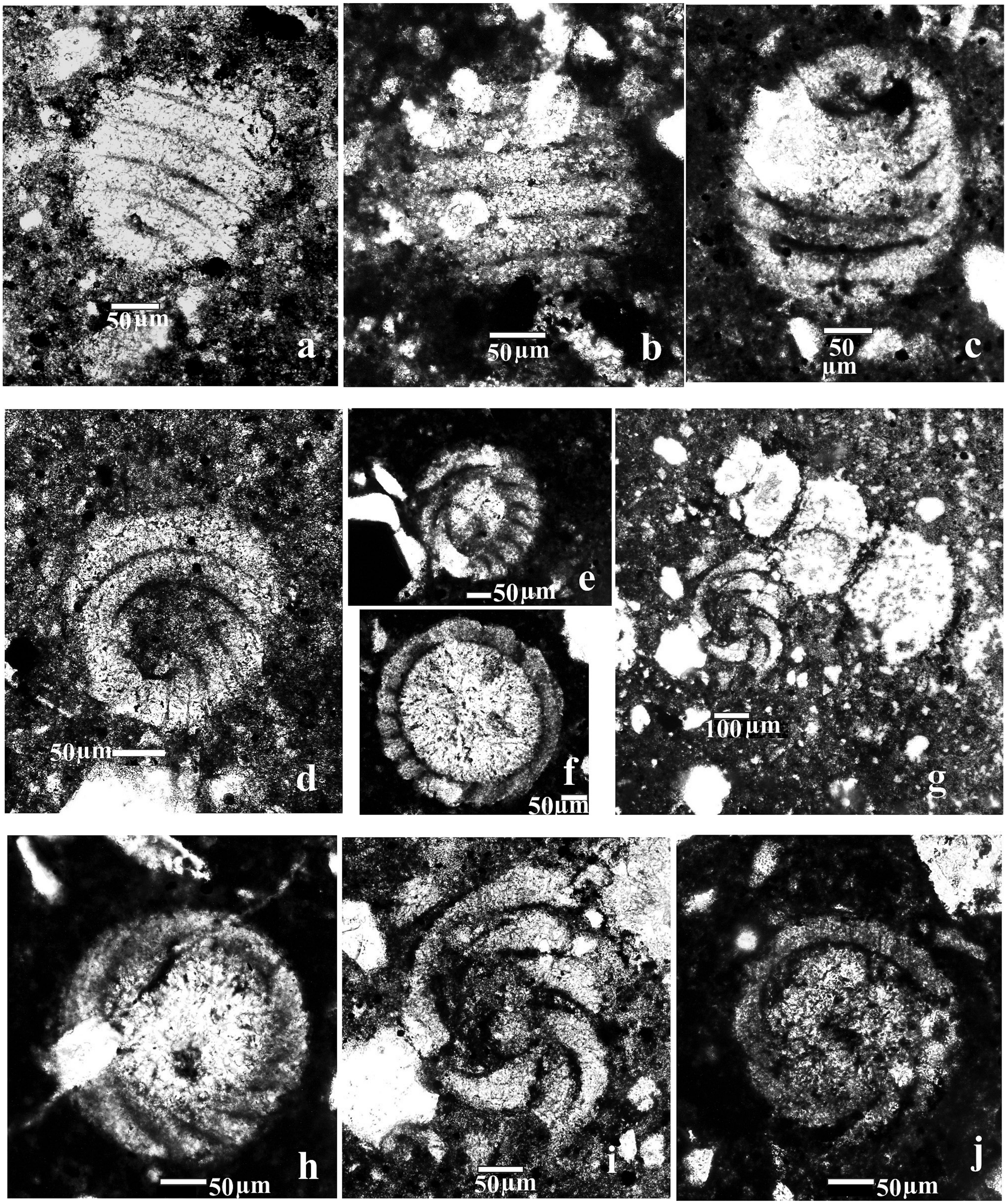

Figure 3. Microfossils from the San Juan Formation. a, b, c: Gyrogonite in tangential longitudinal section, Sample FV-139-1. d: Oblique tangential section of apical area of gyrogonite, Sample FV-139-1. e, f: Gyrogonite view in oblique longitudinal section, Sample FV-139-2. g: Oblique tangential section of a gyrogonite and gastropod, Sample FV-139-3. h: Oblique tangential section showing the orientation of the spiral cells, Sample FV-139-2. i:Detail of Figure 3g showing an oblique tangential section of the gyrogintes's apical area, Sample FV-139-3. j: Polar section of gyrogonite, Sample FV-139-2.

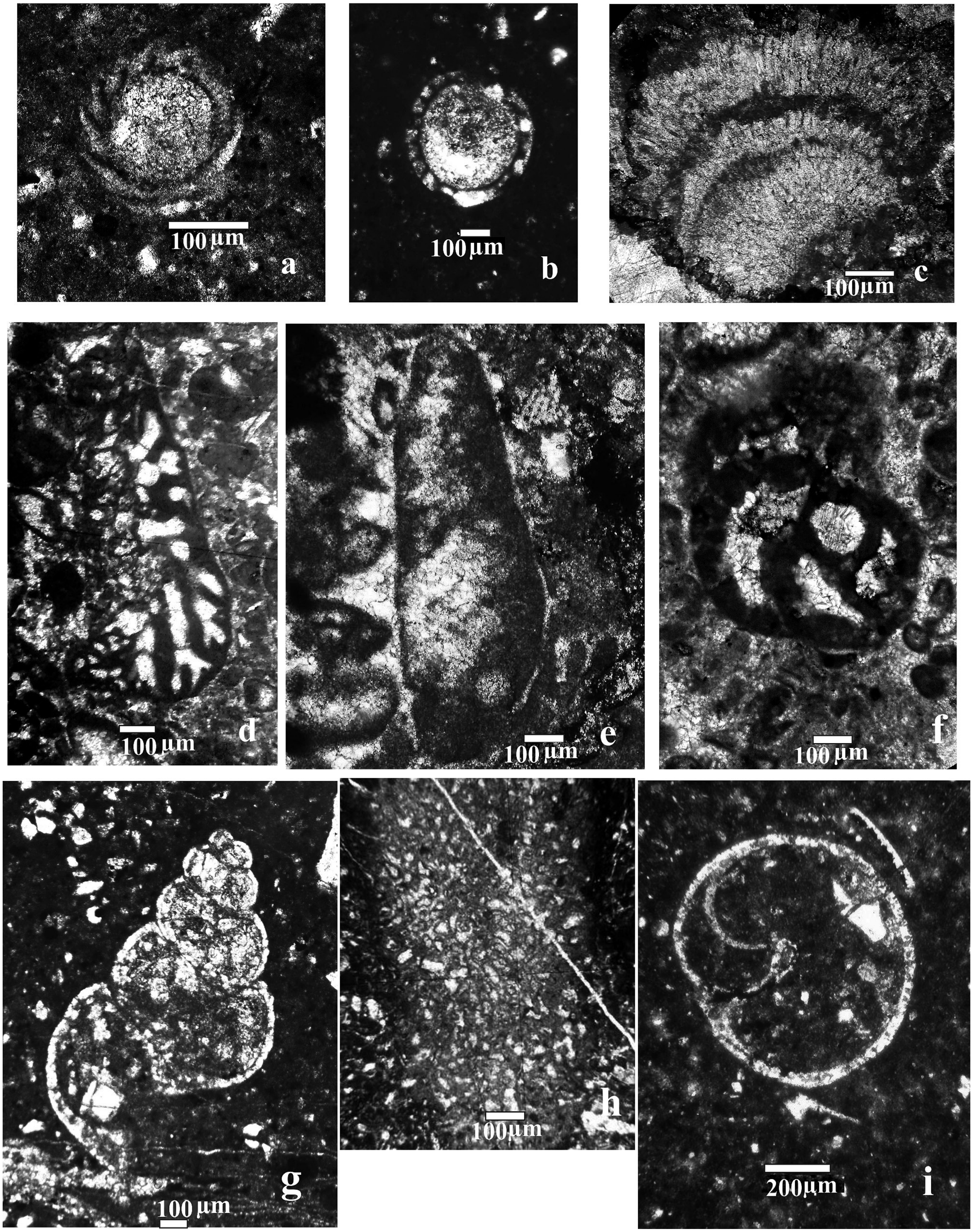

Figure 4. Microfossils from the San Juan Formation. a: Oblique-transversal section of gyrogonite, Sample FV-139. b: Oblique-transversal section of gyrogonite, Sample FV-139. c: Transversal section of Rivulariacean-like cyanobacteria showing the hemispherical thallus, Sample, FV-134-1. d: *Labyrinthyna mirabilis* Weynschenk, Subequatorial section showing the early planispiral coiled becoming uncoiled, Sample FV-134-1. e: Subaxial section of a conical benthic foraminifera with weakly developed central column, showing the horizontal partitions, Sample FV-134-1. f: *Everticyclammina* sp. Longitudinal sections passing through the coiled stage, Sample FV-134-1. g: Gastropod Sample, FV-139-3. h: *Cladocoropsis mirabilis* Felix, Sample FV-134-1. i: Gastropod, Sample FV-139-3.

4. Results

Sample FV-134 is a grainstone-packstone with the larger benthic foraminifer *Labyrinthina mirabilis*, *Everticyclammina* sp., the Rivularaean-like cyanobacteria and *Cladocoropsis mirabilis* (Figures 4 d, e, f, h). It is assigned to a warm marine shallow-water platform environment.

Sample FV-139 consist of a dark micrite mudstone type with charophyte gyrogonites and gastropods (Figure 3 g), considered a lacustrine deposit.

The samples consist of limestone in which the gyrogonites are studied in section. We present various non-oriented sections and we tried to obtain measures and a short description of some specimens. The size is highly variable from 200 µm up to 500 µm in length and 160 µm to 300 µm in width. The gyrogonites are spherical and slightly ovoidal in shape, composed of clockwise coiled spiral cells, base broadly rounded, six to seven convolutions with concave spiral cells almost uniform in width, and are separated by narrow and well defined intercellular ridges (Fig. 3 a, b, c). The cross-sections show a charophyte gyrogonite with preserved walls in which the inside is replaced with sparry calcite (Figures 3 e, f; 4 a, b).

4.1. Age

The studied area consists of continental fresh-water sediments and shallow-water marine deposits, which contain the larger benthic foraminifera *Labyrinthina mirabilis*; this species was described by Weynschenk (1951) of the Sonnwend mountains (West Austria) from a limestone reef dated as Upper Triassic. Later, in 1956, the same author revised the age of the species and placed it in the Upper Jurassic. This species has been recorded in the Kimmeridgian of the Albacete province in Spain (Fourcade and Neumann, 1966). In Portugal, the French Pyrenees and Bulgaria *Labyrinthina mirabilis* was recorded from the Oxfordian–Kimmeridgian (Ramalho, 1971; Pelissé *et al*., 1984; Ivanova and Koleva-Rekalova, 2004) respectively.

Therefore, the entire interval including the continental lacustrine limestone with charophyte gyrogonites and gastropods is considered as Oxfordian–Kimmeridgian.

4.2. Paleoenvironment

The origin and distribution of lacustrine carbonates in lake basins are controlled by the presence of carbonate source rocks, the tectonic situation (hydrology) and the climate of the depositional lake system (Soulié-Märsche and García, 2015). The microfacies consists of charophycean algal mudstone with detritical quartz carries gyrogonites and gastropods, we inferred a lacustrine environment with little terrigenous input. According to Flügel (2004) this microfacies type could be comparable to standard microfacies Lacustrine Microfacies Type 7. The group of larger foraminifera provided a valuable means for defining the conditions in which the sediments were deposited, so we interpreted it as a shallow-water marine carbonate platform. The bioclastic grainstone–packstone is interpreted as Standard Microfacies Type (SMF) 18 (Flügel, 2004), corresponding to Facies Zone 7 (ZF 7) of Wilson (1975).

5. Conclusions

The succession studied is composed of two types of deposit; belonging respectively to continental lacustrine and to shallow-water marine environments. The most important finding of this study is the record of Late Jurassic charophyte gyrogonites and gastropods, which represent a continental lacustrine environment, as well as the larger foraminifera occurrence for dating this interval. For the studied interval we inferred an Oxfordian-Kimmeridgian age on the basis of the stratigraphic distribution of the larger foraminifer *Labyrinthina mirabilis*. The charophyte-bearing deposits are interpreted as part of the terrestrial-influenced part of fresh-water facies representing a continental lacustrine environment, whereas a shallow-marine platform deposit is inferred by the occurrence of the larger foraminifera, the Rivulariacean-like cyanobacteria and *Cladocoropsis mirabilis*.

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and micropaleontology. She also organized the National Paleontology Collection to safeguard research material and founded the journal *Paleontología Mexicana*.

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