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An emended diagnosis of *Gangamopteris buriadica* Feistmantel from the Permian of Gondwana

Diagnose emendada de Gangamopteris buriadica Feistmantel do Permiano do Gondwana

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Abstract

This study aims mainly to revaluate the diagnostic characters of *Gangamopteris (?) buriadica* Feistmantel based on the analysis of the type material, housed at the collection of the Geological Survey of India, Calcutta, and other specimens, housed in distinct collections of southeastern (São Paulo, Rio de Janeiro) and southern Brazil (Porto Alegre). A recent reexamination of the type material revealed an unusual taphonomic feature which is characterized by the lateral folding of the leaf lamina under itself. This fact leads to a new interpretation of the leaf shape from a lanceolate-spathulate to a more ovate to obovate outline. Additionally, the partial view of the lamina hinders the observation of the true lateral veins pattern in their full extent, which inclines towards the lateral margins. As a consequence of this reinterpretation, we propose an amendment to the species original diagnosis, to include the curled lamina and lateral venation pattern of leaf margins as diagnostic characters of the species. Some specimens from the Early Permian strata of the Paraná Basin also show the same diagnostic characters and therefore have been included in this fossil-species. Consequently, the occurrence of *G. buriadica* Feistm. emend. is confirmed and extended to the Paraná Basin, being stratigraphically (e.g., Itararé Group and Rio Bonito Formation) and geographically (e.g., São Paulo and Rio Grande do Sul states) spread over southeast-southern Brazil. Finally, the taxonomic, taphonomic and ecological implications of the presence of curled leaves are briefly discussed.

Keywords: *Gangamopteris buriadica*; Morphotaxonomy; Curled leaf; Indo-Brazilian Gondwana flora; Early Permian.

Resumo

O principal objetivo deste estudo é reavaliar os caracteres diagnósticos de *Gangamopteris (?) buriadica* Feistmantel com base na análise do material tipo, depositado na coleção do Serviço Geológico da Índia, Calcutá, e outros espécimes depositados em distintas coleções situadas no sudeste (São Paulo, Rio de Janeiro) e sul (Porto Alegre) do Brasil. Um recente reexame do material tipo revelou uma feição tafonômica única: a lâmina foliar está lateralmente dobrada sobre si mesma. Este fato implica em uma nova interpretação da forma da folha de um contorno lanceolado-espatulado para um mais ovalado-obovado. Além disso, a visão apenas parcial da lâmina não permite o entendimento do verdadeiro padrão das veias laterais por completo, as quais se inclinam em direção às margens laterais. Como uma conseqüência desta reinterpretação, propomos uma emenda à diagnose original desta espécie, a fim de incluir a lâmina curvada e o padrão de venação das margens laterais da folha como características diagnósticas da mesma. Alguns outros espécimes dos estratos permianos iniciais da Bacia do Paraná, também demonstraram essas mesmas feições diagnósticas e por isso foram incluídas nesta espécie fóssil. Conseqüentemente, a ocorrência de *G. buriadica* Feistm. emend. é confirmada e estendida para a Bacia do Paraná, sendo estratigráfica (Grupo Itararé e Formação Rio Bonito) e geograficamente (estados de São Paulo e Rio Grande do Sul) distribuída pelo sudeste-sul do Brasil. Por último, os significados taxonômico, tafonômico e ecológico da presença de folhas curvadas são brevemente discutidos.

Palavras-chave: *Gangamopteris buriadica*; Morfotaxonomia; Folhas enroladas; Flora Gondvânica Indo-Brasileira; Eopermiano.

INTRODUCTION

Feistmantel (1879) erected a new fossil species of Glossopteris-like leaf, naming it *Gangamopteris* (?) *buriadica*. According to him, the new form should be doubtfully assigned to *Gangamopteris* mainly due to the unusual shape of its leaf which was not found amongst the other species belonging to this genus. This leaf shape was described as being "lanceolate spathulate, pretty long, broader and obtusely rounded at the apex and narrower at the base". Another distinct feature mentioned by Feistmantel corresponds to the middle region with straight venation, which is considered distinct from those of other species described before. Taking into consideration the radiant disposition of veins and their anastomosing feature, Feistmantel justified its inclusion in *Gangamopteris*. Later, Arber (1905) highlighted that the erect course of the central veins of *Gangamopteris* (?) *buriadica* was similar to the venation pattern observed in leaves attributed to *Noeggerathiopis hislopi* (Bunbury) Feistmantel emend. McLoughlin & Drinnan, 1996, although the presence of anastomosed veins would normally be related to Glossopteris-type leaves. Much later, Maithy (1998) proposed the new genus *Karharbariphyllum* to accommodate Feistmantel's species (specimens # 5123 and 5124) on the basis of the two distinct features mentioned above i.e., leaf shape and pattern of middle veins. According to Maithy, these characters would make this species an intermediate form between the leaves classified as *Noeggerathiopis* and *Gangamopteris*, therefore deserving to be included in a new genus. Thus, a new combination was proposed by him for this leaf form, naming it as *Karharbariphyllum buriadicum* (Feistmantel) Maithy. Also, he designated a lectotype (specimen # 5124) for the new taxon.

Recently (2011), the authors (RI, MECBO, SSKP) reexamined the *Karharbariphyllum buriadicum* (Feistmantel) type material studied by Maithy (1998). Additionally, other specimens from the São Paulo (southeastern Brazil) and Rio Grande do Sul states (southern Brazil), described by Millan and Dolianiti (1982), Tybusch and Iannuzzi (2008), Tybusch (2013) and Hoelzel (2014) were examined and compared. Therefore, the main goal of this study is to reevaluate this species diagnostic characters based on the type material housed at the collection of the Geological Survey of India (under prefix GSI), Calcutta, India, and other specimens housed at the collections of the Department of Geology and Paleontology (DGP) of the National Museum (MN) of Federal University of Rio de Janeiro (UFRJ), southeastern Brazil, and of the Department of Paleontology and Stratigraphy (DPE) of Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, in southern Brazil, under codes DGP-MN Pb and MP-Pb, respectively. Also there are some new specimens of *G. buriadica* from Cerquilho (upper Itararé Group) housed at the Institute of Geosciences of the University of São Paulo (USP) under the code GP/3E. Considering our new interpretation of the type material, the leaf form described by Feistmantel can be accepted as a valid species included in the genus *Gangamopteris*. Consequently, an emendment to the original diagnosis is proposed here as follows.

PALEONTOLOGICAL SYSTEMATICS

Division: TRACHEOPHYTA
Class: GYMNOSPERMOPSIDA
Order: GLOSSOPTERIDALES
Genus: *Gangamopteris* McCoy, 1847
Type-species: *Cyclopteris angustifolia* McCoy, 1847 (*G. angustifolia* McCoy, 1875)
Gangamopteris buriadica Feistmantel, 1879 emend. Iannuzzi, Bernardes-de-Oliveira, Pillai
Figures 1A-E, 5A-G

1982. *Rubidgea obovata* Maithy. Millan and Dolianiti, p. 58-61, Est. 1, Fig. 6.
1982. *Rubidgea lanceolata* Maithy. Millan and Dolianiti, p. 58-59, 60-61, 63, Est. 1, Fig. 7.
1982. *Rubidgea itapemensis* Millan and Dolianiti, p. 60, 62-64, Est. 2, Fig. 4-7.
1998. *Karharbariphyllum buriadicum* (Feistmantel) Maithy, p. 86-87, Pl. I.
2008. *Gangamopteris buriadica* Feistmantel. Tybusch and Iannuzzi, p. 65-67, Fig. 5E-F.

Emended diagnosis: Obovate to spathulate-shaped leaf with strongly curled lamina forming a oblong outline when compressed, obtuse apex and contracted base; subparallel somewhat strong veins radiating from attenuated base, tapering upwards, running erect in the middle of the lamina and inclining laterally towards margins, dichotomizing and anastomosing by oblique or X-type vein connections, forming straight, long and narrow meshes in median region.

Syntypes: GSI 5023 and 5024.

Additional material: DGP-MN Pb 1186, 1370A-B, 1371A-B, 1372A-B, 1373, 1374, 1428, 1503; MP-Pb 3157, 4041ab; GP/3E 1488ab, 4572, 6737.

Remarks: The specimens GSI 5023 and 5024 here referred were erroneously mentioned by Maithy (1998) under the numbers 5123 and 5124, respectively (op. cit., pp. 86 and 87). Furthermore, Maithy elected the specimen GSI 5124 as lectotype of species. However, for Arber (1905) both of these specimens should be considered syntypes. We prefer to maintain them as syntypes, because both specimens show important diagnostic characters: the specimen # 5023 demonstrates clearly that part of the lamina is folded, as shown below, while the specimen # 5024 consists of a complete leaf, including the basal portion which cannot be seen in the other specimen.

Descriptive analysis of syntypes: The examination of Feistmantel's type material, which was also studied by Maithy (1998), revealed an unusual taphonomic feature; the lamina is laterally folded under itself. The leaf laminae folding over themselves can be seen at the borders of the lateral margins of his lectotype (GSI 5024) and the other specimen (GSI 5023), through the thickness and the discontinuity presented by their laminae in relation to the matrix and the other specimens overlaid by them (Figure 1). This feature is highlighted by shadings that the lateral margins of the laminae make on the matrix and overlapped specimens when illuminated sideways (Figure 1). This feature requires a new interpretation of the leaf shape. Also, in the specimen GSI 5023 it is noticeable that an inner piece of leaf lamina is inserted under the exposed lamina in the apical part of leaf due to the partial removal of matrix, indicating the existence of two planes containing the leaf lamina, one outer and other inner, separated by a thin layer of sediment (Figure 1A-B). Hence, this inner plane shows an impressed lamina with the venation running in an opposite direction to the exposed (outer) lamina (Figure 1B). In fact, what can be seen is the preservation of the upper (?) leaf surface in

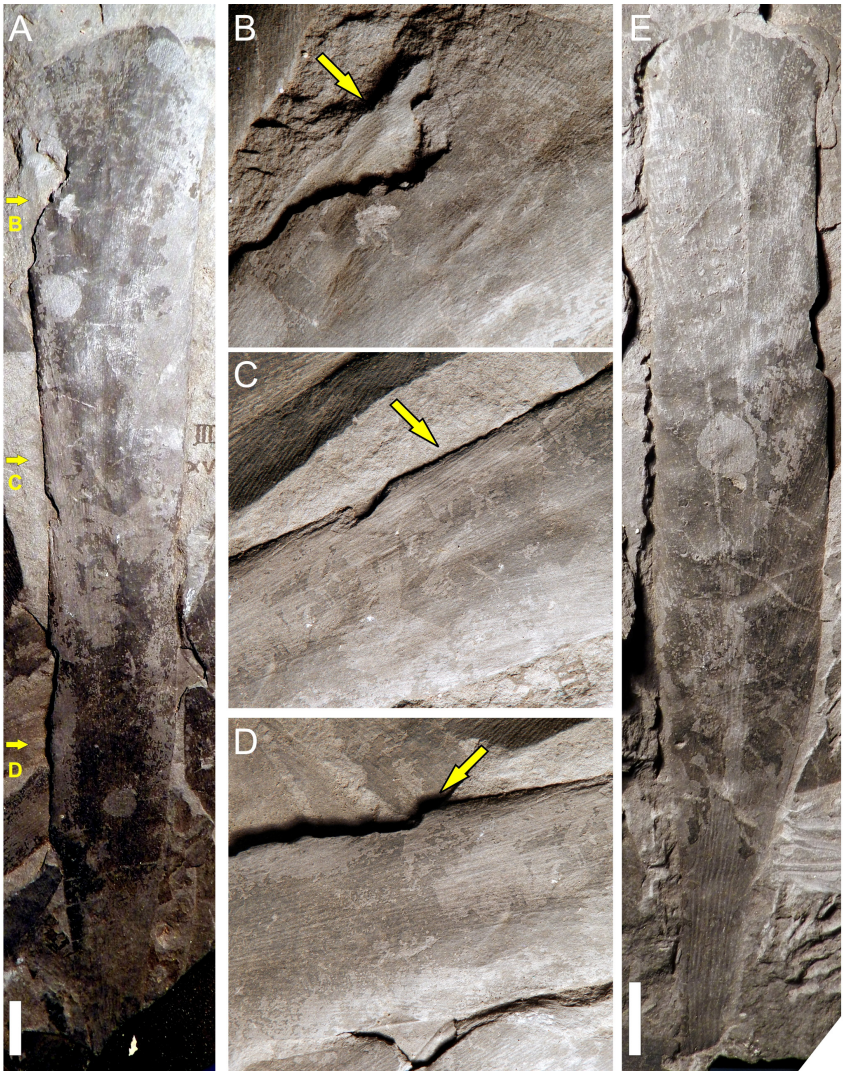

Figure 1. Photos of syntypes GSI 5023 and GSI 5024. (A) General view of GSI 5023. (B-D) Detailed views of portions of GSI 5023 (see arrows in A for location). (B) Apical part of leaf showing the partial removal of specimen (arrow), indicating the existence of two planes containing the leaf lamina, one (inner) adhered to the sediment and the other one (outer) free (= exposed), being that the inner displays a lamina with venation running in an opposite direction (arrow). (C) Middle part of leaf showing the volume and the individualization presented by its border in relation to the matrix highlighted by shadings that the lateral margins of the lamina make on the matrix (arrow). (D) Basal part of leaf showing the volume and the individualization presented by its border in relation to the matrix highlighted by shadings that the lateral margins of the lamina make on the matrix and overlapped specimens when illuminated sideways (arrow). (E) General view of GSI 5024 showing the salient lateral margins of lamina highlighted by shadings on the matrix. Scale bars = 1 cm.

two planes, the outer that exposes most of the leaf lamina, and the inner, hidden below the outer, and which can only be accessed by removing the specimen (= outer lamina and thin layer of rock matrix). This preservation configuration is well illustrated in Figure 2.

Thus, our partial view of the lamina, where only the middle part of leaf is shown, does not permit to fully understand the pattern of lateral veins. One can observe that the lateral veins incline towards lateral margins indicating the beginning of a slender curvature of them which cannot be followed ahead once the lamina is folded under itself (Figure 1C-D). However, the unique piece of lamina preserved as an impression on the inner side of the matrix that can be seen in the top of specimen GSI 5023 shows veins running in a curve, forming a broad arch (Figures 1B, 2A). It indicates slight curvilinear course of lateral veins seen in middle part of leaf is continuous until it reaches the lateral leaf margins (Figures 1B, 2A). Consequently, the arching of lateral veins is stronger than expected by the previous authors, demonstrating the presence of two kinds of veins: (i) median subparallel and straight veins; (ii) lateral slightly arching veins.

A schematic reconstruction of these specimens is provided at Figure 3 in order to clarify that this preservation feature was generated during the fossil diagenesis. In this case, the unusual lanceolate-spathulate outline (= razor shape) of lamina described by previous researchers (viz. Feistmantel and Maithy) cannot be considered as true leaf shape of this species, but only a feature created by the original winding of fresh lamina which have been compressed and

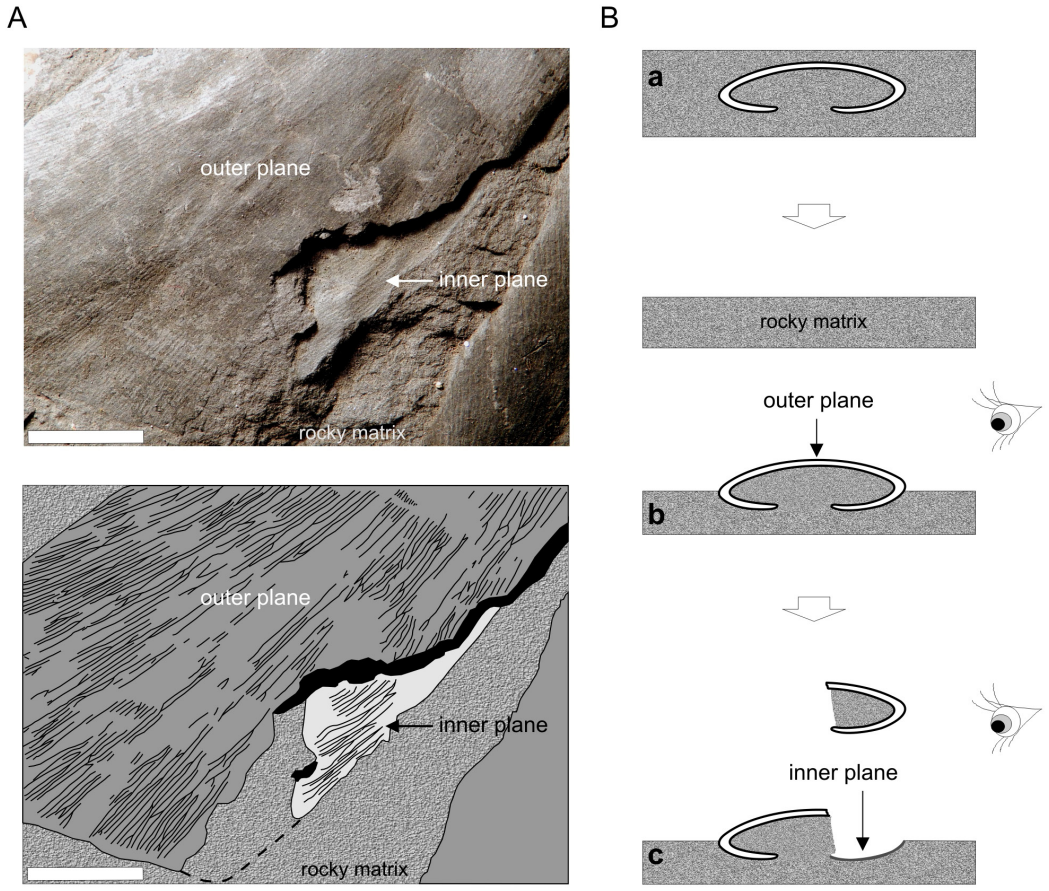

Figure 2. Preservation features in syntype GSI 5023. (A) detailed view (photo and drawing) of apical part of fossil leaf showing the partial removal of specimen (arrow), indicating the existence of two planes containing the compressed leaf lamina, one outer, free (= exposed), and the other one inner, adhered to the sediment, being that the latter displays a lamina with venation running in an opposite direction (arrow). (B) Steps (in cross section) of cleavage (a-c) that generated the two distinct planes for observation of specimen, one outer and the other inner; in the outer plane the observer may see the upper(?) leaf surface (= coalfield compression) normally exposed when the rock matrix is broken apart during the collection while in the inner plane one can be access the marginal region of the same upper(?) leaf surface printed on the matrix (= impression), since that it was folded and hidden under the middle region of the lamina and the thin layer of sediment. Legends; (A) Dashed line = the original outline of the leaf lamina removed; (B) The thickness of fossil lamina in cross-section was purposely exaggerated to facilitate an understanding of the illustrative scheme. Scale bars = 1 cm.

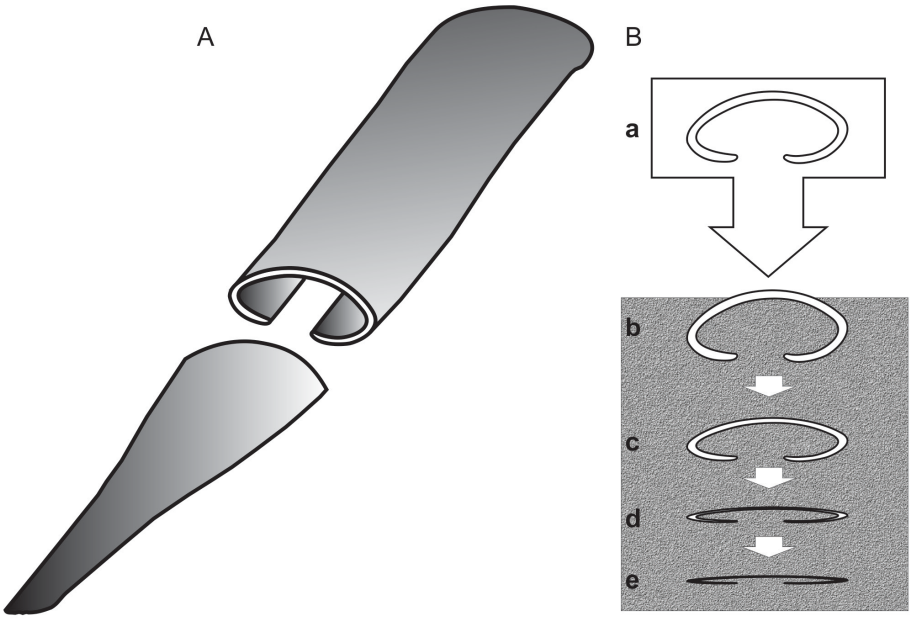

Figure 3. Taphonomic scheme. (A) Reconstruction of the curling leaf, showing a possible original shape of fresh lamina. (B) Steps (in cross section) of incorporation (a-b) and fossil diagenesis (c-e) that generated the unusual preservation feature, viz. the oblong outline (= razor shape) of lamina, described by previous researches; in this process, small quantity of sediment remained trapped in between the two lamina surfaces (d-e) giving rise to thin layer of matrix present in the middle of laminas of apical part of specimen GSI 5023.

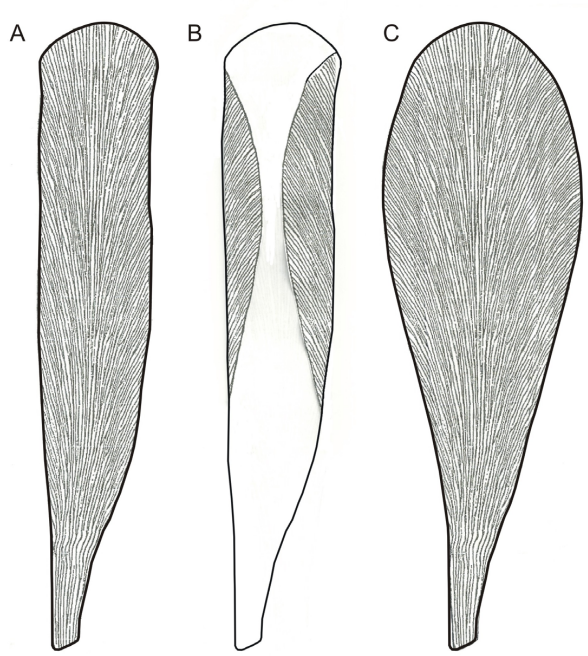

Figure 4. Reconstructing the leaf of *G. buriadica* Feistm. emend. Iannuzzi, Bernardes-de-Oliveira, Pillai. (A) Upper surface (reproduced from Arber, 1905). (B) Reconstruction of lower surface of the folded leaf, inferred from observation of specimens GSI 5023 and GSI 5024. (C) Reconstruction of the unfolded leaf, showing the possible obovate to spathulate shape of the lamina.

consequently folded during the course of incorporation in the sedimentary matrix. In this process, small quantity of sediment remained trapped in between the two parts of the abaxial (?) surface keeping them separate during the fossil diagenesis and giving rise to a thin layer of matrix present in between them (see Figure 3). In conclusion, the original shape of this kind of leaf is not known and a speculative format could be proposed based on the unfolding of lateral margins only, resulting probably in an ovate to obovate leaf shape (Figure 4).

All other morphographic features of the leaf follow exactly the description provided by Maithy (1998) in the emended diagnosis of the species erected by him as *Karharbariphyllum buriadicum* (Maithy, 1998, p. 87).

DISCUSSION

The leaf shape and venation pattern used by Maithy (1998) as arguments to create the genus *Karharbariphyllum* do not correspond to the original form. But on the contrary, based on the above mentioned reinterpretation, the lanceolate-spathulate shape is a taphonomic feature produced by a foliar lamina previously curled which was preserved as a compression inside the sedimentary matrix (Figures 3, 4). Therefore, the leaf shape similar to leaves attributed to *Noeggerathiopis hislopi* can be discarded herein. Furthermore, the venation consists not only of middle subparallel erect veins, as

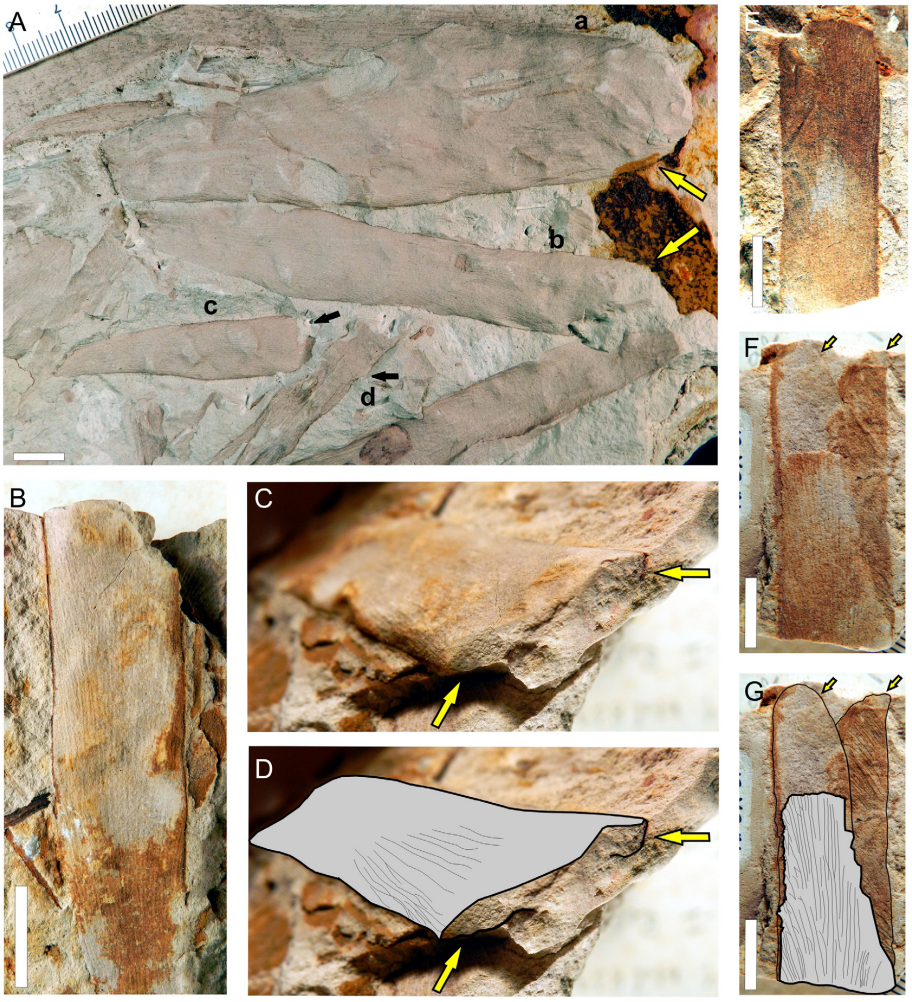

Figure 5. Brazilian specimens of *G. buriadica* Feistm. emend. Iannuzzi, Bernardes-de-Oliveira, Pillai. (A) Specimens (a-d) found in the sample DGP-MP Pb 1503; note the presence of one partially folded obovate-shaped leaf (a) in comparison with oblong-shaped others totally folded (b-d) and their different sizes, some of them bigger (a-b, arrows whiteness) and others smaller (c-d, arrows darkness), all occurring side by side. (B-D) Detailed views of DGP-MP Pb 1371B. (B) Partial view of upper surface showing veins running upwards apical portion that has been removed by cleavage of sample. (C-D) Lateral view of broken apical portion of leaf, showing in cross-section the folded lamina merged in the rock matrix (arrows). (E-G) Detailed views of DGP-MP Pb 1372A-B. (E) Part of specimen (1372A) showing middle-to-apical portion of leaf with upper surface and venation preserved. (F-G) Counter-part of specimen (1372B) showing the upper surface of leaf partially removed and the lower surface folded forming two flaps (arrows) on the right and left, overlapping each other; note the partially preserved venation in right flap (outlined in G) running in the opposite direction of the venation of the outer surface. Legends; (D, G) grey colored lamina = upper surface of leaf. Scale bars = 1 cm.

described by Feistmantel and Maithy, but also of lateral slightly arching veins, according to our observations. This venation pattern fits in generic circumscription of the genus *Gangamopteris* as proposed by McCoy. In conclusion, the specimens originally described by Feistmantel can be included in the genus *Gangamopteris*. The new data are enough to discourage the proposition of a new genus to accommodate these foliar specimens. Therefore, we propose an emend to the original diagnosis of this fossil-species, including (i) the curled lamina and (ii) the venation pattern of leaf lateral margins as diagnostic characters of the same.

Some other specimens from the Early Permian strata of the Paraná Basin, southeast-southern Brazil, also showed same diagnostic characters, e.g., a straight venation pattern of the middle portion of a leaf with razor shape generated by winding of its lamina (Figure 5). Amongst the specimens identified by Tybusch and Iannuzzi (2008), such as *Gangamopteris buriadica* Feistm in deposits of the Rio Grande do Sul State (Quitéria and Acampamento Velho outcrops); only very few (listed above) can be kept within this fossil-species in view of the new diagnostic characters added here. Therefore, the remaining specimens described

by Tybusch and Iannuzzi (2008) would be reassigned into another taxon to be defined. Furthermore, the specimens (listed above) recovered from the São Paulo State (Itapema Sítio outcrop, in Cerquilho municipality) and used by Millan and Dolianiti (1982) to erect the species *Rubidgea itapemensis* were recently reassigned by Tybusch (2013) and Hoelzel (2014) to *Gangamopteris buriadica* Feistm. The analysis of all these specimens taking into account with respect to current information, confirmed that they also exhibit the new diagnostic characters established herein and therefore should be maintained as *G. buriadica* Feistmantel emend. Iannuzzi, Bernardes-de-Oliveira, Pillai (Figure 5). Also, a new collection from Itapema Sítio outcrop studied recently by Hoelzel (2014) showed the presence of identical leaf forms (under prefix GP/3E) which have already been mentioned herein and included in this fossil-species, thereby further expanding the list of specimens that reveal such diagnostic morphological features. Consequently, the occurrence of this fossil-species is confirmed and extended to Paraná Basin, where it is present in at least two stratigraphic units, e.g. the upper portion of Itararé Group and Rio Bonito Formation, being geographically spread over two Brazilian states, e.g. São Paulo and Rio Grande do Sul, thereby occurring from north to south portions of the basin (Table 1).

Gangamopteris buriadica Feistmantel emend. Iannuzzi, Bernardes-de-Oliveira, Pillai differs from all others species of the genus by having curled lamina (synthesis of *Gangamopteris* species in Maithy, 1966; Pant and Singh, 1968; McLoughlin, 1990, 1994a, 1994b), except for the species *G. revoluta* Tybusch et Iannuzzi, 2008 from the Early Permian deposits, e.g. the upper portion of Itararé Group and Rio Bonito Formation of the Rio Grande do Sul State, in Paraná Basin (Tybusch and Iannuzzi, 2008). Despite the fact that both species have a winding lamina, *G. buriadica* is distinguished by obovate-spathulate shape of the lamina, similar to a razor when curled, while *G. revoluta* has a more lanceolate outline, gradually tapering to an acute apex if the lamina is curled. Furthermore, another marked difference is noted in the middle veins of *G. buriadica* which are only marked and somewhat thick at the base, tapering immediately after their insertion at leaf lamina and running up to apex with the same caliber of the lateral veins. In *G. revoluta*, the middle veins start and continue marked and relatively thicker throughout the lamina, up to the last third of the leaf, forming a well-defined bundle of middle veins which is even inserted into a distinct groove. More details on the comparison between the leaves of the two fossil-species can be seen in Table 2.

Table 1. Study specimens of *G. buriadica* Feistm. emend. Iannuzzi, Bernardes-de-Oliveira, Pillai from India and Brazil, showing their measurements (length × width) and respective geographic and stratigraphical data set. Note the differences in the sizes and preservation mode of leaves (there are three leaves partially unfolded). Legends: C = Coalfield; RS = Rio Grande do Sul State; SP = São Paulo State; Gr = Group; B = Basin; Fm = Formation.

Specimens of *G. buriadica*	Length	Width (leaf folded)	Locality / Country	Stratigraphy
GSI 5023	17.9	3.2	Giridih C., Buriadi, India	Karharbari Fm.
GSI 5024	14.2	2.3	Giridih C., Buriadi, India	Karharbari Fm.
MP-Pb 3157	7.1*	2.8	Acamp. Velho, RS, Brazil	Itararé Gr., Paraná B.
MP-Pb 4041ab	10.1*	3.0	Quitéria, RS, Brazil	R. Bonito Fm., Paraná B.
DGP-MN Pb 1186a	7.4	1.1	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1186b	8.5	1.8	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1370B	6.8*	1.6	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1371B	6.5*	1.3	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1372A	4.4*	1.4	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1373a	7.5*	3.3#	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1373b	6.5*	1.4	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1374	6.5	1.5	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1428a	5.6*	1.4	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1428b	6.7*	2.0#	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1503a	11.9	3.0#	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1503b	10.9	1.8	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1503c	5.4*	1.3	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1503d	5.8*	1.0	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
DGP-MN Pb 1503e	9.2*	1.6	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
GP/3E 1488ab	7.7*	2.3	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
GP/3E 4572	9.6	2.4	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.
GP/3E 6737	6.0*	2.0	Cerquilho, SP, Brazil	Itararé Gr., Paraná B.

*Measured a partial length due to incompleteness of the specimen; # partially unfolded leaf.

Table 2. Comparison of diagnostic characters between *G. buriadica* Feistm. emend. Iannuzzi, Bernardes-de-Oliveira, Pillai and *G. revoluta* Tybusch et Iannuzzi.

Leaf features	*G. buriadica*	*G. revoluta*
Leaf shape	Obovate-spathulate (maximum width above 1/2 length of the leaf)	Lanceolate to oblong * (maximum width below or at 1/2 length of the leaf)
Leaf outline with curling lamina	Oblong (= razor shape)	Elongate lanceolate, gradually tapering towards apex
Apex	Obtuse	Rounded acute
Base	Contracted	Unknown
Dimensions (cm)	1.0-3.2 wide (folded lamina) and 6.5-18 long	2.2-3.8 wide (folded lamina) and 8.4-14.7 long (incomplete specimens)
Middle veins	Straight and parallel, but thin, forming an ill-defined median band	Straight and parallel, but clear and robust (thick), reaching up the apical region, forming a well-defined median band
Median region	Flat or plain	With prominent groove persisting up to apex

*Not originally described by Tybusch and Iannuzzi (2008).

FINAL REMARKS

The winding or curling of fresh leaf lamina can be phenotypic characteristic of some modern plant species and seems to represent an adaptation to *reduce air movement around under surface of leaves, reducing water loss through less area exposed to direct sun* (Abrams, 1990; *Phebalium* species, Australian National Botanic Gardens, 2000) and/or to *gain structural stiffness, maintaining the efficient sun light interception under adverse conditions* (for instance, as in species of *Phormium*, King et al., 1996). However, this feature can be created in some leaves during their decay process after abscission in the litter or on ground surface (= curled dry leaves), or even while still in connection with mother-plant, at some stage in the leaf aging (Xiao and Chen, 2011). There are other factors reported in the literature that can cause the curling of living leaves: a) under conditions of natural long-term water stress (Bussotti et al., 1995), b) due to infections by bacteria and virus (leaf curly virus-LCV-type virus; Ashraf and Zafar, 2000), c) by insect infestation (Peña and Bullock, 1994), d) owing to nutrient deficiencies (Tanaka and Fujita, 1974).

The above cited facts raise the following question whether the curling feature of leaf lamina could be useful for taxonomic purposes. The answer may be yes; if one can prove or deduce that it is inherent in the fresh and/or attached leaves and not a character created by local factors only, such as a post decay process of leaf or some injury or disease. One way to test this hypothesis, if no leaf has been found in organic connection, as in this case, could be made through the recurrent record of this same leaf form having always the lamina curled in different sites /geographic areas and / or stratigraphic horizons. Because of this, the occurrence of this feature in Indian and similar Brazilian specimens, according to descriptions by Tybusch and Iannuzzi (2008), Tybusch (2013), and Hoelzel (2014), is a very important and significant fact for considering the curled lamina as a valid diagnostic character. This same argument was used by Tybusch and Iannuzzi (2008) to justify the inclusion of the curling trait as a diagnostic feature of the Brazilian species *G. revoluta*. This species was reported by them from three different outcrops and two distinct stratigraphic units, always presenting their leaves with curled laminae. Also, *Gangamopteris buriadica* Feistmantel emend. Iannuzzi, Bernardes-de-Oliveira, Pillai is present in three stratigraphic units (one in India and two in Brazil) and four localities (see Table 1). It should be noted that usually when a leaf curls during its development due to an infection, disease, drought stress or nutrient deficiency, it deforms the lamina, presenting beyond the winding, wrinkles, undulations and irregular contours of the margins. This condition has not been met with in the present case where the fossil leaves display well preserved laminae and apparently normal without signs of other deformations apart from the windings (Figures 1, 5). Finally, it is not possible to assign the winding of the lamina to the stages in the leaf aging, since curled leaves of different sizes were recorded (Table 1), varying from small (1.0-1.1 wide) to relatively large (2.8-3.2 wide). As a result of this analysis, it can be deduced that the leaves can either be (i) originally curled (ii) or may have acquired this feature during the beginning of their decay process. However, the leaves seem to have sufficiently complete and intact laminae, as already stated, to represent leaves in distinct stages of decay process. Hence this feature has been considered as part of the emended diagnosis of *G. buriadica*.

As a conclusion, this is a warning for other researchers to examine the fossilized (megaphyll) leaves and ascertain that they do or do not possess this important and almost unnoticed morphological feature, i.e., the curling of the leaf lamina.

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