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Ferns: a palaeoclimatic significant component of the Cretaceous flora from Livingston Island, Antarctica

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Abstract. Available data on Early Cretaceous Antarctic ferns, based on mega and microfossils from Cerro Negro Formation (Shetland Islands) in Livingston Island are evaluated, together with the information provided by recently collected fossils. Anatomically well preserved Osmundaceous stems are common in the fossil assemblage. The cyatheaceae are represented by fertile foliage with spores *in situ* and the first Antarctic petrified stems of this family are found in Cretaceous strata. Fertile structures support the presence of Marattiaceae in the flora. Spores of Lophosoriaceae and other families are present. This diversity suggests that ferns successfully inhabited these Antarctic areas during the Early Cretaceous, therefore at least warm, frost-free paleoclimatic conditions are proposed.

Key words. Cretaceous. Antarctica. Cerro Negro Formation. Ferns.

Introduction

The importance of ferns as an integral part of Mesozoic communities from Antarctica was pointed out from a palynological perspective (Askin, 1983; Torres *et al.*, 1997). However, in recent times megafloristic studies of Early Cretaceous deposits from the Shetlands Islands have became relevant (Torres *et al.*, 1997; Cantrill, 1997a, 1998; Césari *et al.*, 1999). The Cerro Negro Formation is a sequence of non marine volcaniclastic strata on Livingston Island that was defined and referred to the early Aptian by Hathway (1997) and Hathway *et al.* (1999). $^{40}Ar/^{39}Ar$ dating from Hathway (1997) in 120.3±2.2 My, 119.4±0.6 My and 119.1±0.8 My let to define the age of this formation to the Aptian. Additional K/Ar dating in 125±7 My for a basal dacitic ignimbrite of the continental sequence (Salani *et al.*, 1997) was mentioned by Parica *et al.* (1997). This later information could suggest a slightly older age for the basal part of the unit. Field work at Byers Peninsula, Livingston Island, allowed us to collect a palaeoflora composed mostly of well-preserved ferns as imprints of fertile foliage and anatomically preserved stems from the Cerro Negro Formation. The new flora occurs in strata with very rich non reworked and homogeneous pyroclastic material, probably corresponding to a lacustrine or low energy fluvial system environment. These rocks are mainly composed of 90% vitroclasts (shards) and a small amount of volcanic lithoclasts and crystalclasts. It is possible to recognise several filicalean fern families in the flora that successfully inhabited this area. The stems can be referred to Osmundaceae and Cyatheaceae and the fertile foliage indicates the presence of Marattiaceae, Cyatheaceae and Lophosoriaceae. Recently, the correlation between some megafossil remains and spores has been established by the finding of *in situ* spores (Cantrill, 1998, and this paper). All the illustrated material is housed in the Paleobotanical Collection of the Geology Department of the University of Buenos Aires. The detailed systematic descriptions of the specimens are focusing in contributions in preparation.

Paleobotany

Family OSMUNDACEAE Berchtold and Presl 1820
(see Pichi Sermolli 1970)

This taxon is represented by several axes surrounded with attached petioles and adventitious roots up to 15 cm in diameter that correspond to the *Osmunda* type (figure 1.A). One axis from Byers Peninsula (figures 1.B-C) can be referred to *Ashicaulis* Tidwell and appears to be different from the other known species of the genus. Orlando (1967) described the first petrified osmundaceous rachis from Williams Point on Livingston Island, and recently,

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Cantrill (1997b) analyzed in detail anatomically preserved osmundaceous stems in this locality. Elsewhere in the world, sterile foliage of *Cladophlebis* Brongniart is found in association with petrified osmundaceous stems, and this foliage is common in the Cerro Negro Formation as well as in other Early Cretaceous floras of Antarctica (Gee, 1989).

Family MARATTIACEAE Berchtold and Presl 1820 (see Pichi Sermolli, 1970)

The presence of the Marattiales in Antarctica was previously suggested based on Triassic petrified stems (Delevoryas *et al.*, 1992). Furthermore, Banerjie and Lemoigne (1987) described poorly preserved specimens of *Marattiopsis* sp. from Williams Point (Livingston Island). We had found in Byers Peninsula well-defined fertile structures of *Marattia* type (figure 2.A). Fragments of elongate leaves (figure 2.B) with oblique lateral veins once or twice divided, bear elliptical, submarginal synangia arranged in a single series on either side of the midrib. Each synangium contains six ovate sporangia arising at right angles from the median line of the receptacle. The replacement of the organic material in these bodies is almost complete, therefore nothing is known of the spores or structure.

Family CYATHEACEAE Kaulfuss 1827

The Cyatheaceae are now represented mostly by tropical tree ferns with tall trunks and a crown of large complex pinnate leaves. The adventitious roots cover the stem, sometimes forming a thick root mantle that supports the tall trunk. From the Cerro Negro Formation were recovered stems up to 15 cm in diameter (figure 1.D), which are the first anatomically preserved specimens of this family from Cretaceous sediments in Antarctica. Some of them are characterized by few medullary meristeles, an internal and external sclerenchymatous sheath (figure 1.E), undivided petiolar vascular traces and epidermal hairs. These resemble the extant primitive Cyatheaceae and share features in common with the fossils *Lophosorachis* Nishida and *Thyrsopterorachis* Nishida.

Fertile fronds (figure 2.E) show some similarities to the fossil species *Cyathea tyrmensis* Krassilov. Sori consist of up to 20 shortly pedicellate annulate sporangia (figure 2.G). Spores like *Cyathidites* sp. (figure 2.F) were recovered from these sporangia. Also, fertile fronds (figure 2.D) described earlier as *Gleichenites sanmartinii* Halle (Césari *et al.*, 1999) from the Cerro Negro locality have yielded *Cyathidites* like spores, with a smooth proximal face and a distal hemisphere with small pits (figure 2.C). Spores of some species of the extant *Culcita* Presl and *Trichipteris* Presl show similar features.

Family LOPHOSORIACEAE Pichi-Sermolli 1970

The Lophosoriaceae are represented in the Cerro Negro Formation by the fertile fronds described by Cantrill (1998) as *Lophosoria cupulatus* Cantrill from Snow Island, and some species of the *Cyatheacidites* spore genus. This author considered that the specimens from Livingston Island described by Hernández and Azcárate (1971) as *Gleichenites* cf. *G. sanmartinii* Halle are *Lophosoria cupulatus* Cantrill, and suggested that probably most of the southern fossils assigned to the Gleicheniaceae may be allied to the Lophosoriaceae. However, in this paper we show that foliage similar to *L. cupulatus*, previously described as *Gleichenites sanmartinii* by Césari *et al.* (1999) contains spores unlike *Cyatheacidites* (figure 2.C).

Palynological evidences

Although the idea that Antarctica was the possible centre of development of several fern families, proposed by Copeland (1930) was rejected, palynological studies showed that the continent acted as a bridge between South America and Australasia (Askin, 1989; Dettmann, 1986 and Hathway *et al.*, 1999). According to data from Askin (1983) for Livingston Island and Snow Island, the flora contains diverse ferns with other herbaceous taxa, including lycopods and bryophytes. The fern flora includes Cyatheaceae, Osmundaceae, Gleicheniaceae and Schizaeaceae. She suggested a correlation of the palynoflora with the assemblages of the Baqueró Formation in Patagonia. Torres *et al.* (1997) reported a palynoflora of Snow Island, characterised by several families of ferns: *Gleicheniaceae* (*Gleicheniidites*), Schizaeaceae (4 species of *Cicatricosisporites*), Osmundaceae (*Baculatisporites, Cyathidites*), Lophosoriaceae (*Cyatheacidites annulatus* Cookson et Potonié), Lygodiaceae (*Klukisporites, Trilites*), and Polypodiaceae (*Tuberculatosporites*).

Hathway *et al.* (1999) described from the outcrops of the Cerro Negro Formation in Livingston Island, palynological associations dominated by bisaccate pollen grains and *Cyathidites* spores accompanied by *Cyatheacidites annulatus*, among others species. These assemblages have been correlated with the *Interulobites-Foraminisporis* Zone and the lower part of the *tectifera-corrugatus* Zone of Patagonia.

The strata bearing the plant megafossils here described have also yielded an abundant palynoflora containing a predominance of *Cyathidites* with subordinate spores of *Cyatheacidites annulatus* and cicatricose spores. *Cyathecidites*, a genus closely compared to *Lophosoria* suggests the presence of the family Lophosoriaceae in our assemblage. The recent fin-

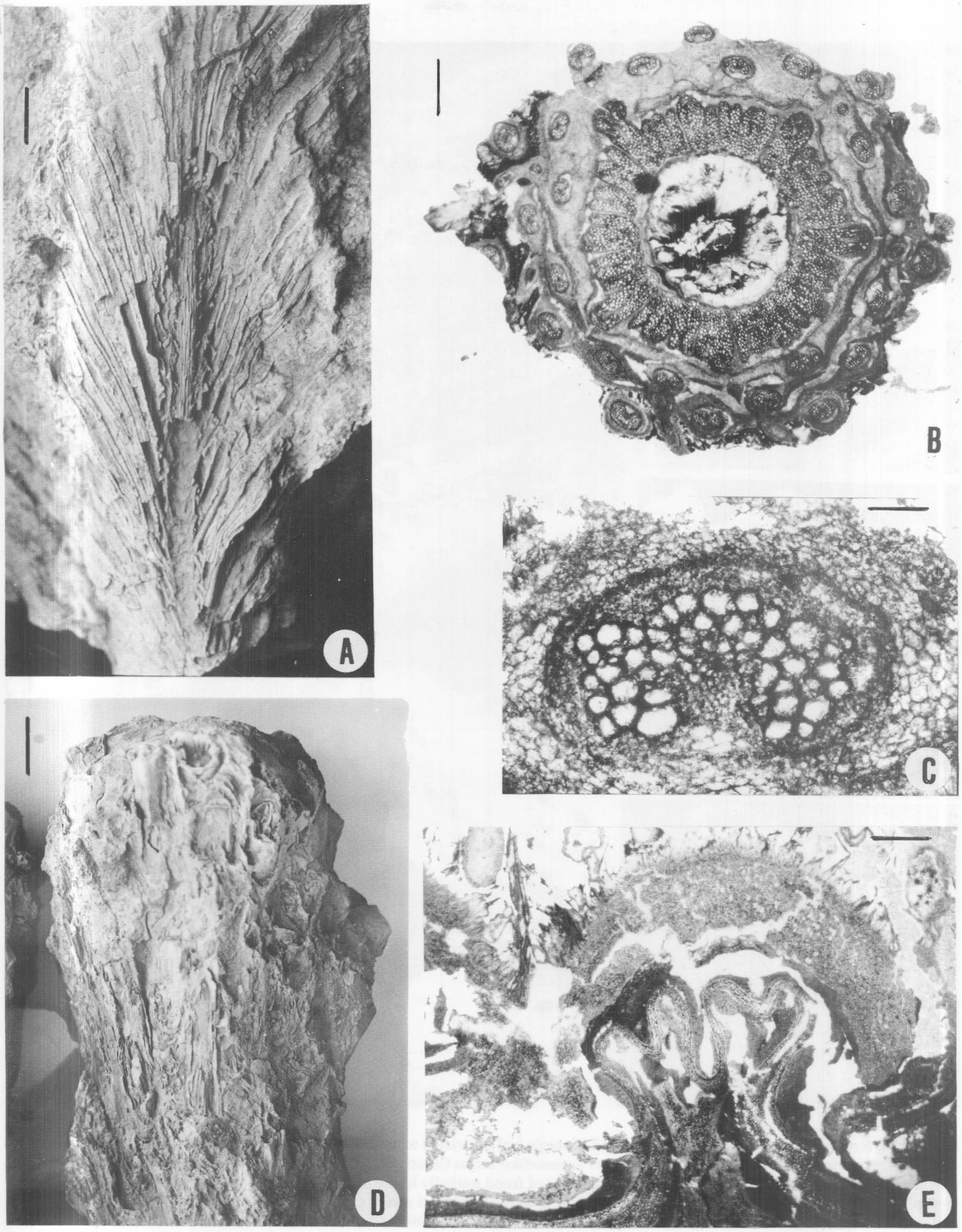

Figure 1. A, general view of an osmundaceous stem with attached petioles. **B,** cross section of an osmundaceous stem. **C,** detail of B showing C-shaped petiole trace. **D,** general view of a cyatheaceous stem. **E,** cross section of cyatheaceous stem showing leaf gap. Scale: A, 2 cm; B, 1,6 mm; C, 0,16 mm; D, 3 cm; E, 4 mm.

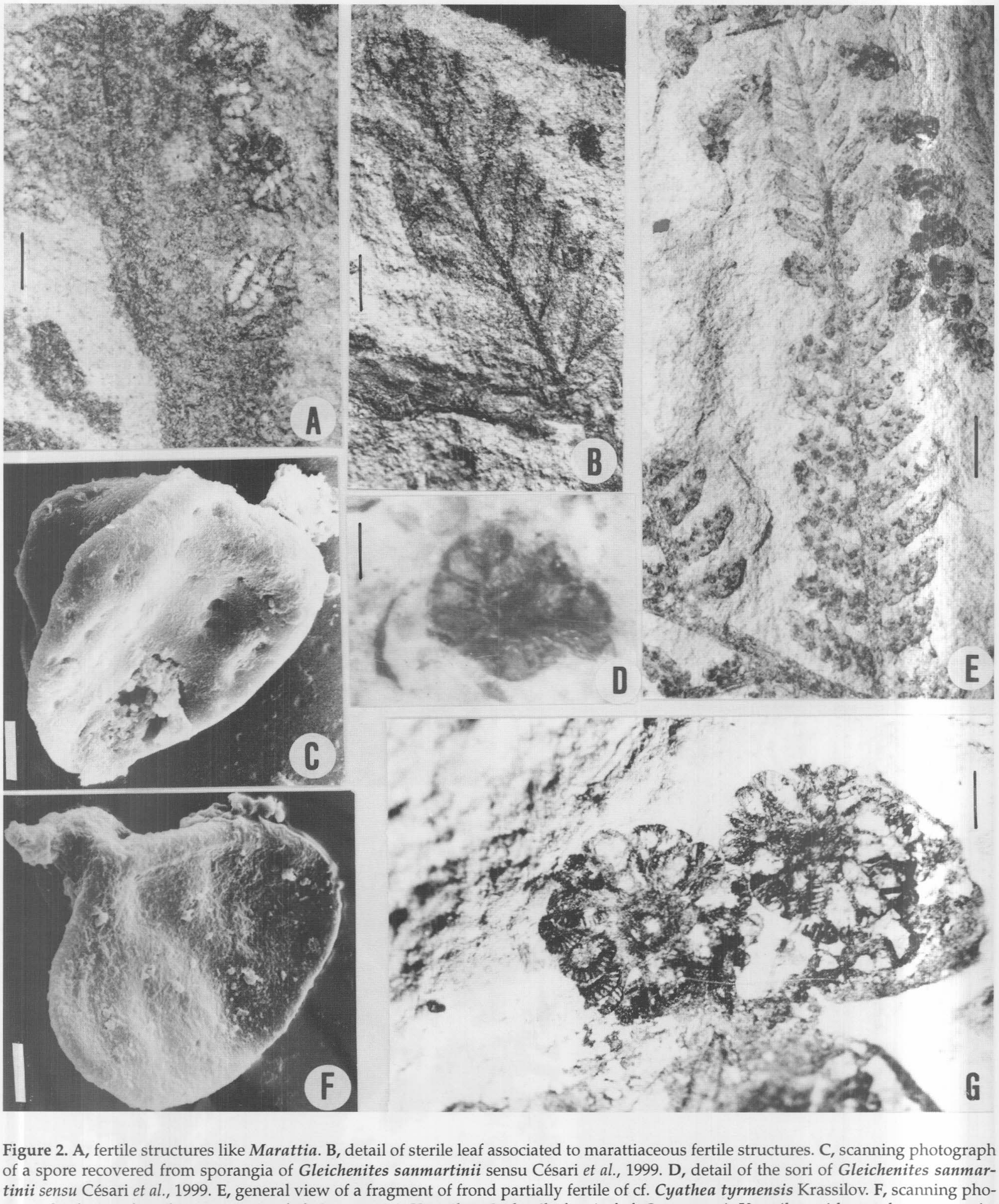

Figure 2. A, fertile structures like *Marattia*. **B,** detail of sterile leaf associated to marattiaceous fertile structures. **C,** scanning photograph of a spore recovered from sporangia of ***Gleichenites sanmartinii*** sensu Césari *et al.*, 1999. **D,** detail of the sori of ***Gleichenites sanmartinii*** *sensu* Césari *et al.*, 1999. **E,** general view of a fragment of frond partially fertile of cf. ***Cyathea tyrmensis*** Krassilov. **F,** scanning photograph of spore found in sporangia of cf. ***C. tyrmensis*** Krassilov. **G,** detail of sori of cf. ***C. tyrmensis*** Krassilov with annulate sporangia. Scale: A, 1,2 mm; B, 2 mm; C, 10 µm; D, 0,5 mm; E, 5 mm; F, 10 µm; G, 0,5 mm.

ding of Cantrill (1998) in the strata of the Cerro Negro Formation at President Head led to a link of a fossil foliage taxon to a species of *Cyatheacidites* (*C. annulatus*) for the first time.

Paleoclimatic significance

Previous palaeoclimatic studies of the Mesozoic floras of Antarctica are based mainly on gymnospermous wood. The new evidence for the presence of several fern families in the plant communities has significant palaeoclimatic implications (*e.g.*, Cantrill, 1998). According to Cantrill (1997a), the ferns make up a small component of the flora of President Head (Snow Island). Among them, the most abundant is *Lophosoria cupulatus* Cantrill whereas *Aculea bifida* Douglas is scarcely represented. However, Torres *et al.* (1997) demonstrated more diversity in the same area and we present a greater variety from Byers Peninsula herein.

Fern diversity is closely linked with high precipitation and increasing warmth. Crabtree (1988) suggested that there are no truly analogous modern communities to support an ecological interpretation for fossil ferns floras because angiosperms have usurped much of the ecological range formerly occupied by Mesozoic ferns. However, today many fern genera are restricted to well defined ecological conditions. For example, according to Tryon and Gastony (1975) one of the principal features of the biogeographic distribution of Cyatheaceae is the strong development of local endemism. These tree ferns, which may grow to a height of 20 m, have a pantropical distribution with only a few extratropical extensions. The species are concentrated in the major wet mountainous regions of the world, typically at an elevation ranging from 1000 to 1500 m. Tryon and Gastony (1975) suggested that local endemics (44% of the species) are ecologically specialized to small environmental areas not duplicated within their range of dispersal.

Today, *Lophosoria* occupies cool wet regions between 20° N and 51° S, usually at altitudes between 1000 and 3800 m. Cantrill (1998) pointed out that *L. quadripinnata* (Gemmel.) Christensen grows where the mean annual temperature is between 8° and 22°C. Dettmann (1986) suggested that *Lophosoria* was associated in the past with a variety of plant communities, ranging between temperate rain forest to open habitats.

Osmunda with an almost cosmopolitan distribution, inhabits mostly temperate to subtropical, moist areas, specially where the soils are perpetually moist to wet. *Osmunda* usually occurs in areas with altitudes ranging from 1000 to 1500 m. Marattiaceous are ferns of wet tropical and subtropical to warm temperate forests on stream banks, where the canopy is dense, up to c. 3000 m altitude. In South America it occurs in the Andes from Venezuela to Bolivia, and it is somewhat isolated in southeastern Brazil. It is present in Africa and the Pacific Ocean area, including New Zealand, also.

The existence of these families in the Cerro Negro flora suggests a frost-free climate during the Aptian. Also, Cantrill (1998) suggests that the presence of *Lophosoria cupulatus* indicates that the MAT was at least 8°C in the southern high latitudes. The current knowledge of the unquestionable presence of Osmundaceae, Cyatheaceae, Lophosoriaceae, Marattiaceae and the possible presence of Schizaeaceae, Lygodiaceae and Polypodiaceae allow us to recognise ferns as a diverse group in the Early Cretaceous plant communities of the South Shetlands Islands. According to the present requirements of those families, some of which are restricted to montane forests, tropical and subtropical, the climate was mild enough all the year round, so that these ferns could reach an important ecological role in the community, which is reflected in the fossil record.

Conclusions

Several macro and microfossil fern taxa were present during the Early Cretaceous in this Antarctic region. These belong to several families including the Osmundaceae, Marattiaceae, Cyatheaceae, and Lophosoriaceae with the probable representation of Schizaeaceae, Lygodiaceae and Polypodiaceae. Many of the taxa found in the strata belong to ferns, which now live in wet tropical to subtropical forests. Moreover, some of them could develop arborescent habit, therefore very cold conditions are untenable in the area during the early Aptian.

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