ADDITIONAL SYSTEMATIC INFORMATION ON THE EARLY CARBONIFEROUS PALYNOFLORA FROM THE AMBO FORMATION, PONGO DE MAINIQUE, PERU

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INTRODUCTION

Publications on palynology of Late Palaeozoic sequences of Peru are scarce (e.g., Wood et al., 2002; Azcuy et al., 2002; Azcuy & di Pasquo, 2005). This work is part of a major research that attempts to increase the palaeontological knowledge of Late Palaeozoic sequences in southern South America in the framework of projects that allow work in collaboration with other palaeontologists. This is the second contribution on Early Carboniferous palynofloras from Peru and it is an addition to the first one recently published (Azcuy & di Pasquo, 2005). This paper aims to complete the systematic analysis of a late Viséan palynoflora in Peru, to discuss the correlation with other stratigraphic units dated by palaeontologic means and to confirm once again that international (Euramerican) and Western Gondwanan (mainly derived from Brazilian and Argentinian basins) miospore zonal schemes, can be successfully applied to the dating of Carboniferous rocks of this region.

MATERIAL AND METHODS

A significant number of palynological samples were collected throughout the Ambo Formation; six of them yielded palynomorphs from the upper most part, last 100 m (Azcuy & di Pasquo, 2005). The state of preservation of the miospores varies from highly carbonized to good or excellent. Standard methods of palynomorph recovery have been used. The slides have been housed with sample numbers from the Laboratory of Palynology of Petroperú S.A., in the Laboratory of Palynology, Department of Geology, University of Buenos Aires, Argentina. Palynomorph identifications were made using a Leitz Orthoplan binocular transmitted light microscope No 871080, with 1000x maximum magnification. The photomicrographs were taken with a Pixera digital camera. Coordinates of specimens are denoted by an England Finder (EF) reference.
BRIEF GEOLOGIC INFORMATION

The palynologic results presented in this contribution come from six productive samples located in the upper part of the Ambo Formation at Pongo de Mainique (12°20’S, 72°50’W), Peru. This locality displays one of the complete sedimentary sequences, ranging in age from Silurian to Tertiary, located in the Andean Range, about 450 km to the east of Lima and 160 km to the northwest of Cusco. The Upper Palaeozoic sedimentary rocks present in the Madre de Dios Basin are mainly siliciclastic in the Early Carboniferous and calcareous sediments appear in the Late Carboniferous and increase to the Permian. The Upper Palaeozoic sequence in this region is subdivided into four formational units that in ascending stratigraphic order are: Ambo, Tarma, Copacabana and Ene Formations (see Azcuy & di Pasqu, 2005).

The Ambo Formation is presented. The species are arranged in taxonomic order, their stratigraphic and geographic occurrences outside Peru, morphologic remarks for some taxa (genera or species) and occurrence. The species are arranged in taxonomic order, their stratigraphic and geographic occurrences outside Peru, morphologic remarks for some taxa (genera or species) and occurrence.

ANOTATED LIST OF MIOSPORES

An annotated species list including taxonomic and morphologic remarks for some taxa (genera or species) and their stratigraphic and geographic occurrences outside Peru, is presented. The species are arranged in taxonomic order, although suprageneric categories are not cited. The references cited in occurrence sections include detailed systematic works and those with illustrated lists of species. Synonymies are only provided if not previously published. Rules given in the last edition of the ICBN in its Spanish version (Kiesling, 2002) are here adopted for the treatment of form taxa. Morphological terminology adopted herein is mainly in accordance with the last glossary provided by Punt et al. (1994). The reference list includes only the works cited in the remarks, synonymy lists and occurrences.

Waltzispora lanzonii Daemon 1974
(Figure 1A)

Occurrence. Early Carboniferous of Brazil (Daemon, 1974; Melo et al., 1999).

Waltzispora polita (Hoffmeister, Staplin & Malloy) Smith & Butterworth 1967

Leiotriletes politus Hoffmeister et al.; Menéndez & Azcuy, 1969:80, pl. 1: figs. A, B.
Leiotriletes politus Hoffmeister et al.; González Amicón, 1973:11, pl. I, fig. 2.

Occurrence. Widely recorded in microfloras from Early to Late Carboniferous rocks of South America, North America, Australia, Africa and Europe (Playford, 1991; di Pasqu, 2002).

Punctatisporites lucidulus Playford & Helby 1968

Punctatisporites resolutus Playford; Souza et al., 1997, pl. I, fig. 2.

Occurrence. Late Carboniferous of Argentina (Gutiérrez & Césari, 1988), Brazil (Souza et al., 1997), Australia (Playford & Helby, 1968; Jones & Truswell, 1992).

Retusotriletes anfractus Menéndez & Azcuy 1969

Occurrence. It is a very common component of Late Carboniferous microfloras from Argentina, and recently, it was also recorded in the Itararé Subgroup of Brazil (di Pasqu et al., 2003).

Retusotriletes crassus Clayton in Clayton, Johnston, Sevastopolu & Smith 1980
(Figure 1B)

Retusotriletes sp. A Higgs; Keegan, 1977:548, pl. 1 figs. 4, 5.
Retusotriletes sp. A Higgs; Clayton et al., 1977:7, pl. 6 fig. 4.
Retusotriletes sp. A Higgs; Utting, 1987a:79, pl. 2, fig. 11.


Apiculiretusispora semisenta (Playford) Massa, Coquel, Loboziak & Taugourdeau-Lantz 1980
(Figure 1C)
Figure 1. Selected miospores from the Ambo Formation (in parenthesis are the slide number and the England Finder coordinate). A, Waltzispora lanzonii (1039, S54/3); B, Retusotriletes crasus (1043, Q51); C, Apiculiretusispora semisenta (1039, P43/3); D, Anapiculatisporites cf. A. austrinus (1043, Q52/4); E, Dibolisporites microspicatus (1037, Q33/2); F, Verrucosisporites congestus (1035, W62); G, Verrucosisporites nitidus (1037, E54/2-4); H, Convolutispora insulosa (1039, P46); I, Densosporites anulatus (1037, Q33/1-3); J, Schopfipollenites ellipsoides (1043, U36/3); K, Cordylosporites magnidictyus (1035; N41/1); L, Cristatisporites peruvianus (1039, D29/4); M, Schofites claviger (1043, M51/4); N, Velamisporites minutus (1043, P66/3). Scale bar = 10 mm in K; scale bar = 15 mm in A-J, L-N.
**Verrucosisporites depressus** Winslow 1962


**Verrucosisporites morulatus** (Knox) Potonié & Kremp 1955 emend. Smith & Butterworth 1967


**Verrucosisporites nitidus** Playford 1964 (Figure 1G)

**Lectotype.** Verrucosisporites nitidus Playford, 1964:13, pl. 3, fig. 6 (designated herein).

**Remarks.** Turnau et al. (1994:290) examined the type material of *Lophotriletes grumosus* Naumova (1953) and found that the proximal face is laevigate. Therefore, it was separated from *Verrucosisporites nitidus* and it was stated in the text that one specimen amongst the four illustrated by Playford (1964) would be selected as the lectotype but finally, none was proposed. This task is here resolved by proposing as lectotype the specimen figured in Playford (1964, pl. 3, fig. 6).


**Verrucosisporites perverrucosus** (Loose) Potonié & Kremp 1955 emend. Smith 1971
Occurrence. This species has been reported from the Early to Late Carboniferous of Europe (Smith, 1971).

*Verrucosisporites verrucosus* (Ibrahim) Ibrahim 1933


**Remarks.** The generic diagnosis states that the contact areas lack ornamentation, distinguishing it from *Raistrickia* Schopf et al. 1944. Indeed, the original description of *Raistrickia*, later amended by Potonié & Kremp (1954), suggests that the sculpture is distributed on both faces like in all or almost all the known species of this genus.

*Schopfites claviger* Sullivan 1968

(Figure 1M)

*Schopfites delicatus* Higgs, 1975:396-397, pl. 2, figs. 6, 7. *Schopfites cf. S. delicatus* Higgs et al., 1988:60, pl.5, fig.9, 14.

**Discussion.** In this work the criterion of Playford & Satterthwait (1986) to assign this species to the genus *Raistrickia* is not followed because of the absence of sculpture over almost all the proximal face. Besides, in accordance with Playford (1991), the amendments proposed by Higgs et al. (1988) for *Schopfites claviger* Sullivan (1968) and *S. delicatus* Higgs (1975) are not accepted herein. The mentioned species, including also *S. cf. delicatus* Higgs et al. (1988), display a gradational ornamentation, as shown in Higgs et al. (1988, fig. 30). Therefore, in order to avoid an artificial separation of these forms, they are considered herein as one same taxon. *Ceratosporites delicatus* (Higgs) Van der Zwan 1980 is rejected herein because it lacks a description and the illustration does not show ornamentation on the equator of the spore, a feature mentioned in the diagnosis of the species.


*Convolutispora insulosa* Playford 1978

(Figure 1H)

**Remarks.** The absence or scarcity of sculptural elements on the contact areas and the lack of anastomosing ornamentation characterize this species.


**Convolutispora oppressa** Higgs 1975

**Remarks.** This species is characterized by a verrucose ornamentation, which to a large extent is fused to form rugulae that meet and anastomose without defining a true reticulum. The presence of rugulae prevents its assignment to the genus *Verrucosisporites*, in accordance with Higgs et al. (1988).

**Occurrence.** Strunian of Libya (Massa & Moreau-Benoit, 1985). Late Devonian – Early Carboniferous of Europe (Higgs, 1975; Higgs et al., 1988; Loboziak et al., 1994), Bolivia (Vavrdová et al., 1993).

**Convolutispora cf. C. elimata** Playford 1978

**Occurrence.** Viséan of Australia (Playford, 1978; Playford & Satterthwait, 1985).

**Convolutispora cf. C. varicosa** Butterworth & Williams 1958

**Remarks.** The Peruvian specimens differ from the original material and others recorded by Smith & Butterworth (1967) and Playford & Satterthwait (1988) only by their smaller size.


**Cordylosporites magnidictyus** (Playford & Helby) Melo & Loboziak 2000

(Figure 1K)

**Remarks.** In spite of the scarce and incomplete specimens recorded in the Peruvian samples, it was possible to recognize the diagnostic characters to justify its specific allocation.


**Crassispora kosankei** (Potonié & Kremp) Bharadwaj 1957 emend. Smith & Butterworth 1967

**Remarks.** The sculpture distribution in the studied specimens is slightly denser than in the European ones; this character seems insufficient to establish a new taxon, in agreement with di Pasquo (2002).


**Bascaudaspora submarginalata** (Playford) Higgs, Clayton & Keegan 1988

Densosporites anulatus (Loose) Schopf, Wilson & Bentall 1944 (Figure 11)


Kraeuselisporites mitratus Higgs 1975


Cristatisporites echinatus Playford 1963


Cristatisporites indignabundus (Loose) Potonié & Kremp 1954 emend. Staplin & Jansionius 1964


Cristatisporites peruvianus Azcuy & di Pasquo 2005 (Figure 1L)

Remarks. This cave species bears a cingulum ornamented with biformal elements fused in the equatorial region; equator and distal face with galeae and coni are fused forming rugulae which give it a beady appearance. These rugulae may be branched or anastomosed into an irregular reticulum. The proximal exoexine is microgranular or smooth. Comparisons may be consulted in Azcuy & di Pasquo (2005).

Occurrence. Early Carboniferous of Ireland (Van der Zwan, 1980a; Higgs et al., 1988).

Vallatisporites vallatus Hacquebard 1957

Remarks. This species is distinguished from others of the genus by having small, discrete coni and grana and less common spines on distal surface. The zona width is narrower than that of Vallatisporites ciliaris (Luber) Sullivan 1964 with a thinner outer portion without a “limbus”.


Grandidispora debilis Playford 1971


Spelaeotrilletes balteatus (Playford) Higgs 1996

Remarks. From the discussions on Spelaeotrilletes presented by Higgs et al. (1988) and Playford et al. (2001) it is concluded that the main distinguishing feature of this genus with relation to Grandispora is the presence of discrete and fused, variably apiculate and verrucose elements that form short rugulae. The variability of other features in both genera is considered to be almost the same.


Spelaeotrilletes cf. S. pretiosus (Playford) Utting 1987

Comparisons. This specimen bears a close similarity to S. pretiosus var. bellii (Playford) Utting (1987b, pl. 4, figs. 2-4) in respect of the type and size of the sculpture, but it is more closely spaced. Another comparable species is Spelaeotrilletes sp. A Neves & Belt (1971, plate 2, fig. 14), which is almost identical to the Peruvian specimen except for the diameter of the spore. An imprecise assignment is therefore maintained till more specimens are obtained.

Genus *Velamisporites* Bharadwaj & Venkatachala 1962

**Remarks.** Recently and in agreement with Ravn (1991), di Pasquo et al. (2003) have discussed the status of the genera *Rugospora* and *Velamisporites* and concluded that *Rugospora* is a junior synonym of *Velamisporites*. This conclusion is followed herein.

*Velamisporites minutus* (Neves & Ioannides) Ravn 1991 (Figure 1N)

**Basionym.** *Rugospora minuta* Neves & Ioannides, 1974, pl. 8, figs. 7, 8.


Genus *Auroraspora* Hoffmeister, Staplin & Malloy 1955

**Remarks.** Pseudosaccate spores assigned to *Auroraspora* are characterized by the following diagnostic characteristics: thick, dark coloured central body; delicate and spongy outer layer; distinction between pseudosaccus and body sometimes poorly defined; trilete mark generally with lips that do not extend beyond the edge of the spore body; exoexine sometimes carrying minute granulose sculpture.

*Auroraspora macra* Sullivan 1968


**Remarks and comparisons.** The Peruvian specimens show close affinity with the original specimens illustrated by Bharadwaj & Venkatachala (1962) and *Colatisporites decorus* variant A of Van der Zwan (1980b). *Velamisporites auratensis* (Playford & Helby) di Pasquo, Azcuy & Souza 2003 differs in having a densely microfolded-microrugulate exoexine as described by Jones & Truswell (1992).


*Schopfipollenites ellipsoides* (Ibrahim) Potonié & Kremp 1954 (Figure 1J)

**Remarks.** The Peruvian specimens show a diffuse and irregular central body, and the laesurae are not visible. *Endoculeospora gradzinskii* Turnau 1975

**Remarks.** The Peruvian specimens show a diffuse and irregular central body, and the laesurae are not visible. *Endoculeospora rarigranulata* var. *densigranulata* Staplin 1960 is closely comparable to this species, but differs in having a more distinct and less dense central body and ornamentation apparently restricted to grana. The features observed in *A. macra* (without visible ornamentation) and *E. gradzinskii* (with minute ornamentation) appear to confirm the *Aurorasporites* morphon proposed by Van der Zwan (1980b).


*Colatisporites decorus* (Bharadwaj & Venkatachala)

**Occurrence.** Widely recorded in microfloras spanning Late Viséan to Stephanian in Euramerica, Middle East (Libya, Saudi Arabia) and Argentina (di Pasquo, 2002). There are also Late
Viséan records in Brazil (Loboziak et al., 1998; Melo et al., 1999; Melo & Loboziak, 2003), Libya (Coquel et al., 1988), Saudi Arabia (Clayton, 1995), Russia (Reitlinger et al., 1996) and Canada (Utting, 1987b).

CONCLUDING REMARKS

This is the second paper ever published on the Early Carboniferous palynology of Peru. The palynoflora of Pongo de Mainique is composed of 55 species, mostly defined at specific level, of which only one resulted a new one (Cristatisporites peruvianus, Figure 1L). The assemblages are generally abundant, diverse and variably preserved and the percentages for the parent plants sources of the groups of palynomorphs are showed in Figure 2. Pteridophyta and Lycophyta dominate the assemblage; Sphenophyta, spores with unknown botanical affinity and reworked spores/microplankton are subordinated. Scarce acritarchs and other algal cysts (e.g., *Veryrchachium trispinosum* (Eisenack) Deunnf, *Gorgonisphaeridium* sp., *Umbellasphaeridium deflandrei* (Moreau-Benoit) Jardine et al., *Palacanthus* sp., *Maranhites insulatus* Burjack & Oliveira, *Quadrisporites granulatus* (Cramer) Ströther) and some typically Devonian spore species like *Grandispora* sp. cf. *G. mammillata* Owens and *Retispora lepidophyta* (Kedo) Playford were considered as reworked. The geographical and stratigraphical distribution, and age range of selected species found in the Ambo Formation, were displayed and discussed in detail in Azcuy & di Pasquo (2005).

The comparison of the Peruvian palynoflora with others of the Early Carboniferous of the world presented by Azcuy & di Pasquo (2005) support its correlation to the Cordylosporites magnidictyus Palynozone of the late Viséan of the Amazon Basin, Brazil. Moreover, a greater affinity with Western Europe (66% of common species), Canada (57%) and South America (54%) and a lesser affinity with Africa (45%) and Australia (30%) was established based on the number of common species. The Poti Formation in the Parnaíba basin (Brazil, Melo & Loboziak, 2000) is the most similar association to the Peruvian microflora sharing more than 40% of its species and another comparable but slightly younger one is recovered from the Kaka Formation (Bolivia, Loboziak et al., 2006). The location of all these assemblages analysed in palaeogeographical reconstructions, supports the idea of a ecotonal palaeofloristic province (Paracas Kingdom, Díaz Martínez, 2001) and Siripaca Formations (Díaz Martínez, 1991), it would be desirable to consider the convenience of not using the same established name to designate nondivisible sequences described in other region. On the other hand, some authors (Díaz Martínez, 1999; Suárez Soruco & Díaz Martínez, 1996; Díaz Martínez et al., 1999) have extended the correlation between the Ambo “Group” to units of the southern Subandean Belt of Bolivia and northern Argentina, i.e., to the Macharetí and Mandiyuti Groups. This attempt at correlation has been rejected on the evidence of palynological data from those groups as also discussed by di Pasquo et al. (2001) and di Pasquo (2002, 2003).

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