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# Early Cambrian archaeocyathan limestone blocks in low-grade meta-conglomerate from El Jagüelito Formation (Sierra Grande, Río Negro, Argentina)

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**ABSTRACT**

Massive grey limestone blocks containing a fairly diverse but poorly preserved archaeocyath fauna were recovered from a meta-conglomerate bed in the El Jagüelito Formation (Sierra Grande area, Eastern North Patagonian Massif, Río Negro, Argentina). This is the first documented reference of the presence of archaeocyaths in continental Argentina. Seven different taxa were identified, preliminary described and figured. Recrystallization of the skeletons due to regional low-grade metamorphism and deformation of the unit does not allow observation of key detailed features and prevents identification to genera and species. Nevertheless, the specimens studied show general affinities with archaeocyathan assemblages from the Australia-Antarctica palaeobiogeographic province and indicate a middle Early Cambrian (Atdabanian-Botomian) maximum age for the deposition of the El Jagüelito Formation protoliths. The similarities between the North Patagonian Early Paleozoic El Jagüelito Formation and those rocks from Antarctica suggest a geologic and biologic common history of these regions on the same southwest margin of Gondwana during that time.

**KEYWORDS** Archaeocyatha. Early Cambrian. El Jagüelito Formation. Low-grade metamorphism. North Patagonian Massif. Argentina.

## INTRODUCTION

The protolith depositional age of the very low- to low-grade meta-sedimentary rocks of the El Jagüelito Formation (Sierra Grande, Río Negro Province, Argentina) has been controversial, since the biostratigraphic value of their scarce fossils and trace fossils has only been sufficient to define the age in a wide sense. For instance, inarticulate brachiopods (linguloids) were described from this Formation and assigned to the "pre-Silurian, Lower Paleozoic" (Arnolds, 1952). The subsequent revision of these fossils made by Braitsch (1965) did not provide more systematic information about them. In addition to being poorly known, the specimens are not available in any collection, and then it was impossible to provide a more precise age for the sedimentation of the El Jagüelito Formation (Manceñido and Damborenea, 1984).

Trace fossils described by González et al. (2002) in phyllites, together with the U-Pb zircon magmatic crystallization age of 476Ma of a granitoid pluton that intrudes these rocks (Varela et al., 1997, 1998), allow discarding a Precambrian age and constraint the sedimentation age range between Cambrian and Early Ordovician (Tremadocian). U-Pb detrital zircon provenance age pattern for a meta-greywacke has a youngest peak at ~535Ma, which was interpreted as the maximum possible sedimentation age of the unit (Pankhurst et al., 2006), reinforcing the conclusions of González et al. (2002).

Recent detailed geological mapping and structural and metamorphic analyses revealed the occurrence of archeocyaths within meta-sedimentary rocks of the El Jagüelito Formation (41º39'S-65º25'W, Fig. 1A, B). This is the first record of archeocyaths in continental Argentina. The fossils are in limestone blocks of a meta-conglomerate intercalated in phyllites, indicating that the deposition of the limestone would have occurred during the Early Cambrian. Then, the meta-conglomerate is somewhat younger than this age, and its deposition is considered at least latest Early- to Late Cambrian, taking into account that the meta-sedimentary succession in which this meta-conglomerate is intercalated is intruded by El Molino pluton of Early Ordovician magmatic crystallization age (U-Pb SHRIMP zircon of 472Ma, González et al., 2008a).

The limestone blocks provenance attains an additional meaning because until now, in situ outcrops with archaeocyathan limestones have not been found in the Eastern North Patagonian Massif of Argentina. From a regional point of view, the blocks studied appear to have affinities with Early Cambrian units of other regions of southwestern Gondwana, e.g. Shackleton Limestone in Transantarctic Mountains at the western edge of East Antarctica.

In this contribution, we provide both the geological characterization of a meta-conglomerate of the El Jagüelito Formation at Sierra Grande area, and the description of its archaeocyaths. This shows that the protoliths of the El Jagüelito Formation were deposited in a narrow time range between Early and Late Cambrian. It must be emphasized that the archaeocyathan limestone blocks may have been derived from the Shackleton Limestone of East Antarctica, and then we can envisage a Patagonia-Antarctica connection before Gondwana final amalgamation.

## GEOLOGICAL SETTING

In the Eastern North Patagonian Massif (Fig. 1A), the low-grade metamorphic basement rocks of the El Jagüelito and Nahuel Niyeu Formations are known for their mainly psammo-pelitic protoliths and only minor psefitic and volcanic protoliths (Ramos, 1975; Caminos and Llambías, 1984; Giacosa, 1987, 1994; Varela et al., 1997, 1998, 2008; González et al., 2008a). High grade metamorphic basement rocks of the Mina Gonzalito Complex (Ramos, 1975; Giacosa, 1987) are also present. Several small granitoid plutons intruding the low-grade metamorphic rocks have been included in the Punta Sierra Plutonic Complex (Busteros et al., 1998, and references therein). The magmatic crystallization age of the complex ranges between 476 and 462Ma (Varela et al., 1997, 1998, 2008; Pankhurst et al., 2006; González et al., 2008b), whereas the deposition of meta-sedimentary successions may have occurred prior to the oldest intrusion (e.g. 476Ma), during the Cambrian and not later than the earliest Ordovician times (geologic time scale of Ogg et al., 2008), according to trace fossil evidences given by González et al. (2002) and detrital zircon provenance age pattern provided by Pankhurst et al. (2006).

The low- to high-grade metamorphic and igneous basement rocks are unconformably covered by psammitic sedimentary rocks of the Sierra Grande Formation (Silurian-Early Devonian, Müller, 1965; Manceñido and Damborenea, 1984), pyroclastic and volcanic rocks of the Jurassic Marifil Volcanic Complex (Malvicini and Llambías, 1974; Cortés, 1981) and by the Gaiman and Puerto Madryn Formations of Oligo-Miocene age (Busteros et al., 1998, and references therein).

To simplify the reading and comprehension, Figure 1B only shows the outcrops of the metamorphic-igneous basement rocks of the Sierra Grande area.

## LOCAL GEOLOGY

Our study area is located to the West of Hiparsa Mine (Southwest of Sierra Grande town), where the local stratigraphy includes the basement composed by meta-sedimentary rocks of the El Jagüelito Formation and two groups of deformed and non-deformed Ordovician granitoids of the Punta Sierra Plutonic Complex (Fig. 1B). Their sedimentary and volcano-pyroclastic covers are Siluro-Devonian quartzites of the Sierra Grande Formation and the Jurassic Marifil Volcanic Complex, respectively (Fig. 2).

The outcrops of the El Jagüelito Formation cover an area of approximately 5km x 4km and consist mainly of phyllites, slates and meta-greywackes, with minor hornfels and meta-conglomerates (containing archaeocyathan limestone blocks, see details below). The sequence and timing of polyphase deformation and metamorphic events ($D_1$-$M_1$ / $D_3$-$M_3$) of the El Jagüelito Formation is available at González et al. (2008a).

## Structure and metamorphism of fossiliferous meta-conglomerate

The bed of meta-conglomerate mapped in the El Jagüelito Formation is boudinaged at regional scale, and then at least three decameter scale boudins were recognized and named North, Central and South according to their geographical outcrop situation (Fig. 2). The geological features described below refer to the northern boudin of the meta-conglomerate, which contains fossiliferous limestone blocks (see location in Fig. 2). The two other layers are not treated in the text because they share mostly the same geological features as the former, and until now we have not identified fossiliferous limestone blocks within them.

The meta-conglomerate is only affected by $D_1$ ductile deformation structures and $M_1$ greenschist facies (chlorite zone) regional metamorphism, whereas $D_2$-$D_3$ tectono-metamorphic events have not been documented. $D_2$-$D_3$ events are only conspicuous at the southern meta-conglomerate outcrop (Fig. 2).

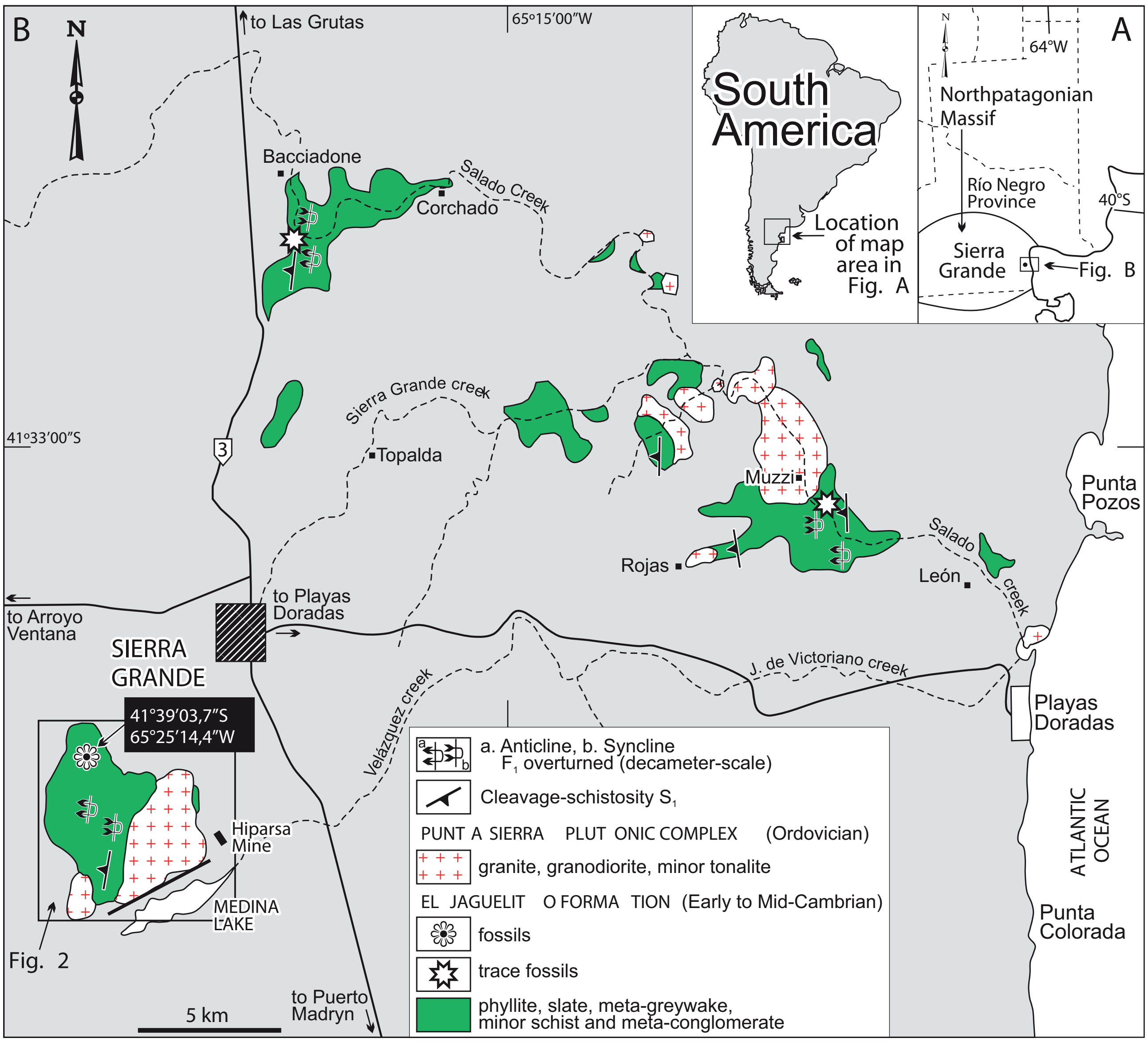


FIGURE 1 | **A) Location of the Sierra Grande study area within Eastern North Patagonian Massif (Río Negro Province of Argentina). B) Sketch map of the igneous-metamorphic basement from Sierra Grande area and surroundings, with the location of fossiliferous place of the El Jagüelito Formation.**

The meta-conglomerate is a lens-shaped bed approximately 1060m long and 10.32m thick. It is composed of intercalations of at least two meta-conglomerate strata ≤1m thick, coarse grained meta-greywackes and meta-sabulites, with minor phyllite strata ≤0.50m thick (Fig. 3, see location of the profile in Fig. 2). The bedding/cleavage relationship was used to determine the major $F_1$ fold structure and to locate the major fold hinge, whereas well preserved primary sedimentary structures (oscillatory ripple marks, normal graded bedding and cross bedding, flutes and load casts) were employed as polarity markers. The primary sedimentary structure of the meta-conglomerate is preserved as bedding $S_0$ (meta-psefite/pelite/psammite banding) that is folded following E-verging, overturned

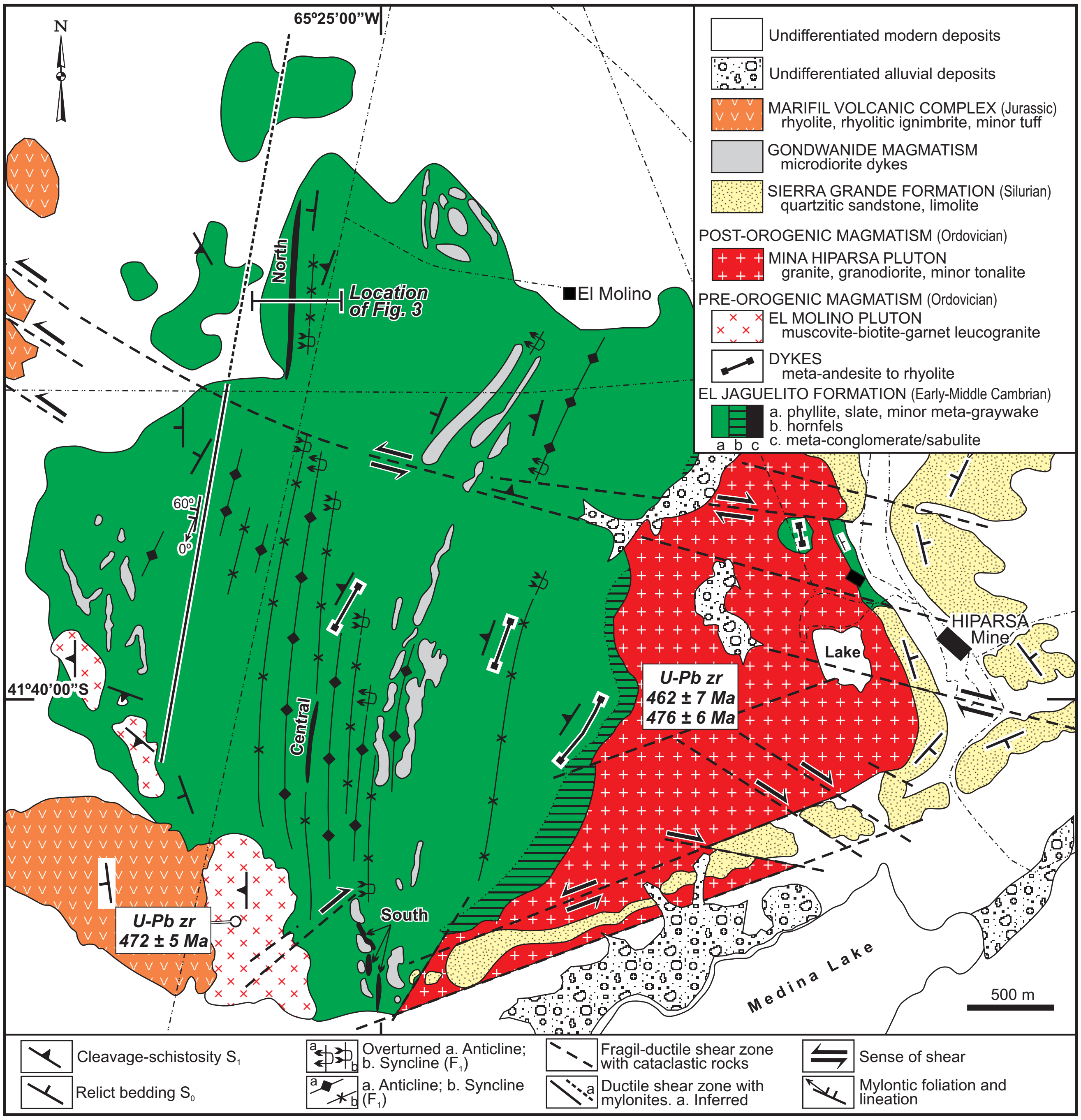


FIGURE 2 | **Simplified geological map of the igneous-metamorphic basement from west of Hiparsa Mine, Sierra Grande (Río Negro), showing location of the El Jagüelito Formation fossiliferous meta-conglomerate. Adapted after González et al. (2008a).**

tight syncline $F_1$ of decameter scale (Fig. 3). ~N-S trending $S_0$ dips 30°-60° to the west, whereas N-S to NNE-SSW trending pervasive axial plane cleavage $S_1$ dips 45°-70° to the west.

## Petrography

From a sedimentary point of view, the meta-conglomerate is classified as a polymict paraconglomerate (Fig. 4A to C). All its clasts are flattened due to deformation. They mainly consist of sub-rounded to rounded, medium sphericity and poorly sorted pebbles and cobbles of granitoids, intermediate to acidic volcanic rocks, mono- and polycrystalline quartz and meta-pelites (now transformed to shale and phyllite), and minor boulders and blocks of gray fossiliferous limestones, mostly ≤50cm diameter (Fig. 4A to C). Fine grained psammitic limestone clasts are also recognized (see below). The matrix shares the same components as those of clasts.

At microscopic scale, $S_1$ cleavage planes are marked by sericite + chlorite + quartz alignment. This assemblage with lepidoblastic texture is typical of greenschist facies (chlorite zone) $M_1$ metamorphism. The intracrystalline deformation of minerals inside clasts is distinguished by deformation lamellae, undulose extinction and sub-grains in quartz, and kinked or tapered albite twins towards the grain boundary and also undulose extinction in feldspars (Fig. 4D). Mantled limestone clasts are composed of a relict core aggregate of carbonate crystals with undulose extinction and bended twins, and a fine grained mantle of the same composition and mostly polygonal granoblastic texture (Fig. 4E and F).

# ARCHAEOCYATHS FROM THE EL JAGÜELITO FORMATION

## Introduction

Archaeocyaths are a benthic group of mostly sessile organisms which inhabited the carbonate shelf and reef environments of the Cambrian seas (Hill, 1972), and which attained their highest diversity during the Early Cambrian (Rozanov and Debrenne, 1974). Their skeleton (the cup) is basically an inverted cone with a central cavity, with perforated double walls enclosing an intervallum, and with different kinds of internal structures (i.e. septa, tabulae, dissepiments, synapticula). Due to the calcareous composition of their skeletons they are usually well represented in the fossil record. Archaeocyaths have been regarded as an independent phylum by some authors (Okulitch and Laubenfels, 1953; Okulitch, 1955; Hill, 1972; Rigby and Gangloff, 1987), but present consensus is that they are morphologically, functionally and phylogenetically related to the Phylum Porifera (Kruse and Debrenne, 1989; Zhuravlev, 1989; Wood et al., 1992; Rowland, 2001).

Archaeocyaths have been described from Early Cambrian deposits in different continents, within a palaeo-equatorial and -subequatorial warm water belt, and their distribution defines two realms (Eurasian and Lauraustral) with five distinct faunal provinces (North America-Koryakia, Europe-North Africa, Siberia-Mongolia, Central Eastern Asia and Australia-Antarctica; see Brock et al., 2000). They are usually associated with trilobites, hyolithids, brachiopods and cyanobacteria. Despite their abundance and wide geographical distribution, previous references from South America are limited to the preliminary description of specimens preserved in limestone clasts of possible Antarctic provenance within the Fitzroy Tillite Formation (Late Carboniferous) in the Malvinas (=Falkland) Islands, transported and redeposited during the great Late Palaeozoic Gondwanan glaciation (Stone and Thomson, 2005). Other records from Argentina are restricted to doubtful, undocumented mentions, for the Los Estados Island (Hyades, 1887, p. 222, dismissed by Feruglio, 1949, p. 161, 164; see also Hill, 1965), and for the Argentine Precordillera (Debrenne, 1964; Hill, 1972; Spjeldnaes, 1981).

## Material and methods

Among the archaeocyaths found in the El Jagüelito Formation meta-conglomerate, the most interesting specimens are a group of 6 solitary cups arranged near each other in an angular massive grey limestone block about 20cm long (Figs. 5A, 6B), and a specimen partially free from matrix preserved in a smaller clast (Fig. 6E). The skeletons seem to have been replaced by coarse calcite (Fig. 7), and preservation of all specimens is poor to bad. Although most morphological features are affected by the metamorphic recrystallization of the specimens and

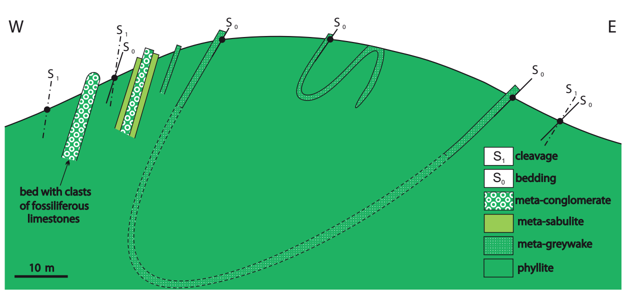


FIGURE 3 | **Simplified and schematic E-W profile across the northern meta-conglomerate of the El Jagüelito Formation (compare Fig. 2 for location). The meta-conglomerate and its host low grade metamorphic rocks were affected by the $D_1$ deformation. The vergence of $D_1$ structures is eastward.**

their matrix, it is clear that they are conical or cilindro-conical double walled cups, with a septate intervallum of variable width, except for one specimen characterized by a somewhat irregular shape in transverse section, with a very narrow intervallum (Fig. 6C). The specimens diameters vary between a few millimeters to 3.5cm. There is no other preserved fauna associated to the archaeocyaths in the examined blocks.

The skeletons remain calcareous in limestone, and thus specimens were first observed directly on the naturally weathered surfaces of the limestone blocks, sometimes

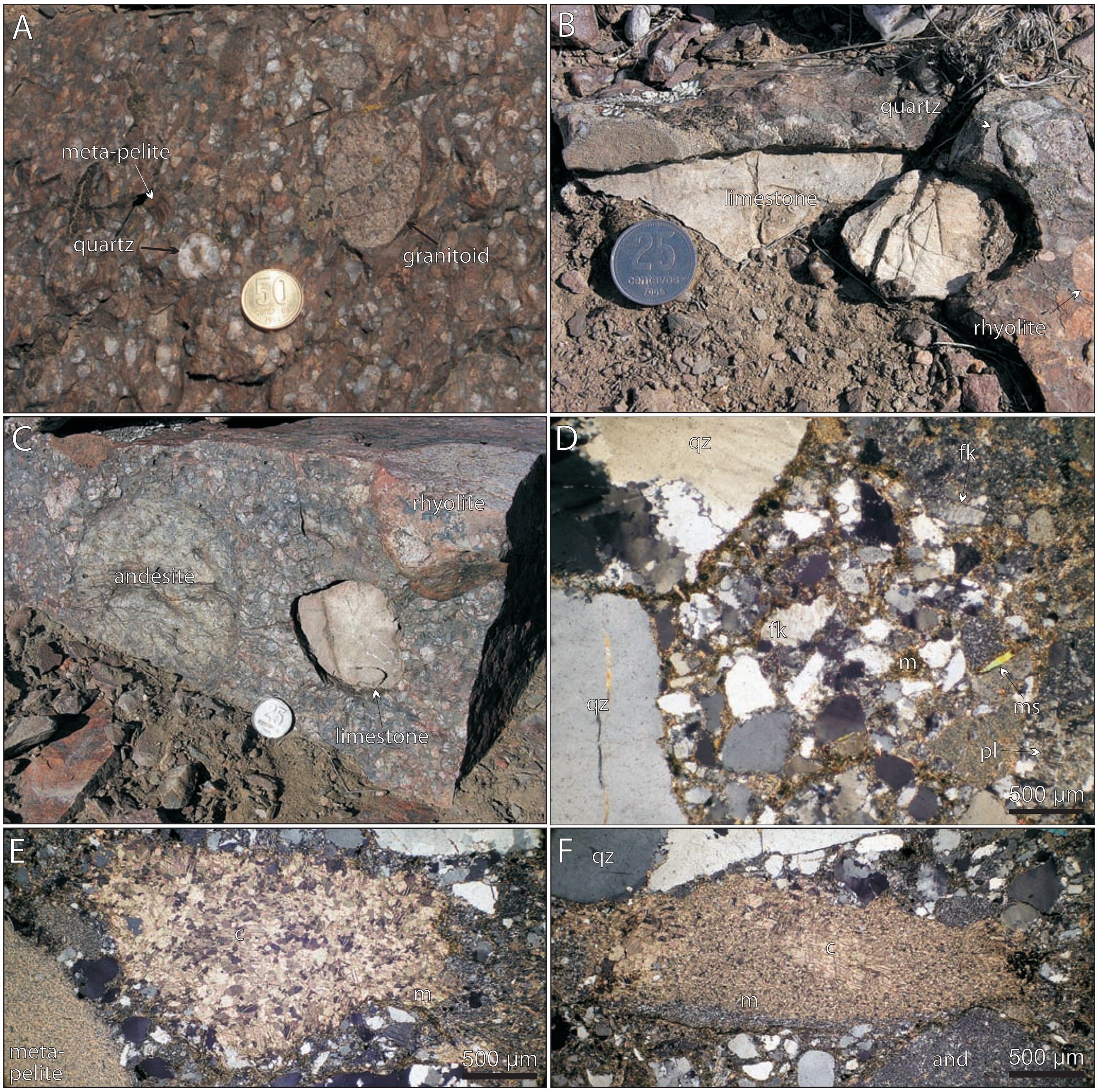


FIGURE 4 | **A-C) View of the polymictic (meta-) paraconglomerate of the El Jagüelito Formation. Diameters of coins are 2.5cm. A) Clasts of granitoid, milky quartz, and meta-pelite. B) Fossiliferous limestone block that is more eroded than the hardened matrix and quartz and rhyolite clasts. C) Cobbles of fossiliferous limestone, andesite and rhyolite. D-F) Photomicrographs from thin-sections, crossed polarizers. D) Textures of intracrystalline deformation in minerals from clasts of the meta-conglomerate. qz: quartz with ondulose extinction; fk: alkali feldspar and pl: plagioclase, both with deformed twins; ms: flake of detrital muscovite; m: matrix. E) Recrystallized meta-pelitic clast with quartz-chlorite-sericite $M_1$ association, and mantled texture in limestone clast (c: relict core; m: recrystallized mantle). F) Mantled texture in limestone clast. qz: quartz; and: andesitic clast with felty texture.**

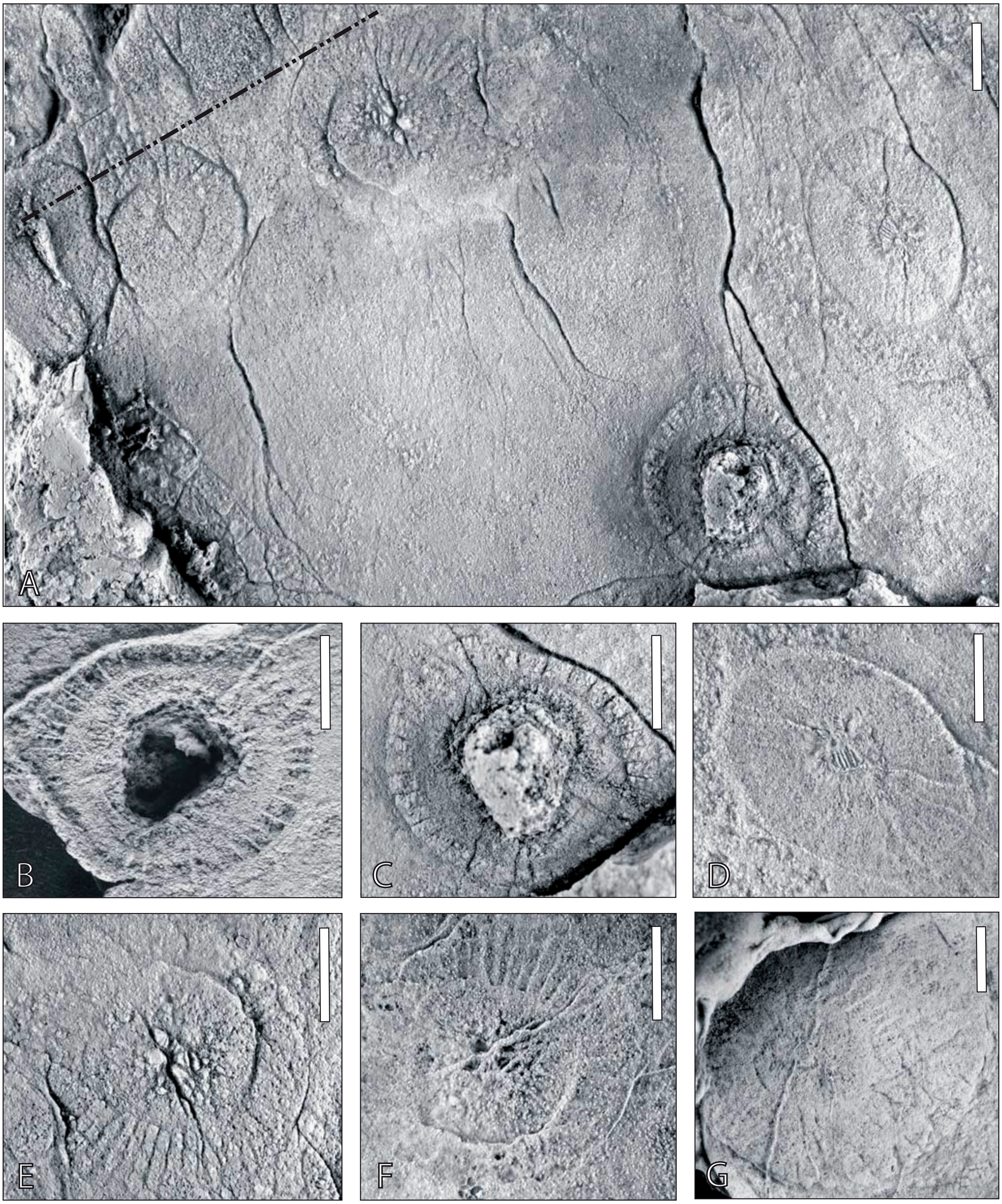


FIGURE 5 | **Archaeocyaths from limestone blocks of the El Jagüelito Formation, transverse sections on naturally weathered surfaces. A) General view of a block with "*Archaeocyatha sp. 1*" (2 specimens, above, center and left, longitudinal sections of these specimens -see dotted line- on Fig. 7G), MLP 32580-5a, b; *"Archaeocyatha sp. 3"* (below, right), MLP 32580-5c; and *"Archaeocyatha sp. 4"* (above, right), MLP 32580-1a. B-C) *"Archaeocyatha sp. 3"*, MLP 32580-5c (B: latex cast). D-G) *"Archaeocyatha sp. 4"*, latex cast; D) MLP 32580-1a; E-F) *"Archaeocyatha sp. 1"*, MLP 32580-5a (F: latex cast). G) MLP 32581-2. Scale bars: 5mm.**

with the help of a thin coating of magnesium sublimate. Occasionally latex casts were prepared of the weathered surfaces. Differential meteorization on the clasts surfaces favored preservation and observation of morphological features of some specimens (e.g. Figs. 5C, 5E, 6C). Polished sections were done in order to observe transverse, oblique

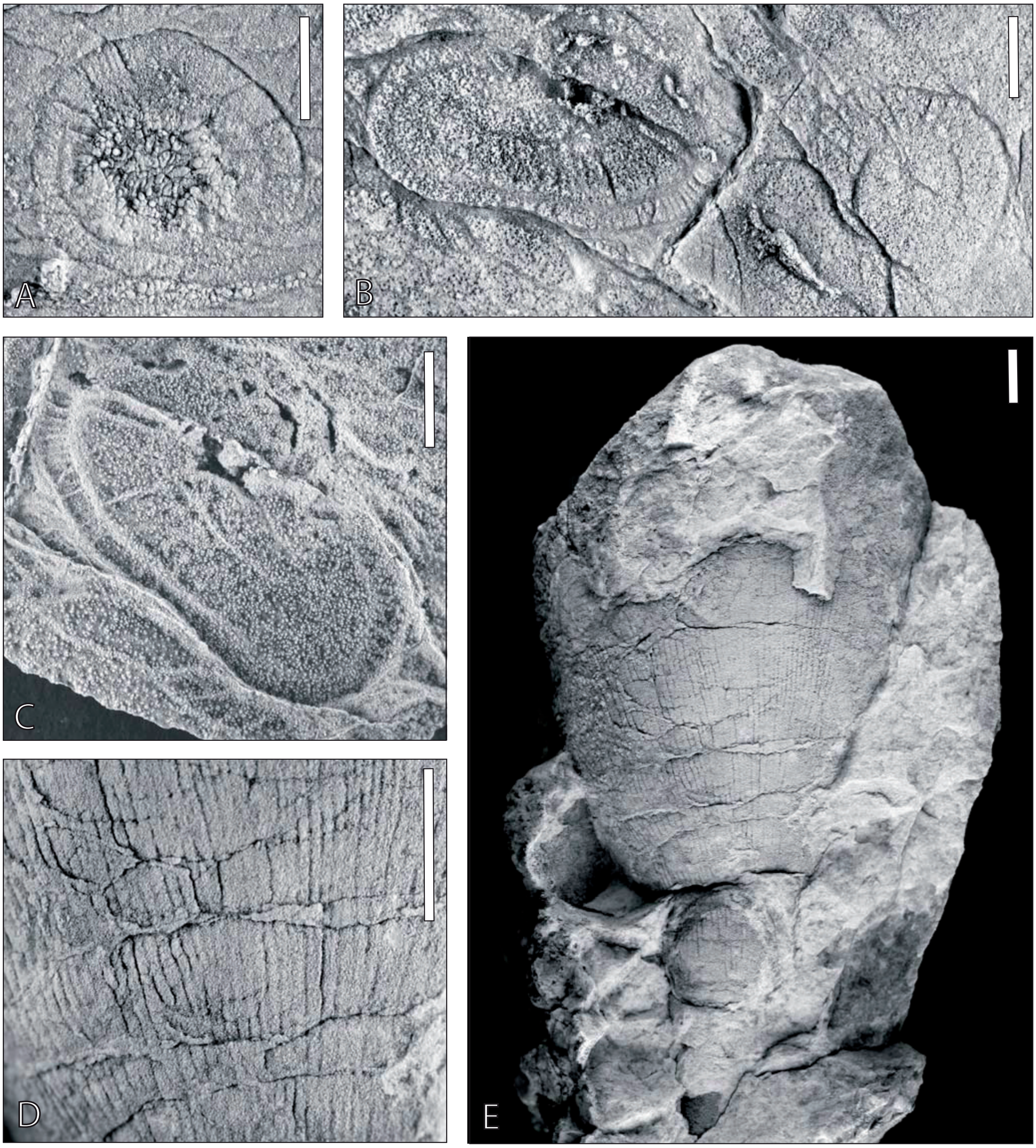


FIGURE 6 | **Archaeocyaths from limestone blocks of the El Jagüelito Formation, transverse sections on naturally weathered surfaces. A) *"Archaeocyatha sp. 2"*, transverse section, MLP 32580-1b. B) *"Archaeocyatha sp. 5"* (left), MLP 32580-3a, and *"Archaeocyatha sp. 1"* (right), MLP 32580-5b, transverse section. C) *"Archaeocyatha sp. 5"*, transverse section, latex cast, MLP 32580-3a. D-E) *"Archaeocyatha sp. 6"*, MLP 32581-1; D: detail; E: general morphology. Scale bars: 5mm.**

and longitudinal sections of the skeletons which might show details of their internal anatomy. Unfortunately, these sections show that the material is thoroughly recrystallized (Figs. 7A-G) to such a degree that the preservation of delicate details (e.g., type, quantity and arrangement of pores on walls and septa) is seriously hindered. These features are key to specific and generic identifications. The specimens were photographed with a digital reflex camera and 1:1 macro lens.

The material is housed in the Invertebrate Palaeontology collections of the La Plata Natural History Museum (MLP 32580 to 32582), Argentina.

## Description and comparison

*"Archaeocyatha sp. 1"* (MLP 32580-5a,b; Figs. 5A above, center and left, 5E, 5F, 6B right, and 7G). Five specimens are referred to this species. Their cups are circular to subcircular in transverse sections and up to 15mm in diameter. The intervallum is moderately wide and the central cavity is about 50% of the cup diameter. Radial septa are numerous (about 50), straight and narrow, apparently of even thickness and closely spaced. Septa are complete, in contact with both the outer and inner walls of the cup. In some specimens delicate septal pores are evident (Fig. 5E), but the poor preservation does not allow to describe their arrangement pattern. Two longitudinal sections of this species can be seen on a polished surface (Fig. 7G), but little detail of internal structures can be observed. This taxon has a general superficial similarity with "*species 1*" described from the Fitzroy Tillite Formation from the Malvinas Islands (Erismacoscinina; Stone and Thomson, 2005, Fig. A1.a-c), they share a wide intervallum with numerous narrow septa, but the material from Malvinas shows a few incomplete septa which do not contact the inner wall, while all septa in the Patagonian specimens seem to be complete.

*"Archaeocyatha sp. 2"* (MLP 32580-1b; Fig. 6A). The only specimen referred to this taxon differs from "Archaeocyatha sp. 1" by having a narrower intervallum, a wider central cavity and a large number of septa, more than 75. In transverse section, the cup diameter is 13mm. The central cavity width is nearly 75% of the cup diameter. "Archaeocyatha sp. 2" is superficially comparable to *"species 2"* from the Fitzroy Formation in the Malvinas Islands (see Stone and Thomson, 2005, Fig. A2.b), since both have a reduced intervallum, a wide central cavity and numerous complete septa. The specimens from Malvinas have hair-like spinose structures protruding from the inner wall to the central cavity, these features seem to be present in the Patagonian specimen. "Archaeocyatha sp. 2" is also similar, in the intervallum dimensions and number and arrangement of septa, to material from moraines of the Recovery Glacier, Whichaway Nunataks, Antarctica, assigned by Hill (1965) to the genus *Ladaecyathus* Zhuravleva (see Hill, 1965, pl. 5, Fig. 4), and also with specimens (referred as gen. et sp. indet.) preserved in limestone blocks found in the Shetland Islands, Antarctic Peninsula (Morycowa et al., 1982, pl. 1, Fig. 2 above).

*"Archaeocyatha sp. 3"* (MLP 32580-1d, 32580-5c; Figs. 5A below right, 5B, 5C, 7C). A specimen referred to this taxon is represented by a longitudinal section showing tabulae (Fig. 7C), whereas an additional individual, preserved as a transverse section (Figs. 5A below right, 5B, 5C), is possibly conspecific. The latter has a circular shape, with a diameter of about 15mm. Septa are about 40, defining a septal index (n/D) of 2.6. "Archaeocyatha sp. 3" is characterized by a much reduced intervallum, with widely spaced, thick porous septa, moderately spaced tabulae, and a very wide central cavity. Poor preservation of the Patagonian specimen hinders evaluation of number and arrangement of pores on the inner and outer walls. Nevertheless this specimens shows similarities to Erismacoscinina from moraine blocks in Whichaway Nunataks, Antarctica (Hill, 1965), particularly with those assigned to *Erismacoscinus stephensoni* (Hill, 1965, pl. 7, Fig. 18).

*"Archaeocyatha sp. 4"* (MLP 32580-1a, 32580-4e, 32581-2; Figs. 5A above right, 5D, 5G, 7D). Three specimens are characterized by their ovoid section, a small central cavity and a well developed intervallum, which contains slightly sinuous septa. One of the specimens attains a large size, it is 20mm in maximum diameter. The central cavity only occupies 30% of the maximum diameter of the cup. "Archaeocyatha sp. 4" is similar to "species 3" informally described by Stone and Thomson (2005, Fig. A1.g) from limestone blocks of the Fitzroy Tillite Formation in the Malvinas Islands. Stone and Thomson (2005) regarded the sinuous portions of the Malvinas specimens septa as possible "taeniae", structures that are present in some irregular archaeocyaths, such as *Pycnoidocyathus* Taylor (= *Flindersicyathus* Bedford and Bedford, see Debrenne, 1970), well documented from the Whichaway Nunataks, Antarctica by Hill (1965, pl. 11.8). "Archaeocyatha sp. 4" also shows some superficial similarities to *Palmericyathellus* Debrenne, from the Early Cambrian of Ajax Mine, southern Australia (see Debrenne, 1970, pl. 2, Fig. 2).

*"Archaeocyatha sp. 5"* (MLP 32580-3a; Figs. 6B left, 6C). One specimen is referred to this species, and it is characterized by an irregular ovoid outline in transverse section, a very wide central cavity and an extremely reduced intervallum, which represents only 20% of the cup maximum diameter. Septa are

numerous, according to counts done on the best preserved part of the cup, they were more than 100. The cup maximum diameter is 21mm. This species is comparable to one specimen from the limestone blocks in the Fitzroy Tillite Formation from the Malvinas Islands, which was illustrated but not described by Stone and Thomson (2005, Fig. A1.a, above left), they have a comparable irregular outline in transverse section and similar intervallum dimensions.

*"Archaeocyatha sp. 6"* (MLP 32581-1; Figs. 6D, 6E). This specimen has a large conical cup and is partially

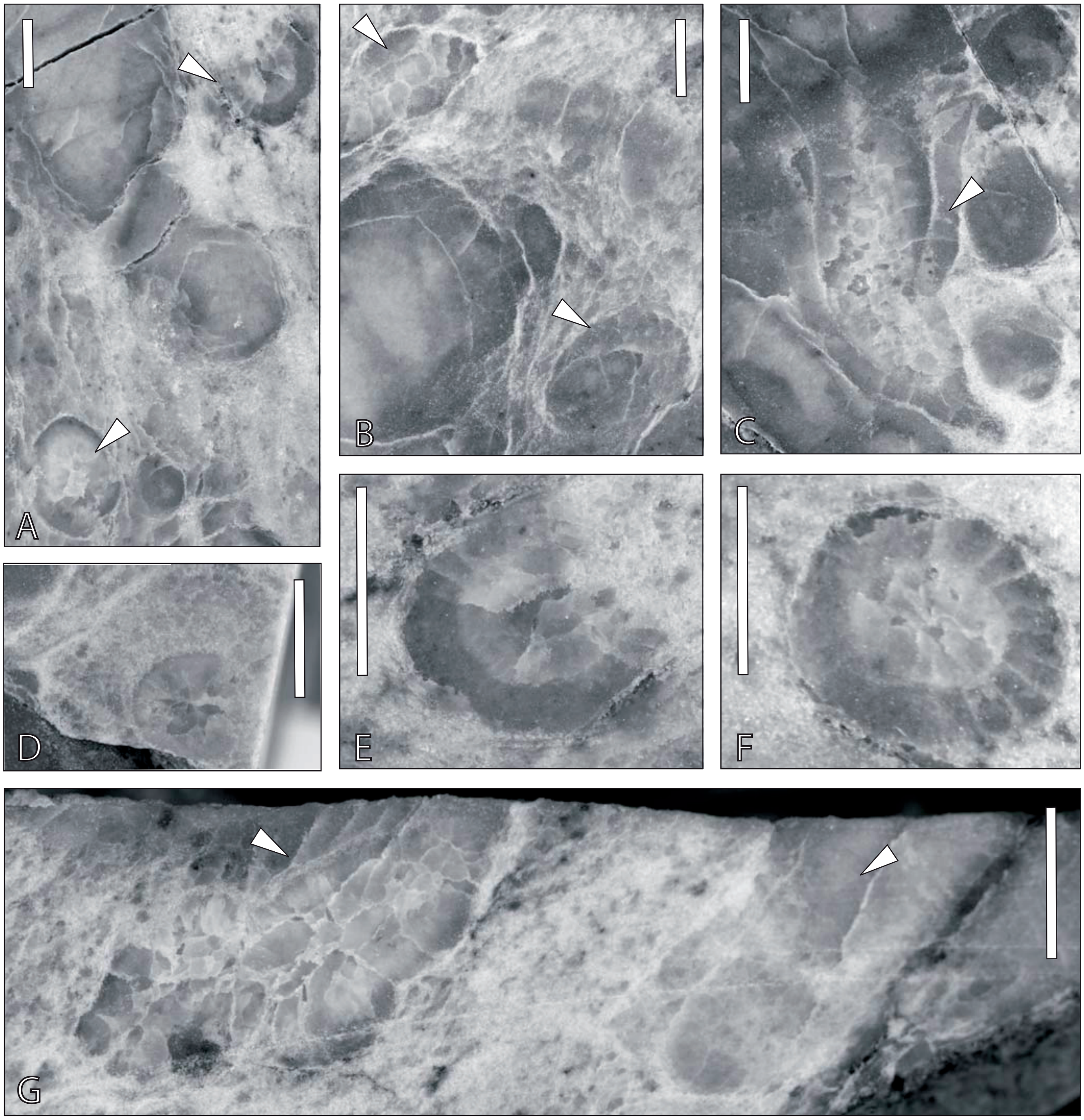


FIGURE 7 | **Archaeocyaths from limestone blocks of the El Jagüelito Formation, polished sections (note the recrystallization of the material). A) Transverse sections of an undetermined species (see arrows), MLP 32580-2. B) Transverse sections of undetermined specimens (see arrows), MLP 32580-1c. C) *"Archaeocyatha sp. 3"*, longitudinal section (see arrow), MLP 32580-1d. D) *"Archaeocyatha sp. 4"* transverse section, MLP 32580-4e. E) Undetermined species, transverse section, MLP 32580-3b; F) *"Archaeocyatha sp. 7"*, MLP 32580-3c. G) Longitudinal sections (see arrows) of *"Archaeocyatha sp. 1"*, MLP 32580-5a,b, transverse sections of these specimens on Fig. 5A. Scale bars: 5mm.**

separated from the matrix. It is more than 80mm high and its maximum diameter is near 40mm. On the outer wall external surface it bears numerous closely spaced longitudinal striae, which represent indications of the septa (Fig. 6D).

*"Archaeocyatha sp. 7"* (MLP 32580-3c; Fig. 7F). Despite the extensive recrystallization, there is one specimen which shows some features that distinguish it from "Archaeocyatha sp. 3", such as the longitudinally slightly plicate outer wall with shallow furrows at outer ends of the septa. Septa are about 24. In transverse section this specimen is reminiscent of members of Robustocyathidae, and it is similar to material referred to *Robustocyathus* Zhuravleva described from moraines in the Whichaway Nunatak, Antarctica (Hill, 1965, pl. 3, figs. 2-7).

## DISCUSSION WITH IMPLICATIONS

The main geological interpretation to be drawn to El Jagüelito Formation at Sierra Grande area is that its siliciclastic meta-sedimentary sequence, in which the meta-conglomerate is intercalated, underwent ductile deformation and regional low-grade (greenschist facies) metamorphism during $D_1$-$M_1$ event. Eastward vergence of the pile indicates ~E-W direction of contraction. On a larger scale, these geological features can be compared with those recognized by Giacosa and Paredes (2001) and González et al. (2002) in Arroyo Salado area (Fig. 1), and related to the same tectono-metamorphic event (see also von Gosen, 2002). Then, the $D_1$-$M_1$ event of the El Jagüelito Formation seems to be of regional extent within Eastern North Patagonian Massif. The timing of protoliths deposition and $D_1$-$M_1$ event is constrained to Early to Mid-Cambrian (see below) and to Early Ordovician (González et al., 2008a) respectively. The $D_2$-$D_3$ events are considered only of local importance to the El Jagüelito Formation, and they are post-Ordovician (Varela et al., 2009).

The archaeocyaths of the limestone blocks included in the conglomerate of the El Jagüelito Formation show close relationships with material previously described from blocks of Late Carboniferous tillites from the Malvinas Islands (Stone and Thomson, 2005), as well as from blocks of the South Shetland Islands, Antarctic Peninsula, and from the Recovery Glacier near the Whichaway Nunataks in East Antarctica (Hill, 1965). In all these cases, the Shackleton Limestone, widely distributed in the Antarctic continent (e.g., Hill, 1972; Shergold et al., 1985; Debrenne and Kruse, 1986; Rees et al., 1989; Cooper and Shergold, 1991), is believed to be the most likely source for the limestone blocks with archaeocyaths. Among the genera probably related to the Patagonian specimens, *Ladaecyathus* was described from the Early Cambrian (Atdabanian-Botomian) of Russia, Canada and Antarctica, and was particularly abundant during the Botomian (Hill, 1965, 1972). *Erismacoscinus*, *Pycnoidocyathus* and *Robustocyathus* are all cosmopolitan genera of similar stratigraphic range (Atdabanian-Botomian), whilst *Palmericyathellus* is restricted to the late Atdabanian-Early Botomian of southern Australia. Therefore, the affinities shown by the archaeocyaths from Sierra Grande suggest a middle Early Cambrian (Atdabanian-Botomian) maximum age for the deposition of the meta-conglomerate of the El Jagüelito Formation. The validity of this interpretation was recently confirmed by LA-ICPMS U-Pb provenance studies on detrital zircon analysis, on a sample from the same meta-conglomerate containing the fossils, that exhibits a main peak at Early Cambrian (523Ma; Naipauer et al., 2010). However, we can not completely rule out a Middle-to-Late Cambrian age to some meta-sedimentary protoliths of the El Jagüelito Formation, in particular those of unknown age which are intruded by Tremadocian plutons (Varela et al., 1998, 2008; González et al., 2008b).

Although the issues of provenance of the El Jagüelito Formation and its original links with other Gondwana units are beyond the scope of this research, it is necessary to mention that several Early Cambrian outcrops with archaeocyathan limestones are recorded along the western margin of Gondwana (Fig. 8). The local Argentinean Patagonia provenance of the limestone clasts within the El Jagüelito Formation is still not clear. The marbles from the Mina Gonzalito Complex are widely distributed in the region and could be regarded as the high-grade metamorphic equivalent of the limestone clasts in the studied conglomerate. Alternatively, the fossiliferous clasts could have derived directly from the Shackleton Limestone, which crops out in several localities along the Transantarctic Mountains of East Antarctica (Fig. 8).

A close analogue to the Sierra Grande stratigraphic situation can be seen in Antarctica, where the Shackleton Limestone is uncomformably covered by the Douglas Conglomerate (Goodge et al., 2004 and references therein), which bears clasts of the underlying limestones and is petrographically quite similar to the El Jagüelito Formation meta-conglomerate. It is evident that the Transantarctic Mountains limestones were the source of limestone blocks and erratics for a very long time, as has been proposed for the fossiliferous Permo-Carboniferous tillites from Antarctica (Debrenne, 1992), South Africa (Debrenne, 1975) and the Malvinas Islands (Stone and Thomson, 2005), as well as for recent moraines (Hill, 1965).

The archaeocyath faunas described herein have their greatest affinities with those of the Australia-Antarctica paleobiogeographic province (Brock et al., 2000), that seem to have extended towards the West up to Patagonia, along the paleo-Pacific margin of Gondwana (Fig. 8).

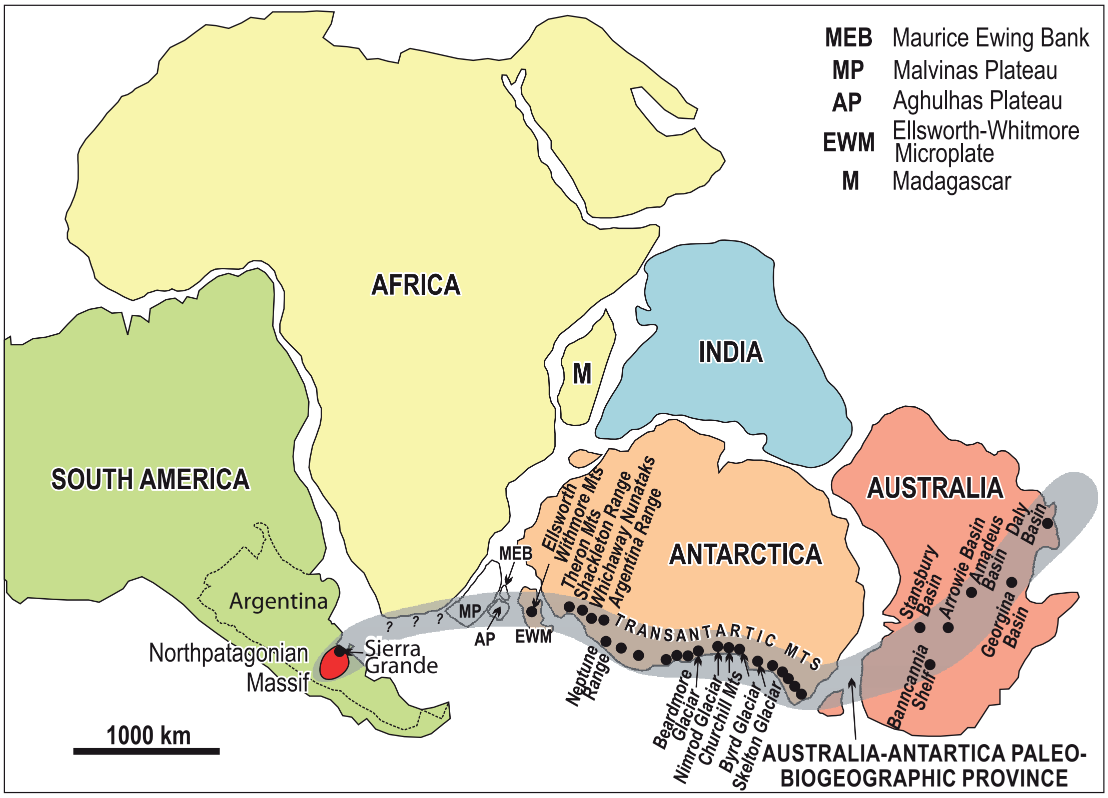


FIGURE 8 | **Paleogeographic reconstruction of Gondwana at Early Cambrian times (~520Ma), adapted after Boger and Miller (2004) and Meert and Liberman (2008) and references therein. Location of Cambrian fossiliferous (Archaeocyaths) rock outcrops in Antarctica, Australia and New Zealand (black circles) referred to Wrona (2003) and references therein. Archaeocyathan limestone blocks in low-grade meta-conglomerate from El Jagüelito Formation in South America is also labeled as a black circle.**

The similarities between the Early Paleozoic successions of North Patagonian Massif and those of Antarctica strongly suggest a sedimentologic and biologic common history of these regions on the same margin of Gondwana during that time. Therefore, two possible geotectonic scenarios can be envisaged for the Cambro-Ordovician igneous-metamorphic basement of the Eastern North Patagonian Massif. The first considers an autochthonous position at the western end of the Australia-Antarctica palaeobiogeographic province. The second alternative postulates that the basement could be para-autochthonous and derived from some place of the Transantarctic Mountains, suggesting a Patagonia-Antarctica connection before Gondwana final amalgamation.

We are carrying out new geological and paleontological studies on several meta-sedimentary protoliths of the El Jagüelito Formation to better appreciate their age, compositional, metamorphic and deformational features, extension in the Eastern North Patagonian Massif and correlation with other basement blocks from southwest Gondwana. All these data will provide more accurate evidences for a better understanding of the El Jagüelito Formation geotectonic context as part of the Patagonia in this segment of the western Gondwana margin.

## CONCLUSIONS

The structural and metamorphic analyses of the El Jagüelito Formation at Sierra Grande area, combined with the archaeocyaths study, allow the delineation of the following conclusions:

The meta-conglomerate of the El Jagüelito Formation is affected by regional greenschist facies metamorphism and ductile deformation that can be related to the Early Ordovician $D_1$-$M_1$ event, which is widely developed throughout Eastern North Patagonian Massif.

Among other clasts, the meta-conglomerate contains fossiliferous limestone blocks with archaeocyaths.

This is the first documented reference of the presence of archaeocyaths in the continental territory of Argentina.

Despite poor preservation, at least seven different archaeocyath taxa were recognized in the available blocks.

The affinities of the fossils from Sierra Grande are clearly closest to the archaeocyath faunas from the Australia-Antarctica paleobiogeographic province.

The fauna suggests a middle Early Cambrian (Atdabanian-Botomian) maximum age for the deposition of the protolith of the El Jagüelito Formation meta-conglomerate.

The overall similarities of the archaeocyaths are congruent with two possible paleo-positions of Patagonia during the Early Cambrian along the southwestern Gondwana margin. The first is autochthonous in its present position and the other is para-autochthonous, close to Antarctica.

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