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Biostratigraphy based on trilobites from the Floresta Formation (Tremadocian) in Mojotoro Range (Salta) and its correlation with diverse units and localities of the Argentine Eastern Cordillera

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Resúmen: *BIOESTRATIGRAFÍA BASADA EN TRILOBITES DE LA FORMACIÓN FLORESTA (TREMADOCIANO) EN LA SIERRA DE MOJOTORO (SALTA) Y SU CORRELACIÓN CON DIVERSAS UNIDADES Y LOCALIDADES DE LA CORDILLERA ORIENTAL ARGENTINA.* Se analiza aquí la fauna de trilobites de la Formación Floresta (Tremadociano) en el sector medio de la sierra de Mojotoro con el objetivo de realizar la interpretación bioestratigráfica de la unidad. Se analizaron cuatro secciones que, de norte a sur, son: quebrada de la Virgen del Cerro, quebrada de Tres Cerritos, Villa Floresta y Finca Miraflores. Se identificaron 18 especies agrupadas en asociaciones en función de su procedencia estratigráfica y geográfica. Se reconocieron con certeza las Biozonas de *Kainella meridionalis* y *Bienvillia tetragonalis* mientras que se enuncia con dudas la presencia de la Biozona de *Kainella teichii*. Se pone en duda si la Biozona de *Notopelthis ortomethopa* pertenece a la Formación Floresta o a niveles basales de la Formación Áspero. Así mismo, se realizan correlaciones bioestratigráficas para otras áreas de la Cordillera Oriental argentina. De acuerdo al esquema bioestratigráfico vigente a base de trilobites para el Tremadociano, se interpreta que esta unidad litoestratigráfica se habría depositado entre finales del Tr1 y el Tr2.

Abstract: The trilobite fauna of Floresta Formation (Tremadocian) in the middle part of Mojotoro range is studied here with the aim to make a biostratigraphic interpretation. Four sections were analyzed, which from north to south are Virgen del Cerro creek, Tres Cerritos creek, Villa Floresta, and Finca Miraflores. 18 species were identified and grouped into four associations considering their stratigraphical and geographical procedence. It's recongnized with certainty *Kainella meridionalis* and *Bienvillia tetragonalis* biozones. *Kainella teiichi* were identified with doubts. It is questioned whether *Notopelthis ortomethopa* Biozone really belongs to Floresta Formation or, instead, corresponds to basal levels of Áspero Formation. In addition, a biostratigraphic correlation is carried out between Floresta Formation and other lithostratigraphic units from diverse areas of argentine Eastern Cordillera. Considering the current biostratigraphic scheme for Tremadocian based on trilobites, it is interpreted that Floresta Formation would be deposited during the end of Tr1 and Tr2.

Palabras clave: Trilobites. Bioestratigrafía. Formación Floresta. Tremadociano. Correlación. Argentina.

Key words: Trilobites. Biostratigraphy. Floresta Formation. Tremadocian. Correlation. Argentina.

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Introduction

Correct taxonomic assignment at the species level has the consequence of the taxa are well located in time or, at least, its biochron is more accurate. Under this basic and already known rule, biostratigraphic schemes can be made that allow to calculate the age of the carrier deposits of a determinate association of fossils.

For furongian and tremadocian units of argentine Eastern Cordillera, trilobites contribute better than other groups (conodonts and graptolites) to define the age of the different units of Santa Victoria Group. In this sense, Vaccari *et al.* (2010) and Meroi Arcerito *et al.* (2018) present comparisons between trilobites, graptolites, and conodonts about the degree of resolution of its biozones for the ages mentioned above.

Considering the first studies of taxonomic identification of trilobites, one of the most classic and complete works on ordovician trilobites from Argentina was carried out by Harrington and Leanza (1957). The authors, based on the uncountable taxa defined and described, added to the comprehensive sedimentological analysis done in several localities, made a biostratigraphic scheme for the Tremadocian composed by the following biozones in ascendent order: *Parabolina argentina*, *Kainella meridionalis*, *Triarthrus tetragonalis–Conoprhys minutula* and *Notopelthis orthometopa*.

Posterior researchers emended diagnostic characters of genera and species, changed some taxonomic positions at levels superior to families, completed descriptions, described new species, defined new taxonomic categories and species, made ontogenetic explanations, synonymized genera and species, among so many modifications. The principal and more recently works referred to this aspects are those of Malanca (1996), Waisfeld and Vaccari (2003), Tortello and Esteban (2003), Aris (2005), Aris and Malanca (2005), Zeballo and Tortello (2005), Aris and Malanca (2006), Tortello and Clarkson (2008), Vaccari and Waisfeld (2010), Monti *et. al.*, (2016), Monti (2018), Meroi Arcerito *et al.* (2015), Tortello and Esteban (2014, 2016), Meroi Arcerito *et al.* (2018) and Tortello and Esteban (2020).

As a consequence, the biostratigraphic scheme was evolving in time getting more and more precise (Waisfeld y Vaccari, 2008a y b), Vacarri *et al.* (2010), Toro *et al.* (2015), Tortello and Esteban (2016), Meroi Arcerito *et al.* (2015) and Meroi Arcerito *et al.* (2018). This works were accompanied by the discovery of new localities and formations with its paleoenvironmental and estratigraphic interpretations. In addition, the successive schemes sometimes were correlated internationally.

The multiple paleontological, stratigraphical, and sedimentological studies made in different localities of Eastern Cordillera for Santa Victoria Group resulted in the use of many formational names what is probably the same paleoenvironment of deposition. Therefore, there is a general confusion about the relationships between these lithostratigraphic units that makes it difficult, in some cases, the correlation and the interpretation of the deposition conditions and evolution of this basin. This statement is not new to those who investigate these units and the efforts are directed to give a solution to this problem.

Mojotoro range has the particularity that the vegetation cover prevent having complete sections, its lithostratigraphic units were deposited in a border of the basin and, in addition, the stratigraphic scheme for Santa Victoria Group is very different from the rest of the Eastern Cordillera. However, it contains very important deposits based on the quality, diversity, and abundance of its fossil record. Concerning the paleontological content of the formations of Santa Victoria Group, many of the previously mentioned works include material from this orographic unit. Floresta Formation is the most fossiliferous lithostratigraphic unit of this Group in the Mojotoro range and, therefore, the most studied. It provides a diverse and abundant fauna of graptolites (Moya *et al.*, 1994, Monteros, 1999; Monteros, 2005 and Moya and Monteros, 2014), mollusks (Sánchez and Vaccari, 2003; Aris and Pinilla, 2019; Chichowolsky *et al.*, 2022), brachiopods (Benedetto and Carrasco, 2002; Saiz Cobbe, 2007; Saiz Cobbe and Moya, 2008; Eveling, 2015; Benedetto and Muñoz, 2017 Aris *et al.*, 2022), cnidarians (Aris *et al.*, 2017a), sponges (Aris *et al.*, 2020) and marrelids (Aris *et al.*, 2017b). The trilobitofauna was studied by Malanca (1996), Aris (2005), Aris and Malanca (2005, 2006), and Aris (2022a, b).

In light of recent findings resulting from new samplings and the current biostratigraphic scheme provided by Vaccari *et al.* (2010) and Meroi Arcerito *et al.* (2018) for the Tremadocian, its necessary to carry out a biostratigraphic review of the trilobite fauna of Floresta Formation and start doing correlation with another lithostratigraphic units of Salta and Jujuy, contributing in this way to order the current stratigraphic schemes. This work consists in a first aproximation to resolve the nomenclatural disorder, starting with making a correlation scheme and will be complemented with the sedimentological and paleoenvironmental analyses (Aris and Bosso, 2024 in preparation).

Geological setting

Eastern Cordillera as a morphostructural unit extends from Colombia, Peru, Bolivia, its southernmost extreme being northern Argentina. It constitutes a double–vergent mountain range separated by deep valleys, where the Paleozoic and post–Paleozoic cover forms thrust strips on its western and eastern margins, and where the precambrian basement controls the deformation in its internal sector (Ramos, 2017 and authors there cited).

Mojotoro range is located at the southern end of the Eastern Cordillera. It is an overturned anticline in a north–south course that is limited to the North by the San Antonio River (Jujuy) and to the South by the Castillejos range (Salta). The Siancas Valley delimits it to the East, while the Lerma Valley does the same on the West. On the western flank, the basement of this range is formed by the Puncoviscana Complex (Zimmerman, 2005), deposited in the Lower Ediacaran–Cambrian. It is conformed by Chachapoyas, Alto de La Sierra and Guachos formations, in increasing order of age (Aparicio Gonzalez *et al.,* 2011).

The Tilcara unconformity separates Puncoviscana Complex from the cambrian sediments of Mesón Group (Turner, 1960), which is made up of the temporarily ascending Lizoite, Campanario, and Chalhualmayoc formations (Turner, 1960). This group is well represented along the western flank of range, while only a few incomplete sections were recognized on the eastern flank (Moya, 1988). According to the ichnofossils found in this Group, Mángano and Buatois (2004) assigned an early Cambrian to middle Cambrian age. More recent dating of zircons gave an age between 500 and 513 Ma (Adams *et al.*, 2008; Augustsson *et al.*, 2011; Aparicio González *et al.*, 2014).

Overlies, in an erosive unconformity (Iruya unconformity), Santa Victoria Group conformed by various sedimentary units corresponding to the Upper Furongian–Low Upper Ordovician (Harrington, 1957; Moya, 1988, 1998). Unlike what happens in other sectors of the Eastern Cordillera, the current stratigraphic scheme for Santa Victoria Group for Mojotoro range is the one provided by Moya (1988 and 1998) who integrated eight formations (some of them previously defined by Harrington, 1957) which, from base to top, are: Pedrera, San José, Caldera, Floresta, Áspero, San Bernardo, Mojotoro and Santa Gertrudis. The criteria used by the author was based on the alternation of sandstone and shale bodies whose stratigraphic relationships are of concordance and transition, reflecting the classic ordovician transgressive–regressive events.

To the south of the range, cretaceous deposits of the Salta Group (Turner, 1960) overlie in unconformity, which consists of a powerful siliciclastic sedimentary sequence with carbonate and volcaniclastic levels integrating the three Subgroups that, from the oldest to the most modern, are: Pirgua, Balbuena and Santa Bárbara.

Tertiary deposits of Orán Group (Russo, 1972) overlie Salta Group in angular unconformity, and the Quaternary ones are made up of sandstones and conglomerates indicating alluvial fans, intertwined fluvial systems, alluvial cones and lacustrine deposits. The Orán Group covers the paleozoic units on the eastern flank of the Mojotoro range (Moya, 1988).

The study area is located in the middle section of the Mojotoro range and includes, from north to south, Virgen del Cerro and Tres Cerritos creeks, where came the most complete profiles of Floresta Formation, Villa Floresta and Finca Miraflores (Figure 1).

Materials and methods

The present work is based on the analysis of numerous specimens collected from the four sections detailed above. All the specimens are housed in the Paleontology collection of National University of Salta under the acronym CNS–PI. The material was observed using a Leika binocular loupe with a built–in Canon Power Shot S10 camera. The morphological characters selected for the recognition and distinction of the different species are the classic ones listed by Harrington and Leanza (1957) to which the most up to date bibliography is added: Vaccari and Waisfeld (2010), Meroi Arcerito *et al.* (2015, 2018), Monti (2018), Monti *et al.* (2016), Tortello and Esteban (2014, 2016, 2020).

Maps, figures and photographs were made using Corel Draw Graphics Suites 2023 and PhotoShop (version 12.0).

Described species

The material listed below comes from the four localities mentioned above (Table 1).

According to the geographic and stratigraphic origin of the material, four associations were defined:

Virgen del Cerro creek Association (Figure 2): This creek provided a fauna of only two species: *Kainella meridionalis* and *Leptoplastides argentinensis*.

Tres Cerritos creek Association (Figure 3): This section contributed a fauna corresponding to *Bienvillia tetragonalis*, *Parabolinella argentinensis*, *P. boliviana*, *P. clarisae*, *Apatokephallus*

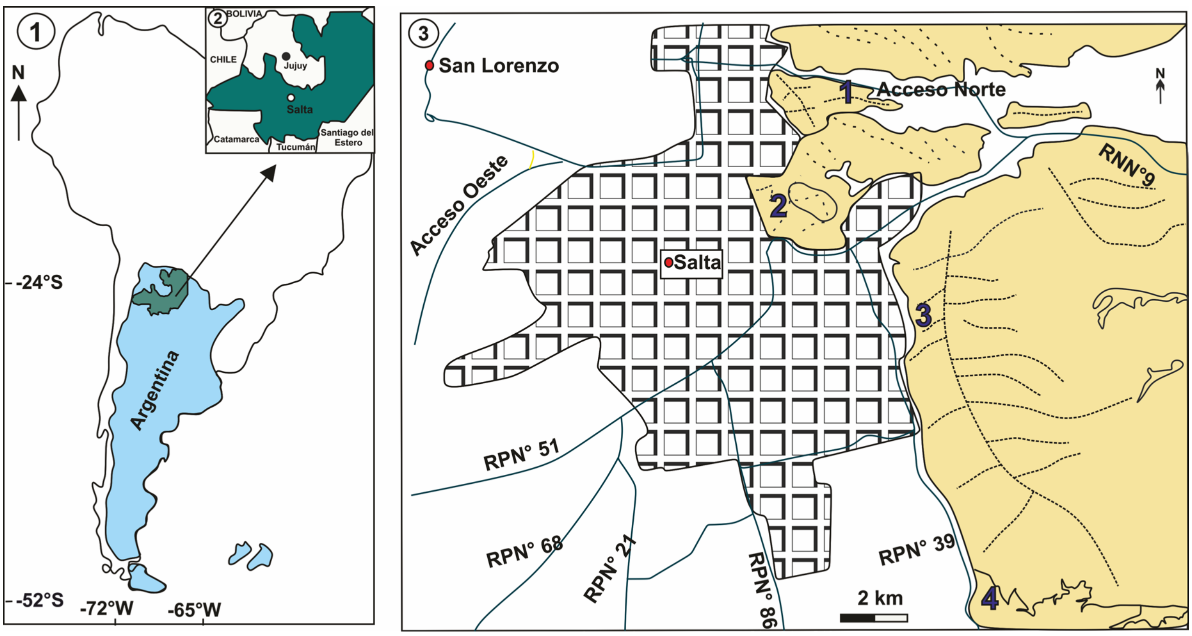

Figure 1. Location and access roads to the study area. **1.** Virgen del Cerro creek. **2.** Tres Cerritos creek. **3.** Villa Floresta. **4.** Finca Miraflores. / **Figura 1.** *Ubicación y vías de acceso al área de estudio. 1. Quebrada de la Virgen del Cerro. 2. Quebrada de Tres Cerritos.*

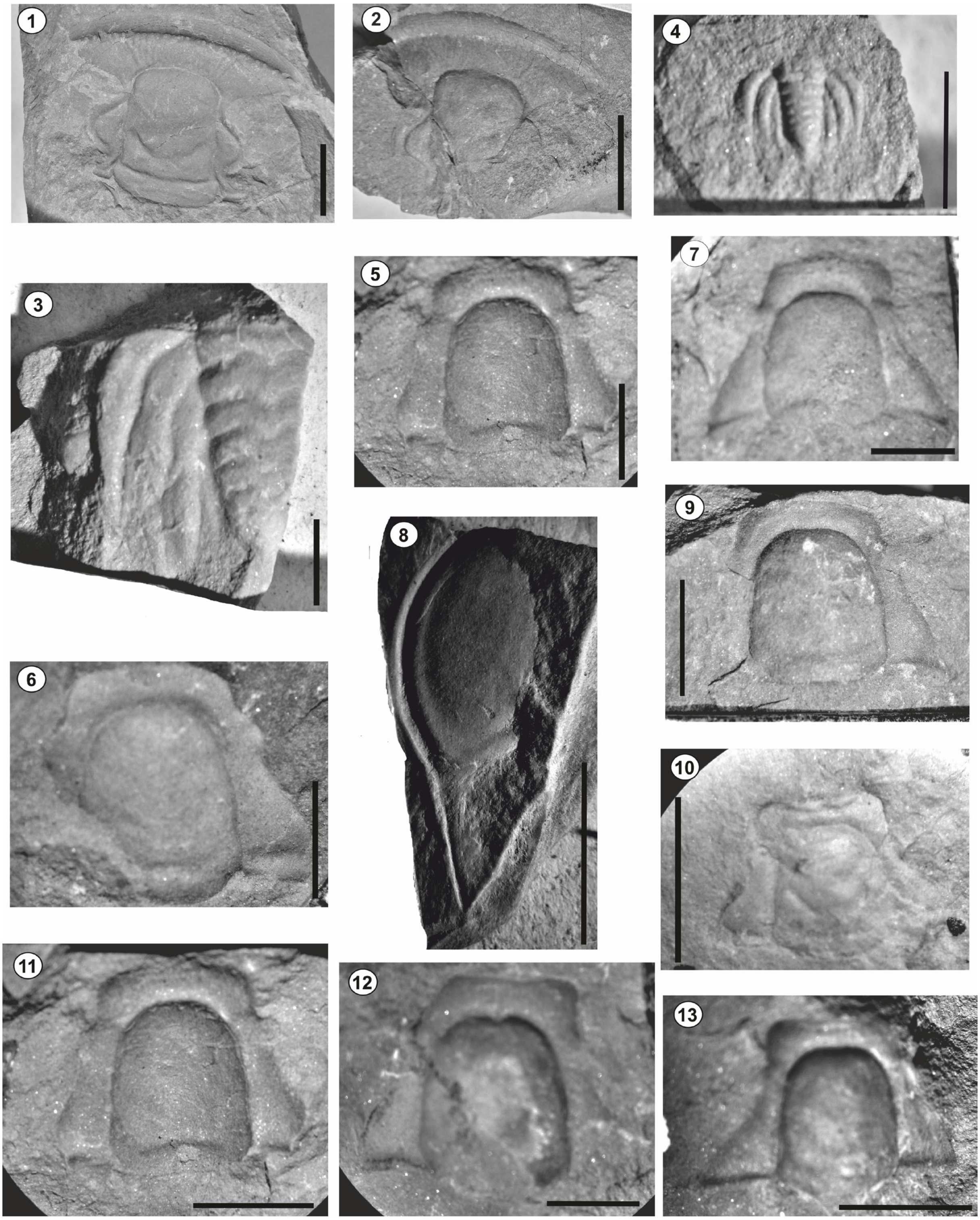

Figure 2. Virgen del Cerro creek association. **1-4.** *Kainella meridionalis* CNS- Pi 150/205, CNS-I 150/33, CNS- Pi 150/79, CNS-I 150/80 respectively. **5-13.** *Leptoplastides argentinensis* CNS- Pi 150/35a, CNS- Pi 150/206, CNS- Pi 150/69a, CNS- Pi 150/15, CNS- Pi 150/209, CNS- Pi 150/81, CNS- Pi 150/168b, CNS-Pi 150/51b, CNS- Pi 150/2a respectively. Scale bars equals 1cm (1-2,8), 0,5 cm (3-7 and 9-13). / **Figura 2.** *Asociación de la quebrada de la Virgen del Cerro.* **1-4.** Kainella meridionalis *CNS- Pi 150/205, CNS-I 150/33, CNS- Pi 150/79, CNS-I 150/80 respectivamente.* **5-13.** *Asociación de la quebrada de la Virgen del Cerro.* **1-4.** Kainella meridionalis *CNS- Pi 150/205, CNS-I 150/33, CNS- Pi 150/79, CNS-I 150/80 respectivamente.* **5-13.** Leptoplastides argentinensis *CNS- Pi 150/35a, CNS- Pi 150/206, CNS- Pi 150/69a, CNS- Pi 150/15, CNS- Pi 150/209, CNS- Pi 150/81, CNS- Pi 150/168b, CNS- Pi 150/51b, CNS- Pi 150/2a respectivamente. Las escalas gráficas equivalen a 1cm (1-2; 8) y 0,5 cm (3-7; 9-13).*

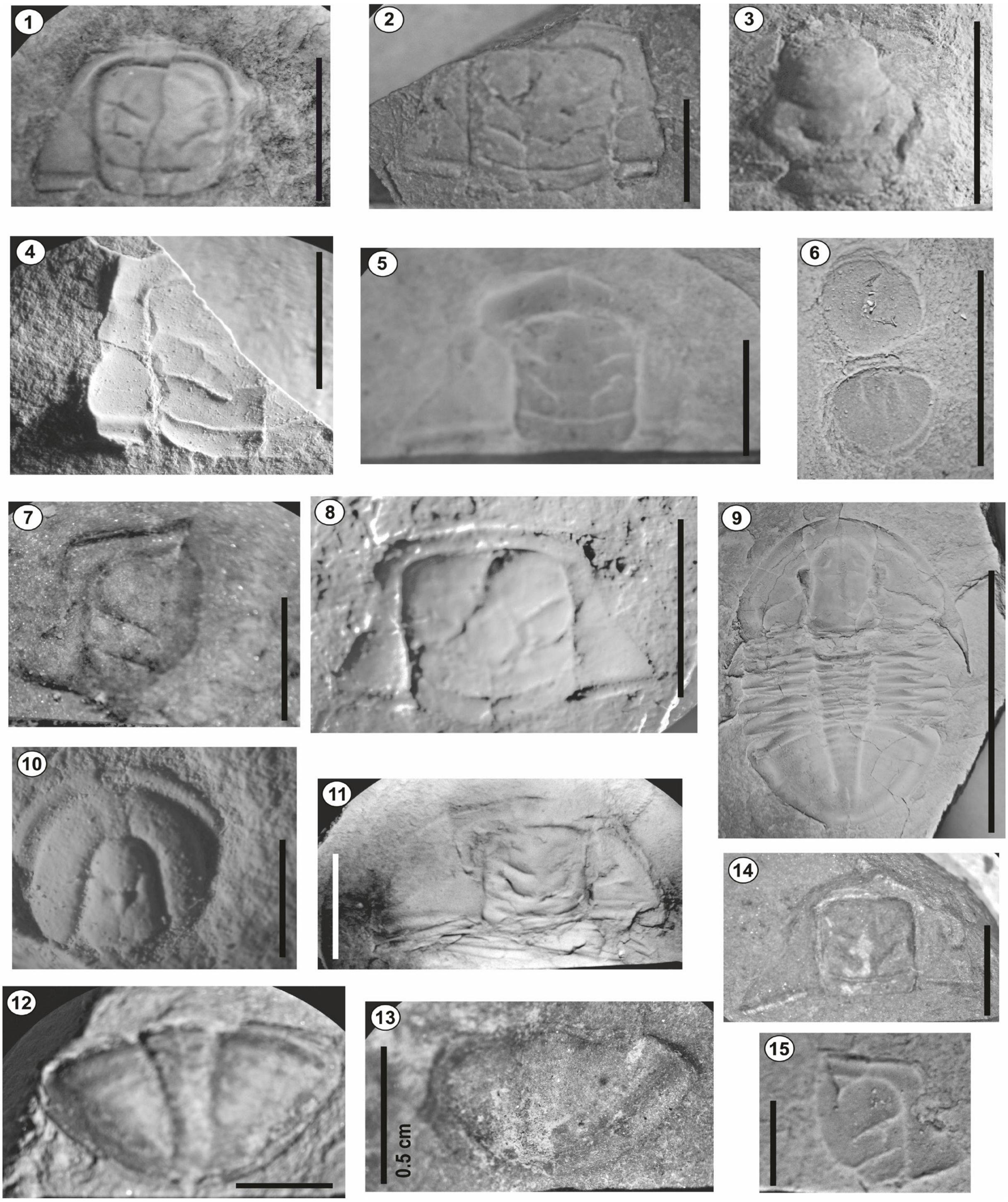

Figure 3. Tres Cerritos creek association. **1, 2, 4, 7, 8, 15.** *Bienvillia tetragonalis.* CNS- Pi 151/342, CNS-Pi 151/344, CNS- Pi 151/ 345, CNS- Pi 151/345, CNS- Pi 151/346, CNS- Pi 151/348. **3**. *Apatokephallus tibicen* CNS- Pi 151/349. **5.** *Parabolinella boliviana* CNS- Pi 151/350. **6.** *Gymnagnostus* sp. CNS- Pi 151/351. **8, 12.** *Asaphellus albae* CNS- Pi 151/352, CNS- Pi 151/353 respectly. **10.** *Geragnostus nesossii* CNS- Pi 151/347. **11.** *Parabolinella argentinensis* CNS- Pi 151/538. **14.** *Parabolinella clarisae* CNS- Pi 151/354. **13.** *Asaphellus stenorhachis* CNS- Pi 151/592. Scale bars equals 0,5 cm (1-8;12-14), 4 cm (9), 0,3 cm (10) and 0,25 cm (15). / **Figura 3.** *Asociación de la quebrada de Tres Cerritos.* **1, 2, 4, 7, 8, 15.** Bienvillia tetragonalis. *CNS- Pi 151/342, CNS- Pi 151/344, CNS- Pi 151/ 345, CNS- Pi 151/345, CNS- Pi 151/346, CNS- Pi 151/348.* **3**. Apatokephallus tibicen *CNS- Pi 151/349.* **5**. Parabolinella boliviana *CNS- Pi 151/350.* **6.** Gymnagnostus *sp. CNS- Pi 151/351.* **8, 12.** Asaphellus albae *CNS- Pi 151/352, CNS- Pi 151/353 respectivamente.* **10.** Geragnostus nesossii *CNS- Pi 151/347.* **11.** Parabolinella argentinensis *CNS- Pi 151/538.* **14.** Parabolinella clarisae *CNS- Pi 151/354.* **13.** Asaphellus stenorhachis *CNS- Pi 151/592. Las escalas gráficas equivalen a 0,5 cm (1-8; 12-14); 4 cm (9); 0,3 cm (10) y 0,25 cm (15).*

tibicen, *Asaphellus albae*, *A. stenorachis*, *Geragnostus nesossii*, *Gymnagnostus sp*.

Villa Floresta Association (Figures 4-5): The fossil set from this locality provided a fauna composed of *A. exiguus*, *P. argentinensis*, *B. tetragonalis*, *B.cf. B. shinetonensis*, *Illaenopsis nov. sp.*, *N. taurina*, *C. sulcata*, *Hapalopleura nov. sp.* and *G. (G.) nesossii*.

Finca Miraflores Association (Figure 6): For this locality, the material corresponding to the CNS–132 collection was reviewed. In addition, new material collected was studied. It provided a trilobite fauna consisting of *B. tetragonalis*, *P. argentinenesis*, *P. boliviana*, *A. exiguus* and *G. nesossii*.

Biostratigraphy

Kainella meridionalis **Biozone**

This biozone was recognized in the basal section of Virgen del Cerro creek (Virgen del Cerro creek Association) which corresponds to fine to very fine, massive sandstones of variable thickness with HCS and SCS structures. At the base four superimposed storms are observed, while towards the top the levels corresponding to storm events increase their thickness. With drip marks on the tops. The HCS and SCS structures can be observed in the A–B plane of some of the sandy stratum. The sandstones interbedded with levels of olive–green muddy shales corresponding to post–storm events. Towards the top, the muddy shales turn into clayey shales, evidencing a decrease in the energy of the sea. The remains of Virgen del Cerro creek Association were rescued from those pelitic levels.

Bienvillia tetragonalis **Biozone**

Corresponds to Tres Cerritos creek Association and Finca Miraflores Association.

Three levels with taxa from this biozone were identified at Tres Cerritos creek. At the lower level, *B. tetragonalis* is associated with *P. argentinenesis*, *P. boliviana*, *P. clarisae*, *G. nesossii* and *Gymnagnostus* sp. At the intermediate level, the guide species is accompanied by *A. tibicen* and *Parabolinella* sp. At the last level, *B. tetragonalis* is accompanied by *A. tibicen*, *P. clarisae*, *P. argentinensis*, *A. albae*, *A. stenorachis*, *G. nesossii*.

In all cases, these taxa are closely associated with specimens of *Bryograptus kjerulfi*.

At Finca Miraflores, the Biozone is represented by the guide species accompanied by *P. argentinensis*, *P. boliviana*, *A. exiguus* and *G. nesossii*. In very close upper strata, the species *B. kjerulfi* stands out.

Kainella teiichi **Biozone**

In Villa Floresta section, in the absence of guide fossils, the fauna reported in this work is *A. exiguus*, *P. argentinensis*, *B. cf.B. shinetonensis*, *Illaenopsis nov.* sp, *Niobina taurina, Hapalopleura nov.* sp. and *G. nesossii, A. rugosus, Conoprhys sulcata, Pseukainella keideli*. The last three taxa integrate this Biozone *sensu* Tortello and Esteban (2016), mentioning *Conophrys* just as a genus only. At nearby upper levels, *B. kjerulfi* was found.

Asaphellus nazarenensis **Biozone**

It was not recorded in this work. However, its presence is cited by Meroi Arcerito *et al.* (2018) for Santa Laura mountain pass on the cornice road to Jujuy province, eastern flank of Mojotoro range. The authors define this Biozone as an interval given by the first appearance of *A. nazarenensis* at the base and the first appearance of *Notopelthis orthometopa* at the top. Companion taxa are *Bienvillia rectifrons* (Harrington, 1938), *Parabolinella triarthroides* Harrington, 1938, *Mekynophrys nanna* (Harrington and Leanza, 1957), *Asaphellus jujuanus*, *Pyrimetopus pyrifrons* (Harrington and Leanza, 1957), *Apatokephalus exiguus* Harrington and Leanza, 1957, *A. tibicen* Přibyl and Vanek, 1980, *Ceratopyge forficuloides* Harrington and Leanza, 1957, *Conophrys* sp., and *Rossaspis* sp., among others.

Notopelthis orthometopa **Biozone**

It was not found for this work. However, Moya (1988, 1998) cites the presence of *Notoplethis orthometopa* and *P. argentinensis* in the area of Manjón hill (a place currently inaccessible because it is part of private property), where, according to the author, top levels of the Floresta Formation outcrop.

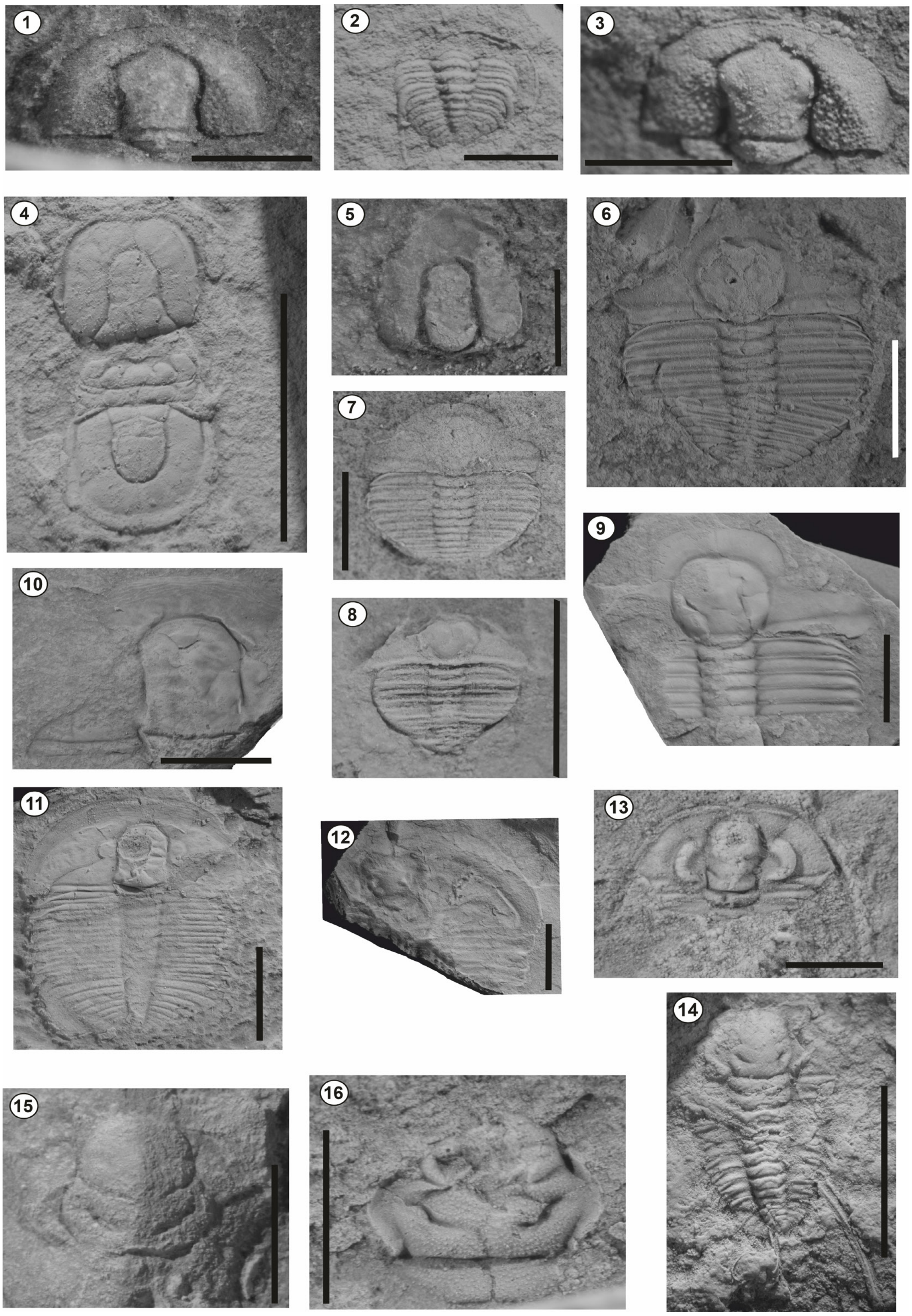

Figure 4. Villa Floresta Association. **1-3.** *Conoprhys sulcata* CNS- Pi 153/1, CNS-I 153/2, CNS- Pi 153/3. **4-5**. *Geragnostus nesossi* CNS- Pi 153/4, CNS- Pi 153/5. **6-9.** *Hapalopleura nov.* sp. CNS- Pi 153/6, CNS-Pi 153/7. **10-12.** *Niobina taurina* CNS- Pi 153/8, CNS-I 153/9. **13-14.** *Pseudokainella keideli* CNS- Pi 153/10, CNS- Pi 153/**11. 15**. *Apatokephallus exiguus* CNS- Pi 153/**12. 16**. *Apatokephallus rugosus* CNS-Pi 153/13. Scale bars equals 0,1 cm (1-3; 13), 0,2 cm (5; 15), 0,25 cm (7), 0,4 cm (6) and 0,5 cm (4; 8-12.).. / **Figura 4.** *Asociación de Villa Floresta.* 1-3. Conoprhys sulcata *CNS- Pi 153/1, CNS-I 153/2, CNS- Pi 153/3.* **4-5.** Geragnostus nesossi *CNS- Pi 153/4, CNS- Pi 153/5.* **6-9.** Hapalopleura nov. *sp. CNS- Pi 153/6, CNS- Pi 153/7.* **10-12.** Niobina taurina *CNS- Pi 153/8, CNS-I 153/9.* **13-14.** Pseudokainella keideli *CNS- Pi 153/10, CNS- Pi 153/11.* **15**. Apatokephallus exiguus *CNS- Pi 153/12.* **16**. Apatokephallus rugosus *CNS-Pi 153/13. Las escalas gráficas equivalen a 0,1 cm (1-3; 13); 0,2 cm (5; 15); 0,25 cm (7); 0,4 cm (6) y 0,5 cm (4; 8-12.)..*

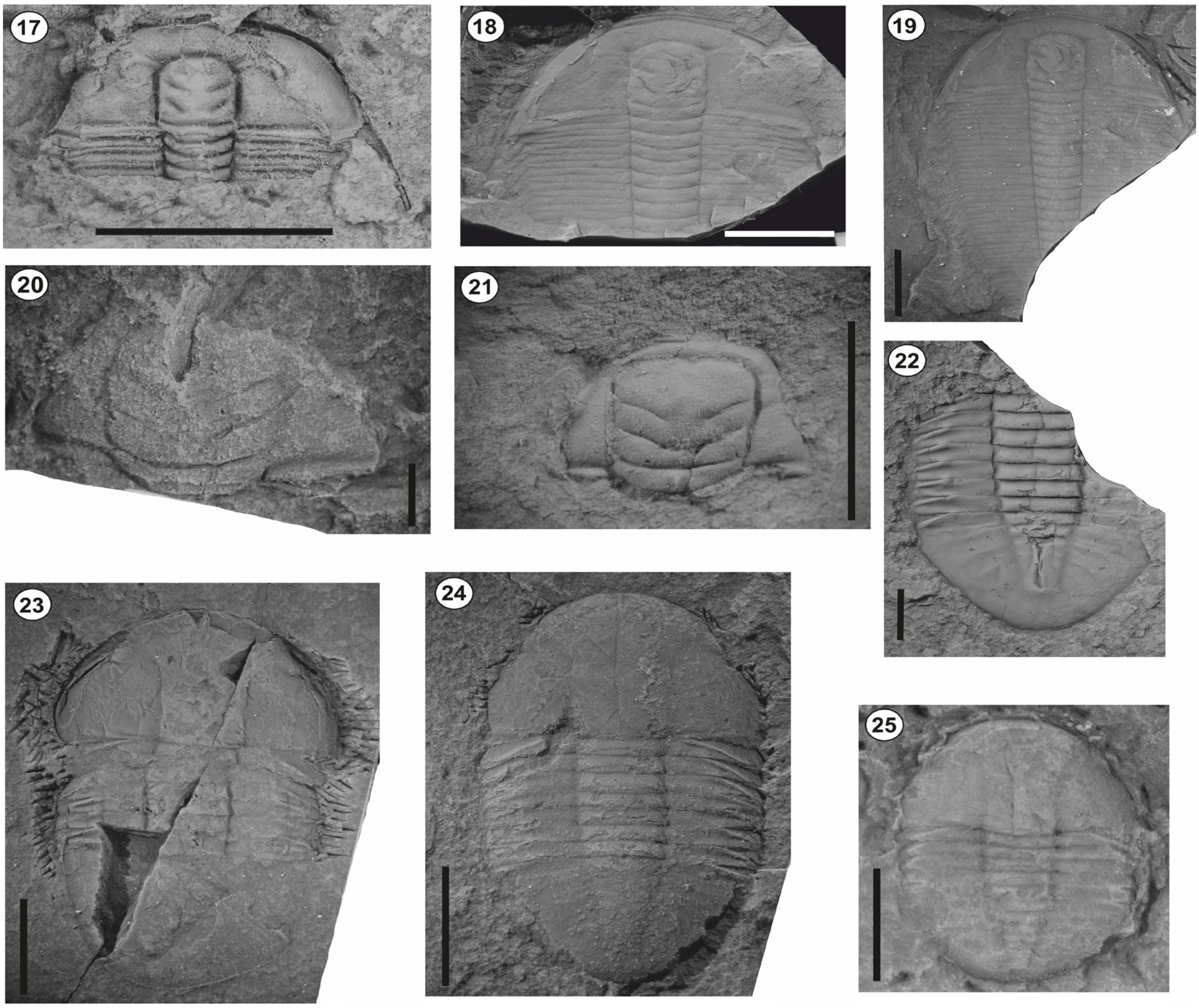

Figure 5. Villa Floresta Association. **17-19.** *Parabolinella argentinensis.* CNS- Pi 153/14, CNS- Pi 153/15. **20-21**. *Bienvillia* cf. *B. shinetonensis* CNS- Pi 153/16, CNS-I 153/17. **22-25**. *Illaenopsis nov.* sp. CNS- Pi 153/18, CNS- Pi 153/19, CNS- Pi 153/20, CNS- Pi 153/21. Scale bars equals 0,1 cm (20), 0,5 cm (14, 16-17, 21-22), 1 cm (18-19, 23-24). **/ Figura 5.** *Asociación de Villa Floresta.* 17-19. Parabolinella argentinensis. *CNS- Pi 153/14, CNS- Pi 153/15. 20-21.* Bienvillia cf. B. shinetonensis *CNS- Pi 153/16, CNS-I 153/17.* **22-25.** Illaenopsis nov. *sp. CNS- Pi 153/18, CNS- Pi 153/19, CNS- Pi 153/20, CNS- Pi 153/21. Las escalas gráficas equivalen a 0,1 cm (20); 0,5 cm (14;16-17; 21-22) y 1 cm (18-19; 23-24).*

Discussion and conclusions

Regarding *Kainella meridionalis* Biozone, Moya (1988) mentions the presence of shellstone with *Kainella meridionalis* in the basal levels of Floresta Formation. On the other hand, Aris (2005) and Aris and Malanca (2005) recognized these shellstones on a lateral road of Chachapoyas creek. The species recognized on that occasion were *K. meridionalis*, *L. marianus* (currently *L. argentinensis*), *Asaphellus catamarcensis* (Kobayashi, 1935), *Parakainella conica* (Kobayashi, 1935), *P. lata* (Kobayashi, 1935), *P. argentinensis* and *P. coelatifrons* Harrington and Leanza, 1957. Currently, the site where the outcrops were located constitutes private properties private properties to which access is not possible.

The fauna found in this work that belongs to *Kainella meridionalis* Biozone (Virgen del Cerro creek Association) is stratigraphically located above the mentioned shellstones, so it is a relict fauna of the original, transported and deposited due to the storms described before. As a consequence, the thickness involved in the bearing strata of this biozone is not limited only to the shellstone so it reaches a greater thickness.

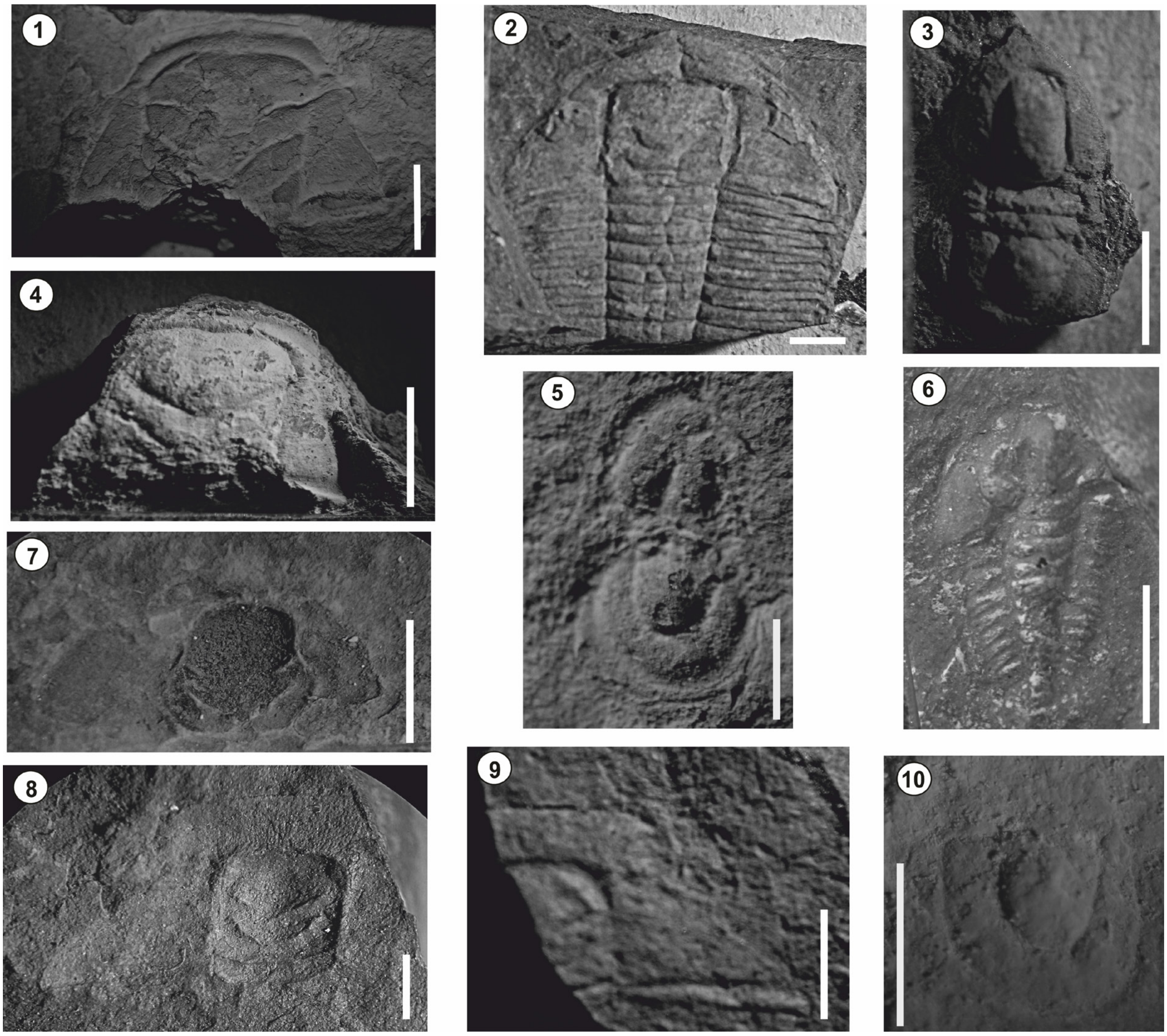

Figure 6. Finca Miraflores Association. **1 y 4.** *Bienvillia tetragonalis* CNS- Pi 152/166. *B. Parabolinella boliviana* CNS- Pi 152/165. **3, 5 y 10.** *Geragnostus nesossii* CNS- Pi 152/167, CNS- Pi 152/168, CNS-Pi 152/359 respectively. **6 y 7.** *Apatokephallus exiguus* CNS-Pi 152/183, CNS- Pi 152/189 respectively. **8 y 9.** *Parabolinella argentinensis* CNS- Pi 152/178, CNS- Pi 152/174 respectively. Scale bars equals 0,2 cm (3-8; 10); 0,3 cm (2;9) and 0,5 cm (1;4). **/ Figura 6.** *Asociacion de Finca Miraflores.* **1 y 4**. Bienvillia tetragonalis *CNS- Pi 152/166*. B. Parabolinella boliviana *CNS- Pi 152/165.* **3, 5 y 10.** Geragnostus nesossii *CNS- Pi 152/167, CNS- Pi 152/168, CNS-Pi 152/359 respectivamente.* **6 y 7**. Apatokephallus exiguus *CNS-Pi 152/183, CNS- Pi 152/189 respectivamente.* **8 y 9**. Parabolinella argentinensis *CNS- Pi 152/178, CNS- Pi 152/174 respectivamente. Las escalas gráficas equivalen a 0,2 cm (3-8;10); 0,3 cm (2; 9) y 0,5 cm (1; 4).*

On the other hand, Vaccari *et al.* (2010) mention the presence of this Biozone for Arenal creek (stratotype), Colorada creek, and Bocoyá and La Caldera rivers. So, the discovery of *Kainella meridionalis* biozone in Virgen del Cerro creek constitutes a new section where is recorded.

Considering Arenal creek and according to Vaccari *et al.* (2010) *Kainella meridionalis* Biozone is situated in the high part of Alfarcito Member and the lower part of Rupasca member; both of Santa Rosita Formation. In adittion, the authors referrs to Buatois *et al.* (2006) to interpret the deposition environment saying that these levels corresponds to a low to medium shoreface. Therefore, in this work, we are in conditions to assert that the levels of Floresta Formation where *Kainella meridionalis* Biozone was rescued, are correlable with both Members of Santa Rosita Formation not only for the coincidence in the age but also because of the paleoenvironment is the same in general. Torte-

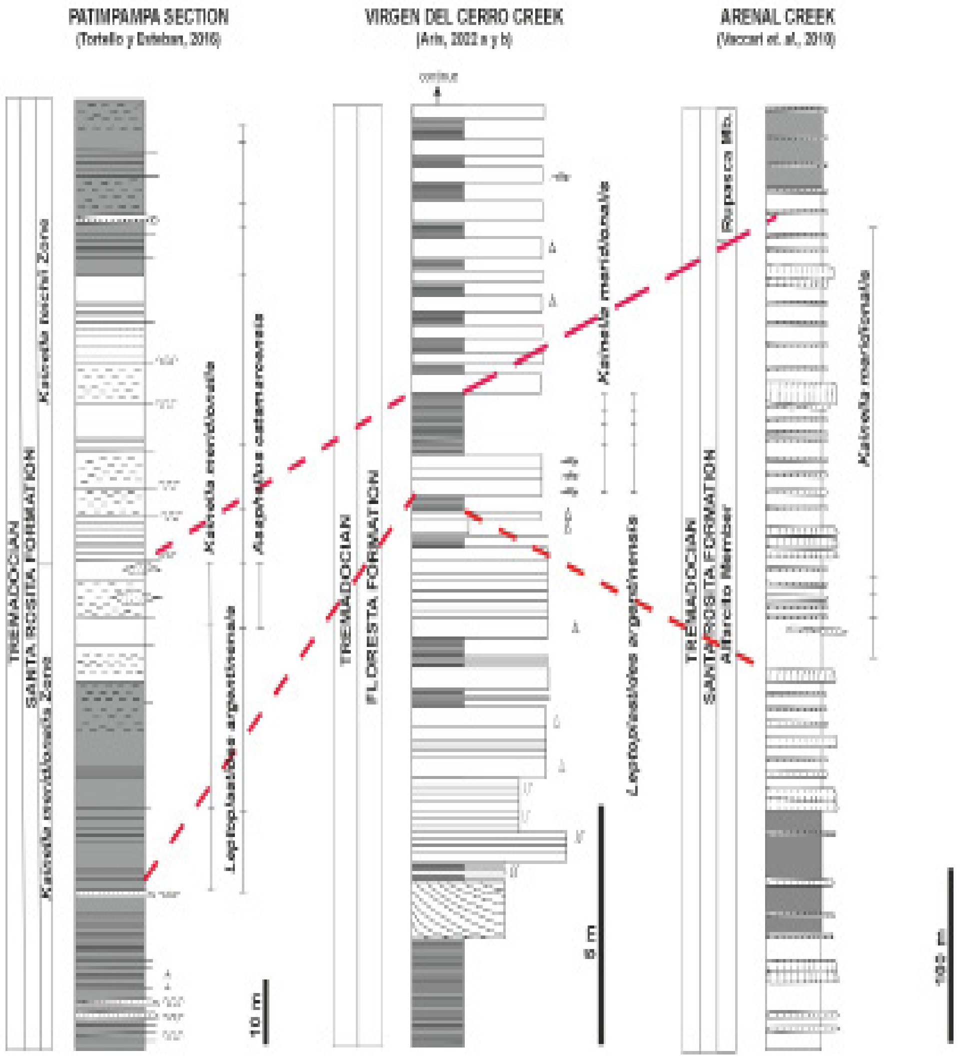

Figure 7. Correlation scheme **1.** Correlation of the *Kainella meridionalis* Biozone of the Floresta Formation with the Members of the Santa Rosita Formation, Patipampa section and Arenal creek. 2-3. Correlation of the *Bienvillia tetragonalis* Biozone of the Floresta Formation with the middle-upper part of the Rupasca Member of the Santa Rosita Formation, areas of the Arenal creek, Humacha creek, Iturbe and Iruya zone.4. References columnar profiles. **/ Figura 7.** *Esquemas de correlación. 1. Correlación de la Biozona de* Kainella meridionalis *de la Formación Floresta con los Miembros de la Formación Santa Rosita, sección Patipampa y quebrada del Arenal. 2-3. Correlación de la Biozona de* Bienvillia tetragonalis *de la Formación Floresta con la parte media alta del Miembro Rupasca de la Formación Santa Rosita, zonas de quebrada del Arenal, quebrada de Humacha, zona de Iturbe y de Iruya. / 4. Referencias de los perfiles columnares.*

llo and Esteban (2016) conducted a study in the Iruya Area (Patimpampa section) where they found *Kainella meridionalis* Biozone in the lower part of Santa Rosita Formation, Patimpampa section (see correlation scheme 7.1). Tortello and Aceñolaza (2010) also found this Biozone in Abra de Zenta (Jujuy) from levels whose age is corroborated with acritarchs (Aráoz, 2009). So, this part of Floresta Formation is also correlable with these units for both localities too.

Regarding the possible presence of the *Kainella teiichi* Biozone rescued from Villa Floresta, Tortello and Esteban (2016) mention the presence of *A. rugosus* and *Pseudokainella keideli* and *Conprhys* sp. as companions of the guide species, so *a priori* it could be presumed that this association belongs to this Biozone. However, and despite the fact that the presence of *B. kje-*

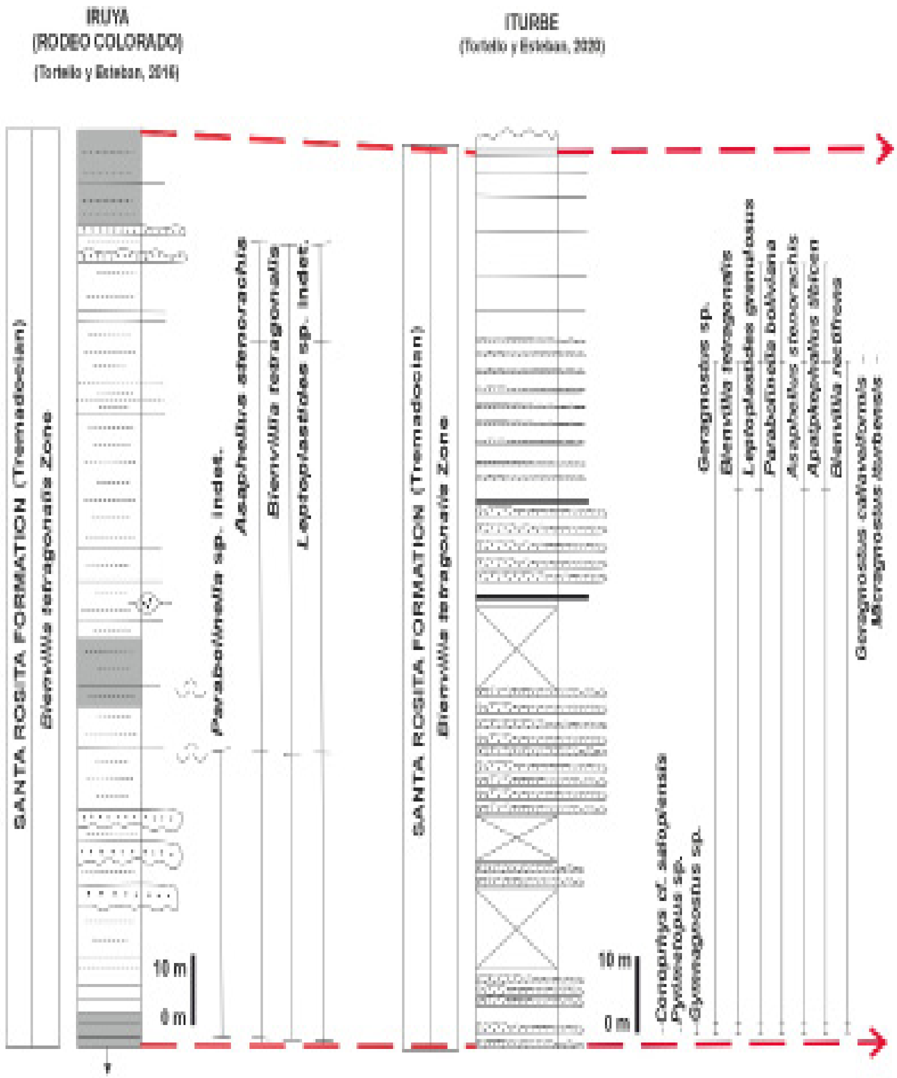

Figure 7. Correlation scheme **1.** Correlation of the *Kainella meridionalis* Biozone of the Floresta Formation with the Members of the Santa Rosita Formation, Patipampa section and Arenal creek. 2-3. Correlation of the *Bienvillia tetragonalis* Biozone of the Floresta Formation with the middle-upper part of the Rupasca Member of the Santa Rosita Formation, areas of the Arenal creek, Humacha creek, Iturbe and Iruya zone.4. References columnar profiles. **/ Figura 7.** *Esquemas de correlación. 1. Correlación de la Biozona de* Kainella meridionalis *de la Formación Floresta con los Miembros de la Formación Santa Rosita, sección Patipampa y quebrada del Arenal. 2-3. Correlación de la Biozona de* Bienvillia tetragonalis *de la Formación Floresta con la parte media alta del Miembro Rupasca de la Formación Santa Rosita, zonas de quebrada del Arenal, quebrada de Humacha, zona de Iturbe y de Iruya. / 4. Referencias de los perfiles columnares.*

rulfi in immediately higher strata could contribute to support the assignment, this assertion is not made preventively. Anyway, it is clear that the Association belongs to Tr2. Taking into account that we are not sure of this association corresponds to *Kainella teiichi* Biozone, we do not make any correlation with other units of the Eastern Cordillera where this biostratigraphic unit is recorded.

Considering the *Bienvillia tetragonalis* Biozone, Meroi Arcerito *et al.* (2018) mention the following species as companions of the guide fossil: *Leptoplastides granulosus* (Harrington, 1938); *Parabolinella clarisae; Peltocare norvegicum* (Henningsmoen, 1957), *Pseudokainella keideli*; *Asapellus stenorhachis*; *Apatokephalus rugosus*; *Apatokephalus tibicen*, *Conoprhys* sp. and *Pharostomina* sp. Tortello and Esteban (2020) cite the

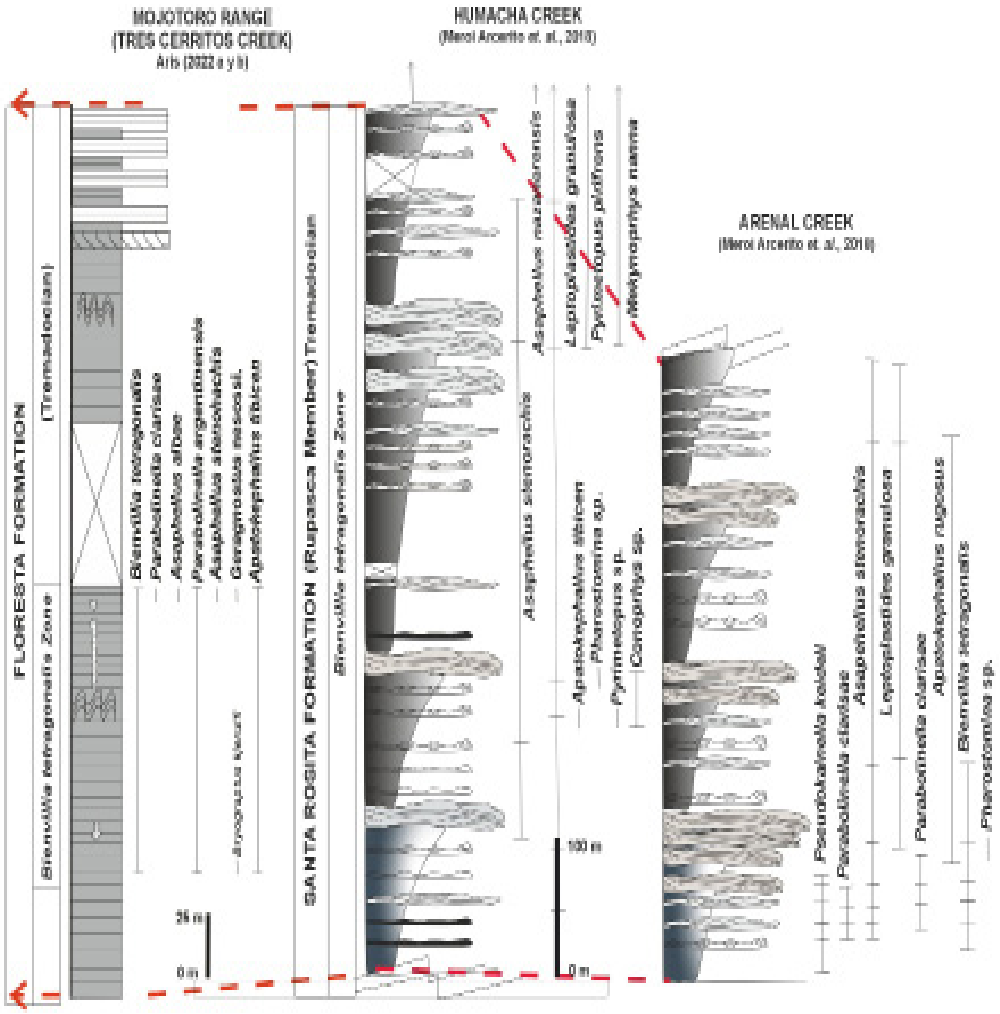

Figure 7. Correlation scheme **1.** Correlation of the *Kainella meridionalis* Biozone of the Floresta Formation with the Members of the Santa Rosita Formation, Patipampa section and Arenal creek. 2-3. Correlation of the *Bienvillia tetragonalis* Biozone of the Floresta Formation with the middle-upper part of the Rupasca Member of the Santa Rosita Formation, areas of the Arenal creek, Humacha creek, Iturbe and Iruya zone.4. References columnar profiles. **/ Figura 7.** *Esquemas de correlación. 1. Correlación de la Biozona de* Kainella meridionalis *de la Formación Floresta con los Miembros de la Formación Santa Rosita, sección Patipampa y quebrada del Arenal. 2-3. Correlación de la Biozona de* Bienvillia tetragonalis *de la Formación Floresta con la parte media alta del Miembro Rupasca de la Formación Santa Rosita, zonas de quebrada del Arenal, quebrada de Humacha, zona de Iturbe y de Iruya. / 4. Referencias de los perfiles columnares.*

presence of the guide species associated with *Gymnagnostus* sp., *Micragnostus iturbensis* Tortello and Esteban, 2020; *Geragnostus callaveiformis* Harrington and Leanza, 1957; *Geragnostus* sp., *Conophrys* cf. *salopiensis* (Callaway, 1877), *Leptoplastides granulosus* (Harrington, 1938), *B. rectifrons* (Harrington, 1938), *Parabolinella boliviana*, *Asapellus stenorhachis*, *Apatokephalus tibicen* and *Pyrimetopus* sp.

It is noteworthy that for the two sections of Floresta Formation where *Bienvillia tetragonalis* Biozone was recognized (Tres Cerritos creek Association and Finca Miraflores Association), the accompanying fauna of the guide fossil partially differs from each other. However, these are temporally equivalent levels, and the difference is probably due to environmental conditions with some degree of variability or a sampling artifact.

On the other hand, some of the species cited by Meroi Arcerito *et al.* (2018) and Tortello and Esteban (2020), are present in Floresta Formation, while others are absent. Therefore, taxa

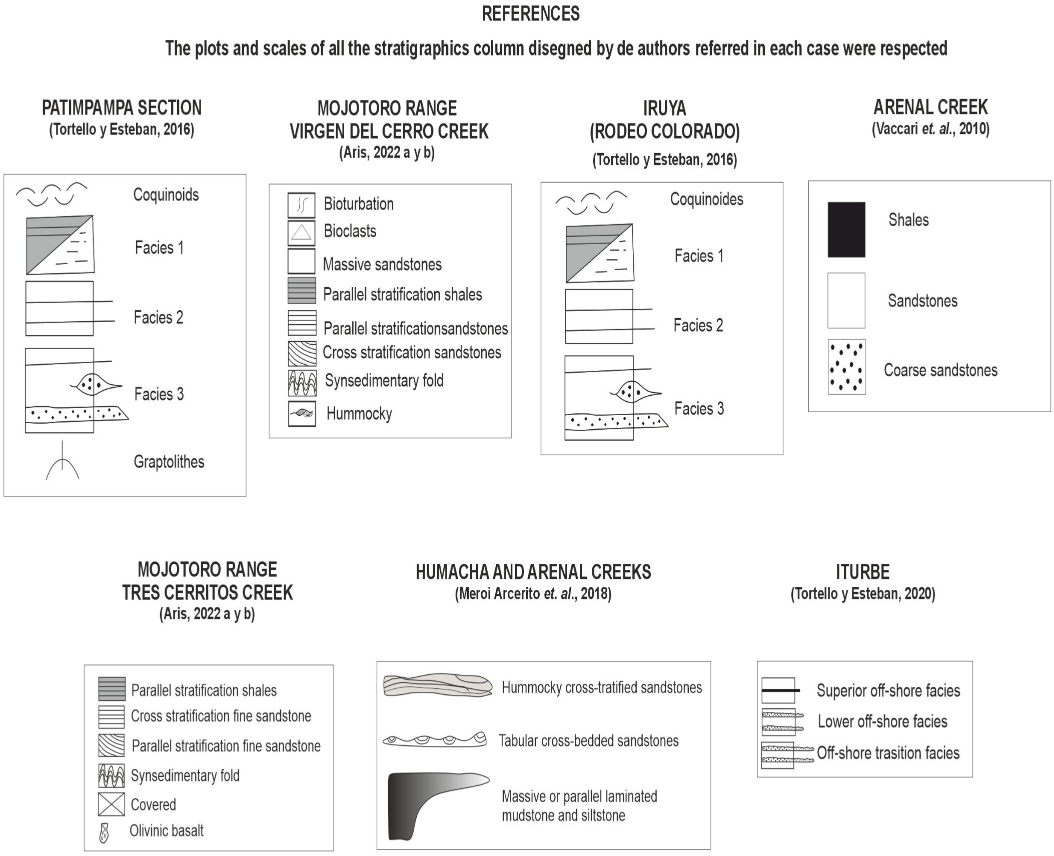

Figure 7. Correlation scheme **1.** Correlation of the *Kainella meridionalis* Biozone of the Floresta Formation with the Members of the Santa Rosita Formation, Patipampa section and Arenal creek. 2-3. Correlation of the *Bienvillia tetragonalis* Biozone of the Floresta Formation with the middle-upper part of the Rupasca Member of the Santa Rosita Formation, areas of the Arenal creek, Humacha creek, Iturbe and Iruya zone.4. References columnar profiles. **/ Figura 7.** *Esquemas de correlación. 1. Correlación de la Biozona de* Kainella meridionalis *de la Formación Floresta con los Miembros de la Formación Santa Rosita, sección Patipampa y quebrada del Arenal. 2-3. Correlación de la Biozona de* Bienvillia tetragonalis *de la Formación Floresta con la parte media alta del Miembro Rupasca de la Formación Santa Rosita, zonas de quebrada del Arenal, quebrada de Humacha, zona de Iturbe y de Iruya. / 4. Referencias de los perfiles columnares.*

not cited to the date are added to this association and reported for Floresta Formation: *A. albae, G. nesossii, P. boliviana* and *P. clarisae*. It is interesting the presence of *A. albae* in the Tres Cerritos creek Association. According to Meroi Arcerito *et al.* (op. cit.), the species is cited as a companion to *Notopelthis orthometopa* for the eponymous biozone. However, its finding in levels belonging to the *Bienvillia tetragonalis* Biozone suggests that the species is older than previously known; understanding therefore that the beginning of its record is in this Biozone.

Considering the spatial distribution of *Bienvillia tetragonalis* Biozone, Tortello and Esteban (2020) made a synthesis of the localities where it has been recognized: Alfarcito area, Nazareno region, north of Iruya, Huacalera area and Santa Bárbara range. Therefore, its identification in the Mojotoro range constitutes a new locality where this biostratigraphic unit is registered.

In this case, and from a paleoenvironmental point of view, *Bienvillia tetragonalis* Biozone in Floresta Formation was deposited in a distal shoreface marine environment approaching the off–shore transition. This interpretation coincides in general with what was specified for this biozone by Meroi Arcerito *et al.* (2018) for the middle and upper part of Rupasca Member of Santa Rosita Formation in Arenal creek (Jujuy), Humacha creek, Angosto de Chucalezna, and Nazareno river. Tortello and Esteban (2020) identified this Biozone in Santa Rosita Formation in Iturbe zone, Humahuaca creek (Jujuy) and Tortello and Esteban (2016) arrived at the same conclusions for Iruya area in Salta province. In this sense, this part of Floresta Formation is correable with the units referred by the above mentioned authors (see correlation scheme 7.2 and 7.3).

As we said before, *Asapehllus nazanerensis* Biozone was not found in this work but is mentioned by Meroi Arcerito *et al.* (2018). In addition, the authors enumerate the presence of this Biozone for upper part of Rupasca Member of Santa Rosita Formation in Humacha creek (stratotype), Santa Rosita Formation in Nazareno river (unnamed biozone by Tortello and Esteban, 2014) and lower part of upper part of Coquena Formation in Purmamarca. So, the levels of Floresta Formation where this Biozone came from are correlable with the lithostratigraphic units detailed above.

In this work, we questioned about whether *Notopelthis ortomethopa* Biozone belongs to Floresta Formation or to Áspero Formation that overlies the first one. This doubt arises because this Biozone is also cited by Moya (1988, 1998) for the basal levels of Áspero Formation. Considering that the stratigraphic relation between both units is transitional (Moya, 1998; Aris, 2022), it is probably that what Moya (op. cit.) recognized as cuspidal levels of Floresta Formation in Manjón Hill in fact could belong to basal levels of Áspero Formation.

Finally, based on the analysis made here, and considering the current biostratigraphic scheme for the Tremadocian based on trilobites, we can affirm that Floresta Formation was deposited between the ends of Tr1 and a big part of Tr2.

Acnowlegments

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Tables

TABLE 1. TRILOBITE SPECIES FOUND IN THE 4 LOCALITIES

Species	Localities	Biozone	Material examined
Kainella meridionalis Harrington, 1938	Virgen del Cerro creek	***Kainella meridionalis*** Biozone	6 pygidia, 1 cranidium, 1 librigena
Pseudokainella keideli Harrington, 1938	Villa Floresta	***Kainella teichii?*** Biozone	2 almost complete specimens, 1 cephalothorax, 1 cranidium, 2 glabellae
Apatokephalus rugosus Tortello y Esteban, 2016	Villa Floresta	***Kainella teichii?*** Biozone	2 glabellae and 1 pygidium
Apatokephallus exiguus Harrington y Leanza, 1957	Virgen del Cerro creek. Villa Floresta. Finca Miraflores	***Kainella teichii***? Biozone ***Bienvillia tetragonalis*** Biozone	several cranidia and glabellae. 2 complete specimens
Apatokephallus tibicen Přibyl y Vaněk, 1980	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	3 glabellae and 1 pygidium
Asaphellus albae Meroi Arcerito, Waisfeld, Vaccari y Muñoz, 2018	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (complete specimens, pygidia and cranidia).
Asaphellus stenorachis Meroi Arcerito, Waisfeld, Vaccari y Muñoz, 2018	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	1 pygidium
Niobina taurina Harrington y Leanza, 1957	Villa Floresta	***Kainella teichii***? Biozone	2 almost complete specimens, 2 almost complete cephalothorax, 1 cranidium, 2 incomplete pygidia, 1 hypostome.
Leptoplastides argentinensis Kobayashi, 1935	Virgen del Cerro creek	***Kainella meridionalis*** Biozone	Numerous specimens (librigenae and cranidia).
Bienvillia tetragonalis Harrington, 1938	Tres Cerritos creek. Finca Miraflores	***Bienvillia tetragonalis*** Biozone	About twenty cranidia
Bienvillia cf. B. shinetonensis Raw, 1908	Villa Floresta	***Kainella teichii***? Biozone	2 cranidia and an almost complete thoracopygidium

Parabolinella argentinensis Harrington, 1938	Tres Cerritos creek Villa Floresta	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia, cephalothorax)
Parabolinella pompadorius Monti, 2015	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia,)
Parabolinella clarisae Monti, 2015	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia, cephalothorax)
Conophrys sulcata Malanca, 1996	Villa Floresta	***Kainella teichii*?** Biozone	Large number of complete specimens, cephalons and pygidia
Geragnostus nesossii Harrington y Leanza, 1957	Tres Cerritos creek. Villa Floresta	***Bienvillia tetragonalis*** Biozone ***Kainella teichii?*** Biozone	Numerous specimens (complete specimens, pygidia and cephalon)
Gymnagnothus sp.	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	3 complete specimens
Hapalopleura sp.	Villa Floresta	***Kainella teichii*?** Biozone	
Kainella meridionalis Harrington, 1938	Virgen del Cerro creek	***Kainella meridionalis*** Biozone	6 pygidia, 1 cranidium, 1 librigena
Pseudokainella keideli Harrington, 1938	Villa Floresta	***Kainella teichii*?** Biozone	2 almost complete specimens, 1 cephalothorax, 1 cranidium, 2 glabellae
Apatokephalus rugosus Tortello y Esteban, 2016	Villa Floresta	***Kainella teichii*?** Biozone	2 glabella and 1 pygidium
Apatokephallus exiguus Harrington y Leanza, 1957	Virgen del Cerro creek. Villa Floresta. Finca Miraflores	***Kainella teichii*?** Biozone ***Bienvillia tetragonalis*** Biozone	several cranidia and glabella. 2 complete specimens
Apatokephallus tibicen Přibyl y Vaněk, 1980	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	3 glabellae and 1 pygidium
Asaphellus albae Meroi Arcerito, Waisfeld, Vaccari y Muñoz, 2018	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (complete specimens, pygidia and cranidia)
Asaphellus stenorachis Meroi Arcerito, Waisfeld, Vaccari y Muñoz, 2018	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	1 pygidium

Niobina taurina Harrington y Leanza, 1957	Villa Floresta	***Kainella teichii*?** Biozone	2 almost complete specimens, 2 almost complete cephalothorax, 1 cranidium, 2 incomplete pygidia, 1 hypostome
Leptoplastides argentinensis Kobayashi, 1935	Virgen del Cerro creek	***Kainella meridionalis*** Biozone	Numerous specimens (librigenae and cranidia)
Bienvillia tetragonalis Harrington, 1938	Tres Cerritos creek. Finca Miraflores.	***Bienvillia tetragonalis*** Biozone	About twenty cranidia
Bienvillia cf. B. shinetonensis Raw, 1908	Villa Floresta	***Kainella teichii*?** Biozone	2 cranidia and 1 almost complete thoracopygidium
Parabolinella argentinensis Harrington, 1938	Tres Cerritos creek Villa Floresta	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia, cephalothorax)
Parabolinella boliviana Juarez Haurachi, 2010	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia)
Parabolinella clarisae Monti, 2015	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalons, cranidia, cephalothorax)
Conophrys sulcata Malanca, 1996	Villa Floresta	***Kainella teichii*?** Biozone	Large number of complete specimens, cephalon and pygidia
Geragnostus nesossii Harrington y Leanza, 1957	Tres Cerritos creek. Villa Floresta	***Bienvillia tetragonalis*** Biozone ***Kainella teichii*?** Biozone	Numerous specimens (complete specimens, pygidia and cephalon)
Gymnagnothus sp.	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	3 complete specimens
Hapalopleura sp.	Villa Floresta	***Kainella teichii*?** Biozone	
Kainella meridionalis Harrington, 1938	Virgen del Cerro creek	***Kainella meridionalis*** Biozone	6 pygidia, 1 cranidium, 1 librigena
Pseudokainella keideli Harrington, 1938	Villa Floresta	***Kainella teichii*?** Biozone	2 almost complete specimens, 1 cephalothorax, 1 cranidium, 2 glabellae
Apatokephalus rugosus Tortello y Esteban, 2016	Villa Floresta	***Kainella teichii*?** Biozone	2 glabellae and 1 pygidium

Apatokephallus exiguus Harrington y Leanza, 1957	Virgen del Cerro creek. Villa Floresta. Finca Miraflores	***Kainella teichii***? Biozone ***Bienvillia tetragonalis*** Biozone	several cranidia and glabellae. 2 complete specimens
Apatokephallus tibicen Přibyl y Vaněk, 1980	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	3 glabella, 1 pygidium
Asaphellus albae Meroi Arcerito, Waisfeld, Vaccari y Muñoz, 2018	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (complete specimens, pygidia and cranidia)
Asaphellus stenorachis Meroi Arcerito, Waisfeld, Vaccari y Muñoz, 2018	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	1 pygidium
Niobina taurina Harrington y Leanza, 1957	Villa Floresta	***Kainella teichii***? Biozone	2 almost complete specimens, 2 almost complete cephalothorax, 1 cranidium, 2 incomplete pygidia, 1 hypostome
Leptoplastides argentinensis Kobayashi, 1935	Virgen del Cerro creek	***Kainella meridionalis*** Biozone	Numerous specimens (librigenae and cranidia)
Bienvillia tetragonalis Harrington, 1938	Tres Cerritos creek. Finca Miraflores	***Bienvillia tetragonalis*** Biozone	About twenty cranidia
Bienvillia cf. B. shinetonensis Raw, 1908	Villa Floresta	***Kainella teichii***? Biozone	2 cranidia and an almost complete thoracopygidium
Parabolinella argentinensis Harrington, 1938	Tres Cerritos creek Villa Floresta	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalons, cranidia, cephalothorax)
Parabolinella pompadorius Monti, 2015	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia
Parabolinella clarisae Monti, 2015	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	Numerous specimens (cephalon, cranidia, cephalothorax)
Conophrys sulcata Malanca, 1996	Villa Floresta	***Kainella teichii***? Biozone	Large number of complete specimens, cephalons and pygidia
Geragnostus nesossii Harrington y Leanza, 1957	Tres Cerritos creek. Villa Floresta	***Bienvillia tetragonalis*** Biozone Biozone ***Kainella teichii***?	Numerous specimens (complete specimens, pygidia and cephalon)
Gymnagnothus sp.	Tres Cerritos creek	***Bienvillia tetragonalis*** Biozone	3 complete specimens