



UNIVERSIDADE FEDERAL DO CEARÁ
CENTRO DE CIÊNCIAS
DEPARTAMENTO DE GEOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM GEOLOGIA

ANA PAULA DE ASSIS OLIVEIRA WESTERKAMP

**CRETACEOUS CONIFERS FROM THE ARARIPE BASIN,
WITH EMPHASIS ON CONE ANALYSES**

FORTALEZA

2018

ANA PAULA DE ASSIS OLIVEIRA WESTERKAMP

CRETACEOUS CONIFERS FROM THE ARARIPE BASIN,
WITH EMPHASIS ON CONE ANALYSES

Tese apresentada ao Programa de Pós-Graduação em Geologia do Centro de Ciências da Universidade Federal do Ceará, como requisito parcial à obtenção do título de doutor em Geologia. Área de Concentração: Paleontologia e Geologia Histórica

Orientador: Prof. Dr. Roberto Iannuzzi

FORTALEZA

2018

Dados Internacionais de Catalogação na Publicação
Universidade Federal do Ceará
Biblioteca Universitária
Gerada automaticamente pelo módulo Catalog, mediante os dados fornecidos pelo(a) autor(a)

- W539c Westerkamp, Ana Paula de Assis Oliveira.
Cretaceous conifers from the Araripe Basin, with emphasis on cone analyses / Ana Paula de Assis Oliveira Westerkamp. – 2018.
108 f. : il. color.
- Tese (doutorado) – Universidade Federal do Ceará, Centro de Ciências, Programa de Pós-Graduação em Geologia, Fortaleza, 2018.
Orientação: Prof. Dr. Roberto Iannuzzi.
1. Conifer cones. 2. Cretaceous. 3. Araripe Basin. I. Título.

CDD 551

ANA PAULA DE ASSIS OLIVEIRA WESTERKAMP

CRETACEOUS CONIFERS FROM THE ARARIPE BASIN,
WITH EMPHASIS ON CONE ANALYSES

Tese apresentada ao Programa de Pós-Graduação em Geologia do Centro de Ciências da Universidade Federal do Ceará, como requisito parcial à obtenção do título de doutor em Geologia. Área de Concentração: Paleontologia e Geologia Histórica

Aprovada em: 29 de Janeiro de 2018

BANCA EXAMINADORA

Prof. Dr. Roberto Iannuzzi (Orientador)
Universidade Federal do Rio Grande do Sul (UFRGS)

Dr. Lutz Kunzmann
Senckenberg Naturhistorische Sammlungen Dresden (Alemanha)

Prof. Dr. Wellington Ferreira da Silva Filho
Universidade Federal do Ceará (UFC)

Prof^a Dr^a Maria Somália Sales Viana
Universidade Estadual Vale do Acaraú (UVA)

Dr. Rodrigo Neregato
Universidade Federal do Rio Grande do Sul (UFRGS)

To

Dircionita and Christian

ACKNOWLEDGEMENTS

Thanks . . .

To my supervisors Roberto Iannuzzi and Lutz Kunzmann for their incentive, understanding and professionalism that led me to the conclusion of this dissertation. To you my respect, admiration and gratitude.

To the Department of Geology for receiving a biologist and allowing for my academic progress.

To FUNCAP for a doctorate scholarship.

To my mother Dircionita, my example of force and faith, and my father Francisco (in memoriam) for being the pillars of my personal development.

To my husband Christian, my safe harbour, for all his support, incentive, suggestions, instructions, for the huge work of typesetting this dissertation with \LaTeX , for having survived my absences and to believe in me more than I in myself. Words are missing to express my gratitude for all that you did and do for me. Zusammen bleiben!!!

To my sisters Fernanda and Érika, my brothers-in-law Francisco and Deusdete and the nephews Miguel and Rafael for allowing for a strengthening based on our mutual differences.

To Karla Janaísa Gonçalves Leite, our "Karinha", for sharing happiness and desperation, doubts and conquests and for always helping me when I was in need. Without your presence this way might have been much more difficult, our friendship I'll keep in my heart!

To Maria Helena Hessel for having me introduced to and helped with my first steps in palaeontology.

To Professor José de Araujo Nogueira Neto, "Zeca", for his incentive and support during the doctorate.

To Professor Wellington Ferreira da Silva Filho for his field course instructions, his support during the doctorate and for having accepted my invitation to participate in the defence committee.

To Professor Márcio Mendes for having accepted me in the Paleontology lab, for giving me access to the UFC fossils, for having housed the fossils of the Fundação Phoenix and for his presence and paying attention whenever I needed.

To the curators of the palaeontological collections: Wagner Souza Lima (FPH) and José Artur Ferreira Gomes de Andrade (DNPM) for lending me fossils for my studies.

To Professor Juliana de Moraes Leme and Ivone Cassab who, with their trainees, did not measure efforts to provide me with all the conditions needed to study the cones of the scientific collection of the USP.

To Professor Ismar de Souza Carvalho and Flávia Alessandra da Silva Figueiredo for their kind reception and support during my visit to the Museu da Geodiversidade (UFRJ).

To Joel Pedrosa and Antônio Leal for their help and hours of observation in the Laboratório de Microscopia Eletrônica (UFC).

To the Centro Regional para o Desenvolvimento Tecnológico e Inovação (Crti) of the Universidade Federal de Goiás (UFG) for fossil SEM analyses.

To the Central Analítica (UFC) for the realization of SEM analyses of fossils.

To Maria Valdete Lira for editing the maps.

To Professor Maria Somália Sales Viana and Rodrigo Neregato for participating in my defence committee.

To Daniel Ballester Marques, maintainer of bib \LaTeX -abnt, for some last-minute help – on Easter Sunday.

To Felipe Cavalcante da Rocha, who, in long hours of dedication, helped to resolve hidden problems in the \LaTeX model $UFCT\TeX$.

*"... nothing in our life makes sense,
if we do not touch the people's hearts."*

(Cora Coralina)

"No meio do caminho tinha uma pedra
tinha uma pedra no meio do caminho
tinha uma pedra
no meio do caminho tinha uma pedra.

Nunca me esquecerei desse acontecimento
na vida das minhas retinas tão fadigadas.
Nunca me esquecerei que no meio do caminho
tinha uma pedra
tinha uma pedra no meio do caminho
no meio do caminho tinha uma pedra."

(Carlos Drummond de Andrade)

"Mitten im Weg lag ein Stein
Lag ein Stein mitten im Weg
Lag ein Stein
Mitten im Weg lag ein Stein.

Nie werde ich dieses Ereignis
Im Leben meiner so ermüdeten Netzhaut vergessen.
Nie werde ich vergessen dass mitten im Weg
Lag ein Stein
Lag ein Stein mitten im Weg
Mitten im Weg lag ein Stein."

(German version by Curt Meyer-Clason)

ABSTRACT

Conifers have played a major role in terrestrial ecosystems since the end of the Carboniferous. The arrival of angiosperms in the Aptian (Early Cretaceous) triggered a competition from the Late Cretaceous onwards, finally resulting in an exclusion of conifers from certain regions or habitats. Nowadays, conifers are the most dominant and remarkable gymnosperms in floras throughout the world; they have a high economic and ecological importance. Cones, the conifer reproductive organs, are conspicuous and reflect the adaptive traits developed during the evolutionary process of the group. In the Crato Formation (Santana Group, Araripe Basin) diversity and preservation types of conifer-related fossils were investigated, giving special emphasis on cone structures. Information on whole-plant aspects and pollen records were taken from current literature. Cone data were obtained studying external aspects of the fossils. Vegetative shoot SEM analyses confirmed the presence of charcoal. A total of 140 cone specimens were encountered in the palaeontological collections visited. They were grouped into 26 morphotypes. Conifer macrofossils and palynology prove the occurrence of five conifer families: Araucariaceae, Cheirolepidiaceae, Cupressaceae, Pinaceae, and Podocarpaceae. The number of coalified cones exceeded the sum of all other preservation modes. Iron oxide was second followed by charcoal and impression. All types of preservation were observed in both greyish and yellowish sediments, with higher numbers in the first. Aspects of plant and animal diversity as well as their ecological relationships are presented for the Crato biome. The morphological diversity of the studied cones indicates a richness hitherto unsuspected for conifer species/families in the Araripe Basin. The variety of fossil taxa found in exceptional state of preservation in the Crato Formation reflects the intricate ecological relationships that existed in the Early Cretaceous in northeastern Brazil. .

Keywords: Conifer cones. Cretaceous. Araripe Basin.

RESUMO

As coníferas têm desempenhado um papel importante nos ecossistemas terrestres desde o final do Carbonífero. A chegada das angiospermas no Aptiano (Eocretáceo) desencadeou uma competição do Neocretáceo em diante, resultando na exclusão de coníferas de certas regiões ou habitats. Atualmente, as coníferas são as gimnospermas mais dominantes e notáveis das floras em todo o mundo, com alta importância econômica e ecológica. Seus órgãos reprodutores, os cones, são conspícuos e refletem os traços adaptativos desenvolvidos durante o processo evolutivo do grupo. Foram investigados os tipos de preservação e a diversidade de fósseis de coníferas que ocorrem em calcários laminados da Formação de Crato, com especial ênfase nos cones. Informações sobre microfósseis e registros polínicos foram retiradas da literatura corrente. Os dados dos cones foram obtidos por observações de aspectos externos dos fósseis. Análises de MEV em fragmentos de um caule confirmaram a presença de charcoal. Um total de 140 espécimes de cones foram encontrados nas coleções paleontológicas visitadas. Eles foram agrupados em 26 morfotipos. Macrofósseis e pólen comprovam a ocorrência de cinco famílias de coníferas: Araucariaceae, Cheirolepidiaceae, Cupressaceae, Pinaceae e Podocarpaceae. O número de cones preservados por coalificação excedeu a soma de todos os outros modos de conservação. Óxido de ferro foi a segunda forma, seguido por charcoal e impressão. Todos os tipos de preservação foram observados em ambos os sedimentos cinza e amarelo, com o predomínio de cones nos acinzentados. Aspectos da variedade vegetal e animal bem como suas relações ecológicas no bioma Crato foram apresentados. A diversidade morfológica dos cones estudados indica uma riqueza até então inesperada de espécies/famílias de coníferas na Bacia do Araripe. A multiplicidade de táxons fósseis encontrados em excepcional estado de conservação na Formação Crato reflete as intrincadas relações ecológicas que existiam no início do Cretáceo no nordeste do Brasil.

Palavras-chave: Cones. Coníferas. Cretáceo. Bacia do Araripe.

ZUSAMMENFASSUNG

Koniferen haben seit dem Ende des Karbons eine bedeutende Rolle in terrestrischen Ökosystemen gespielt. Das Auftauchen der Angiospermen im Apt (Frühe Kreide) hat zu einer Konkurrenzsituation geführt, die schließlich zum Ausschluss der Koniferen aus bestimmten Regionen oder Habitats führte. Heutzutage sind Koniferen die dominantesten und auffälligsten Gymnospermen weltweit; sie haben eine enorme ökonomische und ökologische Bedeutung. Zapfen, die Fortpflanzungsorgane der Koniferen, sind auffällig und widerspiegeln adaptive Merkmale, die sich während der Evolution der Gruppe entwickelten. In der Crato-Formation (Santana-Gruppe, Araripe-Becken) wurden Diversität und Erhaltungstypen von Koniferen-Fossilien untersucht; Zapfenstrukturen wurden dabei besonders berücksichtigt. Informationen zu Pflanzen und Pollen wurden der aktuellen Literatur entnommen. Zapfendaten wurden durch das Studium der externen Morphologie gewonnen. REM-Analysen eines vegetativen Sprosses bestätigten das Vorhandensein von Holzkohle. Insgesamt 140 Zapfenfossilien wurden in den besuchten palaeontologischen Sammlungen studiert. Sie wurden in 26 Morphotypen unterschieden. Koniferen-Makrofossilien und -Pollen belegen das Vorhandensein von fünf Familien: Araucariaceae, Cheirolepidiaceae, Cupressaceae, Pinaceae, und Podocarpaceae. Die Anzahl verkohlter Zapfen übertraf die Summe aller anderen Erhaltungstypen. Eisenoxid lag an zweiter Stelle, gefolgt von Holzkohle und Abdrücken. In grauen Sedimenten fanden sich mehr fossile Zapfen als in gelblichen. Aspekte der Pflanzen- und Tiervielfalt im Crato-Biom sowie mögliche ökologische Interaktionen werden vorgestellt. Die morphologische Diversität der untersuchten Zapfen deutet auf einen bisher unvorstellbaren Reichtum an Koniferenarten und -familien im Araripe-Becken hin. Die Vielfalt fossiler Taxa in äußerst gutem Erhaltungszustand in der Crato-Formation spiegelt die komplexen ökologischen Beziehungen wider, die in der Frühen Kreide in Nordost-Brasilien geherrscht haben müssen.

Schlüsselworte: Koniferenzapfen. Kreidezeit. Araripe-Becken.

LIST OF FIGURES

Figure 1 – Phanerozoic intracratonic basins in Northeastern Brazil	20
Figure 2 – Simplified geological map of the Araripe Basin	21
Figure 3 – Coniferales	26
Figure 4 – Coniferales 2	27
Figure 5 – Welwitschiaceae	28
Figure 6 – Gnetales	28
Figure 7 – Basal Angiosperms	29
Figure 8 – Monocotyledons	30
Figure 9 – Dicotyledons	30
Figure 10 – Crato Formation fungus	36
Figure 11 – Crato Formation invertebrates	38
Figure 12 – Crato Formation vertebrates	45
Figure 13 – Outcrop of the Crato Formation in Santana do Cariri	55
Figure 14 – Observed characteristics	56
Figure 15 – SEM analyses	57
Figure 16 – Conifer cone aspects	58
Figure 17 – Seed Cones	59
Figure 18 – Pollen cones	59
Figure 19 – Pollination participants	62
Figure 20 – Cone average sizes	64
Figure 21 – Sediment features	66
Figure 22 – Cone preservation modes in the Crato Formation	68
Figure 23 – Charcoal wood	70
Figure 24 – Cone response to humidity	73
Figure 25 – Morphological aspects of pollen cones	74

LIST OF TABLES

Table 1 – Simplified chronostratigraphic column of the Araripe Basin	22
Table 2 – Coniferales of the Crato Formation	60
Table 3 – Cone morphotypes	65
Table 4 – Sediment features	66

CONTENTS

1	INTRODUCTION	16
2	GEOLOGICAL AND PALEONTOLOGICAL BACKGROUND	19
2.1	Geology of the Araripe Basin	19
2.2	The Crato flora – state of the art	24
2.2.1	<i>Pteridophytes</i>	25
2.2.2	<i>Gymnosperms</i>	25
2.2.3	<i>Angiosperms</i>	28
2.2.4	<i>The significance of the Paleoflora</i>	30
2.3	The Crato biome – a brief introduction	31
2.3.1	<i>Abiotic conditions</i>	32
2.3.2	<i>Biotic components</i>	33
3	CRETACEOUS CONIFERS	47
3.1	Systematic overview	47
3.2	The South American record	52
4	MATERIAL AND METHODS	54
4.1	Study materials	54
4.2	Methods	55
5	RESULTS AND DISCUSSION	58
5.1	Conifer morphotypes	59
5.2	Taphonomy of Conifer remains	63
5.3	Whole-plant reconstructions	73
5.4	Paleoecology of conifer remains	74
6	CONCLUSIONS	76
	REFERENCES	77
	APPENDICES	
	APPENDIX A – Plate I	101
	APPENDIX B – Plate II	102
	APPENDIX C – Plate III	103
	APPENDIX D – Plate IV	104
	APPENDIX E – Plate V	105
	APPENDIX F – Plate VI	106

APPENDIX G – Plate VII	107
APPENDIX H – Plate VIII	108
APPENDIX I – Plate IX	109
APPENDIX J – Plate X	110