The palynology of the Cañadón Asfalto Formation (Jurassic), Cerro Cóndor depocentre, Cañadón Asfalto Basin, Patagonia, Argentina: palaeoecology and palaeoclimate based on ecogroup analysis

Daniela E. Olivera\textsuperscript{ab}, Ana M. Zavattieri\textsuperscript{c} & Mirta E. Quattrocchio\textsuperscript{b}

\textsuperscript{a} Departamento de Geología, Universidad Nacional del Sur, San Juan 670, 8000 Bahía Blanca, Argentina
\textsuperscript{b} CONICET-INGEOSUR, San Juan 670, (8000) Bahía Blanca, Argentina
\textsuperscript{c} CONICET-IANIGLA, Centro Científico Tecnológico-Mendoza, A. Ruiz Leal s/n, Parque Gral San Martín, CC 330, 5500 Mendoza, Argentina.

Published online: 11 Mar 2015.

To cite this article: Daniela E. Olivera, Ana M. Zavattieri & Mirta E. Quattrocchio (2015): The palynology of the Cañadón Asfalto Formation (Jurassic), Cerro Cóndor depocentre, Cañadón Asfalto Basin, Patagonia, Argentina: palaeoecology and palaeoclimate based on ecogroup analysis, Palynology, DOI: \texttt{10.1080/01916122.2014.988382}

To link to this article: \texttt{http://dx.doi.org/10.1080/01916122.2014.988382}

PLEASE SCROLL DOWN FOR ARTICLE
The palynology of the Cañadón Asfalto Formation (Jurassic), Cerro Cóndor depocentre, Cañadón Asfalto Basin, Patagonia, Argentina: palaeoecology and palaeoclimate based on ecogroup analysis

Daniela E. Olivera\textsuperscript{a,b,*}, Ana M. Zavattieri\textsuperscript{c} and Mirta E. Quattrocchio\textsuperscript{b}

\textsuperscript{a}Departamento de Geología, Universidad Nacional del Sur, San Juan 670, 8000 Bahía Blanca, Argentina; \textsuperscript{b}CONICET-INGEOSUR, San Juan 670, (8000) Bahía Blanca, Argentina; \textsuperscript{c}CONICET-IANIGLA, Centro Científico Tecnológico-Mendoza, A. Ruiz Leal s/n, Parque Gral San Martín, CC 330, 5500 Mendoza, Argentina.

The Cañadón Asfalto Formation, Cañadón Asfalto Basin, Patagonia, Argentina, is interpreted as fluvial-lacustrine deposits. A palynological study of the lower and middle parts of the unit, at the Cañadón Lahuincó and Cañadón Caracoles sections, Cerro Cóndor Depocentre Chubut province, northwestern Patagonia, Argentina is presented. The quantitative composition of the palynofloras is characterised by the dominance of pollen produced by the conifer families Cheirolepidiaceae (\textit{Classopollis}) and Araucariaceae (mainly \textit{Araucariacites} and \textit{Callialasporites}), suggesting that warm-temperate and relatively humid conditions under highly seasonal climate prevailed during the depositional times of the unit. The abundance of \textit{Botryococcus} supports the presence of a shallow lake with probably saline conditions. Five palynomorph ecogroups (PEGs) were recognised: upland, lowland, riverside, coastal lake and aquatic. The ecological requirements of the different plant families forming the PEGs enable the inference of a sub-tropical palaeoclimate for the Cañadón Asfalto region during late Early Jurassic to mid Middle Jurassic, which is consistent with the ‘seasonally dry (winterwet)’ biome.

**Keywords:** palynology; palaeoecology; palaeoclimate; Cañadón Asfalto Formation; Patagonia; Early to Middle Jurassic; Argentina

1. Introduction

The Cañadón Asfalto Formation at Cerro Cóndor Depocentre, Cañadón Asfalto Basin, represents one of the most important records from the continental Jurassic in Extra-Andean Patagonia, Argentina. It is typically exposed in the middle valley of the Chubut River and surrounding areas, between the localities of Paso de Indios and Paso del Sapo, Chubut Province, southern Argentina (Figure 1). These deposits are known for their well-preserved biota, mainly dinosaurs and other vertebrates. The vertebrate faunas of this unit are one of the most important representatives of Gondwana by their richness, with more than 20 species from different taxonomic groups, including sauropods, theropods, ornithischians, pterosaurs, sphenodonts, mammals, fish, frogs, turtles and crocodiles (Sterli et al. 2010). Additionally, several fossil plants, freshwater invertebrates and insect taxa were recorded from the lacustrine sediments (Escaña et al. 2008; Cabalerí et al. 2010; Monferrán et al. 2010). Despite the diversity and richness of the fossil assemblages recorded in the Cañadón Asfalto Formation, some aspects remain unresolved, such as its chronological age range and the palaeoecological and palaeoclimatic implications based on palynological data.

The earliest palynological studies on the Cañadón Asfalto Formation in the study area were carried out by Volkheimer (1971), Pothe de Baldis (in Nullo & Proserpio 1975) and Volkheimer et al. (2001, 2008). Volkheimer et al. (2008) proposed a Middle Jurassic age (latest Early Bajocian to Early Bathonian) for a palynological assemblage recognised in the Lahuincó creek (Figure 1). Zavattieri et al. (2010) suggested an Early Middle Jurassic (Late Aalenian—Middle Bathonian) age, based on its palynological content recorded in a partial section of the Cañadón Asfalto Formation.

This paper focuses on the palynological study of the Cañadón Asfalto Formation outcropping in the Cerro Cóndor area (Figure 1), where three stratigraphical sections were measured. Two of them were sampled at Lahuincó creek, which is located 15 km south of Cerro Cóndor village (Figure 1), named Cañadón Lahuincó ‘A’ (S43°30'59", W69°8'20") and Cañadón Lahuincó ‘B’, situated about 250 m west of the former (Figure 2). The third section is located 11 km north of Cerro Cóndor village, at Cañadón Caracoles creek (S43°24'8.01", W69°9'34.79") (Figures 1 and 2). The detailed palynological study of these stratigraphical sections increases the palaeofloristic knowledge on the

*Corresponding author. Email: daniela.olivera@uns.edu.ar

© 2015 AASP – The Palynological Society
Cañadón Asfalto Formation, at Cerro Condor Depocentre.

In order to understand plant distribution and evolution through time, we used sporomorph ecogroups (SEGs), a term introduced by Abbink (1998) and Abbink et al. (2004), with some modifications. This concept is based on particular taxa with broadly similar ecological preferences that characterise distinctive habitats or palaeocommunity types. The total types of dispersed spores and pollen of land plants reflect, partially, the composition of an individual terrestrial source community. In the present analysis, we also take into account the distribution of aquatic palynomorphs (Charophyta, Chlorophyta algae and acri-tarchs) in order to propose an integrated palaeoenvironmental setting recorded for the Jurassic Cañadón Asfalto Formation deposition. Therefore, the term ‘sporomorph ecogroup’ is herein substituted by ‘palynomorph Ecogroup’ (PEG). Cluster analysis was applied to analyse the present palynological data in order to characterise different ecosystems on the bases of the palynomorph groups. The aim of this paper is to assess the palaeoecological significance of the Cañadón Asfalto palynoflora and its importance in the evolution of the ecosystem.

2. Geologic setting and sedimentary environment of the Cañadón Asfalto Basin

Two interpretations were proposed for the tectono-sedimentary evolution of the Cañadón Asfalto Basin. Figari & Courtade (1993), Cortinhas (1996), Figari et al. (1996) and Figari (2005) interpreted the Cañadón Asfalto Basin as a rift developed from the Triassic through to the Late Cretaceous, related to the widespread extensional forces during the Gondwana breakup that affected Patagonia. More recently, Silva Nieto et al. (2007) and Cabaleri et al. (2010), among others,
suggested that the Cañadón Asfalto Basin could have been formed by several depocentres (i.e. Cerro Cóndor, Cañadón Calcáreo, Estancia Fossati and Yanketruz) which were not strictly contemporaneous. They related them to extensional to transtensional tectonism (strike-slip or pull-apart basin) and thermal subsidence. According to these authors, each Depocentre would be composed of an isolated basin with its own evolutionary tectono-sedimentary history.

The basement of the basin exposed near the study area consists of igneous and metamorphic rocks from the Mamil Choique Formation assigned to the Early Permian (Cúneo et al. 2013). This unit is characterised by the presence of migmatics, foliated granitoids and
granitoids without deformation (Costa et al. 1996). The rocks of the Jurassic basin overlie this basement. The sequence starts with a thin unit of volcaniclastic and fluvial sediments named the Las Leoneras Formation (and its correlatives), assigned to the Early Jurassic, most probably the latest Sinemurian (Cúneo et al. 2013). The Lonco Trapial Formation overlies this unit; it is composed of a thick (up to 300 m) sequence of brecciated andesitic lavas, dacitic and andesitic tuffs, conglomerates and fine to medium tuffaceous sandstone intercalations, lahar deposits and poorly stratified volcanic agglomerates (Cabaleri & Armella 2005). This unit has been recently assigned to an age range between 188.95 and 178.77 Ma (Pliensbachian—Toarcian) (Cúneo et al. 2013). The Cañadón Asfalto Formation overlies the Lonco Trapial Formation by concordant or gradational contact (Figari 2005). This unit is composed of fluvio-deltaic lacustrine sediments, with basaltic intercalations in the lower part of the sequence and tuffs at the top. Cúneo et al. (2013) proposed an Early/Mid Toarcian—Aalenian/ Bajocian age to the Cañadón Asfalto Formation, based on the analysis of six tuff samples by the Uranium—Pb (lead) analyses of zircon (chemical abrasion-thermal ionization mass spectrometry [CA-TIMS] method). Silva Nieto et al. (2003) and Cabaleri et al. (2010) identified two members in this unit: the Las Chacritas Member in the lower part of the sequence and the Puesto Almada Member in the upper section. The former consists of lacustrine sediments with volcanic intercalations at the base, while the latter is mainly siliciclastic and represents a prograding fluvial system on the previous lacustrine deposits. In this study, we do not recognise such a subdivision for the Cañadón Asfalto Formation (Olivera 2012; Olivera et al. 2014). This formation is unconformably overlain by fluvial to lacustrine deposits of the Cañadón Calcáreo Formation. The deposition of the Cañadón Calcáreo Formation started prior to ca. 158 Ma, probably in the Oxfordian, and continued during the Late Jurassic (Cúneo et al. 2013). The previously mentioned formations are unconformably overlain by continental Cretaceous deposits of the Chubut Group (Cabaleri & Armella 2005).

3. Materials and methods

3.1. Sampling and laboratory treatments

A total of 114 outcrop samples of very fine sandstones, siltstone and mudstone were collected from the lower and middle parts of the Cañadón Asfalto Formation (Figure 2; Table 1). Fifty-one palynologically productive samples were studied. The physical and chemical extraction of palynomorphs was carried out at the Palynological Laboratory of the Instituto Geológico del Sur.

<table>
<thead>
<tr>
<th>Stratigraphical sections</th>
<th>Field number</th>
<th>Lab code</th>
<th>Depth from base (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cañadón Lahuincó ‘A’</td>
<td>28032008 01</td>
<td>MLP 551</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>28032008 02</td>
<td>MLP 552</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>28032008 03</td>
<td>MLP 553</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>28032008 04</td>
<td>MLP 554</td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td>28032008 05</td>
<td>MLP 555</td>
<td>4.30</td>
</tr>
<tr>
<td></td>
<td>28032008 06</td>
<td>MLP 556</td>
<td>5.60</td>
</tr>
<tr>
<td></td>
<td>28032008 07</td>
<td>MLP 557</td>
<td>7.00</td>
</tr>
<tr>
<td></td>
<td>28032008 09</td>
<td>MLP 559</td>
<td>9.50</td>
</tr>
<tr>
<td></td>
<td>28032008 10</td>
<td>MLP 560</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>28032008 11</td>
<td>MLP 561</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>28032008 14</td>
<td>MLP 564</td>
<td>15.3</td>
</tr>
<tr>
<td>Cañadón Lahuincó ‘B’</td>
<td>CC01</td>
<td>MPEF-PALIN154</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>CC02</td>
<td>MPEF-PALIN155</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>CC05</td>
<td>MPEF-PALIN157</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>CC08</td>
<td>MPEF-PALIN161</td>
<td>103.2</td>
</tr>
<tr>
<td></td>
<td>CC13</td>
<td>MPEF-PALIN166</td>
<td>114.5</td>
</tr>
<tr>
<td></td>
<td>CC15</td>
<td>MPEF-PALIN168</td>
<td>136.9</td>
</tr>
<tr>
<td></td>
<td>CC16</td>
<td>MPEF-PALIN169</td>
<td>139.4</td>
</tr>
<tr>
<td></td>
<td>CC18</td>
<td>MPEF-PALIN170</td>
<td>165.9</td>
</tr>
<tr>
<td></td>
<td>CC20</td>
<td>MPEF-PALIN172</td>
<td>170.1</td>
</tr>
<tr>
<td></td>
<td>CC22</td>
<td>MPEF-PALIN174</td>
<td>177.4</td>
</tr>
<tr>
<td></td>
<td>CC23</td>
<td>MPEF-PALIN175</td>
<td>177.6</td>
</tr>
<tr>
<td></td>
<td>CC24</td>
<td>MPEF-PALIN176</td>
<td>178.9</td>
</tr>
<tr>
<td></td>
<td>CC26</td>
<td>MPEF-PALIN178</td>
<td>180.7</td>
</tr>
<tr>
<td></td>
<td>CC27</td>
<td>MPEF-PALIN179</td>
<td>181.1</td>
</tr>
<tr>
<td></td>
<td>CC29</td>
<td>MPEF-PALIN181</td>
<td>182.3</td>
</tr>
<tr>
<td></td>
<td>CC30</td>
<td>MPEF-PALIN182</td>
<td>183.0</td>
</tr>
<tr>
<td></td>
<td>CC32</td>
<td>MPEF-PALIN183</td>
<td>185.0</td>
</tr>
<tr>
<td></td>
<td>CC35</td>
<td>MPEF-PALIN186</td>
<td>186.0</td>
</tr>
<tr>
<td></td>
<td>CC43</td>
<td>MPEF-PALIN194</td>
<td>205.08</td>
</tr>
<tr>
<td></td>
<td>CC49</td>
<td>MPEF-PALIN200</td>
<td>214.08</td>
</tr>
</tbody>
</table>

Table 1. List of 51 palynologically productive samples from the Cerro Cóndor area used for the present study.
may show palaeoclimatic trends. The upland plant communities (mainly represented by saccate pollen grains) provide a long-distance influx (allochthonous elements) to the depositional setting, reflecting a wider diversity of the regional vegetational influence to the autochthonous coastline and lowland plant communities. However, as mentioned by many authors (e.g. Bat-ten 1974; Quattrocchio et al. 1996), the distribution of pynomorphs is related to the sedimentary facies. Thus, in the same sequence, in different positions of a transect, the composition of the palynological assemblages can change in a lateral direction.

The botanical affinities of spores, pollen grains and organic-walled microplankton from the Cañadón Asfalto Formation are given in Table 2.

The high frequencies of Classopollis (Cheirolepidiaceae) may be the product of many factors, such as transportational sorting, allowing an enrichment of this pollen type in the assemblages (Volkheimer et al. 2008; Schrank 2010), a possible high productivity of the parent plants and/or the habitat in which they were developed (marginal vegetation) near the site of deposition. The palaeoecological significance of Classopollis and its parental plant has been widely discussed. Many authors have considered that they were drought resistant (seasonal climate) thermophyous shrubs and trees (Sajjadi & Playford 2002b). However, this condition may vary within quite broad limits (Alvin 1982). Va-krameev (1981) suggested that, if the Araucariaceae grow together with the Cheirolepidiaceae, the climate conditions might be warm to moderate-warm and relatively humid. The majority of the current araucariacean plants are developed in rainy forests under subtropical-temperate climate (mesothermal) and, less frequently, under temperate to temperate-cold conditions (microthermal climate) (Panti et al. 2012). However, Abbink (1998) interpreted that their thick-cuticled leaves, which characterise their foliage, allow them to develop in regions submitted to periodic dry seasons. Quattrocchio et al. (2001) observed that this group actually grows in the Planalto of southern Brazil (mountain region up to 1000 m above sea level) where they are associated with the podocarpaceae. When an increase in temperature occurred, the Podocarpaceae disappeared, and the auracariaceans migrated to the lower part of the valleys (with high humidity levels). Caccavari (2003) demonstrated that, due to the morphological and structural features of auracariacean pollen, such as the large size and the exine structure, they have a weak capacity for long-distance transport, especially wind transport. Therefore, it is suggested that rivers and/or runoff were the main transportation agents of these pollen types.

The extant Podocarpaceae comprise trees or shrubs that occupy a wide range of ecological niches, from
lowland heaths to forests and subalpine vegetation (Scholtz 1985). They especially develop in mountainous areas of tropical and subtropical regions (Schrank 2010). Sajjadi & Playford (2002b, p.152), by analogy with the modern *Microcachrys* – a shrubby podocarp inhabiting the present Tasmanian subalpine region – suggested that the ancient taxon might have grown in cool-temperate conditions in upland situations. In general, most of the fossil-genera representatives of pinaceous plants lived in temperate and relatively dry environments under cool conditions, at least in upland situations (Abbink 1998).

Pteridosperms are represented by the genera *Alisporites* and *Vitreisporites*. The parental family of the fossil genus *Alisporites* presents xeromorphic features, and they are common under seasonal climates (Artabe et al. 2001). The producers of *Vitreisporites* pollen grains (Caytoniaceae) are thought to have

<table>
<thead>
<tr>
<th>Division</th>
<th>Class</th>
<th>Order</th>
<th>Family</th>
<th>Genera-Palynoflora</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bryophyta</strong></td>
<td>Anthocerotopsida</td>
<td>Anthocorales</td>
<td>Anthocerotaceae</td>
<td>Nevesisporites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sphagnaceae</td>
<td>Steresporites, Antulusporites</td>
</tr>
<tr>
<td><strong>Lycopsida</strong></td>
<td>Selaginellales/ Selaginellaceae</td>
<td>Lycopodiaceae</td>
<td>Retritiles, Ceratosporites, Neoraistickia</td>
<td>Stiplinisporites</td>
</tr>
<tr>
<td></td>
<td>Lycopodiophyta</td>
<td>Lycopodiaceae</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ficopsida</strong></td>
<td>Marattiales</td>
<td>Marattiaefo</td>
<td>Biretisporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filicales</td>
<td>Filicaefo</td>
<td>Cyathecaceae/Dicksoniaace</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dipteridaceae/Matoniaace</td>
<td></td>
</tr>
<tr>
<td><strong>Tracheophyta</strong></td>
<td>Undifferentiated</td>
<td>(Incertae sedis)</td>
<td>Deltoidospora, Dictyophyllidites, Trilobosporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Incertae sedis)</td>
<td>?Gramulatisporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gleicheniaceae</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gleicheniidites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Osmundaceae</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Todisporites, Verrucosisporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Schizaceae</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Klukisporites, Ischyosporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Undifferentiated (Incertae sedis)</td>
<td>Cadargasporites</td>
</tr>
<tr>
<td><strong>Cycadales/ Benettitales</strong></td>
<td>Filicaefo</td>
<td>Filicaefo</td>
<td>Cycladaceae</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycladopites, Monosulcites</td>
<td></td>
</tr>
<tr>
<td><strong>Gymnospermopsida</strong></td>
<td>Pteridospermales</td>
<td>Corystospermaceae</td>
<td>Alisporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Caytoniaceae</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vitreisporites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Araucariaceae</td>
<td>Inaperturopollenites, Araucariacites, Callialasporites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cheirolepidiaceae</td>
<td>Classopolis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pinaceae</td>
<td>Indusistripites, Cerebropollenites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Podocarpaceae</td>
<td>Podocarpidites, Microcachryidites, Podosporites, Trisaccites</td>
</tr>
<tr>
<td><strong>Charophyta</strong></td>
<td>Zygmenatophyceae</td>
<td>Zygmenatales</td>
<td>Zygmenataceae</td>
<td>Ovoidites</td>
</tr>
<tr>
<td><strong>Chlorophyta</strong></td>
<td>Trebouxiphyceae</td>
<td>Botryococcaefo</td>
<td>Botryococcus</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Quantitative distribution of major palynomorph groups in the Cañadón Asfalto Formation, expressed in percentages of total palynoflora based on 51 selected samples.
5. Results

5.1. Composition of the Cañadón Asfalto palynoflora

The studied strata interval contains taxonomically diverse spore assemblages, pollen grains and organic-walled microplankton from freshwater environments, comprising 71 species (see Table 2; Appendix 1). The trilete spores (Plate 1, figures 1–20) are represented by 24 species belonging to 20 genera. Pollen grains (Plate 2; Plate 3, figures 1–12) record 41 species allocated in 12 genera and four aquatic species of Zygmemataceae and Botryococcaceae families’ algae (Plate 3, figures 13–15) and acritarchs (Leiosphaeridia spp.) (Plate 3, figure 16).

In this section, we analyse the most important palynomorph groups that contributed to the composition of the Cañadón Asfalto Formation palynoflora. The three studied sections are characterised by a high diversity of vegetation sources; the coniferophytes were clearly the most abundant component as indicated by the palynological record (Figure 3). The most conspicuous feature of this palynoflora is the dominance of Cheirolepidiaceae (Classopolis), reaching up to 95% of the total spectrum of palynomorphs (Figure 3). This family is associated to araucariacean pollen, which constitutes the numerically second most important sporomorph group (Figure 3).

The distribution of the palynomorphs in the three studied sections is thoroughly analysed below, based on applied statistical methods.

5.2. Cañadón Lahuínco ‘A’ section

The palynological assemblages recorded in this section are characterised by the greatest abundance and diversity of conifer pollen grains and the lowest frequencies of spores of the three studied sections (Figure 3). In the cluster analysis, four groups of samples, designated A–D (Figure 4), are recognised. The cophenetic correlation coefficient of the cluster analysis is 0.8831.

Samples MPEF-PALIN104 and MPEF-PALIN106, of claystone and siltstone lithologies, were excluded from this analysis due to the fact that the palynomorph content is only represented by Botryococcus colonies. These palynological associations contain the highest percentages of this alga identified in the three studied sections (Figure 3). The assemblages are characterised by colonies with an excellent preservation state, where ‘growth rings’ are recognised, without autospores, and by skeletal colonies with the tendency to form structureless masses (Plate 3, figures 13 and 15). These palynofloras are assigned to the Aquatic PEG (Table 3; Figure 5).

5.2.1. Group A (Figure 4)

This group of two siltstone samples has high percentages of Botryococcus colonies (46.5 to 57%), and the terrestrial component is represented by the association...
of cheirolepidean and araucariacean pollen (Figures 3 and 4). In the two levels, Classopollis pollen shows similar frequencies (ca. 35%), but in MPEF-PALIN119, araucariacean grains are particularly prominent (18%). These characteristics are mainly indicative of coastal and lowland vegetation (e.g. Alvin 1982). These conditions are in accordance with the Coastal Lake and Lowland PEGs (Table 3; Figure 5). In addition, the abundant presence of chlorophytic algae indicates an important development of Aquatic PEG (Table 3).

5.2.2. Group B (Figure 4)

This group comprises four siltstone samples (Table 1 and Figure 2). These associations are characterised by high percentages of Botryococcus colonies (96 to 70%) indicating the predominance of the Aquatic PEG (Table 3; Figure 5). However, Upland (mainly Podocarpaceae and Pinaceae and in part Araucariaceae), Coastal Lake (Cheirolepidiaceae) and Riverside (bryophyte, lycophyte and fern spores, Corytostpermaeae, Caytoniaceae, Cheirolepidiaceae and Araucariaceae) PEG components are also present (Table 3; Figure 3). The association of pinean and podocarpacean pollen (Upland PEG) reflects the incoming of the upland forest by air and/or runoff to the basin (Table 3).

5.2.3. Group C (Figure 4)

This group of siltstone samples and thin coal presents the highest percentages of Classopollis pollen grains in the Cañadón Lahuincó ‘A’ section (81.45 to 91.75%; Figures 3 and 4), showing a strong contribution of the Coastal Lake PEG to these associations. In these assemblages, araucariacean pollen is present in all studied samples. The co-occurrence of these two conifer groups suggests the development of the Riverside and/or Lowland PEGs. Caytoniacean pollen (up to 0.8%) reinforces the existence of these PEGs (Table 3). The presence of Botryococcus colonies (2 to 4.7%) in three of the six samples grouped here points to the development of the Aquatic PEG in these levels (Figures 3 & 5).

5.2.4. Group D (Figure 4)

5.2.4.1. Subgroup D1. Three samples of siltstone and very fine sandstone define this cluster (Table 1; Figure 2). Although these assemblages have high frequencies of Classopollis (57 to 70%), they also show the highest percentages of araucariacean pollen of all the samples studied (14 to 25%; Figure 3). Stukins et al. (2013, p. 120) interpreted the association of Cheirolepidiaceae and Araucariaceae pollen as a vegetal community that commonly grows on floodplains with mature and well-drained soils. Therefore, the Araucariaceae is mainly related to the Riverside and/or Lowland PEGs (Table 3; Figures 3 and 5). However, the Araucariaceae also grow in mixed forests with Podocarpaceae and Pinaceae in upland regions. Consequently, part of this material may arrive to the basin by runoff and fluvial currents from the Upland PEG, particularly in samples in which araucariaceans, podocarpaceans and/or piceane occurred together (Table 3; Figure 5). The presence of chlorophytic algae, especially in MPEF-PALIN133 (16.6%), may be suggesting the development of the Aquatic PEG (Table 3; Figures 3 and 5).

5.2.4.2. Subgroup D2. This cluster comprises siltstone and very fine sandstone samples (Table 1; Figure 2). The palynological assemblages are dominated by Classopollis pollen grains (71.25% on average) and show the common presence of Botryococcus colonies (14 to 25.6%) and Caytoniaceae pollen (0.4 to 1.1%). Podocarpaceae (2.2 to 3%) and Araucariaceae (ca. 5%) were identified in the two lower samples, and Pinaceae in the upper sample (1.8%; Table 1; Figures 2–4). Podocarpaceae and Pinaceae, and part of the Aracucariaceae pollen, constitute long-distance fluvial and/or atmospheric inputs.
mainly originating from the terrestrial vegetation of adjacent uplands (Upland PEG). The coexistence of Cheirolepidiaceae, Caytoniaceae and Botryococcaceae in the three levels suggests a littoral lacustrine environment with an important fluvial influx in the lacustrine sediments (Coastal Lake, Riverside and Aquatic PEGs; Table 3; Figure 4).

5.3. Cañadón Lahuincó ‘B’ section (Figures 1 and 2)
Although the Cheirolepideaceae is the most conspicuous element in the Cañadón Asfalto palynoflora, comparatively, these assemblages show the greatest abundance and diversity of bryophyte, lycopsid and filicopsid spores of the three studied sections. The planktonic material is scarce; few colonies of Botryococcus in a poor state of preservation and some spores of Ovoidites (related to the extant Zygmemataceae family) (Zippi 1998) are registered (Figure 3). Cluster analysis recognised three groups of samples and one outlier (MLP561), with the cophenetic correlation being 0.8085 (Figure 6). Sample MLP561 of siltstones with wavy lamination (Table 1; Figure 2) shows a long association distance in cluster analysis (Figure 6). The main difference from the other assemblages is the relatively high percentage of trilete spores (14.2%), among which ferns represent the most abundant group. They are associated with the higher percentages of pinacean, podocarpic and araucariacean pollen of the studied section. The other components (except Classopollis

Figure 4. Cluster analysis, using Euclidean distance and the unweighted pair group method (UPGM), showing the grouping of the identified palynological assemblages in the Cañadón Lahuincó ‘A’ section.
Table 3. Schematic classification of the proposed palynomorph ecogroups (PEGs) with an overview of the common sporo-morphs and phytoplankton recorded in the present study and considered to be characteristic of the various PEGs (modified from Abbink 1998). Principal source of climatic inferences: Abbink (1998), Guy-Ohlson (1992), Quattrocchio et al. (2001) and Martínez et al. (2008). Bryophyte spores are included in the PEGs, indicating local humid conditions.

<table>
<thead>
<tr>
<th>Palynomorph ecogroups (modified from Abbink 1998 and Abbink et al. 2004)</th>
<th>Genera</th>
<th>Palaeoclimate indicators</th>
</tr>
</thead>
</table>
| Upland (UpL) | **Inaperturopollenites**  
**Araucariacites Calliadasporites** | ?Warm to temperate, relatively wet |
|  | **Microacryhidites**  
**Podocarpidites**  
**Podosporites**  
**Indusisporites** | Temperate, relatively dry |
|  | **Neoraistrickia**  
**Obtuissporis**  
**Deltoispora, Dictyophyllidites**  
**Trilobosporites**  
**Todisporites**  
**Klukisporites**  
**Ischyosporites**  
**Cadargasporites** | Warm to temperate, relatively wet |
|  | **Nevesisporites**  
**Stereisporites**  
**Antulsporites**  
**Todisporites**  
**Verrucosisporites** | Can withstand long periods of drought; seasonal climate |
| Lowland (LoL) | **Biretisporites**  
**Deltoispora, Dictyophyllidites**  
**Trilobosporites, Granulatisporites**  
**Gleichenidites**  
**Klukisporites**  
**Ischyosporites**  
**Cadargasporites**  
**Retitriletes**  
**Ceratosporites**  
**Neoraistrickia**  
**Staphlinisporites** | Warm to temperate, relatively wet |
|  | **Inaperturopollenites**  
**Araucariacites Calliadasporites** | ?Warm to temperate, relatively wet |
|  | **Classopollis** | Warm to temperate, can withstand long periods of drought; seasonal climate |
| Riverside (RS) | **Retitriletes**  
**Ceratosporites**  
**Neoraistrickia**  
**Staphlinisporites**  
**Biretisporites**  
**Deltoispora, Dictyophyllidites**  
**Trilobosporites**  
**Granulatisporites**  
**Gleichenidites**  
**Klukisporites**  
**Ischyosporites**  
**Cadargasporites** | Warm to temperate, relatively wet |
|  | **Nevesisporites**  
**Stereiisporites**  
**Antulsporites**  
**Alisporites**  
**Vitreisporites**. | Can withstand long periods of drought; seasonal climate |
|  | **Alisporites** | Warm, can withstand long periods of drought; seasonal climate |
|  | **Vitreisporites.** | Warm, relatively wet |
|  | **Inaperturopollenites**  
**Araucariacites Calliadasporites** | ?Warm to temperate, relatively wet |
| Coastal lake (CL) | **Classopollis** | Warm to temperate, can withstand long periods of drought; seasonal climate |
| Aquatic (A) | **Botryococcus** | Highly seasonal climate |
|  | **Ovoidites** | Temperate to warm; seasonal climate |
pollen) are present in lower proportions (Figure 3). Stukins et al. (2013, p. 120) interpreted the co-occurrence of Podocarpaceae conifers and ferns as possibly indicative of an upland ecosystem. Consequently, the Upland PEG is considered an important component of this association.

5.3.1. Group A (Figure 6)
The palynological associations have been recorded in laminated siltstones and massive claystones (Table 1; Figure 2). Although the Classopollis pollen is the most abundant taxon (69.5 to 73.5%), these assemblages also present the highest percentages of Araucariaceae pollen (16 to 19.5%) in the studied section (Figure 3). The other gymnosperm families and spores recognised in the Cañadón Asfalto palynoflora are regularly present in the three samples (Figure 3). These features suggest an important presence of the Riverside, Lowland and Coastal Lake PEGs. Conversely, the common presence in these assemblages of pinacean and podocarpacean pollen associated with the araucariacean suggests some influence of long-distance fluvial and/or atmospheric supply originating from forest regions in upland situations (Upland PEG component) (Table 3; Figure 5).

5.3.2. Group B (Figure 6)
Group B comprises five laminated siltstones samples. This cluster shows a strong influence of the Riverside, Lowland and Coastal Lake PEGs (Table 3; Figure 5), as indicated by the co-occurrence of Cheirolepidiaceae and Araucariaceae families (Figures 3 and 6). The common presence of pteridosperms and spores reinforces this inference. The development of wood communities in the upland regions is represented in the palynological assemblages by the association of podocarpacean and pinacean pollen (Figures 3). Although zygospores of Ovoidites are scarce (between 0.4 and 1%), they are regularly present in these samples, suggesting the development of a water fluvial-paludal environment that may be ephemeral (Zippi 1998).

5.3.3. Group C (Figure 6)
These assemblages have been recorded from laminate siltstone samples (Table 1; Figure 2). They show the
highest percentages of *Classopollis* (89.6–89.7%) and the lowest percentages of araucariaceous pollen in the whole studied section (4.4–6.3%; Figure 3). These characteristics suggest a strong influence of Riverside, Lowland and Coastal Lake PEGs in the ecosystem. The presence of Araucariaceae and Podocarpaceae in very low frequencies could indicate the development of forest communities relatively far from the site of deposition, the scarce representation of these communities or a decrease in runoff which may indicate a dry season (Figure 5).

5.4. Cañadon Caracoles section (Figures 1 and 2)

The palynoflora identified in this section shows high percentages of Cheirolepidiaceae associated with the common presence of Araucariaceae pollen (Figure 7). Trilete spores are represented by lycophytes and ferns. Riverside, Lowland and Coastal Lake are the PEGs with stronger representation in these palynological associations, suggesting more proximity to the terrestrial source in this part of the basin.

Two groups of samples and two outliers (MPEF-PALIN194 and MPEF-PALIN200) emerged when the palynological data were transferred into a cluster analysis (Figure 7). The cophenetic correlation is 0.9918.

5.4.1. Group A (Figure 7)

This group comprises siltstone samples (Table 1; Figure 2). These associations are characterised by the highest percentages of Araucariaceae (13.8 to 15.13 %), associated with important frequencies of *Classopollis* (73 to 81.6%; Figure 3).
5.4.1.1. Subgroup A1. This group is characterised by the highest representation of Podocarpaceae (2.3–8%; UpL PEG) in the studied section. The presence of Botryococcaceae and Zygnemataceae indicates the Aquatic PEG.

5.4.1.2. Subgroup A2. The main difference between this subgroup and the upper (A1) is the low frequencies of podocarpacean pollen (1%; Upland PEG). The presence of Zygnemataceae suggests the development of ephemeral water bodies that may be related to fluvial environments. The abundant presence of Araucariaceae and Cheirolepidiaceae, associated with pteridosperms and spores, is indicative of Riverside, Lowland and Coastal Lake PEGs (Table 3; Figure 5).

5.4.2. Group B (Figure 7). This group comprises mostly siltstone and very fine sandstone samples (Table 1; Figure 2). The most conspicuous feature of this cluster is the high contribution of the Cheirolepidiaceae to these assemblages, reaching up to 95% of the total palynomorph spectrum (Figure 3). The long-distance component (sporomorphs from upland regions), mainly represented by bisaccate pollen grains of podocarpaceans and pinaeans, is scarce or absent (Figure 3).

5.4.2.1. Subgroup B1. This subgroup comprises one sample and presents the highest percentages of spores (4.8%) in the studied section, associated with araucariacean, podocarpacean and pteridosperm (mainly corytusperms) pollen grains (Figure 3). These assemblages are indicative of Lowland, Coastal Lake and Upland PEGs (Table 3).

5.4.2.2. Subgroup B2. The Riverside, Lowland and Coastal Lake PEGs are well represented, and the
Aquatic PEG is characterised by the presence of Botryococcaceae and Zygnemataceae (Figure 3).

5.4.3. **Outlier samples (Figure 7).** The high frequencies of *Botryococcus* in samples MPEF-PALIN194 and MPEF-PALIN200 produce the separation of these levels in the cluster analysis (Figure 7). In the former, the algae represent about the 76% of the total spectrums of palynomorphs, and in the latter, this chlorophytic alga reaches 19%, indicating an important development of the Aquatic PEG (Figures 3 and 5). In these assemblages, the terrestrial material was represented by cheirolepidiacean, podocarpacean and araucarialean pollen (Figure 3), suggesting a coastal lake and upland supply to the lacustrine environment.

5.5. **Palynological correlation of the studied stratigraphical sections in the Cañadón Asfalto Formation**

Biostratigraphic units, particularly those defined by the first occurrences of taxa, allow drawing correlation lines that generally coincide with time lines (Boggs 1987). The chronostratigraphic correlation of the three studied sections (Olivera 2012) was based on the first occurrence of *Callialasporites turbatus* (*Callialasporites turbatus* Subzone of Neuquén Basin, Late Toarcian; Quattrocchio et al. 1996) and the first appearance of *Microcachryidites antarcticus* (basal boundary of *Ischyosporites marburgensis* Subzone of Neuquén Basin, Early Bajocian age; Quattrocchio et al. 1996) in the studied sections. The last occurrence of *Ischyosporites marburgensis* in two of the three sections (Cañadón Lahuinco ‘B’ and Cañadón Caracoes) suggests a Late Bajocian age by comparison with the upper boundary of *Ischyosporites marburgensis* Subzone of the Neuquén Basin (Quattrocchio et al. 1996) (Table 1; Figures 2 and 8).

It is important to remark the presence of an erosional surface (paraconcordance) in the Cañadón Lahuinco ‘A’ section (Olivera et al. 2013), below and above which the incoming of *C. turbatus* (MPEF-PALIN121) and *M. antarcticus* (MPEFPALIN123) is registered in 25 cm of thickness of this section.

6. **Palaeoecological evolution of the Cañadón Asfalto palynoflora**

Figure 8 shows the chronostratigraphic correlation of the Cañadón Asfalto Formation at Cañadón Caracoes, Cañadón Lahuinco ‘A’ and ‘B’ sections, based on palynological data. The palaeoenvironmental trend (D: dry; H: humid) of Figure 8 is based on the PEGs (Table 3).

The lowest stratigraphical part of the Cañadón Asfalto Formation is only identified in the Cañadón Lahuinco ‘A’ section (Table 1; Figures 2 and 8). It corresponds to a clastic sequence (siltstones and very fine sandstones) intercalated between two basaltic flows (Table 1; Figure 2). These sediments are characterised by the presence of monotypic *Botryococcus* assemblages (Figure 3). This chlorophytic algae suggests shallow-water conditions (Guy-Ohlson 1992; Guy-Ohlson & Lindström 1994). Bryant et al. (1994) suggested that the absence of sporomorphs in palynological associations could be related to alkaline pH, relatively oxidant Eh and biogenic activity. Therefore, the absence of sporomorphs in these samples may be the result of a selective preservation of the more resistant algal material. This notion is reinforced by the presence of the abundant taphoflora in lateral chronocorrelation levels (Escapa 2008) located on the opposite side of the Lahuinco creek. Despite this, the Aquatic PEG appears as the dominant ecosystem in this part of the sequence. The presence of simple and compound colonies showing different development stages in a single association suggests that variable seasonal conditions of the environment existed for a long time (Guy-Ohlson & Lindström 1994). Sporomorphs are gradually incorporated into the associations in the three subsequent samples included in groups B, A and D1 (Table 1; Figures 2–4), which may be in response to a relative increase in humidity, especially for MPEF-PALIN120 (Group D1), presenting a high frequency of araucarialean pollen. This enables the inference of a higher water supply in the system, which would cause the increase in the runoffs and/or ephemeral rivers. Consequently, higher percentages of araucarialean pollen and a gradual decrease of *Botryococcus* colonies are observed. These may be result of a eutrophication process (Ottone & Mancuso 2006), which could be related to a higher input of nutrients to the lake. Although the Araucariaceae family is mainly related to Lowland and Riverside PEGs, when it is associated to the Podocarpaceae and the Pinaceae, part of this group may have an upland forest source (Upland PEG).

Upwards in the Cañadón Lahuinco ‘A’ section, the incoming of *Callialasporites* is registered (Figure 8). In this part of the sequence, it was possible to identify group C, which was related to a relatively dry period and an important presence of Riverside, Lowland and Coastal Lake PEGs. Although *Classopollis* is the most abundant component of the assemblage, the influence of regional vegetation is represented by pinean and podocarpacean pollen (Upland PEG; Figure 3). North of this locality (Figure 1), in the Cañadón Caracoes section, it was also possible to recognise dry conditions (Subgroups A1 and B2) and an important contribution of the regional plant communities, especially in
subgroup A1 (Figure 8). The extensive representation of upland forests may suggest a lower position of eco-
tones, bringing these communities into closer proxim-
ity to the lowland site of deposition (Quattrocchio et al. 1996, p. 479), probably because cooler and dry
conditions prevailed. During this dry period, the
incoming of *M. antarcticus* in the Early Bajocian is reg-
istered (Figure 8, Groups B and B3).

In Cañadón Lahuincó ‘A’, Group B, a *Botryo-
coccus* bloom and an important decrease of the local
input (Cheirolepidiaceae and Araucariaceae) were identified. A negative correlation between the Cheirolepidiaceae and Araucariaceae and the Botryococcaceae (Table 2; Figure 3) was observed. The high percentages of this alga are recorded in limestones and finely laminated pelites and marls, which also yield abundant conchostracan valves (Figure 2). The numerous conchostracan assemblages were interpreted by Cabaleri et al. (2010) as episodes of mass mortality when living conditions turned unfavourable, probably due to a decrease in the water level of the palaeolake under drying conditions. The high percentages of Botryococcus and the corresponding lower values of Cheirolepidiaceae and Araucariaceae (Figures 2 and 3) agree with a dry season and consequently a reduction of water transport palynomorphs in the depositional site. In these levels, the pteridosperms are mainly represented by the fossil genus Alisporites, reinforcing the suggested drought conditions.

In the Cañadón Caracoles section, Subgroup B2, it was also possible to recognise this dry event, without the Botryococcaceae bloom. Pteridosperms in this part of the sequence are also represented by the fossil genus Alisporites. The difference between Cañadón Caracoles, north of the studied area, and Cañadón Lahuincó ‘A’ at the south is the higher presence of planktonic material and regional vegetation input (Upland PEG; Podocarpaceae/Pinaceae) in the second section in comparison to the records from the former. Remarkably, both sections end with abundant Botryococcus and low percentages of Cheirolepidiaceae and Araucariaceae pollen grain content, suggesting dry conditions and a return to an oligotrophic palaeolake. Fluctuations between relatively dry and relatively wet conditions are registered after the incoming of C. turbatus (Figure 8).

The Cañadón Lahuincó ‘B’ section represents the lateral facies towards the west of the sequence studied in the Cañadón Lahuincó ‘A’ section (Figures 1, 2 and 8). These palynological assemblages show local conditions yielding higher percentages of spores than in the other two profiles (Figure 3). Only a few Botryococcus colonies in a poor state of preservation were recognised in this sequence. Conversely, Zygmemataceae has more participation in these palynological associations. This may be related to local conditions of water bodies, e.g. stagnant ponds. Except for the MLP561 level, the Riverside, Lowland and Coastal Lake PEGs are the ecosystems with more representation in this sequence. In the mentioned sample, the high frequencies of ferns associated with long-distance pollen suggest an important influence of regional vegetation in this assemblage (Upland PEG). In fact, this level registered the first appearance of Microcachryidites antarcticus (Figure 8).

7. Palaeoclimatic considerations

Global palaeobiogeographic patterns are mainly dependent on climate and continental tectonics. Rees et al. (2000, p. 12) emphasised that ‘the effects of continental motion can be pronounced and must be considered when interpreting paleoclimates’. During the Jurassic, Argentina was located in the mid-palaeolatitudes of southwestern Gondwana. Palaeomagnetic data analyses (Iglesias Llanos et al. 2006) show that the Cañadón Asfalto Basin shifted from its highest palaeolatitude (ca. 56°) by the end of the Triassic to the end of the Sinemurian. During the Pliensbachian–Toarcian, the region moved northward, reaching the lowermost palaeolatitudes (ca. 30°) and subsequently, during the Middle to Late Jurassic, the area moved south again and eventually attained a similar position to the present day (ca. 43°).

The high proportion of Cheirolepidiaceae and Araucariaceae associated with components from upland forest ecosystems, mainly Podocarpaceae and Pinaceae which represent plants morphologically and physiologically adapted to greater moistures stress (Graham 2012), in several levels of the studied sections, suggests that the Cañadón Asfalto palynoflora accumulated under a warm-temperate climate with strong seasonality. These climatic characteristics are in agreement with the climate zone named the ‘seasonally dry (winterwet) biome’ sensu Rees et al. (2000), recording relatively dry summers and wet winters under warm-temperate climates. This biome has also been inferred by Escapa (2008) on the basis of the Cañadón Asfalto taphoflora at the Lahuincó Creek. The climatic inferences based on palynological data herein presented are supported by other proxies, such as the abundant presence of turtles and biothermal belts (Sterli 2008; Cabaleri & Armella 2005).

Abundant plant remains were also recorded in the Cañadón Lahuincó creek, mainly represented by conifers (about 90%) belonging to Araucariaceae and Cupressaceae sensu lato families and minor amounts of equisetaleans and ferns (Escapa 2008). Palynological evidence also shows a dominance of conifer pollen grains over sphenophyte, bryophyte, lycophyte and fern trilete spores. The vegetation diversity recorded in this unit provides a broad testimony to the existence of profuse late Early to mid Middle Jurassic flora, allowing the development of spectacular dinosaurs and other vertebrate faunas registered in the Cañadón Asfalto Formation (Figure 5).
8. Conclusions

The present palynological research on the Cañadón Asfalto Formation, Cerro Cónord depocentre, Cañadón Asfalto Basin, allows the following conclusions to be drawn:

- The present study increases the palynological knowledge of the Cañadón Asfalto Formation, at Cerro Cónord Depocentre. Seventy-one species of spores, pollen grains and organic-walled microplankton were recognised.
- The incoming of C. turbatus, in the sample MPEF-PALIN121 located above the second basaltic flow at Cañadón Lahuínco ‘A’ section, indicates a Late Toarcian age. The last occurrence of I. marburgensis, registered in Cañadón Lahuínco ‘B’ and Cañadón Caracoles sections, suggests a late Bajocian age. Thus, the palynoflora of the lower and middle part of the Cañadón Asfalto Formation outcropping in the surrounding area of the Cónord Cónord locality between those levels has a Late Toarcian to Late Bajocian age. Below these levels, an Early/Mid Toarcian age was proposed by Cúneo et al. (2013) based on the analysis of one tuff sample by the U–Pb analysis of zircon (CA-TIMS method).
- Five palynomorph egcroups (PEG) were recognised: Upland, Lowland, Riverside, Coastal Lake and Aquatic. Their distribution in the three studied sections is provided. A greater representation of the Lowland and Coastal Lake PEGs at the north of the studied area (Cañadón Caracoles section) suggests the development of a littoral zone in this sector. The higher presence of planktonic material (mainly Botryococcus colonies, Aquatic PEG) and long-distance transported pollen grains (Podocarpaceae and Pinaceae, Upland PEG) in the assemblages of the Cañadón Lahuínco ‘A’ sections may indicate the presence of a more distal situation in this part of the depocentre.
- Fluctuations between relatively dry to relatively wet conditions are registered after the incoming of C. turbatus (Late Toarcian). The Cañadón Lahuínco ‘A’ section and the Cañadón Caracoles section end with important frequencies of Botryococcaceae and low percentages of terrestrial palynomorphs (Cheirolepidiaceae and Araucariaceae pollen grains), suggesting the presence of a dry period during the Middle Jurassic (Late Bajocian) in this region.
- The palynological evidence suggests a highly seasonal, warm-temperate palaeoclimate for the Cañadón Asfalto region during late Early to mid Middle Jurassic time, which is consistent with the ‘seasonally dry (winterwet) biome’, sensu Rees et al. (2000).
- The Cañadón Asfalto Formation is interpreted as accumulated in a dominantly lacustrine environment, characterised by carbonatic and silicilastic facies associations, interfering with volcanic and volcaniclastic deposits. From a palynological viewpoint, the development of a shallow, saline and oligotrophic palaeolake is supported by the presence of abundant Botryococcaceae in a good state of preservation in several of the studied associations. The different inferred ecosystems show the distribution of the late Early to mid Middle Jurassic vegetation in the Cañadón Asfalto Formation, Cerro Cónord Depocentre.

Acknowledgements
The authors thank Dr. Eckart Schrank, two anonymous reviewers and the Editor for their helpful suggestions which improved the final version of the manuscript. The authors kindly acknowledge Eugenia Zavattieri for their help with graphics. The authors are grateful to Lic. Eugenia Soreda for field assistance and contributing resources in the field work. Dr. Ignacio Escapa and Dr. Rubén Cúneo are also kindly acknowledged for their help during fieldwork. The logistic support in the field work provided by the Edigio Feruglio Museum is greatly appreciated.

Funding
This work was supported by the Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT) under the following Research Projects [PICT 2006-01516 and PICT 2012-1520, BID 1728/OC-AR to R.N. Cúneo and PICT 2011-2546 BID 1728/OC-AR to A.M. Zavattieri]; Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) [under Grant PIP 11220090100605-A.M. Zavattieri] and Secretaría General de Ciencia y Tecnología de la Universidad Nacional del Sur (SEGCyT) [under Grant PGI-24/H126-M.A. Martínez].

Author biographies
DANIELA E. OLIVERA is a postdoctoral fellow at the Consejo Nacional de Investigaciones Científicas y Técnicas (CCT-CONICET) in Bahía Blanca, Argentina and is also a teaching assistant in palaeontology at the Universidad Nacional del Sur, Bahía Blanca, Argentina. She obtained a PhD in 2012 from the Universidad Nacional del Sur. Daniela’s research interests include palynofacies analysis and the palynostratigraphy of Argentinian Mesozoic and Cenozoic successions.
ANA M. ZAVATTIERI is an independent researcher for the National Research Council of Argentina. She specialises on the Upper Permian to Lower Jurassic biostratigraphy, palaeontology and palynology of Argentina and surrounding areas.

MIRTA E. QUATTROCCHIO specialises in terrestrial and marine palynomorphs as applied to Mesozoic and Cenozoic biostratigraphy and sedimentary basin analysis in Argentina. She is a researcher for the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Bahía Blanca, Argentina.

References


Nullo FE, Proserpio C. 1975. La Formación Taquetreán en Cañadón del Zaino (Chubut) y sus relaciones estratigráficas en el ámbito de la Patagonia de acuerdo a la flora, República Argentina. Revista de la Asociación Geológica Argentina 30:133—150.


Quattrocchio ME, Zavala CA, García V, Volkheimer W. 1996. Paleogeographic changes during the Middle Jurassic in the southern part of the Neuquén Basin, Argentina. GeoResearch Forum 1:467–484.


Appendix 1
Alphabetical list of identified species and illustration references.

Trilete spores
Antulpsorites saevis (Balme) Archangelsky & Gamero emend. [ = A. baculatus (Archangelsky & Gamero) Archangelsky & Gamero, 1966]
Cadargaspores sp. cf. C. reticulatus de Jersey & Paten 1964 (Plate 1, figure 5)
Clavatisporites ssp.
Deltoidospora australis (Couper) Pocock 1970
Deltoidospora minor (Couper) Pocock 1970 (Plate 1, figure 1)
Dictyophyllidites harrisii Couper 1958 (Plate 1, figure 3)
Ischyosporites marburgensis de Jersey 1963 (Plate 1, figure 10)
Klukisporites labiatus (Volkheimer) Baldoni & Archangelsky 1983 (Plate 1, figure 6)
Klukisporites lacanus Filatoff 1975 (Plate 1, figure 7)
Klukisporites variegatus Couper 1958 (Plate 1, figure 9)
Klukisporites sp. cf. K. scaberis (Cookson & Dettmann) Dettmann 1963 (Plate 1, figure 8)
Neoaraiictria cf. saratensis McKellar 1974
Nevisesporites cf. undatus Backhouse 1988 (Plate 1, figure 11)
Nevisesporites vallatus de Jersey & Paten emend. McKellar 1998 (Plate 1, figures 12–16)
Obtusisporis modestus (McKellar) McKellar 1998 (Plate 1, figure 4)
Retitriletes australisastrotaviadites (Cookson) Döring, Krutzsch, Mai & Schulz in Krutzsch 1963 (Plate 1, figure 17)
Retitriletes seminarius (Danžé-Corsin & Laveine) McKellar 1974
Retitriletes sp. 1 (Plate 1, figure 18)
Stereisporites sp. cf. S. psilatus (Ross) Pflug 1953
Todisporites minor Couper 1958 (Plate 1, figure 2)
Trilobosporites sp. (Plate 1, figure 20)
Verrucosisporites varians Volkheimer 1972 (Plate 1, figure 19)

Gymnosperm pollen grains
Alisporites lowoodensis de Jersey 1963 (Plate 2, figure 1)
Alisporites simulis (Balme) Dettmann 1963 (Plate 2, figure 2)
Aracaracites australis Cookson ex Couper 1953 (Plate 2, figure 4)
Aracaracites fissus Reiser and Williams 1969
Aracaracites pergranulatus Volkheimer 1968
Aracaracites sp. cf. A. pergranulatus Volkheimer 1968 (Plate 2, figure 5)
Aracaracites sp. A (in Volkheimer 1972)
Callialasporites dampieri (Balme) Sukh Dev 1961 (Plate 2, figure 6)
Callialasporites microvelatus Schulz 1966 (Plate 2, figure 7)
Callialasporites minus (Tralau) Guy 1971 (Plate 2, figure 8)
Callialasporites segmentatus (Balme) Srivastava 1963
Callialasporites turbaria (Balme) Schulz 1967 (Plate 2, figure 9)
Callialasporites sp. 1 (Plate 2, figure 10)
Classopolis classoides (Pflug) Pocock and Jansonius 1961 (Plate 3, figures 6–7)
Classopolis intrareticulatus Volkheimer 1972 (Plate 3, figures 8–9)
Classopolis itunensis Pocock 1962 (Plate 3, figures 10–11)
Classopolis simplex (Danžé-Corsin & Laveine) Reiser and Williams 1969 (Plate 3, figure 12)
Classopolis torosus (Reissinger) Balme 1957
Cerebropollenites macrovverrucosus (Thiergart) Schulz 1967
Cerebropollenites mesozolicus (Couper) Nilsson (in Couper, 1958)
Cerebropollenites carlylensis (Balme) Archangelsky & Gamerro
Cerebropollenites mesozoicus (Couper) Nilsson (in Couper, 1958)
Cerebropollenites macrovverrucosus (Thiergart) Schulz 1967
Cerebropollenites mesozolicus (Couper) Nilsson (in Couper, 1958)
Clavatisporites australis (Balme) Archangelsky & Gamerro emend. [ = A. baculatus (Archangelsky & Gamero) Archangelsky & Gamero, 1966]
Cadargaspores sp. cf. C. reticulatus de Jersey & Paten 1964
Biretisporites sp. A (in Volkheimer 1974)
Cadargaspores sp. cf. C. reticulatus de Jersey & Paten 1964 (Plate 1, figure 5)
Clavatisporites ssp.
Deltoidospora australis (Couper) Pocock 1970
Deltoidospora minor (Couper) Pocock 1970 (Plate 1, figure 1)
Dictyophyllidites harrisii Couper 1958 (Plate 1, figure 3)
Ischyosporites marburgensis de Jersey 1963 (Plate 1, figure 10)
Klukisporites labiatus (Volkheimer) Baldoni & Archangelsky 1983 (Plate 1, figure 6)
Klukisporites lacanus Filatoff 1975 (Plate 1, figure 7)
Klukisporites variegatus Couper 1958 (Plate 1, figure 9)
Klukisporites sp. cf. K. scaberis (Cookson & Dettmann) Dettmann 1963 (Plate 1, figure 8)
Neoaraiictria cf. saratensis McKellar 1974
Nevisesporites cf. undatus Backhouse 1988 (Plate 1, figure 11)
Nevisesporites vallatus de Jersey & Paten emend. McKellar 1998 (Plate 1, figures 12–16)
Obtusisporis modestus (McKellar) McKellar 1998 (Plate 1, figure 4)
Retitriletes australisastrotaviadites (Cookson) Döring, Krutzsch, Mai & Schulz in Krutzsch 1963 (Plate 1, figure 17)
Retitriletes seminarius (Danžé-Corsin & Laveine) McKellar 1974
Retitriletes sp. 1 (Plate 1, figure 18)
Steresporites sp. cf. S. psilatus (Ross) Pflug 1953
Todisporites minor Couper 1958 (Plate 1, figure 2)
Trilobosporites sp. (Plate 1, figure 20)
Verrucosisporites varians Volkheimer 1972 (Plate 1, figure 19)

Algae
Botryococcus sp. cf. B. braunii Kützing 1849 (Plate 3, figures 13–15)
Ovoidites ssp.

Acritharch
Leiosphaeridia sp. 1 (Plate 3, figure 16)