IARA IGUASSU, A NEW TAXON OF AQUATIC ANGIOSPERM FROM THE CRATO PALAEOFLORA (LOWER CRETACEOUS, SANTANA FORMATION, ARARIPE BASIN, NORTHEASTERN BRAZIL)

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ABSTRACT – *Iara iguassu gen. et sp. nov.*, a new taxon of aquatic angiosperm that occurs in the Crato Palaeoflora is described. The new species contributes to improve the knowledge of early angiosperms diversity and evolution, since the West Gondwana could be the spreading center of the first flowering plants in an older time. The Crato Member consists of laminated limestones of shallow lacustrine origin with marine influence and of Late Aptian/Early Albian age. *Iara iguassu* is an filamentous plant that consists of a cylindrical, articulate and furrowed stem that bear leaves elongated, tubular, flexible and inserted whorly. The fertile structures are represented by thin elongated flexible and striated peduncles that emerge near the stem nodal region. The peduncles distal portion consists of a spindle-shaped structure. The plant would live submersed in shallow lacustrine environments, probably with saline waters, depositional palaeoenvironments already suggested for the Crato Member. *Iara iguassu* features are partly found in extant and not related aquatic herbaceous families such as *Potamogetonaceae*, *Cymodoceaceae* and *Ruppiaceae* (Monocots) and also *Podostemaceae* (Dicot). Therefore, *Iara iguassu* may represent an extinct member of a putative lineage of aquatic flowering plants, not related to extant monocots or dicots (convergence habit).
Keywords: Aquatic angiosperm, Early Cretaceous, Crato Member, Araripe Basin.

RESUMO – *J.C.M. Fanton, F. Ricardi-Branco, D. Dilcher, M. Bernardes-de-Oliveira – Iara iguass, um novo taxon de angiosperma aquática da paleoflora do Crato (Eocretáceo, Formação Santana, Bacia do Araripe, nordeste do Brasil).* Iara iguassu gen et sp. nov., uma angiosperma aquática pertencente à paleoflora do Crato é descrita. A inédita planta fóssil lança nova luz ao estudo da morfologia, diversidade e evolução das primeiras angiospermas do Cretáceo, já que o Gondwana ocidental pode ter sido o cenário dispersor destas. O Membro Crato consiste em calcários laminados de origem lacustre rasa com influência marinha, de idade neoaptiana/eoalbiana. Os espécimes, preservados como impressões, consistem num caule cilíndrico, articulado e sulcado, do qual emergem apicalmente folhas sésseis, arranjadas num verticilo. As longas folhas cilíndricas, sulcadas e flexíveis portam ápice arredondado ou filamentoso, além de denteações papilosas marginais. Longos, delgados e estriados pedúnculos emergem do nó e terminam numa estrutura fusiforme, também estriada, representando estruturas férteis flutuadoras. Características similares parecem ser compartilhadas com as atuais famílias de ervas aquáticas: Potamogetonaceae, Ruppiaceae e Cymodoceaceae (Monocots) e Podostemaceae (Eudicots). O hábito aquático é sugerido a partir da morfologia cilíndrica, filamentosa e flexível bem como da organização verticilada. A planta viveria parcialmente submersa em corpos lacustres, talvez em águas salinas, paleoambientes já descritos para o Membro Crato. Iara iguassu pode representar uma convergência de hábito e, assim, uma linhagem extinta de angiosperma aquática, não relacionada a monocots ou dicots.
Palavras-chave: Angiosperma aquática, Eocretáceo, Membro Crato, Bacia do Araripe.

INTRODUCTION

In contrast to prodigious modern presence of the angiosperms, the fossil record reveals that flowering plants and their ecological ascendancy have geologically recent development. The earliest angiosperm radiation has been documented during the Late Valanginian to Early Barremian (Crane et al., 1994, 1995) and by the Barremian/Aptian angiosperms already exhibiting a considerable taxonomic diversity (Friis et al., 1999; Dilcher, 2001; Mohr & Eklund, 2003). New fossil-calibrated molecular clock studies also suggest that

some of the most diversifications of lowland tropical angiosperm clades may have originated during Aptian times or earlier (Bremer, 2000; Davies et al., 2004).

The main sources for understanding evolutionary patterns in radiation and development of major angiosperm clades are meso and macrofossils (Mohr & Eklund, 2003). Microfossil registers from the Early Cretaceous of the Gondwana realm are well documented although macrofossils are rare (Doyle et al., 2000).

In the current research a new fossil angiosperm is described, an aquatic taxon from the palaeoequatorial regions of northern Gondwana from the Brazilian Crato Member of Aptian/Albian age. These remains that were presented in a preliminary study by Fanton et al. (2005) are important in providing a new source of information on the morphology of ancient aquatic flowering plants. It contributes to a more complete picture of the early angiosperm morphology and taxonomic diversity, once the West Gondwana could be the spreading center of the first flowering plants in an older time.

GEOLOGICAL SETTING AND LOCATION MAP

The plant fossils are from the Araripe Basin of Northeastern Brazil. The Araripe Basin was formed in the northwestern Gondwanan realm by tectonic action during the continental rifting and spreading of the Atlantic Ocean. It contains several hundred meters of Jurassic and Cretaceous rocks. The sequence is partly fossiliferous, including the Early Cretaceous Crato Member, the most basal unity of the Santana Formation (Figure 1). The Crato Member consists of organic rich mudstones and laminated micritic plattenkalk limestones of shallow lacustrine origin (influenced by marine oscilations marginally; Assine, 1992; Neumann et al. 2003). The suggested age is "Late Aptian to Early Albian", based on sedimentological and palaeontological correlations and supported by palynological studies (Lima, 1978). For Coimbra et al. (2002) the age is Late Aptian, based on palynological and ostracodes data.

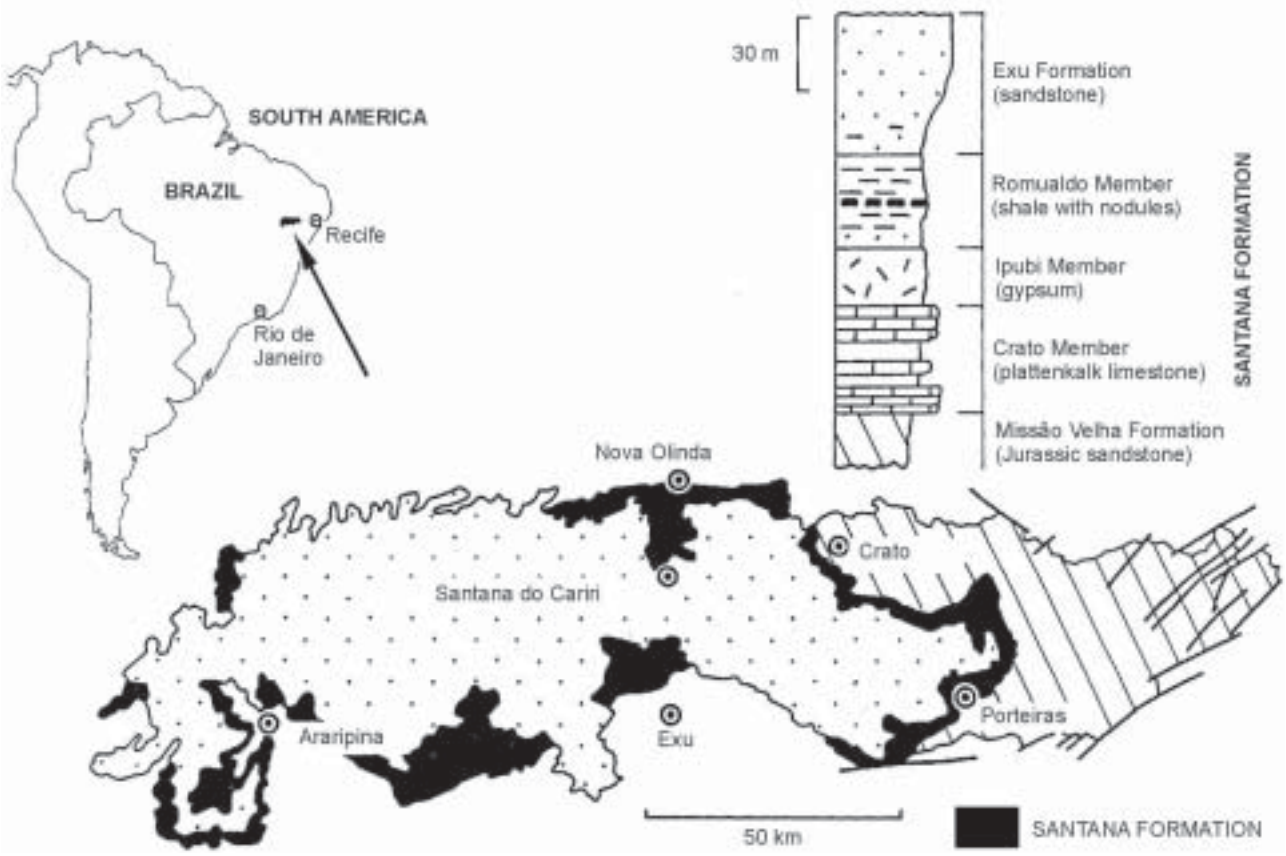

FIGURE 1. Location map of the Araripe Basin and its geological settings. Modified from Maisey (1991).

MATERIALS AND METHODS

Specimens were collected from outcrops located in the CE-166 Road, between Nova Olinda and Santana do Cariri cities, in State of Ceará. They probably were recovered from the lower part of the plattenkalk limestone series (Crato Member). The fossils are well preserved as impressions and also replacements by limonite. The collection Murilo Rodolfo de Lima shelters the samples and those are housed at the Geological Institute of the University of São Paulo. Various members of extant families from the Herbarium of the Department of Botany, State University of Campinas (UNICAMP), were analyzed, such as: *Characeae* (Green Algae), *Potamogetonaceae*, *Ruppiaceae* and *Cymodoceaeceae* (Monocots) and *Podostemaceae* (Eudicots). The fossils were studied on a C. ZEISS Stem SV6 optic stereomicroscope and documented with a Pentax Optio 555 digital camera (78-39 mm smc Pentax macro-lens), of the Laboratory of the Palaeo-Hydrogeology (Department of Geology and Natural Resources, Institute of Geosciences, UNICAMP) and also Paleobotanical Laboratory (Institute of Geosciences, University of São Paulo).

SYSTEMATIC

After the systematic classification proposed by Stewart & Rothwell (2001) and based on morphological characters of the specimens vegetative and reproductive structures, the following systematic description is suggested.

Division: TRACHEOPHYTA
Class: ? ANGIOSPERMOPSIDA
Iara Fanton, Ricardi-Branco, Dilcher *et* Bernardes-de-Oliveira *gen. nov.*

Generic diagnosis: Aquatic submersed filamentous plant. Stem cylindrical slender, furrowed and jointed by nodal and internodal regions (articulate). Leaves sessile, flexible and inserted whorly on the stem apical portion. Cylindrical, tubular and furrowed leaves. Rounded or bristle-pointed apex. Marginal pimpled teeth on the leaf and stem surfaces.

Etymology: World derived from the Tupi Brazilian indigenous mythological name of a female entity and that means lady or queen of the waters.

Type species: *Iara iguassu* Fanton, Ricardi-Branco, Dilcher *et* Bernardes-de-Oliveira *sp. nov.*

Iara iguassu Fanton, Ricardi-Branco, Dilcher *et* Bernardes-de-Oliveira *sp. nov.*

Specific diagnosis: Characters as for the genus. Thin elongated flexible and striated peduncles emerge near the stem nodal region. The peduncles distal portion consists of a spindle-shaped structure.

Etymology: World derived from the Tupi Brazilian indigenous toponym which nominates a large water body, river or stream, similar to the Crato Member lacustrine palaeoenvironment related to the natural habitat of that aquatic plant.

Holotype: GP3T/2431.

Paratypes: GP3T/2432, GP3T/2433 and GP3T/2434.

Type Locality: Between Nova Olinda and Santana do Cariri, Ceará, Araripe Basin, Northeastern Brazil.

Type stratum: Crato Member, Santana Formation.

Age: Late Cretaceous (Late Aptian/ Early Albian).

DESCRIPTION

Vegetative morphology: Filamentous plant. Incomplete and slender stem, measuring 6 to 150 mm in length and 3 to 6 mm in width. Articulate stem with 1 to 2 nodes with internodal region measuring until 63,7 mm. Furrowed stem marked by longitudinal and parallel grooves, usually until 10 on its surface and each furrow measuring 0,1 mm. Four to eight sessile and flexible whorly arranged leaves emerge from the stem apical portion. Cylindrical and tubular leaves measuring 39 to 88 mm in length and 3 to 5,5 mm in width. Furrowed leaves marked by longitudinal and parallel grooves, usually until 5. Rounded or bristle-pointed apex 26 to

26,5 mm long. Marginal pimpled teeth on the leaf and stem surface measuring until 1,6 mm in length.

Reproductive morphology: Two to three thin elongated flexible peduncles, attached to a common insertion point or not, 10,6 to 35,3 mm long and 0,3 to 1 mm width emerge from the stem nodal region. Until five longitudinal lines, measuring 0,2 mm in width mark the peduncles surface (striated aspect). The peduncles distal portion consists of a striated and spindle-shaped structure, measuring 3,2 to 8,1 mm in length and 1 to 1,9 mm in width. Two striated elongated bractform structures, measuring 21,6 to 22,8 mm in length and 0,5 to 1 mm in width come out near the nodal region.

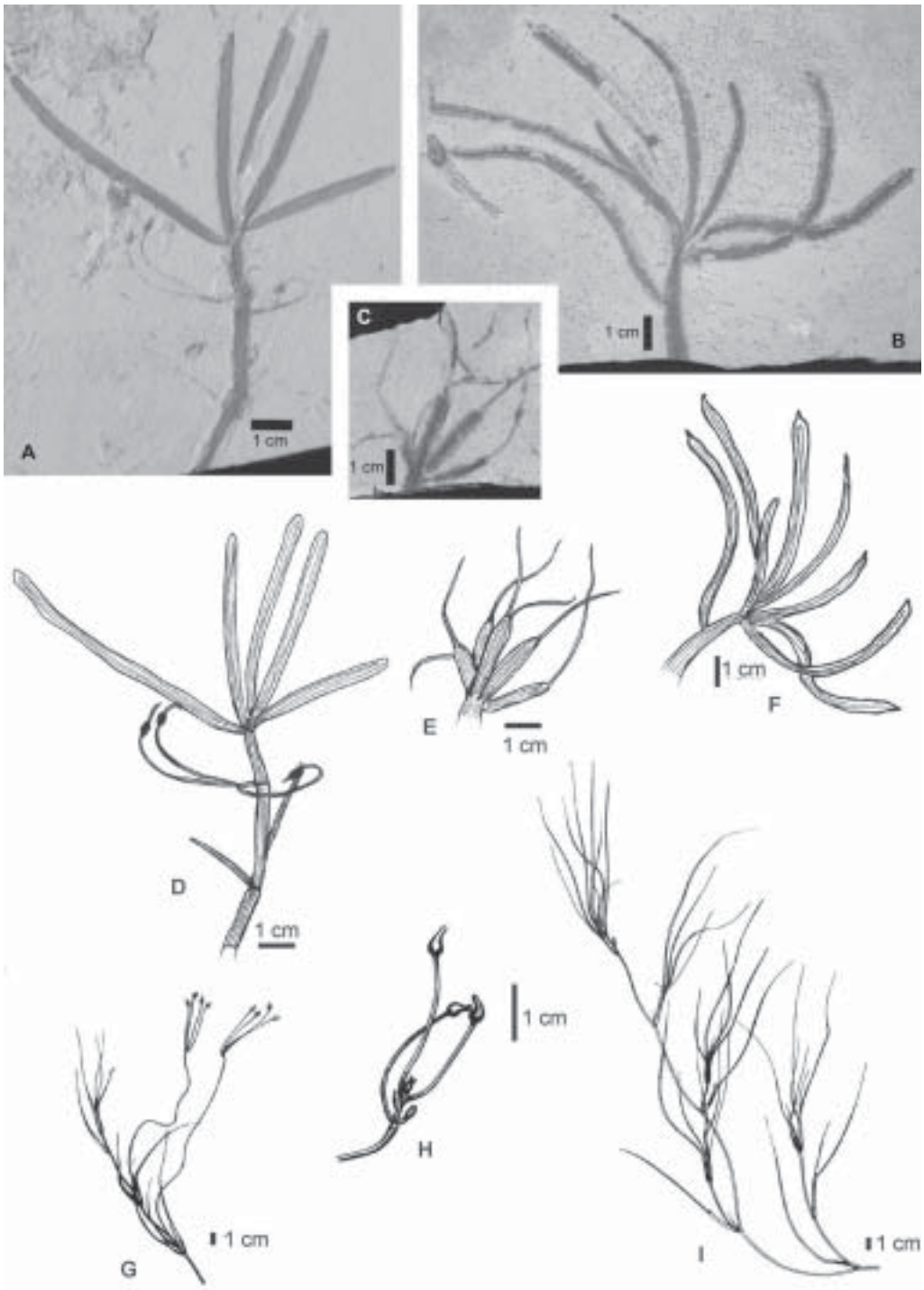

PLATE 1. Morphological aspects of *Iara iguassu gen. et sp. nov.* **A:** GP3T/ 2431, *Holotype*: stem with fertile and vegetative structures attached. **B-C:** GP3T/2432 and GP3T/2434, *Paratypes*: filamentous aspect, stem with vegetative structures, note the diverse morphology of the leaves and its apex. **D-F:** Artistic reconstructions of the samples. **G-I:** Morphological comparisons with the living aquatic monocot, *Ruppia cirrhosa* (*Ruppiaceae*). Note the habit, the filamentous aspect (G and I) and shoot with floating fruiting axes (**H**). Modified from Tonlinson (1982).

RESULTS AND DISCUSSION

Morphology and habit: The morphological features and its measurements (mm) are summarized in the Table 1. Anatomy of *Iara iguassu* is much reduced in relation to its aquatic habit. The cylindrical, filamentous and flexible morphology of the vegetative structures and also the whorled organization would indicate that *Iara iguassu* was adapted to grow in water (hydrophyte). The plant could have lived wholly or partly submerged in an aquatic habitat but the reproductive structures could have stayed on the surface of the water column.

TABLE 1. Comparisons of the morphological features and its measurements (mm) from the specimens studied of *Iara iguassu*. (The specimens are identified with the catalog number).

Characters & Measurements (mm)/Specimens		GP3T/ 2431	GP3T/ 2432	GP3T/ 2433	GP3T/ 2434
Vertical axis		115	53.5	147	107
Horizontal axis		114	52.5	-	149
Stem	Length	55	6	150	30
	Width	3	3	4.9	6
	Furrows	Longitudinal	Longitudinal	Longitudinal (n=10)	Longitudinal
	Furrows width	X	X	0.1	X
Axis articulation	Nodes quantity (n)	n=2	-	n=1	n=1
	Internodes length	14-25	-	> 63.5	>17
Leaf	Quantity (n)	n=5	n=4	-	n=8
	Total length	45-74.5	39-50.5	-	46-88
	Width	3.5	3-3.5	-	3.5-5.5
	Arrangement	Whorled	Whorled	-	Whorled
	Insertion	Sessile	Sessile	-	Sessile
	Form	Cylindrical, tubular	Cylindrical, tubular	-	Cylindrical, tubular
	Bristle-pointed apex length	-	26-26.5	-	-
	Furrows	Longitudinal (n<5)	Longitudinal (n<4)	-	Longitudinal
	Marginal teeth width	X	1.2	1.2	1.2-1.6
Elongated bractform structure	Quantity (n)	n=2	-	-	-
	Total length	21.6-22.8	-	-	-
	Proximal width	0.8-1	-	-	-
	Distal width	0.5-1	-	-	-
	Striation	Longitudinal (n<6)	-	-	-
	Striae width	0.2	-	-	-
Elongated fusiform structure	Quantity (n)	n=3	-	n=2	-
	Total length	40.2-42.5	-	11.2-16	-
	Peduncle length	29.5-35.3	-	10.6-12	-
	Spindle length	4-8,1	-	3.2-4	-
	Peduncle width	0.8-1	-	0.3-0.5	-
	Spindle width	1.2-1.9	-	1	-
	Striation	Longitudinal (n<5)	-	Longitudinal	-
	Striae width	0.2	-	X	-

The symbol "-" means absent and the symbol "X" means not preserved or poorly preserved.

Life environment: The shallow lacustrine environment, with probably saline waters is a possibility of life habitat for that aquatic plant. This palaeoenvironment has already been suggested for the Crato Member in the literature.

Comparison with living aquatic angiosperms families: The combination of these features is partly found today in extant and not related aquatic herbaceous taxa. The plant fossils have similar characters with some families of the *Monocots*, particularly with *Ruppiaceae*, *Potamogetonaceae* and *Cymodoceaceae*.

The unique fossil registers of the *Potamogetonaceae*/*Ruppiaceae* based on endocarps and seeds are reported from Poland, Moldavia, Germany and China. The fossil species of *Ruppia*, informally grouped in "*Fossil-Ruppia grouping*"

(Collinson, 1982), includes three species: *R. maritime-miocenica* Szafer and *R. palaeomaritima* Negru, both of the Miocene from Poland, Moldavia and Germany (Szafer, 1961; Negru, 1968) and *R. yushensis* Zhao from the Pliocene of China (Zhao et al., 2004).

The living genus *Ruppia* includes features such as articulate cylindrical stem with whorled, elongated flexible and parallel-veined leaves, floating pedunculate flowers and fruits, filamentous aspect (Plate 1: G-I) and also occurring in brackish coastal or hipersaline waters (Tonlinson, 1982). *Iara iguassu* shares with these characters. In addition, other angiosperm family, *Podostemaceae*, *Eudicots*, have similar features such as floating, pedunculate, spiciform and spatheate inflorescence. Greater comparisons between *Iara iguassu* and the green algae *Characeae* family do not allowed due to the possible *Iara* vascular arrangement of the stele.

Therefore, *Iara iguassu* from the Crato palaeoflora may represent an extinct member of a putative lineage of aquatic flowering plants, not related to extant monocots or dicots (convergence habit).

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