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GEOBIOS

Geobios 44 (2011) 601–608

Original article

The oldest Ordovician foraminifers (*Oepikodus evae* conodont Zone, Floian) from South America☆

Les plus vieux foraminifères (Zone à conodontes Oepikodus evae*, Floien) d'Amérique du Sud*

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Received 15 October 2010; accepted 10 February 2011
Available online 12 October 2011

Abstract

The oldest occurrences of the monothalamous foraminifer species *Amphitremoida longa* Nestell and Tolmacheva and *A. laevis* Nestell and Tolmacheva are found in the San Juan Formation together with conodonts of the *Oepikodus evae* Zone of the Floian (Lower Ordovician), in the Salagasta 2 section, southern Precordillera, Argentina. These discoveries represent the oldest record for foraminifers in South America. The foraminifers, species of which were originally described from the Lower Ordovician of northwestern Russia, are found in shallow high energy carbonate platform deposits in the Precordillera, together with a North Atlantic province conodont fauna. The carbonate sequence of the San Juan Formation in the Salagasta region is interpreted as a succession ranging from shallower tidal deposits to carbonate crinoidal shoaling bar deposits.
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Keywords: Foraminifers; Conodonts; Lower Ordovician; Precordillera; Argentina

Résumé

Les plus anciennes occurrences des espèces de foraminifères monothalames *Amphitremoida longa* Nestell et Tolmacheva et *A. laevis* Nestell et Tolmacheva sont identifiées dans la Formation San Juan, aux côtés de conodontes de la Zone à *Oepikodus evae* (Floien, Ordovicien inférieur), dans la coupe de Salagasta 2, Précordillère méridionale, Argentine. Il s'agit des plus anciennes occurrences de foraminifères en Amérique du Sud. Ces espèces, initialement décrites dans l'Ordovicien inférieur du nord-ouest de la Russie, proviennent de dépôts de plateformes carbonatées peu profondes et à haute énergie de la Précordillère ; elles sont associées à des faunes de conodontes de la province nord-atlantique. La séquence carbonatée de la Formation San Juan, région de Salagasta, est interprétée comme une succession allant de dépôts tidaux peu profonds à des dépôts carbonatés de haut-fond à crinoïdes.
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Mots clés : Foraminifères ; Conodontes ; Ordovicien inférieur ; Précordillère ; Argentine

1. Introduction

The San Juan Formation has its southernmost outcrops in the Salagasta region, in the northern part of Mendoza Province, southern Precordillera. The outcrops at Salagasta consist of Ordovician carbonate (San Juan and Gualcamayo Formations), Silurian-Devonian clastics (Villavicencio Formation), and Triassic fluvial sandstone (Uspallata Group) (Rolleri and Criado Roqué, 1969; Beresi et al., 1998) (Figs. 1 and 2). The San Juan Formation outcrops at Salagasta have been previously studied by Beresi et al. (1998) and Heredia et al. (2009), and are composed mostly of white and grey carbonate. The lower contact is faulted (thrust fault) and the Ordovician sequence overlies Triassic age strata of the Uspallata Group. The top is covered by black carbonate and shale of the Lower-Middle?

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doi:10.1016/j.geobios.2011.02.007

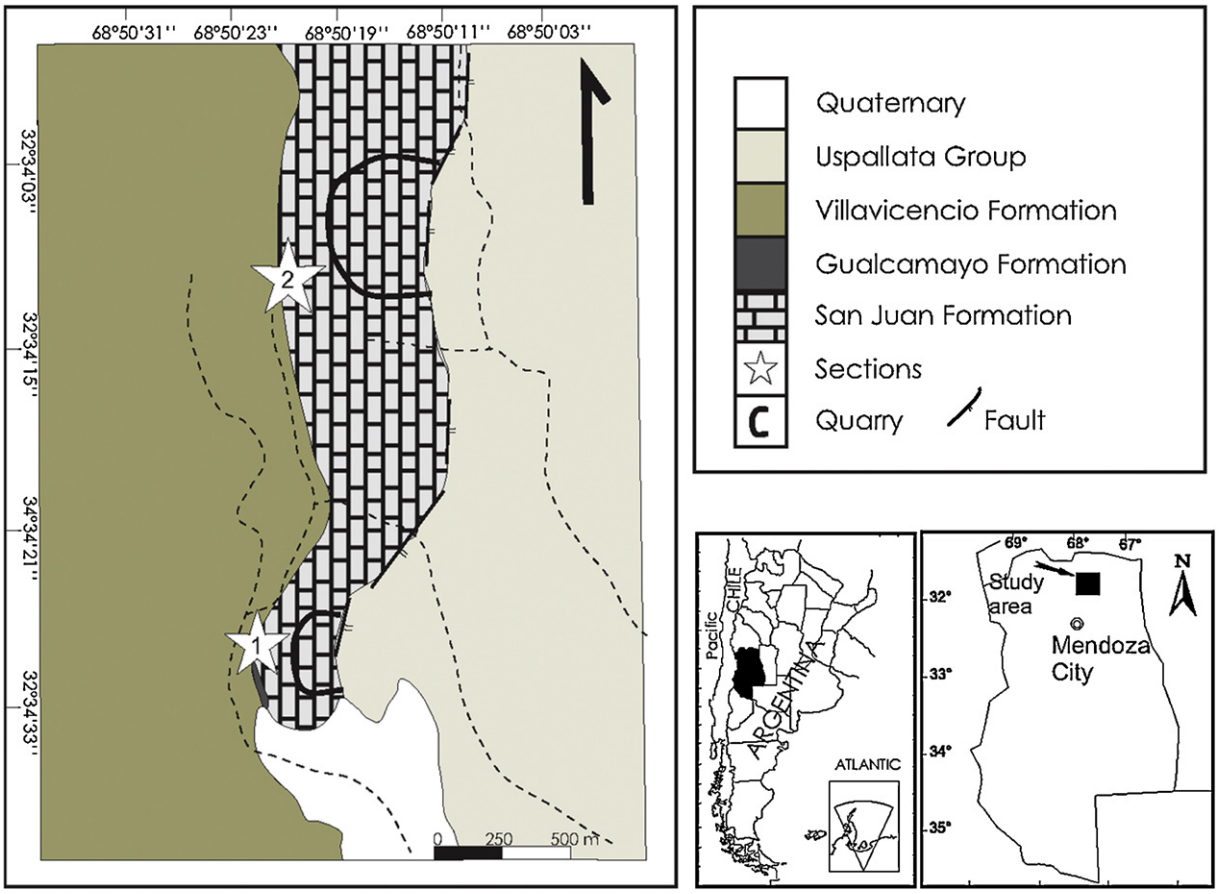

Fig. 1. Sierra de La Higuera location map and Geological map showing the Salagasta 1 and Salagasta 2 sections. Dotted lines indicate small streams.

Ordovician Gualcamayo Formation. The maximum thickness of the San Juan Formation in the Salagasta region is 70 m. It is represented by shallow water carbonate platform deposits with high energy bioclastic sand barriers at the top (Heredia et al., 2009). Macro- and microfossils are present mostly in the middle and upper part of the San Juan Formation where brachiopods, trilobites, crinoids, gastropods, conodonts and sponge spicules are common components.

Two sections were sampled for conodonts. One of them, the Salagasta 2 section (Fig. 1) contains agglutinated foraminifers that represent the oldest record of these forms from South America. This section is the second section in the Precordillera where foraminifers and conodonts are found together. The first one has been recorded by Nestell et al. (2009) from Middle Ordovician strata in the San Juan province of the Cerro Viejo region, Central Precordillera.

The appearance of the guide conodonts *Oepikodus evae* Lindström in the middle and upper part of the section (Fig. 2: samples Sal10 and Sal0 in the section Salagasta 2), and *Texania heligma* Pohler at the very top of the San Juan Formation and lowermost part of the Gualcamayo Formation (Fig. 2: Salagasta 1 section), indicates the *Oepikodus evae* and *Oepikodus intermedius* zones (Floian stage, Lower Ordovician) in the Sierra de La Higuera (Beresi et al., 1998; Heredia et al., 2009).

2. Stratigraphy of the San Juan Formation

Beresi et al. (1998) divided the San Juan Formation into two members: the lowermost represented by massive limestone (30 m-thick) and the uppermost composed of thin bedded limestone (15.5 m) and crinoidal limestone intercalated with silty limestone (25 m). A carbonate breccia is present in the lower part of the Upper Member in both sections (Fig. 2). Heredia et al. (2009) suggest low to middle energy for the deposition of the Lower Member, which is indicated by sedimentary structures present in the shallow platform carbonate microfacies. In contrast, the strata of the Upper Member are characterized by pelletoidal packstone and fossiliferous grainstone. The uppermost part of the Upper Member of the San Juan Formation is composed of crinoidal grainstone showing mechanical distribution of the crinoidal bioclasts. The Salagasta 1 section ends with 6 m of black mudstone and pelloidal wackestone of the Gualcamayo Formation indicating a deepening of the basin whereas in the Salagasta 2 section this interval is absent (Fig. 2).

The Salagasta 2 section is located at S32° 34′ 13.1″ W68° 50′ 16.8″ at the southern end of the Sierra de La Higuera. In this section, the San Juan Formation is bounded by two faults (Figs. 1 and 2). The sample that provided the tests of foraminifers and conodonts was taken from the crinoidal grainstone (sample Sal0) (Fig. 2).

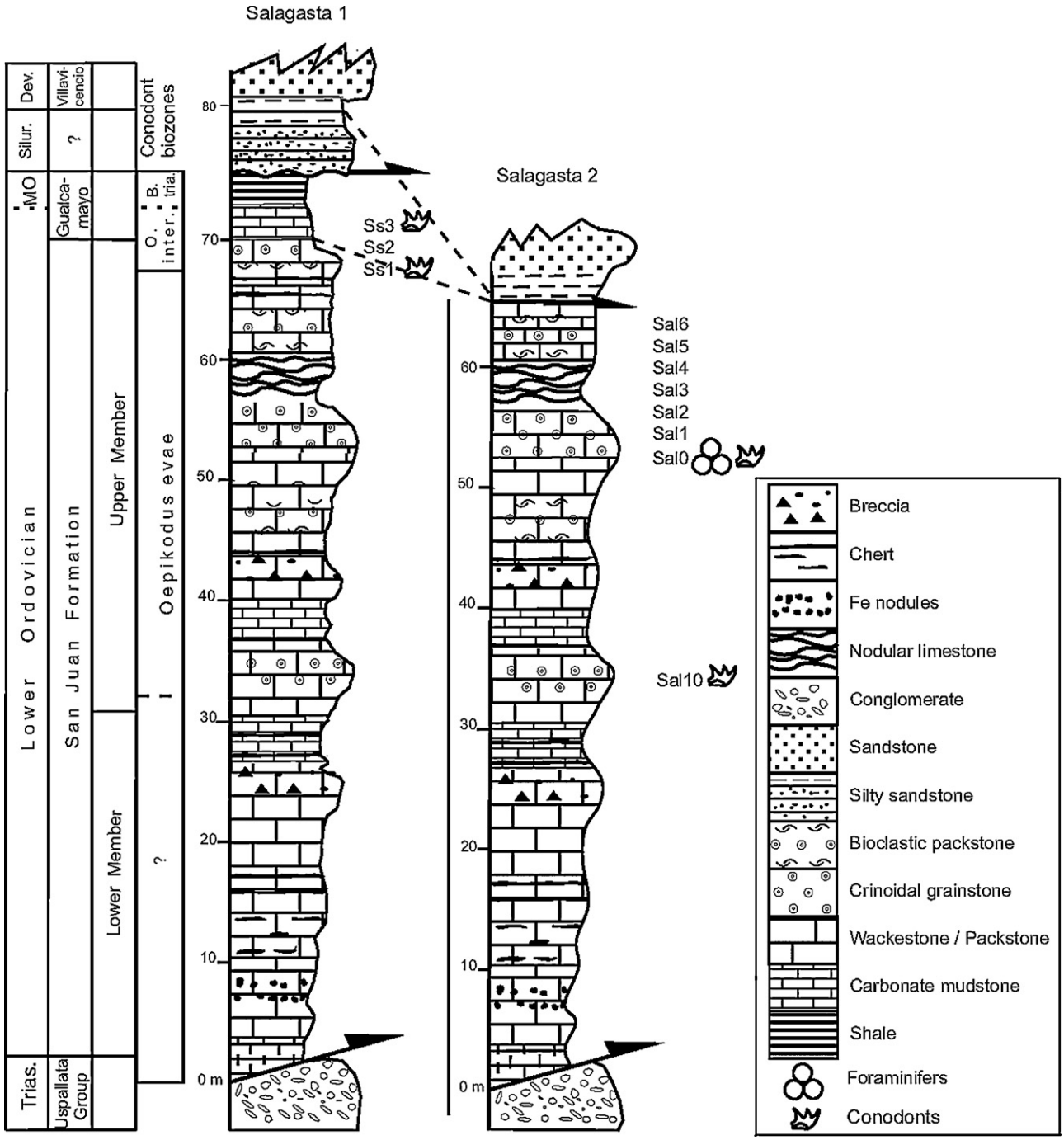

Fig. 2. Stratigraphic sections of the San Juan Formation in Salagasta region. Abbreviations: MO: Middle Ordovician, O. inter.: *Oepikodus intermedius*, B. tria.: *Baltoniodus triangularis*.

3. Material and method

Several samples of about 1.5 kg each were collected from the section Salagasta 2 (Fig. 2). Only sample Sal0 produced scarce foraminifers (26 specimens) and conodonts together with crinoidal debris, ostracods, sponge spicules, and trilobite spines. For extracting the microfossils, the samples were treated with 10% acetic acid following the standard methods of Stone (1987). The preservation of the conodonts and foraminifers is poor and the CAI of conodonts is 3 (Epstein et al., 1977). This collection is housed in INSUGEO, Universidad Nacional de Tucumán, under accession numbers PIL-MPF 3070 to 3079.

4. Systematic palaeontology

The authors use the system of higher protozoan taxa proposed by Cavalier-Smith (2002), and higher foraminiferal taxa proposed by Kaminski (2004) and Mikhalevich (2004).

Kingdom PROTOZOA Goldfuss, 1817; emend. Owen, 1858.

Subkingdom GYMNOMYXA Lankester, 1878 stat. nov. emend. Cavalier-Smith, 2002.

Infrakingdom RHIZARIA Cavalier-Smith, 2002.

Phylum RETARIA Cavalier-Smith, 1999 stat. nov. Cavalier-Smith, 2002.

Subphylum FORAMINIFERA (d'Orbigny, 1826) Eichwald, 1830 stat. nov. Margulis, 1974; stat. emend. Cavalier-Smith, 2002 [pro phylum Foraminifera].

Class ASTRORHIZATA Saidova, 1981; emend. Mikhalevich, 1995.

Subclass ASTRORHIZANA Saidova, 1981.

Order ASTRORHIZIDA Lankester, 1885 [nom. correct. Calkins, 1909 pro order Astrorhizidea Lankester, 1885; = Astrorhizida Fursenko, 1958].

Family HIPPOCREPINELLIDAE Loeblich and Tappan, 1984; emend. Mikhalevich, 1995.

Genus ***Amphitremoida*** Eisenack, 1938; emend. Nestell and Tolmacheva, 2004 [= *Croneisella* Dunn, 1942; = *Pachyammina* Eisenack, 1967; = *Quasibeothuka* Wang in Wang et al., 2008].

Type species: *Amphitremoida citroniforma* Eisenack, 1938.

Occurrence: Lower Ordovician, Floian (*Tetragraptus phyllograptoides* graptolite Zone)–Carboniferous, Mississippian (Tournasian).

Remarks: a detailed discussion about the genus *Amphitremoida* and its synonymy and distribution is given in Nestell and Tolmacheva (2004). Recently, Wang et al. (2008) published new discovery of radiolarians from the Middle Ordovician (Dapingian) Heituao Formation in the Kuruktag region, Tarim basin, Xinjiang, China. In this paper, Wang described four new genera (*Quasibeothuka*, *Batoballa*, *Protosegmentum* and *Tetrasphaera*) and 10 new species of the listed genera that he referred to the radiolarians. We note here that only the genus *Tetrasphaera* probably belongs to the Radiolaria according to its morphology (Wang et al., 2008: pl. 2, fig. 10).

The genus *Quasibeothuka* with type species *Q. fusiforma* is characterized by a fusiform shape of the test, two polar ''spines'' which appear to be apertures located on the necks, and furthermore, these apertures differ: one has a conical shape, and the other is of a thin cone shape. Also, the tests of this genus have a very large size (~ 0.65 mm) compared with radiolarians. The wall structure, with reference to fig. 2 on pl. 1 in Wang et al. (2008), is not spongy, but agglutinated. All the features mentioned above are characteristic for the agglutinated foraminiferal genus *Amphitremoida*. Moreover, Wang et al. (2008) wrote that tests of the genus *Quasibeothuka* are hollow inside, which coincides with the description of the internal structure of monothalamous foraminifers. Based on all morphological features mentioned above, we consider that the genus *Quasibeothuka* is a junior synonym of the genus *Amphitremoida* and should be referred to the Foraminifera.

We also consider that the tests of the species named *Q. fusiforma*, *Q. ovata*, and *Q. ellipsoidala* illustrated on pl. 1, figs. 1, 2, 3, 6, 8, 10 (Wang et al., 2008) are the same species with just morphological variations of the test, and are very similar to *Amphitremoida minuta* Eisenack (1967: pl. 25, fig. 8) which, according to Nestell and Tolmacheva (2004), is a junior synonym of the species *A. fusiforma* Eisenack. Wang's species (in Wang et al., 2008) differ from that species by having slightly larger test sizes.

Wang's species illustrated on pl. 1, fig. 5 as *Quasibeothuka ovata*, and figs. 11 and 12 as *Q. ellipsoidala* probably belong to the foraminiferal monothalamous agglutinated genus *Ordovicina* Eisenack, 1938, that is characterized by a vase shape of the test with one.

We are not sure that tests illustrated by Wang et al. (2008) on pl. 1, fig. 4 as *Quasibeothuka fusiforma*, fig. 7 as *Q. ovata*, fig. 9 as *Q. ellipsoidala*, figs. 14, 17, 18 as *Q. longifusiforma*, fig. 15 as *Q. bithornya*, and fig. 16 as *Beothuka longispiniforma* belong to radiolarians either. According to their morphology as fusiform tests with long thin outgrowths, they probably belong to the xenophyophorean genus *Pelosina* Brady, 1879 (Bell, 1996; Nestell et al., 2009 with references).

Wang's species (in Wang et al., 2008) illustrated on pl. 1, fig. 13 as *Beothuka longispiniforma*, probably indeed belong to the radiolarian genus *Beothuka* Aitchison, Flood and Malpas (Aitchison et al., 1998) because of its small shell size with two robust and long polar spines. Wang's new genus *Protosegmentum* with type species *P. xinjiangensis* described by him as a radiolarian is a junior synonym of the hexactinellid sponge genus *Polycornua* described by Botting (2005) from the Middle Ordovician (Llanvirn) of the Llangegley rocks Lagerstätte in Wales, England. Wang's new genus *Batoballa* (in Wang et al., 2008) is probably also not a radiolarian because of the very large (for radiolarians), thin and long cigar-shaped test that is not observed in any radiolarian genus.

Amphitremoida longa Nestell and Tolmacheva.

Fig. 3(3).

2004. *Amphitremoida longa* nov. sp. - Nestell and Tolmacheva, p. 264, pl. 4, figs. 1-3; pl. 10, fig. 3.

Material: seven specimens (in 0.54 kg of sample).

Occurrence: Lower Ordovician, Floian; Argentina, Mendoza Province, southern Precordillera, Salagasta region, Salagasta 2 section, San Juan Formation, *O. evae* conodont Zone; northwestern Russia, Lava River section, Leetse Formation, upper part of the *Paroistodus proteus* and lower part of the *Prioniodus elegans* conodont zones.

Description: test is free, monothalamous, fusiform, elongate, and brown in color, with two apertures, one at each end. Apertures are located on small necks. One neck is slightly narrower and smaller than the other. Wall is agglutinated. Dimensions: test length (L) 0.38 mm, width (W) 0.16 mm, ratio L/W 2.3; width of the neck of one aperture 0.04 mm, height 0.015 mm; width of the neck of the other aperture 0.05–0.06 mm, height 0.025 mm.

Remarks: the described specimens are very similar to *Amphitremoida longa* Nestell and Tolmacheva (2004: p. 264, pl. 4, figs. 1–3, pl. 10, fig. 3), slightly differ by the presence of distinct small necks on both apertural ends.

Amphitremoida laevis Nestell and Tolmacheva.

Fig. 3 (4, 5).

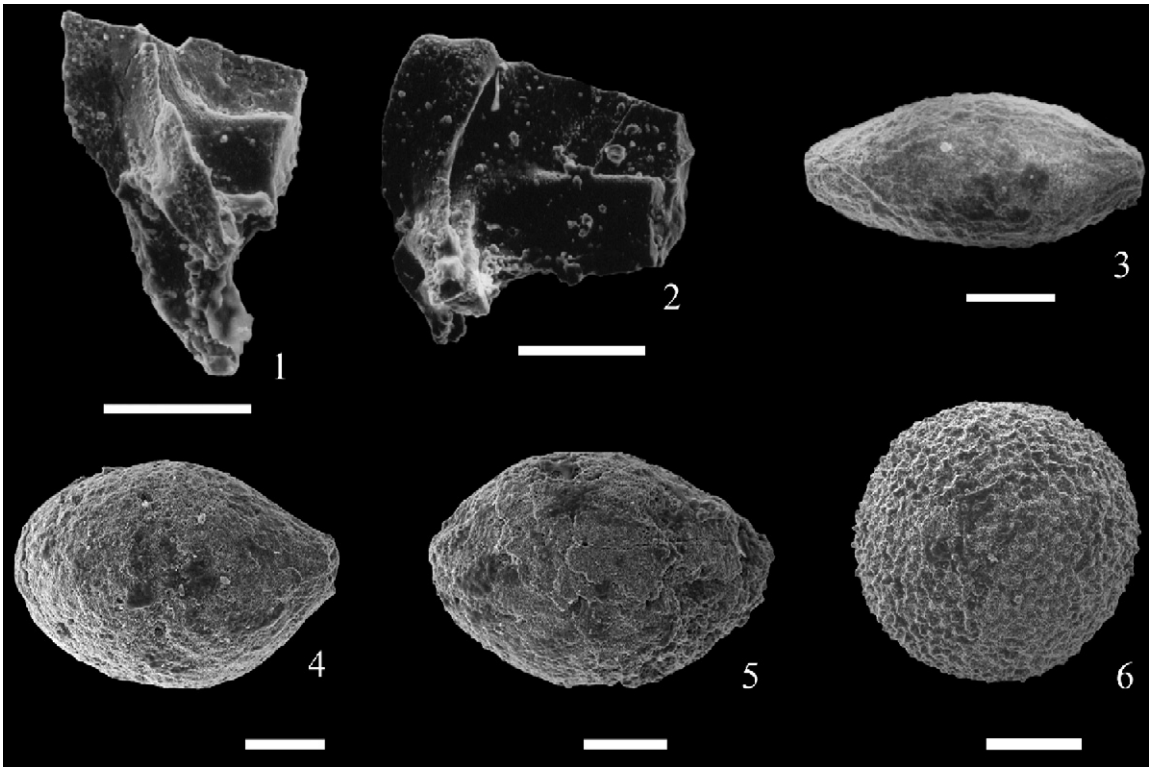

Fig. 3. Scanning Electron Microscope microphotographs of conodonts and foraminifers. All figured specimens are from the Floian, San Juan Formation, Salagasta 2 section, sample Sal0; northern Mendoza Province. **1, 2**. *Oepikodus evae* Lindström, lateral view of P elements, PIL-MPC 3075(1, 2). **3**. *Amphitremoida longa* Nestell and Tolmacheva, PIL-MPF 3070 (1). **4, 5**. *Amphitremoida laevis* Nestell and Tolmacheva; 4, PIL-MPF 3071(1); 5, PIL-MPF 3071(2). **6**. Incertae Sedis 2, PIL-MPF 3072(1). Scale bars = 100 μm.

2004. *Amphitremoida laevis* nov. sp. – Nestell and Tolmacheva, p. 262, pl. 2, fig. 2; pl. 3, figs. 1–5; pl. 10, figs. 4–5.

Material: two specimens.

Occurrence: Lower Ordovician, Floian; Argentina, Mendoza Province, southern Precordillera, Salagasta region, Salagasta 2 section, San Juan Formation, *O. evae* conodont Zone; northwestern Russia, Lava River section, Leetse Formation, upper part of the *Paroistodus proteus* and lower part of the *Prioniodus elegans* conodont zones.

Description: test is free, monothalamous, lemon-shaped, with a slightly expressed small projection on one end and rounded on the other end. The surface is irregular but this feature could be a result of acid etching. Wall is probably agglutinated. Dimensions: test length (L) 0.40–0.42 mm, width (W) 0.29 mm, ratio L/W 1.40–1.47; width of the projected aperture 0.07 mm height 0.001 mm.

Remarks: described specimens are very similar to the type species.

Phylum UNCERTAIN.

Incertae Sedis 2.

Fig. 3(6).

Material: four specimens.

Remarks: such spherical forms with rugose surface are known from the Middle Ordovician, Darriwilian, *Eoplacognathus pseudoplanus/Dzikodus tablepointensis* conodont Zone of the San Juan Formation in Cerro Viejo region, Argentina (Nestell et al., 2009). These forms are still of uncertain identity.

5. Discussion

5.1. Foraminifers

The first foraminifers from Argentina were found in the upper part of the San Juan Formation of the Del Aluvión creek section in the Cerro Viejo region, Central Precordillera, together with conodonts of the *Eoplacognathus pseudoplanus/Dzikodus tablepointensis* Zone indicating a Darriwilian (Middle Ordovician) age. This assemblage of foraminifers consists of the monothalamous agglutinated genera *Lakites*, *Amphitremoida*, *Lavella*, *Ordovicina* and the xenophyophorean *Pelosina* (Nestell et al., 2008, 2009). In the studied section at Salagasta, the foraminifers are represented by several agglutinated monothalamous tests of the species *Amphitremoida longa* Nestell and Tolmacheva, *Amphitremoida laevis* Nestell and Tolmacheva, and Incertae Sedis 2 (Fig. 3(3–6)). The species *Amphitremoida longa* and *Amphitremoida laevis* are known from the Lower Ordovician, *Tetragraptus phyllograptoides* graptolite Zone, corresponding to the *Tetragraptus approximatus* graptolite Zone that marks the lower boundary of the Floian (upper part of the *Paroistodus proteus* and lower part of the *Prioniodus elegans* conodont zones) of the Russian part

of Baltoscandia (Nestell and Tolmacheva, 2004). The foraminifers at the Salagasta 2 section have been found together with conodonts of the *O. evae* conodont Zone (Fig. 3(1, 2)) that characterize the upper part of the Floian.

Early Ordovician foraminifers from Argentina appear to be related to a North Atlantic or Baltic conodont and foraminifer fauna, where the uppermost part of the *Paroistodus proteus* and the lowermost part of the *Prioniodus elegans* conodont zones is characterized mainly by the presence of the genus *Amphitremoida*. Thus, the entire Floian is characterized by the presence of foraminifers of the genus *Amphitremoida*. Ordovician foraminifers have been reported from only a few places in the world: Baltoscandia (Eisenack, 1954, 1967, 1969; Bykova, 1956; Schallreuter, 1983, 1985; Riegraf and Niemeyer, 1996; Nestell and Tolmacheva, 2004), the Bohemian Massif in the Barrandian area (Bubík, 1995, 1997; Holcová, 1999), North America (Moreman, 1930, 1933; Conkin and Conkin, 1965, 1977; Gutschick, 1986), South America, Argentina, Cerro Viejo region (Nestell et al., 2008, 2009), and recently China (Wang et al., 2008; see above, remarks about the genus *Amphitremoida*). In these regions a few assemblages of foraminifers have been described from strata of most of the new global Ordovician stages except for the Tremadocian and Hirnantian.

Recently, Sabirov and Gushchin (2006) published Early Ordovician calcareous foraminifers from the Beshtash Formation in the interfluve of the Kainar-Karagain area (southern slope of the Talass Mountains) of Tien Shan region, Kyrgyzstan. These authors described 12 new species of the calcareous monothalamous foraminifer genera *Parathurammina*, *Parathuramminites*, *Bisphaera*, *Archaesphaera*, and *Vicinesphaera*. Vishnevskaya and Sedaeva (2002a, 2002b) showed that all of these genera but *Bisphaera* are radiolarians, the tests of which were calcified under diagenesis. We are not sure that Sabirov and Gushchin's species of the genus *Bisphaera* belong to foraminifers because of the irregular shape of their tests, the uneven thickness of the wall, ''abrupt constriction and bends of the wall'' and also ''angular projections'' (Sabirov and Gushchin, 2006: p. 15). Thus, we consider that ''calcareous'' monothalamous foraminifers did not exist in the Early Ordovician, probably not in the entire Ordovician and even possibly not in the Silurian. Trustworthy findings of calcareous foraminifers are well-known from the Devonian.

5.2. Conodonts

Previous works on biostratigraphic data come from Hünicken et al. (1996) and Beresi et al. (1998), where the *O. evae* conodont Zone was defined for the Salagasta 2 section. Studies in progress allow the assignment of new conodonts found in Salagasta region to zones already recorded in the Argentine Precordillera: the *O. evae* Zone and the *O. intermedius* Zone. The assemblage of the *O. evae* Zone is similar to the ''Fauna B'' defined by Serpagli (1974) for the first time at the San Juan River section (San Juan) for Argentina and South America. Recently, the *O. evae* Zone was noted for several precordillerean localities (an exhaustive list is presented in Mestre, 2008), and also in allochtonous blocks in the Ponón Trehué Formation (San Rafael, Mendoza) (Lehnert et al., 1997).

The widely spread *O. evae* Zone characterizes a thick part of every outcrop of the San Juan Formation, ranging from 40 to 230 meters in thickness (Beresi and Heredia, 1992). A maximum flooding surface is recorded at the base of the biozone and represents a change in mud-supported microfacies with a shallowing-upward sequence of grainstone and reef facies (Cañas and Aguirre, 2005).

Zonal index-species of the North Atlantic and North American Midcontinent biostratigraphic successions are recognizable in the Salagasta 2 section conodont faunas. The occurrence of *O. evae* and *Texania heligma* in the San Juan Formation suggests the *O. evae* Zone of the North Atlantic faunal scheme, or the *Reuterodus andinus* to *Cooperignathus aranda* zones (upper part of the Ibexian stage) of the North American Midcontinent succession.

The *O. evae* Zone has been recognized in Ordovician strata on almost all continents. A global highstand of the sea level took place during this time interval (references in Nielsen, 2004). This global highstand allowed deposition of thick carbonate sequences in Ordovician basins (except in Siberia) that can also be recognized in strata of the San Juan Formation (Beresi and Heredia, 1992).

6. Conclusions

The oldest foraminifers of the monothalamous species *Amphitremoida longa* Nestell and Tolmacheva and *A. laevis* Nestell and Tolmacheva have been found in the San Juan Formation together with conodonts of the *O. evae* conodont Zone of the Floian, Lower Ordovician in the Salagasta 2 section, southern Precordillera, Argentina. These discoveries represent the oldest record for foraminifers in South America. The species of foraminifers, originally described from the Lower Ordovician of northwestern Russia, appeared associated with shallow high energy carbonate platform deposits in the southern Precordillera, together with a North Atlantic province conodont fauna.

Acknowledgements

Authors thank the CONICET for economical support through the research project PID 6555. The authors are grateful to Dr. Merlynd Nestell (Arlington, USA) for valuable comments and English checking, and to Drs Tatiana Tolmacheva (St. Petersburg, Russia), Graciela Sarmiento (Madrid, Spain) and Michael Kaminski (London, UK) who reviewed this manuscript and made suggestions that improved this paper.

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