GRAPTOLITE-TRILOBITE BIOSTRATIGRAPHY IN THE SANTA VICTORIA AREA, NORTHWESTERN ARGENTINA. A KEY FOR REGIONAL AND WORLDWIDE CORRELATION OF THE LOWER ORDOVICIAN (TREMADOCIAN–FLOIAN)

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Abstract. New graptolite-trilobite records provide relevant information for the biostratigraphic framework of the lower Paleozoic in western Gondwana. *Aerograptus victoriae* (T. S. Hall), together with *Adelograptus* cf. *A. altus* Williams and Stevens and *Ancoragraptus bulmani* (Spjeldnaes) are described for the first time in the Santa Victoria area. These species come from the upper beds of the Santa Rosita Formation, expanding the distribution of the *A. victoriae* Biozone. The complete succession of the *Aerograptus victoriae, Araneograptus murrayi, Hunnegraptus copiosus, Tetragraptus phyllograptoides, T. akzharensis, Baltograptus* cf. *B. deflexus* and *Didymograptellus bifidus* biozones is confirmed for the first time at a single locality in the Cordillera Oriental, indicating a late Tremadocian–late Floian age for the upper deposits of the Santa Rosita Formation and the Acoite Formation in the studied area. The co-occurrence of trilobites with the records of these graptolite biozones enables a better resolution of the upper boundary of the *Notopeltis orthometopa* Biozone and the definition of associations partially filling gaps in the succession of traditional trilobite biozones (*Asaphellus* cf. *A. stenorhachis/Leptoplastides* and *Megistaspis* (*Ekeraspis*) associations). It also contributes towards clarifying the distribution of some members of the well-known *Thysanopyge* Fauna (*T. taurinus, T. victoriensis* and *T. clavijoi*). Together with the proposed framework, we also discuss previous records of conodonts and key palynomorphs (particularly chitinozoans) related to graptolite occurrences. Additionally, we provide new insights on regional and intercontinental correlation with classic Early Ordovician sections in northwestern Argentina (*e.g.*, Pascha-Incamayo, Los Colorados, Mojotoro range and Humahuaca area), southern Bolivia and Balto-Scandinavia.

Key words. Graptolites. Trilobites. Tremadocian. Floian. Northwestern Argentina. Western Gondwana.

Resumen. BIOESTRATIGRAFÍA DE GRAPTOLITOS Y TRILOBITES DEL ÁREA DE SANTA VICTORIA, NOROESTE DE ARGENTINA. UNA CLAVE PARA LA CORRELACIÓN REGIONAL E INTERCONTINENTAL DEL ORDOVÍCICO INFERIOR (TREMADOCIANO–FLOIANO). Nuevos registros de graptolitos y trilobites presentados en este trabajo, permiten ajustar el esquema bioestratigráfico del Paleozoico Inferior del oeste de Gondwana. *Aerograptus victoriae* (T. S. Hall), junto a *Adelograptus* cf. *A. altus* Williams y Stevens y *Ancoragraptus bulmani* (Spjeldnaes) se describen por primera vez en el área de Santa Victoria (niveles superiores de la Formación Santa Rosita), extendiendo la distribución de la Biozona de *Aerograptus victoriae*. Se confirma por primera vez la sucesión completa de las biozonas de *Aerograptus victoriae, Araneograptus murrayi, Hunnegraptus copiosus, Tetragraptus phyllograptoides, T. akzharensis, Baltograptus* cf. *B. deflexus* y *Didymograptellus bifidus* en una misma localidad en la Cordillera Oriental, que indica una edad tremadociana tardía–floiana tardía para los depósitos superiores de la Formación Santa Rosita y de la Formación Acoite. Los nuevos hallazgos, permiten precisar el límite superior de la Zona de *Notopeltis orthometopa*, la definición de asociaciones que completan vacíos de información bioestratigráfica en la sucesión de trilobites (*e.g.*, asociación de *Asaphellus* cf. *A. stenorhachis/Leptoplastides* y de *Megistaspis* (*Ekeraspis*)), y los rangos estratigráficos de miembros clave de la conocida Fauna de *Thysanopyge* (*T. taurinus, T. victoriensis* y *T. clavijoi*). Se discuten también registros previos de conodontes y palinomorfos guías (particularmente quitinozoos) asociados con graptolitos. Se brindan además nuevas precisiones para la correlación regional e intercontinental con secuencias clásicas del Ordovícico Inferior de las provincias de Salta y Jujuy del noroeste de Argentina, como Pascha-Incamayo, Los Colorados, Sierra de Mojotoro y la Quebrada de Humahuaca, y del sur de Bolivia y Balto-Escandinavia.

Palabras clave. Graptolitos. Trilobites. Tremadociano. Floiano. Noroeste de Argentina. Gondwana Occidental.

MANY studies have been published on Ordovician graptolite faunas from the Central Andean Basin of northwestern Argentina and southern Bolivia. However, the only complete biostratigraphic framework available for the Lower Ordovician in the region is based on a composite section derived from graptolite records in numerous incomplete stratigraphic sections exposed mainly in the Cordillera Oriental (Egenhoff *et al.*, 2004; Albanesi *et al.*, 2008, and references therein).

Toro (1994, 1997) proposed a modern biostratigraphic framework including four graptolite biozones for the Floian deposits of the Acoite Formation exposed in the Cordillera Oriental of northwestern Argentina. The biostratigraphic succession included the *Tetragraptus phyllograptoides*, *T. akzharensis*, *Baltograptus deflexus* (= *Baltograptus* cf. *B. deflexus*) and *Didymograptellus bifidus* biozones. These had been described for the first time in the Los Colorados area, along the western flank of the Cordillera Oriental (Toro, 1994, 1997). This framework was later extended to the Santa Victoria area, along the eastern flank of this geological province (Toro, 1999a,b; Toro and Brussa, 2003; Toro and Maletz, 2007). Ortega and Albanesi (2002), Monteros and Moya (2003), and Moya and Monteros (2014) among others, presented additional biostratigraphic information based on Tremadocian graptolites from the San Bernardo and Parcha formations in the Sierra de Mojotoro and Pascha-Incamayo areas, respectively. A number of conodont-graptolite biostratigraphic correlation frameworks were successively established later in different areas of the Cordillera Oriental, such as Pascha-Incamayo (Ortega and Albanesi, 2003), Huacalera and Purmamarca (Zeballo *et al.*, 2008) and Sierra de Zenta (Albanesi *et al.*, 2011). In a recent paper, Giuliano *et al.* (2013) reported conodonts of the *Paltodus deltifer pristinus* Subzone from Nazareno –a locality approximately 30 km southwest of Santa Victoria– in association with *Bryograptus* cf. *kjerulfi* Lapworth, 1880. The authors assigned a middle Tremadocian (Tr2) age to the fossil-bearing beds included in the Santa Rosita Formation (Giuliano *et al.*, 2013, p. 39).

Additionally, Egenhoff *et al.* (2004) postulated an Early Ordovician graptolite biostratigraphic framework based on data from a number of stratigraphic sections in southern Bolivia. The authors described the *Rhabdinopora flabelliformis*, *Adelograptus* sp., *Aorograptus victoriae*, *Araneograptus murrayi*, *Hunnegraptus copiosus*, *Tetragraptus phyllograptoides*, *Expansograptus protobalticus*, *E. holmi*, *Baltograptus minutus*, *Azygograptus lapworthi* and *Isograptus victoriae* local biozones. They provided a detailed international correlation with the graptolite biozonations in Scandinavia and Eastern North America (Egenhoff *et al.*, 2004: fig. 7), but they did not correlate their biozones with those previously proposed in northwestern Argentina.

Most of the graptolite biostratigraphic frameworks in the Central Andean Basin have been based on incomplete sections and are syntheses encompassing preliminary correlations with other fossil groups such as conodonts, trilobites and palynomorphs. They commonly correlate non-continuous fossil records and establish tentative boundaries between the recognized biostratigraphic biozones.

On the other hand, the biostratigraphic significance of the trilobites from the Santa Victoria Group –and their value for regional correlation– were largely envisaged by Harrington and Leanza (1957). Based on their own stratigraphic and paleontological observations and those by previous authors, they divided the remarkably thick successions of the Cordillera Oriental into a series of informal trilobite biozones or assemblages. Subsequent authors either expanded the geographic record of these zones or attempted refining their chronological resolution based on other fossil groups (*e.g.*, Moya *et al.*, 1994; Tortello *et al.*, 2002; Benedetto, 2005; Ortega and Albanesi, 2005; Zeballo *et al.*, 2008; Zeballo and Albanesi, 2013; Tortello and Esteban, 2014, among others). In a series of contributions, Waisfeld and Vaccari (2003, 2008a), Waisfeld *et al.* (2006), Vaccari *et al.* (2010) called into question the biostratigraphic value of some of the zones, which mostly overlooked the complex stratigraphic and structural nature of the basin, highlighting several problems in their use for regional correlations.

Recently, Vaccari *et al.* (2010) formally proposed a succession of trilobite biozones for the early Tremadocian deposits in the Cordillera Oriental based on modern criteria. On the basis of a detailed taxonomic revision and a careful analysis of the stratigraphic and geographic distributions of the species, the authors proposed the following succession: *Jujuyaspis keideli*, *Kainella andina*, *Kainella meridionalis*, and *Kainella teiichii* biozones. The *Bienvillia tetragonalis* Biozone overlies the *K. teiichii* Biozone in eastern areas of the Cordillera Oriental (Humahuaca area, see Vaccari *et al.*, 2010: fig. 4).

Here we discuss the succession of trilobites and associations occurring above the *B. tetragonalis* Biozone.

Palynomorphs from northwestern Argentina have been traditionally correlated with graptolites and trilobites (*e.g.*, Rubinstein, 1997; Rubinstein and Toro, 2001; Waisfeld *et al.*, 2006). Particularly, Chitinozoans have been calibrated with graptolite and trilobite biozones (de la Puente and Rubinstein, 2009; de la Puente, 2010a,b; Toro *et al.*, 2010). In a recent synthesis, de la Puente and Rubinstein (2013) described four late Tremadocian–late Floian chitinozoan associations and calibrated their correlation with graptolite, conodont and trilobite biozones with the stage slices of Bergström *et al.* (2009).

Thus, an updated graptolite-trilobite biostratigraphy for the Tremadocian–Floian deposits in northwestern Argentina is still needed in order to complete previous frameworks. In this contribution we analyze the succession of trilobite-graptolite faunas combining stratigraphic and paleontological information drawn from four different sections in the Santa Victoria area. On the basis of this integrated study, we propose a graptolite biostratigraphic framework including eight biozones. These had been previously established in different areas but we now accurately constrain their boundaries and correlations. This analysis also provides new chronological information about previously known trilobite biozones, defining new associations –potentially meaningful from a biostratigraphic perspective– that partially fill previous gaps in the succession of trilobite biozones. The calibration of key palynomorphs with the new described graptolite-trilobite biostratigraphy is updated.

FOSSIL LOCALITIES AND STRATIGRAPHY

The Central Andean Basin (Sempere, 1995) is one of the thickest (over 5000 m thick) Lower Paleozoic basins of Argentina and is characterized by its rich fauna. It is located in northwestern Argentina (Salta and Jujuy provinces), near the Andes Range, and also spreads over parts of Chile, Bolivia and Peru (Astini, 2003). Northwestern Argentina includes the geological provinces of Puna, Cordillera Oriental, Sierras Subandinas and Sistema de Santa Bárbara (Fig. 1. 1–2).

The new faunal records analyzed come from exposures of the Santa Victoria Group in its type area (Turner, 1960,

1964) at the northern end of the Cordillera Oriental in Argentina near the border with Bolivia (Fig. 1. 2–3). This unit (Late Cambrian–Late Ordovician) unconformably overlies the Early to Middle Cambrian Mesón Group (see discussions about the nature of this unconformity in Moya, 1998; Buatois and Mángano, 2003, and references therein). On the other hand, glacial deposits of the Mecoyita Formation (northernmost equivalent of the Hirnantian Zapla Formation) overlie the Santa Victoria Group at different levels in the studied area, involving a regional unconformity related to the Ocloyic Orogeny (cf. Astini, 2008).

Turner (1960, 1964) simplified the stratigraphic nomenclature of Harrington (in Harrington and Leanza, 1957) and divided the Santa Victoria Group into only two units, which are more commonly referred to in the literature as the Santa Rosita (late Furongian–Tremadocian) and Acoite (Floian) formations. The biostratigraphic analysis we present here includes the upper part of the Santa Rosita Formation (uppermost Tr2 and Tr3) and all of the Acoite Formation (Fl1-Fl3). In the type area, both units are composed of alternating sandy and shaly packages, but the Acoite Formation is coarser-grained and with thicker beds, especially towards the top of the succession (Astini, 2003).

Along the Río Santa Victoria (Fig. 1.3), the Santa Rosita Formation exposes about 2300 m of fossil-bearing dark gray shale and mudstone interbedded with greenish sandstone. These rocks constitute the type section (Turner, 1960) and show the maximum thickness reached by the unit. Structurally, they are broad NNW trending anticlines and synclines.

Astini (2003) previously noted that intervals of thick-bedded sandy packages are absent from the upper part of the Santa Rosita Formation in its type section. However, Voldman *et al.* (2014) recently described fine to middle-grained sandstone packages up to 2 m thick, interbedded with shales yielding *A. murrayi* in levels that they considered as the uppermost portion of this unit, right at the confluence of the Quebrada de Chulpíos (also called San Luis or Chulpiojos) and the Río Acoite (also called Lizoite River). These authors placed the upper boundary of the Santa Rosita Formation in that sandstone package at the mouth of the Quebrada de Chulpíos and assigned to the Acoite Formation the overlying shale interbedded with sandstone. Besides, they suggested a late Tremadocian age for the

Figure 1. 1, Map of different geological provinces of the Central Andean Basin. **2,** Fossil localities in the Argentinean Cordillera Oriental (modified from Astini, 2003); **A,** Santa Victoria; **B,** Nazareno; **C,** Quebrada de Humacha, Huacalera area; **D,** Quebrada de Coquena, Purmamarca area; **E,** Sierra de Mojotoro; **F,** Los Colorados area; **G,** Pascha-Incamayo. **3,** Geologic map of the Santa Victoria area with studied stratigraphic sections (bottom left); modified from Turner (1960) and Rubinstein and Toro (2001); sections: **A-A',** Río La Huerta; **B-B',** Río Acoite; **C-C',** Quebrada de Chulpíos; **D,** Pucará area.

lower part of the Acoite Formation, based on the conodont record of the *Acodus deltatus-Paraistodus proteus* Biozone and graptolites probably referable to *Hunnegraptus copiosus* Lindholm, 1991. It is interesting to note that Turner (1960) formerly considered that the contact between the Santa Rosita Formation and the overlying fine sandstones of the Acoite Formation was not at the mouth of the Quebrada de Chulpíos, but downstream of the junction between the Río Acoite and the Quebrada de Chulpíos.

Interestingly, Astini (2008) noted that in the Sierra de Zenta area (120 km south of Santa Victoria) the Santa Rosita and Acoite formations are hard to distinguish because the Santa Victoria Group is a 3000-m-thick monotonous alternation of shaly intervals and sandstone beds, forming large-scale upward-shallowing cycles interpreted as deltaic lobes in a wave dominated deltaic system. Sandstone bodies display great lateral variability as a result of onshore-offshore and along-shore variations, and are often diachronic; hence, they are difficult to correlate at a regional scale.

Beyond the previous discussions, it is clear that the subdivision of the Santa Victoria Group into the Santa Rosita and Acoite formations is largely subjective and differs according to diverse stratigraphic criteria such as color variations or sandstone/shale rate (among others) followed by different authors in different sections. Therefore, until a reliable revision based on modern sedimentologic/stratigraphic criteria is carried out in the area, we prefer to retain here the traditional viewpoint, also followed in previous works (Toro, 1999b; Rubinstein and Toro, 2001; Toro and Maletz, 2007), referring the base of the Acoite Formation in the Santa Victoria area to the first shale-dominated interval where the earliest Floian faunas appear (A 17, Fig. 2; Tab. 1).

According to our observations in the Santa Victoria area (mainly at Río Acoite and Río La Huerta sections), a particularly outstanding section spanning the upper Tremadocian (*Aorograptus victoriae* Biozone) to the upper Floian (*Didymograptellus bifidus* Biozone) includes the Tremadocian/Floian boundary and the transitional contact between the Santa Rosita and Acoite formations.

However, along the western margin of the Cordillera Oriental the Floian Acoite Formation overlies the Tremadocian deposits (Santa Rosita Formation and equivalent units), separated from them by an early Tremadocian to late Tre-madocian–early Floian unconformity related to local tectonic events (Tumbaya uncomformity) (Moya, 1997; Astini, 2008).

The upper part of the Santa Rosita Formation in the La Huerta section begins (SVO 11, Fig. 2; Tab. 1) with a coquina-rich fine- to medium-grained sandstone interbedded with light brown siltstone and gray mudstone with trilobites from the *Notopeltis orthometopa* Biozone. Fine to medium sandstone intercalated with gray and greenish shale with *H. copiosus* predominate toward the top of the unit. The beds are conformably overlain by a dark gray and greenish shale referable to the Acoite Formation and containing *Tetragraptus phyllograptoides* (Strandmark, 1902) (Fig. 2).

The Acoite Formation is widely represented in the Cordillera Oriental by thick, upward-shallowing beds related to a storm-dominated deltaic system (Astini and Waisfeld, 1993; Waisfeld and Astini, 2003). This unit, with a maximum thickness of almost 2300 m in the Los Colorados area (Astini *et al.*, 2004), reaches *ca.* 800 m in the La Huerta section (Fig. 2). It is mainly composed of greenish gray shale and fine-sandstone, alternating with dark-gray and black shale and siltstone deposited in a middle to distal shelf setting (Waisfeld *et al.*, 2003). A transition from oxygen deficient laminated black shale to increasingly bioturbated green shale and sandstone occurs toward the top of the La Huerta section, which carries the upper part of the *T. akzharensis* and the *Baltograptus* cf. *B. deflexus* biozones. The upper part of the unit is a massive highly bioturbated sandy facies abruptly developed on top of an upward-thickening meso-scale cycle with tidal influence (Astini, 2003; Waisfeld and Astini, 2003). Above this interval, a short transgressive green shale interval yields graptolites of the *D. bifidus* Biozone.

The framework in Figure 3 shows updated correlations with units exposed in different regions of the Cordillera Oriental such as the Los Colorados, Pascha-Incamayo, Sierra de Mojotoro and Purmamarca areas (Fig. 1–2). Several contributions provided key geological, biostratigraphic and taxonomic information from these areas (*e.g.*, Moya, 1998; Benedetto and Carrasco, 2002; Astini, 2003, 2008; Ortega and Albanesi, 2003; Waisfeld *et al.*, 2006; Zeballo *et al.*, 2008; Salas and Vaccari, 2010; Zeballo and Albanesi, 2013; Moya and Monteros, 2014, among others).

It is important to note that lateral facies variations among different sections of the Santa Rosita Formation led to an array of lithostratigraphic names that complicated

T.	G.	M. F.

References

Sandstone

Shale and siltstone

Diamictite

100m

0

Famatinolithus — *D. bifidus*

B. cf. *B. deflexus*

T. clavijoi

T. akzharensis

T. victoriensis — *T. phyllograptoides*

M. (Ekeraspis) — *T. taurinus* — *H. copiosus* — *A. murrayi*

Notopeltis orthometopa — *Aurograptus victoriae*

FORMATION

ACOITE FORMATION

SANTA ROSITA FORMATION

Puc-a

A 17
A 24
Chu 100
A 36

CA 4

SVO 11

Mudstone
F M C
Sandstone

Baltograptus deflexus
Baltograptus minutus
Pseudophyllograptus sp.

Baltograptus cf. B. deflexus
Baltograptus turgidus

Baltograptus vacillans

Famatinolithus sp.

Emanuelaspis? sp.
Niobides sp.
Porterfieldia sp.

Thysanopyge clavijoi

Nileus? sp.

Australopyge russoi ?

Tetragraptus phyllograptoides
Cymatograptus cf. C. rigoletto

Aurograptus victoriae
Adelograptus cf. A. altus
Ancoragraptus bulmani
Araneograptus murrayi
Hunnegraptus copiosus

Notopeltis orthometopa
Mekynophrys nanna
Pliomeroides sp.
Pyrimetopus sp.
Asaphellus jujuanus

Hypermecaspis sp.
Apatokephalus sp.
Megistaspis (Ekeraspis) sp. 1
Megistaspis (Ekeraspis) sp. 2
Megistaspis (Ekeraspis) cf. pugiocauda
Kayseraspis sp.
Thysanopyge taurinus
Colpocoryphoides sp.
Conophrys sp.
Saltaspis sp.
Thysanopyge victoriensis

stratigraphic correlations. Buatois *et al.* (2006) provided an updated sedimentological and stratigraphical analysis, mainly focused on the lower and middle part of the Santa Rosita Formation (Furongian to early Tr2 interval) exposed in the Tilcara area.

Besides, in the Huacalera area (Fig. 1.2) a thick interval (ca. 1000 m) included in the upper Tr2 is exposed on top of the Alfarcito Member of the Santa Rosita Formation (in the Quebrada del Arenal) and below the Humacha Member (in the Quebrada de Humacha) (Benedetto and Muñoz, 2015). To avoid further complications of the local lithostratigraphy we follow Benedetto and Muñoz (2015) and provisionally refer this interval to the Rupasca Member. Yet, we acknowledge significant differences in thickness and facies with the Rupasca Member exposed in the type area (Sierra de Alfarcito). This member was described and interpreted from a sedimentologic-stratigraphic perspective in its type area by Buatois *et al.* (2006). Later, Balseiro *et al.* (2011) in-

cluded also in this member the succession overlying the Alfarcito Member at Quebrada del Arenal.

MATERIALS AND METHODS

To achieve the main purpose of this work we carried out a detailed sampling along the remarkably complete Tremadocian–Floian section exposed at Quebrada La Huerta, Quebrada de Acoite, Quebrada de Chulpíos and in the town of Pucará (Santa Victoria area, eastern flank of the Cordillera Oriental; Fig. 1.3). The Quebrada La Huerta section is the most complete one stratigraphically, showing the best exposures and the least tectonic deformation; hence, it is considered the reference section for the area. The measured section is depicted in Figure 2. Relevant fossil records from other sites considered in this work (Tab. 1) are integrated into this section. The tentative position of these records in the La Huerta section was based on shared occurrences of graptolite and trilobite taxa together with

TABLE 1. GPS Coordinates of collected samples.

Locality / Sample	GPS Coordinates	Taxa
La Huerta *SVO 11*	*S 22° 15' 10,0"* *W 064° 58' 01,1"*	N. orthometopa, Mekynophrys nanna, Pliomeroides *sp.*, Pyrimetopus *sp.*, Galbagnostus *(*Galbagnostus*)*, Microagnostus *sp.*
Acoite *CA 4*	*S 22° 16' 21,7"* *W 064° 59' 14,6"*	Aorograptus victoriae, Adelograptus *cf.* A. altus, Ancoragraptus bulmani, Megistaspis *(*Ekeraspis*) sp. 1*, M. *(*Ekeraspis*) sp. 2*, Asaphellus *sp.*, Kayseraspis *sp.*, Apatokephalus *sp.*
Acoite *A 36*	*S 22° 16' 31,2"* *W 64° 59' 24,0"*	Araneograptus murrayi, Kiaerograptus *cf.* K. supremus, Corpocoriphoydes *sp.*, Asaphellus *sp.*, Thysanopyge *sp.*
Acoite *A 24*	*S 22° 16' 16,2"* *W 64° 59' 2,7"*	Hunnegraptus copiosus, M. *(*Ekeraspis*) sp.*, Asaphellus *n. sp. 2*, Thysanopyge *sp.*, Zuninaspis *?*, Kayseraspis *sp.*
Acoite *A17*	*S 22° 16' 13,7"* *W 64° 58' 56,9"*	Tetragraptus phyllograptoides, Clonograptus multiplex, Megistaspis*(*Ekeraspis*) cf.* M. *(*Ekeraspis*)* pugiocauda, Bienvillia *sp.*, Asaphellus *n. sp.*, Saltaspis *sp.*
Pucará *Puc-a*	*S 22°10' 51,5"* *W 064° 57' 34,4"*	Tetragraptus phyllograptoides, Cymatograptus *cf.* C. rigoletto, Thysanopyge *sp.*

SVO 11 is the base of the La Huerta Section. Other samples belonging to different localities are shown here and they have been integrated to La Huerta section based on stratigraphical and paleontological criteria.

Figure 2. Stratigraphic section at Quebrada La Huerta showing stratigraphic ranges of the significant graptolite and trilobite taxa. **T,** trilobite biozones and associations. **G,** graptolite biozones. **M.F.,** Mecoyita Formation. Tentative positions of samples from other sections are shown (see Table 1 for further details).

stratigraphic criteria. Focus was placed on the detailed discussion of the remaining problems concerning regional and intercontinental correlations, with emphasis on the better known sections of the eastern and western flanks of the Cordillera Oriental, and southern Bolivia and Scandinavia (Fig. 3).

Although the taxonomic revision of graptolite species and biozones is beyond the scope of this paper, some particular comments are included in the description of each biozone in order to clarify the proposed biostratigraphic correlations. The described biostratigraphic graptolite intervals were based on the first record of the index species or the characteristic taxa associations previously recognized at different levels of a certain biozone in different stratigraphic sections in northwestern Argentina. These biozones have a mainly local and regional value; nevertheless, due to the completeness of the studied section the proposed biostratigraphic framework is potentially useful to clarify remaining gaps or uncertainties at an intercontinental scale.

It is important to note that in order to avoid potential confusion in the use of terms defining trilobite entities, in Figure 3 and in the text we retain names that are traditional and well-known in the geological and paleontological litera-

ture. In this sense, we use "biozone" and "fauna" for the entities defined by Harrington and Leanza (1957) (*e.g.*, *Notopeltis orthometopa* Biozone, *Thysanopyge* Fauna), while by "associations" we mean a group of species occurring in the same interval and lacking previous labeling.

The studied specimens are housed in the paleontological collections of the Centro de Investigaciones en Ciencias de la Tierra (CICTERRA), CONICET and Universidad Nacional de Córdoba, Córdoba, Argentina (**CEGH-UNC**), and Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales from the CCT-CONICET, Mendoza, Argentina (**IANIGLA-PI**).

BIOSTRATIGRAPHY
Graptolites

The proposed biostratigraphic framework −including stratigraphic ranges of the significant taxa− is presented in Figure 2. In order to complete the biostratigraphic framework of northwestern Argentina and its correlation with southern Bolivia, we included in Figure 3 the *Azygograptus* Biozone, assigned to the latest Floian (Fl3 *sensu* Bergström *et al.*, 2009), which had been not documented in the studied sections until now. Nevertheless, specimens described by Monteros *et al.* (1996) as *Azygograptus eivionicus* Elles,1922,

Figure 3. Biostratigraphic framework of the Lower Ordovician (Tr2 to Fl3) deposits of the Argentinean Cordillera Oriental. *Kainella teiichii* Biozone is only referred to its upper part. Modified from: Toro (1997); Astini (2003); Monteros and Moya (2003); Ortega and Albanesi (2003); Waisfeld and Vaccari (2003; 2008a,b); Albanesi *et al.* (2008); Vaccari *et al.* (2010); Giuliano *et al.* (2013); Toro and Vento (2013); Voldman *et al.* (2013); Zeballo and Albanesi (2013).

from deposits of the Coquena Formation (= Aguada de la Perdiz Formation, *sensu* Brussa *et al.*, 2008) in the Huatiquina section indicate that the *Azygograptus* Biozone is also present in the Argentine Puna region. This biozone was later recognized in southern Bolivia (Egenhoff *et al.*, 2004) and recently along the western flank of the Cordillera Oriental.

Bryograptus kjerulfi *Biozone.* This biozone is well known in northwestern Argentina, where it indicates an early late Tremadocian age (Albanesi *et al.*, 2008, and literature therein). Maletz *et al.* (2010) recently reviewed the *Bryograptus kjerulfi* Biozone in northwestern Argentina based on well preserved specimens from the Floresta Formation in Sierra de Mojotoro (Fig. 4.1). The author correlated the biozone with the lower part of the *A. victoriae* Biozone from southern Bolivia (Egenhoff *et al.*, 2004) and eastern North America (Maletz and Egenhoff, 2001) and also proposed an intercontinental correlation with the *Bryograptus ramosus* Biozone in Scandinavia (*sensu* Egenhoff *et al.*, 2004). In a more recent paper, Giuliano *et al.* (2013) reported *Bryograptus* cf. *kjerulfi* from the upper part of the Santa Rosita Formation at Nazareno, together with conodonts of the *Paltodus deltifer pristinus* Subzone of the *Paltodus deltifer* Biozone. They (Giuliano *et al.*, 2013, p. 39) assiged a middle Tremadocian age –Tr2 *sensu* Bergström *et al.* (2009)– to the fossil-bearing levels. Subsequently, Hammer and Grandstein (in Cooper and Sadler, 2012: fig. 20.1) considered that the *Paltodus deltifer* Biozone represents a short interval corresponding to the late middle Tremadocian.

Previously mentioned records allow expanding the distribution of the *Bryograptus kjerulfi* Biozone in the studied area up to a few kilometres southwest of Santa Victoria. These records also allow including the biozone as the oldest biozone (early Tr2) in the proposed regional biostratigraphic framework (Fig. 3). Interestingly, the new records assigned to the *A. victoriae* Biozone that we discuss below seem to suggest that in the Santa Victoria area the *Bryograptus kjerulfi* Biozone occurs in the levels immediately below the *A. victoriae* Biozone, as lately confirmed by Toro and Carrera (2013) in the Pascha-Incamayo area. Based on a similar biostratigraphic succession, these authors reported that the *A. victoriae* Biozone occurs a few meters above the levels with the monospecific assemblage of *B. kjerulfi* (Fig. 4.2;

Bryograptus Zone *sensu* Ortega and Albanesi, 2003), and assigned the middle part of the Saladillo Formation to the late Tremadocian. Accordingly, the correlation is reconfirmed here between these levels in the Pascha-Incamayo area with the upper part of the Santa Rosita Formation in the Santa Victoria-Nazareno area, and the Floresta Formation in the Sierra de Mojotoro area (Fig. 3).

Aorograptus victoriae *Biozone.* Mature pendent multiramous tubaria of *Aorograptus victoriae* T. S. Hall, 1899 (Fig. 4.3), together with numerous bi-radiate juvenile stages of the species (Fig. 4.7) occur abundantly in fine sandstone corresponding to the upper portion of the Santa Rosita Formation (CA 4, Fig. 2; Tab. 1). The key species are commonly preserved as flattened periderms, associated with slender forms of *Adelograptus* cf. *A. altus* Williams and Stevens, 1991 (Figs. 4.6, 4.14) and *Ancoragraptus bulmani* (Spjeldnaes, 1963) (Figs. 4.11, 4.15), which are commonly better preserved and show an isolated metasicula. These taxa allow recognizing for the first time in the studied area the upper part of the *A. victoriae* Biozone, expanding its range further north along the eastern flank of the Cordillera Oriental. The new records indicate a late Tremadocian age (late Tr2 to probably early Tr3 *sensu* Hammer and Grandstein in Cooper and Sadler, 2012) for the fossil-bearing beds exposed along the right bank of the Acoite River, just in front of the opening of the Quebrada de Chulpíos. The base of this biozone has not been exactly documented in the Santa Victoria area, but *Araneograptus murrayi* (J. Hall, 1865) appears for the first time (see also Voldman *et al.*, 2014) a few meters above the last records of the mentioned key taxa, defining the base of the homonymous overlying biozone (Fig. 3).

The *A. victoriae* Biozone was recognized for the first time in Argentina in the lower part of the San Bernardo Formation in Sierra de Mojotoro (Salta Province), Cordillera Oriental (Monteros and Moya, 2003, and literature mentioned therein). According to the authors, *Paradelograptus mosseboensis* Erdtmann, Maletz and Gutiérrez-Marco,1987, *P. onubensis* Erdtmann, Maletz and Gutiérrez-Marco,1987, *Kiaerograptus supremus* Lindholm,1991, *Paratemnograptus isolatus* Williams and Stevens, 1991, and *Adelograptus* sp. and a number of trilobite species appear as the most relevant associated forms. They assigned the graptolite assem-

blage to the "late upper Tremadocian" (*Kiaerograptus* Zone and lower part of the *Araneograptus murrayi /pulchellus* Zone *sensu* Cooper, 1999). Ortega and Albanesi (2003, 2005) later described a correlative fauna referred to the *Kiaerograptus*

Biozone from the middle part of the Saladillo Formation in the Pascha-Incamayo area, which appears about 70 m above the last occurrence of *Bryograptus* sp. According to these authors, *Kiaerograptus* cf. *kiaeri* (Monsen, 1937), *Adelograptus*
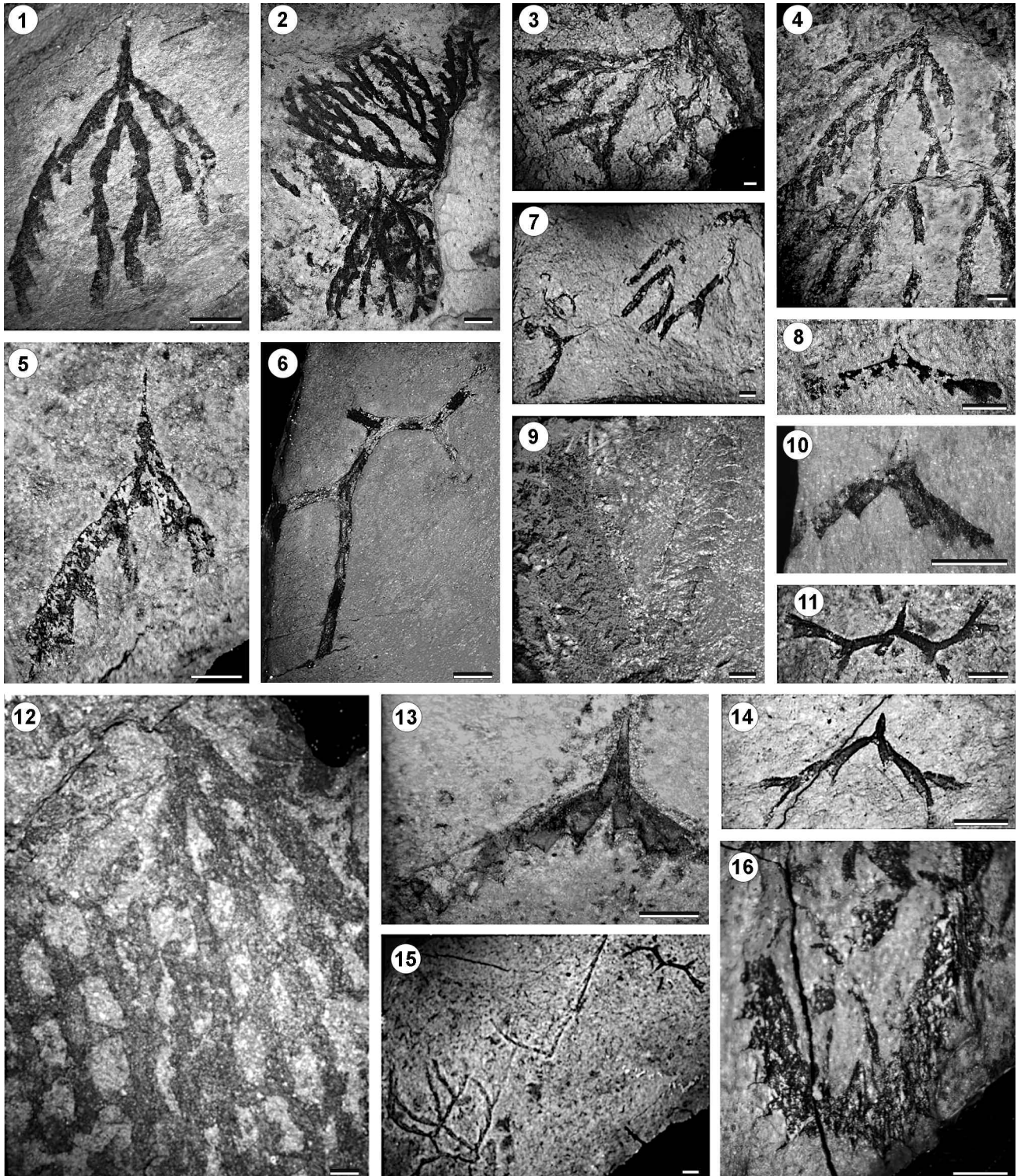
cf. *altus* and *Paradelograptus* sp. are the most representative taxa and indicate an early late Tremadocian age.

Toro and Carrera (2013) lately confirmed the presence of the *A. victoriae* Biozone in coeval beds of the Saladillo Formation in the Pascha-Incamayo area (Figs. 4.4, 4.5). In this biozone the index species appears associated with *Paradelograptus* sp., *Adelograptus* sp. and *Kiaerograptus* sp. a few meters above a monospecific assemblage with *Bryograptus kjerulfi*, previously assigned to the *Bryograptus* Biozone (Ortega and Albanesi, 2003). Based on the discussed graptolite records assigned to this biozone in Pascha-Incamayo and Santa Victoria areas, a correlation between the bearing levels can be proposed.

The *A. victoriae* Biozone was also reported by Zeballo *et al*. (2008) in partially coeval strata of the Coquena Formation and the Rupasca Member of the Santa Rosita Formation at Quebrada de Coquena, Quebrada de Chalala, and Quebrada de Humacha (Huacalera and Purmamarca areas, Jujuy Province). These authors integrated two discontinuous records of the guide species together with *Ancoragraptus* cf. *A. bulmani,* and *Adelogratus* cf. *A. altus* respectively, in order to postulate a preliminary biostratigraphy based on the partial correlation between the *A. victoriae* graptolite biozone, *Paltodus deltifer, Acodus deltatus-Paroistodus proteus* Biozone and *Notopeltis orthometopa* Biozone. They assigned to the bearing levels a "... late early to late, but not latest Tremadocian age..." (Zeballo *et al*., 2008, p. 134). Our new records from the Santa Victoria area allow correlating with the above mentioned records based on the presence of the *A. victoriae* Biozone. A partial correlation with the graptolite assemblage containing *A. victoriae* in Sierra de Mojotoro is also possible (Fig. 3).

The graptolite-bearing beds of the Chiquero Formation exposed in the eastern Puna, in which Benedetto *et al*. (2002) identified the *Kiaerograptus* cf. *kiaeri, Clonograptus* sp. and *Paradelograptus* sp. assemblage, can be tentatively correlated with the studied deposits of the Santa Rosita Formation in which this biozone occurs.

This biozone can be also tentatively correlated with the *A. victoriae* Biozone, previously recognized by Maletz and Egenhoff (2001) and Egenhoff *et al*. (2004) in southern Bolivia, although these authors highlighted that the taxonomy of the middle to late Tremadocian graptolites it is still vague. A partial correlation with the homonymous biozone defined in western Newfoundland (Williams and Stevens, 1991) is possible, even though its base is unknown. Tremadocian graptolite biostratigraphy still needs additional discussion, but a thorough international revision of this biozone is beyond the scope of this paper.

Araneograptus murrayi *Biozone*. This biozone was widely recognized in the Cordillera Oriental and Puna regions in northwestern Argentina (Gutiérrez-Marco and Aceñolaza, 1987; Ortega and Albanesi, 2005) although the exact biostratigraphic range of the key species has not been clarified.

Beds carrying the key species of this biozone were also mentioned previously by Voldman *et al*. (2014) associated with conodonts of the *Acodus deltatus-Paraistodus proteus* Biozone approximately 600 m below the recorded specimens doubtfully assigned to *Hunnegraptus copiosus* Lindholm,1991, at Quebrada de Chulpíos. According to our data (A 36, Fig. 2; Tab. 1), specimens assigned to *Araneograptus murrayi* —a few flattened proximal ends and more commonly

Figure 4. Relevant graptolite taxa from the upper Tremadocian to lower Floian of the Argentinean Cordillera Oriental. **1–2**, *Bryograptus kjerulfi*; **1**, **IANIGLA**-PI 2271 flattened mature specimen showing triradiate pendent proximal end and long sicula, Sierra de Mojotoro; **2**, **IANIGLA**-PI 1000 monospecific assemblage, Pascha–Incamayo area. **3–5, 7**, *Aorograptus victoriae*; **3, 7**, Santa Victoria area; **3**, **CEGH-UNC** 24911 mature and juvenile associated specimens; **7**, **CEGH-UNC** 24912 juvenile specimen showing conspicuous sicula with nema, associated to a fragmentary mature tubarium; **4, 5**, Pascha-Incamayo area; **4**, **CEGH-UNC** 24901 large flattened tubarium; **5**, **CEGH-UNC** 24902 biradiate proximal part of the tubarium exhibiting nema. **6, 14**, *Adelograptus* cf. *A. altus*, Santa Victoria area; **6**, **CEGH-UNC** 24916 mature flattened specimen in horizontal view; **14**, **CEGH-UNC** 24917 juvenile specimen showing sicular bitheca. **8, 10**, *Hunnegraptus copiosus*, Santa Victoria area; **8**, **CEGH-UNC** 24929 flattened specimen exhibiting small sicula with nema, and the position of the sicular bitheca; **10**, **CEGH-UNC** 24928 proximal end showing sicular bitheca. **9, 16**, *Tetragraptus phyllograptoides*, Santa Victoria area; **9**, **CEGH-UNC** 17582 complete mature specimen with characteristic reclined stipes; **16**, **CEGH-UNC** 24925 juvenile specimen exhibiting conspicuous sicula. **11, 15**, *Ancoragraptus bulmani*, Santa Victoria **CEGH-UNC** 24918; **11**, enlargement of the juvenile specimen illustrated in 11; **15**, flattened mature tubarium in horizontal view associated with a juvenile showing long free metasicula. **12**, *Araneograptus murrayi*, **CEGH-UNC** 24906 mature tubarium exhibiting characteristic strong mesh, Pascha-Incamayo area. **13**, *Cymatograptus* cf. *rigoletto*, Santa Victoria area, **CEGH-UNC** 23924, specimen preserved in low relief and obverse view, showing long sicula and origin of the first theca. Scale bar= 1 mm.

to distal mesh fragments (Fig. 4.12)– are recorded between the first appearance of the key species and the first record of *Hunnegraptus copiosus*, indicating a late Tremadocian age for the fossil-bearing beds of the Santa Rosita Formation (Fig. 2). A number of regularly preserved tubaria referred to *Kiaerograptus* cf. *supremus* Lindholm, 1991, were recorded through an equivalent stratigraphic range in the La Huerta section. Nevertheless, following Maletz and Egenhoff (2001) we consider that the *Kiaerograptus supremus* Biozone represents a local Scandinavian biozone. Therefore, in the Santa Victoria area, in Pascha-Incamayo (Waisfeld *et al.*, 2006) and in southern Bolivia (Maletz and Egenhoff, 2001) it is not possible to differentiate the *Kiaerograptus supremus* Biozone as a separate interval. Accordingly, both taxa co-exist in levels corresponding to the *A. murrayi* Biozone in the Central Andean Basin, where this biozone indicates a late Tremadocian (early Tr3) age.

Ortega and Albanesi (2003) recognized *Kiaerograptus supremus* Lindholm, 1991, in the basal part of the Parcha Formation and assigned these levels to the eponymous biozone. Monteros and Moya (2003) mentioned this species in the upper part of the graptolite assemblage referred to *Araneograptus murrayi/pulchellus* Zone (*sensu* Cooper, 1999) in the San Bernardo Formation.

It is important to point out that according to our correlation of the graptolite successions from the Pascha and Santa Victoria areas, the *Araneograptus murrayi* Biozone occurs immediately above the last records of *Aorograptus victoriae*. Consequently, the upper portion of the graptolite assemblage defined by Monteros and Moya (2003) in the lower deposits of the San Bernardo Formation seems to correspond to the *Araneograptus murrayi* Biozone because it contains *Kiaerograptus supremus*. The *Araneograptus murrayi* Biozone was also recognized by Albanesi *et al.* (2011) in strata from the upper part of the Santa Rosita Formation in the Sierra de Zenta area, based on the association of the index species and *Kiaerograptus* cf. *supremus*. The regional and intercontinental correlations were discussed by these authors. Additional correlations of this biozone are presented in the Figure 3.

The upper part of the Saladillo Formation and the overlying Parcha Formation in the Pascha-Incamayo area contain one of the oldest chitinozoan associations recorded in the world, *Euconochitina paschaensis*, which is associated with the late Tremadocian peri-Gondwanan *messaoudensis-trifidum* acritarch assemblage (sub-assemblages 1 and 2) and calibrated with graptolites. It is regarded as a time equivalent of the *conifundus*/"*brevicollis*" Biozone, which is assigned to the late Tremadocian in northern Gondwana. This chitinozoan assemblage is also recorded in equivalent levels assigned to the Santa Rosita Formation in the Sierra de Zenta area, along the eastern flank of the Cordillera Oriental (de la Puente and Rubinstein, 2009, 2013).

Hunnegraptus copiosus *Biozone.* Specimens coming from the Quebrada de Chulpíos in the Santa Victoria area were doubtfully assigned to *Hunnegraptus copiosus* Lindholm, 1991, by Voldman *et al.* (2014). A number of poorly preserved tubaria recently recorded in the Río Acoite section (A 24−14, Fig. 2; Tab. 1) confirm the presence of the *Hunnegraptus copiosus* Biozone in the Santa Victoria area. Despite its poor preservation, the material exhibits the characteristic sicular bitheca and simple dichograptid thecae of the key species (Figs. 4.8, 4.10). This biozone occurs through approximately 50 m, between the last appearance of *A. murrayi* and the first record of *Tetragraptus phyllograptoides*; it indicates a latest Tremadocian age for the upper beds of the Santa Rosita Formation (Fig. 2).

The *Hunnegraptus copiosus* Biozone was previously documented in the Chiquero Formation in the Puna region (Benedetto *et al.*, 2002), and in the middle to upper parts of the Parcha Formation in the Pascha-Incamayo area (Ortega and Albanesi, 2003), but its total range remained uncertain because of the structural deformation affecting these sections. In the Parcha Formation in the Pascha-Incamayo area, this biozone also contains *E. paschaensis* and the peri-Gondwanan *messaoudensis-trifidum* acritarch assemblage (sub-assemblages 3) of the late Tremadocian, which represents the lowest latitudinal occurrences of all the peri-Gondwanan localities (de la Puente and Rubinstein, 2009, 2013).

Hunnegraptus cf. *novus* (Berry, 1960) and *Paradelograptus* sp. from the Sierra de Zenta area were recently assigned to the *Hunnegraptus copiosus* Biozone (Albanesi *et al.*, 2011). The fossil-bearing beds can be considered as the southernmost prolongation of the Santa Rosita deposits containing this biozone in the Santa Victoria area. Additional regional and worldwide correlations have been proposed by Albanesi *et al.* (2011) and in this work (Fig. 3).

Tetragraptus phyllograptoides *Biozone.* Well preserved specimens assigned to *Tetragraptus phyllograptoides* were previously recorded in the lower beds of the Acoite Formation in the Río Acoite section (A 17, Fig. 2; Tab. 1), Santa Victoria area (Toro, 1999b; Toro and Maletz, 2007). Additional material of the key species was recently collected (Figs. 4.9, 4.16) together with *Cymatograptus* cf. *C. rigoletto* Maletz, Rushton and Lindholm, 1991 (Figs. 4.13) from equivalent levels in the Pucará section (Fig. 1; Puc-a, Fig. 2; Tab. 1). The stratigraphic range previously assigned to *Baltograptus vacillans* (Toro and Maletz, 2007) seems to correspond to *Cymatograptus* cf. *C. rigoletto*. The *Tetragraptus phyllograptoides* Biozone was first described in South America by Toro (1994, 1997) along the western flank of the Cordillera Oriental and its geographic distribution was later expanded to the Sierra de Santa Victoria (Toro, 1999b; Toro and Maletz, 2007) and the Sierra de Aguilar (Toro and Vento, 2013) areas. The new records mentioned allowed to constrain the upper boundary of this biozone, expanding its stratigraphic range in the studied area, which spans approximately 170 m through the lower part of the Acoite Formation between the first and last record of the index species (Fig. 2). A direct correlation with the worldwide *T. phyllograptoides* Biozone from Scandinavia (Maletz *et al.*, 1996) was recently proposed by Toro and Vento (2013), and therefore this biozone is considered as an indicator of the earliest Floian (Fl1) in the Central Andean Basin. As a result of this revision of the upper boundary of the *T. phyllograptoides* Biozone, chitinozoans and phytoplankton assemblages previously included in the *T. akzharensis* Biozone are now also recorded in northwestern Argentina (see previous data in de la Puente and Rubinstein, 2013). The upper part of the *T. phyllograptoides* Biozone includes taxa of the *messaoudensis-trifidum* acritarch assemblage (sub-assemblages 5), which are typical of the base of the Floian (*T. phyllograptoides* Biozone) in other peri-Gondwanan regions.

Tetragraptus akzharensis *Biozone.* This biozone was previously described in the Acoite Formation by Toro (1999b), in the middle portion of the La Huerta section in the Santa Victoria area. Although the index species has not been recorded until now, the presence of other characteristic taxa such as *B. geometricus* Törnquist, 1901 (Toro and Maletz, 2008: figs. 4.2, 4.3) and *Baltograptus vacillans* (Tullberg, 1880) allowed to recognize the occurrence of this interval above the last

record of *T. phyllograptoides* (Fig. 2). Toro and Vento (2013, and references therein) recently reviewed the *T. akzharensis* Biozone in Sierra de Aguilar and they discussed in-depth its distribution in northwestern Argentina and global correlations. Levels corresponding to this biozone occur extensively in the lower portion of the Acoite Formation in the Los Colorados area, the locality where it was first recorded in northwestern Argentina (Toro, 1994, 1997: fig. 2). Previous records of *B. vacillans* (Ortega and Rao, 1994) and *T. akzharensis* (Toro and Vento, 2013) also indicate a correlation of the fossil-bearing beds of the Acoite Formation (= Cieneguillas Formation) at the La Ciénaga section with the deposits in which this biozone occurs in the Santa Victoria area (Fig. 3).

Albanesi *et al.* (2014) recently assigned the records of *Acrograptus filiformis* (Tullberg, 1880) and *Baltograptus* sp., associated with conodonts of the "*Gothodus*" Biozone, to the *Baltograptus* cf. *B. deflexus* Biozone. These records come from an isolated 55-m-thick outcrop of Ordovician strata unconformably overlain by Cretaceous sediments located west of Cuesta de Lipán (Jujuy Province). They postulated a late Floian age for the fossil-bearing beds. Nevertheless, considering that in northwestern Argentina *A. filiformis* begins to appear in the upper part of the *T. akzharensis* Biozone (early Floian, Fl1 *sensu* Toro and Vento, 2013), and that the *B.* cf. *B. deflexus* Biozone indicates a middle Floian age (*sensu* Toro and Maletz, 2008, and this work), we suggest that an early to middle Floian age is more likely than a late Floian one for these deposits. Thus, a partial correlation with this biozone can be postulated.

In the Santa Victoria area, the *T. akzharensis* Biozone also contains *Eremochitina brevis* morphotype A of Paris (1981). *Eremochitina brevis* Benoît and Taugourdeau, 1961, is the index species of the late middle Floian in North Gondwana, approximately equivalent to the Fl2–Fl3 stage slices of Bergström *et al.* (2009). Therefore, this record in the *T. akzharensis* Biozone indicates that an even older stratigraphic appearance of the species in northwestern Argentina, *i.e.* in the upper part of the Fl1 (de la Puente and Rubinstein, 2013). Typical taxa of the *messaoudensis-trifidum* acritarch assemblage (sub-assemblages 5) are also present in this biozone as well as in the successive *Baltograptus* cf. *B. deflexus* and *Didymograptellus bifidus* biozones, showing as well longer records in northwestern Argentina (de la Puente and Rubinstein, 2013).

Baltograptus *cf.* **B. deflexus** *Biozone.* This biozone is widely known throughout the Cordillera Oriental (Toro and Maletz, 2007, and references therein). Nevertheless, some misunderstanding about its stratigraphic range and regional correlation seems to persist in the literature in spite of the revision of the index species carried out by Toro and Maletz (2007). These authors differentiated a new species of the genus *Baltograptus* (*Baltograptus* sp. nov. *sensu* Toro and Maletz, 2007) as the index species of the unit, previously called "*B. deflexus*" Biozone, and emphasized that the first record of the true *Baltograptus deflexus* (Elles and Wood, 1901) in fact occurs in the overlying biozone associated with *Didymograptellus bifidus* (J. Hall, 1865) and *B. minutus* (Törnquist, 1879). To avoid further confusions we propose naming this biozone as the *Baltograptus* cf. *B. deflexus* (= *Baltograptus* sp. cf. *B. deflexus* sensu Maletz and Ahlberg, 2011) Biozone (Toro, in Vento *et al.*, in prep.) until a revision of its index species is completed (Toro *et al.*, in prep.).

In the studied area, this biozone spans approximately 150 m of the upper part of the La Huerta section in clearly tectonized beds referable to the Acoite Formation. The presence of *Baltograptus* cf. *B. deflexus* (*B. deflexus* sensu Toro, 1999a: figs. 3.J–L, 4.A–E) together with *B. turgidus* (Lee, 1974) (Toro, 1999a: figs. 3.A–D, 4.F–H) allows recognizing the lower part of the biozone, which is middle Floian (Fl2) in northwestern Argentina (Toro and Maletz, 2007, 2008). These authors provided a complete regional correlation of this biozone. Toro *et al.* (2011) and Figure 3 herein offer additional worldwide correlations. A partial correlation may also be possible between the deposits bearing *A. filiformis* and *Baltograptus* sp. from the Aguas Blancas section (*sensu* Albanesi *et al.*, 2014) and beds of the Acoite Formation in which this biozone occurs in the studied area.

This biozone also records *E. brevis* morphotype B of Paris (1981) associated with chitinozoans common in northern Gondwana, Australia and southern China.

Didymograptellus bifidus *Biozone.* In the Santa Victoria area (Rio La Huerta section) this biostratigraphic interval is represented by the assemblage of *Baltograptus minutus* and *B. deflexus*. This assemblage together with *Didymograptellus bifidus* also occurs in different sections along the western and eastern flanks of the Cordillera Oriental and Puna regions (Toro, 1995, 1997; Toro and Maletz, 2008). Its presence indicates a late Floian (Fl3) age for the upper beds

of the Acoite Formation (Fig. 2) exposed in the La Huerta section. This biozone can be correlated with the *Baltograptus minutus* Biozone in southern Bolivia, *Pseudophyllograptus densus* Biozone in Scandinavia and *D. bifidus* Biozone in eastern North America (Egenhoff *et al.*, 2004: fig. 7). Chitinozoans recorded in the Santa Victoria area come from the upper part of the *Didymograptellus bifidus* Biozone and show affinities with those from northern Gondwana, Australia and South China but also with others from Laurentia (de la Puente and Rubinstein, 2013).

Trilobites

On the basis of the vertical distribution of trilobite taxa (Fig. 2) we propose a succession of trilobite biozones and informal associations (Fig. 3), the ranges of which are calibrated with graptolite biozones. This succession includes the late Tremadocian (late Tr2) to Floian (Fl3) interval, and allows correlation –based on trilobites– of the deposits in the Santa Victoria area with other well-known sections in northwestern Argentina.

In order to provide a more complete picture of the succession of the trilobite faunas, and its relationships with the graptolite biozones, we included in Figure 3 the trilobite biozones recognized in the early late Tremadocian (lower Tr2) related to the *Bryograptus kjerulfi* Biozone, from the upper part of *K. teiichii* Biozone (cf. Vaccari *et al.*, 2010) to the *B. tetragonalis* Biozone (revised by Waisfeld and Vaccari, 2008a). The age of the *B. tetragonalis* Biozone was referred to the *P. deltifer pristinus* conodont Subzone by Zeballo and Tortello (2005). None of these trilobite biozones had been previously recorded in the Santa Victoria area but they are widespread farther south in the Purmamarca-Humahuaca area.

Asaphellus *cf.* **A. stenorhachis-Leptoplastides** *Association.* Following Harrington and Leanza (1957), several authors considered a continuous transition between the *B. tetragonalis* and the *N. orthometopa* biozones (*e.g.*, Moya *et al.*, 1994; Benedetto and Carrasco, 2002; Ortega and Albanesi, 2005; Zeballo *et al.*, 2008; Voldman *et al.*, 2013; Zeballo and Albanesi, 2013). However, Waisfeld and Vaccari (2008a) first noticed that the *N. orthomethopa* Biozone did not directly overlie the *B. tetragonalis* Biozone. Instead, there was a relatively thick sedimentary section between them (interval "lacking definition of zones" of Waisfeld and Vaccari,

2008a: fig.1, p. 123). Muñoz (2009) recorded an approximately 500-m-thick section below the *N. orthometopa* Biozone at Quebrada de Humacha. Salas and Vaccari (2012) also identified this interval in that section.

More recently, Zeballo and Albanesi (2013: fig. 5) assigned the interval below the *N. orthometopa* Biozone in the Coquena Formation (Purmamarca area) to an "unnamed biozone". However, there is no mention of this issue in the text. Tortello and Esteban (2014: fig. 2) also suggested the existence of an "unnamed biozone" below the *N. orthometopa* Biozone in the Nazareno area.

Tortello and Esteban (2014) reported an association of *Leptoplastides* sp. and *Asaphellus* sp. [= *Asaphellus* cf. *A. stenorhachis* (Harrington, 1938) herein] ranging through an interval of about 200 m just below their "unnamed biozone".

Interestingly, a work in progress by the authors (Meroi Arcerito *et al.*, in prep.) indicates that a broadly similar low diversity association of *Asaphellus* cf. *A. stenorhachis* (very close to *Asaphellus stenorhachis* in Meroi Arcerito *et al.*, 2015) along with *Leptoplastides* sp. occurs right over the *B. tetragonalis* Biozone in the Rupasca Member exposed at Quebrada del Arenal and Quebrada de Humacha (Huacalera area). Besides, associations from both areas occur in a largely similar environmental setting, namely lower shoreface in the Huacalera area (Balseiro *et al.*, 2011) and offshore transition-shoreface in the Nazareno area (Tortello and Esteban, 2014).

The composition and space-temporal distribution of this trilobite association is currently under study. Unfortunately, no biostratigraphically diagnostic elements are related with this association in any of the two areas. Giuliano *et al.* (2013) reported the *B. kjerulfi* Biozone in the Nazareno area. However, its relationship with the trilobite fauna described by Tortello and Esteban (2014) is difficult to establish. Because it occurs right above the *B. tetragonalis* Biozone we tentatively refer this association to the upper part of the *B. kjerulfi* Biozone (Fig. 3). Despite its low diversity, the consistent stratigraphic position and relatively broad geographic distribution suggest that this association may be potentially significant for filling —at least in part— the gap between the *B. tetragonalis* and *N. orthometopa* biozones.

Notopeltis orthometopa *Biozone.* Harrington and Leanza (1957) and subsequent authors recognized this biozone at several localities in the Cordillera Oriental (*e.g.*, Moya *et al.*,

1994; Moya, 1998; Waisfeld and Vaccari, 2003; Zeballo *et al*., 2008; Zeballo and Albanesi, 2013, among others). Waisfeld and Vaccari (2003, 2008a) suggested that the taxonomy and distribution of the index species and the diverse trilobite fauna associated with it required revision. Zeballo *et al*. (2008) documented the *N. orthometopa* Biozone in the upper part of the Coquena Formation and the Humacha Member of the Santa Rosita Formation (Purmamarca and Huacalera areas). The authors referred it to the upper part of the *P. deltifer deltifer* and to the *A. deltatus-P. proteus* biozones, and from the upper part of the *A. victoriae* Biozone to the upper part of the *A. murrayi* Biozone. Waisfeld and Vaccari (2008a: fig.1) followed this assignment. The assignment was modified in subsequent papers (*e.g.*, Voldman *et al*., 2013; Zeballo and Albanesi, 2013) in which *N. orthometopa* is restricted to the *P. deltifer*, *A. victoriae* and *Bryograptus* biozones.

Recently, Tortello and Esteban (2014) reported the *N. orthometopa* Biozone in the Río Nazareno section, while reviewing the trilobite species occurring in the Santa Rosita Formation exposed in that section and providing their stratigraphic ranges. Unfortunately, in the absence of associated biostratigraphically significant fossil groups, no further precisions about its age were provided.

The *N. orthometopa* Biozone is fairly well documented in the Río La Huerta section, where it measures at least 250 m. *Notopeltis orthometopa* (Harrington, 1938) is associated with *Asaphellus jujuanus* Harrington, 1937, *Mekynophrys nanna* Harrington, 1938, *Pliomeroides* sp., and *Apatokephalus* sp., apart from several olenids and agnostids.

The lower boundary of this biozone is difficult to establish accurately due to local folding and faulting beneath the base of the La Huerta section. However, the upper boundary of the *N. orthometopa* Biozone can be established with confidence in the Río La Huerta section, where *N. orthometopa* and the associated fauna disappear and are replaced by a different association dominated by the trilobite *Megistaspis* (*Ekeraspis*) Tjernvik, 1956. The very first records of the *M.* (*Ekeraspis*) association occur along with graptolites indicative of the upper part of the *A. victoriae* Biozone (see below). Thus, the upper part of the *N. orthometopa* Biozone cannot be younger than late Tr2.

Megistaspis *(*Ekeraspis*) Association.* As mentioned above, an association dominated by *Megistaspis* (*Ekeraspis*) spp.

appears right above the *N. orthometopa* Biozone in a continuous section in the Río La Huerta section and also in the Río Acoite section. In the latter section the first records of *M.* (*Ekeraspis*) occur in the same beds as *A. victoriae* and other graptolites such as *Adelograptus* cf. *A. altus* and *Ancoragraptus bulmani*, indicative of the upper part of the *A. victoriae* Biozone (early Tr3). On the other hand, in the Río La Huerta section the last records of *M.* (*Ekeraspis*) are coincident with the first appearance of *Tetragraptus phyllograptoides*, the index species for the base of the Floian. Thus, the *M.* (*Ekeraspis*) association appears as a relatively wide-ranging unit spanning several graptolite biozones, *i.e.*, from the top of the *A. victoriae* Biozone through the *A. murrayi* and *H. copiosus* biozones up to the very base of the *T. phyllograptoides* Biozone (Fig. 3).

Toro and Waisfeld (1998) and Waisfeld (2001) reported the occurrence of *M.* (*Ekeraspis*) cf. *pugiocauda* (Harrington and Leanza, 1957) associated with *Saltaspis* sp. related to the *T. phyllograptoides* Biozone in the Río La Huerta section (Figs. 2, 3). A detailed taxonomic analysis of species of *M.* (*Ekerapsis)* is in progress. Currently, two additional species are tentatively documented herein, *i.e.*, *M.* (*Ekeraspis*) sp. 1 (Fig. 4. 8–11) and *M.* (*Ekeraspis*) sp. 2 (Fig. 4–7). The two occur related to the *A. victoriae* Biozone and associated with *Kayseraspis* sp. and *Conophrys* sp. (Fig. 2).

It is important to remark that several authors assumed a continuous succession between the *N. orthometopa* Biozone and the *Thysanopyge* Fauna (*e.g.,* Harrington and Leanza, 1957; Ortega and Albanesi, 2005; Zeballo *et al.*, 2008; Zeballo and Albanesi, 2013). Waisfeld and Vaccari (2008b) pointed out that the relationship between the *N. orthometopa* Biozone and the *Thysanopyge* Fauna has not been established with certainty at any locality in the Cordillera Oriental. In this scenario, the well constrained record of the

Megitaspis (*Ekeraspis*) association documented herein in a continuous succession in the Santa Victoria area fills the gap between both entities.

The distribution of the *M.* (*Ekeraspis*) association in the basin requires further field studies. Waisfeld *et al.* (2006) described *Megitaspis* (*Ekeraspis*)? sp. from the Saladillo Formation in the Pascha-Incamayo area associated with graptolite records assigned to the *Kiaerograptus* Zone (*sensu* Ortega and Albanesi, 2003) and reinterpreted as the *A. victoriae* Biozone (Toro and Carrera, 2013; this work). Hence, this record may be correlated with the lower part of the *M.* (*Ekeraspis*) association from the Santa Victoria area. Besides, Harrington and Leanza (1957) defined and reported *Megalaspis pugiocauda* [=*M.* (*Ekeraspis*) *pugiocauda*] at Potrero del Río Castillo (Salta Province). However, its age and stratigraphic position remain uncertain. These records outside the Santa Victoria area appear promising biostratigraphic tools. Further studies may prove that the *M.* (*Ekeraspis*) association is indeed significant from a regional biostratigraphic viewpoint.

Interestingly, the range of the *M.* (*Ekeraspis*) association includes the ranges of the *Ogygiocaris araiorhachis* and *Kayseraspis asaphelloides* "biozones". These associations were traditionally considered as two successive biozones (Harrington and Leanza, 1957, and subsequent authors). Yet, Waisfeld *et al.* (2006) demonstrated that they correspond to broadly coeval and geographically restricted lateral ecological equivalents thriving during the late Tremadocian (late Tr2 and Tr3) in different areas of the Cordillera Oriental. We recorded a few specimens referable to *Kayseraspis* sp. associated with the earliest records of the *M.* (*Ekeraspis*) association but their preservation prevents a reliable specific identification. The first occurrence of representatives of the *Thysanopyge* Fauna (*sensu* Waisfeld and Vaccari, 2008b)

Figure 5. Dorsal view of trilobites from the Santa Victoria area. **1, 5, 6,** ***Notopeltis orthometopa***, **CEGH-UNC** 26031/26032/26033, pygidia internal moulds. **2, 3** *Megistaspis* (*Ekeraspis*) **cf.** *pugiocauda* **CEGH-UNC** 26034/26035, pygidia internal moulds showing a slightly subtriangular margin and a broad based caudal spine. **4, 7,** *Megistaspis* (*Ekeraspis*) **sp. 2, CEGH-UNC** 26039/26038, pygidia internal moulds, showing a markedly subtriangular margin, and a slender axis and caudal spine. **8, 11,** *Megistaspis* (*Ekeraspis*) **sp. 1. CEGH-UNC** 26037/26036, pygidia internal moulds, distorted juvenile probably referable to this species and undistorted adult with subelliptical pygidium respectively. **9, 10, 13, 14,** ***Thysanopyge taurinus***, **CEGH-UNC** 26040/26041/26042/26043, pygidia internal moulds, lacking of marginal spines in the posterior second half (exag.) of the margin. **12, 17,** ***Thysanopyge clavijoi***, **12, CEGH-UNC** 23419, pygidium internal mould, **17, CEGH-UNC** 23414 cranidium internal mould. **15,** ***Famatinolithus* sp. CEGH-UNC** 26128, cranidium internal mould. **16,** ***Thysanopyge victoriensis***, **CEGH-UNC** 23429, holotype, pygidium internal mold, Scale bars: **1, 3, 6 – 11, 15** = 0. 25 cm; **2, 4, 5, 12–14, 16, 17** = 0.5 cm.
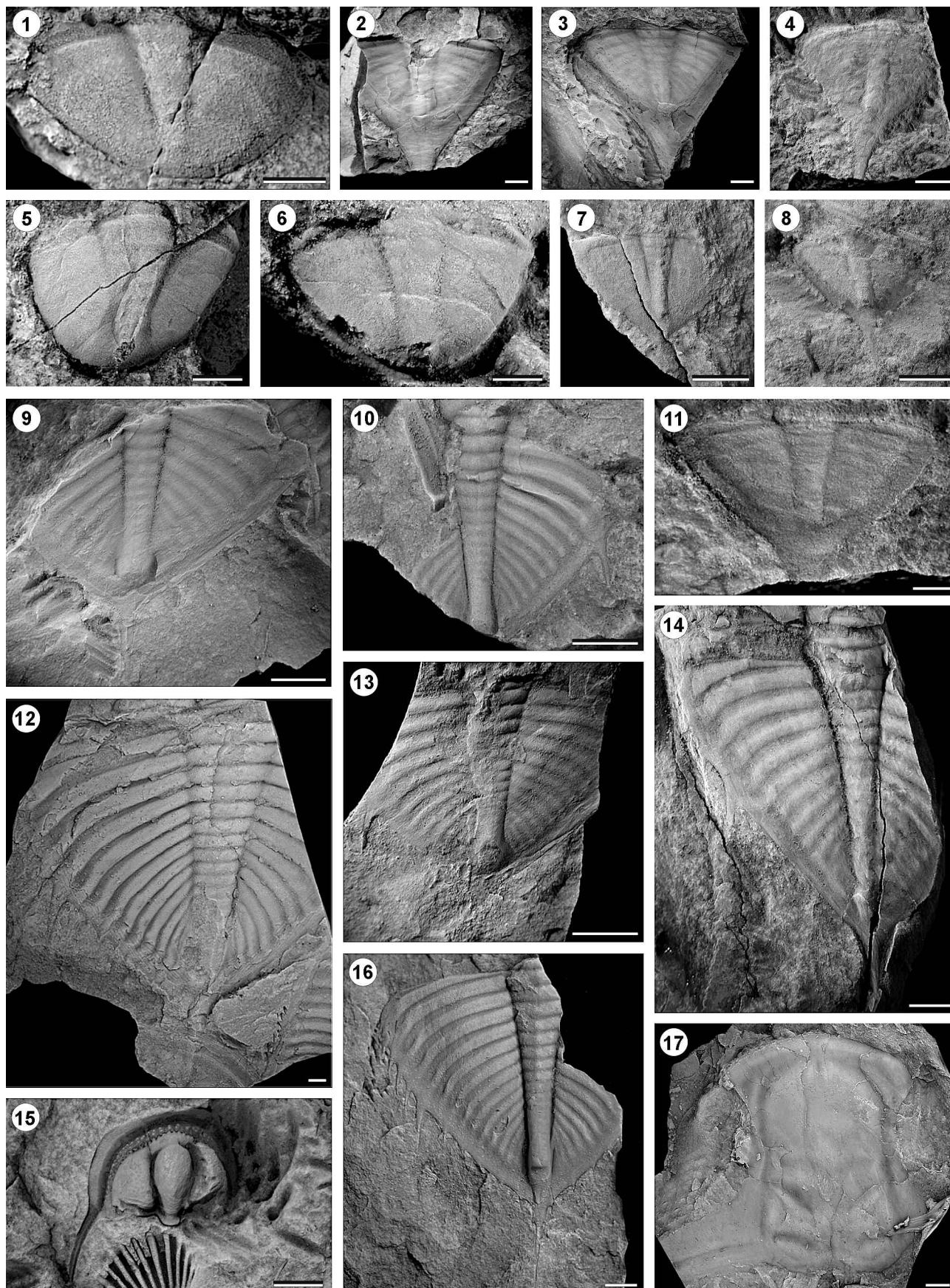
is also recorded within the range of the *M.* (*Ekeraspis*) association (see below).

Thysanopyge *Fauna.* Since Harrington and Leanza (1957), *Thysanopyge* Kayser, 1898, and especially *T. argentina*, had been considered markers of the "Arenigian". Waisfeld and Vaccari (2008b) recognized six different species of the genus, spanning from the late Tremadocian to the Floian. Most of them exhibit a restricted geographic distribution; hence their value from a biostratigraphic perspective is limited. In the Santa Victoria area we document three *Thysanopyge* species, the range of which is now well constrained to the late Tremadocian (early Tr3)–middle Floian (Fl2) on the basis of their co-occurrence with key graptolites.

Thysanopyge taurinus *(Harrington, 1937).* This species was recorded for the first time outside the Pascha-Incamayo area in the Río Acoite section. In the Pascha-Incamayo area, *T. taurinus* ranges from the upper part of the Saladillo Formation to the Parcha Formation where it is related with the *A. murrayi* and *H. copiosus* biozones (Waisfeld *et al.*, 2006: fig. 4). In the Río Acoite section this species co-occurs with *Kierograptus* sp. and thus is referred to the *A. murrayi* Biozone. This record can be correlated with the earliest occurrence of this species in the western area of the Cordillera Oriental (Fig. 3).

Thysanopyge victoriensis *Waisfeld and Vaccari, 2008b.* The species *T. victoriensis* was defined by Waisfeld and Vaccari (2008b) in the Acoite Formation exposed in the Río La Huerta section. Following the framework by Toro (1999a) and Rubinstein *et al.* (1999) it was assigned to the lowermost part of the *B. deflexus* Biozone. New sampling in the Río La Huerta section together with the systematic revision of the index species and the graptolite biozone boundaries allow better constraining of the vertical range and age of the species. According to the new data, first occurrences of *T. victoriensis* are now documented in the uppermost part of the *H. copiosus* Biozone (late Tr3), whereas the uppermost record is documented within the lower part of the *T. akzharensis* Biozone (late Fl1). The trilobite fauna associated with *T. victoriensis* is scarce throughout its range. It co-occurs with *Nileus*? sp. and *Australopyge russoi*? Harrington and Leanza, 1957, in the Río La Huerta section. *Thysanopyge victoriensis* has not been recorded outside the Santa Victoria area.

Thysanopyge clavijoi *Harrington and Leanza, 1957. Thysanopyge clavijoi* was defined by Harrington and Leanza (1957)

in the Acoite Formation at the Río La Huerta section in the Santa Victoria area. Waisfeld and Vaccari (2008b) referred this species to the upper part of the *B. deflexus* Biozone. Again, new collections and calibration with revised graptolite biozones indicate that its oldest records occur within the upper part of the *T. akzahrensis* Biozone (Fl1), while the youngest ones occur within the lower-middle part of the *B.* cf. *B. deflexus* Biozone (Fl2). This species is widespread in the Santa Victoria area, with records in the La Huerta river section, Acoite river section, and the upper part of the Quebrada de Chulpíos section. It is associated with an abundant but poorly diverse fauna including mainly *Emanuelaspis*? sp., *Niobides* sp. and *Porterfieldia* sp. (*cf.* Waisfeld, 2001). *Thysanopyge clavijoi* was reported by Waisfeld and Vaccari (2008b) in the Acoite Formation (= Cieneguillas Formation) at La Ciénaga (Purmamarca area), expanding the geographic distribution of the species across the basin (see also Vaccari *et al.*, 2006). In this area *T. clavijoi* is associated with graptolites of the *T. akzharensis* Biozone (Toro and Vento, 2013).

Famatinolithus *Fauna.* During the Floian the *Thysanopyge* Fauna is replaced by a completely different array of trilobites called the *Famatinolithus* Fauna (Waisfeld *et al.*, 2003, and references therein). The latter was widespread in offshore transition-shoreface settings across the basin. However, it was better developed and more diverse in western localities (Los Colorados-Chamarra area) than in eastern ones (Waisfeld and Astini, 2003). This Fauna exhibited a higher diversity than the preceding *Thysanopyge* Fauna, including mainly asaphids, raphiophorids, nileids, olenids and calymenaceans among others. The first records of the *Famatinolithus* Fauna in the Santa Victoria area are slightly younger than those reported for the western localities in the Cordillera Oriental. The *Famatinolithus* Fauna is associated with the *D. bifidus* Biozone (late Floian, Fl3) in the Río La Huerta section, whereas its first records in western localities is in the upper part of the *B.* cf. *B. deflexus* Biozone (Fl2). As the upper levels of the Acoite Formation are cut by Late Ordovician glacial deposits, the *Famatinolithus* Fauna is strongly reduced in the region. Space-temporal distribution of some of the members of the *Famatinolithus* Fauna suggests that they might be significant from a biostratigraphic point of view. Their regional distribution and potential value as biostratigraphic markers is currently under study.

DISCUSSION

The easily recognizable association of *A. victoriae*, *Adelogratus* cf. *A. altus* and *Ancoragraptus* cf. *A. bulmani*, coming from the remarkably continuous deposits of the upper part of the Santa Rosita Formation in the Santa Victoria area allows to recognize the *A. victoriae* Biozone occurring a few meters below the first appearance of *A. murrayi* (Fig. 2). On top of the previous records of the *Bryograptus kjerulfi* Biozone, a few kilometres to the south of the studied area, and also in the Pascha-Incamayo area, the occurrence of the *A. victoriae* Biozone allows to confirm that it overlies the *Bryograptus kjerulfi* Biozone in northwestern Argentina (Fig. 3).

Voldman *et al.* (2013) assigned a conodont fauna coming from the deposits of the Santa Rosita Formation in the Santa Victoria area (Peña Blanca and San Felipe sections) to the *Paltodus deltifer deltifer* Subzone of the *Paltodus deltifer* Biozone. Following previous contributions (*e.g.*, Albanesi *et al.*, 2008; Zeballo *et al.*, 2008, among others) the author proposed a middle Tremadocian (Tr2) age for the studied deposits and also correlated the *P. deltifer* Biozone with the *Bienvillia tetragonalis* and *N. orthometopa* trilobite biozones and the *Adelograptus*, *Bryograptus*, *A. victoriae* and *Kiaerograptus supremus* graptolite biozones. Nevertheless, according to the intercontinental correlation proposed by Hammer and Grandstein (*in* Cooper and Sadler, 2012: fig. 20.1) the *Paltodus deltifer* Biozone, which defines the stage slice Tr2 (*sensu* Bergström *et al.*, 2009), represents a short interval corresponding to the late Tremadocian and partially corresponds to the *A. victoriae* Biozone. This allows assigning a late Tremadocian age (Tr2 to probably early Tr3) to the levels of the Santa Rosita Formation exposed in the San Felipe and Peña Blanca sections. Furthermore, the *A. victoriae* Biozone from northwestern Argentina correlates with the upper part of the homonymous biozones of Newfoundland and Australia.

Voldman *et al.* (2014) and Albanesi *et al.* (2014) concluded that conodonts of the "*Gothodus*" Zone (*sensu* Albanesi *et al.*, 2008) and associated graptolites indicate a late Floian age for the fossil-bearing beds. Nevertheless, at the Quebrada de Chulpíos in the Santa Victoria area Voldman *et al.* (2014) reported the presence of this conodont biozone a few meters above the beds with *Hunnegraptus copiosus*, which is the marker of the late Tremadocian (late Tr3). This finding is not consistent with our data from the La Huerta

section, where the stratigraphic interval corresponding to the late Tremadocian (*Hunnegraptus copiosus* Biozone)–late Floian (*D. bifidus* Biozone) measures approximately 860 m. This interval includes the upper part of the Santa Rosita Formation and the entire Acoite Formation and several graptolite biozones (*T. phyllograptoides*, *T. akzharensis*, *B.* cf. *B. deflexus* and *D. bifidus* biozones)*. Therefore, the record of the late Tremadocian *H. copiosus* Biozone closely followed by the late Floian "*Gothodus*" Biozone reported by Voldman *et al.* (2014) at Quebrada de Chulpíos requires further revision as it implies a significant stratigraphic gap not verified in nearby sections.

In the same vein, other reports of the late Floian "*Gothodus*" Biozone from the Acoite Formation (= Cieneguillas Formation) in the Purmamarca area are also in need of revision (Albanesi *et al.*, 2008, 2014). This conodont biozone appears in this area associated with *Baltograptus vacillans* (Ortega and Rao, 1994) and *T. akzharensis* Tzaj, 1968 (recently reported by Toro and Vento, 2013, p. 294). The two graptolite species are key species for recognizing the upper part of the *T. akzharensis* Biozone in northwestern Argentina (Toro and Vento, 2013). Thus we here emphasize that their presence indicates an early Floian age (late Fl1) for the fossil-bearing levels and not a late Floian one as suggested by Albanesi *et al.* (2008) and Albanesi *et al.* (2014).

Albanesi *et al.* (2014) reported conodonts of the "*Gothodus*" Biozone and graptolites assigned to the *Baltograptus* cf. *B. deflexus* Biozone in an isolated outcrop at Quebrada de Aguas Blancas, west of Cuesta de Lipán. The authors referred this section to the Cieneguillas Formation, a name that Harrington and Leanza (1957) had employed for another local Ordovician outcrop at La Ciénaga (Purmamarca area). They postulated a "late Floian age" for the fossil-bearing levels, which they correlated with the outcrops of this unit exposed in the La Ciénaga section. However, according to our data the *Baltograptus* cf. *B. deflexus* Biozone is constrained to the middle Floian (Toro and Maletz, 2008, and this work: Fig. 3). We propose that both –the isolated outcrop studied by Albanesi *et al.* (2014) and that one exposed at La Ciénaga section– could be better referred to different stratigraphic levels of the Acoite Formation.

Finally, in some of the successions where this conodont biozone has been reported, our data indicate a partial correlation between the "*Gothodus*" Biozone and the *T. akzharen-*

sis and possibly the lower part of the *B.* cf. *B. deflexus* biozones (late Fl1 to Fl2). Consequently, its unusually long range (late Fl1 to Fl3) and the endemic character of the "*Gothodus*" species (Albanesi *et al.*, 2008) reinforces the need of its calibration with other fossil groups in order to be considered a valuable biostratigraphic marker to correlate Floian rocks in northwestern Argentina.

CONCLUSIONS

The outcrops of the Santa Victoria Group in its type area are one of the most complete sections with Ordovician trilobite-graptolite faunas in the Central Andean Basin, including eight graptolite biozones and a succession of well constrained trilobite biozones and associations.

New records of *Aorograptus victoriae*, *Adelogratus* cf. *A. altus* and *Ancoragraptus bulmani* allow expanding the distribution of the *A. victoriae* Biozone into the Santa Victoria area, indicating a late Tremadocian (late Tr2 to probably early Tr3) age for the fossil-bearing levels of the Santa Rosita Formation.

The remarkably complete section of the Santa Rosita and Acoite formations in the Santa Victoria-Nazareno area confirms for the first time the succession of the *Bryograptus kjerulfi, Aorograptus victoriae, Araneograptus murrayi, Hunnegraptus copiosus, Tetragraptus phyllograptoides, T. akzharensis, Baltograptus* cf. *B. deflexus* and *Didymograptellus bifidus* biozones (late Tremadocian–late Floian) in northwestern Argentina.

Graptolite biozones enable refining the biostratigraphic framework based on trilobites and delimitation of trilobite associations (*e.g.*, *Asaphellus/Leptoplastides, M.* (*Ekeraspis*) of potencial biostratigraphic significance, but also reveal problems still remaining concerning correlation using other fossil groups.

The calibration of the new and better resolved graptolite biostratigraphic framework for the Santa Victoria area with trilobite biozones and associations provides new insights for the understanding of their complex space-temporal distribution. The occurrence of the *Asaphellus* cf. *A. stenorhachis-Leptoplastides* association recognized herein between the well-known *B. tetragonalis* and *N. orthometopa* biozones fills –at least partially– the gap formerly identified by Waisfeld and Vaccari (2008a) as an interval without definition of biozones. Besides, the occurrence of the *Megitaspis* (*Ekeraspis*) association along with graptolites indicative of the upper *A. victoriae* Biozone immediately above the *N. orthometopa* Biozone, renders possible the identification and chronological constraint of the upper boundary of the *N. orthometopa* Biozone for the first time in the Cordillera Oriental.

On the other hand, three key representatives of the *Thysanopyge* Fauna were found in the Santa Victoria area, namely *T. taurinus, T. victoriensis*, and *T. clavijoi*. Their range has been calibrated based on their co-occurrence with the *A. murrayi, T. phyllograptoides*, and *T. akzharensis-Baltograptus* cf. *B. deflexus* graptolite biozones (respectively). Finally, two new trilobite associations are tentatively proposed herein, *i.e.*, the *Asaphellus* cf. *A. stenorhachis-Leptoplastides* association and the *Megistaspis* (*Ekeraspis*) association. Their biostratigraphic usefulness remains to be confirmed. However, a preliminary analysis of their geographic and stratigraphic distributions provide good perspectives for the future.

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