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Stratigraphy, palynology, and conchostracans of a Lower Cretaceous sequence at the Cañadón Calcáreo locality, Extra-Andean central Patagonia: age and palaeoenvironmental significance

Wolfgang Volkheimer[a,*], Oscar F. Gallego[b], Nora G. Cabaleri[c], Claudia Armella[c], Paula L. Narváez[a], Diego G. Silva Nieto[d], Manuel A. Páez[e]

[a] Unidad de Paleopalinología, Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Centro Científico Tecnológico (CCT), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), C.C. 330, 5500 Mendoza, Argentina

[b] Paleontología, Facultad de Ciencias Exactas y Naturales y Agrimensura, Universidad Nacional del Nordeste (UNNE). Área Paleontología, Centro de Ecología Aplicada del Litoral (CECOAL), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), C.C.128, 3400 Corrientes, Argentina

[c] Instituto de Geocronología y Geología Isotópica (INGEIS), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad de Buenos Aires, Ciudad Universitaria, C1428EHA, Buenos Aires, Argentina

[d] Instituto de Geología y Recursos Minerales, Servicio Geológico Minero Argentino (SEGEMAR), Av. Julio A. Roca 651, 10° Piso, C1067ABB, Buenos Aires, Argentina

[e] Comisión Nacional de Energía Atómica (CONEA), Regional Patagonia, C.C. 178, Parque Industrial, 9100 Trelew, Chubut, Argentina

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A B S T R A C T

The first palynologic record in a Lower Cretaceous sequence at the Cañadón Calcáreo locality of Extra-Andean central Patagonia is presented. It contributes a more precise chronology and palaeoenvironmental characterization of the sequence. The conchostracan faunal records support the palynologic results. Sedimentary environments are studied in relation to a tectogenetic development model. Detailed measurement of stratigraphic/sedimentologic sections in the field was complemented by sampling for palynology, conchostracans and sedimentary facies/microfacies analysis. The depositional environment is lacustrine/palustrine in the lower part, grading to fluvial. The middle and upper sections of the unit are fluvial and characterized by prevailing sandstones, conglomerates and tuffs. Dominant genera of the palynoflora are *Classopollis* and *Callialasporites*, with an incipient presence of *Cyclusphaera*. The prevalence of the thermophilous genus *Classopollis* indicates warm climatic conditions, and the high frequency and diversity of trilete spores, corresponding to a hygrophile vegetation of ferns and bryophytes, indicates locally humid conditions. The fauna of conchostracans identified is composed of species of the genera *Nemestheria* (*Zhestheria*), *Pseudestherites*, *Euestheria*?, and probably *Congestheriella*. A Valanginian age is inferred for the middle part of the sequence.

1. Introduction and geologic setting

The basement of the Chubut Extra-Andean region is composed of igneous and metamorphic rocks of the Mamil Choique Formation (Ravazzoli and Sesana, 1977) (Fig. 1). This unit is widely distributed within the depositional centres of the Cañadón Asfalto Basin and is characterized by the presence of migmatites, foliated granitoids and granitoids without deformation (Costa et al., 1996). The rocks are cut by thin aplitic and pegmatitic dikes. A wide spectrum of radiometric ages, from the Ordovician to the early Mesozoic, has been obtained for the Mamil Choique Formation (Dalla Salda et al., 1999; López de Luchi et al., 1999; Varela et al., 1999).

During the Mesozoic, from the Early Jurassic to the Late Cretaceous (Maastrichtian), and as a consequence of the beginning of the break-up of Gondwana, marine and continental sedimentary successions and igneous accumulations derived from volcanic episodes. In the Middle Jurassic, an important period of volcanism is related to the convergence on the western border of the South American plate. Stratovolcanoes developed on a magmatic arc located on the northern lineaments of the Gastre System (Coira et al., 1975; Rapela et al., 1991). This volcano-sedimentary sequence comprises the Lonco Trapial Formation (Lesta and Ferello, 1972). Its volcanic facies are characterized by andesites, andesitic breccias, dacitic and andesitic tuffs and volcanic agglomerates, while the sedimentary facies consist of conglomerates, conglomeratic sandstones and fine to coarse-grained, greenish-grey sandstones (Lizuain and Silva Nieto, 2005). This unit is assigned a Middle Jurassic age based on several studies (Stipanicic and Bonetti, 1969; Franchi and Page, 1980; Lesta et al., 1980). At the Sierra de Lonco Trapial

* Corresponding author.
E-mail address: volkheim@lab.cricyt.edu.ar (W. Volkheimer).

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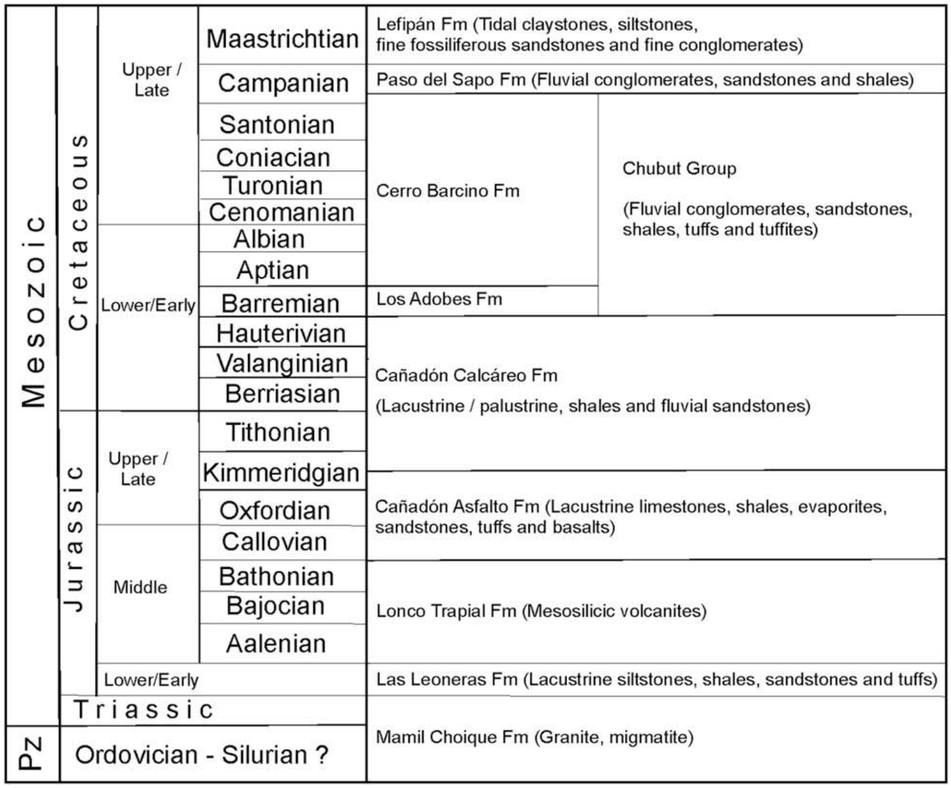

Fig. 1. Stratigraphy of the middle Chubut River valley and related areas.

locality, Silva Nieto (2004) obtained a K-Ar radiometric age of 173 Ma, corresponding to the Bathonian.

Deposition continued in the Jurassic in lacustrine-fluvio-deltaic conditions, with basaltic intercalations present near the base of the sequence that correspond to the Cañadón Asfalto Formation (Stipanicic et al., 1968). This formation has been assigned to the Callovian-Oxfordian by Silva Nieto et al. (2002a) and the Callovian-Kimmeridgian(?) by Figari and Courtade (1993). It rests, with angular unconformity, on the Lonco Trapial Formation, and is overlain by the Cañadón Calcáreo Formation (Proserpio, 1987) in the Cañadón Calcáreo locality. At many other places of the middle Chubut River, the Cañadón Asfalto Formation is overlain unconformably by the Middle to Late Cretaceous Chubut Group. The facies in the mentioned localities correspond to prograding fluvial cycles of the Los Adobes Formation (Barremian; Codignotto et al., 1979). The subsequent thermal subsidence and a pyroclastic cycle of wide areal extent are indicated in the Cerro Barcino Formation (Aptian to Campanian?, Codignotto et al., 1979).

Sedimentation in the Cañadón Asfalto Basin depocentres is a consequence of the development of pull-apart basins related to the transcurrent faults of the Gastre mega-lineament (Silva Nieto et al., 2002b; Lizuain and Silva Nieto, 2005). These basins were filled with lacustrine and fluvial sediments (Cabaleri and Armella, 1999, 2003, 2005a,b; Cabaleri et al., 1999, 2005, 2006). Rifting was responsible for the eruption of the mantle-derived olivine basalts observed in the Cerro Cóndor and Yanquetruz depositional centres. Palaeolake depths were variable and related to the characteristics of the different depositional centres in the region (Silva Nieto et al., 2002a).

1.1. Cañadón Calcáreo Formation

Proserpio (1987) proposed this name for the continental fluvial deposits outcropping in the central- eastern part of his mapping area, characterized by a thick basal conglomerate covered by alternating pelites, psammites and coarse clastic rocks, resting above the Cañadón Asfalto Formation with a moderate angular unconformity. Previously, these rocks were included in the Cañadón Asfalto Formation or the Chubut Group. They are distinguished from those of the Cañadón Asfalto Formation by the nearly total absence of calcareous rocks and the weaker faulting and folding, and from the Chubut Group that was not affected by synsedimentary deformation. Another difference is the presence of conchostracans and unidentified fish scales in the Cañadón Calcáreo Formation. The features mentioned indicate that they are different from the facies associations of the Cañadón Asfalto Formation and show a change towards facies similar to those of the Chubut Group.

There are no previous palaeontologic investigations of the age of the Cañadón Calcáreo Formation at its type locality. Fishes were described from basal lacustrine parts of the formation, in outcrops located 25 km west of the type locality, near Puesto Almada (on Estancia El Torito). The three taxa (*Coccolepis groeberi*, *"Tharrias" ferruglioi* and *Luisiella inexcutata*) found in these basal sediments were assigned a Late Jurassic age by Bordas (1942), Bocchino (1967), and López-Arbarello (2004). Rauhut et al. (2005) discovered a short-necked sauropod dinosaur, *Brachytrachelopan mesai*, of Tithonian age, 25 km to the north-northeast of Cerro Cóndor village, within the formation's fluvial sandstones. Additional fragmentary sauropod remains have been described by Rauhut (2006).

In this paper, we present the first biostratigraphic record of a well-preserved palynomorph assemblage, recovered from the middle part of the Cañadón Calcáreo Formation, which contributes to a more precise chronology. The study of conchostracans complements and reinforces the palynologic results. Palaeoenvironmental inferences are also provided from stratigraphic and facies analysis.

1.2. Area of study

The Cañadón Calcáreo Formation type locality is to the north of the middle Chubut River valley, north of Paso de Indios (43°17′30″S

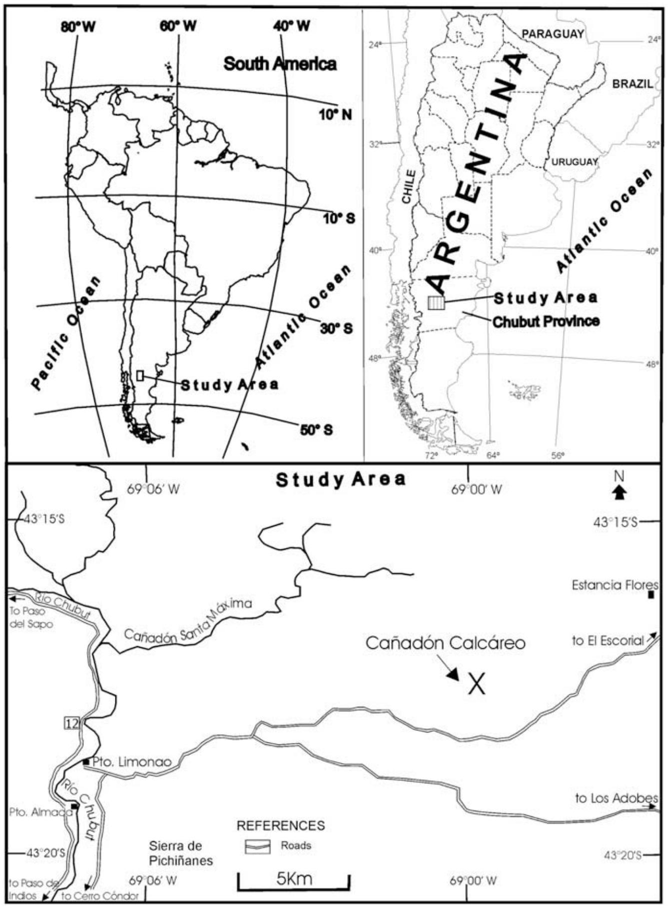

Fig. 2. Location map and geologic setting.

and 68°59′40″W), in central northern Patagonia, Chubut Province (Figs. 2 and 3). The outcrops are exposed in the Estancia Flores area, in a dry river valley called Cañadón Calcáreo, 25 km northwest of the Los Adobes outpost of the National Atomic Energy Agency.

The section of the Cañadón Calcáreo Formation at its type locality is 122 m thick (Fig. 4). The basal part of the formation is covered by Quaternary deposits and does not allow the presence of an angular unconformity to be observed. The upper limit is characterized by a change to coarser grained sediments of the Chubut Group. The latter consists of a cyclic sequence of fine to medium grained pyroclastic rocks (tuffs) and channel fillings of fluvial sandstones and conglomerates. It is also characterized by the absence of pelitic intercalations. In the outcrops of the type section it is difficult to observe the local unconformity between the Cañadón Calcáreo Formation and the Chubut Group.

2. Material and methods

2.1. Stratigraphy

The stratigraphic fieldwork consisted of detailed measuring of a complete section of the Cañadón Calcáreo Formation at its type locality. We also identified facies associations and stratigraphic architecture of the deposits.

2.2. Palynology

Nine stratigraphic levels were sampled from the entire section for palaeopalynologic studies. A few poorly preserved specimens of plant megafossils, not treated in this paper, were also recovered. The physical and chemical extraction of palynomorphs was carried out in the Palaeopalynologic Laboratory of IANIGLA (Mendoza). The standard palynologic extraction techniques involve treatment with hydrochloric and hydrofluoric acids (Volkheimer and Melendi, 1976).

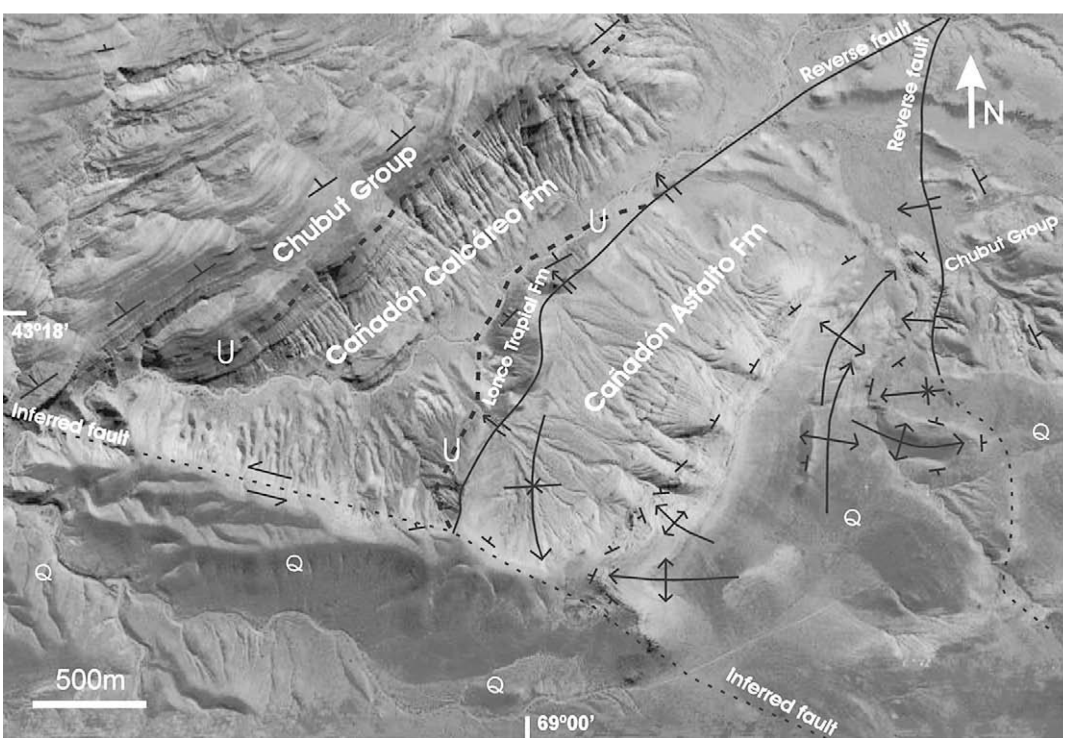

Fig. 3. Stratigraphic and structural relations of Jurassic and Cretaceous formations outcropping in the southern part of the Cañadón Calcáreo depocentre at the type locality of the Cañadón Calcáreo Formation. The angular unconformities (U) between Cañadón Asfalto and Cañadón Calcáreo formations and between the Cañadón Calcáreo Formation and the Chubut Group (Los Adobes Formation) can be observed. Q: Quaternary deposits. (Modified from Google Earth).

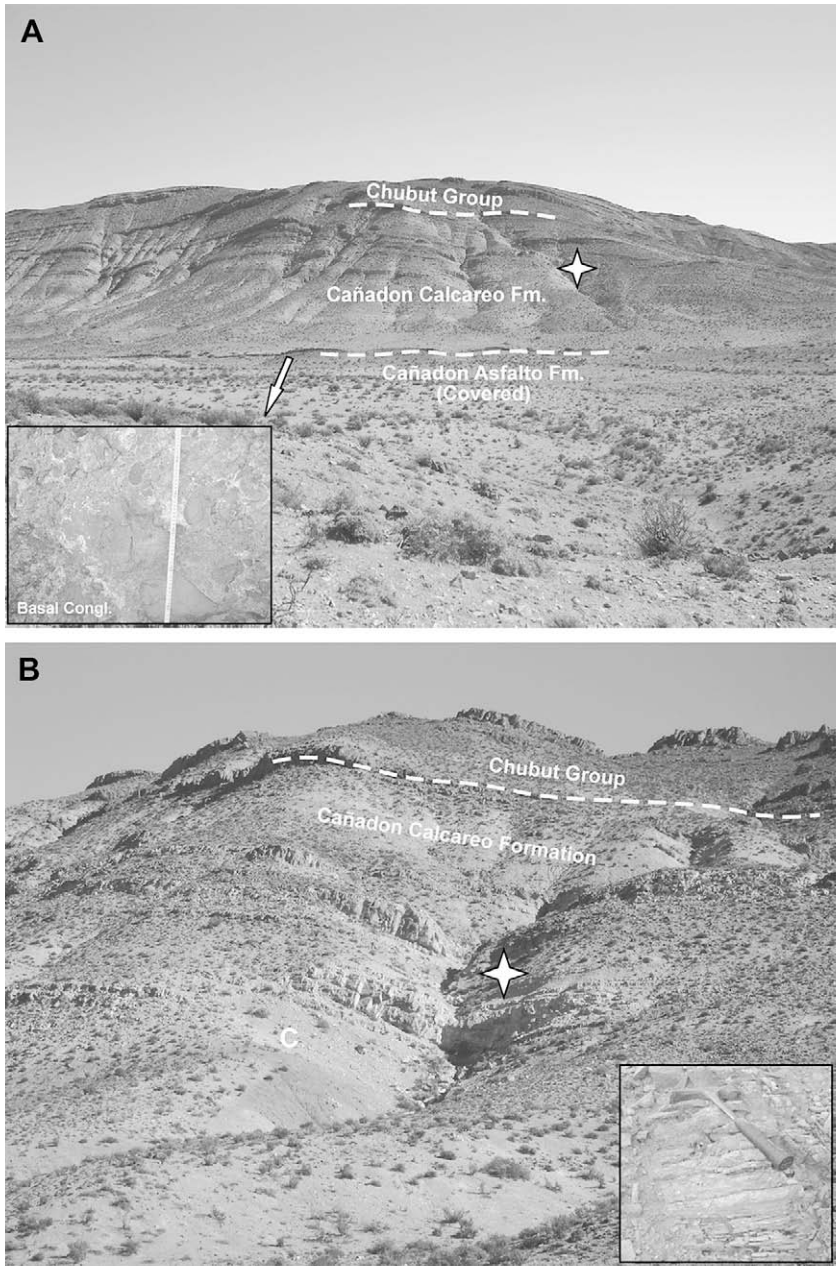

Fig. 4. A. Panoramic view of the type locality of the Cañadón Calcáreo Formation: Upper picture: General view. Left lower corner: Basal conglomerate of the formation. **B.** Middle and upper part of the Cañadón Calcáreo Formation (note the contact between Cañadón Calcáreo Formation and Chubut Group); asterisk: Sample site of the palynobiota; **C**: Sample site of conchostracans in lacustrine environment. Right lower corner: Detail of C, conchostracan bearing marls.

The slides were systematically examined in normal transmitted light with a Leitz Dialux 20 microscope at IANIGLA. For more detailed systematic studies, selected specimens were examined under a scanning electron microscope at the Museo Argentino de Ciencias Naturales "B. Rivadavia" (Buenos Aires). The palynologic slides are housed in the collection at IANIGLA, catalogue numbers 9045, 9045[1], 9046-9052 MPLP (Mendoza-Palinoteca-Laboratorio-Palaeopalinología).

2.3. Conchostracans

Conchostracans were sampled at different places from the same stratigraphic level (marls at 70 m above the base of the formation). The samples were examined under an Olympus SZ 51 stereoscopic microscope. Photographs were taken with the digital camera Olympus SP-350 (8.1. megapixels) at CECOAL-CONICET (Corrientes). SEM studies were undertaken at the Servicio de Microscopía Electrónica of the SECyT-UNNE (Corrientes).

The conchostracan samples have been catalogued in the Palaeoinvertebrates Collection, Museo Paleontológico Egidio Feruglio, Trelew (Chubut), and at the Palaeozoological Collection, Facultad de Ciencias Exactas, Naturales y Agrimensura, Universidad Nacional del Nordeste (Corrientes), with the catalogue numbers 1176-1177 MPEF-PI and 7394 CTES-PZ respectively.

3. Stratigraphy and sedimentary environment

At the type locality of the Cañadón Calcáreo Formation we observed that the "basal conglomerate" mentioned by Proserpio (1987) is an andesitic agglomerate of the Lonco Trapial Formation,

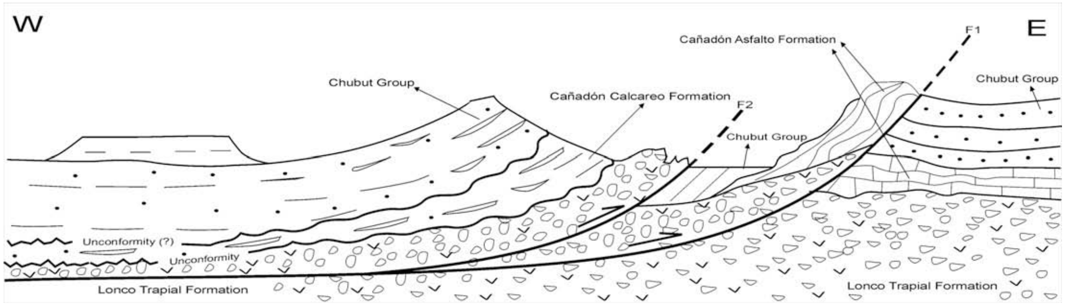

Fig. 5. Schematic cross section at Cañadón Calcáreo (out of scale).

limited by high angle faults, towards the Cañadón Calcáreo Formation in the west and the Cañadón Asfalto Formation in the east (Fig. 5).

From the lowermost 35 m of the sequence, which are partially covered by Quaternary deposits, only two lenticular conglomerates and coarse sandstones crop out, followed by 7 m of cross-bedded, fine-grained fluvial sandstones. Further up there are 13 m of finely laminated shales followed by 7 m of limestones and grey marls with conchostracans, tree stumps, bioturbations and mudcracks, covered by 3 m of tuffitic sandstones. The upper part of the section (75 to 122 m above the base) alternates between shales (21 intervals), sandstones (14), conglomerates (3), tuffites (9) and tuffs (2) (Fig. 6).

The basal section of the Cañadón Calcáreo Formation reflects a fluvio-lacustrine system, deposited in a trans-tensional basin setting. Different palaeoenvironments are indicated in the depressions: shallow littoral, marginal, and palustrine with ponds and small lakes grading to fluvial channels. Sedimentation began with a shallow environment, with littoral to palustrine facies. The subaqueous fresh water facies are represented by limestones and finely laminated pelites and marls and these contain remains of pelecypods, conchostracans and fragments of charophytes. The

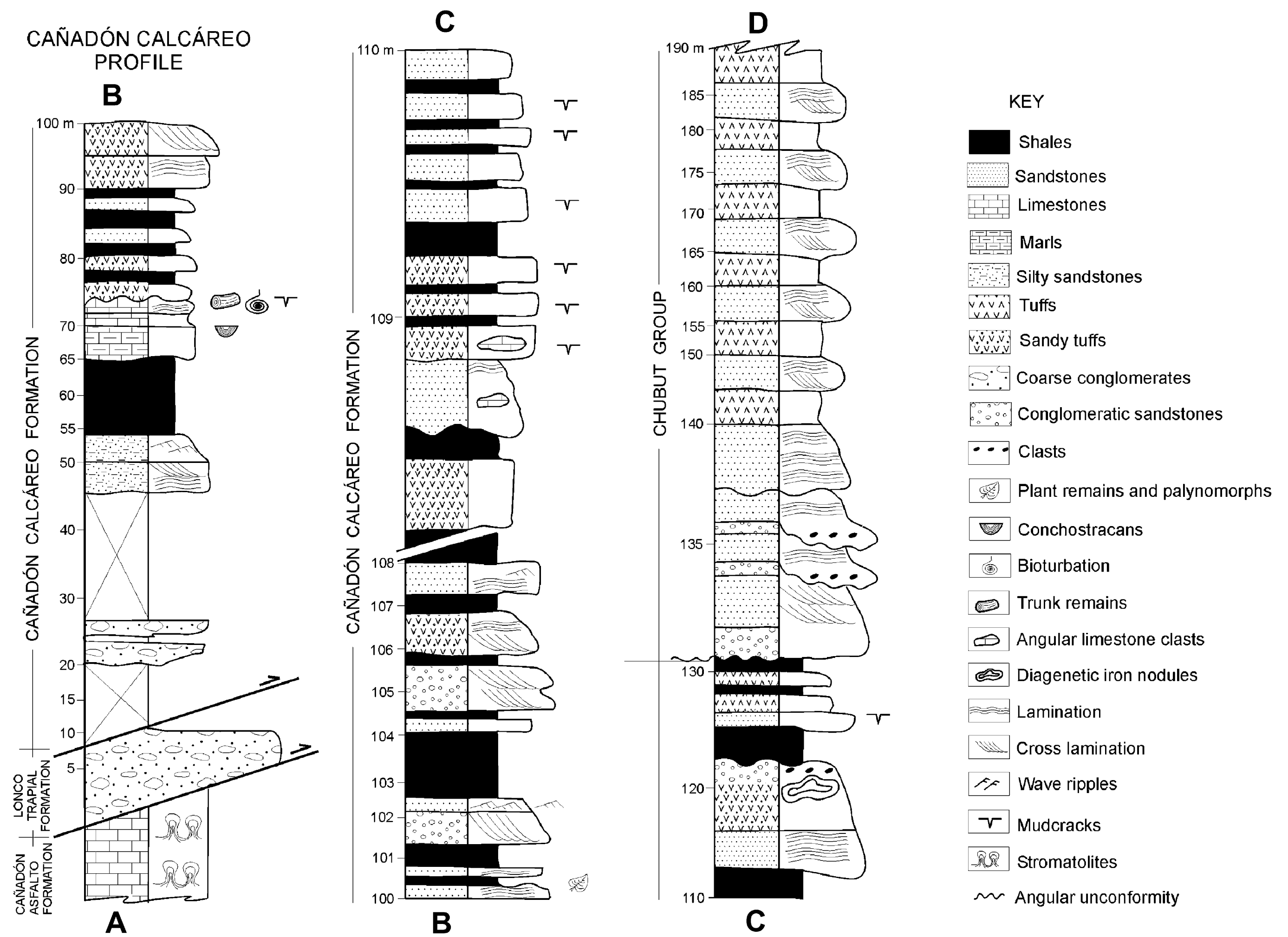

Fig. 6. Columnar section of the Cañadón Calcáreo Formation at its type locality.

wetland deposits are characterized by wackestones with planar stratification and structures, indicating wave interference. In some cases, a fine cross-stratification can be observed.

Lacustrine sedimentation was interrupted by the input of pyroclastic and silicoclastic materials. The alternation of sandstones, conglomerates and tuffites indicates the presence of multi-episodic fluvial channel systems that alternate with fine-grained flood-plain deposits. The conglomerate levels with erosive to planar bases, resting on the pelites, corresponding to deposition on the channel bottoms under a high energy regime. Above some of these deposits are sandstone facies with a fining-upward tendency resulting from the overflowing of the principal channels over the flood plain.

The sandstones of the upper section indicate the existence of bars generated by the lateral migration of channels on the flood plains.

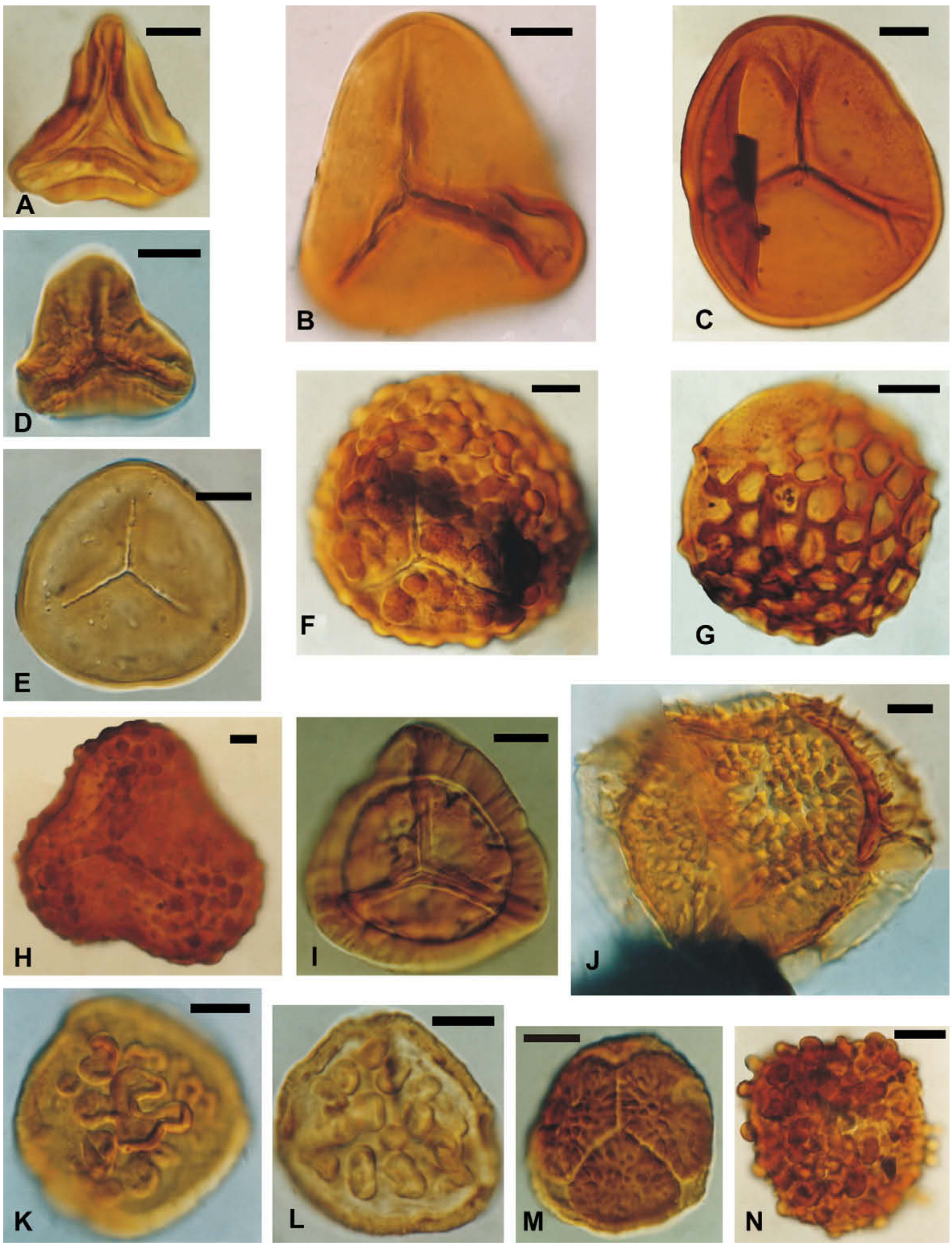

Fig. 7. A. *Gleicheniidites* sp., D29/2. **B.** *Biretisporites* sp., S37/2. **C.** *Divisisporites* sp., O30/4. **D.** *Concavisporites laticrassus* Volkheimer, O43/4. **E.** *Deltoidospora minor* (Couper) Pocock, V29/4. **F.** *Leptolepidites major* Couper, D38/1. **G.** *Klukisporites pseudoreticulatus* Couper, E24. **H.** *Trilobosporites* sp., E23/3. **I.** *Antulsporites* spp., F44/4. **J.** *Aequitriradites spinulosus* (Cookson and Dettmann) Cookson and Dettmann, W27/2. **K-L.** *Stoverisporites lunaris* (Cookson and Dettmann) Norwick and Burger, K: S27/3, L: D28/2. **M.** *Taurocusporites segmentatus* Stover, W38/2. **N.** *Uvaesporites* sp., H33. All from sample 9049 MPLP. Scale bar = 10 μm.

Some of these levels, which are cross-bedded and laminated near their tops, represent migratory channels with unidirectional currents. The tuff levels were preserved in local depressions on the flood plain.

A clear change in the sedimentation pattern indicates the beginning of the fluvial sequence with intercalations of the Chubut Group tuffs. This unit is represented by conglomeratic channels with erosive bases, with a bottom load that was rapidly deposited during high-output events. The levels of coarse-grained, cross-bedded sandstones, passing laterally to planar bedding, reflect the presence of laterally migrating bars.

4. Palynology

Remarkably well-preserved palynomorphs were obtained from one sample (N° 9049 MPLP) of the middle portion of the Cañadón Calcáreo Formation at its type locality (100.4 m above the base of

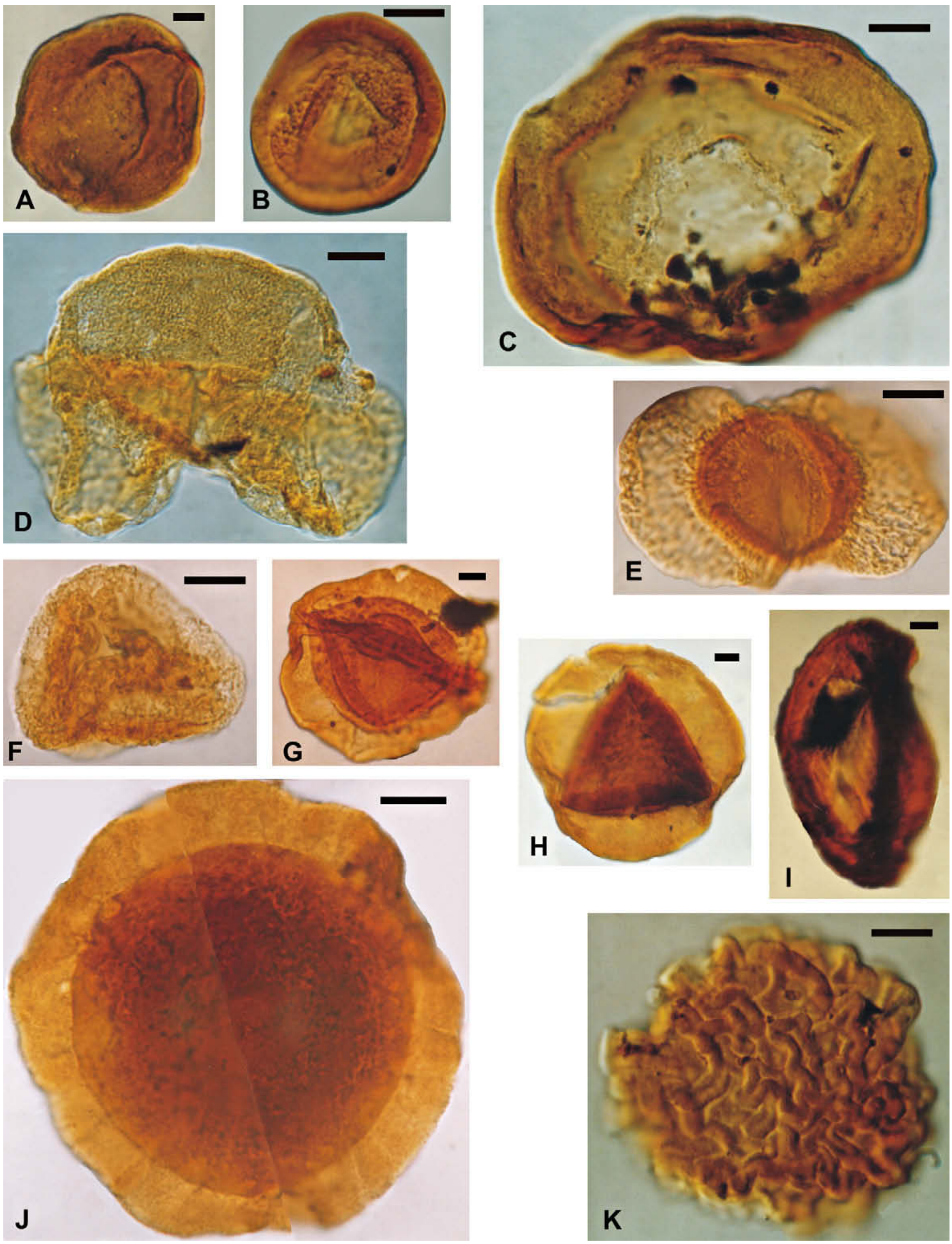

Fig. 8. **A.** *Coptospora* sp., T23/3. **B.** *Classopollis* sp., F43/2. **C.** *Balmeiopsis limbatus* (Balme) Archangelsky, P35/3. **D.** *Podocarpidites* sp., K24/1. **E.** *Podocarpidites ellipticus* Cookson, D43/4. **F.** *Trisaccites* sp., S37/3. **G.** *Callialasporites turbatus* (Balme) Schulz, S35/1. **H.** *Callialasporites trilobatus* (Balme) Dev, R44. **I.** *Cyclusphaera* sp.cf. *Cyclusphaera psilata* Volkheimer and Sepúlveda, F43. **J.** *Callialasporites turbatus* (Balme) Schulz, Z23. **K.** *Cerebropollenites macroverrucosus* (Thiergart) Schulz, O31. All from sample 9049 MPLP. Scale bar = 10 μm.

the formation). The palynologic association consists of 59 species (Figs. 7–9), cited with their suggested botanical affinity in Table 1.

4.1. Palaeocommunities, palaeoenvironment and palaeoclimate

The palynomorph assemblage at the sampling locality reflects a swampy environment with a hygrophilic community consisting of Anthocerotopsida (*Stoverisporites lunaris*), Hepaticae (*Aequitriradites spinulosus, Coptospora* sp.), Bryopsida (=Musci) (*Sphagnumsporites* sp.), and Lycopodiopsida (*Antulsporites* spp., *Camarozonosporites* sp., *Concavisporites* spp.and *Retitriletes* spp.).

A second, less extreme hygrophilic community is composed of several fern families: Osmundaceae (*Baculatisporites* spp., *Rugulatisporites* sp.), Gleicheniaceae (*Gleicheniidites* sp.), Schizaeaceae (*Contignisporites* sp., *Klukisporites* spp., *Pilosisporites* cf. *trichopapillosus*), Hymenophyllaceae (*Biretisporites* sp.), Matoniaceae (*Trilobosporites* spp.), Cyatheaceae-Dicksoniaceae (*Deltoidospora* spp.), and Polypodiaceae-Pteridaceae (*Leptolepidites* spp.), growing near the swampy areas.

We infer the existence of a third, mesophilic community of conifers, of wide distribution on well-drained soils in the lowlands. This is suggested by the presence of abundant rimulate pollen grains of the thermophilous Cheirolepidiaceae (*Classopollis* spp.).

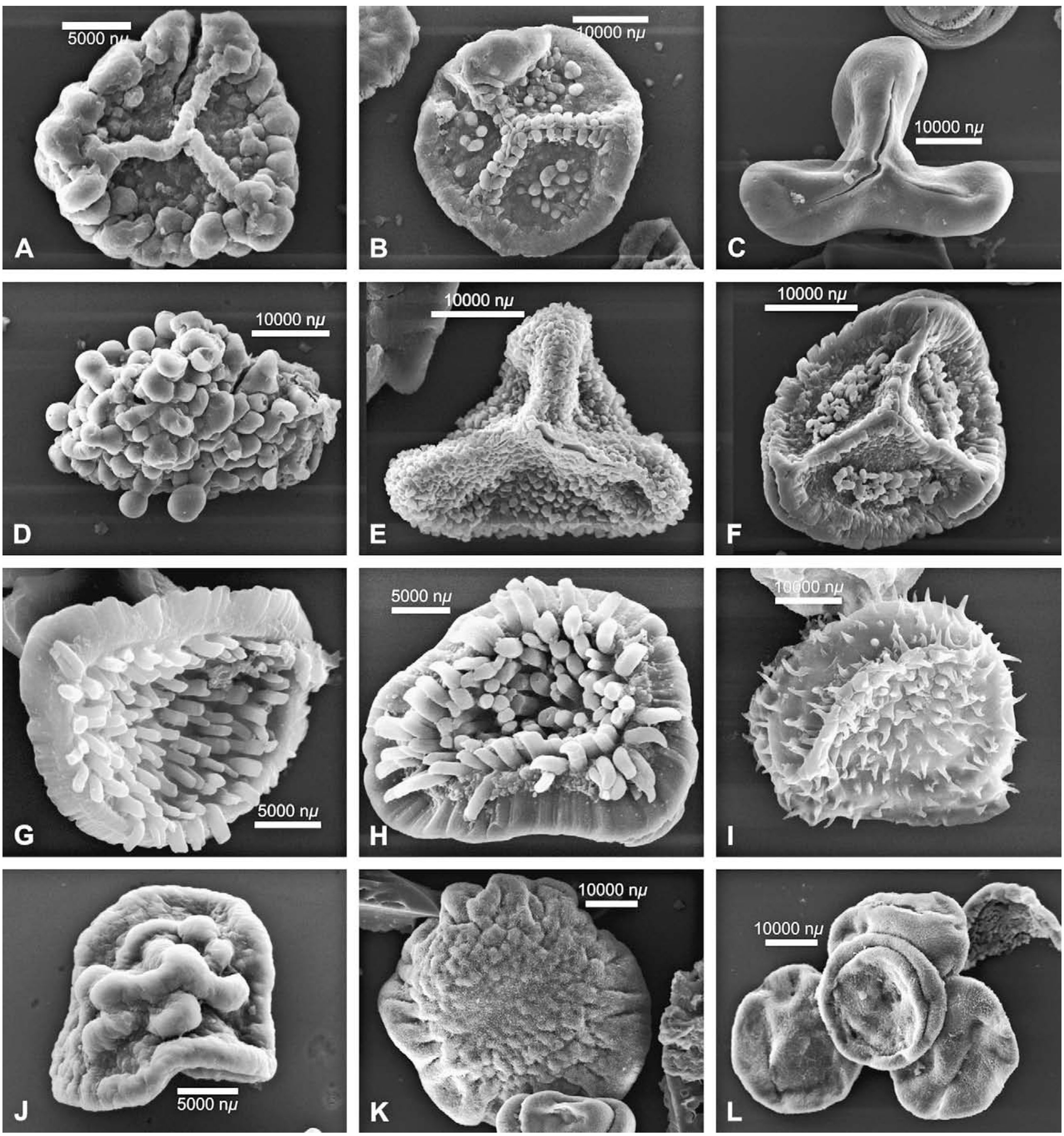

Fig. 9. A. *Leptolepidites* sp. **B.** *Taurocusporites segmentatus* Stover. **C.** *Concavisporites* sp. **D.** *Uvaesporites* sp. **E.** cf. *Concavissimisporites* sp. **F.** *Antulsporites sp.*, proximal view. **G-H.** *Antulsporites baculatus* (Archangelsky and Gamerro) Archangelsky and Gamerro. **I.** *Pilosisporites* cf. *trichopapillosus* (Thiergart) Delcourt and Sprumont. **J.** *Bullasporis* sp. **K.** *Callialasporites dampìeri* (Balme) Dev. **L.** *Classopollis* sp. All from sample 9049 MPLP.

Table 1
Taxonomic list and botanical affinities of the palynomorph species found in the Cañadón Calcáreo Formation

Taxa	Botanical affinity
Algae	
Ovoidites sp.	Zygnemataceae
Pteridophytes and bryophytes	
Aequitriradites spinulosus (Cookson and Dettmann) Cookson and Dettmann 1961	Sphaerocarpaceae
Antulsporites baculatus (Archangelsky and Gamerro) Archangelsky and Gamerro 1966	Selaginellaceae
Antulsporites sp.	
Baculatisporites comaumensis (Cookson) Potonié 1956	Osmundaceae-
Baculatisporites sp.	Hymenophyllaceae?
Biretisporites sp.	Hymenophyllaceae-Pteridaceae?
Bullasporis sp.	Briophyta?
Camarozonosporites sp.	Lycopodiaceae
Concavisporites laticrassus Volkheimer 1972	
Concavisporites sp.	
Concavissimisporites penolaensis Dettmann 1963	
Concavissimisporites sp.	
Contignisporites sp.	Schizaeaceae
Coptospora sp.	Sphaerocarpaceae
Deltoidospora minor (Couper) Pocock 1970	Cyatheaceae, Dicksoniaceae?
Deltoidospora australis (Couper) Pocock 1970	Cyatheaceae
Dictyophyllidites sp.	Dipteridaceae
Foveotriletes cf. *parviretus* (Balme) Dettmann 1963	
Gleicheniidites sp.	Gleicheniaceae
cf. *Hamulatisporites* sp.	
Klukisporites pseudoreticulatus Couper 1958	Schizaeaceae
Klukisporites sp.	
Leptolepidites macroverrucosus Schulz 1967	Pteridaceae,
Leptolepidites major Couper 1958	Ophioglossaceae,
Leptolepidites sp.	Polypodiaceae, Dennstaedtiaceae, Selaginellaceae
Pilosisporites cf. *trichopapillosus* (Thiergart) Delcourt and Sprumont 1955	Schizaeaceae?
Retitriletes austroclavatidites (Cookson) Döring, Krutzsch, Mai and Schulz 1963	Lycopodiaceae
Retitriletes sp.	
Rouseisporites sp.	
Rugulatisporites sp.	Osmundaceae?
Sphagnumsporites sp.	Sphagnaceae
Stoverisporites lunaris (Cookson and Dettmann) Norwick and Burger 1975	Anthocerotaceae
Taurocusporites segmentatus Stover 1962	Pteridophyta
Trilobosporites cf. *trioreticulatus* Cookson and Dettmann 1958	Matoniaceae
Trilobosporites sp.	
*Uvaesporites*sp.	
Verrucosisporites varians Volkheimer 1972	Pteridophyta
Verrucosisporites sp.	
Gymnosperms	
Alisporites similis (Balme 1957) Dettmann 1963	Pteridospermales
Araucariacites australis Cookson 1947	Araucariaceae
Araucariacites cf. *pergranulatus* Volkheimer 1968	
Balmeiopsis limbatus (Balme) Archangelsky 1977	
Callialasporites dampieri (Balme) Dev 1961	
Callialasporites microvelatus Schulz 1967	
Callialasporites segmentatus (Balme) Srivastava 1963	
Callialasporites trilobatus (Balme) Dev 1961	
Callialasporites turbatus (Balme) Schulz 1967	
Cerebropollenites macroverrucosus (Thiergart) Schulz 1967	Taxodiaceae?
Classopollis classoides (Pflug) Pocock and Jansonius 1961	Cheirolepidiaceae
Classopollis simplex (Danzé, Corsin and Laveine) Reiser and Williams 1969	
Classopollis sp.	
Cyclusphaera sp.cf. *Cyclusphaera psilata* Volkheimer and Sepúlveda 1975	Coniferae
Gamerroites sp. A Archangelsky and Villar de Seoane 2005	
Microcachryidites antarcticus Cookson 1947	Podocarpaceae
Phrixipollenites sp.	
Podocarpidites ellipticus Cookson 1947	
Podocarpidites verrucosus Volkheimer 1972	
Podocarpidites sp.	
Trisaccites sp.	

The Araucariaceae (represented by *Araucariacites* spp. and the very frequent *Callialasporites* spp.), represent a fourth, subhumid community, growing not far from the depositional site, considering their high percentages in the palynologic assemblages.

The Podocarpaceae (anemophilous bisaccate and trisaccate pollen grains: *Podocarpidites* spp., *Phrixipollenites* sp., *Microcachryidites antarcticus*, *Trisaccites* sp., *Gamerroites* sp. A) were probably distributed from somewhat higher topographic levels.

Warm climatic conditions are inferred by the dominance of the thermophilous genus *Classopollis*, and locally humid conditions by the high frequency and diversity of ferns and bryophytes.

4.2. Palynostratigraphy

The palynomorph assemblage identified in the middle part of the Cañadón Calcáreo Formation at its type section is clearly different from the Middle Jurassic palynoflora of the underlying Cañadón Asfalto Formation at the Cañadón Lahuincó locality (Volkheimer et al., in preparation). It is also different from the Hauterivian/Barremian assemblages of the Neuquén Basin, which are characterized by high frequencies of *Cyclusphaera psilata* (Volkheimer and Sepúlveda, 1976), and from the Aptian-Albian association of the Huitrín Formation, which contains the first appearance of early angiospermous pollen (Volkheimer and Salas, 1975).

The association has similarities with palynologic “Zone A”, of Berriasian-Valanginian age (southwestern Extra-Andean Chubut and northwestern Extra-Andean Santa Cruz provinces), characterized by the dominance of the genera *Classopollis* and *Callialasporites* (Archangelsky et al., 1981). It has also many species in common with the somewhat younger Lower Cretaceous Baqueró Group of the Santa Cruz Province, which is part of “Zone B”, characterized by *Cyclusphaera psilata* (Archangelsky et al., 1981). The stratigraphic distribution of selected species and morphotypes is represented on the range chart (Fig. 10), and suggests a Valanginian age for this palynomorph assemblage.

5. Conchostracans

The knowledge of the Cretaceous conchostracan faunas in the Southern Hemisphere has increased during the last decade, but is still poor. It includes mainly the faunas from northeastern Brazil, Argentina, Uruguay, Africa and Australia. There are about 35 Cretaceous species in the Southern Hemisphere and many of them need new detailed SEM studies to establish their real affinities. Among them are probably several species that belong to Asiatic or other South American forms and may be useful for chronologic studies (Gallego and Martins-Neto, 2006). Since the contribution of Zhang et al. (1976), Chen and Hudson (1991), Chen (1994), Li et al. (2007), and others (for more references see Gallego and Martins-Neto, 2006), the use of conchostracan assemblages for dating has increased significantly.

5.1. Conchostracan association

The association recorded in the Cañadón Calcáreo Formation is composed of new species of *Nemestheria* (*Zhestheria*), *Pseudestherites* and *Euestheria*. *Congestheriella* is tentatively reported for these levels.

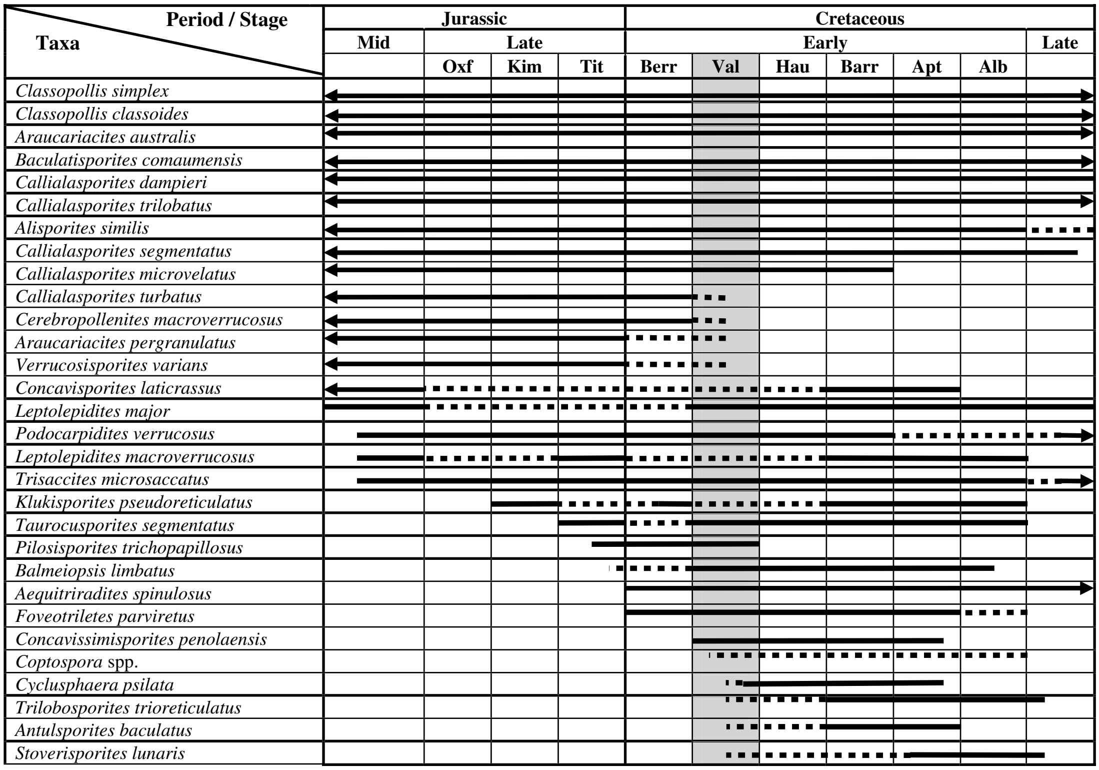

Fig. 10. Stratigraphic range of selected species and palynomorph morphotypes.

Nemestheria (*Zhestheria*) sp. is assigned to this genus on the basis of such characters as the ovate to subcircular outline, the radial striae ornamentation intercalated with short striae in the lower half of each growth band, and fine serrated growth lines. The type species of the genus *Nemestheria* Zhang and Chen was originally described from the early Late Cretaceous Qingshankou Formation from China. Other species of this genus have been recorded from the Cretaceous of Mongolia and the United States (Chen and Shen, 1982). The genus belongs to the Family Jilinestheriidae Zhang and Chen (in Zhang et al., 1976) and the subgenus *N.* (*Zhestheria*) was recently defined by Shen (2003).

The Family Jilinestheriidae was recorded for the first time in the São Carlos Formation (Coniacian-Santonian), Bauru Group, south-east Brazil (Rohn et al., 2005). Preliminary studies on *Nemestheria* (*Zhestheria*) sp. (Fig. 11.A-B) from the Cañadón Calcáreo Formation show that it resembles the Chinese species *Zhestheria subquadrata*, *Z. nemestheriformis*, *Z. gracilis* and *Z. zhunanguanensis* from the Upper Cretaceous of China (Chen and Shen, 1982).

Pseudestherites sp. is assigned to this genus based on its elliptical outline and growth bands ornamented only by small ovate cavities (Fig. 11.C–D). This genus belongs to the family Antronestheriidae Chen and Hudson, 1991. The type species of the genus, *P. qinghemenensis* Chen, is from the Lower Cretaceous (Hauterivian) Sahai Formation (western Liaoning province; Zhang et al., 1976) and Xiagou Formation (Hexi Corridor, Gansu province; Shen et al., 1982). Four other species of the genus have been recognized from Chinese Lower Cretaceous successions. *P. elliptica* Dong from the Lower Cretaceous Hengtongshan Formation, (southern Jilin province; Dong, 1988); *P. jianchangensis* W. Wang from the Lower Cretaceous Sahai Formation (Wang, 1987); *P. zhangwuensis* W. Wang and *P. leijiaensis* W. Wang from the Lower Cretaceous (Hauterivian) Sahai Formation, (Zhangwu, Liaoning province; Wang, 1989).

Two other species of *Pseudestherites* have been recorded from Lower Cretaceous Argentinian sequences: *P. musacchioi* Gallego and Shen (Fig. 11.G) in the late Hauterivian-Barremian La Amarga Formation (Bañados de Caichigüe Member, Cerro China Muerta locality, Neuquén) (Gallego and Shen, 2004), and *P. rivarolai* Gallego in the Albian Lagarcito Formation (San Juan) (Prámparo et al., 2005). There are other two undescribed "*Pseudestherites* forms" (Fig. 11.F,H-I) from the Puesto Yanquetruz and El Portezuelo localities, in the northern depocentres of the Cañadón Asfalto Basin. Their stratigraphic position is still under revision.

Several South American and African forms are closely related to the *Pseudestherites* species, such as: *Tenuestheria canelonesensis* Gallego from the Castellanos Formation in Uruguay (Albian) (Gallego et al., 1999) and *Pseudestheria abaetensis* Cardoso from the Areado Formation in Brazil (Lower Cretaceous), *Cyzicus (Euestheria) lefranci* Tasch from Algeria, Africa (Senonian, Upper Cretaceous) and *Cyzicus (Euestheria) anomala* Jones from the Uitenhage Series in South Africa (Lower Cretaceous) (Tasch, 1987).

Preliminary studies on *Pseudestherites* sp. from the Cañadón Calcáreo Formation indicate that it resembles *P. musacchioi* from the La Amarga Formation. These South American findings of the genus *Pseudestherites* and related forms are the first records outside China. Therefore, they provide additional information on the wide palaeogeographic and short stratigraphic distribution of this conchostracan genus and also its great potential as a chronologic tool.

The record of *Congestheriella* sp. in this study supports previous studies on the Cañadón Asfalto Formation (upper section) that report the presence of this genus at three different localities (Sierra de la Manea, Puesto Limonao and Estancia Fossati). This genus has also been documented from the Upper Jurassic (Kimmeridgian to Tithonian) to Lower Cretaceous (Berriasian to Barremian) successions from Brazil, Venezuela and Central Africa (Gallego et al., 2003).

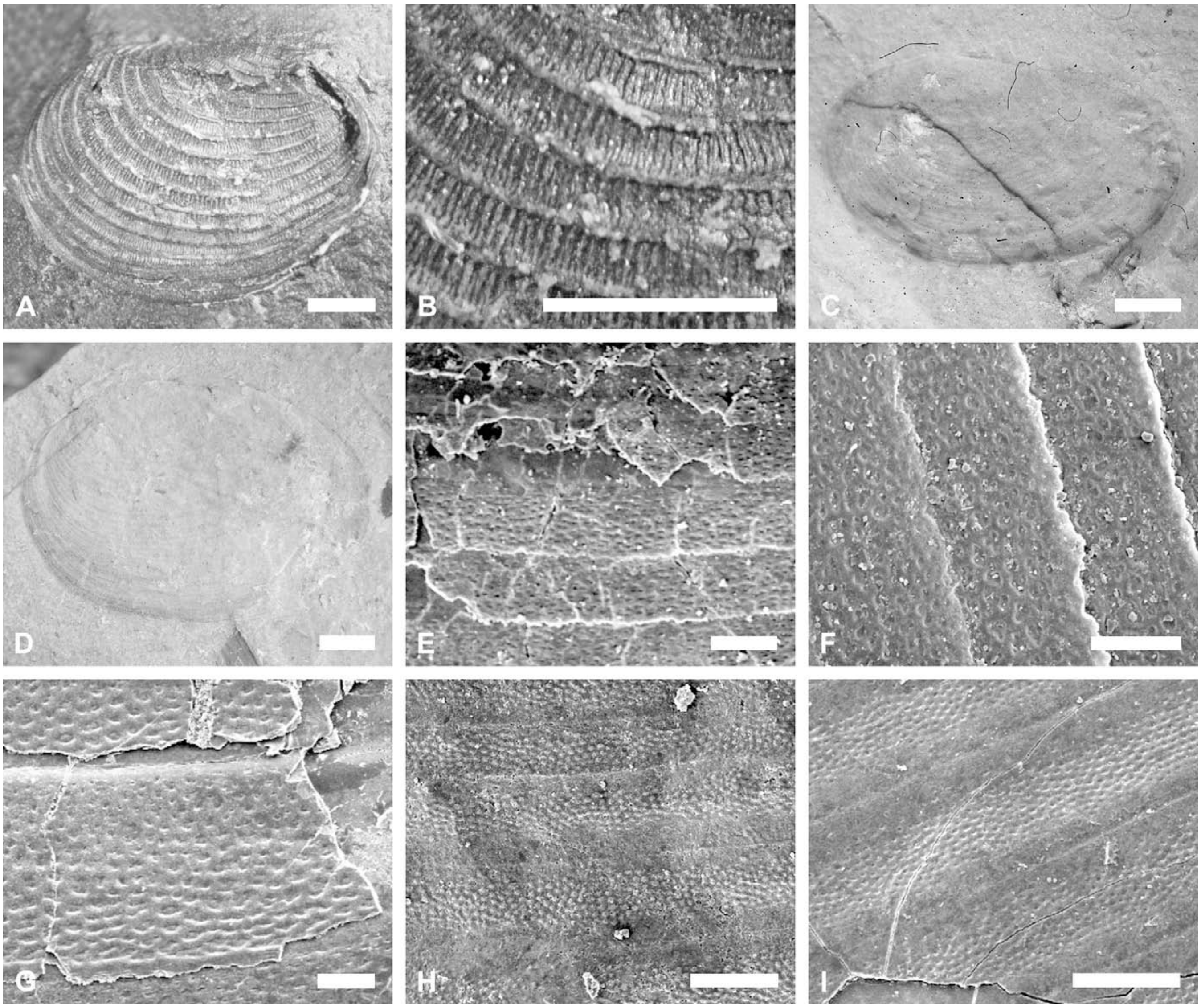

Fig. 11. A-B. *Nemestheria* (*Zhestheria*) sp. **A.** General view of the ovate outline carapace and the strong radial striae. **B.** Detail of the carapace surface showing the striated ornamentation bifurcated downward and with beads on the growth lines, 1176 MPEF-PI. **C-D.** *Pseudestherites* sp. **C.** Elliptical outline carapace, 1177 MPEF-PI. **D.** Ovate outline carapace, 1177 MPEF-PI. **E.** *Pseudestherites* sp., SEM micrograph showing details of the cavernous ornamentation in mid-ventral area of the carapace, 7389 CTES-PZ. **F, H-I.** *Pseudestherites* sp. from El Portezuelo locality, details of the carapace surface showing the ornamentation ranging from small to large elliptical cavities, 7394 CTES-PZ. **G.** *Pseudestherites musacchioi* Gallego and Shen (2004), 7294 CTES-PZ. **A-D**: Scale bar = 1 mm. **E-I**: Scale bar = 0.05 mm.

5.2. Conchostracostratigraphy

The conchostracan assemblage identified in this unit is notably different from the Middle Jurassic conchostracan faunal records of the underlying Cañadón Asfalto Formation (“lower section”), studied at different localities of the Cerro Cóndor depocentre (Tasch and Volkheimer, 1970; Vallati, 1986). It is composed of species of the families Euestheriidae, Eosestheriidae, Palaeolimnadiopseidae and Fushunograptidae (Gallego et al., 2002, 2003). On the other hand, the Cañadón Calcáreo assemblage shares with the “upper section” of the Cañadón Asfalto Formation, the presence of *Pseudestherites* and probably *Congestheriella*.

There is also a remarkable difference with the Tithonian *Nestoria-Keratestheria* fauna (early Jehol Biota, Upper Jurassic) and the *Eosestheria* fauna (Jehol Biota, Lower Cretaceous) recorded from northern Hebei, China, due to their different taxonomic composition (Li et al., 2007). However, our association resembles the *PYDEO* assemblage from North China (Chen, 1994), which includes the genera *Pseudestherites*, *Yanjiestheria*, *Diestheria*, *Eosestheria* and *Orthestheria*, recovered from four Berriasian to Hauterivian stratigraphic units. He also mentioned the *Nemestheria* and *Euesthertes* faunas. The first of these is restricted to the early Late Cretaceous (Cenomanian), and includes several species of *Nemestheria* and also the genera *Ganestheria*, *Sinoestheria* and *Orthestheria.* This fauna is recorded from the Qingshankou Formation (northeastern China) and the Matoushan Formation (southwestern China). The Cenomanian age of the fauna is based on its presence in non-marine intercalations between the marine Cenomanian formations from Texas and western China. The *Euestherites* fauna, on the other hand, is restricted to the Turonian-Santonian of northern China. It is composed of members of the Jilinestheriidae (*Nemestheria*), Halysestheriidae, Estheriteidae and Dismorphostraciidae families, with descriptions of more than 100 species.

The records of *Pseudestherites* sp. and *Nemestheria* (*Zhestheria*) sp. in the Cañadón Calcáreo Formation bring new additional information to establish the age in the unit. The appearance *Pseudestherites* in the global record ranges from the Berriasian to the

Albian in the Lower Cretaceous. The Cenomanian age of the *Nemestheria* (*Zhestheria*) species from China would indicate that the Cañadón Calcáreo species could be an ancestral Early Cretaceous form of this genus.

6. Conclusions

The sedimentary environments in which the Cañadón Calcáreo Formation of Extra-Andean central Patagonia accumulated correspond to lacustrine and fluvial facies associations in the lower part of the formation and to multi-episodic fluvial channels, alternating with flood-plain in the middle and upper parts of the section.

These associations differ from the facies associations of the Cañadón Asfalto Formation depocentres but are comparable to those of the Chubut Group.

The palynomorph assemblage is characterized by the dominance of the genera *Classopollis* and *Callialasporites.* It is comparable with "Palynozone A" (Berriasian and Valanginian), of Archangelsky et al. (1981), for associations that developed immediately before the massive influx of *Cyclusphaera psilata.*

A swampy palaeoenvironment is inferred from the palynomorph assemblage, through the presence of a hygrophile community of Bryophyta, and another composed of Lycopodiaceae, Selaginellaceae and numerous families of ferns. *Classopollis* indicates warm climatic conditions and the presence of well drained soils in the lowlands. The Araucariaceae (*Araucariacites* spp., *Callialasporites* spp.) inhabited areas not far from the lowland depositional site studied here, while the Podocarpaceae were probably at higher topographic levels.

The conchostracan assemblage is characterized by the dominance of *Nemestheria* (*Zhestheria*) sp. and *Pseudestherites* sp., both of which comprise monospecific associations that probably indicate two different phases in the lacustrine system. The first is similar to the younger (Cenomanian) *Nemestheria* fauna from China (Chen, 1994), and is also partially comparable to Assemblage VII from South America (Gallego and Martins-Neto, 2006), with species that range in age from the Valanginian to the Santonian; one of these (*Bauruestheria sancarlensis*), belongs to the same family as *Nemestheria*. Chronologically, *Pseudestherites* is an interesting form because it ranges from the Berriasian to the Albian. It is comparable to the *PYDEO* assemblage from China (Berriasian to Hauterivian) and is also related to the Neocomian Assemblage IV (Gallego and Martins-Neto, 2006) by the presence of *P. musacchioi* (late Hauterivian-Barremian).

The conchostracan association suggests an Early Cretaceous age for the assemblage-bearing level. The assemblage of palynomorphs indicates a Valanginian age for the middle part of the Cañadón Calcáreo Formation at its type locality.

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