AMEGHINIANA - 2014 - Tomo 51 (3): 226 – 242 ISSN 0002-7014

NEW BRACHIOPOD RECORDS AND CONSIDERATIONS ON THE *TIVERTONIA-STREPTORHYNCHUS* (MOSCOVIAN) AND *COSTATULUMUS AMOSI* (SAKMARIAN–ARTINSKIAN) FAUNAS FROM WESTERN ARGENTINA: THE KEY SECTIONS AT QUEBRADA AGUA DEL JAGÜEL AND QUEBRADA SANTA ELENA REVISITED

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Abstract. The brachiopod *Coolkilella aredesi* sp. nov. and *Calytrixia piersoni* sp. nov. are proposed on the basis of specimens from the Del Salto, Río del Peñón and Agua del Jagüel formations. Their biostratigraphic implications are discussed together with new records of *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* Lech and *Streptorhynchus inaequiornatus* Leanza at the top of the latter unit. The stratigraphic record, paleontological content and age of both the *Tivertonia-Streptorhynchus* assemblage (Moscovian) and the younger *Costatumulus amosi* fauna (Sakmarian–Artinskian) were reviewed and assessed based on outcrops at Quebrada Agua del Jagüel and Quebrada Santa Elena. Faunal content confirms the most recent stratigraphic, biostratigraphic and paleoclimatic frameworks. These recognize a diachronic nature of the Agua del Jagüel and Cordón del Jagüel formations, supporting the absence of an early Permian glacial event in western Argentina.

Key words. Late Paleozoic. Western Argentina. Biostratigraphy. *Tivertonia-Streptorhynchus* fauna. *Costatumulus amosi* fauna. *Coolkilella*. *Calytrixia*. *Septosyringothyris*.

Resumen. NUEVOS REGISTROS DE BRAQUIÓPODOS Y CONSIDERACIONES SOBRE LAS FAUNAS DE *TIVERTONIA-STREPTORHYNCHUS* (MOSCOVIANO) Y *COSTATUMULUS AMOSI* (PÉRMICO TEMPRANO) DEL OESTE ARGENTINO: REEXAMEN DE LAS SECCIONES CLAVE DE LAS QUEBRADAS AGUA DEL JAGÜEL Y SANTA ELENA. Se proponen las nuevas especies de braquiópodos *Coolkilella aredesi* sp. nov. y *Calytrixia piersoni* sp. nov. sobre la base de especímenes provenientes de las formaciones Del Salto, Río del Peñón y Agua del Jagüel. Se analizan sus implicancias bioestratigraficas junto al significado de nuevos registros de *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* Lech y *Streptorhynchus inaequiornatus* Leanza en el techo de la última unidad mencionada. Se revisan y precisan el registro estratigráfico, contenido paleontológico y edades de la asociación de *Tivertonia-Streptorhynchus* (Moscoviano) y de la fauna más joven de *Costatumulus amosi* (Sakmariano–Artinskiano) en los afloramientos de las Quebradas de Agua de Jagüel y Santa Elena. El contenido faunístico permite corroborar los más recientes esquemas estratigráficos, bioestratigráficos y paleoclimáticos, reconociendo las formaciones Agua del Jagüel y Cordón del Jagüel como unidades diacrónicas y desestimando a su vez la existencia de un evento glacial Pérmico en el oeste de Argentina.

Palabras clave. Paleozoico Tardío. Oeste de Argentina. Bioestratigrafía. Fauna de *Tivertonia-Streptorhynchus*. Fauna de *Costatumulus amosi*. *Coolkilella*. *Calytrixia*. *Septosyringothyris*.

THE *Tivertonia-Streptorhynchus* fauna stretches along 1000 km of the Andean belt (*c.* 28°30′S–37°11′S) in western Argentina (Fig. 1). It has been recorded in the Río del Peñón, Tupe, Quebrada Larga and upper part of the Cerro Agua Negra formations (Río Blanco Basin), the Del Salto and Agua del Jagüel formations, and the Jarillal Member of the Santa Elena Formation (Calingasta-Uspallata Basin) in central- and northwestern Argentina (Sabattini *et al.*, 1991; Taboada, 1999, 2006; Lech, 2002; Cisterna, 2010 and references provided therein). The *Tivertonia-Streptorhynchus* fauna reaches southward into the San Rafael Basin, in the El Imperial Formation (Sabattini *et al.*, 1991), its southernmost lying in the Neuquén Basin, in the Huaraco Formation (Leanza, 1945; Zöllner and Amos, 1955).

The *Tivertonia-Streptorhynchus* faunal assemblage represents a middle to high- paleolatitude temperate and mixed fauna with Boreal and Gondwanan taxa (Taboada, 2010; see also Sterren, 2004) that lived in arc-related basins along the

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southwestern margin of Gondwana. Its appearance followed a faunal turnover (the *Marginovatia-Maemia* fauna) connected with a regional climatic amelioration trend (Taboada, 2010) after the onset of the Late Paleozoic Ice Age in western Argentina. Mild climatic conditions ascribed to a postglacial climatic amelioration (López Gamundi *et al.*, 1992) of a terminal glacial stage (Limarino *et al.*, 2013a) in the region were linked with the *Tivertonia-Streptorhynchus* fauna.

Over the last decades, the recognition of a glacial-related interval stratigraphically contiguous to the early Permian *Costatumulus amosi* fauna (Taboada, 1998) supported the existence of an early Permian glacial episode in western Argentina. This spurred the search for the possible occurrence of the *Tivertonia-Streptorhynchus* fauna during a previous interglacial interval (González, 1993; Taboada, 2006, 2010; González and Díaz Saravia, 2010). Such an occurrence was recently clarified and rejected by Limarino *et al.* (2013b). Nevertheless, new brachiopod records presented herein together with discussions about controversial stratigraphic and biostratigraphic interpretations of key sections bearing the *Tivertonia-Streptorhynchus* and *Costatumulus amosi* faunas provide new insights into the biostratigraphy of the units considered and the paleoclimatic conditions during the Late Paleozoic in the region.

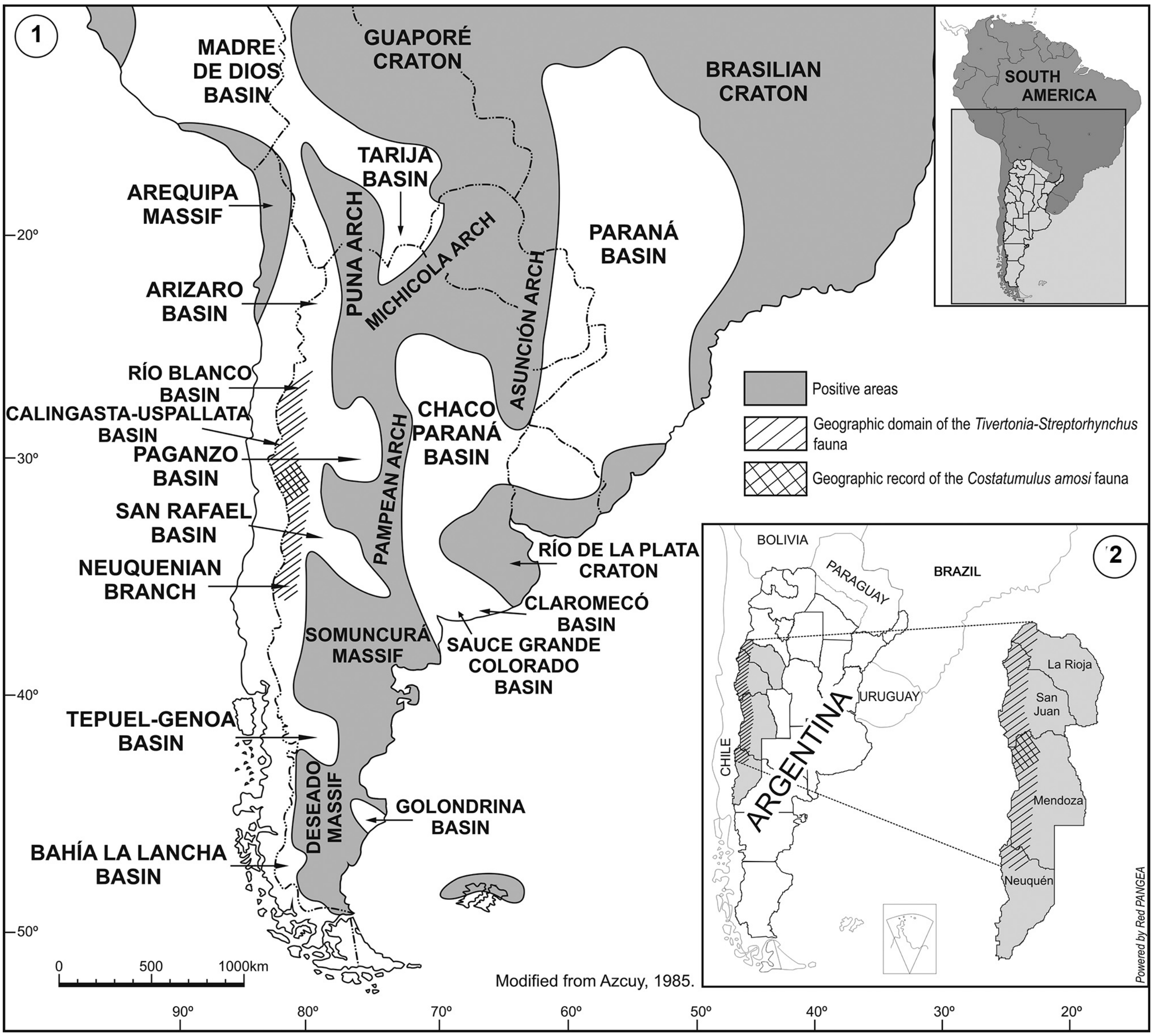

Figure 1. 1, Upper Paleozoic basins and positive relief areas of southern South America. **2,** Geographic records of the *Tivertonia-Streptorhynchus* and *Costatumulus amosi* faunas in western Argentina.

COMPOSITION AND AGE OF THE *TIVERTONIA-STREPTORHYNCHUS* FAUNA

The *Tivertonia-Streptorhynchus* fauna is mainly known by its abundant and relatively diverse brachiopod and bivalve content (Leanza, 1945, 1948; Antelo, 1972; Manceñido *et al*., 1976; González, 1992, 1997; Lech, 1986, 2002; Lech and Aceñolaza, 1987a-b; Sterren, 2000, 2004; Cisterna and Simanauskas, 2000; Archbold and Simanauskas, 2001; Cisterna *et al*., 2002, 2006, 2011; Taboada, 2006, 2010; Cisterna and Archbold, 2007; Cisterna and Sterren, 2007; Díaz Saravia, 2009; and others), but it also includes some gastropods (Manceñido and Sabattini, 1974; Sabattini *et al*., 1991; Cisterna and Sabattini, 1998) and some body-remains of fish (chondricthyan and actinopterygian teeth and scales) (Manceñido, 1973; Díaz Saravia, 2001; Cione *et al*., 2010), and scarce unidentified conodonts (Henderson in Taboada, 2010).

The faunal assemblage and biozone were named because of the frequent concurrence of the brachiopods *Tivertonia jachalensis* (Amos, 1961) and *Streptorhynchus inaequiornatus* Leanza, 1945 (Sabattini *et al*., 1991). Other representative brachiopods of the *Tivertonia-Streptorhynchus* fauna are *Kochiproductus riojanus* (Leanza, 1948), *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* Lech, 1986 (Cisterna, 2011), *Pericospira* spp, Cisterna and Archbold, 2007, *Saltospirifer guevarii* Cisterna and Archbold, 2007, *Coronalosia paganzoensis* Archbold and Simanauskas, 2001, *Rhynchopora* sp. Cisterna and Simanauskas, 2000, *Crurithyris* spp. George, 1932, *Neochonetes pegnonensis* Cisterna and Simanauskas, 2000, and the new species *Coolkilella aredesi* sp. nov. and *Calytrixia piersoni* sp. nov., among others.

Different authors considered the *Tivertonia-Streptorhynchus* Biozone variably within the late Carboniferous–earliest Permian according to its faunal affinities (Manceñido *et al*., 1976; Sabattini *et al*., 1991; Archbold *et al*., 2004; Lech and Raverta, 2005; González and Díaz Saravia, 2010; Taboada, 2010; Cisterna *et al*., 2011). Recent radiometric dates provided by Gulbranson *et al*. (2010) from beds linked to the transgression bearing the *Tivertonia-Streptorhynchus* fauna (Tupe and Río del Peñón formations in the Río Blanco Basin) yielded $^{206}Pb/^{238}U$ ages of 312.82 ± 0.11 Ma and 310.63 ± 0.1 Ma thus constraining the *Tivertonia-Streptorhynchus* Biozone to the Moscovian (according to the timescale of Davydov *et al*., 2010). This supports the late Carboniferous age previously suggested by Sabattini *et al*. (1991) for the biozone (Césari *et al*., 2011).

THE *TIVERTONIA-STREPTORHYNCHUS* AND *COSTATUMULUS AMOSI* FAUNAS IN THE QUEBRADA AGUA DEL JAGÜEL SECTION

Stratigraphic setting

Stratigraphic scenarios and age estimations for the Upper Paleozoic exposed at Quebrada Agua del Jagüel –located roughly 20 km northeast of Uspallata, Mendoza Province (Fig. 2)– have been historically controversial. Since the recognition of the Agua del Jagüel Formation in that area, three main different stratigraphic frameworks have been alternatively accepted for this unit (Amos and Rolleri, 1965, *nom. nov.* for Jagüel Formation of Harrington, 1954 *in schedis*, published in 1971; *emend.* Limarino *et al*., 2013b).

The first was originally established by Harrington (1971) (see also Amos and Rolleri, 1965), who argued for a continuous but folded stratigraphic succession uncomformably overlying the pre-Carboniferous basement (Villavicencio Formation) at a high angle clearly discernible north of Quebrada Agua del Jagüel. The succession unconformably underlies Permo–Triassic volcanoclastic strata of the Choiyoi Group. This general scheme, consisting of a conspicuous glacial-related section interpreted as intercalated within the stratigraphic column, was followed by Taboada (1987, 2010) and Lech (1990, 2002), among few other authors.

The second and historically most accepted stratigraphic interpretation states that the glacial-related interval constitutes the lower part of the Agua del Jagüel Formation, the base of which remains unknown south of Quebrada Agua del Jagüel. (López Gamundi and Amos, 1982; Bercowski and Vallecillo, 1996; Ciccioli *et al*., 2008; Henry *et al*., 2010; and others). However, none of the authors supporting this interpretation discussed the stratigraphic relationship of this glacial-related interval north of Quebrada Agua del Jagüel, ignoring Harrington's original statement about it.

This was recently acknowledged by Pérez Loinaze *et al*. (2010) and Limarino *et al*. (2013b), who suggested a third stratigraphic interpretation. This new interpretation is mainly based on the columnar sections provided by Taboada (1987) and Lech (1990), although it includes a regionally significant inverse fault between the basal glacial-related strata of the emended Agua del Jagüel Formation and the recently pro-

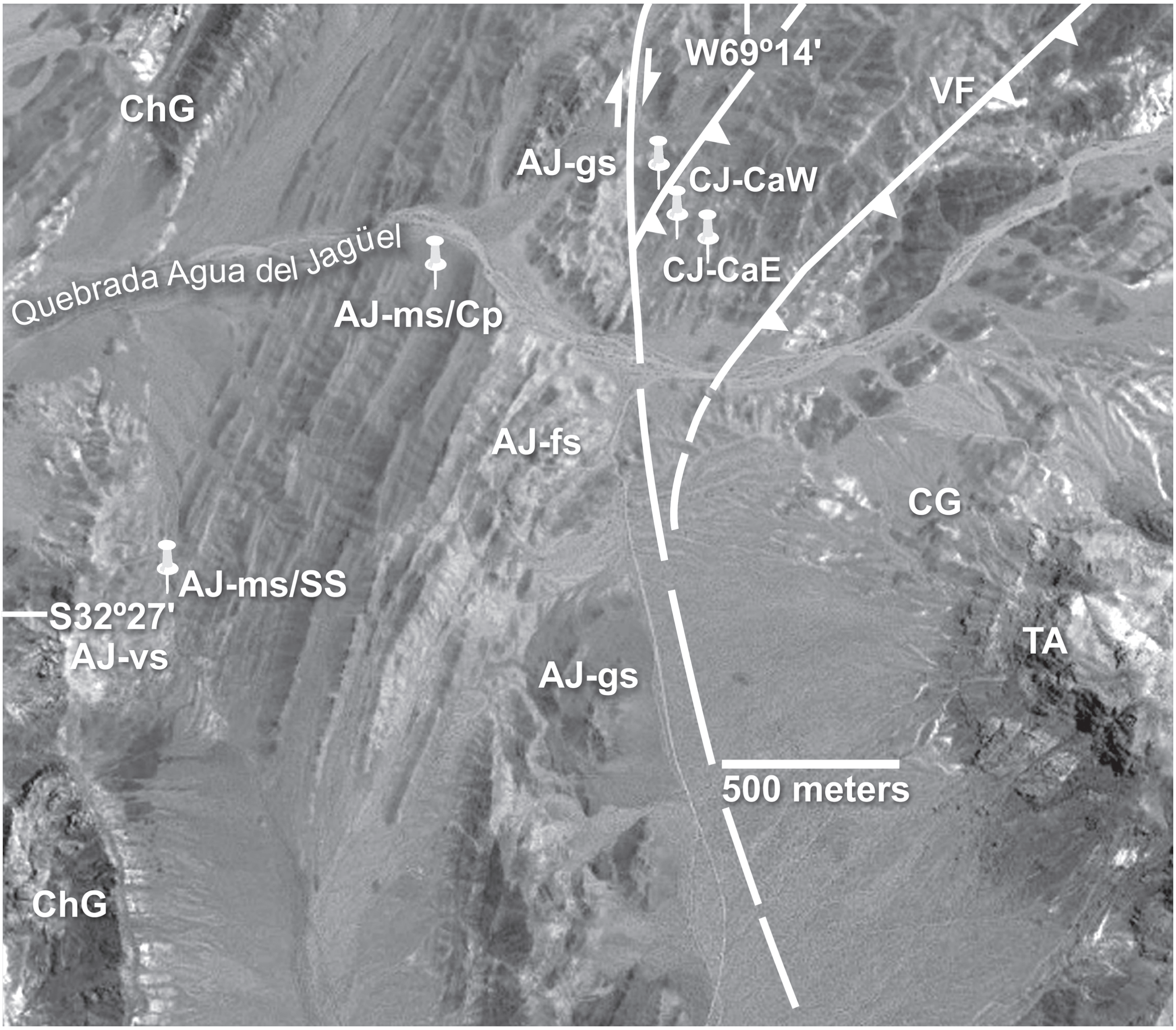

Figure 2. Satellite image from the Quebrada Agua del Jagüel area (from public domain sources). **VF,** Villavicencio Formation (Lower Paleozoic); **AJ,** Agua del Jagüel Formation; **AJ-gs,** glacial-related section; **AJ-fs,** fluvial section; **AJ-ms,** marine section; **AJ-ms/Cp,** beds with *Calytrixia piersoni* sp. nov.; **AJ-ms/SS,** beds with *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* and *Streptorhynchus inaequiornatus* here figured; **CJ,** Cordón del Jagüel Formation; **CJ-CaE,** eastern beds with *Costatumulus amosi*; **CJ-CaW,** western beds with *Costatumulus amosi*; **ChG,** Choiyoi Group (Permo-Triassic); **CG,** Cacheuta Group (Triassic); **TA,** Terciary andesites. White lines: indicate main faults.

posed Cordón del Jagüel Formation (Fig. 2). The latter unit is currently separated as a section from the Agua del Jagüel Formation of previous schemes: "Agua del Jagüel section" of Césari *et al*., 2011 or Permian strata of Pérez Loinaze *et al*., 2010; "lower section of the Agua del Jagüel Formation" *sensu* Taboada (1987) (Limarino *et al*., 2013b). Although a northern branch of this inverse fault (mapped in Taboada, 1984; see also Freije, 2004) shows an apparently locally weak field expression (Fig. 2), the different paleontological content on either side of the faulting highlights the non-normal stratigraphic relationship between the mentioned sections, as suggested recently by Ciccioli *et al*. (2008), Pérez Loinaze *et al*. (2010) and Limarino *et al*. (2013b).

Review and new data on paleontological content and biostratigraphy

The subsequent discussion on paleontological content and biostratigraphy refers to the two main Upper Paleozoic units exposed at Quebrada Agua del Jagüel, *i.e.*, the Agua del Jagüel and the Cordón del Jagüel formations (Fig. 2). The Agua del Jagüel Formation comprises the glacial-related horizon and the overlying strata cropping out along both sides (south and north) of Quebrada Agua del Jagüel, while the Cordón del Jagüel Formation is located between the pre-Carboniferous basement of the Villavicencio Formation to the east and the glacial-related strata of the Agua del Jagüel Formation to the west, mostly north Quebrada Agua del Jagüel (Fig. 2).

The Agua del Jagüel Formation. Carboniferous spores (Césari in Henry *et al.*, 2010) and scarce fossils have been recovered from the glaciomarine-related horizon (sequence 1 of Henry *et al.*, 2010) in the lower part of the unit. Bivalves were reported by Amos and Rolleri (1965), and others mollusks (bivalves, gastropods and scaphopods) have been recorded in small spheroidal concretions in a shale interbedded with the diamictite (fossiliferous bed N3 of Taboada, 1987, 1992) (stage 2 of sequence 1 of Henry *et al.*, 2010). Brachiopods and gastropods referred to the yet undescribed *Rhipidomella-Micraphelia* assemblage were indicated from the shale with dropstones overlying diamictitic beds (Martínez *et al.*, 2001; Cisterna, 2010). Chonetids, the nautiloid *Sueroceras* sp. and U-shaped burrows referred to *Tisoa* sp. (Taboada, 1987; Lech, 2002) were recovered from the concretions, but also from a shale located stratigraphically above the diamictitic interval (fossil bed N5 of Taboada, 1984, 1987; fossil zone ZF-2 of Lech, 1990, 2002; mudrocks with marls of stage 4 at the uppermost part of sequence 1 of Henry *et al.*, 2010). According to Henry *et al.* (2010), this glacial-related interval was estimated to measure a compiled maximum of 520 m thick. An incision surface separates the glacial-related interval from the overlying section (Ciccioli *et al.*, 2008; Henry *et al.*, 2010), estimated to be nearly 340 m thick. This part of the unit begins with a mainly fluvial interval, while the uppermost 250 m correspond to a marine horizon with several fossil-bearing beds. From this uppermost interval of the Agua del Jagüel Formation, González (1982) described the bivalves *Oriocrassatella sanjuanina* González, *Cypricardinia*? sp. nov., *Sanguinolites* sp., *Schizodus* sp., *Streblochondria*? sp. and Pectinacea indet., mentioning also the brachiopods *Cancrinella* aff. *C. farleyensis* (Etheridge and Dunn, 1909), *Septosyringothyris*? Vandercamenn, 1955, *Orbiculoidea* d'Orbigny, 1947, *Crurithyris roxoi* (Oliveira, 1936) *sensu* González, 1985, and the gastropods *Glabrocingulum* Thomas, 1940, *Peruvispira* sp. Chronic, 1949, and Bellerophontacea indet. This faunal assemblage was previously recognized by different authors as representative of the *Costatumulus amosi* Biozone (Taboada, 1998, 2006, 2010; Martínez *et al.*, 2001; Cisterna, 2010; González and Díaz Saravia, 2010), although recognized as belonging to the *Tivertonia-Streptorhynchus* fauna discussed herein.

On the other hand, Lech (1986, 1990, 2002) has illustrated –also from this upper part of the Agua del Jagüel Formation– brachiopods such as *Septosyringothyris* (*Precosyringothyris*) *jaguelensis*, *Costatumulus* sp. [=*Cancrinella farleyensis* (Etheridge and Dunn) and *Cancrinella* sp. of Lech, 1990], *Linoproductus cora* (d'Orbigny) *sensu* Lech, 1990, *Streptorhynchus inaequiornatus*, *Crurithyris* sp. of Lech, 1990 and *Lissochonetes* sp. of Lech, 1990, among others. This brachiopod assemblage led Lech (2002) to uphold the presence in the area of the *Tivertonia-Streptorhynchus* Biozone of Sabattini *et al.* (1991). Lech (2002) also suggested that the age of the fossil assemblage was Moscovian–Ghzelian. A late Carboniferous biotite K/Ar age of 307.2 ± 5.2 Ma (Moscovian–Kasimovian) was obtained from a 6 m thick intercalation of dacitic lava found in the middle part of the Agua del Jagüel Formation (Lech, 2002; Koukharsky *et al.*, 2009), constraining the base of the marine section (base of sequence 3 of Henry *et al.*, 2010) roughly to an early Moscovian maximum age.

New data provided herein on the fossil content of the Agua del Jagüel Formation are based on new and previous findings that allow confirmation and/or taxonomic reassignment of some key elements of the fauna. New specimens of *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* Lech (Fig. 3, 1–2) (Cisterna, 2011; formerly *Histosyrinx jaguelensis* (Lech) Lech and Raverta, 2005) and *Streptorhynchus inaequiornatus* Leanza (Fig. 3.3–7) were found at the top of the marine section, just below the volcanic suite indicated by Koukharsky *et al.* (2009) at the westernmost outcrops of the Agua del Jagüel Formation (32°27′07″S–69°15′4.5″W) (Figs. 2, 4). The record of *Streptorhynchus inaequiornatus* in this part of the marine section (fossil "zone" Zf 5 of Lech, 2002) was previously illustrated by Lech (1990) and is confirmed here. In addition, associated fossil remains (formerly *Cancrinella* and/or *Costatumulus*) are referred to two other new brachiopod species, *i.e.*, *Coolkilella aredesi* sp. nov. and *Calytrixia piersoni* sp. nov. (Fig. 5). As previously interpreted by Lech (1990, 2002), these species are present in other coeval units bearing the *Tivertonia-Streptorhynchus* fauna, such as the Del Salto and Río del Peñón formations.

It is worth noting that specimens from the Agua del Jagüel Formation formerly classified as *Cancrinella* aff. *C. farleyensis* (Etheridge and Dunn) by Taboada (1987, table 1, fossiliferous beds N6 and N7), were erroneously proposed to be conspecific with *Costatumulus amosi* Taboada, 1998, from the Cordón del Jagüel Formation (Taboada, 1998). This supposition was followed by different authors until recently (Cisterna, 2010; Taboada, 2010; González and Díaz Saravia, 2010; Cisterna *et al.*, 2011). However, *Costatumulus amosi* was never described or illustrated from the Agua del Jagüel Formation (as emended by Limarino *et al.*, 2013b). Furthermore, specimens from the upper part of the Agua del Jagüel Formation –more precisely those collected from the fossil bed N7 of Taboada (1987)– are here reassigned to *Calytrixia piersoni* sp. nov. Consequently, the *Tivertonia-Streptorhynchus* fauna is recognized in the upper part of the Agua del Jagüel Formation (in agreement with Lech, 2002), while available evidence does not support the presence in it of *Costatumulus amosi* as previously inferred.

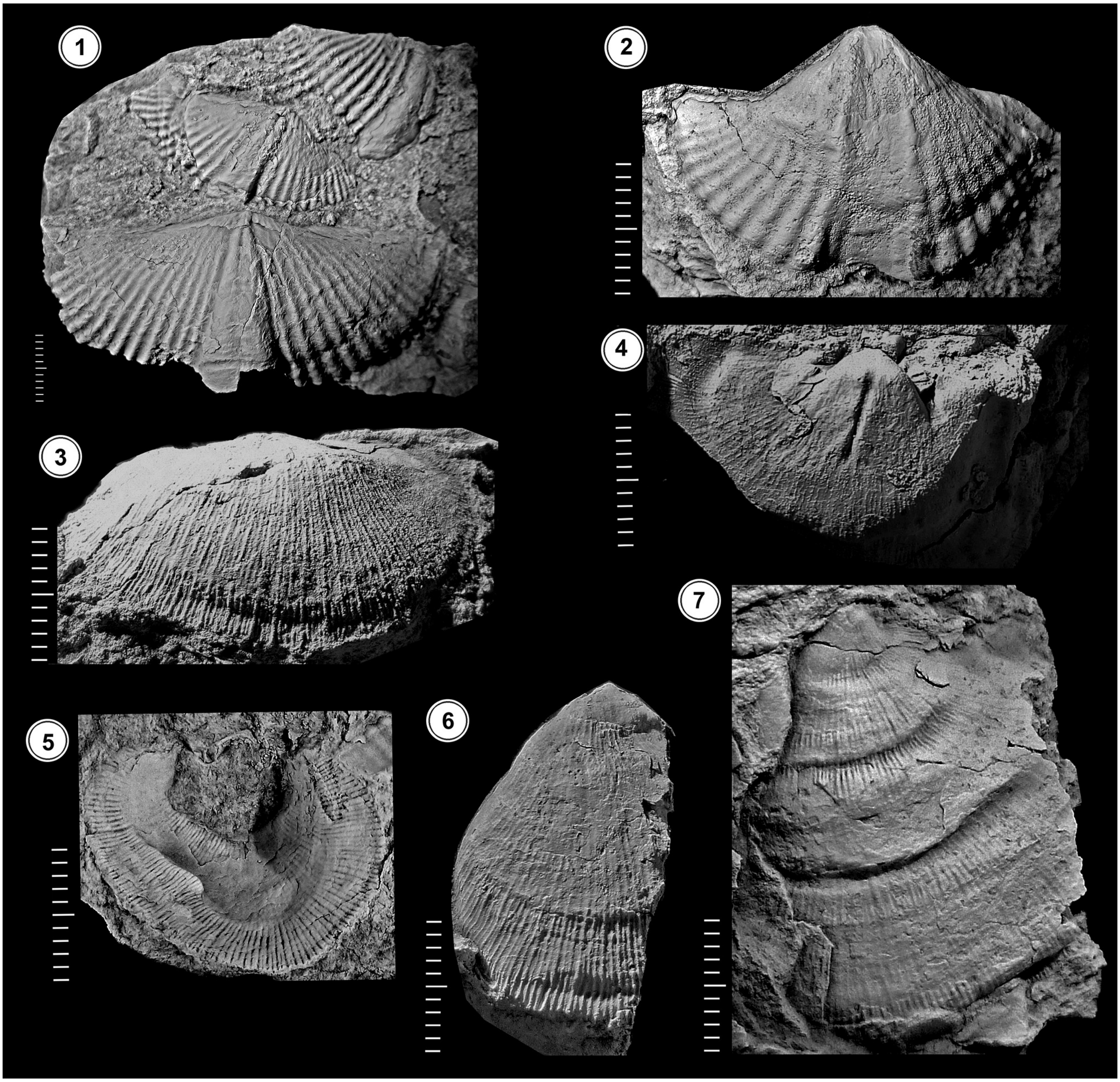

Figure 3. 1–2, *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* Lech LIEB-PI 320; **1,** partially decorticate dorsal valves LIEB-PI 326, **2,** exterior of ventral valve. **3–7, *Streptorhynchus inaequiornatus*** Leanza, **3,** LIEB-PI 332, exterior of dorsal valve in anterior view; **4,** LIEB-PI 335, mould interior of dorsal valve; **5,** LIEB-PI 331, interior of ventral valve; **6,** LIEB-PI 334, partially decorticate dorsal valve; **7,** LIEB-PI 333, exterior of ventral valve. All figured material from near the top of the marine section of the Agua del Jagüel Formation, 1 km south of the eponymous creek (32°27′07″S–69°15′4,5″W) (Fig. 2). Scale bar= 10mm.

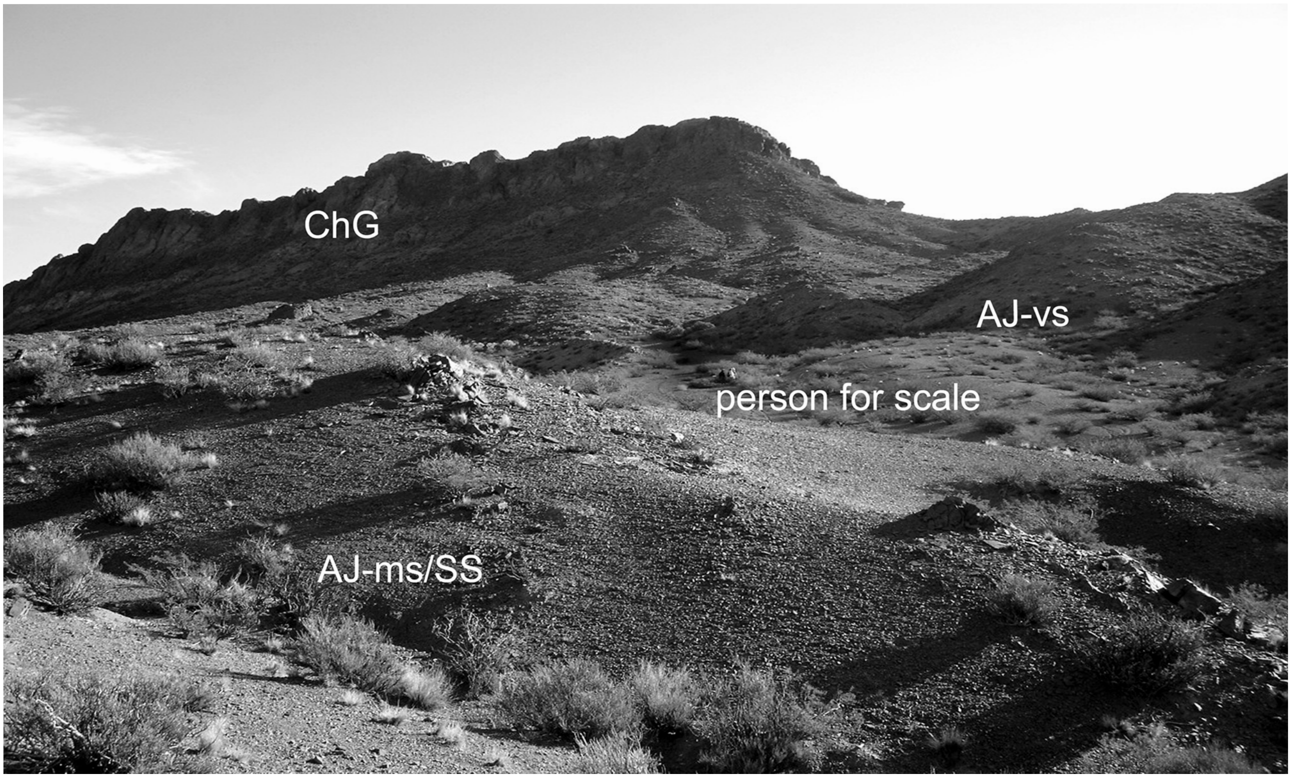

Figure 4. Photograph of the southwesternmost outcrops of the Agua del Jagüel Formation. **AJ,** Agua del Jagüel Formation; **AJ-ms/SS,** top of the marine section bearing ***Septosyringothyris* (*Precosyringothyris*) *jaguelensis*** Lech and ***Streptorhynchus inaequiornatus*** Leanza; **AJ-vs,** volcanic suite; **ChG,** Choiyoi Group (Permo–Triassic).

The Cordón del Jagüel Formation. Fossil remains from the Cordón del Jagüel Formation include gastropods, bivalves and abundant but non-diverse brachiopods from calcareous lenses within a shale (fossil bed 3 of Taboada, 1987, at and nearby 32°26′30.9″S–69°14′07″W). *Cancrinella* aff. *C. farleyensis* of Taboada (1987) from this bed was reassigned to *Costatumulus amosi* Taboada which is conspecific with the specimens from this section assigned by Lech (1990, 2002) to *Cancrinella/Costatumulus?*. Other brachiopods such as *Coolkilella keideli* Taboada, 1998, and *Tivertonia leanzai* Taboada, 2006 (= *Lissochonetes* sp./*Tivertonia* sp. of Lech, 1990, 2002,) were profusely recorded associated to *Costatumulus amosi*. Westernmost occurrence of this last mentioned key species was also recorded in calcareous lenses at 32°26′29.3″S–69°14′11.9″W, less than 10 m east from the faulting zone that separates the Cordón del Jagüel Formation from the basal glacial-related interval of the Agua del Jagüel Formation. This record, together with an apparently not highly disturbed stratigraphic succession, prompted Taboada (2006, 2010) to reaffirm an equivocal "normal" stratigraphic succession.

On the other hand, Lech (2002) suggested the presence of the *Tivertonia-Streptorhynchus* fauna in the Cordón del Jagüel Formation. Nevertheless, none of the conspicuous species that characterize the *Tivertonia-Streptorhynchus* faunal assemblage are present in this unit or associated to the *Costatumulus amosi* fauna in other localities. Martínez *et al.* (2001) and other authors (Cisterna, 2010; Cisterna *et al.*, 2011) proposed the repetition of a tectonic wedge of the Agua del Jagüel Formation (wrongly supposed to yield the *Costatumulus amosi* fauna) exposed as the Cordón del Jagüel Formation bearing true *Costatumulus amosi,* to explain its occurrence to the east ("below") of the glacial-related stratigraphic interval at Quebrada Agua del Jagüel. Nevertheless, the different stratigraphical relationships and distinctive paleontological content of each section mentioned of the Agua del Jagüel and Cordón del Jagüel formations, as discussed above, reinforce the stratigraphic interpretations of Pérez Loinaze *et al.* (2010) and Limarino *et al.* (2013b), but not the hypothetical tectonic repetition of any part of the mentioned units exposed at Quebrada Agua del Jagüel.

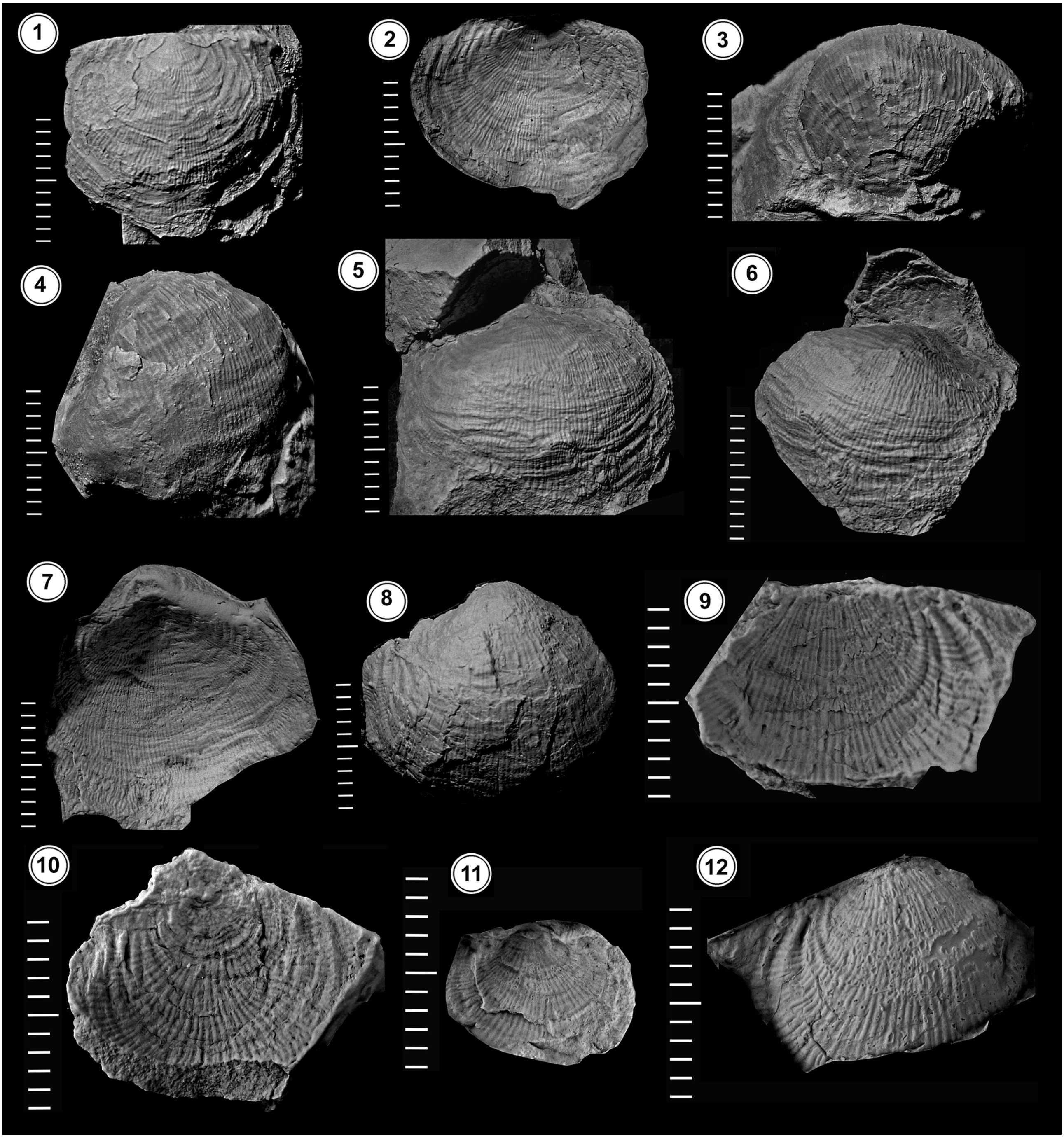

Figure 5. 1-8, *Coolkilella aredesi* sp. nov.; **1-2,** paratype LIEB-PI 168; **1,** external mould of dorsal valve; **2,** silicone mould of exterior of dorsal valve; **3-4,** paratype LIEB-PI 170; **3,** partially decorticate ventral valve in posterior view; **4,** same in ventro-lateral view; **5–7,** holotype LIEB-PI 171; **6,** fragmentary external mould of an articulated specimen in anterior viewviews; **7,** silicone mould of exterior of dorsal valve in dorsal view; **8,** LIEB-PI 172, ventral valve exterior in oblique view; **9–12, *Calytrixia piersoni*** sp. nov.; **9, 12,** PIL 13394-3; **9,** fragmentary external mould of ventral valve; **12,** silicone mould of ventral valve exterior; **10,** PIL 13394-2, dorsal valve exterior of a partially preserved articulate specimen; **11,** PIL 13394-1, silicone mould of dorsal valve exterior. Scale bar= 10mm.

THE *COSTATUMULUS AMOSI* FAUNA AND BIOZONE

The *Costatumulus amosi* Biozone was proposed instead of the *Cancrinella* Biozone of Amos and Rolleri (1965) (in part; Taboada, 1998, 2006) by the reassignment of specimens assigned to *Cancrinella* aff. *C. farleyensis* (Etheridge and Dunn) by Taboada (1987) to *Costatumulus amosi* Taboada. The *Costatumulus amosi* fauna is a low-diversity fauna geographically restricted to the southernmost part of the Calingasta-Uspallata Basin (Taboada, 1998, 2010) (Fig. 1). Besides the nominal species, the other few identified brachiopods are *Coolkilella keideli* Taboada, *Tivertonia leanzai* Taboada, *Crurithyris* sp., and *Argentiella stappenbecki* Archbold, Cisterna and Sterren (Taboada, 1998, 2006; Archbold *et al.*, 2005; Cisterna, 2010), among other poorly known syringothyrids and spiriferids.

The *Costatumulus amosi* Biozone was estimated to be Asselian–Tastubian (Taboada, 1998, 2006) and recently late Sakmarian-early Artinskian, in agreement with the currently recognized age-range of its known brachiopods (Taboada, 2010; Taboada and Pagani, 2010). In addition, elements of the Sakmarian?–Artinskian *Lueckisporites-Weylandites* palynological assemblage, distinguished by the dominance of taeniate pollen grains, were recently described from the same strata supporting a middle Cisuralian age for the *Costatumulus amosi* -faunal assemblage (Césari *et al.*, 2008, 2011; Pérez Loinaze *et al.*, 2010).

Current stratigraphic and paleontological evidence allows restricting the *Costatumulus amosi* Biozone to the Cordón del Jagüel Formation and the topmost strata of the neighboring Cerro La Cantera section, to those outcrops located at the junction of Quebrada Santa Elena and Quebrada del Telégrafo, and to a thin tectonic wedge intercalated between the Tramojo and Jarillal members of the Santa Elena Formation at Sierra de Uspallata. *Costatumulus amosi* was originally described from all these localities (Taboada, 1998) (Fig. 6).

STRATIGRAPHY AND RECORDS OF THE *TIVERTONIA-STREPTORHYNCHUS* AND *COSTATUMULUS AMOSI* FAUNAS AT QUEBRADA SANTA ELENA

Excepting the late early Permian volcanoclastic Siete Colores Formation (Cortés *et al.*, 1997; Gregori and Strazzere, 2012), the Upper Paleozoic exposed at Quebrada Santa Elena (also known in previous reports as Quebrada Uspallata) was assigned to the Santa Elena Group (Yrigoyen, 1967, *nom. transl.* Cortés *et al.*, 1997) which includes –with formational rank the former Tramojo and Jarillal "Series" of Keidel

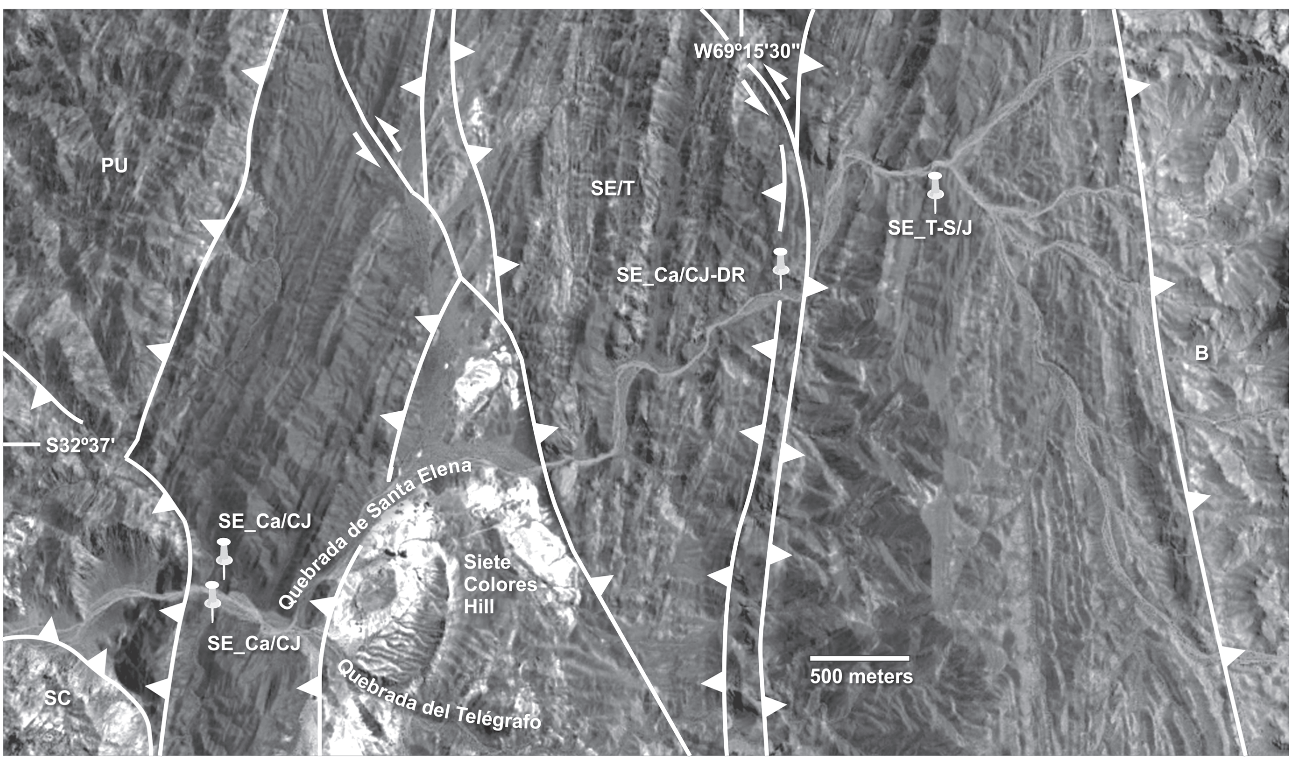

Figure 6. Satellite image from the Quebrada Santa Elena area (from public domain sources). **PU,** Puntilla de Uspallata Formation (Cambro–Ordovician); **SE_Ca/CJ,** Santa Elena Group/Formation partial section yielding the early Permian *Costatumulus amosi* fauna and possibly correlated to the Cordón del Jagüel Formation; **SC,** Siete Colores Formation (late early Permian); **SE/T:** early Late Carboniferous Tramojo Formation/Member; **SE_Ca/CJ-DR,** Santa Elena Group/Formation partial section yielding the early Permian *Costatumulus amosi* fauna at the locality mentioned by Dessanti and Rossi (1950) and possibly correlated to the Cordón del Jagüel Formation; **SE_T-S/J,** Jarillal Formation/Member bearing the Moscovian *Tivertonia-Streptorhynchus* fauna; **B,** Bonilla Formation (Cambro–Ordovician). White lines indicate main faults.

(1939; *nom. transl.* Polansky, 1970). Likewise, the Tramojo and Jarillal "Series" were considered as members of the Santa Elena Formation, maintaining the original rank of Yrigoyen (1967) (Taboada, 1998, 2006). Nevertheless, two tectonic wedges bearing the *Costatumulus amosi* fauna were separated from the Tramojo "Series"/ Formation/ Member and correlated (Taboada, 1998) with the strata currently defined as Cordón del Jagüel Formation by Limarino *et al*. (2013b); such a correlation is reaffirmed here. One of these wedges corresponds to a thin stratigraphic interval located between the Tramojo and Jarillal units, just at the place where Dessanti and Rossi (1950) reported their "beds with *Productus*" (= *Costatumulus amosi* of locality 4 of Taboada, 1998, at 32°36′40.5″S–69°15′06″W) (Fig. 6). The other outcrop yielding *Costatumulus amosi* is located at the junction of Quebrada Santa Elena and Quebrada del Telégrafo ("Grupo" Occidental or J of Dessanti and Rossi, 1950; section 1 of Rodríguez, 1966; upper fossil green shales member the Tramojo Formation of Cortés *et al*., 1997), where this species was previously reported as *Cancrinella* aff. *farleyensis* by Archangelsky and Lech (1987) (Fig. 6). Figure 7 synthesizes the main lithostratigraphic and biostratigraphic units recognized in western Argentina basins, including those recognized at Quebrada Agua del Jagüel and Quebrada Santa Elena discussed herein.

On the other hand, some authors unfortunately misunderstood the geographic location, stratigraphic record and/or faunal identity of the different faunal assemblages recognized at Quebrada Santa Elena. As mentioned above, *Costatumulus amosi* was actually described from outcrops of the Santa Elena Formation at the junction of Quebrada Santa Elena and Quebrada del Telégrafo (Taboada, 1998; see also Cisterna, 2010), but never associated –even at a single locality– with *Tivertonia jachalensis* (Amos), as wrongly stated by Cisterna (2010). *Tivertonia jachalensis* (Amos) was described and illustrated from a different outcrop located 5 km eastward (32°36′27.5″S –69°14′28.7″W) from the former, in the stratigraphically distinctive Jarillal Member (Polansky, 1970 *nom. transl.* Taboada, 1998= Sección 4 of Rodríguez, 1966) of the Santa Elena Formation (Fig. 6) and associated to elements of the *Tivertonia-Streptorhynchus* fauna (Taboada, 1998, 2006). This occurrence of the *Tivertonia-Streptorhynchus* fauna was mistakenly confused with the *Costatumulus amosi* fauna by Cione *et al.* (2010).

The recognition of the *Tivertonia-Streptorhynchus* fauna in the Jarillal Member and the *Costatumulus amosi* in strata correlated to the Cordón del Jagüel Formation was pointed out by Taboada (1998, 2006), who disagreed with the coeval age-range recently attributed to the two units by Cisterna (2010). The different stratigraphic records and distinct faunal identities prevent their assignment to either the *Tivertonia-Streptorhynchus* or *Costatumulus amosi* faunas. Explaining the presence of genera such as *Coolkilella*, *Tivertonia* and *Crurithyris* in the *Costatumulus amosi* fauna requires more than a coeval condition and possibly indicates a relict impoverished fauna derived, at least in part, from the ancestral *Tivertonia-Streptorhynchus* faunal stock.

REPOSITORIES

The material described and figured herein is housed in the fossil invertebrate collections at the Laboratorio de Investigaciones en Evolución y Biodiversidad, Facultad de Ciencias Naturales, Sede Esquel, Universidad Nacional de la Patagonia, Esquel (**LIEB-PI**), and the Instituto Miguel Lillo (**PIL**) and Fundación Miguel Lillo (**FML-PI**; formerly IPI), Tucumán, Argentina.

SYSTEMATIC PALEONTOLOGY

Suprageneric classification follows Waterhouse (2001, 2002, 2010).

Superfamily LINOPRODUCTOIDEA Stehli, 1954
Family KANSUELLIDAE Muir-Wood and Cooper, 1960
Subfamily PAUCISPINAURIINAE Waterhouse, 1986
Tribe COOLKILELLINI Waterhouse, 2001

Genus ***Coolkilella*** Archbold, 1993

Type species. *Coolkilella coolkilyaensis* Archbold, 1983, original designation. Kungurian, Coolkilya Greywacke, Carnarvon Basin, Western Australia.

Coolkilella aredesi sp. nov.
Figures 5.1–8

?1990 *Cancrinella farleyensis* (Etheridge and Dunn); Lech, p. 225, Pl. 2, figure 2.
?1990 *Linoproductus cora* (d'Orbigny); Lech, p. 225, figure 3.
?2000 *Costatumulus* sp. C; Cisterna and Simanauskas, p. 141–142, figures 5e–l.
?2010 *Costatumulus* sp. C; Cisterna and Simanauskas, Cisterna, p. 94, figure 2T (copy Cisterna and Simanauskas, 2000, figure 5i).
2010 *Coolkilella* sp.; Taboada, p. 169, figures 14B–D.

Derivation of name. Dedicated to Mr. Miguel Ángel Aredes (technician of the CONICET), a resourceful assistant during fieldwork.

Diagnosis. Average-sized subglobose *Coolkilella* of subcircular-slightly transverse outline with maximum width at posterior third of valve. Finely costellate (3–5/ mm at 5 mm from umbo), with costellae increasing ventrally by splitting, bearing sub-postrate spines (2–3/5 mm at 5 mm from the umbo) from slightly swollen evenly elongate spine bases (2–3 mm in length). Costellae increasing dorsally by intercalation. Geniculation beginning with angle of 60°, reaching 110° at full maturity.

Type material. Holotype, LIEB-PI 171; paratypes: LIEB-PI 168, 170.

Additional material. Eight specimens, mainly fragmentary articulate specimens, external moulds of dorsal and ventral valves and one internal mould of ventral valve. LIEB-PI 172-176.

Geographic and stratigraphic provenance. Material comes from Quebrada de la Arena, 4 km south from Kilometer 114 of National Highway 20, San Juan Province. Del Salto Forma-

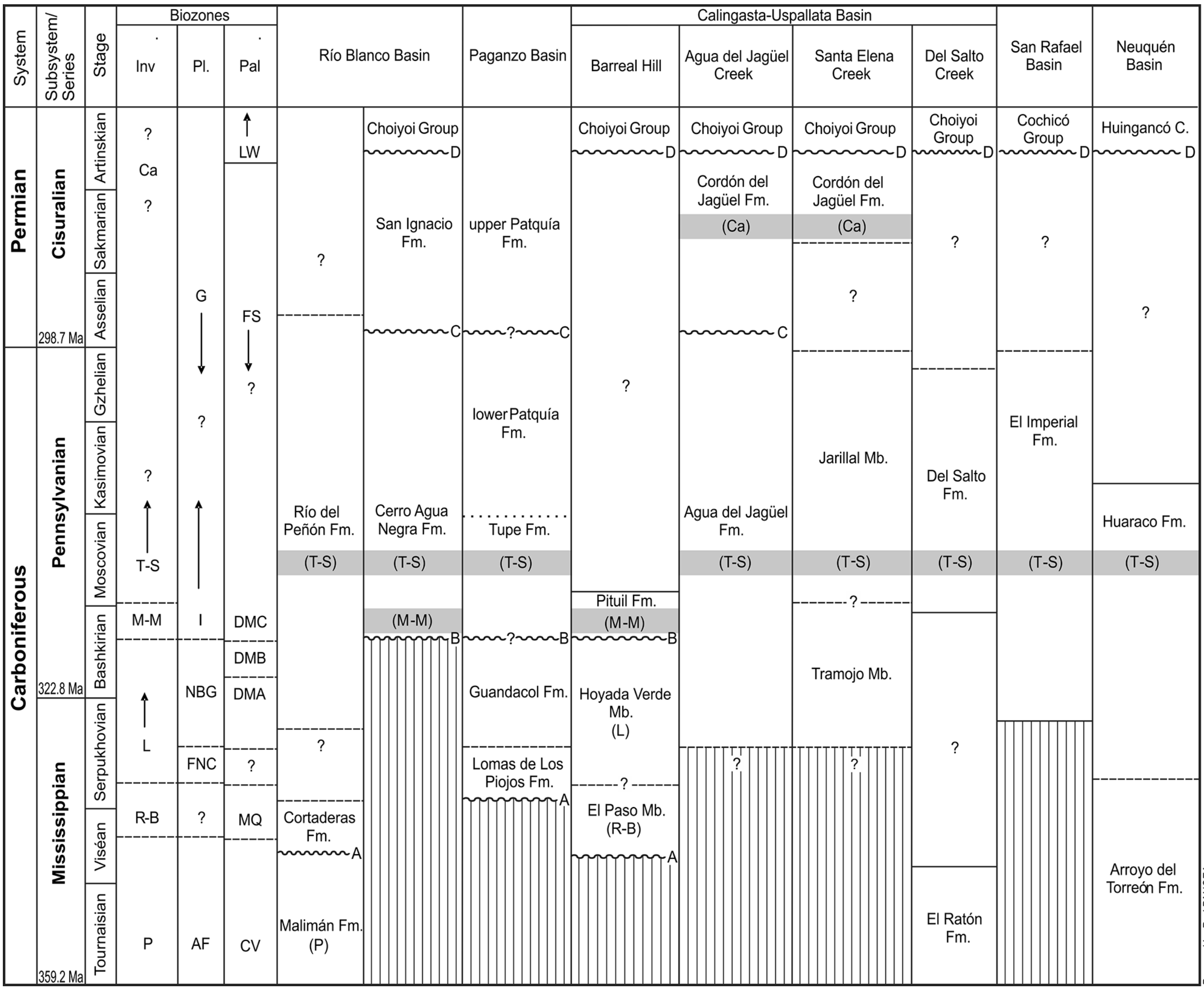

Figure 7. Correlation chart of Late Paleozoic select lithostratigraphic units and invertebrates, plants and palinological biozones of basins in western Argentina. Stages and stratigraphic units of higher hierarchy according to the International Stratigraphic Chart published by Gradstein *et al*., 2004; Litho- chronostratigraphic and geochronological units without scale. Invertebrate biozones: **P,** *Protocanites-Azurduya*; **R-B,** *Rugosochonetes-Bulahdelia*; **L,** *Levipustula levis*; **M-M,** *Marginovatia-Maemia*; **T-S,** *Tivertonia-Streptorhynchus*; **Ca,** *Costatumulus amosi*; Plant biozones: **A-F,** *Archaeosigilaria-Frenguellia*; **FNC,** *Frenguellia-Nothorhacopteris-Cordaicarpus*; **NBG,** *Nothorhacopteris-Botrychiopsis-Gingophyllum*; **I,** Interval; **G,** *Gangamopteris*. Palynological biozones: **CV,** *Cordylosporites-Verrucosisporites*; **MQ,** *Reticulatisporites-Verrucosisporites*; **DMA,** *Raistrickia-Convolutispora* Subzone; **DMB,** *Raistrickia-Convolutispora* Subzone; **DMC,** *Raistrickia–Convolutispora* Subzone; **FS,** *Pakhapites-Vittatina*; **LW,** *Lueckisporites-Weylandites*. **A,** Río Blanco orogenic phase; **B,** San Eduado epeirogenic phase; **C,** Atacama orogenic phase; **D,** San Rafael orogenic phase. Invertebrate biozones after Taboada (2010); Plant and palynological biozones after Césari *et al*.; Diastrophic phases after Taboada (2010) and Limarino *et al*. (2013b). Boundary between Arroyo del Torreón and Huaraco formations after Zappettini *et al.* (2012). Mississippian and Pennsylvanian boundaries after Davydov *et al*. (2010).

tion, "Areniscas y Pelitas multicolores" Member, fossiliferous bed "D" of Manceñido (1973) (Fig. 8).

Description. Average-sized *Coolkilella*, subcircular outline and strong concave-convex profile. Valve length almost equal to width, or slightly transverse, with maximum dimensions up to 26 mm wide, 25 mm long, and 5 mm thick. Ventral valve subglobose, evenly convex, with small ears and maximum width at posterior third of valve. Ornamentation of fine radial costellae (3–5/ mm at 5 mm from the umbo), faint concentric growth lines, weak rugae on venter and well developed ones on auricles. Costellae number increasing by splitting into two or three ribs anteriorly from a spine base, and occasionally also by intercalation, with flexuous sectors. Spines subpostrate (2–3/5 mm at 5 mm from umbo) from slightly swollen evenly elongate spine bases (2–3 mm long). Dorsal valve concave, strongly geniculate. Geniculation beginning at a 60° a 60° angle and reaching 110° toward the anterior end of visceral disc. Ornamentation similar to ventral valve but without spines, with elongate dimples and stronger rugae, particularly on trail. Costellae increasing by intercalation. Interior of ventral valve with abundant and minute endospines anteriorly. Other features not observed.

Discussion. The shell shape, ornamentation and particularly the strong geniculation of the dorsal valve suggest it belongs in *Coolkilella* Archbold, 1993. *Coolkilella maitlandi* Archbold, 1996, from the Artinskian Mingenew Formation (Perth Basin) of Western Australia is the closest species to *Coolkilella aredesi* sp. nov. in size, shell shape and ornamentation. Nevertheless, the Argentine species exhibits a less spinose, finely split costellate pattern and a less abrupt geniculation. Other comparable species are *Coolkilella coolkilyaensis* (Archbold) Archbold, 1993 from the Kungurian Coolkilya Greywacke (Carnarvon Basin) of Western Australia (Archbold, 1993), *Coolkilella bella* (Etheridge) Archbold, 1993 from the Artinskian Noonkanbah (Canning Basin) and Wandagee (Carnarvon Basin) formations of Western Australia (Archbold, 1983, 1993) and *Coolkilella pseudovilliersi* Chen and Shi, 2006, from the Kungurian Qipan Formation (Tarim Basin) of northwest China (where *Coolkilella bella* was also recorded by Chen and Shi, 2006). *Coolkilella coolkilyaensis* –when compared with *Coolkilella aredesi* sp. nov.– possesses a more elongate outline, coarser costulation and a flattened dorsal valve, unlike the Argentine species which has a subcircular to slightly transverse outline, very fine costellae and a concave dorsal valve. *Coolkilella bella* can be easily differentiated from *Coolkilella aredesi* sp. nov. by a coarser ornamentation and the non-splitted condition of the costellae anterior to the spine bases in the former. *Coolkilella pseudovilliersi* has a diagnostic and distinctive elongate suboval to subtrigonal shell outline and coarse ribs, different from the subcircular or slightly transverse shell outline and fine costellate pattern of *Coolkilella aredesi* sp. nov.

In Argentina, the genus was previously identified as *Coolkilella keideli* Taboada, 1998, from the *Costatumulus amosi* Biozone recorded in outcrops of the Cordón del Jagüel Formation and in a partial section of the Santa Elena Formation at the junction of Quebrada Santa Elena and Quebrada del Telégrafo in the Sierra de Uspallata (Taboada, 1998). *Coolkilella aredesi* sp. nov. is close to *Coolkilella keideli* but can be distinguished by its more globose profile, more numerous spines and longer and more swollen spine bases. In addition, *Coolkilella aredesi* sp. nov. is larger, more transverse in outline and the dorsal valve is more concave with the geniculation beginning at a lower angle when compared to the younger Argentine species *Coolkilella keideli*. Dorsal valves of *Coolkilella aredesi* sp. nov. exhibit costellae increasing by intercalation, unlike the bifurcate pattern of costellae on the dorsal valve of *Coolkilella keideli.*

On the other hand, fragmentary specimens assigned to *Costatumulus* sp. C by Cisterna and Simanauskas (2000) from the Río del Peñón Formation at Rincón Blanco possess a subglobose profile and comparable dimensions, collectively suggesting a tentative conspecific condition with *Coolkilella aredesi* sp. nov. Likewise, specimens illustrated as *Linoproductus cora* (d'Orbigny) (from fossil zone ZF-3 of Lech, 2002) and *Cancrinella farleyensis* (Etheridge and Dunn) by Lech (1990) (=*Costatumulus* sp. from fossil zone ZF-5 of Lech, 2002) from the upper part of the Agua del Jagüel Formation are also included with caution in *Coolkilella aredesi* sp. nov.

Genus ***Calytrixia*** Waterhouse, 2010

Type species. *Terrakea capillata* Waterhouse in Foster and Waterhouse, 1988; original designation. Early Permian, Calytrix Formation, Canning Basin, Western Australia.

Discussion. The diagnosis provided by Waterhouse (2010) indicates small size (maximum width and length close to 15 mm) with relatively thin body cavity, moderately wide hinge at less than maximum width, and long ventral ears bearing a number of erect spines not arranged in one or two hinge rows, both valves ornamented by firm, narrow and close-set ribs with sturdy ventral spines arising from short elongate bases, no dorsal spines.

The type species was originally referred to *Terrakea* Booker, 1930 (Waterhouse in Foster and Waterhouse, 1988) but the presence of anterior dorsal spines was rejected by Archbold (1995), who reassigned the species to *Costatumulus* Waterhouse, 1983, although taking note that its small size is highly distinctive within the genus. Waterhouse (2010) recently stressed the nature of the ribbing, the stout ventral spine bases and the numerous ear spines in *Calytrixia* to differentiate it from *Costatumulus*. *Calytrixia* also resembles *Coolkilella* Archbold, 1993, in the ornamentation pattern but can be readily distinguished by its numerous ventral ear-spines, a thinner body cavity (Waterhouse, 2010), and by its smaller size, its non-subglobose profile with short trail and its weak geniculation. The numerous ear-spines in *Calyxtria* suggest *Auriculispina* Waterhouse, 1975, although the firm ribbing and broad ventral spines in the former are not typical of *Auri-*

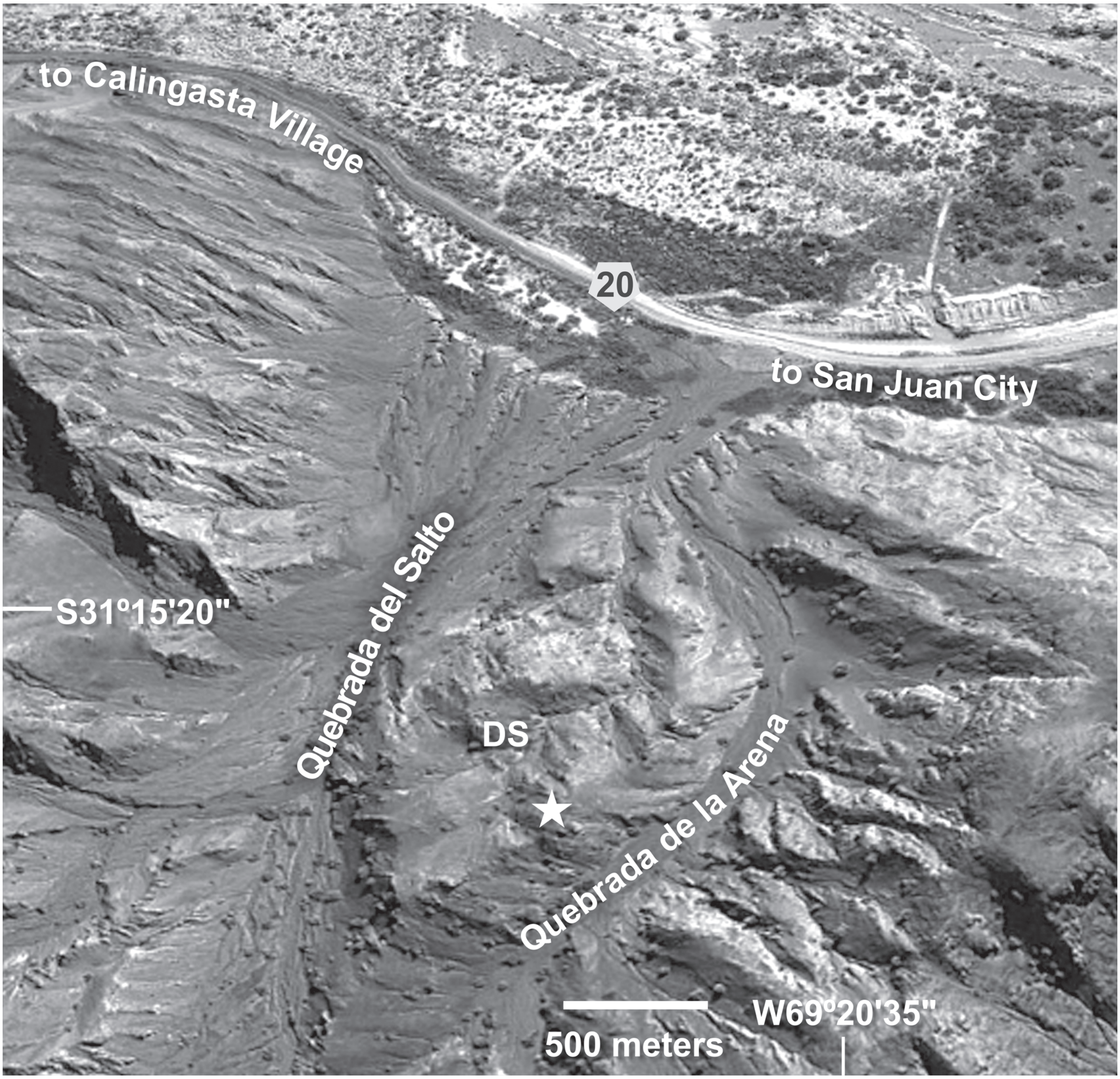

Figure 8. Satellite image of the fossil type locality with *Coolkilella aredesi* sp. nov., Quebrada de la Arena (from public domain sources). **DS,** Del Salto Formation; Star= fossil indicates fossil locality.

culispina (Waterhouse, 2010).

Calytrixia Waterhouse, originally recognized in Western Australia, is here reported also in western Argentina as *Calytrixia piersoni* sp. nov.. It is also probably recorded in the Antarctic Peninsula (specimens referred to as cf. *Cancrinella* sp. by Kelly *et al*., 2001.

Calytrixia piersoni sp. nov.
Figures 5.9–12

1987b *Cancrinella* sp.; Lech and Aceñolaza, p. 108, figures 2a–2c.
1990 *Cancrinella* sp.; Lech, p. 225, pl. 2, figure 8.
2000 *Costatumulus* sp. B; Cisterna and Simanauskas, p. 141, figures 5a–d.

Derivation of name. Dedicated to the chemist and naturalist Mr. Roger Pierson, Academician at Deakin University, Melbourne, Australia.

Diagnosis. Shell with subcircular to slightly elongate outline, profile gently concavo-convex, maximum length up to 17 mm and maximum width near the middle of the valve. Ventral valve with very weak rugae, more strongly marked on ears. Finely costellate (2–4/ mm on ventral disc) with costellae increasing by bifurcation anterior to spine bases and less frequently by intercalation. Ventral spines subprostrate, irregular to subquincunxially arranged, with 3 to 5 spines in 25 mm^2. Dorsal valve with stronger rugae, costellae coarser and interspaces narrower than those of ventral valve. Ribs increasing by bifurcation. Small, elongate dimples variably arranged.

Holotype. *Costatumulus* sp. B (Cisterna and Simanauskas, 2000, p. 141, figs.5a–b; FML-PI 3176a1–b1; formerly IPI), from the middle member of the Río del Peñón Formation, Moscovian of La Rioja Province, Argentina; designated herein.

Additional material. Two fragmentary isolated dorsal and ventral valve exteriors and an articulated specimen partially preserved, PIL 13394-1/3, from the upper marine section (fossil bed N7 of Taboada, 1987) of the Agua del Jagüel Formation (Fig. 2).

Discussion. Specimens previously assigned to the genera *Cancrinella* Fredericks, 1928, and/or *Costatumulus* Waterhouse, 1983, from the Río del Peñón (Lech and Aceñolaza, 1987b; Cisterna and Simanauskas, 2000) and Agua del Jagüel (Lech, 1990) formations, are smaller, with a subcircular or slightly elongate shell outline and gently concavo-convex profile, the spines are crowded on ears; such features together with the ornamentation pattern and sturdy ventral spines suggest it belongs in *Calytrixia* Waterhouse, 2010. The Argentine specimens closely resemble *Calytrixia capillata* (Waterhouse) (Waterhouse in Foster and Waterhouse, 1988; Archbold, 1995; Waterhouse, 2010) from the Calytrix Formation of the Canning Basin, Western Australia. They share a similar shell size, outline, and profile, as well as a comparable density of costellae (3-4 per mm), although *Calytrixia piersoni* sp. nov. differs from *Calytrixia capillata* (Waterhouse) mainly by its more sparsely distributed ventral spines (3–5 spines per 25 mm^2 in average) and also by a weak fine ribbing pattern.

Other fragmentary material (Figs. 5.9–12) from the upper part of the Agua del Jagüel Formation previously mentioned as *Cancrinella* aff. *C. farleyensis* (Etheridge and Dunn) by Taboada (1987, table 1, fossiliferous beds N6 and N7) is considered to be conspecific with *Calytrixia piersoni* sp. nov. The specimens have gently concave dorsal valves (10.1 and 17 mm wide, 12.6 and 15 mm long) with subcircular outline showing maximum width at midlength. Dorsal rugae are more marked anteriorly, with fine growth lines and scattered, irregularly distributed, small elongate dimples. Costellae (2–4/ mm over disc) increase dorsally by bifurcation. Ventral valve radial costellae (2–3/ mm over disc) bifurcate after scarce spine bases and also rarely by intercalation.

In addition, specimens mentioned as *Cancrinella* sp. by Taboada (1998) from the Jarillal Member of the Santa Elena Formation at Quebrada Santa Elena, as well as *Cancrinella* aff. *farleyensis* (Etheridge and Dunn) of Sessarego *et al.* (1987) from the Del Salto Formation, *Costatumulus* sp. of Cisterna *et al.* (2002, 2006) from the Tupe Formation at Quebradas La Herradura and La Delfina and *Costatumulus* sp. of Cisterna and Sterren (2007) from the Quebrada Larga Formation at Quebrada Larga, all of them associated to the T-S fauna, may be conspecific or closely related to *Calytrixia piersoni* sp. nov.

Finally, scarce small linoproductids referred to as cf. *Cancrinella* sp. by Kelly *et al.* (2001) from the Mount King beds in the Antarctic Peninsula, would be closely comparable to *Calytrixia piersoni* sp. nov. in terms of costae and rugae. Such similarity was noted by Archbold *et al.* (2004), although specimens from Antarctica are not well-known enough for accurate comparisons.

CONCLUSIONS

Two new species, *Coolkilella aredesi* sp. nov. and *Calytrixia piersoni* sp. nov., are proposed based on specimens from the Del Salto and Río del Peñón formations. These would also be present in the upper part of the Agua del Jagüel Formation and associated with new records of *Septosyringothyris* (*Precosyringothyris*) *jaguelensis* Lech and *Streptorhynchus inaequiornatus* Leanza, indicating the presence of the *Tivertonia-Streptorynchus* faunal assemblage.

The previously supposed occurrence of *Costatumulus amosi* in the upper section of the Agua del Jagüel Formation is dismissed, thus confirming the existence of two different faunal assemblages, and also the exposure of Upper Paleozoic diachronic units at Quebrada Agua del Jagüel. The two different faunal assemblages are the *Tivertonia-Streptorhynchus* fauna in the upper part of the recently emended Agua del Jagüel Formation (Moscovian) and the *Costatumulus amosi* fauna in the Cordón del Jagüel Formation (Sakmarian?–Artinskian). The faunal differences and the presence of a regional fault between these last two lithostratigraphic units are highlighted, supporting the lack of a lower Permian glacial event in western Argentina.

The stratigraphic record of both the *Tivertonia-Streptorhynchus* assemblage (Moscovian) and the younger *Costatumulus amosi* fauna (Sakmarian–Artinskian) are documented at Quebrada Santa Elena, overruling the previous anachronistic interpretation that they match in age.

ACKNOWLEDGEMENTS

Gratitude is expressed to O. Limarino, P. Ciccioli, S. Césari, V. Pérez Loinaze, J. Isbell and E. Gulbranson for fruitful discussions and fieldwork assistance. Suggestions to the manuscript by reviewers G. Cisterna and Jun-Ichi Tazawa and editor L. Benedetto are acknowledged. I am grateful to M. Fraiser and the editors M. Griffin and M.A. Pagani for the English language revision. The Instituto Superior de Correlación Geológica (INSUGEO, Tucumán) allowed examination of specimens housed in the PIL collection. M. Campaña draw figures 1 and 7 and L. Montes helps with figures 2, 6 and 8. Thanks are also extended to the Laboratorio de Investigaciones en Evolución y Biodiversidad (LIEB), Universidad Nacional de la Patagonia “San Juan Bosco” (UNPSJB), which supplied laboratory facilities. The Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) provided financial support (Grant PIP 237).

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doi: 10.5710/AMGH.11.12.2013.846

Recibido: 13 de marzo de 2013
Aceptado: 11 de diciembre de 2013