

# NEW GYMNOSPERM RELATED WITH GNETALES FROM THE CRATO PALAEOFLORA (LOWER CRETACEOUS, SANTANA FORMATION, ARARIPE BASIN, NORTHEASTERN BRAZIL): PRELIMINARY STUDY

Jean Carlo Mari FANTON <sup>1</sup>, Fresia RICARDI-BRANCO <sup>1</sup>,  
David DILCHER <sup>2</sup>, Mary BERNARDES-DE-OLIVEIRA <sup>3</sup>

- (1) Departamento de Geologia e Recursos Naturais, Instituto de Geociências, Universidade Estadual de Campinas (UNICAMP). Cidade Universitária Zeferino Vaz – Barão Geraldo. CEP 13083-970. Campinas, SP. E-mail: jeanfanton@ige.unicamp.br.  
(2) Florida Museum of Natural History, University of Florida. Cultural Plaza. SW 34<sup>th</sup> Street and Hull Road. FL 32611-2710. Gainesville, Florida, USA. (3) Centro de Pós-Graduação, Pesquisa e Extensão, Curso de Pós-Graduação em Análise Geoambiental (CEPPE), Universidade Guarulhos (UnG). Praça Tereza Cristina, 1 – Centro. CEP 07023-070. Guarulhos, SP. e Programa de Pós-Graduação em Geologia Sedimentar, Instituto de Geociências, Universidade de São Paulo. Cidade Universitária Armando Sales de Oliveira. Rua do Lago, 562 – Butantã. CEP 05508-080. São Paulo, SP.

Introduction  
Geological Setting and Location Map  
Materials and Methods  
Systematic and Description  
Results and Discussion  
Acknowledgments  
Bibliographic References

**ABSTRACT** – A new gnetalean taxon from the Crato palaeoflora is proposed. It occurs in the Crato Member, most basal unit of the Santana Formation, dated as Late Aptian/Early Albian and which consists of horizontal thin laminated limestones. Its deposition was in a continental lacustrine system with several shallow lakes and that evolved under semiarid climate. Gnetales has attracted attention because of its potential for understanding the seed plants phylogeny. Previously, diverse gnetalean macro and microfossils were reported to the Araripe Basin record and recent studies have provided important new data about the occurrence of the Gnetales. The specimens carry cylindrical, articulate and striate stems. Two opposite branches with opposite oblong parallel-veined leaves emerge from the stem basal portion. The roots constitute a dense system and exhibit a central furrow. A pair of strobili emerges oppositely from the nodes. The general organization indicates a woody plant while the small size suggests that it was a short shrub. This plant shares with gnetaleans characters, such as leaves and branches oppositely inserted, distinct nodes, parallel-veined leaves and also strobilar reproductive structure. This plant would live near of the shallow lacustrine environment, maybe in the stream margins, palaeoenvironment already suggested to the Crato Member.

**Keywords:** Gnetales, gymnosperm, Early Cretaceous, Crato Member, Araripe Basin.

**RESUMO** – *F. Ricardi-Branco, D. Dilcher, M. Bernardes-de-Oliveira, J.C.M. Fanton – Nova gimnosperma relacionada a Gnetales da paleoflora do Crato (Eocretáceo, Formação Santana, Bacia do Araripe, Nordeste do Brasil): estudo preliminar.* Um novo taxon gnetaliano da paleoflora do Crato é proposto. Os fitofósseis ocorrem nos calcários laminados do Membro Crato, unidade mais basal da Formação Santana, de idade neaptiana/eoalbianiana. Seu sistema deposicional é caracterizado como continental, formado por amplos e rasos corpos lacustres, sob um regime climático árido. A ordem Gnetales tem atraído grande atenção devido ao seu potencial de elucidar a filogenia das plantas com sementes. Previamente, micro e macrofósseis foram reportados no registro da Bacia do Araripe e recentes estudos têm contribuído para o incremento destes novos dados sobre a ocorrência e evolução de Gnetales. Os espécimes aqui estudados apresentam caules cilíndricos, articulados e estriados. Dois ramos opostos, portando folhas opostas e oblongas de venação paralela, emergem da porção basal do caule. As raízes, sulcadas centralmente, constituem um denso sistema. Um par de estróbilos emergem opostamente dos nós. A organização geral e o tamanho reduzido sugerem hábito rasteiro arbustivo lenhoso para esta planta. Este táxon compartilha de caracteres gnetalianos tais como folhas e ramos opostamente inseridos, nós distintos, venação paralela das folhas e estruturas férteis estrobilares. O mesmo habitaria as margens próximas dos ambientes lacustres já sugeridos para o Membro Crato.

**Palavras-chave:** Gnetales, gimnosperma, Eocretáceo, Membro Crato, Bacia do Araripe.

## INTRODUCTION

Gnetales has attracted attention because of its potential for understanding the phylogeny of seed plants, despite of to be poorly documented in the fossil record. The gnetalean gymnosperms are a conflicting group,

being considered the closest living relatives of the angiosperms, associated with conifers, or even derived from them or yet a controversial group (Crane, 1996; Chaw et al., 2000). While extant Gnetales

(Ephedraceae, Gnetales and Welwitschiaceae families) are proposed to be monophyletic, with Ephedraceae occupying a basal position (Crane, 1985; Chaw et al., 2000); little is known about the origin, diversification, and evolution of this clade. Gnetales macrofossils are rare and often distinct from living forms (Crane, 1988, 1996; Cornet, 1996; Krassilov et al., 1998), but pollen is quite common (Herngreen & Chlonova, 1981; Lima, 1981; Regali & Viana, 1989).

Their palynological record begins and becomes widespread in the Triassic of the Northern Hemisphere and decreases in the Jurassic. A second radiation occurs in the Mid-Cretaceous when they reach low palaeolatitudes, being, with angiosperms, one of the most characteristic components of the African-South Province. The fossil record of pollen documents that the three extant genera are the relictual living remnants of a group of plants that was once more widespread and much more diverse (Crane, 1996).

Previously, diverse plant macro and microfossils with gnetalean affinities were noted to the Araripe Basin record, but only polyplicate pollens are broadly described. Recent studies of the Lower Cretaceous sedimentary rocks in Brazil provided important new data about the occurrence of the Gnetales. Microfossil registers from the Early Cretaceous of the Gondwana realm are well documented, although macrofossils are rare (Doyle et al., 2000).

A new fossil gymnosperm is described, a complete woody short shrub taxon, related with Gnetales, from the palaeo-equatorial regions of northern Gondwana from the Brazilian Crato Member of Aptian/Albian age. These remains were presented in a preliminary study by Fanton et al. (2005). They are important in providing a new source of information on the morphology of Cretaceous gnetalean gymnosperm and contribute to a more complete picture of the Gnetales taxonomic diversity and evolution.

### GEOLOGICAL SETTING AND LOCATION MAP

The plant fossils occur in exposed sedimentary rocks of the Brazilian palaeo-equatorial region of northern Gondwana that belong to the Araripe Basin. This 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 Crato

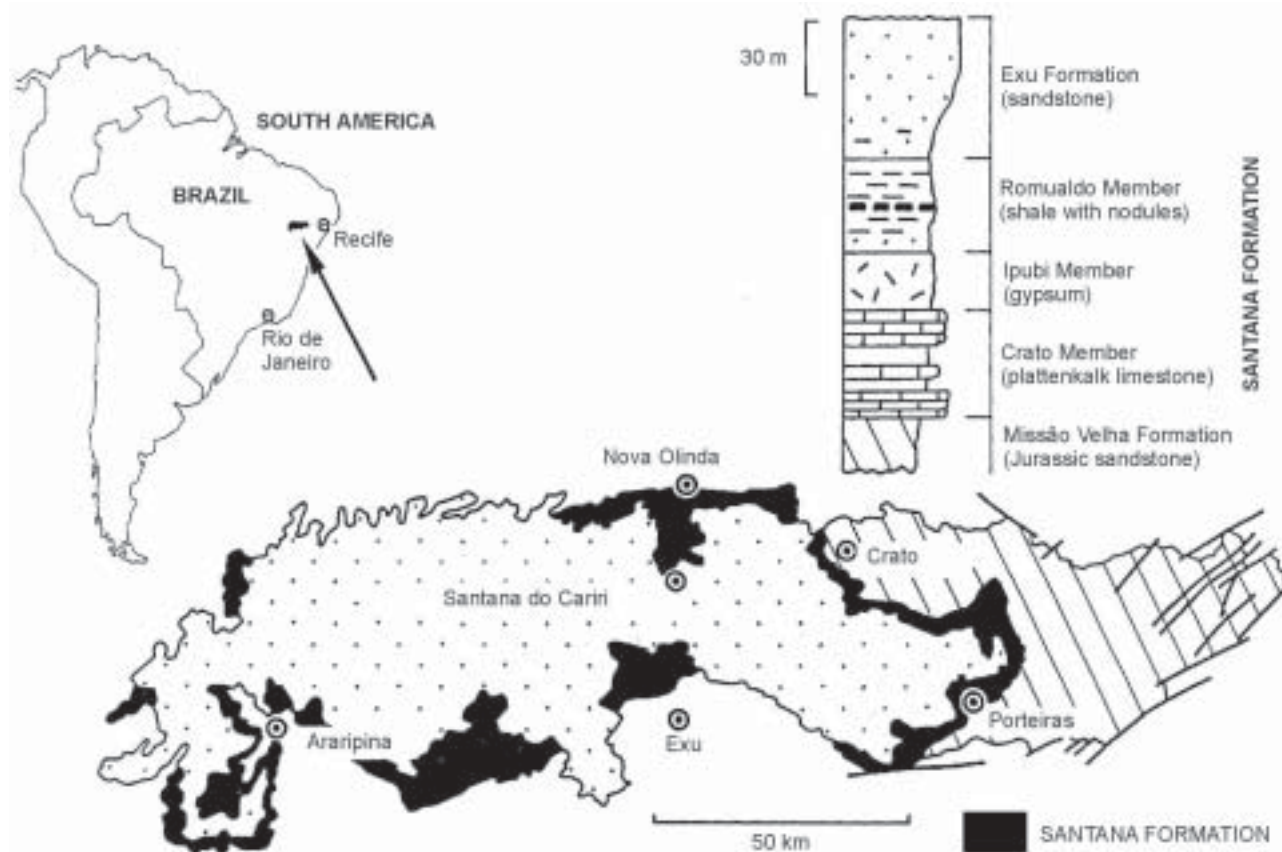


FIGURE 1. Location map of the Araripe Basin and its geological settings. Modified from Maisey (1991).

Member, the most basal unity of the Santana Formation (Figure 1). This unit of the Santana Formation is dated as Late Aptian/Early Albian and consists of horizontal strata of thin laminated plate-like limestone (Assine, 1992). Its deposition was under lacustrine flooding conditions, terrigenous to carbonate sedimentation, in a continental lacustrine system with several shallow

and wide lakes and that evolved in a palaeo-equatorial belt and under warm, semiarid climate (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). The age, for Coimbra et al. (2002), is Late Aptian based on palynological and ostracodes data.

## MATERIALS AND METHODS

**The crato palaeoflora:** The Crato limestone is well known for its rich flora and fauna (Maisey, 1991). Plant fossils are abundant, diverse and very well-preserved. The assemblage is unusual in comprising not only detached and isolated organs but also larger parts of plants, including completely preserved plants with roots, stems, leaves and reproductive organs in organic connection. The Crato palaeoflora comprises a diverse assemblage of free-sporing plants, including quillworts (Isoetites), horsetails (Equisetites) and ferns (mainly Schizaeaceae), and many seed plants including several taxa assignable to Gnetales (Pons et al., 1992; Bernardes-de-Oliveira et al., 1999, 2000) as well as a variety of angiosperms (Mohr & Friis, 2000). Totally, about 80 species have been recognized and the majority appear to represent gymnosperm elements, a common scenario for the floras of the Cretaceous period.

The first to recognize gnetalean macrofossils in the Crato Member, which tentatively were attributed to Ephedraceae and Welwitschiaceae, were Pons et al. (1992) and Bernardes-de-Oliveira et al. (1999, 2000). A diverse assemblage of plants with gnetalean affinities was noted in Mohr & Friis (2000), while Rydin et al. (2003) proposed *Cratonia cotyledon* for a seedling they relate to *Welwitschia*. Dilcher et al. (2005) described both vegetative and reproductive fossils of Welwitschiaceae, such as *Welwitschiella*

*austroamericana* (seedling), *Welwitschiophyllum brasiliense* (leaves) and *Welwitschiostrobus murili* (male strobile axes).

**Specimens of the current research:** The specimens were collected from outcrops located in the CE-166 Road, between Nova Olinda and Santana do Cariri cities, in the State of Ceará. They probably were recovered from the lower part of the plattenkalk limestone succession (Crato Member). Four specimens are well preserved as replacements (remains often show well preserved morphological details, although original tissues are typically replaced by iron oxides) and also impressions. The collection Murilo Rodolfo de Lima shelters the four samples and those are housed at the Institute of Geosciences, University of São Paulo. For the comparative studies, materials of extant genus *Ephedra chilensis*, Ephedraceae family, were analyzed. The fossils were studied under 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 Geosciences and Natural Resources, Institute of Geosciences, university of Campinas – UNICAMP) and also Paleobotanical Laboratory (Institute of Geosciences, University of São Paulo).

## SYSTEMATIC & DESCRIPTION

Based on morphological features of the specimens vegetative and reproductive structures and after the

systematic classification proposed by Stewart & Rothwell (2001), the following systematic description is suggested.

**Division:** TRACHEOPHYTA

**Class:** GNETOPSIDA

**Order:** GNETALES

**Family:** unknown

**Description of the vegetative morphology:** Terrestrial woody short shrubby plant (Plate 1: A-C, H). Stem cylindrical, striate and jointed by nodal and internodal

regions (articulate) (Plate 1: B-C, G, H). Two opposite and articulate branches (Plate 1: A-C) with oblong parallel-veined leaves (Plate 1: D-E, H) inserted oppositely to





**PLATE 1.** New gnetalean taxon from the Crato palaeoflora: morphological aspects. **A:** Two opposite striate and articulate branches bearing a pair of strobili by nodal region, of arrangement opposite. Dense roots system exhibiting central furrows. **B-C:** Complete short woody shrubs with vegetative structures attached (roots, stem and leaves). **D-E:** Detail of the oblong parallel-veined leaves inserted oppositely to pairs in the nodes. **F-G:** Detail of the opposite strobili that consist of overlapping units spirally arranged along a central axis. **H:** The Gnetalean woody short shrub reconstructed. **I-J:** Morphological comparisons with similar taxa: **I:** Living *Ephedraceae* family – a grooved branch and also female (♀) and male (♂) strobili of the extant species *Ephedra chilensis*. **J:** Extinct gnetalean *Drewria potamacensis* with its vegetative parts reconstructed (modified from Crane & Upchurch, 1987). (Scale bar = 1 cm).

pairs in the nodes emerge from the stem basal portion. The roots constitute a dense fascicled system and exhibit a central furrow (Plate 1: A-C, H). The stem surface exhibits anatomical details such as epidermal features and vascular bundle organization.

**Description of the reproductive morphology:** A pair of strobili of opposite arrangement emerge from the branches nodes. The strobilar structure consists of overlapping units spirally arranged along a central axis (Plate 1: A, F-G).

## RESULTS AND DISCUSSION

**Morphology and Habit:** The specimens here studied are excellently preserved on the morphological and anatomical features (Plate 1). The cylindrical equisetoid and woody morphology of the stem and branches (Plate 1: A-C), as well as the general organization (constituting of a stem and dense fascicled roots), indicate a woody plant, while the small size suggests that it was a short shrub (Plate 1: H). The woody aspect is corroborated by the dry climate conditions already proposed for the Crato Member and also by the extant *Ephedra* species (Ephedraceae/Gnetales) that are xerophytics, and that are founded in the arid regions of Eurasia and the Americas (Kubitzki, 1990).

**Life Environment:** The fossil plant would live near of the shallow lacustrine or fluvial environments, probably in the stream margins, in the zone periodically flooded. This possibility is suggested due to the complete preservation of the fossil plant (Plate 1: A-C), indicating a short distance of transport. Similar palaeoenvironment has already been suggested to the Crato Member and other northern Gondwana parts in the literature.

**Comparison with Living and Extinct Gnetalean Taxa:** This plant fossil can not be assigned to any previously described genus of plant but shares significant similarities with some traits of the Gnetales. The general traits of the living Gnetales comprise a

mixture of gymnospermous and angiospermous characters. This extant plant group consists of three highly distinct and rather bizarre genera (Kubitzki, 1990). The fossil plant shares with gnetalean characters, such as woody shrubby habit (typical of the *Ephedra* and *Gnetum* genera), leaves and branches oppositely inserted, distinct nodes (typical of the *Ephedra* and *Gnetum* genera), parallel-veined leaves and also flowers arranged in compound strobili or “inflorescences” (Plate 1: G, I). In the genus *Ephedra*, the leaves are minute scales and are often soon shed, and the photosynthesis occurs in the green, ribbed and young stems (Kubitzki, 1990). For this fossil plant is suggested that the opposite oblong leaves beyond the stem would be able to perform the photosynthetic function.

In comparison with the fossil plant *Drewria potomacensis*, an early cretaceous member of the Gnetales from the Potomac Group of Virginia, USA (Crane & Upchurch, 1987), the oblong form and opposite arrangement of the leaves are similar, but the leaf length is bigger (10-20 mm long) and the nodal length is longer in the genus *Drewria* (Plate 1. J).

Therefore, is suggested that this new gnetalean taxon from the Crato palaeoflora may represent an extinct member of a putative lineage of Gnetales not directly related to the relictual living families or other extinct gnetalean taxa.

## ACKNOWLEDGMENTS

This research was carried out with financial support of CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo). This research is a contribution to FAPESP Project # 03/09407-4.

## BIBLIOGRAPHIC REFERENCES

1. ASSINE, M.L. Análise estratigráfica da Bacia do Araripe, Nordeste do Brasil. **Revista Brasileira de Geociências**, v. 22, n. 3, p. 289-300, 1992.
2. BERNARDES-DE-OLIVEIRA, M.E.C.; DILCHER, D.L.; MANDARIM-DE-LACERDA, A.F.; PONS, D. Registro Aptiano-Albiano de Welwitschiaceae na Formação Santana, Bacia do Araripe, nordeste do Brasil. In: CONGRESSO BRASILEIRO DE PALEONTOLOGIA, 16, 1999, Crato (CE). **Boletim de Resumos...** Sociedade Brasileira de Paleontologia, 1999, p. 25-26.
3. BERNARDES-DE-OLIVEIRA, M.E.C.; DILCHER, D.L.; MANDARIM-DE-LACERDA, A.F.; PONS, D.; RICARDI-BRANCO, F. Gnetalean macrofossils of the Crato Member, Santana Formation, Late Aptian-Early Albian, Chapada do Araripe, Brazil. In: INTERNATIONAL GEOLOGICAL CONGRESS, 30, 2000, Rio de Janeiro. **Abstracts...** Rio de Janeiro: International Union of Geological Sciences and Geological Survey of Brazil, 2000, CD-ROM.
4. CHAW, S.M.; PARKINSON, C.L.; CHENG, Y.; VINCENT, T.M.; PALMER, J.D. Seed plant phylogeny inferred from all

- three plant genomes monophyly of extant gymnosperms and origin of Gnetales from conifers. **Proceedings of the National Academy of Sciences**, v. 97, p. 4086-4091, 2000.
5. COIMBRA, J.C.; ARAI, M.; CARREÑO, A.L. Biostratigraphy of Lower Cretaceous microfossils from the Araripe basin, northeastern Brazil. **Geobios**, v. 35, p. 687-698, 2002.
  6. CORNET, B. A new gnetophyte from the late Carnian (Late Triassic) of Texas and its bearing on the origin of the angiosperm carpel and stamen. In: TAYLOR, D.W. & HICKEY, L.J. (Eds.), **Flowering plant origin, evolution and phylogeny**. New York: Chapman and Hall, p. 32-67, 1996.
  7. CRANE, P.R. Phylogenetic analysis of seed plants and the origin of angiosperms: the origin and early diversification of angiosperms. **Annals of the Missouri Botanical Garden**, v. 72, p. 716-793, 1985.
  8. CRANE, P.R. Major clades and relationships in the "Higher" Gymnosperms. In: BECK, C.B. (Ed.), **Origin and evolution of gymnosperms**. New York: Columbia University Press, p. 218-272, 1988.
  9. CRANE, P.R. The fossil history of the Gnetales. **International Journal of Plant Sciences**, Supplement, n. 6, v. 157, p. 50-57, 1996.
  10. CRANE, P.R. & UPCHURCH, G.R. JR. *Drewria potomacensis*, Gen. et Sp. Nov., an Early Cretaceous member of the Gnetales from the Potomac Group of Virginia. **American Journal of Botany**, v. 74, n. 11, p. 1722-1736, 1987.
  11. DILCHER, D.L.; BERNARDES-DE-OLIVEIRA, M.E.; PONS, D.; LOTT, T.A. Welwitschiaceae from the Lower Cretaceous of Northeastern Brazil. **American Journal of Botany**, v. 92, n. 8, p. 1294-1310, 2005.
  12. DOYLE, J.A. & ENDRESS, P.K. Morphological and phylogenetic analysis of basal angiosperms: Comparison and combination with molecular data. **International Journal of Plant Science**, v. 161, p. S121-S153, 2000.
  13. FANTON, J.C.M.; RICARDI-BRANCO, F.; DILCHER, D.; BERNARDES-DE-OLIVEIRA, M.E. New herbaceous plant from the Early Cretaceous palaeoflora of the Crato Member, Santana Formation, Araripe Basin, Northeastern Brazil. In: CONGRESSO BRASILEIRO DE PALEONTOLOGIA, 19, e CONGRESSO LATINO-AMERICANO DE PALEONTOLOGIA, 6, 2005, Aracaju. **Resumos...** Aracaju: Sociedade Brasileira de Paleontologia, 2005, CD-ROM.
  14. HERNGREEN, G.F.W. & CHLONOVA, A.F. Cretaceous microfloral provinces. **Pollen et Spores**, v. 23, p. 441-555, 1981.
  15. KRASSILOV, V.A.; DILCHER, D.L.; DOUGLAS, J.G. New ephedroid plant from the Lower Cretaceous Koonwarra Fossil Bed, Victoria, Australia. **Alcheringa**, v. 22, p. 123-133, 1998.
  16. KUBITZKI, K. Ephedraceae family. In: KUBITZKI, K. (Ed.), **The families and genera of vascular plants**. Springer-Verlag, p. 379-382, 1990.
  17. LIMA, M.R. DE. Palinologia da Formação Santana (Cretáceo do Nordeste do Brasil). I. Introdução geológica e descrição sistemática dos esporos da Subturma *Azonotriletes*. **Ameghiniana**, v. 15, p. 333-365, 1978.
  18. LIMA, M.R. DE. Palinologia do Mesozóico Brasileiro: uma síntese. In: Comité Sudamericano del Jurásico y Cretácico, **Cuencas sedimentarias del Jurásico y Cretácico de América del Sur**, v. 2, p. 445-460, 1981.
  19. MAISEY, J.G. Fossil plants. In: MAISEY, J.G. (Ed.). **Santana Fossils: an illustrated atlas**. Neptune City (NJ): T.F.H. Publ., 470 p., 1991.
  20. MOHR, B.A.R. & FRISS, E.M. Early angiosperms from the Lower Cretaceous Crato formation (Brazil): a preliminary report. **International Journal of Plant Science**, v. 161, p. S155-S167, 2000.
  21. NEUMANN, V.H.; BORREGO, A.G.; CABRERA, L.; DINO, R. Organic matter composition and distribution through the Aptian-Albian lacustrine sequences of the Araripe Basin, northeastern Brazil. **International Journal of Coal Geology**, v. 54, p. 21-40, 2003.
  22. PONS, D.; OLIVEIRA-BABINSKY, M.E.; LIMA, M.R. DE. Les Ephédrales de la Formation Santana, Crétacé inférieur du bassin d'Araripe (Brésil). In: CONFERENCE DE L'ORGANISATION INTERNATIONALE DE PALÉOBOTANIQUE, 4, Paris. Paris: Muséum National d'Histoire Naturelle, n. 125, 1992.
  23. REGALI, M.S. & VIANA, C.F. **Late Jurassic-Early Cretaceous in Brazilian sedimentary basins: correlation with the international standard scale**. Rio de Janeiro: Petróleo Brasileiro S.A. / Centro de Pesquisas e Desenvolvimento Leopoldo Américo Miguez de Mello (PETROBRÁS/CENPES), Relatório Interno, 95 p., 1989.
  24. RYDIN, C.B.; MOHR, B.; FRISS, E.M. *Cratonia cotyledon* gen. et sp. nov. a unique Cretaceous seedling related to *Welwitschia*. **Proceedings of the Royal Society of London, B**, Biology Letters (Supplement), v. 270, p. 1-4, 2003.
  25. STEWART, W.N. & ROTHWELL, G.W. (Eds.). **Palaeobotany and the evolution of plants**. London, Cambridge University Press, 2<sup>nd</sup> ed., 521 p., 2001.

*Manuscrito Recebido em: 7 de abril de 2006  
Revisado e Aceito em: 26 de julho de 2006*