STRATIGRAPHY AND BRACHIOPOD FAUNA OF THE CARBONIFEROUS EL IMÁN FORMATION, COLOMBIA

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ABSTRACT

The three main outcrops of the El Imán Formation (Departamento de Tolima, central western Colombia) are fully described and revised. The study of a newly collected brachiopod fauna from the upper outcrop of the El Imán Formation, indicates a Carboniferous age (late Bashkirian-Moscovian) for the upper part of the El Imán Formation at the type locality. Although the fauna is not abundant, has low diversity, and is poorly preserved, the Bashkirian-Moscovian age is deduced from the association of the brachiopod genera *Fimbrinia* (Productida), *Orthotichia* (Orthida) and *Alispirifer* (Spiriferida). These occurrences affirm zoogeographic relationships between Australia and South America during the Late Carboniferous.

Keywords: Brachiopods, biostratigraphy, Carboniferous, El Imán Formation, Colombia.

RESUMEN

Se describe la sucesión litoestratigráfica de los tres afloramientos más importantes de la Formación El Imán (Departamento Tolima, centro oeste de Colombia) y se revisa dicha formación. La fauna de braquiópodos que se describe aquí por primera vez es indicadora de una edad Carbonífero (Bashkiriense-Moscoviense) para la parte superior de la Formación El Imán. Aunque la fauna sea poco diversa, escasa y mal conservada, la edad Bashkiriense tardio-Moscoviense se deduce de la asociación de los generos *Fimbrinia* (Productida), *Orthotichia* (Orthida) y *Alispirifer* (Spiriferida). Estos braquiópodos indican relaciones zoogeográficas entre Australia y America del Sur durante el Carbonífero tardio.

Palabras clave: Braquiópodos, bioestratigrafía, Carbonífero, Formación El Imán, Colombia.

INTRODUCTION

Globally speaking, the most important studies on the Palaeozoic of Colombia were done during the 1960-70's with papers dealing with lithology, chronostratigraphy and biostratigraphy of most of the rocks assigned to the Paleozoic. However, progress in more regional geologic studies, within a dynamic context, marked the importance of multidisciplinary studies. The present work takes place in such a perspective.

Carboniferous strata in Colombia are distributed as isolated outcrops, often as structural wedges, associated with the main igno-metamorphic massifs of the Oriental Cordillera (Villarroel and Mojica, 1987). Successions are always incomplete and restricted geographically. Outside this geologic context, localities exposing Carboniferous

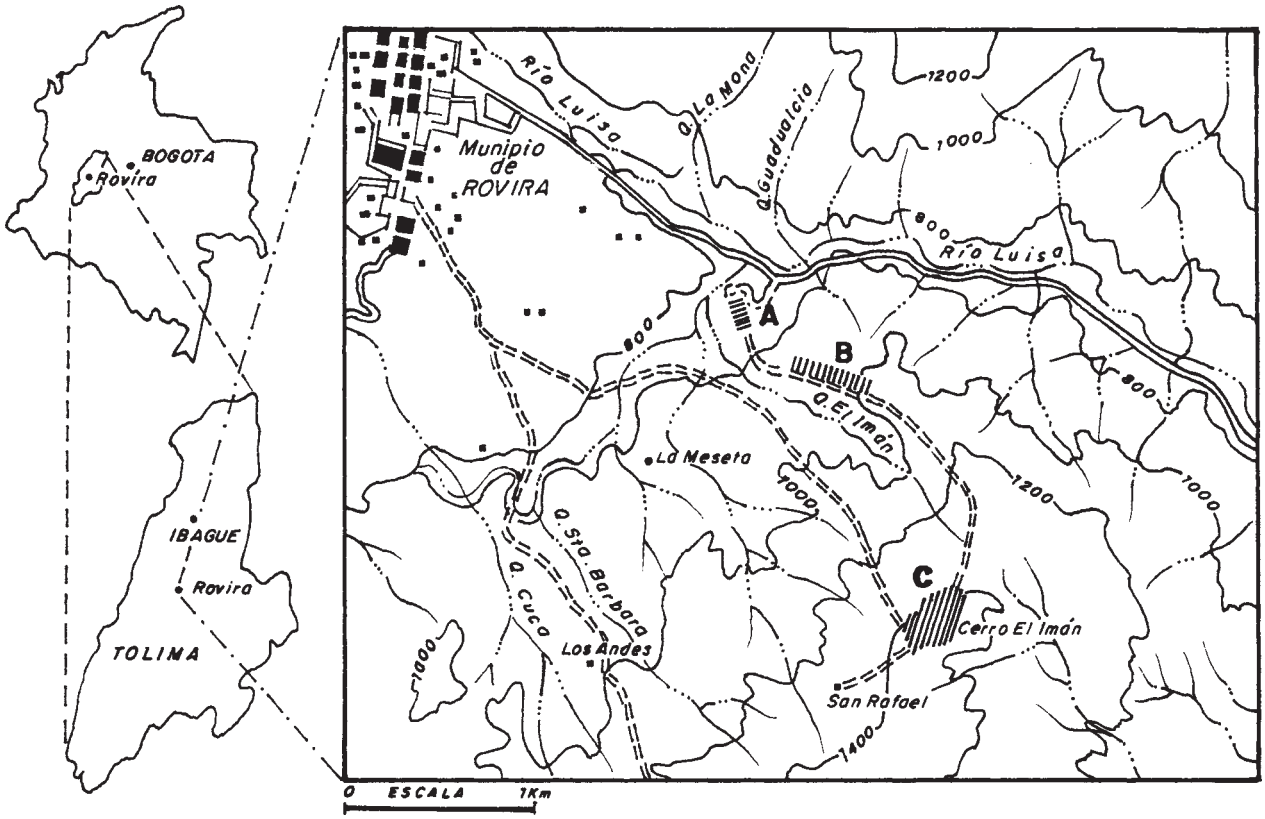

Figure 1. Localisation map of the Carboniferous metasediments of Rovira. A: Lower outcrop; B: Middle outcrop; C: Upper outcrop of the Cerro El Imán which yields the brachiopod-bearing beds.

sequences are rare; among these are the rocks of the Cerro El Imán (Rovira) and the succession of the Serranía de Las Minas, both located on the oriental side of the Central Cordillera.

Since their discovery, the metasediments of the Cerro El Imán were successively assigned to the Middle-Upper Devonian (Forero, 1970, p. 142), then to the Upper Devonian (Frasnian-Famennian; Forero, 1986; 1991, p. 109), or to the Devonian without further precision (Barrett, 1988, p. 708). A Late Carboniferous age (Bashkirian-Moscovian), is proposed herein for the first time on the basis of brachiopods.

LITHOLOGY AND STRATIGRAPHY OF THE EL IMÁN FORMATION

by Carlos Villarroel and Ana Elena Concha

Type locality

According to Nuñez *et al*. (1984), the El Imán Formation, which yields the fauna described below, was initially proposed by Nuñez and Murillo (1982), in an unpublished Report of Ingeominas (n° 1879), to designate «□... una secuencia sedimentaria, que aflora en el cerro El Imán y las quebradas El Imán, San Rafael y Bolaños, en la región NE de la plancha 263.□» The type locality of this lithologic unit, as clearly established by the authors, includes El Imán hill and El Imán ravine, situated 4.2 km SE of Rovira (Fig. 1). Rovira is a small town located in the central part of Tolima department, 22 km south of Ibagué City. The geographic coordinates of the El Imán hill are 4°, 14', 43" N, and 75°, 16' 25" W.

Lithostratigraphy of the El Imán Formation at the type locality

Most Paleozoic outcrops of Colombia occur as isolated tectonic wedges and/or are affected by intrusive igneous rocks which make reconstruction of the Paleozoic sequence difficult. Rocks of the El Imán Formation have been dislocated by an intrusive igneous massif, and they were weakly affected by metamorphism. Moreover they lie as small isolated blocks backed onto the intrusive massif without any apparent order. Such conditions preclude the reconstruction of the original Carboniferous succession.

From bottom to top, Forero (1970) recognized three units within the rocks outcropping on El Imán hill, namely: «□a) Areniscas cuarcíticas y conglomerados□», about 70 m thick; «□b) Shales negros fosilíferos□», 30 m thick, yielding bryozoan remains and poorly preserved brachiopods, and «□c) Areniscas y arcillolitas fosilíferas□».

Along the mule track which climbs up the NW side of El Imán hill, rocks assigned to the El Imán Fm. outcrop discontinuously as metasedimentary fragments. According to their lithology and relative position, three units can be distinguished. These isolated small outcrops are backed up to the «□Stock Granítico del Sur de Rovira□» which is mainly a granodiorite with quartzo-monzonitic to granitic differentiations (Nuñez *et al*., 1984). Following other authors, we consider herein that the three units recognized are parts of the same El Imán Formation.

From their relative superposition it is logical that the unit which outcrops at the top of El Imán hill would be stratigraphically above the two other units. However, it cannot yet be established whether the three units belong to the same continuous succession, or if they are only isolated parts from distinct levels within the original succession. Similarly, the respective position of each of the three units in the lithologic column of the El Imán Formation remains uncertain because the lower and upper limits of the formation are still unknown.

Fracturing is so intense within the two lower units that stratification can be only locally observed, and when strike and dip can be measured, they strongly vary, and no reliable thickness can be established. The upper unit which outcrops at the top of El Imán hill, and which yields the brachiopod fauna described below, is less tectonically affected and it shows a weak plunge towards the NW. However, metamorphism and weathering have developed enough to cancel original lithology and stratification as well.

Lithologic identification of the three units is difficult, using only a standard binocular microscope (x 10). Indeed, original sediments have been weakly metamorphosed and this fact implies the use of the prefixe meta- for the identified rocks, as well as the use of a petrographic microscope.

Two thin sections of the grey-blue lower unit, which outcrops on the NW side of El Imán hill (Fig. 1), corresponding to interbedded beds have been studied. The DR-1 thin section exhibits a meta-arenite with discontinuous intercalated calc-schist levels. Fine, well-sorted, angular to subrounded quartz grains, represent 65%; their sphericity index is low. The clayey matrix, partly sericitized, represents about 15% of the whole rock; the remaining 15% are composed of micaceous-carbonate material and muscovite, the last 5% being represented by accessory minerals including iron oxydes, zircon, sphene and opaque minerals.

The second thin section (DR-2) also corresponds to a meta-arenite in which small, well-sorted, subangular to subrounded, quartz grains have a low sphericity index. They represent about 85% of the rock, while sericite, resulting from metamorphism of the original clayey matrix, does not exceed 7%. Similarly, percentages of clayey-carbonates and accessory minerals (pyrite, hematite, sphene, zircons, and secondary quartz veins) decrease from 5% to 3% respectively. In both thin sections (DR-1 and DR-2), quartz grains are arranged in small isolated groups within the metamorphosed clayey matrix. Limits between grains appear like elongate sutures, with triple points, indicative of weakly dynamic metamorphism. The existence of a previous regional metamorphism cannot be established.

Three thin sections of the middle unit have been studied. Thin section DR-3 is a poorly-sorted, coarse-grained to conglomeratic meta-arenite. Rounded quartz grains represent 90% of the whole rock, of which 85% are monocristalline, while the remaining 15% are polycristalline. This suggests the occurrence of quartzitic rocks in the source area. Such a source area may have been part of the Central Cordillera which actually includes Precambrian cores with similar rocks. Scattered sericite grains, derived from the metamorphosed original clayey matrix do not exceed 9%, while the remaining 1% is composed of volcanic fragments. The average size of quartz grains is about 1.5 mm, though some grains may reach 4 mm.

The two other thin sections of the middle unit (DR-4 and DR-5) show that the conglomeratic meta-arenites are associated with weakly laminated clayey calc-schist. Meta-clay include 85% to 90% sericite and illite; the remaining 10% to 15% are composed of half biotite and half quartz grains. The size of quartz grains is intermediate between mud and clay. Sericite exhibits two perpendicular schistosity directions.

The yellowish and reddish metasediments outcropping at the top of El Imán hill are those which yield the best preserved fossils. Petrologic analysis of thin section DR-6 shows that it is a meta-clay in which sericite represents 70%, and very thin quartz grains 23%. Muscovite and plagioclase represent 2% respectively, the remaining 3% being opaque minerals (iron oxydes). Like in the similar metasediments of the middle unit, sericite exhibits two perpendicular schistosity directions, and some quartz grains are fractured. These two last characters indicate weak dynamic metamorphism.

Age and correlations

Metamorphism of the El Imán Formation makes comparison with other Carboniferous sedimentary units of Colombia difficult. An exception may be the so-called «Grupo Chundua» which outcrops in the Sierra Nevada de Santa Martha, also weakly affected by metamorphism (Julivert, 1968, p. 259). However, the uppermost part of the Chundua Group yields limestones and marbles suggesting that this unit may be younger, as limestones are more commonly developed in upper Carboniferous and Permian strata in the area.

According to the fact that the Amoyá Formation ([first described by Nuñez *et al*., 1984, E of Rovira] and assigned to the Middle Devonian according to palynology [Prossl

and Gossler, 1995]), and the El Imán Formation were deposited contemporaneously (the age of the El Imán Fm was earlier assigned to the Middle and Upper Devonian), Prossl and Grosser proposed (1995, p. 97) to include the rocks of El Imán hill in the Amoyá Fm. Such a position cannot be sustained because of lithologic differences; moreover if a Middle Devonian can be assigned to the Amoyá Fm. (according to Prossl and Grosser, 1995), a late Bashkirian-Moscovian age is assigned herein to the El Imán Formation.

We conclude that sediments of the El Imán Fm. deposited at the beginning of the last Paleozoic marine trangressive event, immediately following the Famennian to late Mississippian gap in sedimentation. Studies of fishes (Janvier and Villarroel, 2000), and plant remains (Berry *et al.*, 2000) from the Cuche Fm. (Givetian-Frasnian of he Floresta area, NE of Bogota) support the idea of a global sealevel drawdown in that the Devonian sea receded from NW South America during the Frasnian and/or the Famennian.

A late Bashkirian-Moscovian age for the El Imán metasediments, is the oldest date proposed up to now for the Pennsylvanian-Permian transgression following the Mississippian gap, as it appears clearly in the comparative stratigraphic scheme established by Villarroel and Mojica (1987, Fig. 3). Cediel (1972), however, suggested that marine sedimentation was continuous from Devonian up to Permian. It is impossible to state if the Famennian-Mississippian gap is related to the Hercynian Orogeny. This stratigraphic gap is almost an equivalent to the «Fase Chiriguana» of the upper Paleozoic orogeny of Bolivia in central South America (Suarez Soruco, 2000, p. 214: Esquema Geocronológico de Bolivia).

SYSTEMATIC PALEONTOLOGY

by Lucia Angiolini
and Patrick R. Racheboeuf

All figured specimens are housed in the collection of the Universidad Nacional de Colombia, Departamento de Geociencias (n° UN-DG).

ORDER PRODUCTIDA Waagen, 1883
SUBORDER PRODUCTIDINA Waagen, 1883
SUPERFAMILY PRODUCTOIDEA Gray, 1840
Family **Productellidae** Schuchert, 1929
Subfamily **Overtoniinae** Muir-Wood and Cooper, 1960
Tribe Overtoniini Muir-Wood and Cooper, 1960.
Genus *Fimbrinia* Cooper, 1972

Type species: *Overtonia plummeri* King, 1938.

Fimbrinia sp.

Figs. 2i-j, l-n

Material: Three specimens: the two casts of a dorsal valve (UN DG 755 and 756; Fig. 2, i-j), the internal and external casts of a distorted dorsal valve (UN DG 757 and 758; Fig. 2, m-n), and the two external casts of a distorted, articulated shell (UN DG 759; Fig. 2, l, and UN DG 760).

Description: Small-sized, concavo-convex shell with deep corpus cavity. Ventral valve with narrow and recurved umbo. Dorsal valve wider than long, weakly concave, with the concave longitudinal profile more accentuated in the posteromedian part of the valve, below the umbo. Ventral valve ornamented by rugae, becoming lamellose anteriorly and bearing stout recumbent spines, arranged in concentric rows. Dorsal valve ornamented by srong lamellose, concentric bands bearing finer spines and few dimples. The best preserved dorsal valve exterior is 14 mm wide and 10 mm long and exhibits nine concentric lamellose bands. On both valves recumbent spines are displayed on a single concentric row, between each concentric lamellae. Ventral spines number 3 to 4 per mm. Dorsal spines are much more finer, and more closely spaced but their density is almost the same as on the ventral valve.

Ventral valve interior unknown.

Dorsal valve interior deeply impressed by the external concentric lamellae, with rather strong marginal ridges extending to the ears. Low and thin median septum not extending anteriorly beyond midlength of the valve, separating two raised, subtriangular, rounded adductor scars. Inner socket ridges low and narrow, rounded and laterally elongated, parallel to hinge line. Surface of the valve covered with numerous, radially arranged, endospines. Cardinal process sessile, trifid, directed posteriorly.

Discussion: The Colombian specimens display the generic characters of the genus *Fimbrinia*, and probably represent a new species. They differ from the type species *F. plummeri* (King, 1938), by more pronounced lamellose bands in the dorsal valve, by a dorsal ornamentation with fewer dimples and by lateral ridges that do not curve anteriorly at the base of the cardinal process. The genus *Fimbrinia* is reported to occur in the Late Carboniferous and Early Permian of North and South America (Muir-Wood and Cooper, 1960; Brunton *et al.*, 2000) and in the late Bashkirian through early Moscovian of the Canadian Arctic Archipelago (Carter and Poletaev, 1998). A certain similarity exists with the levipustulinid genera *Bulahdelia* Roberts (in Roberts *et al.*, 1976) and *Levipustula* Maxwell, 1951 from the Early and Late Carboniferous of Eastern Australia (Brunton *et al.*, 2000). However, the Colombian specimens do not show quincuncially arranged spines and have stronger lamellose bands on both valves.

? Subfamily **Productininae** Muir-Wood and Cooper, 1960
? Tribe Productinini Muir-Wood and Cooper, 1960

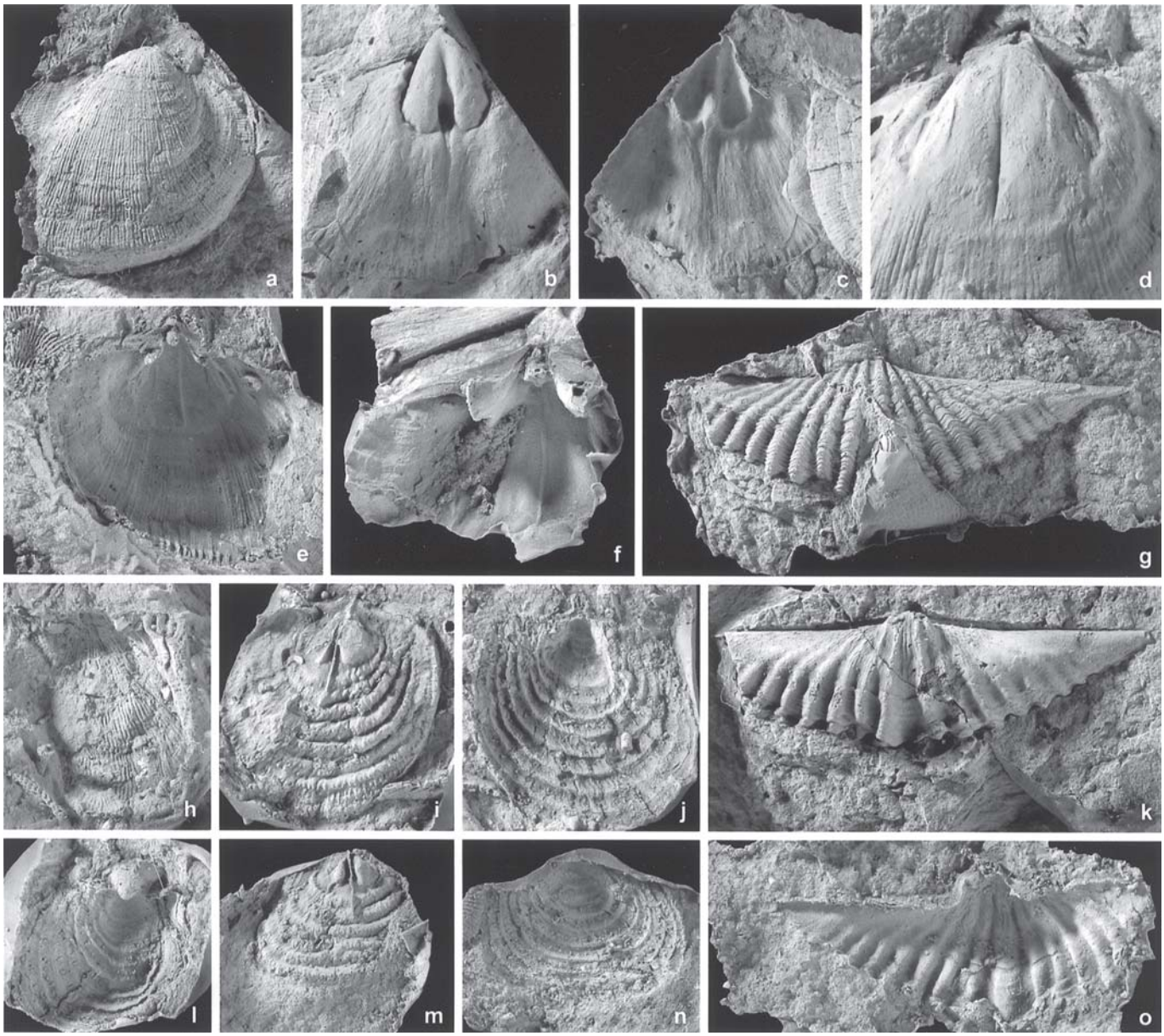

Figure 2. *Brachiopods from the Cerro El Imán*.
a-f: *Orthotichia* sp. **a**: ventral valve exterior, latex, x 2, UN-DG 775. **b-c**, ventral valve interior, internal mould (**b**) and latex (**c**), x 2, UN-DG 764. **d-e**, dorsal valve interior; **d**, enlarged view of the postero-median part of the internal mould (x 3); **e**, latex (x 2), UN-DG 776. **f**, posterior part of an incomplete dorsal valve, latex, x 3, UN-DG 787.
g, k, o: *Alispirifer* cf. *transversus* Maxwell, 1964, x 1,5: ventral valve exterior, latex cast (**g**), internal mold of the same (**k**), and latex cast of the interior (**o**), UN-DG□781.
h: Productida, gen. and sp. indet.: dorsal exterior of a distorted articulated shell, latex cast, x 2, UN-DG 797.
i, j, l-n: *Fimbrinia* sp., x 2: **i-j**, dorsal valve, latex casts of the interior (**i**), and exterior (**j**), UN-DG-755 y 756. **l**, dorsal view of an articulated, distorted shell, latex, x 2, UN-DG 759. **m-n**, latex casts of a dorsal valve, interior (**m**), and exterior (**n**), UN-DG-757 y 758.

Productida genus et species indet.

Fig. 2h

Material: A single fragment of a crushed articulated shell (UN-DG 797; Fig. 2, h), and external cast of a badly preserved dorsal valve (UN-DG 805).

Description: Shell small with markedly concave dorsal valve, with maximum width at hinge line (length = 13 mm; corresponding width = 15 mm). Myophore of the cardinal process relatively large and prominent, deeply bilobed, in dorsal position. Shell surface covered by thin, regular, low and rounded radial ribs (3 to 4 per mm along anterior margin), increasing mainly by intercalation. Concentric rugae developed towards the periphery of the valve, mainly posterolaterally. No spine could be observed.

Discussion: Shell size, concavity of the dorsal valve, and especially the morphology and arrangement of radial ribs, recall the genus *Productina* Sutton, 1938, of the Tribe Productinini. *Productina* is known from the Upper Devonian-Lower Carboniferous (Hastarian) of North America, Europe, Australia and ?northern Africa (Brunton *et al*., 2000).

ORDER ORTHIDA Schuchert and Cooper, 1932
SUPERFAMILY ENTELETOIDEA Waagen, 1884
Family **Schizophoriidae** Schuchert and Le Vène, 1929
Genus *Orthotichia* Hall and Clarke, 1892

Type species: *Orthis* (?) *morganiana* Derby, 1874.

Orthotichia sp.

Fig. 2a-f

Material: Thirty-seven more or less complete, often tectonically distorted and fragmentary isolated ventral and dorsal valves, preserved as natural external and internal casts (UN DG 752, 754, 763, 764: Fig. 2, b-c; 765, 770-772, 774, 775: Fig. 2, a; 776: Fig. 2, d-e; 785, 786, 787: Fig. 2, f; 788-795, and 803-806).

Description: Large, unequally biconvex shell, with rather flat ventral valve. Maximum width at about midlength. Anterior commissure uniplicate. Ventral valve with pointed umbo and narrow interarea nearly perpendicular to plane of commissure.

Dorsal valve convex, with sharply bended anterior margin. Ornamentation finely multicostellate with about 16-18 costellae per 5 mm at midlength. Tubular slightly coarser costellae occurs on both valves. Regularly spaced grow lamellae.

Interior of ventral valve with straight dental plates extending forward to completely enclose a narrow, elongate, bilobed muscle field bisected by a medium septum, that does not extend beyond the anterior ends of ventral adminicula. The median septum is raised and thickened at its distal end.

Interior of dorsal valve with strong and divergent brachiophore plates confining the muscle field, and a long myophragm. Two small, pear-shaped to oval scars occur in the anterior part of the muscle field, whereas two raised, elongated scars are present along the base of the brachiophore plates. Cardinal process prominent.

Discussion: These specimens are included in the genus *Orthotichia* because of their finely multicostellate ornamentation, their long and straight dental plates, with ventral adminicula extending to in front of muscle field, and the well developed median septum, raising to a crest at its anterior end. Furthermore, they show the same pattern of the 'tripartite' dorsal muscle field of *Orthotichia morganiana* (Derby, 1874, pl. III, fig. 1-5), the type-species, from the Late Carboniferous Coal Measures of Itaituba, Brazil. However the type-species shows finer and more numerous costellae besides a much inflated shape.

The similar genus *Schizophoria* King, 1850 shows more divergent and shorter dental plates and a less developed ventral septum. Among the Schizophoriidae, the Permian genera *Acosarina* Cooper and Grant, 1969 and *Kotlaia* Grant, 1993 are also closely related to *Orthotichia*. However, both are smaller with sulcate or emarginate commissure and differently developed dental plates and ventral septum. *Kotlaia* has a very long ventral septum extending to the anterior margin.

ORDER RHYNCHONELLIDA Kuhn, 1949
SUPERFAMILY RHYNCHOPOROIDEA Muir-Wood, 1955
Family **Rhynchoporidae** Muir-Wood, 1955
Genus *Rhynchopora* King, 1865

Type species: *Terebratula geinitziana* de Verneuil, 1845.

Rhynchopora sp.

Material: an internal mold of a ventral valve, on sample UN DG 752 (together with a specimen of *Orthotichia*).

Remarks: The occurrence of the genus *Rhynchopora* is indicated by the presence of a single valve with flaring outline and with coarse ribs widening anteriorly, numbering at least 2 on the sulcus and 3 on each flank. Internally the ventral valve shows dental plates. The specimen exhibits poorly preserved endoponctuation (Savage, 1996).

ORDER SPIRIFERIDA Waagen, 1883

Only two isolated valves of spiriferid brachiopods have been collected. The largest one is described below. The second specimen (UN DG 766) is an internal natural cast of a very small dorsal valve (6 mm wide), very badly preserved, which exhibits four rounded costae on each flank.

SUBORDER SPIRIFERIDINA Waagen, 1883
SUPERFAMILY PAECKELMANNELLOIDEA Ivanova, 1972
Family **Srophopleuridae** Carter, 1974
Subfamily **Pterospiriferinae** Waterhouse, 1975
Genus *Alispirifer* Campbell, 1961

Type species: *Alispirifer laminosus* Campbell, 1961.

Alispirifer cf. *transversus* Maxwell, 1964

Fig. 2g, k, o

Material: External and internal natural casts of a ventral valve (UN DG 779-781).

Description: Ventral valve markedly convex longitudinally, very transverse in outline, with maximum width at hinge line. Length = 15 mm; width (est.) = 51 mm. 'U'-shaped shallow sulcus

about 5 mm wide along anterior margin. Ornamentation of simple rounded costae tapering and becoming indistinct towards cardinal extremities. Eight, possibly nine, costae on each flank. Shell surface covered by very thin, dense and regularly spaced growth lamellae.

Ventral valve interior with very small, short and thick dental plates. Muscle field rhomboidal in outline, ill-limited anterolaterally, 6 mm wide and with anterior margin at 7 mm from the umbo. Diductor scars weakly prominent. Adductor scars long and narrow. Genital markings weakly excavated, elongated and radially arranged.

Dorsal valve unknown.

Discussion: The only available ventral valve is very similar to specimens described by Cisterna (1997) as *Alispirifer transversus* Maxwell, 1964, from Namurian-Westphalian beds of the Las Salinas Formation of the Chubut Province (Argentina). It differs only in subtle details of ornamentation. *Alispirifer transversus* has been originally described from the *Levipustula levis* Zone of eastern Australia (Maxwell, 1964), whose base is dated to the Namurian and whose top ranges up to the Moscovian or possibly higher (Roberts *et al*., 1993). The occurrence of the genus *Alispirifer* in Colombia confirms the paleobiogeographic relationships between Australia and South America during the mid-Late Carboniferous, which continued during the Earliest Permian as proposed by Cisterna *et al*. (2002).

CONCLUSION

Alispirifer cf. *transversus* confirms a Namurian-Moscovian age, according to the known range of *A. transversus*. *Fimbrinia* is known to occur from the late Bashkirian to the Early Permian. *Orthotichia* ranges from the Late Carboniferous to the Middle Permian. Thus a late Bashkirian-Moscovian age appears likely for the brachiopod assemblage described here.

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