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16 Preliminary phytolith analysis of Sarmiento Formation in the Gran Barranca (central Patagonia, Argentina)

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Introduction

The escarpment south of lake Colhué Huapí (Chubut province, Argentina) is considered an important palaeontological locality, named Gran Barranca. Its sedimentary sequences are rich in fossil vetebrates of different groups. Consequently, their study is interesting for bio-, litho- and chronostratigraphical correlations. Palaeobotanical knowledge of these siltstones is less known as micropalaeontological prospecting reveals them to be palynologically sterile and plant macrofossils have yet to be recovered.

In 1979, Mazzoni points out the potential importance of phytolith record in these silts, as much for their morphological variety as for their abundance (Mazzoni 1979, Spalletti and Mazzoni 1979). Study of Gran Barranca phytoliths is being continued (Zucol *et al.* 1999, 2001) and the present contribution reports preliminary results obtained during the year 2001 and 2002 in the original profile of Spalletti and Mazzoni (1979, Fig. 2) and describes the phytolith assemblages from this profile in more detail.

Historical antecedents and paleogrostological significance

The Gran Barranca sediment sequence (Fig. 16.1) south of lake Colhué Huapí (45° 42' SL, 68° 44' WL, Chubut province, Argentina) is composed mainly of the pyroclastic siltstones of the Sarmiento Formation. This formation is one of the first Cenozoic units recognized as loess (or loessite) by virtue of numerous attributes in common with the loess deposits of the Quaternary in the Pampas region. Among these features are the abundance and variety of phytoliths (Andreis *et al.* 1975, Spalletti and Mazzoni 1979, Mazzoni 1979, Spalletti 1992).

Phytolith analysis is of considerable importance within the framework of interdisciplinary studies presently being carried out in this unit, including magnetic polarity stratigraphy and radioisotopic geochronology (Kay *et al.* 2001a), tephrostratigraphy and sedimentology (Bellosi *et al.* 2001, Bellosi, Miquel *et al.* 2002) and ongoing study of the fossil vertebrates (Kay *et al.* 2001b, Dozo *et al.* 2004, Carlini *et al.* 2002a, 2002b).

With respect to palaeophysiography, Pascual and Odreman (1971a) and Andreis (1972) concluded that during Middle Eocene (Muster Formation) the landscape was characterized by the presence of wide plains furrowed by temporary and moving rivers. In relation with the depositional sets, Andreis *et al.* (1975) and Spalletti and Mazzoni (1979) postulated the sub-aereal setting for these deposits, and interpreted them such a paleo-loess with characteristics similar to the Quaternary loess deposits of the Pampas. Spalletti (1992) pointed out that savanna, steppe and prairie regions seem to be preferred sites for the accumulation of loess deposits. Behrensmeyer *et al.* (1992) mentioned that phytoliths are the principal plant microfossils found in aeolian depositional environments, especially in loess deposits.

The abundance of fossil vertebrate remains belonging different mammal ages (SALMA – South American Lands Mammal Age) in Gran Barranca locality (Kay *et*

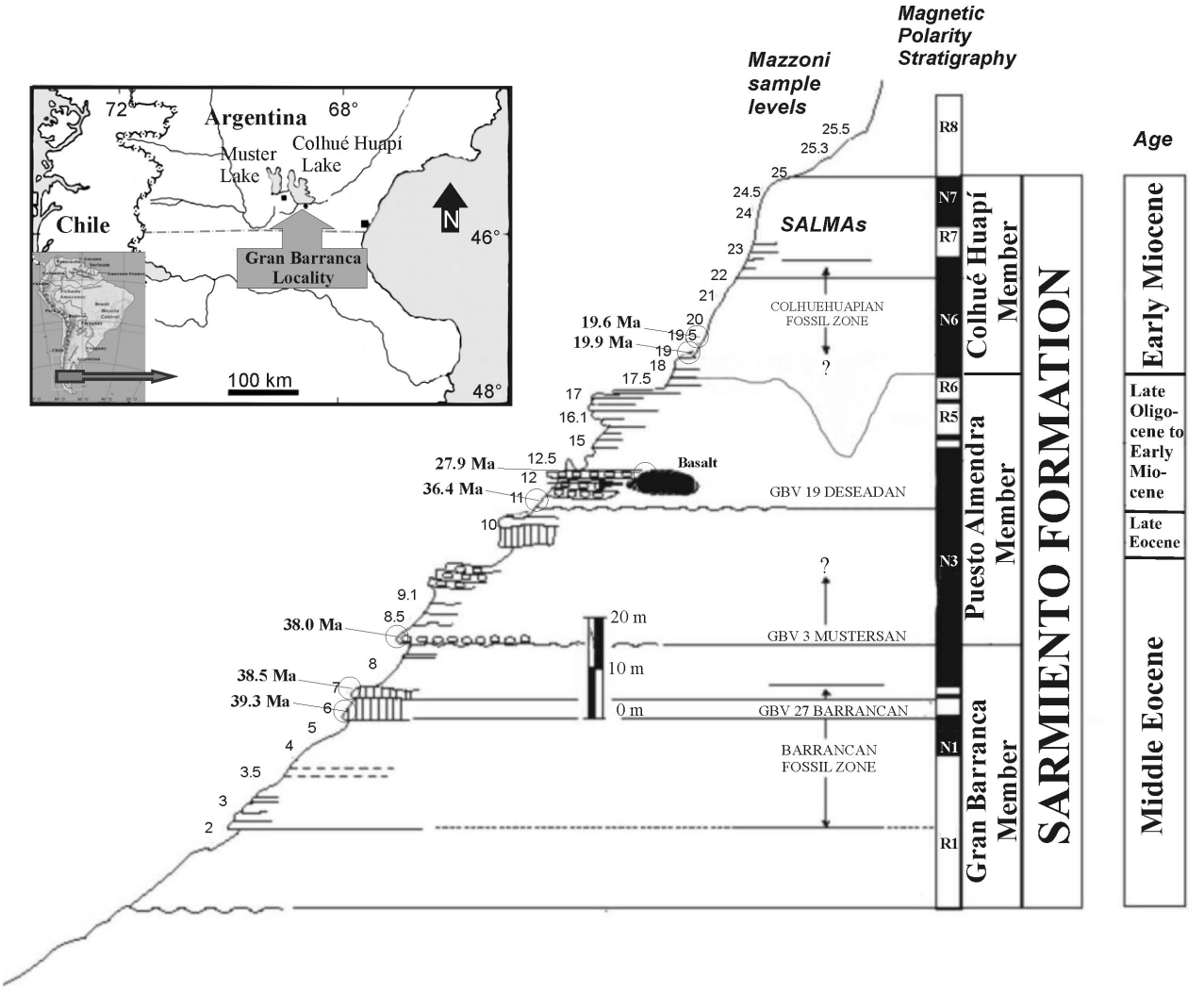

Fig. 16.1: Geographical setting of Gran Barranca locality. Schematic stratigraphical distribution based in the original diagram of M. Mazzoni of Gran Barranca, Puesto Almendra and Colhué Huapí members in MMZ profile.

al. 1999) permits a coarse integration of the phytolith record in the context of palaeoecological studies, especially among the proposed co-adaptative factors intertwinned in the history of grasslands and mammalian herbivory.

The oldest records of grass pollen in South America have been assigned to the Palaeocene (Jacobs *et al.* 1999), although the oldest record of grass phytoliths was reported from the Eocene (Andreis 1972). The presence of grass-dominated ecosystems has been claimed for the Eocene-Oligocene transition (Zucol *et al.* 1999). The presence of these ecosystems has been correlated with evolutionary changes of palaeovertebrate herbivore dentitions (Jacobs *et al.* 1999), an example of coevolutionary adaptation (Stebbins 1981).

The earliest grass-dominated ecosystems were composed of C_3 grasses (Oligocene–Middle Miocene), but later change to mixed C_3/C_4 composition (Middle-Upper Miocene), and then still later to a prevalence of C_4 grass in the Pliocene (MacFadden *et al.* 1996) and Pleistocene (MacFadden *et al.* 1999). During Quaternary geological times, glacial/interglacial cycles begin (Burnham and Graham 1999), with the modification of many terrestrial ecosystems.

The phytolith record in the Sarmiento Formation provides a unique and valuable opportunity to study the early (Eocene) development of palaeograsslands in Patagonia, and to compare this record with the record elsewhere in South America and in other regions of the world (Janis *et al.* 2002, Wooler 2002). Phytolith analysis provides perhaps the most valuable tool for a more complete reconstruction of the Patagonian Palaeogene ecosystems that were dominated by diverse herbivorous mammals, because the composition of Middle Eocene to Oligocene floras in southern South America remains are still incomplete and undated.

Geological and paleontological setting

The Sarmiento Formation at Gran Barranca is a 165 m thick sequence composed mainly of fine-grained pyroclastic sediments of primary and secondary cycle, including vitric tuffs and bentonites modified by pedogenesis (Spalletti and Mazzoni 1979, Bellosi *et al.* 2001). The profile near the west end of Gran Barranca (45° 42' 49" LS, 68° 44' 16" LW), here termed Profile MMZ, is the type locality of this formation (Spalletti and Mazzoni 1979). The sedimentary sequence at Profile MMZ comprises three successive units (Fig. 16.1), which from the base to the top are: Gran Barranca Member – 76 m thick – (Middle Eocene, with abundant vertebrate fossil remains assigned to the Barrancan and Mustersan SALMAs); Puesto Almendra Member – 60m thick – (Middle Eocene – Late Oligocene to Early Miocene, with vertebrate fossil remains of Deseadan and Colhuehuapian SALMAs) and the Colhué Huapí Member -28 m thick- (Early Miocene, with vertebrate fossil remains of the Colhuehuapian SALMA).

The Gran Barranca Member is composed of thick, massive and tabular beds (mantling bedding) of light gray to white "chonites" (silt/clay size volcanic ash) and subordinate greenish yellow bentonites. Manganese oxide nodules, limonite and gypsum crusts and siliceous concretions are common features, forming thin and continuos beds or surfaces in some cases. Palaeosols are frequent and show poor induration and moderate bioturbation. This sequence has been interpreted as an eolian loessite, originated as distal volcanic ash fallout deposits, partially pedogenized.

The Puesto Almendra Member, with lower and upper boundaries at erosional unconformities, is a heterogeneous unit characterized by horizontally-bedded intraformational conglomerates (with tuff and soil fragments), cross bedded tuffaceous arenites, massive tuffs and "chonites", bentonites and paleosols (Bellosi, Miquel *et al.* 2002). These light grey, yellowish to orange facies, are arranged in fining-upward cycles, bounded by laterally continuous discontinuities and palaeosurfaces. Palaeosols are abundant, more mature, better developed and more indurated than in the lower unit, showing distinct calcic horizons and diverse insect trace fossils (Bellosi *et al.* 2001). Lenticular basalt flows and breccias intercalate in the middle section of this member. This succession records a fluvial-eolian sedimentation, frequently interrupted by erosive events and important episodes without deposition.

The Colhué Huapí Member represents the re-deposited and partial primary fill of an incised valley (Bellosi, González *et al.* 2002). It is composed of finning-upward cycles of fine intraformational conglomerates, volcanic sandstones, massive vitric tuffs/"chonites" and poorly to moderately developed palaeosols. The succession is light gray to white in color. Sediment deposition was mainly fluvial and subordinately eolian (loessic).

We recognize thirteen different mammal-bearing levels in the sedimentary sequence of Profile MMZ (Spalletti and Mazzoni originally identified only four). Fossil mammals from Gran Barranca have contributed significantly to the sequence, definition and characterization of the middle Cenozoic portion of the sequence of SALMAs (Cifelli 1985, Pascual *et al.* 1985, Pascual and Ortiz Jaureguizar 1990, Pascual *et al.* 1996). The Sarmiento Formation at Gran Barranca yields mammals assigned to the Barrancan, Mustersan, Upper Mustersan (or "Astraponotéen plus superieur"), Deseadan and Colhuehuapian SALMAs. In particular, Profile MMZ has yielded fossil mammals only of the Barrancan and Colhuehuapian SALMAs, and yet mammal localities in adjacent profiles yielding Mustersan and Deseadan SALMA assemblages can be correlated to particular stratigraphic levels in Profile MMZ.

Ameghino (1906) characterized the "Astraponotus fauna" by the evolutionary first appearances of genera with a very marked tendency toward hypsodonty in several phylogenetically distinct lineages of archaic ungulates. On the basis of the fossil mammal remains from Gran Barranca, Ameghino inferred that the evolutionary transition toward hypsodonty in at least one family, the Notohippidae, occurred sometime between his "Notostylops beds" (= Casamayoran) and the overlying "Astraponotus beds" (= Mustersan). Gaudry (1904, 18) attributed the hypsodont teeth of Deseadan Notohippidae to an herbivorous diet. The greatest faunal transformation toward high percentages of ungulate taxa with high-crowned teeth is known to have occurred during the Mustersan (Simpson 1940). Hypsodoncy is linked with the alimentary habits of herbivorous mammals consuming foods with high percentages of fibre and silica (Simpson 1953, 254) and is further associated with food acquisition at ground level (Williams and Kay 2001). The abrasive agents that accelerate tooth wear include the intrinsic opaline silica in grass (phytoliths) and extrinsic mineral contaminants on the surface of mammalian plant foods (Baker *et al.* 1959, Healey and Ludwig 1965, Barnicoat and Hall 1960).

The ultimate causes of the observed evolutionary change in herbivore tooth crown height in Patagonia during the Mustersan may include the physiographic changes related to the regional tectonism and epeirogenic uplift (Pascual and Odreman 1971b), the establishment of arid grassland ecosystems (Pascual and Odreman 1971a), and/or the deposition of glass-rich pyroclastic silts with abundant fine-grained abrasives (Pascual and Ortiz Jaureguizar 1990).

Stebbins (1981) remarked on the interaction between grass evolution and hypsodonty in herbivorous mammals and proposed it as an example of co-evolution, citing the Patagonian record as the oldest evidence of such co-evolutionary interaction. The increased faunal hypsodonty recorded in middle Cenozoic mammalian paleofaunas of Patagonia seems to have occurred during an evolutionary pulse during the Eocene-Oligocene

transition (Kay *et al.* 1999, 2001a), and this in turn may be linked to a marked climate change associated with the onset of Antarctic glaciation (Zarchos *et al.* 2001). The phytolith record from Gran Barranca is crucial to our understanding of these questions and for establishing the historical relationships between evolutionary events and environmental change in Patagonia.

Materials and methods

Sediment samples were collected along the 164 m type-profile of the Sarmiento Formation (Spalletti and Mazzoni 1979, Fig. 16.2 or Profile MMZ = Mario Mazzoni) in 1995 and 1999 accordingly to the original Mazzoni's sampling levels. In total, 82 samples were carefully collected into sealed zip-lock bags at each magnetic polarity stratigraphy sampling site immediately after the surface weathered mantle had been removed.

Phytoliths were extracted from sedimentary samples using standard wet oxidation and heavy flotation techniques (Zucol and Osterrieth 2002). Laboratory procedures can be summarized as follows: samples were washed and soluble salts dissolved with distilled water; carbonate material was removed with dilute HCl; organic material was removed by adding H_2O_2 (30%) followed by deflocculation in $Na_4P_2O_7$ solution. The silt fraction was extracted by gravity sedimentation methods (<8 μm fraction) and then sieving to separate the >250 μm and 8–250 μm fractions. Heavy liquid flotation was carried out on the 8–250 μm fraction using sodium polytungstate heavy liquid solution at 2.3 g/cm^3. The phytolith concentrations were then mounted in Canada balsam and immersion oil for light microscopy observations.

Preliminary study consisted of registering the different phytolith morphotypes present in each sample along Profile MMZ, prior to counting the number of phytoliths of each different morphotype, a task that is being carried out at present time.

Sediment samples and microscope slides are on deposit in the Laboratory of Palaeobotany of the CICYTTP in Diamante (CDPalbo-mic).

Results

Although this preliminary study does not allow us to establish a comprehensive or detailed phytolith zonation for Profile MMZ, the presence of different morphotypes (Figs 16.2 and 16.3) serves to reveal general tendencies and important changes in the phytolith assemblages up section. In addition, phytolith assemblages throughout the entire sedimentary sequence can be characterized by the conspicuously elevated abundance of certain phytolith morphotypes. In addition, these results can be compared with the published data in Mazzoni (1979).

In the lowest part of the section at Profile MMZ (Gran Barranca Member), spherical to aspherical spinulose phytoliths (Fig. 16.3a, 1–3) are dominant, and occur in association with elongate (Fig. 16.2a), point-shaped (Fig. 16.2b) and phytoliths of uncertain morphological classification (here labeled "incertae sedis").

In the upper part of the Gran Barranca Member and in levels that are transitional into the overlying Puesto Almendra Member, the frequency of spherical spinulose phytoliths declines and there is a concomitant increase in dumbbell (Fig. 16.3b, 1 and 2), point-shaped and fan-shaped (Fig. 16.2a) phytoliths.

In the middle portion of the Puesto Almendra Member in Profile MMZ, the phytolith assemblages show a gradual change or transition in composition. In lower levels, panicoid short cells are less frequent, and roundel to conical (Fig. 16.3b, 3–8) and saddle-shaped phytoliths with pooid (festucoid) and chloridoid affinities become more abundant toward the top. In the upper levels, spherical smooth phytoliths appear (Fig. 16.3a, 16.5 and 16.6) along with elongate, point-shaped, and fan-shaped phytoliths and phytoliths "incertae sedis" (Fig. 16.3b, 9–14), as well as stomatal cell phytoliths and puzzle piece-shaped phytoliths with dicots affinities.

The Colhué Huapí Member yields a heterogeneous distribution of phytolith morphotypes. With levels dominated by spherical to aspherical spinulose, panicoid, pooid or chloridoid phytoliths, interspersed with levels where spongy spicules and diatoms are in considerable abundance.

Paleobotanical affinities and conclusions

Integrating the preliminary identifications presented above with an analysis of the phytolith data from Mazzoni (1979) broad patterns of change in the floristic composition of the phytolith assemblages can be established through the Sarmiento Formation at Profile MMZ.

The Gran Barranca member presents a record (Fig. 16.4) dominated by palm phytoliths (Arecaceae). During the Middle Eocene (Gran Barranca Member), palm phytoliths are replaced up-section by assemblages with more abundant graminoid phytoliths. Panicoid components dominate the upper section of the Gran Barranca Member whereas chloridoid/pooid components dominate in the Puesto Almendra Member.

Following the grass classification of Burkart (1975), the grassland savannas dominated by palms of the lower and middle section of Gran Barranca Member, were replaced by herbaceous grassland paleocommunities with a prevalence of megatermic grasses in the upper section of Gran Barranca Member. These in turn were replaced by grasslands dominated by meso- and microtermic grasses in the lower section of Puesto Almendra Member. The meso-microtermic herbaceous paleocommunity shows evident compositional variation through the upper portion of the Puesto Almendra Member, with the appearance of different incertae sedis phytoliths with angiosperm dicot affinities and a relative decrease in the graminoid morphotype.

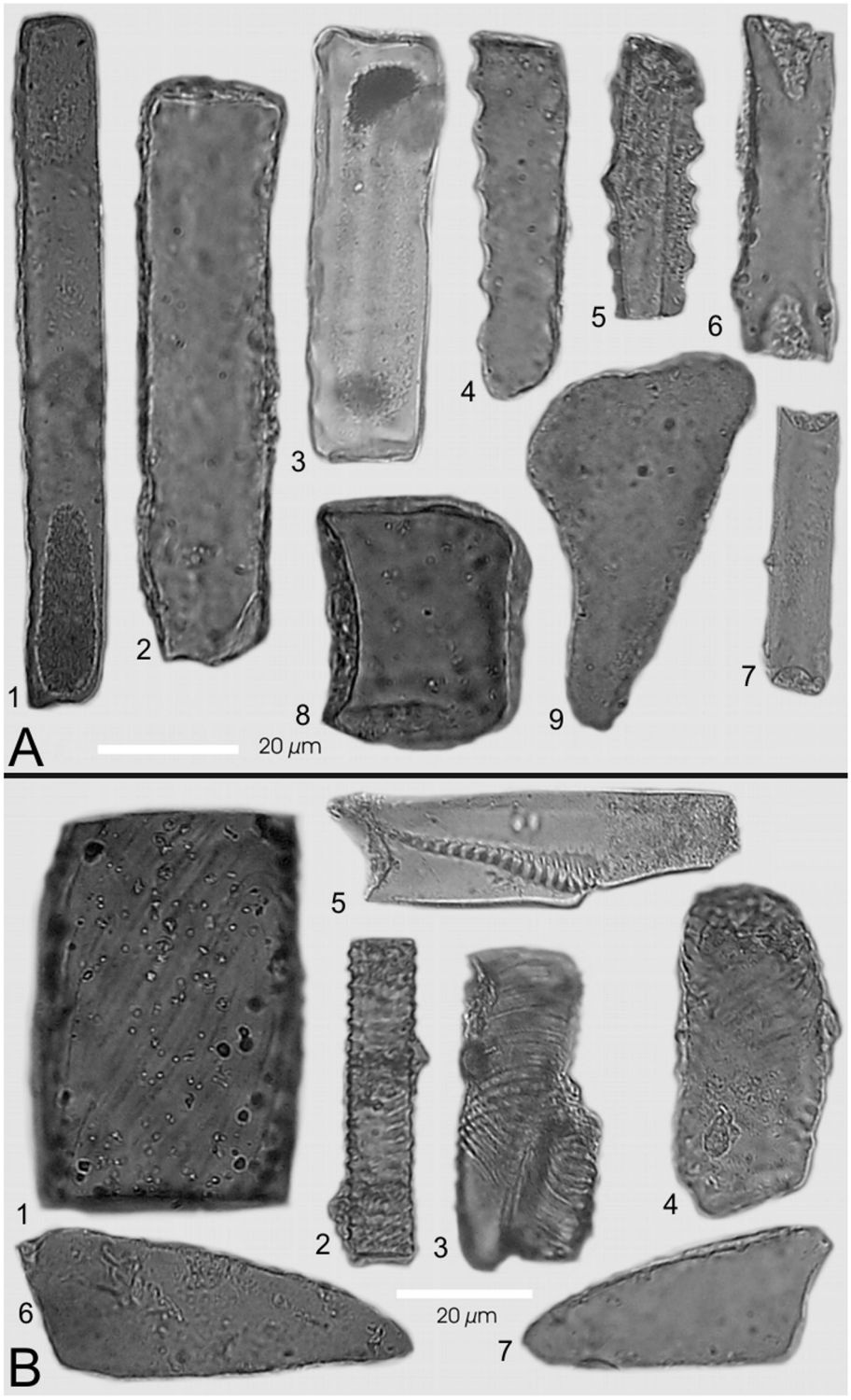

Fig. 16.2: LM photographs of Gran Barranca phytoliths. Elongated phytoliths with smooth (A, 1–3) and sinuous (A, 4–5) edges. Elongated phytoliths with concave ends (A, 6–7). Bulliform cells phytoliths – fan and polyhedric shaped – (A, 8–9). Tracheids and vascular elements isolated (B, 1–2 and 4) and articulated (B, 3 and 5) phytoliths. Point-shaped phytoliths (B, 6–7).

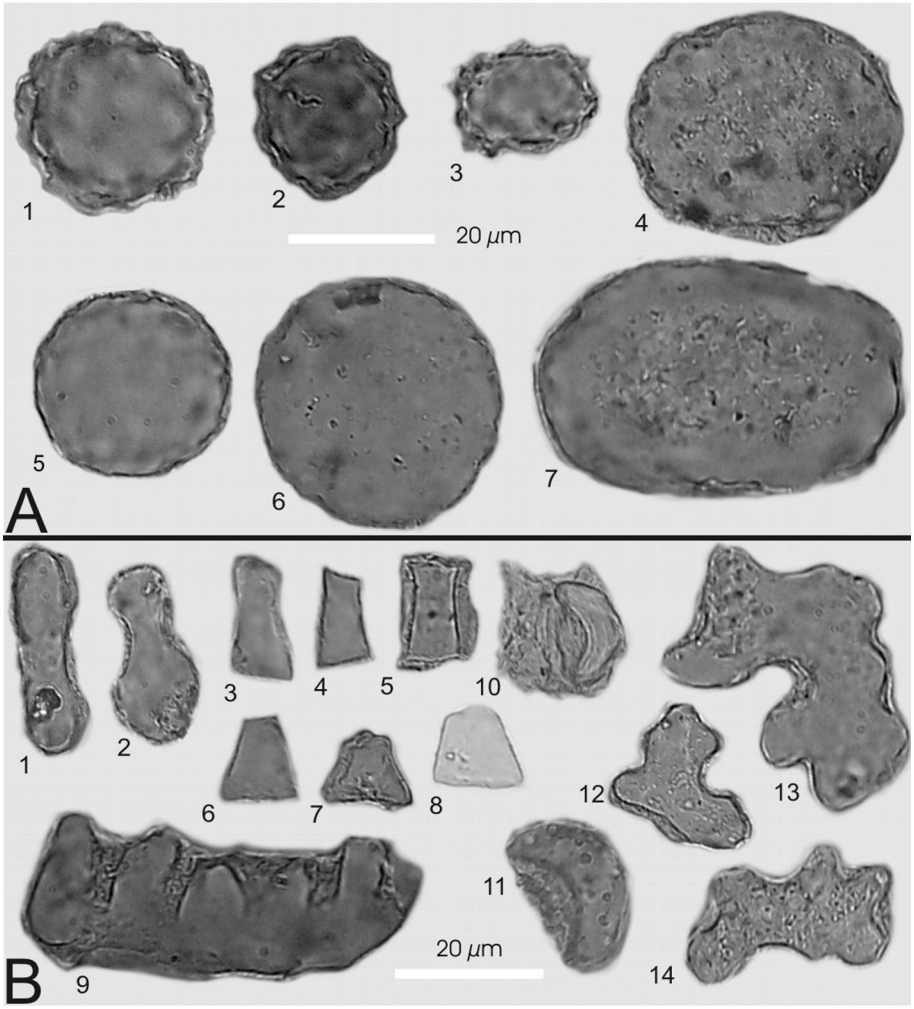

Fig. 16.3: LM photographs of Gran Barranca phytoliths. Spherical to aspherical spinulose phytolith (A, 1–4). Spherical to aspherical smooth phytolith (A, 5–6). Dumbbell phytoliths (B, 1–2). Conical to rondel phytoliths (B, 3–8). Incertis sedis *phytoliths (B, 9). Stomatal cells articulated phytoliths (B, 10–11). Jigsaw puzzle shaped phytoliths (B, 12–14).*

The phytolith assemblages of the upper part of Profile MMZ (Colhué Huapí Member) show the same floristic elements although these are present in relatively lower frequencies. While the Colhué Huapí Member shows more homogeneity (all of the major morphotype groups found in lower levels are also present here), the morphotypes are present in more variable abundances in this part of the section. These oscillations or alternating abundances of arecoid, panicoid, chloridoid and pooid phytolith components throughout the Colhué Huapí Member are of unclear significance.

These results provide confirming evidence for the oldest floristic record of grass-dominated ecosystems in South America and these became established in the middle Eocene. This considerably extends the biocron assigned to this type of plant community (Jacobs *et al.* 1999).

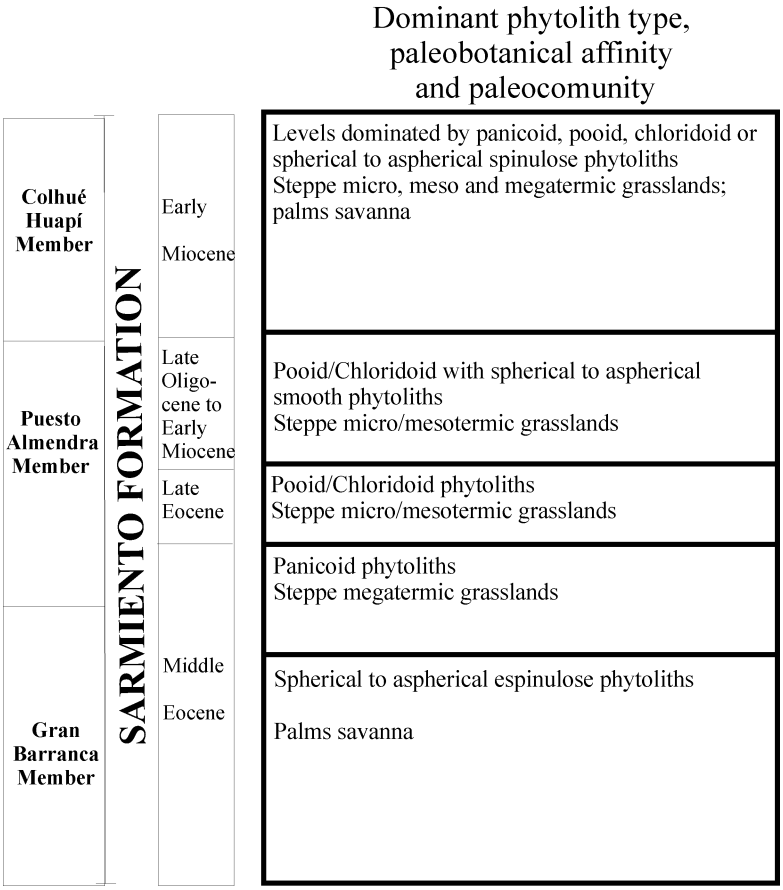

Fig. 16.4: Predominant phytolith morphotypes, palaeobotanical affinities and palaeocommunity found in MMZ profile of Gran Barranca.