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LATE CAMBRIAN ACRITARCHS FROM THE SANTA ROSITA FORMATION: IMPLICATIONS FOR THE CAMBRIAN-ORDOVICIAN BOUNDARY IN THE EASTERN CORDILLERA, NORTHWEST ARGENTINA

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ABSTRACT – Marine phytoplankton from the Late Cambrian are described for the first time in the Eastern Cordillera of northwest Argentina. The acritarch assemblage was recovered from an offshore lower mudstone unit towards the base of the Casa Colorada Member (Santa Rosita Formation) in the Quebrada de Moya section, Jujuy Province. The presence of *Vulcanisphaera africana*, *Saharidia fragilis, Granomarginata squamacea* and *Celtiberium* sp. 1, together with the absence of Tremadocian acritarch species and the scarcity and low diversity of diacrodian acritarchs suggest an age not younger than Late Cambrian for this acritarch assemblage. This age assignment is also supported by stratigraphic information and regional correlations.

Key words: Palynology, acritarchs, Upper Cambrian, Cambrian-Tremadocian boundary, Argentina.

RESUMO – Descreve-se, pela primeira vez, a ocorrência de fitoplâncton marinho em depósitos do Cambriano Superior da Cordilheira Leste, noroeste da Argentina. A assembléia de acritarcas foi recoberta por lamas de *offshore* inferior e situa-se na base do Membro Casa Colorada (Formação Santa Rosita) na região da Quebrada de Moya, Província de Jujuy. A presença de *Vulcanisphaera africana*, *Saharidia fragilis, Granomarginata squamacea* e *Celtiberium* sp. 1, somada à ausência de espécies de acritarcas do Tremadociano e à escassez e baixa diversidade de acritarcas diacrodianos sugere uma idade não mais jovem que Cambriano Superior para a assembléia. Esta idade é também suportada pelo escopo estratigráfico dos depósitos e por correlações regionais.

Palavras-chave: Palinologia, acritarcas, Cambriano Superior, limite Cambriano-Tremadociano, Argentina.

INTRODUCTION

Cambrian acritarchs and related forms (prasinophyte algae) are well known from many regions of the world including the paleocontinents of Baltica, Laurentia, Siberia, Gondwana and its marginal terranes Avalonia, Armorica and South China. In particular, acritarch zonation schemes for the Cambrian-Ordovician boundary have been proposed for eastern Newfoundland (Martin & Dean, 1981, 1988; Parsons & Anderson, 2000), the East European Platform (Volkova *et al.*, 1979, 1983; Volkova, 1990), northern Norway (Welsch, 1986), Alberta, Canada (Martin, 1992) and North Africa (Vecoli, 1996, 1999; Vecoli *et al.*, 1999). An integrated Cambrian acritarch zonation was also established by Vanguestaine & van Looy (1983). Acritarch biozonations for the basal Tremadocian were established for Algeria (Jardiné *et al*., 1974), England (Rasul, 1979) and Morocco (Elaouad-Debbaj, 1988).

At present, the Cambrian acritarch record of South America is restricted to Lower Cambrian assemblages from Venezuela, described by Vanguestaine (Di Giacomo, 1985). Acritarch assemblages from the Cambrian-Ordovician transition are unknown. Acritarch data from the Tremadocian (lower to upper Tremadocian) are restricted to the Eastern Cordillera, northwest Argentina (Bultynck & Martin, 1982; Rubinstein, 1997; Rubinstein *et al.*, 1999; Aráoz & Vergel, 2001; Rubinstein & Toro, 2002). However, studies are still sparse and do not allow elaboration of a regional biostratigraphic scheme. Furthermore, none of these findings come from the lowermost Tremadocian and in fact the position of the Cambrian-Tremadocian boundary remains uncertain.

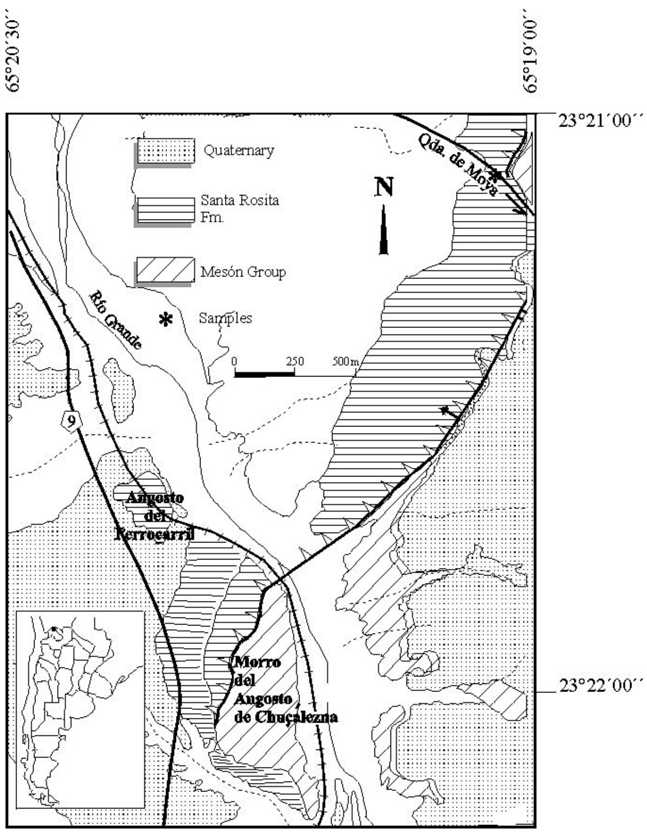

Figure 1. Location map of Quebrada de Moya (after Mángano *et al.,* 2002).

STRATIGRAPHIC AND DEPOSITIONAL SETTING

The Santa Rosita Formation (Upper Cambrian-Tremadocian) is the lowermost unit of the Santa Victoria Group in northwest Argentina (Figure 1). This formation records the vertical passage of restricted fluvial and tide-dominated estuarine environments to open marine settings affected by waves (Mángano & Buatois, 2002; Buatois & Mángano, in press). The Santa Rosita Formation overlies the Cambrian Mesón Group and conformably underlies the Arenigian Acoite Formation. Both the Santa Rosita and the Acoite formations are included in the Santa Victoria Group (Turner, 1960). The Santa Rosita Formation is, in turn, divided from base to top, into five members: the Tilcara, Casa Colorada, Alfarcito, Rupasca, and Humacha members (Moya, 1988).

The samples studied were recovered from outcrops of the Santa Rosita Formation exposed in Quebrada de Moya, located on the left side of the Grande River, along Quebrada de Humahuaca, Eastern Cordillera, Jujuy Province, northwest Argentina (Figure 1). The Santa Rosita Formation at Quebrada de Moya includes three members (Figure 2): the Tilcara, Casa Colorada, and Alfarcito (Mángano *et al*., 2002). The Tilcara Member consists of massive and tabular cross-bedded quartzose sandstone, and interbedded sandstone and mudstone that accumulated in a fluvioestuarine valley. The Casa Colorada Member is made up of mudstone and thinly interbedded rippled sandstone that records deposition in a wave-dominated, open marine setting, during a transgressive event leading to valley drowning. These deposits mostly record sedimentation in lower offshore to offshore transition environments. The Alfarcito Member includes thick packages of amalgamated hummocky cross-stratified sandstone that intercalate with finer-grained intervals consisting of mudstone and thinly interbedded rippled sandstone. This unit records deposition in shoreface and offshore transition environments. The Late Cambrian-Tremadocian age of the Santa Rosita Formation is well constrained; its biostratigraphic zonation is based on trilobites, graptolites, and conodonts (e.g., Harrington & Leanza, 1957; Rao *et al*., 1994; Moya *et al*., 1994; Tortello & Aceñolaza, 1999; Albanesi *et al*., 2001). Although a series of studies have focused on the Cambrian-Tremadocian boundary (Aceñolaza, 1983; Rao *et al*., 1994; Aceñolaza, 1996; Tortello & Aceñolaza, 1999), many stratigraphic problems remain unsolved. In fact, the actual position of the Cambrian-Tremadocian boundary is still uncertain due to the lack of detailed integrated biostratigraphic, sedimentologic and stratigraphic studies.

MATERIAL AND METHODS

Three palynological samples were collected from the Tilcara Member (7624 and 7625) and the Casa Colorada Member (7626). Only one of them, corresponding to the Casa Colorada Member, was found to be productive. Samples were treated using standard palynological HCl-HF-HCl acid maceration techniques. The organic residue was sieved using a 10 µm sieve, and oxidized for two minutes using concentrated nitric acid. Slides were examined using light microscopy with interference contrast.

The acritarch assemblage (Figure 3) was recovered from mudstones of the Casa Colorada Member that reflects fair weather sedimentation alternating with sporadic storm events in a lower offshore environment. Preservation of the acritarchs is poor, with many of the specimens damaged and dark-grey or black in colour, indicating a relatively high degree of thermal maturation. Abundance and diversity was low, yet despite their relatively poor preservation 11 acritarch taxa were identified.

Palynological slides are housed in the Paleopalynoteque of the Unit of Paleopalynology, IANIGLA, CRICyT, Mendoza. The slides in the repository are prefixed MPLP (Mendoza-Paleopalinoteca-Laboratorio de Paleopalinología). Specimen locations are referred to using England Finder coordinates.

LIST OF ACRITARCH AND PRASINOPHYTE TAXA

Acanthodiacrodium sp. cf. *A. ubuii* Martin (1969) 1988.
Caldariola glabra (Martin 1973) Molyneux & Rushton,1988 var. *glabra* autonym.
Caldariola cf. *C. glabra* (Martin 1973) Molyneux & Rushton,1988 var. *glabra* autonym.
Celtiberium sp. 1.
Granomarginata squamacea Volkova 1968.

Heliosphaeridium sp. 1.
cf. *Heliosphaeridium? llyense* Martin in Young, Martin, Dean & Rushton 1994.
Leiosphaeridia spp.
Michrystridium robustum Downie 1958.
Saharidia fragilis (Downie 1958) Combaz 1967.
Vulcanisphaera africana Deunff 1961.
Following Vecoli (1996), *Vulcanisphaera cirrita* Rasul 1976 is considered a junior synonym of *Vulcanisphaera africana*.

DISCUSSION

As pointed out by various authors (Vecoli & Playford, 1997; Vecoli, 1999; Parsons & Anderson, 2000) the palynostratigraphic interpretation of the Cambrian-Ordovician boundary is problematic. The widespread transgressive-regressive events occurring during the latest Cambrian to the earliest Ordovician produced extensive hiatuses, condensations, and fossil reworking (Vecoli & Playford, 1997). A major crisis affecting the phytoplankton community, characterized by a drastic reduction in diversity followed by a large scale renewal in the species composition, has been suggested for the latest Cambrian-earliest Ordovician interval (Tongiorgi & Ribecai, 1990).

Di Milia & Tongiorgi (1992) indicated that, since reworking is expected during regression, some palynomorph assemblages corresponding in age to transgressive intervals are probably reworked into more recent sediments during regressive periods. Additionally, extensive reworking is produced during transgressions, when shoreface retreat produces significant erosion of coastal plain sediments. Therefore, age discrepancies between the preserved palynomorph remains and the host sediment may be common. This is particularly relevant during major transgressive-regressive cycles, as is the case of the Cambrian-Ordovician transition.

Vecoli (2000) has also noted that palaeocological controls on marine palynomorphs may affect the biostratigraphic distribution of these fossils. Therefore, he emphasized that there is a full gradation from species unaffected by paleoenvironmental changes to facies-sensitive acritarchs. According to Vecoli (2000), *Vulcanisphaera* does not seem to have been sensitive to changing environmental conditions.

The acritarch assemblage reported here comes from the lower interval of the Casa Colorada Member of the Santa Rosita Formation. The assemblage was recovered from lower offshore mudstone. A trilobite fauna is present in lower and upper offshore deposits that occur immediately above the acritarch interval. The trilobite fauna includes *Angelina*, *Hapalopleura*, *Leptoplastides* and *Parabolinella* (Waisfeld, personal communication, 2003). These taxa range from the Upper Cambrian to the Tremadocian. Therefore, the acritarch level lacks an independent age control due to the absence of any other age diagnostic fossils. Faunas which undoubtedly indicate the base of the Tremadocian, such as the graptolite *Rhabdinopora flabelliforme* and the trilobite *Jujuyaspis keideli* were not found in the Casa Colorada Member.

The recovered acritarch assemblage is dominated by simple spherical forms as leiospheres and *Saharidia fragilis*. The assemblage contains such taxa as *Vulcanisphaera africana*, *Saharidia fragilis*, *Acanthodiacrodium* sp. cf. *A. ubuii* (*sensu* Martin in Martin & Dean, 1981 and Parsons & Anderson, 2000) and *Caldariola glabra* var. *glabra*, that span the Cambrian-Ordovician boundary. All of these taxa first occur in the Late Cambrian.

The lowest record of *Vulcanisphaera africana* and *Acanthodiacrodium* sp. cf. *A. ubuii*, checked by independent age control, corresponds to the *Parabolina spinulosa* trilobite Zone from Newfoundland (Martin & Dean, 1981, 1988; Parsons & Anderson, 2000). *Saharidia fragilis* first appears in the uppermost Cambrian, in the *Peltura* trilobite Zone, also from Newfoundland, while the oldest record of *Caldariola glabra* var. *glabra* is Upper Cambrian, as documented by Volkova (1990), from the East European Platform.

Vulcanisphaera africana and *Saharidia fragilis* are common species in the Cambrian-Ordovician transition of Gondwana and related terranes (Vecoli, 1996, 1999), as well as Baltica (Di Milia *et al.*, 1989; Tongiorgi & Ribecai, 1990;

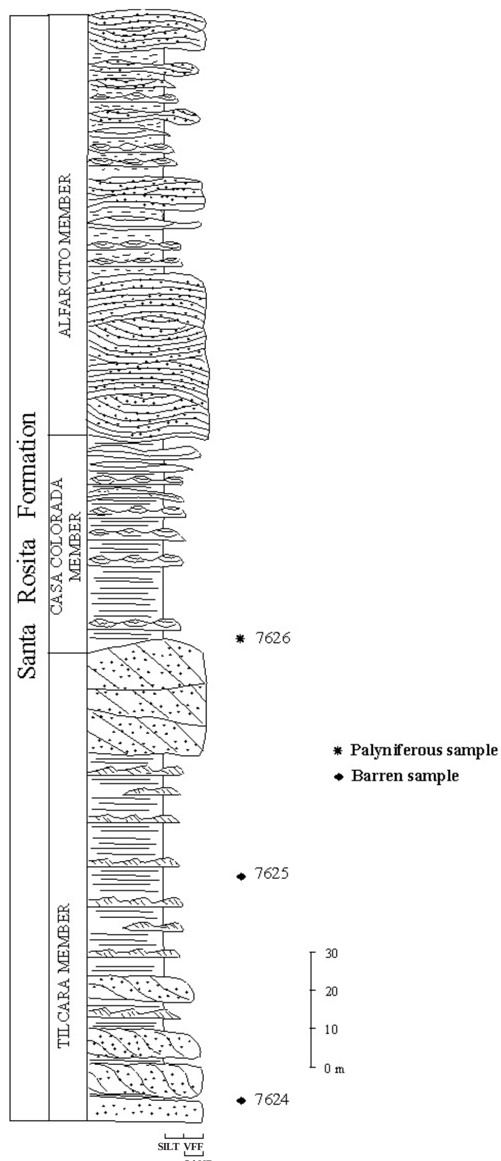

Figure 2. Stratigraphic section of the Santa Rosita Formation at the Quebrada de Moya. Location of palynological samples indicated.

Volkova, 1990). No species from undoubtedly post latest Cambrian have been recovered.

Granomarginata squamacea has a worldwide distribution from the Lower to the Middle Cambrian. Recently, Moczydlowska (1998) suggested the stratigraphic range of this species be extended to the lower Upper Cambrian (it does not seem to be younger than the *Olenus* trilobite Zone) based on data from Silesia, Poland. *Celtiberi-um* (Fombella, 1977) Fombella 1978 ranges from the Lower Cambrian to the Cambrian-Ordo-vician boundary. The latter record corresponds to the Oville Formation in northwest Spain (Fombella Blanco *et al.*, 1993).

Accordingly, the studied assem-blage suggests an age not younger than Late Cambrian. The lack of Trema-docian indicators, together with the scarcity and low diversity of diacro-dian acritarchs, as well as stratigraphic information, support this age assignment. Additionally, similar assemblages have been recovered from the Cambrian-Ordo-vician boundary interval in Arctic Russia, containing *Vulcanisphaera africana*, *Saharidia fragilis, Acantho-diacrodium ubuii*, *Granomarginata squamacea* among others (Moczydlowska personal com-munication, 2003).

A wave-dominated open marine depositional environment during a major transgressive event has been interpreted for the unit containing the productive sample.

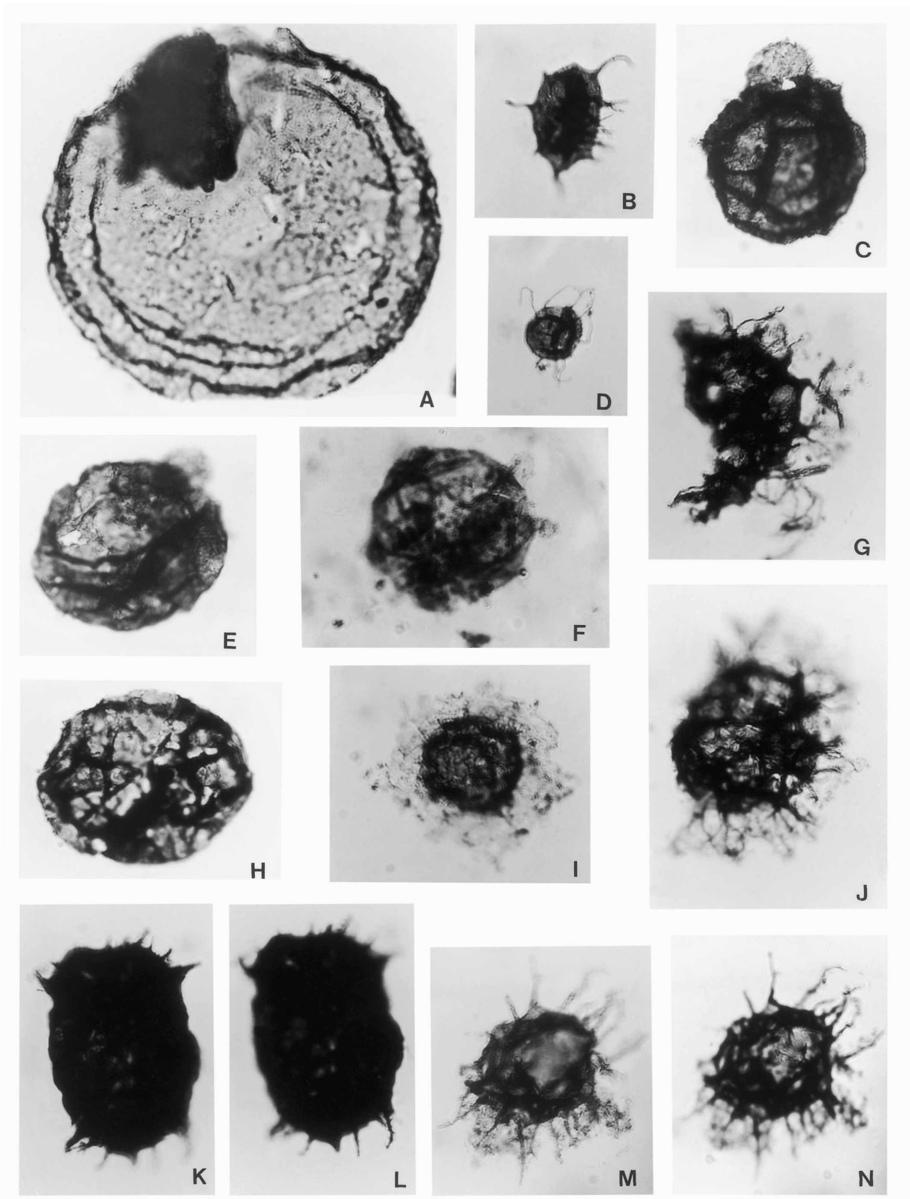

Figure 3. **A**. *Saharidia fragilis*, E40/0, slide MPLP 7626c. Abundance: A; **B**. *Heliosphaeridium* sp., 1. J29/0, slide MPLP 7626f. Abundance: R; **C**. *Caldariola* cf. *C. glabra* var. *glabra* autonym, U38/0, slide MPLP 7626c. Abundance: R; **D**. *Michrystridium robustum*, H30/3, slide MPLP 7626a. Abundance: R; **E**. *Caldariola glabra* var. *glabra* autonym, V37/0, slide MPLP 7626c. Abundance: R; **F**. *Celtiberium* sp. 1., Q44/0, slide MPLP 7626a. Abundance: R; **G**. *Vulcanisphaera africana*, P34/2, slide MPLP 7626g. Abundance: R; **H**. *Leiosphaeridia* sp., G30/4, slide MPLP 7626b. Abundance: A; **I**. *Granomarginata squamacea*, Y24/3, slide MPLP 7626f. Abundance: R; **J**. *Vulcanisphaera africana*, X20/1, slide MPLP 7626g. Abundance: R; **K, L**. *Acanthodiacrodium* sp. cf. *A. ubuii*, R23/1, slide MPLP 7626b. Abundance: R; **M**, **N**. cf. *Heliosphaeridium? llyense*, J42/4, slide MPLP 7626d. Abundance: R. All specimens x 1000. Abundance based on 19 slides examined: R, rare (less than 5 specimens); C, common (5-10 specimens), A, Abundant (more than 10 specimens).

Sample 7626 corresponds to fine-grained transgressive deposits associated with drowning of the underlying estuarine system. The high dominance of leiospheres and *Saharidia* with subordinate small acanthomorphic taxa, together with the low diversity of the assemblage, are indicative of shallow-marine conditions.

Regarding the studied palynological assemblage, no differences in the state of preservation, thermal maturation or other evidence of acritarch reworking are recognized, even if reworking is possible judging from the environmental context.

The finding of a Late Cambrian acritarch assemblage in the Casa Colorada Member has important implications in delineating the Cambrian-Tremadocian boundary and the establishment of a chronostratigraphic framework for basin evolution in the Eastern Cordillera of nortwest Argentina. In Quebrada de Humahuaca, *Jujuyaspis keideli*, which is regarded as an indicator of the Cambrian-Tremadocian boundary (Aceñolaza, 1983; Aceñolaza & Aceñolaza, 1992), is present in the so-called Purmamarca Shales exposed east of the Purmamarca railway station (Harrington, 1957). The Purmamarca Shales were subsequently included in the Casa Colorada Member (Tortello & Aceñolaza, 1999: fig. 1; Aceñolaza *et al*., 2001: fig. 1). Recent field work in the area, however, indicates that the Purmamarca Shales are bounded at their base and top by inverse faults and that the Cambrian-Ordovician succession exposed east of Purmamarca is strongly affected by tectonism. Accordingly, the stratigraphic relations of the Purmamarca Shales are uncertain. A most likely correlation of the Purmamarca Shales is with the lower interval of the Rupasca Member (Buatois & Mángano, in press).

CONCLUSIONS

The first palynological results obtained from the Casa Colorada Member of the Santa Rosita Formation provide valuable information on lower Paleozoic acritarchs of western Gondwana. The recovered acritarch taxa, the scarcity and lack of diversity of diacrodian acritarchs, together with the absence of Tremadocian indicators, suggest an age not younger than Late Cambrian for the palynological assemblage studied. Additionally, this age is consistent with regional stratigraphic correlations. This work represents a first step towards a more accurate definition of the Cambrian-Tremadocian boundary based on the integration of detailed paleontologic, sedimentologic and high-resolution sequence stratigraphic data.

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