UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE GEOCIÊNCIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM GEOCIÊNCIAS

CONODONTES DO DEVONIANO SUPERIOR E PENSILVANIANO DA BACIA DO AMAZONAS, BRASIL
SISTEMÁTICA E ÍNDICE DE ALTERAÇÃO DE COR (IAC)

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“*Your time is limited, so don't waste it living someone else's life. Don't be trapped by dogma - which is living with the results of other people's thinking. Don't let the noise of other's opinions drown out your own inner voice. And most important, have the courage to follow your heart and intuition. They somehow already know what you truly want to become. Everything else is secondary*”.

“*Stay hungry, stay foolish*”.
(Steve Jobs. 2005. *Commencement Speech – Stanford University/USA*)

“Seu tempo é limitado, então não o gaste vivendo a vida de outra pessoa. Não caia na armadilha do dogma – que é viver com os resultados do pensamento de outra pessoa. Não deixe o ruído da opinião alheia sufocar sua voz interior. E mais importante, tenha a coragem de seguir seu coração e sua intuição. Eles de alguma forma já sabem o que você realmente quer se tornar. Tudo mais é secundário”.

“*Stay hungry, stay foolish*”.
(Steve Jobs. 2005. Discurso de Formatura – Universidade de Stanford/EUA)

RESUMO

Conodontes do Devoniano Inferior a Médio estão ausentes no registro geológico dos reinos Malvinocáfrico e das Américas Orientais e sua ocorrência no Devoniano Superior em regiões de latitude alta é extremamente rara. Esse fato contrasta com a abundância e diversidade desses organismos, reconhecidas nas faunas marinhas pensilvanianas. O material examinado é proveniente do Devoniano Superior e Pensilvaniano da Bacia do Amazonas, Grupo Curuá – Formação Barreirinha e Grupo Tapajós – formações Monte Alegre, Itaituba e Nova Olinda, respectivamente. A pesquisa empreendida consiste em estudos de taxonomia e sistemática, objetivando descrição detalhada e investigação da presença ocasional dos conodontes devonianos e o aprimoramento do conhecimento acerca da biodiversidade desses organismos no Pensilvaniano da América do Sul. Além disso, análises do Índice de Alteração de Cor (IAC) foram desenvolvidas com o intuito de avaliar o potencial para hidrocarbonetos e a influência da atividade ígnea e/ou hidrotermal na história térmica da bacia. Os exemplares são oriundos de amostras de poços estratigráficos e de afloramento e foram extraídos de diferentes litologias através de técnicas mecânicas e químicas típicas, com soluções tampão de ácido acético. Após a concentração e recuperação dos espécimes, aqueles selecionados foram observados ao Microscópio Eletrônico de Varredura para obtenção de imagens, com fins à análise taxonômica e de microtexturas. Posteriormente, as espécies descritas foram submetidas à investigação sistemática. O IAC e as alterações texturais foram identificados sob microscópio estereoscópico através da determinação da cor e da análise do estado de preservação da superfície dos espécimes, comparando-os a uma célula de IAC padrão. Em seguida, os intervalos de paleotemperaturas foram obtidos. A variação desse índice foi avaliada sob mapa geológico simplificado, seções estratigráficas e mapas de isolinhas de IAC. Além disso, o estabelecimento do zoneamento de maturação e a elaboração de resumo gráfico e mapa da estimativa de erosão/preservação de unidades do Grupo Tapajós auxiliaram na interpretação da história térmica da bacia. A fauna de conodontes devoniana, indicativa do Frasniano superior, apresenta baixa diversidade, compreendendo cinco espécies. Essa associação possui semelhanças com as faunas do Devoniano Superior da Bolívia, América do Norte central e Europa ocidental, sugerindo o intercâmbio de táxons entre estas regiões durante condições ambientais episódicas. Em contrapartida, os espécimes carboníferos mostram grande diversidade e atualmente constituem o registro mais vasto do Pensilvaniano Inferior-Médio na América do Sul. Foram identificadas vinte e sete novas espécies. Uma espécie nova, *Idiognathodus itaitubensis*, foi proposta para esta Época na Bacia do Amazonas. A afinidade previamente conhecida das faunas amazonenses com aquelas do Reino *Midcontinent-Andean* foi confirmada e a possibilidade de uma conexão marinha durante o Pensilvaniano Médio entre as bacias da América do Sul e o Oceano Paleotethys foi aventada. As formações estudadas apresentam valores de IAC principalmente entre 1.5-3 e condições diagenéticas propícias à geração de óleo pesado/leve e gás úmido/seco. O principal processo envolvido na maturação da matéria orgânica durante o Pensilvaniano-Permiano da bacia foi o soterramento sedimentar e, secundariamente, metamorfismo de contato e processo erosivo pronunciado. A atividade de fluidos condicionou as alterações texturais/microtexturais e as paleotemperaturas máximas alcançaram cerca de 180ºC.

PALAVRAS-CHAVE: conodonte; Devoniano Superior; Pensilvaniano; sistemática; IAC.

ABSTRACT

Conodonts from Lower to Middle Devonian are absent in the geological record of Malvinokaffric and Eastern Americas Realms and its occurrence in the Upper Devonian in high latitude regions is extremely rare. This fact contrasts with the abundance and diversity of these organisms, recognized in Pennsylvanian marine faunas. The material examined is from the Upper Devonian and Pennsylvanian of the Amazonas Basin, Curuá Group - Barreirinha Formation and Tapajós Group, Monte Alegre, Itaituba and Nova Olinda formations respectively. The research undertaken consists of studies of taxonomy and systematics, aiming detailed description and investigation of the occasional presence of Devonian conodonts and improving the knowledge concerning the biodiversity of these organisms in the Pennsylvanian of South America. In addition, the Color Alteration Index analyses (CAI) have been developed in order to evaluate the potential for hydrocarbons and the influence of igneous and/or hydrothermal activity in the thermal history of the basin. The specimens are from samples of stratigraphic wells and outcrop and were extracted from different lithologies through typical mechanical and chemical techniques with acetic acid buffer solutions. After the concentration and recovery of specimens, those selected were observed on Scanning Electron Microscope for imaging, for purposes of taxonomic analysis and microtextures. Subsequently, the species described were subjected to systematic investigation. The CAI and textural changes were identified under a stereomicroscope by determining the color and analysis of the preservation state of the specimens' surface, comparing them to a standard CAI cell. Then the paleotemperatures intervals were obtained. The variation of this index was evaluated in simplified geological map, stratigraphic sections and maps of CAI isolines. In addition, the establishment of maturation zoning and development of graphical summary and map of the estimated erosion/conservation of Tapajós Group units assisted in the interpretation of the thermal history of the basin. The Devonian conodont fauna, indicative of the upper Frasnian has low diversity, comprising five species. This association has similarities to Bolivia Upper Devonian, central North America and Western Europe faunas, suggesting the exchange of taxa between these regions during episodic environmental conditions. In contrast, the Carboniferous specimens show great diversity and currently constitute the broader record of the Lower-Middle Pennsylvanian in South America. Twenty-seven new species were identified. A new species, *Idiognathodus itaitubensis*, has been proposed for this Epoch in the Amazonas Basin. The previously known affinity of Amazonian faunas with those of the Midcontinent-Andean Realm has been confirmed and the possibility of a sea connection during the Middle Pennsylvanian between the basins of South America and the Paleotethys Ocean was discussed. The formations studied have CAI values mainly between 1.5-3 and favorable diagenetic conditions for the generation of heavy/light oil and wet/dry gas. The main process involved in the maturation of the organic matter during the Pennsylvanian-Permian interval in the basin was sedimentary burial and, secondarily, contact metamorphism and pronounced erosion. The fluid activity conditioned textural/microtextural changes and maximum paleotemperatures reached about 180°C.

KEY-WORDS: conodont; Upper Devonian; Pennsylvanian; systematics; CAI.

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Capítulo I – Introdução

Conodontes são vertebrados primitivos, que habitaram mares do Cambriano superior ao Triássico Superior (BRIGGS *et al*., 1983; ALDRIDGE *et al*., 1986, 1993; ALDRIDGE; DONOGHUE, 1998). Os remanescentes microscópicos, porções mineralizadas do aparelho alimentar desses organismos (CLARK *et al*., 1981) denominadas elementos conodontes, geralmente possuem entre 0,1 e 3,0 mm de comprimento e ocorrem sob diversas formas em um único espécime, ocupando posições específicas no aparelho multielementar (DONOGHUE *et al*., 2008).

A grande diversidade morfológica desses microfósseis reflete sua rápida evolução e, por ocorrerem em sequências marinhas do Paleozóico ao Triássico Superior, consagraram-se importantes indicadores bioestratigráficos, tornando-se assim, nos últimos 50 anos, um dos grupos fósseis mais importantes para bioestratigrafia e correlação mundial.

Conodontes de regiões de latitude alta são raros no Devoniano Superior. O artigo Cardoso *et al*. (2015a) ***Frasnian conodonts at high palaeolatitude (Amazonas Basin, north Brazil)*** apresentou o primeiro registro em detalhe dos conodontes desta Idade relatado para a Bacia do Amazonas e analisou a sua presença ocasional. O material fóssil, recuperado de planos de acamamento de folhelho negro (Formação Barreirinha) no testemunho 124 do poço estratigráfico 1-RX-1-AM, é composto por espécimes isolados, bem como inclusos na rocha e moldes externos, pertencentes às ordens Prioniodinida e Ozarkodinida, ocorrendo em associação com tasmanáceas. Além disso, esta formação compreende a principal geradora de hidrocarbonetos na Bacia do Amazonas, aumentando o interesse na idade e no contexto da sedimentação desta unidade.

Conodontes do Pensilvaniano da Bacia do Amazonas, Grupo Tapajós – formações Monte Alegre, Itaituba e Nova Olinda, foram descritos, submetidos à análise sistemática e apresentados no artigo Cardoso *et al*. (2016) ***Carboniferous conodonts from the Tapajós Group (Amazonas Basin, Brazil)***. Identificaram-se seis gêneros de conodontes: *Adetognathus*, *Diplognathodus*, *Idiognathodus*, *Idiognathoides*, *Neognathodus* e *Streptognathodus*. Uma nova espécie, *Idiognathodus itaitubensis*, foi proposta e as ocorrências de vinte e três táxons são consideradas inéditas na América do Sul. Visto que a taxonomia de forma, mais antiga, obscureceu as relações interelementos e considerando que a ocorrência de homólogos em diferentes aparelhos alimentares é evidente também na fauna amazonense; a natureza vicariante de alguns elementos P1 em diferentes associações multielementares foi considerada. Assim, fez-se uso da terminologia "*discrete element*" – DE à frente do nome de determinadas espécies de conodontes (HOROWITZ; REXROAD, 1982), a fim de acomodá-las quando um morfotipo provavelmente integra diversos aparelhos distintos. Além disso, aventou-se a existência de uma conexão ocasional entre a Bacia do Amazonas e a porção Oeste do Oceano Paleotethys durante o Pensilvaniano médio (Moscoviano). A diversidade de espécies observada é maior do que a previamente conhecida, sendo esta associação de conodontes, relativamente abundante, de grande interesse para o aprimoramento do conhecimento acerca da biodiversidade desse grupo no Carbonífero da América do Sul, constituindo uma base importante para estudos posteriores.

Os elementos conodontes são compostos por fosfato de cálcio [$Ca_5Na_{0,14}(PO_4)_{3,01}(CO_3)_{0,16}F_{0,73}(H_2O)_{0,85}$] na forma de cristais de francolita (fluorapatita) e por quantidades traço de matéria orgânica (PIETZNER *et al*., 1968; ELLISON, 1944; ZIEGLER; LINDSTRÖM, 1981; SWEET; DONOGHUE, 2001; MISHIMA *et al*., 2008). Esses microfósseis tornaram-se excelentes índices térmicos, particularmente para rochas entre os graus diagenético e de metamorfismo mais baixo, devido a sua composição e padrão de crescimento, o qual consiste na acreção de lamelas de apatita com ocorrência de matéria orgânica, tanto na forma de delgadas camadas entremeadas quanto disseminada.

O Índice de Alteração de Cor de conodontes (IAC) permite-nos determinar as paleotemperaturas máximas a que as rochas foram submetidas e estabelecer a história térmica de uma bacia. É um implemento significativo em geologia econômica, uma vez que é utilizado para explorar o potencial para hidrocarbonetos e a influência da atividade hidrotermal em bacias. Análises preliminares para IAC em conodontes do Paleozóico da Bacia do Amazonas foram realizadas por Rocha-Campos *et al*. (1988), Scomazzon (2004), Nascimento (2008), Cardoso (2010) e

Cardoso *et al*. (2012), embora a cor dos conodontes não tenha sido comparada a uma lâmina padrão, mas sim a tabelas de coloração[1] publicadas. Além do valor de IAC, Nascimento (2008) observou a textura de conodontes e, mais tarde, Cardoso (2010) e Cardoso *et al*. (2012) ilustraram texturas e microtexturas (já no sentido de BLANCO-FERRERA *et al*., 2011) desenvolvidas em muitos dos conodontes analisados.

No artigo Cardoso *et al*. (2015b) ***Conodont colour alteration index and upper Paleozoic thermal history of the Amazonas Basin, Brazil***, o IAC para a Bacia do Amazonas foi determinado através da análise de oitenta e seis amostras oriundas de vinte e três poços e um afloramento, incluindo a Formação Barreirinha (Frasniano) e o Grupo Tapajós (Pensilvaniano-Permiano). A variação do IAC foi analisada em mapa geológico simplificado e seções transversais para diferentes unidades litoestratigráficas do Paleozóico desta bacia. Os valores de IAC foram complementados com as alterações texturais e microtexturais observadas na superfície dos conodontes, sendo então ambos dados integrados na história tectono-termal da bacia.

Estado da Arte

Registros de conodontes na Bacia do Amazonas

Os conodontes da Bacia do Amazonas ocorrem principalmente nos estratos marinhos do Pensilvaniano (**tabela 1**). Fúlfaro (1965) descreveu, pela primeira vez no Brasil, conodontes provenientes de cinco afloramentos ao longo das margens do Rio Tapajós, Formação Itaituba - Bacia do Amazonas. O autor identificou oito espécies de conodontes: *Cavusgnathus lauta*; *Gnathodus* sp.; *Hindeodella iowaensa*; *Hindeodella* sp.; *Idiognathodus acutus*; *Idiognathodus* sp.; *Ligonodina* sp.; *Ozarkodina delicatula* e concluiu que a presença de *Idiognathodus acutus* seria uma evidência para a datação desses sedimentos como desmoinesianos.

Araújo e Rocha-Campos (1969), analisando onze amostras do poço PEst-2-AM na Bacia do Amazonas, identificaram quinze espécies pertencentes a oito gêneros de

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[1] Munsell Color Company (1971).

conodontes: *Cavusgnathus*; *Gnathodus*; *Hindeodella*; *Idiognathodus*; *Ozarkodina*; *Polygnathus*; *Polylophodonta*; *Streptognathodus*. Os autores indicaram idade pensilvaniana, conforme a distribuição estratigráfica dos espécimes estudados.

As associações de conodonte da Bacia do Amazonas correspondem ao Reino Midcontinent-Andino e sua afinidade com associações norte-americanas permitiu correlação com os Andares Regionais da América do Norte. Zoneamentos locais para a Bacia do Amazonas foram correlacionados com os andares do Morrowano tardio ao Desmoinesiano inicial (LEMOS; MEDEIROS, 1989; LEMOS, 1990, 1992a, 1992b; LEMOS; MEDEIROS, 1996a, 1996b; NEIS, 1996; SILVA; LEMOS, 1996; SCOMAZZON, 1999; LEMOS; SCOMAZZON, 2001; SCOMAZZON, 2004; NASCIMENTO *et al*., 2005; SCOMAZZON; LEMOS, 2005; NASCIMENTO, 2008; NASCIMENTO *et al*., 2009; CARDOSO, 2010; NASCIMENTO *et al*., 2010b; SCOMAZZON *et al*., 2016).

Lemos (1990) estudou dezoito poços oriundos de diversas localidades na calha central e nas plataformas Norte e Sul da Bacia do Amazonas e descreveu três zonas de associação: **(I)** Zona *Neognathodus symmetricus*/*Rhachistognathus muricatus* abrangendo a Formação Monte Alegre e porção inferior da Formação Itaituba, caracterizando o Morrowano inicial, **(II)** Zona *Diplognathodus orphanus*/*Diplognathodus coloradoensis* compreendendo a porção média da Formação Itaituba, marcando o intervalo Atokano-Desmoinesiano inicial e **(III)** Zona *Streptognathodus elongatus*/*Idiognathodus ellisoni*, representativa do Pensilvaniano médio-tardio na Fomação Nova Olinda. A autora desenvolveu a primeira discussão sobre bioestratigrafia com base em conodontes para a Bacia do Amazonas utilizando a taxonomia multielemental.

Lemos (1992a, 1992b) realizou um estudo de cunho sistemático e bioestratigráfico com base em conodontes das formações Monte Alegre, Itaituba e Nova Olinda. A autora analisou quarenta e três testemunhos de treze poços da Bacia do Amazonas e reconheceu dezesseis espécies de conodontes: *Adetognathus lautus*; *Declinognathodus noduliferus*; *Diplognathodus coloradoensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathodus delicatus*; *I. magnificus*; *I. suberectus*; *Idiognathoides sinuatus*; *Neognathodus bassleri*; *Neognathodus roundyi*; *Neognathodus symmetricus*; *Rhachistognathus muricatus*; *Streptognathodus* *elegantulus*; *S. expansus*; *S. parvus*. A associação fóssil permitiu a atribuição de idade morrowana-atokana aos intervalos estratigráficos estudados.

Lemos e Medeiros (1996a), estudando a seqüência carbonífera da Bacia do Amazonas, abrangendo as formações Monte Alegre, Itaituba e Nova Olinda, identificaram dezesseis espécies de conodontes e estabeleceram duas zonas de associação: **(I)** Zona *Neognathodus symmetricus*/*Rhachistognathus muricatus*, com espécies típicas do Morrowano, abrangendo a Formação Monte Alegre e a porção inferior da Formação Itaituba e **(II)** Zona *Diplognathodus orphanus*/*Diplognathodus coloradoensis*, com espécies características do Atokano, registrada nas porções média e superior da Formação Itaituba.

A Zona *Neognathodus symmetricus*/*Rhachistognathus muricatus* é composta ainda pelas espécies *Adetognathus lautus*; *Declinognathodus noduliferus*; *Hindeodus minutus*; *Idiognathodus delicatus*; *I. suberectus*; *Idiognathoides sinuatus*; *Neognathodus bassleri*; *Neognathodus roundyi*; *Streptognathodus elegantulus*; *S. expansus*; *S. parvus*.

A Zona *Diplognathodus orphanus*/*Diplognathodus coloradoensis* abrange ainda as espécies *Adetognathus lautus*; *Declinognathodus noduliferus*; *Hindeodus minutus*; *Idiognathodus delicatus*; *I. magnificus*; *Idiognathoides sinuatus*; *Neognathodus bassleri*; *Neognathodus roundyi*; *Streptognathodus elegantulus*; *S. parvus*.

Os autores reconheceram o limite Morrowano-Atokano na parte média da Formação Itaituba, logo abaixo do folhelho marcador M-65, o qual representa o primeiro evento de inundação máxima que transgrediu sobre o Arco de Purus durante o Carbonífero na bacia.

Lemos e Medeiros (1996b) analisaram rochas carbonáticas coletadas na faixa Sul de afloramentos às margens do Rio Tapajós, atribuídas ao intervalo basal da Formação Itaituba. Os autores identificaram três espécies de conodontes: *Gnathodus bilineatus*; *Gnathodus girtyi*; *Lochriea mononodosa* e posicionaram o intervalo estudado no Chesteriano (Mississipiano Superior).

Neis (1996), com base em quatro poços distribuídos entre as plataformas Norte e Sul da Bacia do Amazonas, sugeriu duas zonas de associação: **(I)** *Idiognathoides ouachitensis*/*Rhachistognathus muricatus*, abrangendo a Formação Monte Alegre e a porção inferior da Formação Itaituba, de idade morrowana e **(II)** *Diplognathodus* spp., ocorrendo dentro da Formação Itaituba, sugerindo idade atokana. O autor propôs que o intervalo analisado estivesse posicionado entre Morrowano superior-Atokano médio.

Silva e Lemos (1996), estudando o controle dos ciclos sedimentares na distribuição estratigráfica dos conodontes da Formação Itaituba, Pensilvaniano da Bacia do Amazonas, reconheceram dezoito espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathoides sinuatus*; *Idiognathodus delicatus*; *I. magnificus*; *I. suberectus*; *Neognathodus bassleri*; *Neognathodus medadultimus*; *Neognathodus roundyi*; *Neognathodus symmetricus*; *Rhachistognathus muricatus*; *Idiopriniodus* sp.; *Streptognathodus elegantulus*; *S. expanses*; *S. parvus*; *Declinognathodus noduliferus*. De acordo com a fauna encontrada, os autores posicionaram cronoestratigraficamente o terço inferior da Formação Itaituba no Morrowano e o terço médio-superior no Atokano.

Scomazzon (1999) estudou afloramentos da plataforma Sul da Bacia do Amazonas, correspondentes à porção superior da Formação Monte Alegre e à Formação Itaituba. A autora definiu três zonas de intervalo local: **(I)** Zona *Idiognathodus sinuosus*/*Rhachistognathus muricatus* compreendendo a porção superior da Formação Monte Alegre e a porção inferior da Formação Itaituba, posicionada no Morrowano inicial, **(II)** Zona *Idiognathodus klapperi*/*Streptognathodus parvus*, correspondendo à porção média da Formação Itaituba, posicionada no intervalo Morrowano tardio-Atokano e **(III)** Zona *Idiognathodus claviformis*/*Idiognathodus incurvus*, abrangendo a porção superior da Formação Itaituba, posicionada no Desmoinesiano inicial.

Lemos e Scomazzon (2001) revisaram dezoito poços e quatro afloramentos da Bacia do Amazonas e renomearam a terceira zona de Lemos (1990, Zona *Streptognathodus elongatus*/*Idiognathodus ellisoni*) como Zona *Idiognathodus claviformis*/*Idiognathodus incurvus*, que ocorre próxima à base da Formação Nova Olinda, e sugeriram idade desmoinesiana inicial para o intervalo revisto.

Scomazzon (2004) analisou dezoito poços e três afloramentos, compreendendo um perfil de Norte-Sul na Bacia do Amazonas. A autora estabeleceu uma zona de amplitude de táxon *Idiognathodus incurvus* para a Formação Itaituba e parte inferior da Formação Nova Olinda e uma subzona *Diplognathodus coloradoensis* para a

Formação Itaituba, sugerindo idade Atokano médio-Desmoinesiano inicial para a seção analisada.

A autora forneceu evidências através de bioestratigrafia e por correlação estratigráfica que o Marco-65 (CAROZZI *et al*., 1972), na realidade, estaria correlacionado com os depósitos siliciclásticos dos estratos mais inferiores do Grupo Tapajós.

Nascimento *et al*. (2005) estudaram setenta de cinco amostras de dois afloramentos na região Sul da Bacia do Amazonas, compreendendo a porção inferior da Formação Itaituba, e identificaram sete gêneros e dez espécies de conodontes. Os autores definiram duas zonas de amplitude de táxon: **(I)** Zona *Idiognathoides sinuatus* abrangendo o intervalo Morrowano-Atokano e **(II)** Subzona *Neognathodus roundyi* marcando o limite entre estes andares, com espécies características do Atokano.

A Zona *Idiognathoides sinuatus* compreende, além da espécie que a define, *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiopriniodus* sp.; *Neognathodus* spp.

A Subzona *Neognathodus roundyi* inclui ainda *Adetognathus lautus*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Neognathodus atokaensis*; *Neognathodus medadultimus*; *Neognathodus roundyi*.

Scomazzon e Lemos (2005) analisaram trinta e nove amostras de quatro poços locados na calha central e nas plataformas Norte e Sul da Bacia do Amazonas. As autoras reportaram a primeira ocorrência de *Diplognathodus ellesmerensis* na Formação Itaituba. A associação identificada compreendia ainda nove espécies de conodontes: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus orphanus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus medadultimus*; *Neognathodus roundyi*. De acordo com a fauna registrada, mas principalmente pela ocorrência de *Diplognathodus orphanus* nas porções inferior e superior da Formação Itaituba, foi sugerida idade atokana para o intervalo estudado.

Nascimento (2008) investigou cinco afloramentos compreendendo 128 amostras na porção superior da Formação Monte Alegre e porção inferior da Formação Itaituba, seção do Tapajós. A autora identificou dezoito espécies de conodontes:

Adetognathus lautus; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Ellisonia conflexa*; *Ellisonia latilaminata*; *Gondolella sp.*; *Hindeodus minutes*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Idiopriniodus sp.*; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus bothrops*; *Neognathodus medadultimus*; *Neognathodus roundyi*; *Rhachistognathus muricatus*; *Ubinates advena* e propôs duas zonas de amplitude de táxon, *Diplognathodus orphanus* e *Rhachistognathus muricatus*, e uma cenozona, *Idiognathodus incurvus*/*Neognathodus atokaensis*/*Neognathodus medadultimus*, posicionando o limite Morrowano-Atokano entre as formações Monte Alegre e Itaituba.

Nascimento *et al*. (2009) apresentaram uma nova abordagem de estudo através da integração de dados bioestratigráficos advindos de conodontes e de palinomorfos recuperados de uma mesma seção aflorante da Formação Itaituba, na borda Sul da Bacia do Amazonas.

A associação de conodontes compreendia sete espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*. A associação de palinomorfos abrangia quatro espécies de esporos: *Apiculatasporites daemonii*; *Spelaeotriletes arenaceus*; *Spelaeotriletes triangulus*; *Vallatisporites punctatus*, doze espécies de grãos de pólen: *Cannanoropolis densus*; *Cannanoropolis janaki*; *Costatascyclus crenatus*; *Cycadopites* sp.; *Illinites unicus*; *Meristocorpus explicatus*; *Meristocorpus* sp.; *Plicatipolenites malabarensis*; *Potonieisporites congoensis*; *Potonieisporites novicus*; *Protohaploxypinus amplus*; *Striomonosaccites incrassatus* e um exemplar de alga, *Botryococcus braunii*. De acordo com a associação faunística encontrada, os autores posicionaram a seção estudada no Atokano médio.

Cardoso (2010) pesquisou 27 amostras de um afloramento da Formação Itaituba e identificou dez espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Ellisonia* sp.; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Neognathodus bothrops*; *Neognathodus medadultimus*. Foram propostas uma zona de amplitude de táxon *Diplognathodus orphanus* e uma zona de concorrência *Idiognathodus incurvus*-*Idiognathoides sinuatus*, posicionando a sucessão analisada no Atokano médio.

Nascimento *et al*. (2010b) propuseram duas zonas de amplitude de taxon: **(I)** Zona *Rhachistognathus muricatus*, correspondendo ao andar Morrowano, correlacionada litoestratigraficamente aos arenitos da porção superior da Formação Monte Alegre e à porção inferior da Formação Itaituba, e **(II)** Zona *Diplognathodus orphanus*, correspondendo ao Atokano, correlacionada litoestratigraficamente à Formação Itaituba. Os autores sugeriram também uma zona de associação *Idiognathodus incurvus*/*Neognathodus atokaensis*/*Neognathodus medadultimus*, correspondendo ao Atokano e correlacionada litoestratigraficamente à Formação Itaituba. A ocorrência de *Diplognathodus orphanus* e *Idiognathodus incurvus* confirma a idade atokana sugerida.

Scomazzon *et al*. (2016) identificaram 17 espécies de conodontes, ao analisarem 3 afloramentos e 18 poços abrangendo porção superior da Formação Monte Alegre, Formação Itaituba e porção inferior da Formação Nova Olinda: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathodus* sp.; *Idiognathoides sinuatus*; *Idioprioniodus* sp.; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus bothrops*; *Neognathodus medadultimus*; *Neognathodus roundyi*; *Neognathodus* sp.; *Neognathodus symmetricus*; *Streptognathodus* sp. Os autores sugeriram uma zona de amplitude de táxon local *Idiognathodus incurvus* e uma subzona de amplitude de táxon local *Diplognathodus coloradoensis*, situando a Formação Itaituba e a porção inferior da Formação Nova Olinda no intervalo entre o Bashkiriano tardio e o Moscoviano (Atokano a Desmoinesiano inicial).

Tabela 1: Relação de estudos de conodontes das formações Monte Alegre, Itaituba e Nova Olinda, Bacia do Amazonas.

Autor	Amostragem	Gêneros/Espécies	Grupo/Formação	Idade
Fúlfaro (1965)	5 afloramentos	8 espécies: *Hindeodella iowaensa*; *Hindeodella* sp.; *Ozarkodina delicatula*; *Ligonodina* sp.; *Idiognathodus acutus*; *Idiognathodus* sp.; *Cavusgnathus lauta*; *Gnathodus* sp.	F. Itaituba	Desmoinesiano
Araújo e Rocha-Campos (1969)	11 amostras, 4 testemunhos, poço PEst-2-	15 espécies/8 gêneros: *Cavusgnathus*; *Hindeodella*; *Streptognathodus*; *Idiognathodus*; *Gnathodus*;	F. Itaituba	Pensilvaniano

	AM	*Ozarkodina*; *Polylophodonta*; *Polygnathus*		
Tengan *et al*. (1976)	-	4 gêneros: *Cavusgnathus*; *Idiognathodus*; *Gnathodus*; *Streptognathodus*	F. Itaituba, F. Nova Olinda	Pensilvaniano inicial-médio)
Lemos e Medeiros (1989)	-	6 espécies: *Diplognathodus coloradoensis*; *Diplognathodus orphanus*; *Idiognathodus magnificus*; *Idognathodus suberectus*; *Neognathodus symmetricus*; *Rhachistognathus muricatus*	F. Monte Alegre, F. Itaituba	Morrowano-Atokano
Lemos (1990)	18 poços	3 zonas de associação: (I) Zona *Neognathodus symmetricus*/*Rhachistognathus muricatus* (II) Zona *Diplognathodus orphanus*/*Diplognathodus coloradoensis* (III) Zona *Streptognathodus elongatus*/*Idiognathodus ellisoni*	F. Monte Alegre, F. Itaituba, F. Nova Olinda	Morrowano inicial (F. Monte Alegre e porção inferior da F. Itaituba) Atokano-Desmoinesiano inicial (porção média da F. Itaituba) Pensilvaniano médio-tardio (F. Nova Olinda)
Lemos (1992a)	43 testemunhos, 13 poços (junto com 1992b)	11 espécies: *Idiognathodus delicatus*; *I. magnificus*; *I. suberectus*; *Streptognathodus parvus*; *S. expanses*; *S. elegantulus*; *Neognathodus bassleri*; *Neognathodus roundyi*; *Neognathodus symmetricus*; *Hindeodus minutus*; *Rhachistognathus muricatus*	F. Monte Alegre, F. Itaituba, F. Nova Olinda	Morrowano-Atokano
Lemos (1992b)	43 testemunhos, 13 poços (junto com 1992a)	5 espécies: *Adetognathus lautus*; *Idiognathoides sinuatus*; *Declinognathodus nodiliferus*; *Diplognathodus orphanus*; *Diplognathodus coloradoensis*	F. Monte Alegre, F. Itaituba, F. Nova Olinda	Morrowano-Atokano
Lemos e Medeiros (1996a)	13 poços	16 espécies: *Adetognathus lautus*; *Declinognathodus noduliferus*; *Diplognathodus coloradoensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathodus delicates*; *I. magnificus*; *I. suberectus*; *Idiognathoides sinuatus*; *Neognathodus bassleri*; *Neognathodus roundyi*; *Neognathodus symmetricus*; *Rhachistognathus muricatus*; *Streptognathodus elegantulus*; *S. expanses*; *S. parvus* 2 zonas de associação: (I) Zona *Neognathodus*	F. Monte Alegre, F. Itaituba, F. Nova Olinda	Limite Morrowano-Atokano na porção média da F. Itaituba

		symmetricus/*Rhachistognathus muricatus* (II) *Diplognathodus orphanus*/*Diplognathodus coloradoensis*		
Lemos e Medeiros (1996b)	afloramentos	3 espécies: *Gnathodus bilineatus*; *Gnathodus girtyi*; *Lochriea mononodosa*	F. Itaituba	Chesteriano (Mississipiano tardio - Carbonífero inicial) na porção basal da F. Itaituba
Neis (1996)	4 poços	2 zonas de associação: (I) Zona *Idiognathoides ouachitensis*/*Rhachistognathus muricatus* (II) Zona *Diplognathodus* spp.	F. Monte Alegre, F. Itaituba	(I) Morrowano (F. Monte Alegre e a porção inferior da F. Itaituba) (II) F. Itaituba
Silva e Lemos (1996)	-	18 espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathoides sinuatus*; *Idiognathodus delicatus*; *I. magnificus*; *I. suberectus*; *Neognathodus bassleri*; *Neognathodus medadultimus*; *Neognathodus roundyi*; *Neognathodus symmetricus*; *Rhachistognathus muricatus*; *Idiopriniodus* sp.; Streptognathodus elegantulus; *S. expanses*; *S. parvus*; *Declinognathodus noduliferus*	F. Itaituba	Morrowano no terço inferior da F. Itaituba e Atokano no terço médio/superior da F. Itaituba
Scomazzon (1999)	-	3 zonas de intervalo local: (I) Zona *Idiognathodus sinuosus*/ *Rhachistognathus muricatus* (II) Zona *Idiognathodus klapperi*/*Streptognathodus parvus* (III) Zona *Idiognathodus claviformis*/*Idiognathodus incurvus*	F. Monte Alegre (porção superior) e F. Itaituba	Morrowano inicial (porção superior da F. Monte Alegre e a porção inferior da F. Itaituba) Morrowano tardio -Atokano (Formação Itaituba) Desmoinesiano inicial
Lemos e Scomazzon (2001)	18 poços e 4 afloramentos	renomearam a terceira zona de Lemos (1990), Zona *Streptognathodus elongatus*/*Idiognathodus ellisoni*, como Zona *Idiognathodus claviformis*/*Idiognathodus incurvus*	base da Formação Nova Olinda	Desmoinesiano inicial
Scomazzon (2004)	18 poços e 3 afloramentos	zoneamentos: (I) Zona *Idiognathodus incurvus*	(I) F. Itaituba e porção inferior da	Atokano médio-Desmoinesiano

		(II) Subzona *Diplognathodus coloradoensis*	F. Nova Olinda (II) Formação Itaituba	
Nascimento *et al*. (2005)	75 amostras de 2 afloramentos	7 gêneros e 10 espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Idiopriniodus* sp.; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus medadultimus*; *Neognathodus roundyi* 2 zonas de amplitude de táxon: (I) Zona de *Idiognathoides sinuatus* (II) Subzona de *Neognathodus roundyi*	F. Itaituba (porção inferior)	Morrowano-Atokano (porção inferior da F. Itaituba) com subzona caracterizando este limite
Scomazzon e Lemos (2005)	39 amostras de 4 poços	10 espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus medadultimus*; *Neognathodus roundyi*	F. Itaituba	Atokano
Nascimento (2008)	128 amostras de 5 afloramentos	18 espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Ellisonia conflexa*; *Ellisonia latilaminata*; *Gondolella sp.*; *Hindeodus minutes*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Idiopriniodus sp.*; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus bothrops*; *Neognathodus medadultimus*; *Neognathodus roundyi*; *Rhachistognathus muricatus*; *Ubinates ádvena* 2 zonas de amplitude de táxon e 1 cenozona: (I) *Diplognathodus orphanus* (II) *Rhachistognathus muricatus* (III) *Idiognathodus incurvus*/*Neognathodus atokaensis*/*Neognathodus medadultimus*	F. Monte Alegre (porção superior) e F. Itaituba (porção inferior)	Morrowano (limite entre as formações) Atokano (F. Itaituba)

Nascimento *et al.* (2009)	1 afloramentos	7 espécies de conodontes: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus* 4 espécies de esporos: *Apiculatasporites daemonii*; *Spelaeotriletes arenaceus*; *Spelaeotriletes triangulus*; *Vallatisporites punctatus* 12 espécies de grãos de pólen: *Cannanoropolis densus*; *Cannanoropolis janaki*; *Costatascyclus crenatus*; *Cycadopites* sp.; *Illinites unicus*; *Meristocorpus explicatus*; *Meristocorpus* sp.; *Plicatipolenites malabarensis*; *Potonieisporites congoensis*; *Potonieisporites novicus*; *Protohaploxypinus amplus*; *Striomonosaccites incrassatus* 1 espécie de alga: *Botryococcus braunii*	F. Itaituba	Atokano médio
Cardoso (2010)	27 amostras de 1 afloramento	10 espécies: *Adetognathus lautus*; *Diplognathodus coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Ellisonia* sp.; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathoides sinuatus*; *Neognathodus bothrops*; *Neognathodus medadultimus* zoneamentos: (I) zona de amplitude *Diplognathodus orphanus* (II) zona de concorrência *Idiognathodus incurvus*-*Idiognathoides sinuatus*	Formação Itaituba	Atokano médio
Nascimento *et al.* (2010b)		2 zonas de amplitude de táxon: (I) Zona *Rhachistognathus muricatus* (II) Zona *Diplognathodus orphanus* 1 zona de associação: (III) Zona *Idiognathodus incurvus*/*Neognathodus atokaensis*/*Neognathodus medadultimus*	Formações Monte Alegre e Itaituba	(I) Morrowano (arenitos da porção superior da F. Monte Alegre e porção inferior da F. Itaituba) (II) Atokano (F. Itaituba) (III) Atokano (F. Itaituba)
Scomazzon *et al.*	3 afloramentos	17 espécies: *Adetognathus lautus*; *Diplognathodus*	F. Monte Alegre (porção superior),	(I) e (II) Bashkiriano

(2016)	e 18 poços	*coloradoensis*; *Diplognathodus ellesmerensis*; *Diplognathodus orphanus*; *Hindeodus minutus*; *Idiognathodus incurvus*; *Idiognathodus* sp.; *Idiognathoides sinuatus*; *Idioprioniodus* sp.; *Neognathodus atokaensis*; *Neognathodus bassleri*; *Neognathodus bothrops*; *Neognathodus medadultimus*; *Neognathodus roundyi*; *Neognathodus* sp.; *Neognathodus symmetricus*; *Streptognathodus* sp. zoneamentos: (I) zona de amplitude de táxon local *Idiognathodus incurvus* (II) subzona de amplitude de táxon local *Diplognathodus coloradoensis*	F. Itaituba e F. Nova Olinda (porção inferior)	tardio-Moscoviano (Atokano-Desmoinesiano inicial) (I) e (II) F. Itaituba e F. Nova Olinda (porção inferior)

Índice de Alteração de Cor de conodontes – IAC

A alteração na cor dos elementos conodontes foi observada pela primeira vez por Ellison (1944), contudo, até meados da década de 1970, essa alteração era vista como um impedimento aos estudos morfológicos desses microfósseis, não sendo explorada nem elucidada (HARRIS, 1981).

As diferenças na coloração dos elementos conodontes foram organizadas sistematicamente em intervalos de cor (IAC - Índice de Alteração de Cor) somente no final da década de 1970, com o trabalho pioneiro de Epstein *et al*. (1977). Esses autores utilizaram amostras de campo oriundas de calcários da Bacia Apalachiana no intervalo Ordoviciano-Pensilvaniano, pirólise experimental de espécimes inalterados e diagrama de Ahrrenius[2] para extrapolar seus dados para outros períodos de tempo geológicos. Epstein *et al*. (1977) demonstraram que os elementos conodontes, quando inalterados, apresentavam cor amarelo claro a âmbar claro e que esses microfósseis sofreram nitidamente alterações na sua cor original (amarelo claro a preto), equivalentes a valores de IAC entre 1 e 5 (**figura 1**),

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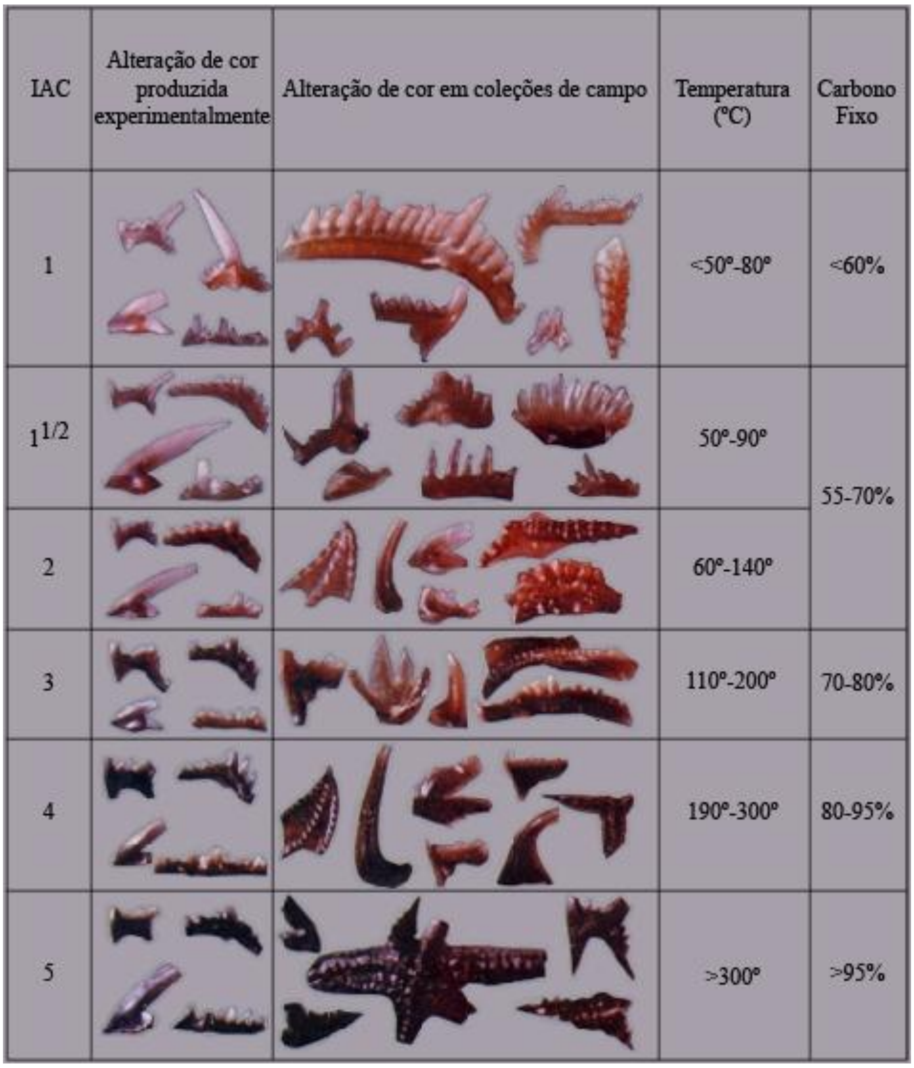
[2] Os limites de temperatura geológica (inferior e superior) para todos os IAC são determinados a partir de um diagrama de *log* de tempo *versus* o recíproco da temperatura absoluta (EPSTEIN *et al*., 1977).

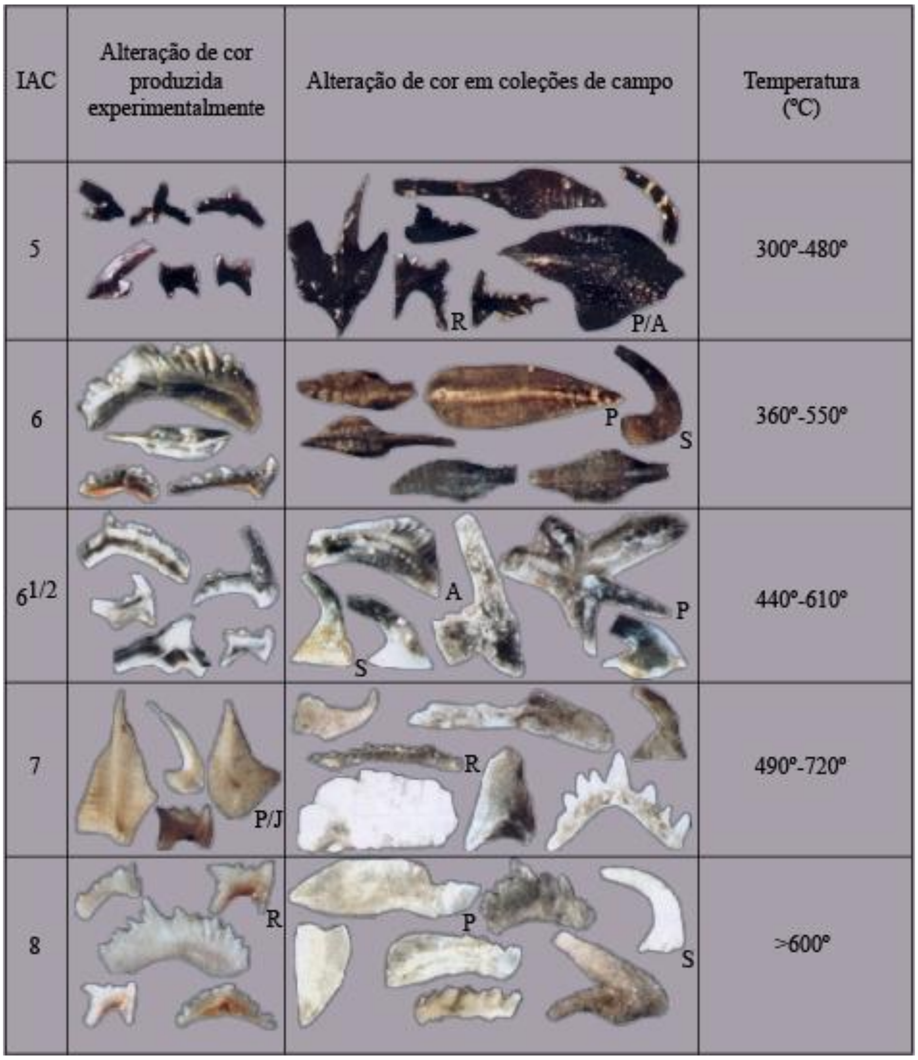
que foram atribuídos a diferentes regimes de temperatura (< 50ºC a > 300ºC) durante a diagênese progressiva.



IAC	Alteração de cor produzida experimentalmente	Alteração de cor em coleções de campo	Temperatura (ºC)	Carbono Fixo
1			<50º-80º	<60%
$1^{1/2}$			50º-90º	55-70%
2			60º-140º	
3			110º-200º	70-80%
4			190º-300º	80-95%
5			>300º	>95%

Figura 1: Variações de cor em elementos conodontes de ocorrência natural e induzidas experimentalmente correlacionadas a intervalos de temperatura para todos os IAC determinados. Fonte: Epstein *et al*. (1977).

Dez anos mais tarde, Rejebian *et al*. (1987), através de dados experimentais e de campo, ampliaram o uso dos elementos conodontes como índices termais quantitativos para regimes de metamorfismo regional, de contato e de alteração hidrotermal. Os autores selecionaram espécimes de cor amarelo claro do Ordoviciano Inferior, médio e Superior da Suécia, Polônia e EUA (Kentucky), respectivamente, além de exemplares do Devoniano Superior dos EUA (Iowa), a fim de obter a maior variedade possível de dimensões e morfotipos para a análise do IAC. Os autores estenderam a escala de Índice de Alteração de Cor (IAC = 1-5) para temperaturas mais altas (360 ºC a > 600 ºC) e valores de IAC entre 6 e 8 (**figura 2**). Rejebian *et al*. (1987) estabeleceram experimentalmente esses intervalos de temperatura utilizando o mesmo método de Epstein *et al*. (1977).



IAC	Alteração de cor produzida experimentalmente	Alteração de cor em coleções de campo	Temperatura (°C)
5		R P/A	300°-480°
6		P S	360°-550°
$6^{1/2}$		A P S	440°-610°
7	P/J	R	490°-720°
8	R	P S	>600°

Figura 2: Variações de cor em elementos conodontes experimentalmente e naturalmente alterados com valores de IAC entre 5 e 8. Alguns morfotipos são identificados: P - plataformados; R - ramiformes; S - cones simples; J - juvenis; A – adultos.
Fonte: Rejebian *et al*. (1987).

A literatura a respeito da diagênese de matéria orgânica enfatiza temperatura e tempo como os fatores dominantes na carbonificação e consequente alteração de cor (ABELSON, 1954; PHILIPPI, 1965; TEICHMÜLLER; TEICHMÜLLER, 1968; BOSTICK, 1973; HOOD *et al*., 1975). A variação na cor dos elementos conodontes, classificada em Índices de Alteração de Cor (IAC de 1 a 8), é resultado da fixação do carbono oriundo das quantidades traço de matéria orgânica contida na estrutura desses microfósseis (LINDSTRÖM, 1964 *apud* HARRIS, 1981; PIETZNER *et al*., 1968; CLARK; MILLER, 1969; EPSTEIN *et al*., 1974, 1975a, 1975b). Sendo assim, a matéria orgânica também é um dos principais contribuintes para a definição da cor desses elementos.

Em Petrogênese Metamórfica, a Geotermometria é empregada na determinação das condições de temperatura de formação de uma associação mineral ou condições a que a rocha foi submetida posteriormente, uma vez que tenha sido estabelecido que a associação se formou em equilíbrio (YARDLEY, 1994). Deste modo, assumindo a variação de cor em elementos conodontes como um processo progressivo, cumulativo e irreversível, esses microfósseis podem ser utilizados como Termômetros Geológicos, ou seja, como parâmetros de paleotemperatura no estudo da Geotermometria, auxiliando ainda na identificação do grau de maturação e do potencial gerador de hidrocarbonetos em regimes diagenéticos a metamórficos de grau baixo.

Alterações texturais/microtexturais e padrões deformacionais

Até meados da década de 1980, as alterações texturais/microtexturais em elementos conodontes eram apenas identificadas e correlacionadas isoladamente a valores de IAC. Rejebian *et al*. (1987) correlacionaram dados experimentais com observações de cor e microtextura de espécimes recuperados de rochas alteradas diageneticamente e por metamorfismos regional, de contato e hidrotermal, com o intuito de auxiliar na distinção de diferentes processos geológicos, ambientes e graus metamórficos.

Entretanto, somente a partir do final da década de 1990, com o estudo pioneiro de Nöth (1998), essas alterações foram devidamente observadas, descritas e correlacionadas a diferentes índices de cor (IAC = 1-5) durante a diagênese progressiva. A autora estudou elementos conodontes provenientes de afloramentos de calcário da Formação Trochitenkalk, Triássico médio do Noroeste da Alemanha, e analisou a correlação existente entre as variações microtexturais e o Índice de Alteração de Cor (IAC). Os exemplares selecionados foram submetidos à diagênese no intervalo entre IAC = 1 (sedimentos imaturos) e IAC = 5 (metamorfismo de grau baixo). Foram realizadas observações quanto ao grau de recristalização, crescimento sintaxial de apatita na superfície, recristalização interna, efeitos de corrosão e sobrecrescimento de minerais neogênicos na superfície dos elementos conodontes (NÖTH, 1998).

Cinco anos após a publicação de Nöth (1998), Königshof (2003) apresentou outros padrões de alteração microtextural em elementos conodontes, bem como descreveu pela primeira vez padrões deformacionais (frágeis e dúcteis) nesses microfósseis, abrangendo em seu estudo toda a escala de índices de alteração de cor. Königshof (2003) analisou espécimes provenientes de rochas de metamorfismo de contato e de metamorfismo regional de grau baixo, do Devoniano Superior ao Carbonífero Inferior da Alemanha (Rheinisches Schiefergebirge) e da França (Montagne Noire). As principais estruturas deformacionais observadas pelo autor foram: alongamento dos espécimes ao longo de planos de cisalhamento paralelos e deslocamento *step-like* ao longo desses planos, seguindo a orientação de deformação estrutural da rocha-fonte.

Quase uma década depois, pesquisando unidades carbonáticas do orógeno variscano no noroeste da Espanha, Blanco-Ferrera *et al*. (2011) descreveram sete texturas (*bleached*; corrosão; pátina cinza; pátina rosa; preenchimento de cavidade basal; sacarosa; superfície lisa) e sete microtexturas (corrosão; cristais grandes; cristais pequenos; dissolução; envelope irregular; moldes externos; superfície inalterada) a partir dos espécimes de conodonte recuperados. Os autores concluíram que os principais processos envolvidos nestas alterações têm origem diagenética, através da dissolução e precipitação de apatita.

Posteriormente, Sanz-López e Blanco-Ferrera (2012) deram ênfase à investigação da microtextura de cristal grande através de uma análise minuciosa, sob microscópio eletrônico de varredura, de exemplares de conodontes provenientes de calcários do Paleozóico médio a superior da zona Cantábrica, Espanha. Os autores subdividiram-na em quatro classes: em bloco; colunar; em leque; denticular e observaram que sua distribuição está condicionada pela morfologia da superfície e histologia dos elementos conodonte em geral. Eles concluiram que as diferentes variações da microtextura de cristal grande foram desenvolvidas durante condições de diagênese inicial e soterramento subsuperficial a moderado, com disponibilidade de fosfato através da dissolução de apatita em porções mais permeáveis e solúveis destes microfósseis.

Deste modo, através do estudo do Índice de Alteração de Cor (IAC), das alterações texturais/microtexturais e dos padrões deformacionais, ratifica-se a utilização dos elementos conodontes como termômetros geológicos e como indicadores do grau de maturação da matéria orgânica. Esses microfósseis contribuem ainda na identificação de regimes de metamorfismo de grau mais baixo.

Aplicações e importância dos elementos conodontes no estudo de histórias térmicas

O emprego dos conodontes não apenas como fóssil índice, mas também como termômetro geológico, demonstrou sua aplicação e importância na Geologia do Petróleo, Geologia Econômica e Geotermometria (EPSTEIN *et al*., 1977; REJEBIAN *et al*., 1987; NÖTH, 1998; KÖNIGSHOF, 2003).

Esses microfósseis são uma ferramenta amplamente utilizada na Geologia do Petróleo através da estimativa da profundidade de soterramento e de paleotemperaturas máximas em rochas sedimentares, bem como da identificação do grau de maturação da matéria orgânica e do potencial gerador de hidrocarbonetos de uma bacia. Constitui um método aplicável a diversos tipos de rochas e intervalos de idade e de temperatura (**tabela 2**), os quais não são facilmente analisados através de outras ferramentas (EPSTEIN *et al*., 1977).

Tabela 2: Comparação de intervalos de idade e de temperatura de três índices de maturação orgânica determinados com o auxílio de técnicas ópticas.

Índices de maturação	Conodontes	Palinomorfos	Vitrinita
Intervalo de idade	€-Tr	pré-€-Holoceno	D-Holoceno
Intervalo de temperatura	50-500ºC	<160ºC	>80ºC

Modificado de: Epstein *et al*. (1977).

Ao longo das últimas décadas, estudos detalhados de IAC foram utilizados mundialmente para avaliar a maturação orgânica e o potencial para geração de hidrocarbonetos em regimes diagenéticos a metamórficos de grau mais baixo. Exemplos de áreas de prospecção de hidrocarbonetos identificadas através da análise do IAC de conodontes incluem o Leste do Canadá (LEGALL *et al*., 1982) e a

Bacia Canning no Oeste da Austrália (NICOLL; GORTER, 1984). Foram produzidos mapas de IAC para algumas áreas dos Estados Unidos da América (HARRIS *et al*., 1978, 1994) e também para algumas regiões da Europa (BELKA, 1982; BURNETT, 1987; HELSEN; KÖNIGSHOF, 1994; BRIME *et al*., 2001).

Elementos conodontes com valores de IAC entre 1,5 e 4 são característicos de rochas que sofreram diagênese. O Índice de Alteração de Cor provê “fronteiras” para geração de óleo, gás condensado (*condensate gás*) e gás seco (*dry gás*, EPSTEIN *et al*., 1977).

Através da comparação de mapas de isógradas de IAC com campos produtores de óleo/gás, da correlação de dados experimentais de tempo e de temperatura com curvas tempo-temperatura de geração de hidrocarbonetos e da correspondência do IAC com outros índices de metamorfismo orgânico demonstrou-se que a alteração de cor inicia antes do princípio da geração de hidrocarbonetos; os valores de IAC entre 1,5 e 2 estão no limiar para produção de óleo e gás condensado; o IAC de 4 está próximo ao limite de produção de gás seco (HARRIS, 1981; SCHIMMELMANN *et al*., 2006).

Os valores de IAC ≥ 5 são característicos de rochas de metamorfismo regional, de contato ou hidrotermal. O grau de uniformidade dos valores de IAC em uma amostra e de amostra para amostra, somado à qualidade da preservação dos elementos conodontes podem auxiliar na distinção do grau (muito baixo-baixo), bem como do tipo de metamorfismo, respectivamente (REJEBIAN *et al*., 1987).

Rochas de metamorfismo hidrotermal e/ou de contato podem estar associadas a depósitos minerais de grande valor econômico. A distribuição areal das variações de textura e/ou de valores de IAC anômalos pode ser utilizada para delinear a extensão de intrusões ígneas e para identificar potenciais depósitos minerais. Portanto, a identificação da atividade hidrotermal através de seus efeitos na cor e na preservação dos elementos conodontes torna-se importante economicamente (NICOLL, 1981; WARDLAW; HARRIS, 1984; ARMSTRONG, 1985; BURNETT, 1987, 1988; KOVACS; ARKAI, 1987; HARRIS *et al*., 1990; KÖNIGSHOF, 1991; KÖNIGSHOF, 1992 *apud* KÖNIGSHOF, 2003).

Além disso, os dados de alteração de cor obtidos a partir de elementos conodontes podem ser correlacionados tanto com mapas de isópacas (profundidades, espessuras de unidades litoestratigráficas, temperaturas, campos de produção gás/óleo, etc.) quanto com dados de carbono fixo, reflectância da vitrinita e Índice de Alteração Termal (IAT) de palinomorfos (**tabela 3**, EPSTEIN *et al*., 1977).

Tabela 3: Correlação de três índices de metamorfismo orgânico.

Elementos Conodontes		**Palinomorfos**		**Vitrinita**	
IAC	**Temperatura (ºC)**	**IAT**	**wt. % carbono em querogênio**	**Reflectância**	**% carbono fixo**
1	< 50-80	1-5	< 82	< 0,8	< 60
$1^{1/2}$	50-90	5->5	81-84	0,7-0,85	60-65
2	60-140	5-6	81-87	0,85-1,3	65-73
3	110-200	> 5-6	83-89	1,4-1,95	74-84
4	190-300	6	84-90	1,95-3,6	84-95
5	300-400	> 6-7	> 90	> 3,6	> 95

Modificado de: Epstein *et al*. (1977).

Capítulo II – Contexto Geológico

A Bacia do Amazonas é uma sinéclise intracratônica, alongada no sentido Leste-Oeste, limitada ao Norte e ao Sul pelos escudos pré-cambrianos das Guianas e Brasileiro, respectivamente (**figura 3**). A Bacia do Amazonas está separada, a Oeste, da Bacia do Solimões pelo Arco de Purus e, a Leste, da Bacia do Marajó pelo Arco de Gurupá, estruturas transversais que condicionaram sua sedimentação e preenchimento (**figura 4**). A ascensão do Arco de Purus parece ter interrompido a conexão da Bacia do Amazonas para Oeste, durante a maior parte do Devoniano (MELO, 1989). Essa bacia é preenchida principalmente por rochas paleozóicas e ocupa uma área de 500.000 km^2 nos estados do Amazonas, Pará e Amapá, norte do Brasil (GONZAGA *et al*., 2000).

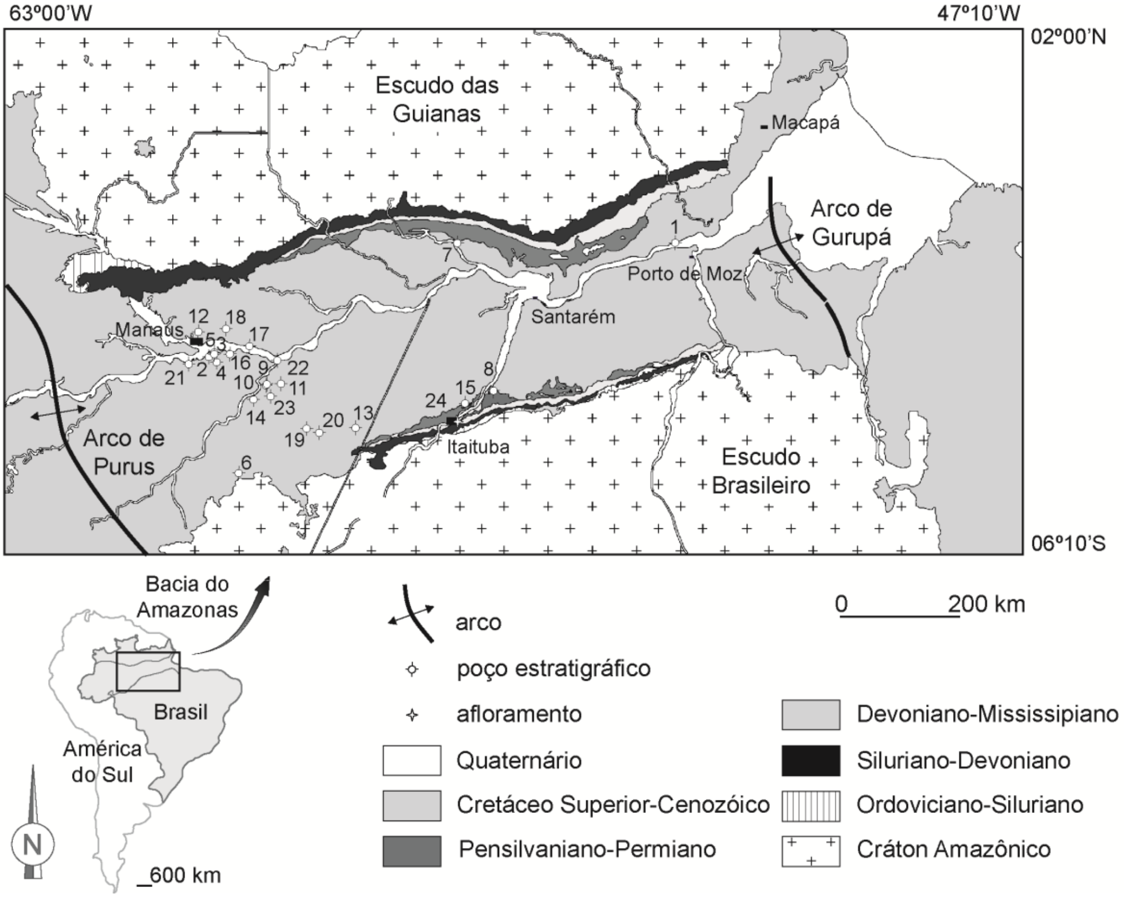


Figura 3: Mapa de localização da Bacia do Amazonas, Brasil. Os números de 1 a 23 correspondem a poços estratigráficos e o número 24, afloramento da pedreira Calminas.
Modificado de: Matsuda *et al*. (2009).

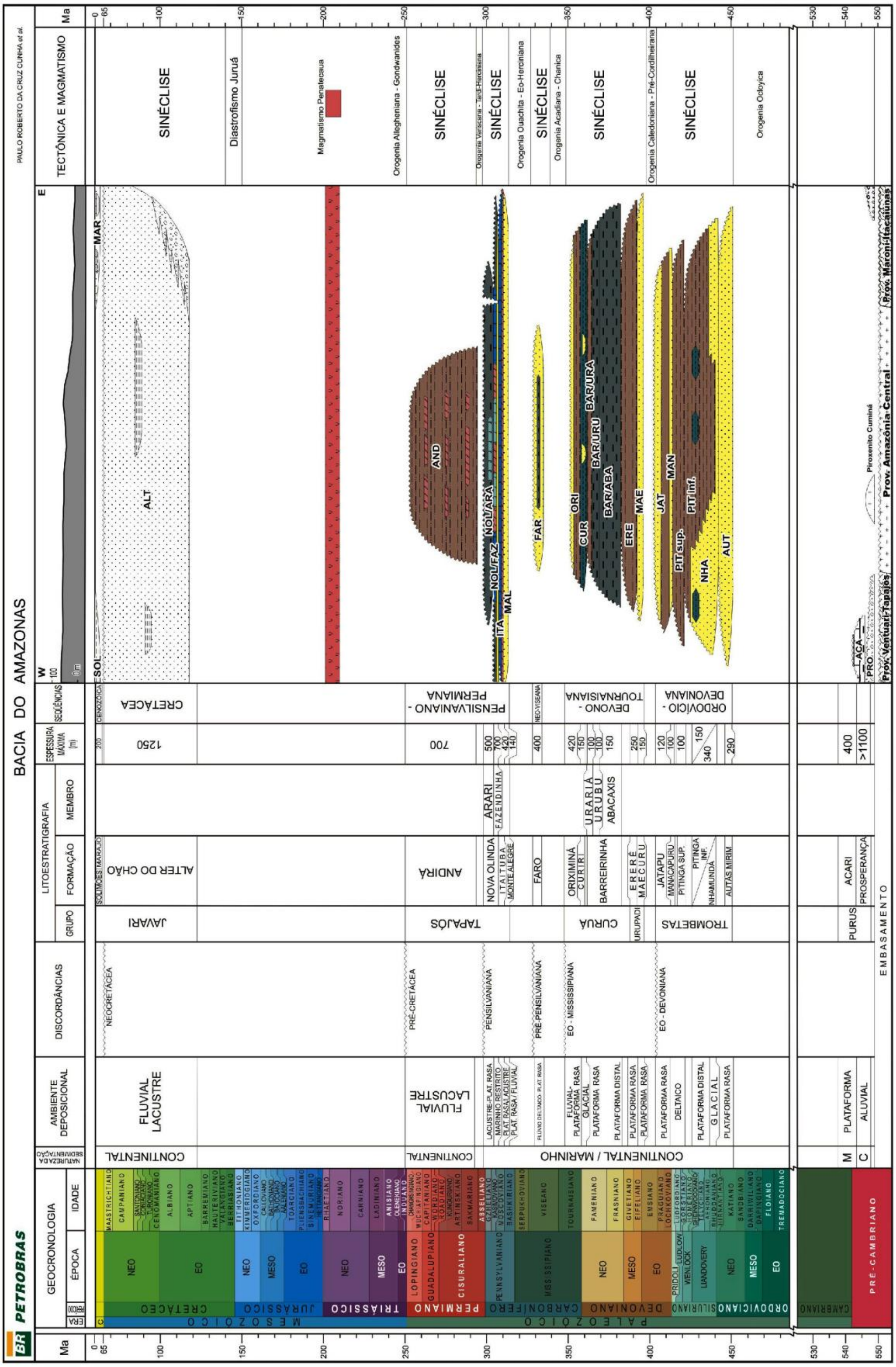


Figura 4: Carta estratigráfica da Bacia do Amazonas.
Fonte: Cunha *et al.* (2007).

Apesar de sua grande dimensão, são raros os registros de rochas paleozóicas em afloramentos devido à ampla sobreposição da cobertura sedimentar Mesozóica e Cenozóica e à densa floresta amazônica. Consequentemente, o estudo das rochas da Bacia do Amazonas se baseia principalmente em poços de subsuperfície e dados sísmicos (GONZAGA *et al*., 2000). A sucessão paleozóica se estende por mais de 5.000 m no depocentro da bacia (NEVES, 1990; CUNHA *et al*., 1994; GONZAGA *et al*., 2000), enquanto a espessura diminui em direção às margens relativamente rasas, chamadas plataformas Norte e Sul (WANDERLEY-FILHO *et al*., 2010). A interação entre as falhas normais de orientação NE-SW e as falhas de transferência de orientação NW-SE subdividiu a bacia em uma série de segmentos alongados com orientação ENE-WSW, os quais se alternam com segmentos mais curtos de orientação E-W (WANDERLEY-FILHO *et al*., 2005, 2010).

Os estratos paleozóicos consistem em várias sequências limitadas por discordâncias regionais (NEVES, 1990; CUNHA *et al*., 1994, 2007; MATSUDA *et al*., 2004). A sequência mais antiga compreende o Grupo Trombetas (Devoniano Inferior-Ordoviciano Superior), incluindo até 1.100 m de estratos marinhos e glaciais. Esse grupo inclui a Formação Pitinga (Siluriano), que contém rochas-fonte de hidrocarbonetos na porção basal (CAROZZI, 1979; GONZAGA *et al*., 2000). Essa unidade é seguida por até 1.320 m da sequência emsiana superior-tournaisiana, que compõe os grupos Urupadi e Curuá. O Grupo Urupadi se encerra no Givetiano inferior com folhelhos, siltitos e arenitos depositados em ambientes costeiro proximal e parálico. Diretamente acima dele, o Grupo Curuá (Devoniano Superior-Mississipiano) consiste das formações Barreirinha, Curiri e Oriximiná.

A Formação Barreirinha (Frasniano-Fameniano médio) tem uma espessura máxima de 350 m no depocentro da bacia, sendo composta principalmente por folhelhos negros, físseis, ricos em matéria orgânica, e em menor grau, por siltitos e arenitos finos. O intervalo de folhelho negro inferior é chamado de Membro Abacaxis e corresponde a uma sedimentação condensada (cerca de 75 m de espessura) em um ambiente euxínico, calmo, provavelmente marinho profundo. A abundância de quitinozoários, acritarcos e esporos contrasta com a escassez de conchas fósseis (raros braquiópodes desarticulados, bivalves e gastrópodes), segundo Melo (1989). O alto teor de matéria orgânica do tipo II torna-o a principal fonte de hidrocarbonetos na Bacia do Amazonas (GONZAGA *et al*., 2000). O conteúdo de esporos indica que a idade do Membro Abacaxis é frasniana inferior a questionável fameniana média-superior (MELO e LOBOZIAK, 2003). Esta unidade é seguida por folhelhos cinza escuro do Membro Urubu (cerca de 70 m) e por folhelhos cinza escuro a claro e siltitos do Membro Urariá (cerca de 90 m). O Membro Urariá foi depositado durante o Fameniano superior (MELO e LOBOZIAK, 2003) e frequentemente contém traços-fósseis de *Spirophyton* e a planta *Protosalvinia*. Grahn e Melo (2002) estudaram bioestratigrafia com base em quitinozoários da Formação Barreirinha na área do Rio Tapajós e correlacionaram-na com zoneamento de miósporos padrão da Euramérica.

Um hiato curto e uma discordância erosiva separam a Formação Barreirinha dos 150 m de diamictitos, folhelhos, siltitos e arenitos da Formação Curiri, depositada em um ambiente glacial ou periglacial durante o Fameniano mais tardio (CAPUTO, 1985; MELO e LOBOZIAK, 2003). Acima da Formação Curiri, a Formação Oriximiná (420 m) é enriquecida em arenito, sendo interpretada como areias litorâneas transgressivas com micropalinoflora de idade entre Fameniano mais tardio e Tournaisiano médio-mais inicial (MELO e LOBOZIAK, 2003).

Uma discordância regional está localizada na base da sequência pensilvaniana-permiana (Grupo Tapajós) e a separa da Formação Faro (Viseano superior), a qual consiste de 400 m de arenitos fluviais, deltaicos e costeiros e de folhelhos com diamictitos glaciais interacamadados, depositados no centro da bacia (CAPUTO *et al*., 2008). O Grupo Tapajós atinge até 2.800 m de espessura. Os estratos mais antigos correspondem à Formação Monte Alegre, que consiste de 5 a 140 m de arenitos fluviais a eólicos, siltitos marinhos litorâneos a lacustres e folhelhos. Sobreposta à Formação Monte Alegre, a Formação Itaituba consiste de até 420 m de camadas de carbonatos marinhos gradando ascendentemente para folhelhos, arenitos e anidrita. Ocorrem fácies de supramaré a intermaré com bioclastos e barras oolíticas, além de fácies de delta de maré (NASCIMENTO *et al*. 2005). Condições ambientais de água limpa e morna possibilitaram a diversidade de braquiópodes, equinodermas, foraminíferos, ostracodes, briozoários, trilobitas, moluscos, corais, conodontes e remanescentes de vertebrados. Idades bashkiriana e bashkiriana–moscoviana são atribuídas às formações Monte Alegre e Itaituba, respectivamente, com base nos conteúdos de conodonte, foraminífero e palinoflora (LEMOS, 1992a, 1992b; ALTINER e SAVINI, 1995; PLAYFORD e DINO, 2000a, 2000b, 2005). Uma idade bashkiriana (Morrowano-Atokano) é atribuída à Formação Monte Alegre em função do conteúdo de conodontes e foraminíferos, enquanto palinomorfos indicam uma idade langsettiana à bolsoviana basal (Westphaliano A-C) (LEMOS, 1992a, 1992b; ALTINER e SAVINI, 1995; PLAYFORD e DINO 2000b, 2005). Uma idade atokana à desmoinesiana inferior ou bolsoviana à asturiana basal (Westphaliano C-D) corresponde à Formação Itaituba (LEMOS, 1992a, 1992b; PLAYFORD e DINO, 2005; NASCIMENTO *et al*. 2009).

A Formação Itaituba mostra um limite gradacional com a Formação Nova Olinda. Esta unidade alcança até 1.200 m de espessura e está subdividida nos Membros Fazendinha e Arari (CUNHA *et al*., 2007). O membro inferior é composto por argilitos, calcários, anidrita e sais depositados em ambientes marinho raso, sabkha e lacustre hipersalino. O Membro Arari é composto por argilitos e siltitos com sais de halita depositados em contexto continental, embora com certa influência marinha. De acordo com Cunha *et al*. (2007), uma idade moscoviana é atribuída para o Membro Fazendinha e kasimoviana/gzheliana é estimada para o Membro Arari. Contudo, Playford e Dino (2000b) indicaram uma idade permiana inferior (transição entre Asseliano/Sakmariano), com base em esporos e pólens da Zona *Vittatina costabilis*, para camadas superiores da Formação Nova Olinda.

A Formação Andirá, de até 700 m de espessura (CUNHA *et al*., 2007, corresponde a camadas vermelhas, siltitos e arenitos, com raras ocorrências de anidrita, em fácies fluviais e lacustrinas. Uma idade permiana é baseada no registro de pólens (PLAYFORD e DINO, 2000a, 2000b). Matsuda *et al*. (2004) propôs um limite inferior diferente para a Formação Andirá, rebaixando-o para incluir a porção superior da Formação Nova Olinda com pólens permianos, restringindo esta última formação ao Membro Fazendinha com microflora de idade asturiana.

A sedimentação paleozóica encerrou-se em um episódio de deformação transcorrente no Permiano-Triássico (SANTOS *et al*., 2011) e, mais tarde, um complexo de soleiras e diques de diabásio intrudiram em volumes significativos toda a bacia. Esse evento corresponde ao episódio magmático Penatecaua, datado do Triássico superior ao Jurássico Inferior (204-179 Ma, de acordo com SANTOS *et al*., 2002; WANDERLEY-FILHO *et al*., 2005). Esse episódio possui natureza toleítica e está vinculado a um quartzo diabásio tipo MORB (*Mid-Ocean Ridge Basalts*), que se formou durante a abertura do Oceano Atlântico central (ALMEIDA, 1986; GONZAGA *et al*., 2000; CUNHA *et al*., 2007; WANDERLEY-FILHO *et al*., 2010). Os corpos intrusivos são principalmente soleiras, com cerca de 500 m de espessura (no máximo 915 m), centenas de quilômetros de extensão, atingindo temperaturas próximas a 1.000ºC, de acordo com Wanderley Filho *et al*. (2006). Essas soleiras intrudiram principalmente as rochas evaporíticas da Formação Nova Olinda, na porção ocidental da bacia, ao passo que são encontradas em todos os níveis da sequência sedimentar na porção oriental (MOSMANN *et al*., 1986; GONZAGA *et al*., 2000).

Um hiato erosivo se estende desde o Triássico até o Cretáceo inicial, sendo em grande parte explicado pelo soerguimento ocorrido no Cretáceo Superior, de acordo com estudos de traço de fissão em apatitas (NEVES, 1990). Esse soerguimento parece estar associado com a inversão de estruturas, o desenvolvimento de dobras assimétricas e a falhas com orientação nordeste, todos elas oriundas do chamado evento tectônico transpressional Juruá, o qual está relacionado com a abertura do Oceano Atlântico equatorial. A deformação contribuiu para a remobilização de hidrocarbonetos e para a formação de armadilhas estruturais (NEVES, 1990).

Uma deposição vinculada a sistemas lacustres e fluviais (Formação Alter do Chão), com drenagem em direção ao Oceano Pacífico e o Mar do Caribe, ocorreu durante o Cretáceo tardio. Esse registro excede 400 m de espessura apenas na porção central da Bacia do Amazonas e aumenta rumo a Oeste, na bacia peruana. O Cenozóico está representado por uma fina camada de depósitos continentais próxima ao Arco de Purus, a Oeste, e por uma sucessão de aproximadamente 1.000 m de espessura no limite oriental com a Bacia do Marajó (MOSMANN *et al*., 1986). Algumas estruturas mostram reativação em relação à formação da Cordilheira dos Andes e deformação de sedimentos cenozóicos entre o Paleógeno tardio e o Holoceno, vinculada a estruturas transpressionais e transtensionais (NEVES, 1990; GONZAGA *et al*., 2000; SANTOS *et al*., 2011).

Capítulo III – Materiais e Métodos

Os espécimes estudados são oriundos de 18 amostras de afloramento da pedreira Calminas, bem como de 76 testemunhos recuperados de 23 poços perfurados pela PETROBRAS – Petróleo Brasileiro S.A. nas formações Barreirinha (Grupo Curuá) e Monte Alegre, Itaituba, Nova Olinda (Grupo Tapajós): 1-AM-1-AM; 1-AM-6-AM; 1-AM-7-AM; 1-AM-9-AM; 1-CM-2-PA; 1-FZ-1-AM; 1-MS-4-AM; 1-NO-1-AM; 1-PB-1-PA; 1-RX-1-AM; 1-RX-6-AM; 1-TR-1-AM; 1-UA-1-AM; 2-AL-1-PA; 2-CA-1-AM; 2-CP-2-PA; 2-MN-1-AM; 2-PC-1-AM; 2-PE-1-AM; 2-PE-2-AM; 2-SA-1-AM; 9-FZ-2-AM; 9-FZ-28-AM.

As amostras provenientes dos poços AM-1; CM-2; MS-4; NO-1; PB-1; RX-6; TR-1; UA-1; CA-1; CP-2; MN-1; PC-1; PE-1; PE-2; SA-1; FZ-28 haviam sido previamente processadas em laboratório pela Dra. Ana Karina Scomazzon, cujos exemplares por ela recuperados foram cedidos pelo Laboratório de Microfósseis Conodontes, Instituto de Geociências, UFRGS (Porto Alegre/RS) para este estudo. As demais amostras foram processadas pela autora desta Tese.

Há grande diversidade quanto ao registro geológico, visto que as amostras da pedreira Calminas, cuja seção atinge 18 m de espessura, provêm dentre algumas centenas de metros acima do nível do mar, ao passo que os testemunhos, vêm de até 3000 metros abaixo dele, como pode ser observado através da seção de afloramento e dos perfis estratigráficos (CARDOSO *et al*., 2015b[3]).

Neste trabalho, foram quantificadas somente as amostras com registro positivo para conodontes, resultando assim em uma amostra de 0.4kg proveniente da Formação Barreirinha e 93 amostras entre 0.3-0.5kg procedentes das demais formações, sendo 13 da Formação Monte Alegre; 56 da Formação Itaituba, 39, porção inferior, e 13, porção superior; 24 da Formação Nova Olinda. Não foi possível enquadrar os poços 1-MS-4-AM e 2-PE-2-AM em porções inferior e superior para a Formação Itaituba, assim quatro amostras desta unidade não são abordadas para tal posicionamento.

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[3] *Cardoso et al.* (2015b) Conodont colour alteration index and upper Paleozoic thermal history of the Amazonas Basin, Brazil. Journal of South American Earth Sciences.

Dentre as litologias, encontram-se calcários, dolomitos, folhelhos, siltitos e arenitos. As amostras foram desagregadas utilizando técnicas mecânicas e químicas típicas, sendo lixiviadas através de soluções tampão de ácido acético, seguindo a metodologia de Jeppsson *et al*. (1999).

A preparação das amostras consistiu na sua fragmentação em pedaços, geralmente entre 2 e 3 cm de diâmetro. Durante a realização desse procedimento, foi adotado máximo cuidado na remoção completa dos resíduos da amostra previamente fragmentada, a fim de evitar a contaminação do material seguinte. Utilizou-se o britador de mandíbulas do Laboratório de Preparação de Amostras, prédio em anexo do Laboratório de Geologia Isotópica, Instituto de Geociências, Universidade Federal do Rio Grande do Sul (UFRGS).

O processamento químico do material, descrito abaixo, deu-se no Laboratório de Microfósseis Calcários, Departamento de Paleontologia e Estratigrafia, Instituto de Geociências, UFRGS.

Inicialmente, as amostras foram pesadas com a utilização de uma balança eletrônica e, posteriormente, cada recipiente plástico (balde), a ser utilizado no processamento das amostras, foi devidamente identificado com etiquetas contendo o nome do poço e o número do testemunho. Foram confeccionadas tampas em papel alumínio com orifícios de diâmetro em torno de 1 mm, com a finalidade de minimizar as perdas de ácido acético e água por evaporação.

As soluções de ácido foram preparadas nos recipientes plásticos com capacidade para 4 litros, a partir de: 20% de solução tampão (*buffer*[4] – solução filtrada de ácido acético gasto ou parcialmente gasto), 5.6% de ácido acético e 74.4% de água da torneira, respeitando esta ordem. Neste momento, apenas cerca de 75 por cento da água foi adicionada, sendo a solução então agitada vigorosamente com auxílio de um bastão de vidro, a fim de garantir sua homogeneidade inicial tanto quanto possível. Optou-se pela mistura da solução diretamente no recipiente, a fim de reduzir tanto a evaporação de ácido quanto a exposição pessoal aos gases.

O pH foi medido diretamente nos recipientes e, quando necessário, ajustado para o valor de 4, o restante da água foi adicionado e a solução agitada. Deixou-se a

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[4] para caracterização/controle da solução tampão, seu pH foi medido previamente e, quando necessário, calibrado para o valor de 5.

solução "repousando" para que alcançasse a temperatura ambiente e o pH, o equilíbrio. Confirmou-se a medida de pH novamente.

Conforme Jeppsson *et al*. (1999), somente a taxa de dissolução (gramas/hora) é dependente da amostra, sendo aquela diretamente proporcional à granulometria desta. Assim, se o tamanho de grão da amostra atinge somente uns poucos milímetros (e.g. fração areia), a taxa de dissolução seria alta. Em contrapartida, uma amostra de granulometria fina (e.g. fração argila), apresentaria uma taxa de dissolução baixa.

A reação iniciou com um borbulhar ativo, o qual pôde ser observado a partir da exposição da amostra à solução. Segundo Jeppsson *et al*. (1999), o processamento, resultando na preservação de espécimes, iniciaria acima de pH 3.6 e a dissolução continuaria além do ponto onde a reação torna-se lenta ou cessa (aproximadamente na faixa de pH 4.8-4.9), contudo com uma taxa de dissolução inferior.

O potencial hidrogeniônico (pH) das soluções foi monitorado com o auxílio de tiras indicadoras de pH, chamadas papel de tornassol. Os ajustes de pH foram feitos através da adição de ácido para diminuí-lo e tampão para aumentá-lo. Além disso, o progresso na dissolução foi monitorado pela observação dos estágios da reação, sugerido por Jeppsson *et al*. (1999) a laboratórios não equipados com pHmetro: **(I)** borbulhar vigoroso e líquido opaco devido à argila dispersa; **(II)** borbulhar disperso e líquido semitransparente; → pH 4.8-4.9[5] → **(III)** nenhuma reação visível, mas muitas bolhas são liberadas se o recipiente for agitado com a mão; **(IV)** nenhuma reação visível, não há bolhas mesmo depois do recipiente ser agitado.

Ao fim de 10 dias, o resíduo do material dissolvido foi cuidadosamente recuperado com o auxílio de duas peneiras com orifícios de 0.841 mm (20 *mesh*) e 0.074 mm (200 *mesh*) e a solução coletada. O material foi limpo sob água corrente, sendo esse processo repetido até que o ácido e o acetato fossem removidos, posto em recipientes de porcelana (cadinhos) e seco em estufa à 100ºC.

O material seco, oriundo da fração mais fina (> 0.074 mm), foi armazenado em frascos de plástico, devidamente identificados, para posterior recuperação dos espécimes (*picking conodonts*). As porções remanescentes das amostras (> 0.841

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[5] para amostras com dissolução/desmembramento lentos, a passagem da fase (2) à (3) dá-se em um pH próximo ao do ponto limite (pH de 3.6), necessitando de monitoramento uma vez por semana.

mm) foram reprocessadas com soluções tamponadas durante o mesmo intervalo de tempo e, quando não dissolvidas completamente, foram coletadas, secas e reservadas.

As soluções foram reunidas em recipientes de plástico (baldes) com capacidade para armazenar 7.5 litros e deixadas em repouso para decantação dos materiais mais finos residuais. Posteriormente, o líquido foi transferido para garrafas de plástico com o auxílio de um funil de vidro e papéis-filtro. O material lamoso remanescente nesses recipientes plásticos, foi então coletado, seco e reservado.

Jeppsson *et al*. (1999) salientou que uma amostra fortemente argilosa levaria tanto tempo para dissolver que o processo provavelmente seria interrompido em um pH muito abaixo de 5.05, tornando-se necessário mais ácido por quilograma de carbonato. Contudo, a quantidade de ácido resultante por quilograma de amostra não seria tão diferente. Os autores observaram ainda que, mesmo uma pequena quantidade de argila, reduziria a taxa de dissolução para menos da metade, de modo que o borbulhar ativo (reação) cessaria a um pH consideravelmente inferior à 5. Sendo assim, as amostras com predomínio de granulometrias finas e litologia rica em minerais não-carbonáticos foram expostas à dissolução por 15 dias em uma solução com 30% a mais de ácido acético, referente à medida já utilizada (5.6%).

A solução gasta (*buffer* residual), já reutilizada, foi reservada em galões e descartada de forma adequada, sendo entregue ao Centro de Gestão e Tratamento de Resíduos Químicos (CGTRQ), Instituto de Química, UFRGS, para evitar possíveis impactos ambientais.

As etapas que completam a concentração e recuperação dos espécimes de conodonte foram realizadas no Laboratório de Microfósseis Conodontes, Instituto de Geociências, UFRGS, e abrangeram: **(I)** coleta dos espécimes (*picking conodonts*) sob lupa binocular; **(II)** acondicionamento dos mesmos em células próprias ao estudo micropaleontológico (*microslides*).

As análises de Índice de Alteração de Cor (IAC), bem como os estudos de taxonomia e sistemática, foram desenvolvidas na *Universidad de Oviedo*, Principado das Astúrias, Espanha, sob orientação dos Professores Doutores Silvia Blanco-Ferrera e Javier Sanz-López, respectivamente.

Foram observados 1.690 elementos conodontes da Bacia do Amazonas com fins ao estudo de IAC, somados de 126 para sistemática, totalizando 1.816 elementos: 137 (13 + 124) elementos oriundos da Formação Barreirinha; 137 da Formação Monte Alegre; 1.151 da Formação Itaituba, sendo 568 (566 + 2) da porção inferior, 571 da porção superior e 12 não posicionados (poços 1-MS-4-AM e 2-PE-2-AM); 391 da Formação Nova Olinda. Do total, 415 exemplares selecionados foram fixados em *stub*s e observados ao Microscópio Eletrônico de Varredura (MEV), com fins à obtenção de imagens das espécies e suas microtexturas.

A metodologia utilizada para determinação do Índice de Alteração de Cor (IAC) dos conodontes está descrita em García-López *et al*. (1997) e Bastida *et al*. (1999). Os valores de IAC foram determinados separadamente pela Doutoranda Cassiane Negreiros Cardoso e pela Prof.ª Dra. Silvia Blanco-Ferrera, a fim de reduzir erros sistemáticos.

O IAC dos conodontes foi identificado através da análise da cor do espécime a partir de uma célula padrão cedida por Anita Harris (*United States Geological Survey* – USGS/Estado Unidos da América), armazenada na *Universidad de Oviedo* (Espanha), aos cuidados da Dra. Silvia Blanco-Ferrera.

O valor do IAC foi mensurado a partir da observação das margens ou porções mais claras dos elementos conodonte, tanto em espécimes delgados e/ou juvenis quanto em grandes e/ou maduros, e em diferentes litologias. Conforme García-López *et al*. (1997), podem ocorrer pequenas variações nos valores de IAC por amostra, relacionadas ao tamanho dos espécimes, sendo essa influência mais evidente em amostras com valores de IAC inferiores a 3. Consequentemente, os resultados consideram a variação nos valores associada com o tamanho do conodonte e a litologia. Os intervalos de classe modal dos valores de IAC também foram determinados para cada amostra.

Os intervalos de temperatura relacionados aos valores de IAC foram obtidos a partir do diagrama de Arrhenius apresentado por Rejebian *et al*. (1987). Os termos definidos por García-López *et al*. (2001): diacaizona (IAC < 4), ancaizona (4 ≤ IAC ≤ 5.5) e epicaizona (IAC > 5.5) são utilizados para fins de zoneamento de metamorfismo.

As diferentes alterações na superfície dos elementos conodonte foram diferenciadas de acordo com Blanco-Ferrera *et al*. (2011) e Sanz-López e Blanco-Ferrera (2012), utilizando-se o termo 'textura' para se referir às características identificadas na escala do microscópio estereoscópico e o termo ‘microtextura’ para se referir a essas na escala do microscópio eletrônico.

Assim, dois esquemas de correlação entre seções estratigráficas, quatro mapas de isolinhas de IAC, um mapa da estimativa de erosão/preservação das diferentes unidades do Grupo Tapajós e um resumo gráfico foram elaborados a partir dos dados obtidos para as quatro formações.

As análises taxonômicas e os estudos de sistemática foram realizados de acordo com as notações de Purnell *et al*. (2000) para a orientação anatômica dos elementos e, como referência para a definição dos caracteres diagnósticos de *Idiognathodus itaitubensis* nov. sp., utilizou-se Rosscoe e Barrick (2009). Materiais previamente publicados a respeito de conodontes brasileiros (e. g. LEMOS, 1992a, 1992b; LEMOS; MEDEIROS, 1996; SCOMAZZON; LEMOS, 2005; NASCIMENTO *et al*., 2005, 2009, 2010a, 2010b) também foram comparados com os espécimes recuperados.

Particularmente, a respeito dos exemplares provenientes da Formação Barreirinha, aqueles mais completos encontram-se inclusos no folhelho. Sendo assim, a fauna de conodontes devoniana foi observada também sob planos de acamamento.

O material estudado encontra-se armazenado no repositório do Laboratório de Microfósseis Conodontes, Instituto de Geociências, UFRGS.

Capítulo IV – Artigos Científicos

Artigo 01

Cardoso, C.N., Sanz-López, J., Blanco-Ferrera, S., Lemos, V.B., Scomazzon, A.K., 2015a. ***Frasnian conodonts at high palaeolatitude (Amazonas Basin, north Brazil)***. Palaeogeography, Palaeoclimatology, Palaeoecology, 418, 57-64.

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Frasnian conodonts at high palaeolatitude (Amazonas Basin, north Brazil)

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ABSTRACT

A conodont fauna is studied from the subsurface of Upper Devonian black shales belonging to the Abacaxis Member of the Barreirinha Formation, Amazonas Basin. Two samples of other members of this formation are barren. The fauna consists of *Cryptotaxis* sp. A, *Mehlina gradata*, '*Ozarkodina*' aff. *sannemanni*, *Polygnathus* sp. and, probably, *Prioniodina* sp. This association suggests a late Frasnian age, agreeing with the age previously assigned to the latest Frasnian to middle Famennian palynomorphs. The conodont fauna is added to another two late Frasnian–middle Famennian conodont occurrences in Bolivia and Brazil. The coincidence in age and facies (black shales) seems to indicate a unique time/environment favourable to the immigration and development of conodonts in the Devonian of northern South America. The low diversity association suggests cold water-dwelling taxa spreading to a high palaeolatitude during an episode of gentler latitudinal temperature gradient.

1. Introduction

South American Devonian conodonts are very scarce, being known from only a few findings. The earliest reports from this continent correspond to communications at congresses, albeit without descriptions and illustrations. The conodonts in question were from the Bolivian Gran Chaco Basin (Cousminer, 1964, in Hünicken, 1989) and from the Brazilian Amazonas Basin (Kroemmelbein, 1967). The Amazonian conodonts were described as bar-like (for example, *Lonchodus* sp.) from the Upper Devonian Barreirinha Formation, but no detailed locations and illustrations were provided. Recently, a subsurface sample from the Barreirinha Formation yielded Devonian conodonts in the Amazonas Basin (Cardoso et al., 2013; Fig. 1). Furthermore, two drill cores yielded Late Devonian conodonts, which were described and illustrated from a 3 m section of the Jandiatuba Formation in the deep part of the Solimões Basin (Brazil; Hünicken et al., 1989) and also from two intervals, one 4 m and the other 4.9 m thick, of black shales in a succession with sandstones and mudstones of the Madre de Dios Basin (Bolivia; Over et al., 2009).

The normal absence of conodonts in South America is due in part to the lack of carbonates where conodonts are easily obtained (Hünicken, 1989), and in part to the fact that conodont-bearing organisms are very sensitive to low water temperature (Geitgey and Carr, 1987). Devonian conodonts are restricted to the low latitude, tropical belt (Klapper and Johnson, 1980; Sweet, 1988). Consequently, cold water temperature explains the absence of conodonts in the Gondwanan Malvinokaffric Realm (Richter and Richter, 1942; Boucot et al., 1969), which includes a number of the South American basins together with South Africa, Antarctica, India and eastern Australia during the Silurian to Middle Devonian. At the same time, the occasional presence of conodonts associated with Upper Devonian black shale in the South American basins may indicate episodic conditions favourable to conodont life. In this context, the present study describes in detail the Devonian conodonts from the Amazonas Basin advanced in Cardoso et al. (2013) and analyses their occasional presence. The probable high palaeolatitude location increases the interest in a group showing cosmopolite taxa and very low levels of latitudinal provincialism. The Frasnian/Famennian extinction known from low latitudes has not yet been proven in subpolar domains (Racki, 2005). Furthermore, the Barreirinha Formation represents the main source of hydrocarbons in the Amazonas Basin, increasing the interest in the age and context of sedimentation of this unit.

2. Geological setting

The Amazonas Basin is an intracratonic syneclise of 500,000 km^2 located in north Brazil (Amazonas and Pará states). It formed with a west–east trending between the Precambrian Guianas and Guaporé (or Brazil) shields and was filled with up to 6000 m of Paleozoic to Cenozoic rocks (Neves, 1990; Cunha et al., 1994). The basin is separated from the

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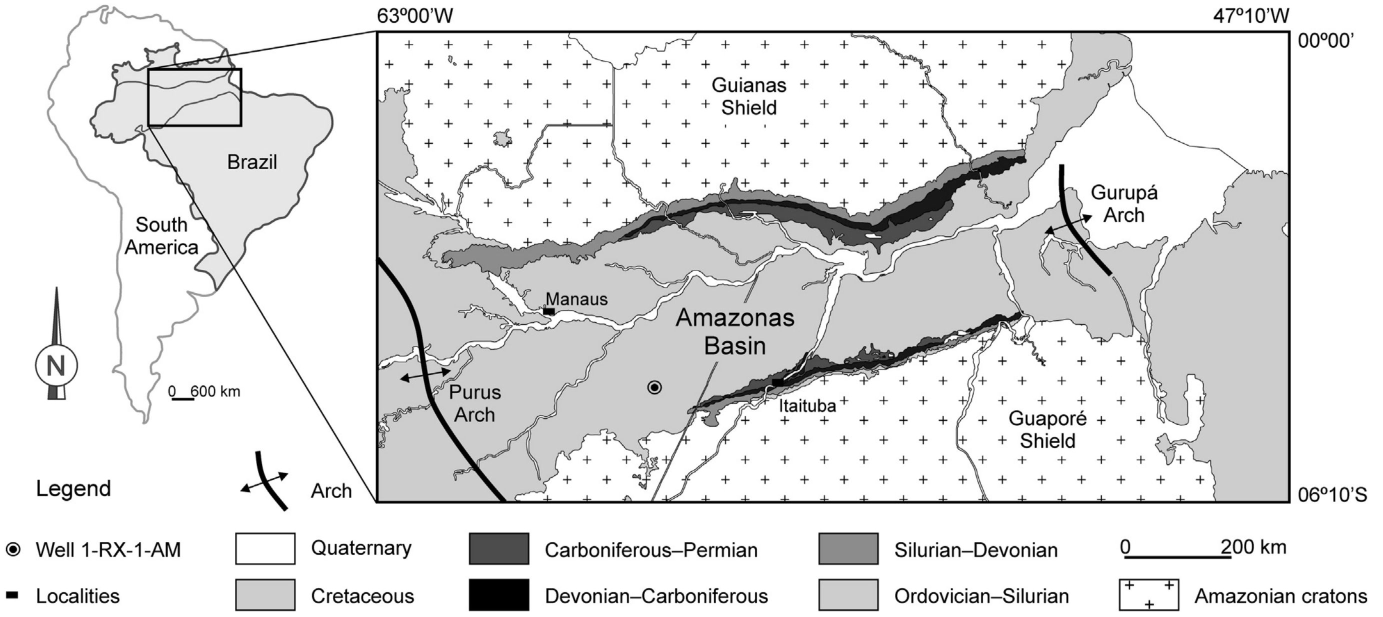


Fig. 1. Map of the Amazonas Basin with outcrops of depositional sequences and location of the studied well (modified from Matsuda et al., 2009). Note the Solimões Basin to the west, separated by the Purus Arch.

Solimões Basin by the Purus arch in the west and from the Marajó Basin by the Gurupá arch in the east. These transverse structures conditioned the Paleozoic sedimentation, since the Purus rise seems to have interrupted the westward connection of the basin during the greater part of the Devonian (Melo, 1989).

The Paleozoic fill of the Amazonas Basin is subdivided into several sequences limited by regional unconformities (Neves, 1990; Cunha et al., 1994; Cunha et al., 2007). The first sequence is the Upper Ordovician–Lower Devonian Trombetas Group, which consists of up to 1100 m of glacial and marine rock. It is followed by up to 1320 m of upper Emsian to Tournaisian sequence composed of the Urupadi and the Curuá groups. The Urupadi Group ends in lower Givetian shales, siltstones and sandstones deposited in nearby coastal and paralic environments. Directly above it, the Curuá Group consists of the Barreirinha, Curiri and Oriximiná formations. The Barreirinha Formation has a maximum thickness of 350 m in the depocenter of the basin. It is mainly made up of fissile, black shales rich in organic matter, and to a lesser degree of siltstones and fine sandstones. The lower black shale interval is the so-called Abacaxis Member and corresponds to a condensed sedimentation (about 75 m) in a calm, probably deep marine, euxinic environment. An abundance of chitinozoan, acritarchs and spores contrasts with the scarcity of fossil shells (rare inarticulate brachiopods, bivalves and gastropods), according to Melo (1989). The high content in type II organic matter makes it the main source of hydrocarbons in the Amazonas Basin (Gonzaga et al., 2000). The spore content indicates that the age of the Abacaxis Member is early Frasnian to questionable late middle Famennian (Melo and Loboziak, 2003). The Abacaxis Member is followed by dark grey shales of the Urubu Member (about 70 m), and by dark grey to light shales and siltstones of the Urariá Member (about 90 m). The latter was deposited during the upper Famennian (Melo and Loboziak, 2003) and commonly contains the trace fossil *Spirophyton* and the plant *Protosalvinia*. Grahn and Melo (2002) studied the chitinozoan biostratigraphy of the Barreirinha Formation in the Tapajós River area and correlated it with the standard miospore zonations of Euramerica.

A short hiatus and an erosive unconformity separate the Barreirinha Formation from 150 m of diamictites, shales, siltstones and sandstones of the Curiri Formation, deposited in a glacial or periglacial environment during the latest Famennian (Caputo, 1985; Melo and Loboziak, 2003). Above the Curiri Formation, the Oriximiná Formation (420 m) is enriched in sandstone and is interpreted as transgressive littoral sands with latest Famennian to earliest middle Tournaisian age micropalynoflore (Melo and Loboziak, 2003).

3. Material and methods

The conodonts studied came from cores of the 1-RX-1-AM well drilled by PETROBRAS in the Barreirinha Formation to the west of Itaituba City, in the central channel region of the Amazonas Basin (Fig. 1). Three 0.4 kg samples, one from each of the members of the formation taken from the cores drilled (Fig. 2), were disaggregated using typical mechanical and chemical techniques. The sample from core 124 in the upper part of the Abacaxis Member yielded conodonts and tasmanaceans (cysts of green alga prasynophytes). It corresponds to 5 m of fissile, black shale with mica grains and pyrite crystals. Core 123 corresponds to 3 m of dark grey shale of the Urubu Member and only provided tasmanaceans. Core 121 from the Urariá Member was barren. In general, the state of preservation of the conodont fauna is not particularly good, since the specimens are observed on bedding planes. Most of the isolated specimens are broken and incomplete; others are preserved as external casts, while more complete elements are included in shale. We have recognized 61 conodonts (among P1, P2, M and S) besides 76 elements or impressions. The recovered material is housed in the Laboratório de Conodontes, Universidade Federal do Rio Grande do Sul (Porto Alegre), and is numbered in ascending order from MP-M-824.

4. Palaeontology

The conodonts studied from the Barreirinha Formation consist of elements included in the order Prioniodinida Sweet, 1988 and order Ozarkodinida Dzik, 1976 (Fig. 3). In the first order, they are assigned to *Cryptotaxis* Klapper and Philip, 1971 (family Cryptotaxidae Klapper and Philip, 1972) and probably to *Prioniodina* Bassler, 1925 (family Prioniodinidae Bassler, 1925). Elements included in Ozarkodinida are from the family Spathognathodontidae Hass, 1959.

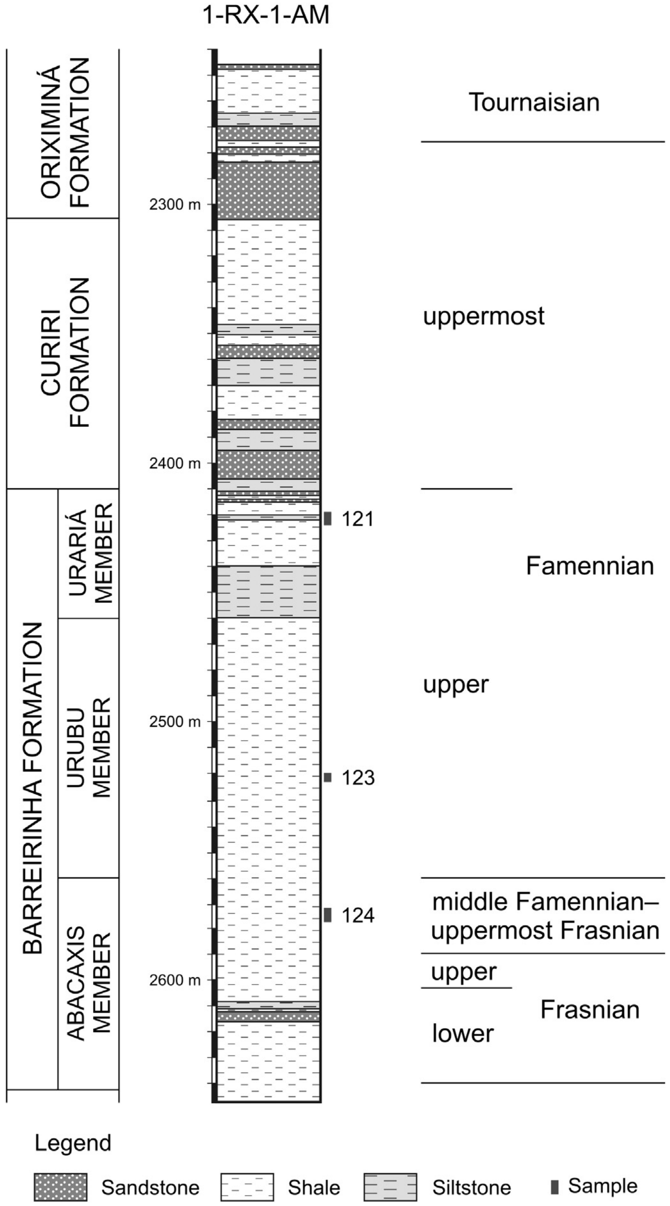


Fig. 2. Stratigraphic scheme of the Barreirinha Formation from the 1-RX-1-AM well showing the location of the studied cores, and chronostratigraphy based on palynomorphs according to Melo and Loboziak (2003).

4.1. Order Prioniodinida

Three studied P1 elements (Fig. 3A–B) are similar to small elements of *Cryptotaxis* sp. A Over (in Over et al., 2009, pl. 1, fig. 6; pl. 2, fig. 6). They are different from the large P1 elements, where teeth of the blade are fused or stout and the short dorsal blade is clearly deflected downward (Over et al., 2009, pl. 1, figs. 1–2). Another two P1 elements are considered *Cryptotaxis* cf. sp. A, since longitudinally they show a straight blade in which the dorsal portion is narrower than the ventral one (Fig. 3C–D). This blade is similar to that of *Cryptotaxis collinsoni* (Scott, 1961) [=*Cryptotaxis culminidirecta* (Scott, 1961)]. However, the latter species shows a more irregular proximal denticulation, with slender and smaller denticles adjacent to the cusp, which is not observed in our material, where the teeth are almost equal in height. *Cryptotaxis* sp. A could include P1 elements with variable downward deflection of the dorsal platform, since Over et al. (2009) assigned them to this species because of the distinct angle elements from those described for the Solimões Basin (*Cryptotaxis* sp. in Hünicken et al., 1989, pl. 1, figs. 1–2). However, the very low number of known elements prevents differentiation into distinct morphotypes. In fact, Over et al. (2009, pl. 1, fig. 4) assigned an element with a dorsal blade, arched slightly downward, to *Ozarkodina semialternans* (Wirth, 1967). It could be a mature element of *Cryptotaxis* cf. sp. A, which shows stout teeth. Moreover, the short dorsal blade of *Cryptotaxis* cf. sp. A is composed of four or five teeth, higher proximally than distally, in a pattern similar to that present in the early–middle Frasnian *Ozarkodina bidentatiformis* (Ngan, 1979).

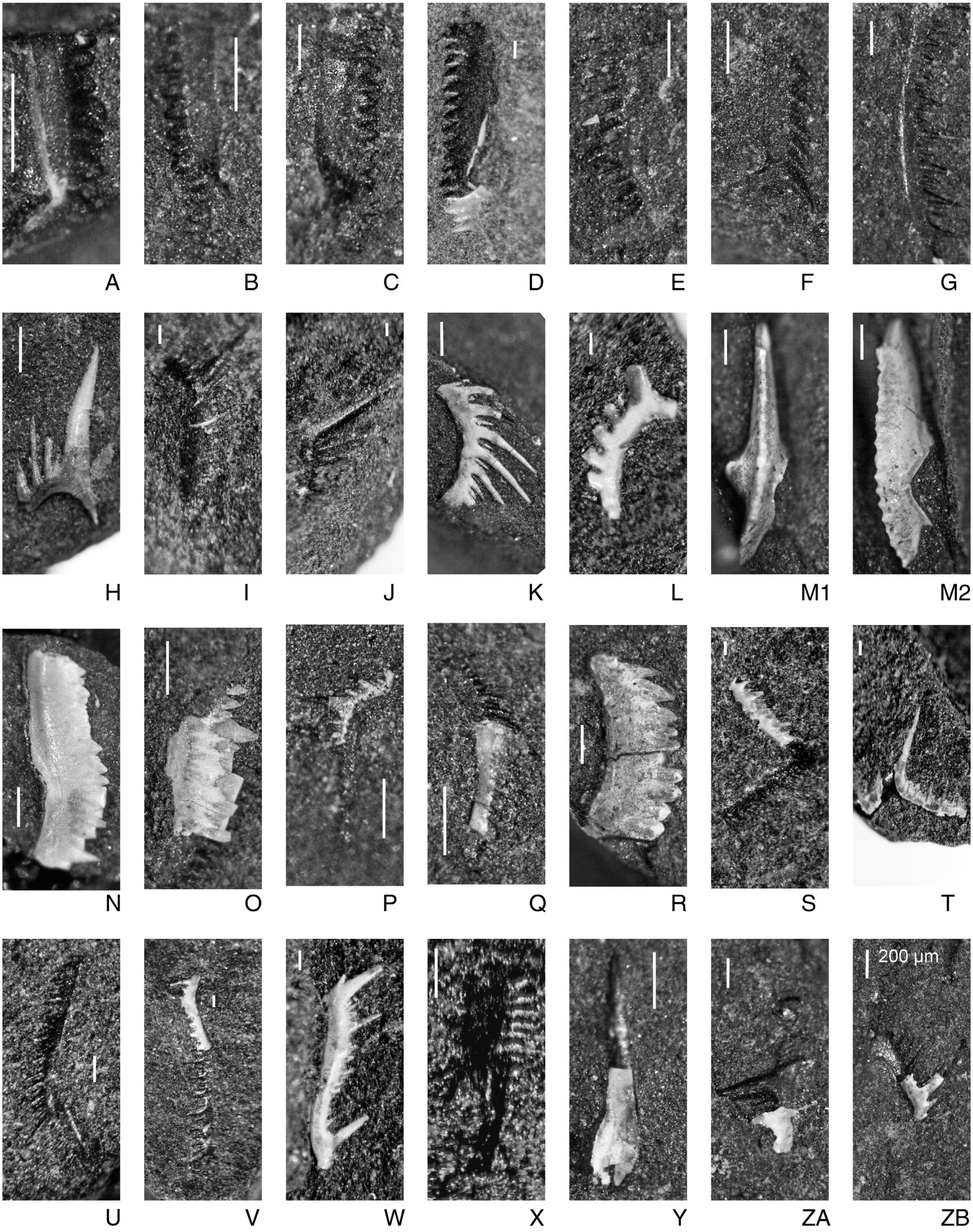
The elements of *Cryptotaxis* apparatuses are hard to differentiate from elements of apparatuses of other genera of the family Prioniodinidae. Some P2 and S elements of *Cryptotaxis* sp. were illustrated by Hünicken et al. (1989, pl. 1, figs. 3–7), although other S and M, which can also be part of the same apparatus, were assigned to *Parapolygnathus* sp. and *Hibbardella* sp. (Hünicken et al., 1989, pl. 1, figs. 8–10). Four P2 elements are recognized in the studied material (Fig. 3E–F). They show long, slender and discrete teeth to both sides of the largest cusp, and a short, downward deflected dorsal blade. The teeth of five S and one M elements here considered in *Cryptotaxis* are discrete, compressed and show a triangular section (Fig. 3G–H). Some elements have one or two small, slender distinctive denticles somewhere between each two larger teeth (Fig. 3G). Chauffe and Nichols (1995) described a similar irregularly distributed pattern of denticulation in some elements belonging to their reconstructed apparatus of *Cryptotaxis collinsoni*. Consequently, it could be a character variable in the *Cryptotaxis* species.

A few elements show teeth separated on the bars or more irregularly distributed denticles than those in *Cryptotaxis* elements. An element P1 is assigned to *Prioniodina*, since it seems to be longitudinally bowed and the dorsal bar is slightly deflected downward (Fig. 3I). The denticulation is more irregular than in *Cryptotaxis*, and small denticles are present between other larger, slender, straight ones. The cusp is about twice as large as adjacent denticles. One M and several S elements (Fig. 3J–K) with alternating denticulation are tentatively related to the P1 element, while four other S elements with small discrete denticles between two high, right denticles could be part of the same apparatus. Furthermore, another four fragments of S elements form part of the apparatus of species of the order Prioniodinida (Fig. 3L).

4.2. Order Orzakodinida

One P1 (Fig. 3M1–M2) is broken at the ventral end and the rostral lobe and is close to the group of ozarkodinids related to *O. sannemanni* (Bischoff and Ziegler, 1957). The dorsal part of the P1 element is twisted downward and toward the caudal side. This disposition is also present in elements of the material type of *O. sannemanni* (Bischoff and Ziegler, 1957, pl. 19, figs. 15, 19–23 and 25). Moreover, the carina disposition is less strongly curved in half of the dorsal platform than in *Ozarkodina trepta* (Ziegler, 1958). The basal cavity is excavated in our element, and is similar to elements of *O. sannemanni* and *O. trepta*, but not to the holotype of the first species, which shows a laterally thickened plate-like basal cavity. Furthermore, the Amazonian element shows a node continuing on a ridge on the caudal expanded lobe of the basal cavity. There is another node on the broken rostral lobe, since an incipient ridge is present on the highest part of the preserved surface. Two nodes may be present in specimens of *O. sannemanni* and *O. trepta*, whereas there is only one on the caudal lobe of *O. proxima* (Pollock, 1968). By contrast, the teeth of the carina-blade in typical elements of *O. sannemanni* are deeply isolated, while the studied element shows fused denticles, except near the tips. This could lead to consider it as a gerontic specimen, or perhaps a homeomorph of *O. sannemanni*, and we therefore prefer to name it informally '*Ozarkodina*'. The features described from the studied element suggest its classification as '*O.*' aff. *sannemanni* (Bischoff and Ziegler, 1957). In this sense, the Mississippian *Bactrognathus* included in Prioniodinidae shows some homeomorph species in common with those of the *O. sannemanni* group, and the teeth of the carina-blade may be totally fused. Chauff (1985) concluded that bactrognathidids might have originated in an ancestor group, perhaps related to *Cryptotaxis* and in our opinion, to ‘*O.*’ aff. *sannemanni*.

Three P1 elements and two fragments of P and S elements are included in *Mehlina gradata* Youngquist, 1945 (Fig. 3N–Q). P1 ones are characterized by gradational variation in the height and size of the



blade denticles (Fig. 3N–O). A few P1 elements show a longitudinal bulge half way along the bar. Elements illustrated as *Pandorinellina* sp. in Hünicken et al. (1989, pl. 1, figs. 13–18) are here considered *M. gradata* and appear to correspond to a well-preserved association of the different elements of the apparatus.

One P1 element is included in *Mehlina* sp., since its basal cavity is narrow and long (Fig. 3R). It is a strong element in which the most ventral part is missing. The rest of the ventral blade supports teeth in palisade distribution, laterally compressed and fused close to the contact of their apices. In contrast, the cusp is a low tooth, and the dorsal teeth are triangular, distally decreasing in height. The tips of these teeth form a concave outline. The element is close to '*Spathognathodus*' cf. *robustus* (Branson and Mehl, 1934) from Western Australia (Nicoll and Druce, 1979, pl. 25, figs. 1–6).

Some of the studied conodonts are considered elements of the apparatus of the genus *Polygnathus* Hinde, 1879, since the bars bear denticles in close contact and alternating in size and height. More precisely, some S0 elements show a long posterior process and cycles of four or five small teeth between two larger ones (Fig. 3S–T). A similar pattern is present in P2, S and M elements (Fig. 3U–W). One poorly preserved element shows a wide ventral blade and a narrow dorsal portion, which is interpreted as the laterally expanded part of the P1 element, probably *Polygnathus* (Fig. 3X). One broken P2 element shows a laterally expanded platform in the middle-dorsal part, particularly developed on the caudal side (Fig. 3Y). Other elements must correspond to another species of *Polygnathus*, since P2 and S2 elements are short and strong (Fig. 3ZA–ZB).

4.3. Biostratigraphy

The association studied from the upper part of the Abacaxis Member in the Amazonas Basin is comparable to those previously described from other South America conodont localities. The occurrence of *Cryptotaxis* sp. A, suggests the correlation with the 4 m thick interval in the uppermost Frasnian, below the base of the Famennian in the Madre de Dios Basin. *Mehlina gradata* and *Cryptotaxis* sp. A are present in 3 m of black shales of the Jandiatuba Formation in the Solimões Basin. The latter conodonts are probably late Frasnian in age, although they were assigned to late Frasnian or early Famennian (Hünicken et al., 1989), since actynopterygian fish scales associated with conodonts were considered latest Devonian or early Carboniferous in age. *M. gradata* is a long-range species present from the early Frasnian of Central Asia (Bardashev, 1992) or from the middle Frasnian *punctata* Conodont Zone and extending to the Lower *marginifera* Conodont Zone (early Famennian; Ziegler and Sandberg, 1990). This does not correspond to the distribution of typical *O. sannemanni,* a late Givetian to early Frasnian species (Ziegler and Sandberg, 1990).

A late Frasnian age for the conodont beds of the Abacaxis Member agrees with the assignation of miospores to the *Teichertospora torquarta-Auraspora pseudocrista* Palynoflora Zone, according to Melo and Loboziak (2003), and latest Frasnian to questionable late middle Famennian age. A similar miospore interval corresponds to conodont beds from the Madre de Dios Basin (Over et al., 2009). However, this zonal interval corresponds to very poorly diversified miospores (Streel et al., 2000) during a climatically conditioned vegetation crisis in Southern Euramerica (Streel, 2007), and is not characterized by Famennian index species. Furthermore, the lower part of the *T. torquarta–A. pseudocrita* Zone may be equivalent to the upper Frasnian Upper *rhenana* Conodont Zone, since poor correlation exits between zonal schemes (Streel et al., 2000; Streel, 2009).

A second, younger interval with conodonts in South America is only known from 4.9 m in the Madre de Dios Basin and considered early to middle Famennian by Over et al. (2009). It shows the first occurrences of *Cryptotaxis madrededios* Over (in Over et al., 2009 and *Branmehla bohlenana* (Helms, 1959), which do not occur in the studied beds of the Amazonas Basin.

5. Palaeoecological and palaeogeographical implications of Late Devonian conodonts from South America

Early and Middle Devonian conodonts are absent from the Malvinokaffric Realm. They are likewise absent from other northern basins of South America belonging to the Eastern Americas Realm (Colombian and Amazon subprovinces in Boucot, 1989), where a mixture of Malvinokaffric trilobites and Eastern Americas Realm brachiopods occurs, as in the case of the Amazonas Basin (Melo, 1989). In general, conodont faunas seem to be confined to the low latitude tropical belt (Sweet, 1988) but are unknown above approximately 45°N and S palaeolatitude (Fig. 4A), simply because the water was too cold for conodonts to exist. The occasional presence of Late Devonian conodonts in the northern South American basins is associated with Upper Devonian black shale and may indicate episodic conditions favourable to conodont life, particularly an ameliorated global climatic gradient during the Late Devonian or the influence of warm currents (Hünicken et al., 1989; Isaacson, 2007).

Warmer climatic conditions are first recognized from the Middle Devonian in South America, since the northward movement of western Gondwana coupled with marine transgression appeared to eliminate many Malvinokaffric taxa and allow the immigration of taxa from Southern Euramerica to South America (Isaacson, 2007). The Frasnian transgressive maximum of the Brazilian Devonian is related to radioactive black shale deposition in the Solimões, Amazonas, Parnaíba and Paraná basins (Melo, 1989; Pereira et al., 2007). Global transgressive and greenhouse states are invoked to explain the abundance of organic-rich black shale deposited between the Frasnian and early Famennian during short oxygen-depleted periods in platforms and longer times in marginal areas of the closing Rheic ocean (North America, northern Africa), eastern Europe and Australia (Lüning et al., 2003; Harris et al. 2013). According to Bond and Wignall (2008), anoxic waters developed within the interior of epicontinental basins at low latitudes, and expanded their range during the transgressive episodes of late Frasnian cycle IId of Johnson et al. (1985). However, the sulphur isotope record from a few sections does not accord with a whole-ocean anoxic event (John et al., 2010).

The Late Devonian black shale deposition in the deep part of the Amazonas and Solimões intracratonic basins shows some wide areas where clastic starvation prevailed and where condensed sedimentation favoured the abundance of conodonts. Furthermore, black shale sedimentation took place between mudstones and sandstones in shelf sand of the Madres de Dios Basin (Over et al., 2009). The wide distribution of black shale deposition suggests water stratification, whereas an abundance of organic matter and plankton production in beds with conodonts (acritarchs, tasmanacean prasinophytes and chitinozoans) could be indicative of an episodic elevated nutrient supply in probably cold and recurring anoxic waters (Hallam and Wignall, 1997). The sedimentation occurred during a transgressive background, thus favouring the link

Fig. 3. Frasnian conodonts from the drill core in the Abacaxis Member of the Barreirinha Formation. Scale bars represent 200 μm. A–B, P1 element of *Cryptotaxis* sp. A Over (in Over et al., 2009) (MP-M-863 and MP-M-861, respectively). C–D, P1 element of *Cryptotaxis* cf. sp. A Over (in Over et al., 2009) (MP-M-859 and MP-M-829). E–H, elements of *Cryptotaxis* sp. apparatus, P2 (E–F; MP-M-860 and MP-M-858), S (G; MP-M-857) and M (H; MP-M-825). I–K, *Prioniodina* sp., P1 (MP-M-879), M (MP-M-874) and S elements (MP-M-827). L, S element of unknown genus in Prioniodinida (MP-M-826).M1–2, lateral and oral views of P1 element of '*Ozarkodina*' aff. *sannemanni* (Bischoff and Ziegler, 1957) (MP-M-824). N–Q, *Mehlina gradata* Youngquist, 1945, P1 elements (N–O; MP-M-839 and MP-M-832), S3/4 (MP-M-848) and S0 elements (MP-M-852). R, P1 element of *Mehlina* sp. (MP-M-846). S–ZB, *Polygnathus* sp., S0 (S–T; MP-M-837 and MP-M-834), P2 (U, Y, ZA; MP-M-880, MP-M-847, and MP-M-856), S3/4 (V and ZB; MP-M-835 and MP-M-871), S2 (W; MP-M-881) and P1 elements (X; MP-M-870).

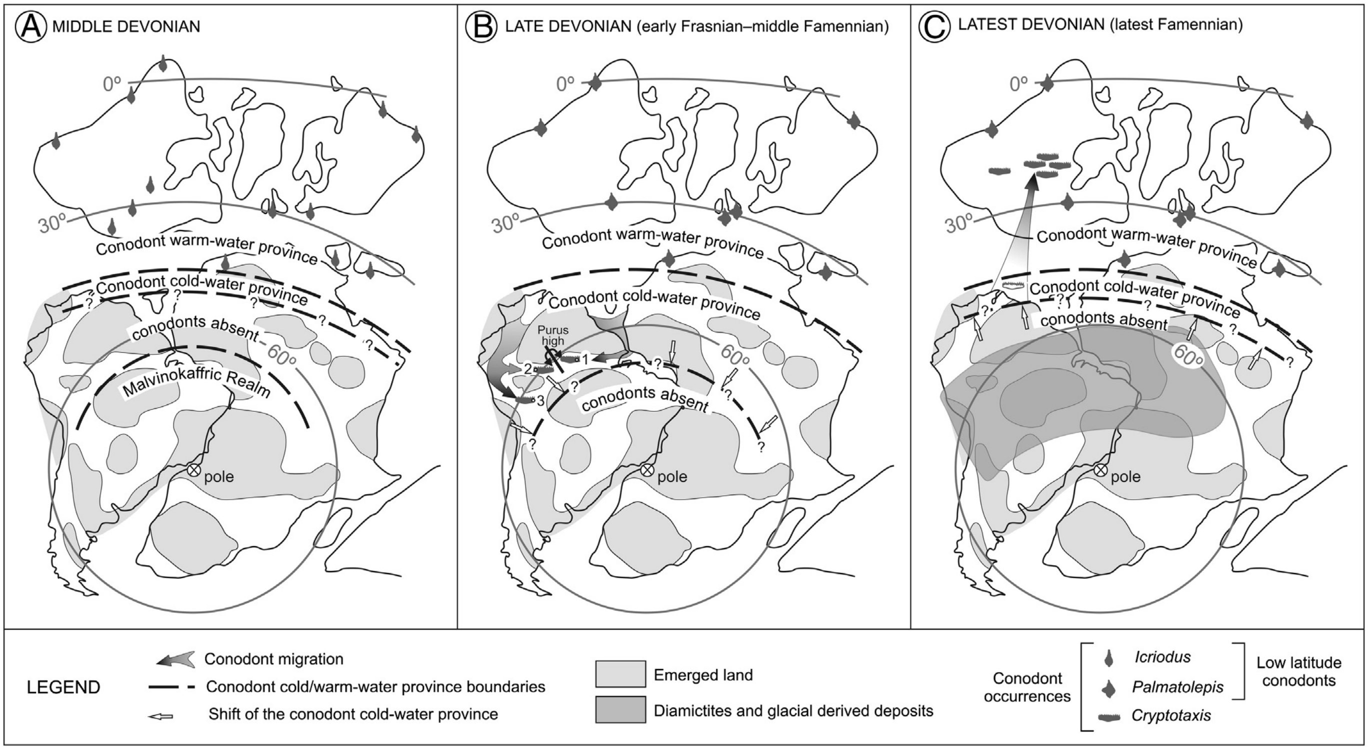


Fig. 4. Devonian palaeogeographic reconstruction (modified after Witzke and Heckel, 1989) showing emerged lands in western Gondwana according to Isaacson et al. (2008) where the conodont warm-water province at low latitudes and conodont absence in northern South America are indicated during the Middle Devonian (A). Immigration of conodonts into the Amazonas Basin-1-, Solimões Basin-2- and Madre de Dios Basin-3-associated with the southward extension of conodont cold-water province during the Late Devonian (B). A high latitudinal temperature gradient during the latest Devonian, indicated by diamictites and glacial derived deposits (Isaacson et al., 2008), contraction of the conodont cold-water province associated with conodont outlet of South America, and *Cryptotaxis* arrival at offshore setting in central and eastern North America (C).

between intracratonic basins and allowing conodont immigration to follow the probable connection between the Madre de Dios and Solimões basins (Over et al., 2009) and to reach at the Amazonas Basin, passing over the Purus high in the Frasnian (Fig. 4B). Alternatively, conodonts could have arrived from the northeast through the main Devonian marine opening at the northeast basin border (Melo, 1989). A different organic productivity probably existed in the Amazonas Basin, since the total organic content of the Barreirinha Formation increases from the south to the northeast (Mosmann et al., 2006).

Wide flooding of the Late Devonian platforms is commonly associated with the worldwide reduction of provincialism in the marine faunas. Cosmopolitism at almost total generic and familial levels can only be compared with that known from the Early Triassic (Boucot, 1989). Late Devonian conodont cosmopolitism is also widely accepted, although Early to Middle Devonian endemism has only been described at species and subspecies, but not genera level, and reflects biofacies dependence (Klapper and Johnson, 1980; Sweet and Bergström, 1984). Endemics are confined largely to nearshore, probably shallow-water facies, and in general more cosmopolitan species characterized offshore, probably deeper-water, biofacies. However, Late Ordovician and Permian conodont provinces have been differentiated by the presence/absence of a few genera and particularly by differences at species level (Sweet and Bergström, 1984; Mei and Henderson, 2001). Furthermore, conodont species diversity decreases from shallow water biofacies of tropical provinces to those in polar provinces (Sweet and Bergström, 1984). In our opinion, the low diversity of the Amazonian conodont fauna represents a cool water community located in relatively shallow water basins at high latitude. Late Devonian highly diversified, low-latitude conodont genera, such as *Icriodus* and *Palmatolepis*, are lacking. Instead, the low diversity conodont faunas from northern South America include cosmopolitan and conservative species (*Mehlina*, '*Ozarkodina*', *Branmehla*, and *Prioniodina*) together with endemic specialist forms (*Cryptotaxis* and *Polygnathus*). *Mehlina* and *Branmehla* are generalist and ubiquitous, since they are interpreted as having lived in the euphotic zone in the highest part of the water column (Ziegler and Sandberg, 1984). They are included in the group of genera (mainly *Bispathodus*) which occurs abundantly in the pelagic far offshore setting of the palmatolepid–bispathodid biofacies (Sandberg, 1976; Sandberg and Ziegler, 1979; Ziegler and Sandberg, 1984), where *Cryptotaxis* is also integrated (Over, 1992). However, the palmatolepid component of this biofacies, dwelling close to the sea bottom in poorly oxygenated water at low latitudes, is lacking in South America. It can be partly replaced by the scarce *Polygnathus*, '*Ozarkodina*' and *Cryptotaxis* species moving through the water column above the anoxic/dysoxic zone. '*Ozarkodina*' aff. *sannemanni* morphology is related to the *O. sannemanni* group (including *O. adventa* Pollock, 1968, *O. proxima* Pollock, 1968, *O. trepta* Ziegler, 1958, and *O. nonaginta* Klapper et al., 1996), which diversified from the late Givetian to the middle Frasnian. *Cryptotaxis* resembles Mississippian *Bactrognathus*, including similar elements in their apparatuses, and ancestors of bactrognathids might have originated in a group that may be related to *Cryptotaxis*, in accordance with Chauff (1985). *Bactrognathus* is considered a mesopelagic swimmer genus, which may have hugged the bottom above the oxygen-minimum zone (Sandberg and Gutschick, 1984).

A high latitudinal location for conodont occurrences in South America (around 60°S latitude) is supported by palaeogeographical reconstructions (Fig. 4B). Permian conodonts only occurred in a zone between 50°N–S palaeolatitude (Mei and Henderson, 2001). The probable high latitude of South American occurrences fits well in the Geitgey and Carr (1987) model, where cold-water conodont provinces expanded towards the polar region during decreases in the latitudinal temperature gradient and, by contrast, contracted as the gradient increased. A warm climate and low latitudinal gradient is assumed during early Late Devonian sea-level rise time. In the same way, the carbonate platform belt extended to palaeolatitudes up to 45°S (Heckel and Witzke, 1979). A considerable warming during the Frasnian is known from low latitudes and estimated through oxygen isotope composition, with two strong δ^{18}O negative shifts in the latest Frasnian and early Famennian (Joachimski et al., 2009). Values from brachiopods translate into unrealistic water palaeotemperatures (31–41 °C according to van Geldern et al., 2006), whereas conodont apatite data indicate average temperatures ranging between 30 and 32 °C in the middle Frasnian to early Famennian (Joachimski et al., 2009).

The recognition of the northern South American conodont cold-water province during the late Frasnian to early Famennian is coincident with the high-latitude microplankton community distinguished by Vavrdová and Isaacson (1999). Furthermore, floras support an Afro-South American Subrealm in the southwestern part of the Gondwana phytogeographical Province. These floras resulted from the effects of palaeolatitude (Wnuk, 1996; di Pasquo et al., 2009). The boundary of this subrealm is located between Venezuela and Colombia on the one hand and the rest of South America on the other, based on different megafloras. However, Streel et al. (2000) recognized a diversity crisis of miospores during the late Frasnian to late Famennian. These authors deduced a latest Frasnian hot climate to explain the maximum width of the distribution of equatorial miospore assemblages, whereas they suggested a scarcity of vegetation and probably compatible climatic conditions from palaeotropical (non-equatorial) to subpolar regions on the basis of the homogeneity of miospore assemblages.

The minimum diversity in miospore and in chitinozoan associations (Melo and Loboziak, 2003), with long ranging and endemic taxa, is coincident with the late Frasnian conodont association and that described for the Bolivian early Famennian (Over et al., 2009). Consequently, the Frasnian/Famennian extinction is not evident and the Frasnian/Famennian boundary was located in an interval of several metres of quartz sandstone between black shale intervals, as was determined using magnetic susceptibility (Over et al., 2009). The boundary position is in agreement with the terminal IId regression of the Johnson et al. (1985) eustatic sea-level curve. If we assume that the maximum expansion of conodont polewards occurred during the maximum warming indicated by latest Frasnian and early Famennian δ^{18}O negative shifts (Joachimski et al., 2009), then late Frasnian South American conodonts may have occurred, whereas the Frasnian/Famennian biodiversity crisis developed at low latitude. This correlation also fits well into a model of biodiversity crisis associated with global warming (Brand, 1989; Thompson and Newton, 1989; Mayhew et al., 2007), such as hothouse episodes of Kidder and Worsley (2004, 2010), where ocean heat transport contributes to high-latitude warming at 60°, and dry and poorly vegetated regions (low miospore diversity) extend to mid to moderately high latitudes.

The disappearance of conodonts from the upper Famennian Urubu Member of the Barreirinha Formation coincides with the sedimentation of shales deposited in a more oxygenated setting with siliciclastic dilution. It can be interpreted as a return to a high latitudinal gradient, which pre-dates the latest Famennian glacial episode, widely accepted in South America on the basis of the evidence provided by diamictites and glacial derived deposits (Caputo, 1985; Melo and Loboziak, 2003). A moderate cooling trend of the water temperature was thus assumed to have occurred during the middle to late Famennian. This trend culminated in glaciation from the oxygen isotope composition at low latitudes (Joachimski et al., 2009). Consequently, the cold water conodont province narrowed, and *Cryptotaxis* seems to have arrived in offshore settings of North America at the colder latest Famennian time (Fig. 4C). To be more precise, *Cryptotaxis collinsoni* (Scott, 1961) occurs first in latest Famennian (Lower to Upper *praesulcata* conodont zones) in central and eastern North America (Over, 1992; Chauffe and Nichols, 1995; Over et al. 2013).

6. Conclusions

The conodonts from the upper part of the Abacaxis Member of the Barreirinha Formation suggest a late Frasnian age, in partial agreement with the previous age assigned to Amazonian palynomorphs. The conodont association is comparable to other faunas occurring in the Frasnian of the Solimões and Madre de Dios basins. All of them represent a low diversity community, clearly differentiated from conodont faunas described in the bibliography for low latitudes and comprising diverse and widely distributed conodont taxa. South American conodonts consist of generalist taxa inhabiting the upper part of the water column, and several specialist probably swimming taxa living above poorly oxygenated waters. They are all restricted to an interval with episodic bottom anoxia related to Frasnian transgression of oceanic water into epicontinental South American seas and warmer marine conditions. Associations are interpreted through the expansion of cold-water dwelling fauna to high latitudes of northern South America during a decrease in the latitudinal temperature gradient in the warmer late Frasnian to early Famennian episode. Here, the Frasnian/Famennian biodiversity crisis described at low latitudes does not occur.

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References

Bardashev, I.A., 1992. Conodont stratigraphy of Middle Asian Middle Devonian. Courier Forschungsinstitut Senckenberg 154, 31–83.
Bassler, R.S., 1925. Classification and stratigraphic use of the conodonts. Bull. Geol. Soc. Am. 36, 218–220.
Bischoff, G., Ziegler, W., 1957. Die Conodontenchronologie des Mitteldevons und des tiefsten Oberdevons. Abhandlungen des Hessischen Landesamtes fur Bodenforschung 22, 1–136.
Bond, D.P.G., Wignall, P.B., 2008. The role of sea-level change and marine anoxia in the Frasnian–Famennian (Late Devonian) mass extinction. Palaeogeogr. Palaeoclimatol. Palaeoecol. 263, 107–118.
Boucot, A.J., 1989. Devonian biogeography: an update. In: McMillan, N.J., Embry, A.F., Glass, D.J. (Eds.), Devonian of the World. Canadian Society of Petroleum Geologists, Memoir vol. 3, pp. 211–223 (imprint 1988).
Boucot, A.J., Johnson, J.G., Talent, J.A., 1969. Early Devonian brachiopod zoogeography. Geol. Soc. Am. Spec. Pap. 119, 113.
Brand, U., 1989. Global climatic changes during the Devonian–Mississippian: stable isotope biogeochemistry of brachiopods. Palaeogeogr. Palaeoclimatol. Palaeoecol. 75, 311–329.
Branson, E.B., Mehl, M.G., 1934. Conodonts from the Grassy Creek Shale of Missouri. Univ. Missouri Stud. 8, 171–259.
Caputo, M.V., 1985. Late Devonian glaciation in South America. Palaeogeogr. Palaeoclimatol. Palaeoecol. 51, 291–317.
Cardoso, C.N., Lemos, V.B., Scomazzon, A.K., 2013. First occurrence of Devonian conodont elements in the Barreirinha Formation, Amazonas Basin, Northeast Brazil. In: Albanesi, G.L., Ortega, G. (Eds.), Conodonts from the Andes. Asociación Paleontológica Argentina, Publicación Especial 13, pp. 91–93.
Chauff, K.M., 1985. Phylogeny of the multielement conodont genera *Bactrognathus*, *Doliognathus* and *Staurognathus*. J. Paleontol. 59, 299–309.
Chauffe, K.M., Nichols, P.A., 1995. Multielement conodont species from the Louisiana Limestone (Upper Devonian) of West-Central Illinois and Northeastern Missouri, U.S.A. Micropaleontology 41, 171–186.
Cunha, P.R.C., Gonzaga, F.G., Coutinho, L.F.C., Feijó, F.J., 1994. Bacia do Amazonas. Boletim de Geociências da Petrobras 8, 47–55.
Cunha, P.R.C., Melo, J.H.G., Silva, O.B., 2007. Bacia do Amazonas. Boletim de Geociências da Petrobras 15, 227–251.
Di Pasquo, M., Amenábar, C.R., Noetinger, S., 2009. Middle Devonian microfloras and megafloras from western Argentina and Southern Bolivia: their importance in the palaeobiogeographical and palaeoclimatic evolution of western Gondwana. In: Königshof, P. (Ed.), Devonian change: case studies in palaeogeography and palaeoecology. The Geological Society, London, Special Publication 314, pp. 193–213. http://dx.doi.org/10.1144/SP314.11.
Dzik, J., 1976. Remarks on the evolution of Ordovician conodonts. Acta Palaeontol. Pol. 21, 395–455.
Geitgey, J.E., Carr, T.R., 1987. Temperature as factor affecting conodont diversity and distribution. In: Austin, R.L. (Ed.), Conodonts: investigative techniques and applicationsBritish Micropalaeontological Society Series. Ellis Horwood Limited, Chichester, pp. 241–255.

Gonzaga, F.G., Gonçalves, F.T.T., Coutinho, L.F.C., 2000. Petroleum geology of the Amazonas Basin, Brazil: modelling of hydrocarbon generation and migration. In: Mello, M.R., Katz, B.J. (Eds.), Petroleum systems of South Atlantic margins. American Association of Petroleum Geologists Memoir 73, pp. 159–178.

Grahn, Y., Melo, J.H.G. de, 2002. Chitinozoan biostratigraphy of the Late Devonian formations in well Caima PH-2, Tapajós River area, Amazonas Basin, northern Brazil. Rev. Palaeobot. Palynol. 118, 115–139.

Hallam, A., Wignall, P.B., 1997. Mass Extinctions and Their Aftermath. Oxford University Press, New York (320 pp.).

Harris, N.B., Mnich, C.A., Selby, D., Korn, D., 2013. Minor and trace element and Re–Os chemistry of the Upper Devonian Woodford Shale, Permian Basin, west Texas: insights into metal abundance and basin processes. Chem. Geol. 356, 76–93. http://dx.doi.org/10.1016/j.chemgeo.2013.07.018.

Hass, W.H., 1959. Conodonts from the Chappel Limestone of Texas. U.S. Geol. Surv. Prof. Pap. 294-J, 365–399.

Heckel, P.H., Witzke, B.J., 1979. Devonian world paleogeography determined from distribution of carbonates and related lithic paleoclimatic indicator. In: House, M.R., Scrutton, C.T., Bassett, M.G. (Eds.), Special Papers in Palaeontology 23, pp. 99–123.

Helms, J., 1959. Conodonten aus dem Saalfelder Oberdevon (Thüringen). Geologie 8, 634–677.

Hinde, G.J., 1879. On conodonts from the Chazy and Cincinnati group of the Cambro–Silurian and from the Hamilton and Genesee shale divisions of the Devonian in Canada and the United States. Geol. Soc. Lond. Q. J. 35, 351–369.

Hünicken, M.A., 1989. Some paleogeographical aspects of South American conodonts and related forms. Courier Forschungsinstitut Senckenberg 117, 29–49.

Hünicken, M.A., de Melo, J.H.G., Lemos, V.B., 1989. Devonian conodonts from the Upper Amazon Basin. In: McMillan, N.J., Embry, A.F., Glass, D.J. (Eds.), Northwestern Brazil. Canadian Society of Petroleum Geologists, Memoir 14 vol. 3, pp. 479–483 (imprint 1988).

Isaacson, P.E., 2007. Mid-Paleozoic biogeography of the Central Andes: endemic faunas, immigrants, and paleogeography. In: Díaz-Martínez, E., Rábano, I. (Eds.), 4th European Meeting on the Palaeontology and Stratigraphy of Latin America Cuadernos del Museo Geominero 8, Instituto Geológico y Minero de España, Madrid, pp. 213–218.

Isaacson, P.E., Díaz-Martínez, E., Grader, G.W., Kalvoda, J., Babek, O., Devuyst, F.X., 2008. Late Devonian–earliest Mississippian glaciation in Gondwanaland and its biogeographic consequences. Palaeogeogr. Palaeoclimatol. Palaeoecol. 268, 126–142. http://dx.doi.org/10.1016/j.palaeo.2008.03.047.

Joachimski, M.M., Breisig, S., Buggisch, W., Talent, J.A., Mawson, R., Gereke, M., Morrow, J.M., Day, J., Weddige, K., 2009. Devonian climate and reef evolution: insights from oxygen isotopes in apatite. Earth Planet. Sci. Lett. 284, 599–609. http://dx.doi.org/10.1016/j.epsl.2009.05.028.

John, E.H., Wignall, P.B., Newton, R.J., Bottrell, S.H., 2010. $\delta^{34}S_{CAS}$ and $\delta^{18}O_{CAS}$ records during the Frasnian–Famennian (Late Devonian) transition and their bearing on mass extinction models. Chem. Geol. 275, 221–234. http://dx.doi.org/10.1016/j.chemgeo.2010.05.012.

Johnson, J.G., Klapper, G., Sandberg, C.A., 1985. Devonian eustatic fluctuations in Euramerica. Geol. Soc. Am. Bull. 96, 567–587.

Kidder, D.L., Worsley, T.R., 2004. Causes and consequences of extreme Permo–Triassic warming to globally equable climate and relation to the Permo–Triassic extinction and recovery. Palaeogeogr. Palaeoclimatol. Palaeoecol. 203, 207–237.

Kidder, D.L., Worsley, T.R., 2010. Phanerozoic Large Igneous Provinces (LIPs), HEATT (Haline Euxinic Acidic Thermal Transgression) episodes, and mass extinctions. Palaeogeogr. Palaeoclimatol. Palaeoecol. 295, 162–191. http://dx.doi.org/10.1016/j.palaeo.2010.05.036.

Klapper, G., Johnson, J.G., 1980. Endemism and dispersal of Devonian conodonts. J. Paleontol. 54, 400–455.

Klapper, G., Philip, G.M., 1971. Devonian conodont apparatuses and their vicarious skeletal elements. Lethaia 4, 429–452.

Klapper, G., Philip, G.M., 1972. Familial classification of reconstructed Devonian conodont apparatuses. Geol. Palaeontol. Spec. 1, 97–105.

Klapper, G., Kuz'min, A.V., Ovnatanova, N.S., 1996. Upper Devonian conodonts from the Timan-Pechora Region, Russia, and correlation with a Frasnian composite standard. J. Paleontol. 70, 131–152.

Kroemmelbein, K., 1967. Devonian of the Amazonas Brazil. In: Oswald, D.H. (Ed.), International Symposium on the Devonian System. Alberta Society of Petroleum Geologists, Calgary vol. 2, pp. 201–208.

Lüning, S., Adamson, K., Craig, J., 2003. Frasnian organic-rich shales in North Africa: regional distribution and depositional model. In: Arthur, T.J., MacGregor, D.S., Cameron, N.R. (Eds.), Petroleum geology of Africa: new themes and developing technologies. Geological Society, London, Special Publication 207, pp. 165–184.

Matsuda, N.S., Winter, W.R., Wanderley Filho, J.R., Cacela, A.S.M., 2009. O Paleozóico da borda sul da Bacia do Amazonas, Rio Tapajós - Estado do Pará. Boletim de Geociências da Petrobras 18, 123–152.

Mayhew, P.J., Jenkins, G.B., Benton, T.G., 2007. A long-term association between global temperature and biodiversity, origination and extinction in the fossil record. Proc. R. Soc. B 1–7.

Mei, S., Henderson, C.M., 2001. Evolution of Permian conodont provincialism and, its significance in global correlation and paleoclimate implication. Palaeogeogr. Palaeoclimatol. Palaeoecol. 170, 237–260.

Melo, J.H.G. de, 1989. The Malvinokaffric Realm in the Devonian of Brazil. In: McMillan, N.J., Embry, A.F., Glass, D.J. (Eds.), Devonian of the World. Canadian Society of Petroleum Geologists, Memoir 14 vol. 1, pp. 669–703 (imprint 1988).

Melo, J.H.G., Loboziak, S., 2003. Devonian–Early Carboniferous miospore biostratigraphy of the Amazon Basin, northern Brazil. Rev. Palaeobot. Palynol. 124, 131–202.

Mosmann, R., Falkenhein, F.U.H., Gonçalves, A., Filho, F.N., 2006. Oil and gas potential of the Amazon Paleozoic basins. In: Halbouty, M.T. (Ed.), Future petroleum provinces of the world. American Association of Petroleum Geologists Memoir 40, pp. 207–241.

Neves, C.A.O., 1990. Prospectos potenciais e áreas prioritárias para exploração na Bacia do Amazonas. Boletim de Geociências da Petrobras 4, 95–103.

Ngan, P.N., 1979. Conodonts from limestone pieces of the Late Paleozoic conglomerates in north-west Bulgaria. Geol. Balc. 9, 77–92.

Nicoll, R.S., Druce, E.C., 1979. Conodonts from the Fairfield Group, Canning Basin, Western Australia. Bull. Bur. Miner. Resour. Geol. Geophys. 190, 1–134.

Over, D.J., 1992. Conodonts and the Devonian–Carboniferous boundary in the Upper Woodford Shale, Arbucle Mountains, south-central Oklahoma. J. Paleontol. 66, 293–311.

Over, D.J., de la Rue, S., Isaacson, P.E., Ellwood, B., 2009. Upper Devonian conodonts from black shales of the high latitude Tomachi Formation, Madre de Dios Basin, northeastern Bolivia. Palaeontogr. Am. 62, 89–95.

Over, D.J., Evans, S.D., Day, J., Hasenmueller, N.R., 2013. The Devonian/Carboniferous boundary and the holotype of *Siphonodella sulcata* (Huddle, 1934) in the upper New Albany Shale, Illinois basin, southern Indiana. Geol. Soc. Am. Abstr. Programs 45, 529.

Pereira, E., Bergamaschi, S., Rodrigues, R., Pessoa de Souza, M.S., 2007. Silurian and Devonian world-wide flooding events in the Paraná Basin. In: Iannuzzi, R., Boardman, D.R. (Eds.), Problems in Western Gondwana geology, I Workshop "South America–Africa correlations: du Toit revisited", pp. 115–120 (Gramado-RS-Brazil, August 27th to 29th, 2007, Extended abstracts).

Pollock, C.A., 1968. Lower Upper Devonian conodonts from Alberta, Canada. J. Paleontol. 42, 415–443.

Racki, G., 2005. Toward understanding Late Devonian global events: few answers, many questions. In: Over, D.J., Morrow, J.R., Wignall, P.B. (Eds.), Understanding Late Devonian and Permian–Triassic Biotic and Climatic Events: Towards an Integrated Approach. Elsevier, pp. 5–36.

Richter, R., Richter, E., 1942. Die Trilobiten der Weismes-Schichten am Hohen Venn, mit Bemerkungen über die Malvinocaffrische Provinz. Senckenbergiana 25, 156–179.

Sandberg, C.A., 1976. Conodont biofacies of Late Devonian *Polygnathus styriacus* Zone in western United States. In: Barnes, C.R. (Ed.), Conodont paleoecology. Geological Association of Canada Special Paper 15, pp. 171–186.

Sandberg, C.A., Gutschick, R.C., 1984. Distribution, microfauna and source-rock potential of Mississippian Delle Phosphate Member of Woodman Formation and equivalents, Utah and adjacent states. In: Clayton, J.L., Meissner, F.F. (Eds.), Hydrocarbon Source Rocks of the Greater Rocky Mountain region. Rocky Mountain Association of Geologists, Denver, Colorado, pp. 135–178.

Sandberg, C.A., Ziegler, W., 1979. Taxonomy and biofacies of important conodonts of Late Devonian *styriacus*-Zone, United States and Germany. Geol. Palaeontol. 13, 173–212.

Scott, A.J., 1961. Three new conodonts from the Louisiana Limestone (Upper Devonian) of western Illinois. J. Paleontol. 35, 1223–1227.

Streel, M., 2007. West Gondwanan and Euramerican climate impact on early Famennian to latest Viséan miospore assemblages. Newsletter of the Subcommission on Devonian Stratigraphy 22, pp. 53–55.

Streel, M., 2009. Upper Devonian miospore and conodont zone correlation in western Europe. In: Königshof, P. (Ed.), Devonian change: case studies in palaeogeography and palaeoecology. The Geological Society, London, Special Publication 314, pp. 163–176. http://dx.doi.org/10.1144/SP314.11.

Streel, M., Caputo, M.V., Loboziak, S., Melo, J.H.G., 2000. Late Frasnian–Famennian climates based on palynomorph analyses and the question of the Late Devonian glaciations. Earth Sci. Rev. 52, 121–173.

Sweet, W.C., 1988. The Conodonta: morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum. Oxford Monographs on Geology and Geophysics 10. Oxford University Press (212 pp.).

Sweet, W.C., Bergström, S.M., 1984. Conodont provinces and biofacies of the Late Ordovician. In: Clark, D.L. (Ed.), Conodont biofacies and provincialism. Geological Society of America Special Paper 196, pp. 69–87.

Thompson, J.B., Newton, C.R., 1989. Late Devonian mass extinction: episodic climatic cooling or warming? In: McMillan, N.J., Embry, A.F., Glass, D.J. (Eds.), Devonian of the World. Canadian Society of Petroleum Geologists, Memoir 14 vol. 3, pp. 29–34 (imprint 1988).

Van Geldern, R., Joachimski, M.M., Day, J., Jansen, U., Alvarez, F., Yolkin, E.A., Ma, X.P., 2006. Carbon, oxygen and strontium isotope records of Devonian brachiopod shell calcite. Palaeogeogr. Palaeoclimatol. Palaeoecol. 240, 47–67. http://dx.doi.org/10.1016/j.palaeo.2006.03.045.

Vavrdová, M., Isaacson, P.E., 1999. Late Famennian phytogeographic provincialism: evidence for a limited separation of Gondwana and Laurentia. Abh. Geol. Bundesanst. 54, 453–463.

Wirth, M., 1967. Zur Gleiderung des höheren Paläozoikums (Givet–Namur) im Gebiet des Quinto Real (Westpyrenäen) mit Hilfe von Conodonten. Neues Jb. Geol. Paläontol. Abh. 127, 179–244.

Witzke, B.J., Heckel, P.H., 1989. Paleoclimatic indicators and inferred Devonian paleolatitudes of Euramerica. In: McMillan, N.J., Embry, A.F., Glass, D.J. (Eds.), Devonian of the World. Canadian Society of Petroleum Geologists, Memoir 14 vol. 1, pp. 49–63 (imprint 1988).

Wnuk, C., 1996. The development of floristic provinciality during the Middle and Late Paleozoic. Rev. Palaeobot. Palynol. 90, 5–40.

Youngquist, W.L., 1945. Upper Devonian conodonts from the Independence Shale (?) of Iowa. J. Paleontol. 19, 355–367.

Ziegler, W., 1958. Conodontenfeinstratigraphische Untersuchungen an der Grenze Mitteldevon/Oberdevon und in der Adorfstufe. Notizblatt des Hessischen Landesamtes Bodenforschung 87, 7–77.

Ziegler, W., Sandberg, C.A., 1984. *Palmatolepis* based revision of upper part of standard Late Devonian conodont zonation. In: Clark, D.L. (Ed.), Conodont biofacies and provincialism. Geological Society of America Special Paper 196, pp. 179–194.

Ziegler, W., Sandberg, C.A., 1990. The Late Devonian Standard Conodont Zonation. Courier Forschungsinstitut Senckenberg 121, 1–115.

Artigo 02

Cardoso, C.N., Sanz-López, J., Blanco-Ferrera, S., 2016. ***Carboniferous conodonts from the Tapajós Group (Amazonas Basin, Brazil)***.

Carboniferous conodonts from the Tapajós Group (Amazonas Basin, Brazil)

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ABSTRACT

Conodonts from ninety samples of the Monte Alegre, Itaituba and Nova Olinda formations were recovered from twenty three wells and one quarry in the Amazonas Basin. Palaeontological systematic study focuses on species of *Adetognathus*, *Diplognathodus*, *Idiognathodus*, *Idiognathoides*, *Neognathodus* and *Streptognathodus*. Several taxa are considered for the first time in the Bashkirian to Moscovian of South America, and one new species, *Idiognathodus itaitubensis*, is proposed. Conodonts confirm the known affinity of Amazonian faunas with those in the Midcontinent-Andean province. The occurrence of

Idiognathodus izvaricus suggests the possibility of an occasional connection of the Amazonas Basin with the western Palaeo-Tethys Ocean in the Moscovian. Finally, a few specimens of *Streptognathodus* occur in Upper Pennsylvanian to Permian beds of the Nova Olinda Formation.

Keywords: Conodonts, Systematics, Bashkirian, Moscovian, Upper Pennsylvanian, Amazonas

1. Introduction

Conodonts from the Amazonas Basin are mainly known from the Carboniferous Tapajós Group, although a few Upper Devonian species have been described (Cardoso et al., 2015; and references therein). To be more specific, conodonts are common in marine beds of the Monte Alegre, Itaituba and Nova Olinda formations. Firstly, Fúlfaro (1965) indicated a Carboniferous age for the Tapajós Group on the basis of the occurrence of *Idiognathodus* cf. *acutus* Ellison, 1941 in outcrops of the Tapajós River. Later, Tengan et al. (1976) concluded the presence of Mississippian associations and other Middle Pennsylvanian ones from the Itaituba and Nova Olinda formations. A synthesis elaborated by Rocha-Campos and Archangelsky (1985) illustrated several species and considered the age of the Amazonian conodonts to be from the upper Mississippian Subsystem to the North American Atokan Stage. Subsequent studies based on samples from many Petrobras drilling holes, and from a few outcrops, confirmed the relationships between the Amazonian conodonts and North American faunas, and proposed different local zonations, which were correlated with late Morrowan, Atokan, early Desmoinesian and probably Virgilian North American regional stages (Lemos, 1990, 1992a, 1992b; Lemos and Medeiros, 1989, 1996; Scomazzon, 1999, 2004; Lemos and Scomazzon, 2001; Scomazzon and Lemos, 2005; Nascimento et al., 2005, 2009, 2010a, b; Cardoso, 2010). In South America, Pennsylvanian to lower Permian conodonts are only known from a few basins in the northern half of the continent: the Brazilian Solimões Basin (Araújo and Rocha-Campos, 1969; Lemos, 1990, 1992a, 1992b; Lemos and Medeiros, 1996), the Brazilian Parnaiba Basin (Campanha and Rocha-Campos, 1979), Colombian Cordillera Oriental (Stibane, 1967; Stibane and Forero, 1969) and Bolivia sub-basins (Suárez Riglos et al., 1987; Grader et al., 2008; Henderson et al., 2009).

The aim of the present study is the determination and study of conodonts recovered from core samples from twenty three drilling holes and a quarry of the Amazonas Basin. This work is particularly necessary since the core samples came from many localities and were small in size. Occurrences of some species are new for South America and the observed diversity is higher than that previously known. The relatively abundant conodont associations from the Amazonas are of great interest to enhance the knowledge of conodont biodiversity in the Carboniferous of South America and constitute an important base for future studies.

2. Geological setting

The Amazonas Basin is an intracratonic, west-east elongated syneclise in northern Brazil, bounded to the north and south by the Precambrian Guianas and Brazilian shields, respectively (Fig. 1). The basin is separated from the Solimões Basin by the Purus Arch to the west and from the Marajó Basin by the Gurupá Arch, transverse structures that conditioned the sedimentation and filling. It is mostly filled by Paleozoic rocks and occupies an area of 500,000 km^2 within the states of Amazonas, Pará, and Amapá. Despite its large dimensions, Paleozoic rocks are rarely seen in outcrops since they are covered by the widespread overlying Mesozoic and Cenozoic sedimentary cover and a dense Amazonian rainforest. The study of the rocks is mostly based on subsurface well and seismic data (Gonzaga et al., 2000). The Paleozoic succession extends for more than 5,000 m of Paleozoic (Neves, 1990; Cunha et al., 1994; Gonzaga et al., 2000) in the deeper central basin, whereas the thickness decreases towards relatively shallow ramps, the so-called North and South platforms (Wanderley-Filho et al., 2010).

Paleozoic strata consist of several sequences limited by regional unconformities (Neves, 1990; Cunha et al., 1994, 2007; Matsuda et al., 2004; and the papers cited therein). A regional unconformity is located at the base of the Pennsylvanian to Permian sequence and separates it from the upper Viséan Faro Formation, which consists of 400 m of fluvial, deltaic and coastal sandstones and shales with interbedded glacial diamictites deposited in the centre of the Amazonas Basin (Caputo et al., 2008). The Tapajós Group reaches up to 2,800 m thick. The lowest 5 to 140 m constitutes the Monte Alegre Formation, which consists of fluvial to eolian sandstones, marine littoral to lagoon siltstones and shales. Adjacent to and above it, the Itaituba Formation consists of up to 420 m of marine carbonate beds grading upward to shales, sandstone and anhydrites. Tidal flat and tidal delta deposits occur in the lower part. The Itaituba Formation yields brachiopods, echinoderms, foraminifers, ostracods, bryozoans, trilobites, molluscs, corals, conodonts and vertebrate remains. A Bashkirian and Bashkirian–Moscovian ages are assigned to the Monte Alegre and Itaituba formations respectively, on the basis of the conodont, foraminifer and palynoflora contents (Lemos, 1992a, b; Altiner and Savini, 1995; Playford and Dino, 2000a, b, 2005). The Itaituba Formation shows a gradational boundary with the Nova Olinda Formation, the latter of which (up to 1200 m thick) subdivides into the Fazendinha and Arari members (Cunha et al., 2007). The lower member is composed of mudstones, limestones, anhydrites and salts deposited in shallow marine, sabkha and hypersaline lagoon environments. The Arari Member is composed of mudstones and siltstones with halite salts deposited in a continental setting, although a few marine incursions occur. A Moscovian age is assumed for the Fazendinha Member, whereas Kasimovian/Gzhelian is estimated for the Arari Member, according to Cunha et al. (2007). However, Playford and Dino (2000b) indicated an early Permian age (transition between Asselian/Sakmarian) on the basis of spores from the upper beds of the Nova Olinda Formation. The Andirá Formation corresponds to red beds, siltstones and sandstones with scarce anhydrites in fluvial and lacustrine facies. A Permian age is based on the miospore record (Playford and Dino, 2000a, b).

3. Material and methods

Seventy two samples, each of 0.3–0.5 kg, from cores provided by Petróleo Brasilerio SA (PETROBRAS) from twenty three drill wells, and eighteen samples from the Calminas quarry outcrop (Fig. 1), were leached with buffer solutions of acetic acid following the methodology in Jeppsson and Anehus (1995) and Jeppsson et al. (1999). The conodont content from the Calminas quarry section (18 m thick, located to the east of Itaituba village) is re-studied here from Cardoso (2010, unpublished). Simplified stratigraphic logs may be found in Cardoso et al. (submitted). Furthermore, previously published illustrations of Brazilian conodonts are compared with the recovered material to complete this study.

4. Systematic palaeontology

The studied specimens are stored in the repository of the Laboratório de conodontes, Universidade Federal do Rio Grande do Sul (Porto Alegre, Brazil) with the abbreviated catalogue notation MP-M 895 to MP-M 1347. The specimens are basically P1 elements (Table 1). Nomenclature for conodonts follows Purnell et al. (2000), but DE (discrete element) ahead of the name of the conodont species (Horowitz and Rexroad, 1982) here indicates parataxonomy in order to designate a morphotype occurring in several distinct conodont apparatuses. Taxa given in inverted commas correspond to those informally considered as forming a distinct genus.

Order OZARKODINIDA Dzik, 1976

Family CAVUSGNATHIDAE Austin and Rhodes, 1981

Genus **Adetognathus** Lane, 1967

Adetognathus lautus (Gunnell, 1933)

Fig. 2(1–2)

1933. *Cavusgnathus lautus* n. sp.- Gunnell, p. 286, pl. 31, figs. 67–68.

1933. *Cavusgnathus gigantus* n. sp.- Gunnell, p. 286, pl. 33, figs. 7–8.

1979. *Cavusgnathus lautus* Gunnell.- Campanha and Rocha Campos, pp. 61–62, pl. 1, figs. 1–2.

1979. *Cavusgnathus gigantus* Gunnell.- Campanha and Rocha Campos, pp. 61–62, pl. 1, figs. 10–12.

1992a. *Adetognathus lautus* (Gunnell).- Lemos, pl. 5, figs. 1–9; figs. 5–8.

1992b. *Adetognathus lautus* (Gunnell).- Lemos, pp. 121–122, 124, pl. 1, figs. 1–9; fig. 4.

2005. *Adetognathus lautus* (Gunnell).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 2J.

2009. *Adetognathus lautus* (Gunnell).- Nascimento, Lemos and Scomazzon in Nascimento et al., fig. 4A.

2010. *Adetognathus lautus* (Gunnell).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5Z.

Material: Nineteen elements, MP-M 901, 902, 927–928, 970, 1033, 1047, 1172–1174, 1177, 1182, 1198, 1274, 1297 and 1312 (Table 1).

Occurrence: The species ranges from the latest Serpukhovian (Carboniferous) to the Sakmarian/Artinskian boundary interval (early Permian). It occurs in the Monte Alegre and Itaituba formations, and occasionally in the Nova Olinda Formation. It is known in the Brazilian Parnaíba and Solimões basins (Campanha and Rocha-Campos, 1979; Lemos, 1992b), the Colombian Andes (Stibane, 1967) and the Bolivian Copacabana Formation (Merino Rodo and Blanco Rojas, 1990).

Adetognathus flexus (Ellison, 1941)

Fig. 2(3)

1941. *Cavusgnathus flexus* n. sp.- Ellison, pp. 126–127, pl. 21, figs. 42–43 and 46.

Material: MPM-M 1127 element from the Nova Olinda Formation in well 1-NO-1-AM.

Remarks: Sinistral P1 element with a widely flared, rounded dorsal platform. A large denticle at the dorsal end of the blade is missing, as was described in the holotype (Ellison, 1941). Nor is this denticle presents in the dextral P1 element (von Bitter, 1972). *A. flexus* may represent a variant of *A. lautus,* although its occasional occurrence does not allow us to confirm this.

Occurrence: The species ranges from the upper Missourian to the Virgilian (von Bitter, 1972).

Family IDIOGNATHODONTIDAE Harris and Hollingsworth, 1933

Genus **Idiognathoides** Harris and Hollingsworth, 1933

Type species: *Idiognathoides sinuatus* Harris and Hollingsworth, 1933

Remarks: Differences between *Idioghathoides* and *Declinognathodus* Dunn 1966 are discussed in Sanz-López et al. (2006), and Sanz-López and Blanco-Ferrera (2012, 2013).

DE *Idiognathoides sinuatus* Harris and Hollingsworth, 1933

Fig. 2(5–6)

1933. *Idiognathoides sinuatus* n. sp.- Harris and Hollingsworth, pp. 201–202, pl. 1, fig. 14.

1992b. *Idiognathoides sinuatus* Harris and Hollingsworth, 1933.- Lemos, pp. 124–125, pl. 2, figs. 3–7 (only).

Material: Eighteen P1 elements MP-M 912–914, 922, 957, 961–966, 1021, 1040–1042 and 1121 from different localities (Table 1).

Remarks: Sinistral P1 elements considered a *nomen dubium*, since it may be the sinistral P1 element in apparatuses of different species (Sanz-López and Blanco-Ferrera, 2012). In the studied samples, it could belong to *I. corrugatus* and *I. ouachitensis*. Furthermore, one element in sample 21 of well 2-CP-2-PA shows a nearly flat dorsal platform with continuous transverse ridges, which is similar to DE *Idiognathoides lanei* Nemirovskaya, 1978 (Fig.

2(6)). The dextral P1 element associated with this morphotype remains unknown, but it could be part of *I. ouachitensis*, based on its stratigraphic distribution.

Occurrence: DE *Idiognathoides sinuatus* was recovered from beds of the Itaituba Formation, although it also occurs in the Monte Alegre Formation (Lemos and Medeiros, 1996). Specimens are also known from the Solimões Basin (Lemos, 1992b) and the Bolivian Huarina area (Grader et al., 2008).

Idiognathoides corrugatus (Harris and Hollingsworth, 1933)

Fig. 2 (7–8)

1933. *Idiognathodus corrugata* n. sp.- Harris and Hollingsworth, pp. 202–203, pl. 1, figs. 7–8.

1985. *Oxynagnathus corrugatus* (Harris and Hollingsworth).- Rocha Campos and Archangelsky, pl. 5, fig. 21.

1992b. *Idiognathoides sinuatus* Harris and Hollingsworth.- Lemos, pp. 124–125, pl. 2, fig. 2 (only).

2009. *Idiognathoides sinuatus* Harris and Hollingsworth.- Nascimento, Lemos and Scomazzon in Nascimento et al., fig. 4A.

Material: Eight P1 elements MP-M 907, 908 (poorly preserved), 921, 963, 1034, 1052 and 1291 from the Itaituba Formation (Table 1).

Remarks: Dextral P1 element with transverse ridges developed on the platform and a medial trough of variable length. One small element (sample 2, well 2-PE-2-AM) shows a short medial trough bordered by a caudal parapet supporting four nodes. It is similar to *I. attenuatus* (Harris and Hollingsworth, 1933), although the immature growth stage prevents it from is being included in the latter species.

Occurrence: *Idiognathodus corrugatus* is a wide ranging species that occurs in the lower Bashkirian and disappears in the lower Moscovian. It is known in the Brazilian Amazonas and Solimões basins (Lemos, 1992b).

Idiognathoides ouachitensis (Harlton, 1933)

Fig. 2(9)

1933. *Polygnathodella ouachitensis* n. sp.- Harlton, p. 14, pl. 4, figs. 14a–c.

1992a. *Idiognathoides sinuatus* Harris and Hollingsworth.- Lemos, pl. 3, fig. 3 and 8.

1992b. *Idiognathoides sinuatus* Harris and Hollingsworth.- Lemos, pp. 124–125, pl. 2, figs. 1 and 8 (only).

2005. *Idiognathoides sinuatus* Harris and Hollingsworth.- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 2B.

2010b. *Idiognathoides sinuatus* Harris and Hollingsworth.- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5Z.

Material: Fourteen P1 elements MP-M 911, 920, 1014–1016, 1029 (poorly preserved), 1239, 1240, 1242, 1303, 1306 and 1342 from the Itaituba Formation (Table 1).

Remarks: *I. ouachitensis* has a wider and deeper medial trough than *I. corrugatus*. It is long, but disappears at the dorsal end, where transverse ridges are developed on a short flat platform. The sinistral element is narrower than the dextral one and corresponds in part to elements included in the variation of DE *I. sinuatus*.

Occurrence: The species is known from the Cheremshannian Horizon in the Donets Basin and the upper part of the Tashastian in the South Urals (upper Bashkirian) and is common in the lower Moscovian (Nemyrovska, 1999; Kulagina et al., 2001). It is known from the uppermost Morrowan to Atokan beds in North America (Grayson, 1984; Barrick et al., 2013). In South America, *I. ouachitensis* occurs in the Amazonas and Solimões basins.

Family SWEETOGNATTHIDAE Ritter, 1986

Genus **Diplognathodus** Kozur and Merrill in Kozur, 1975

Type species. *Spathognathodus coloradoensis* Murray and Chronic, 1965

Remarks: The genus is reported from the Mississippian to middle (or late?) Permian, in accordance with the exhaustive revision carried out by von Bitter and Merrill (1990).

Diplognathodus coloradoensis (Murray and Chronic, 1965)

Fig. 2(12)

1965. *Spathognathodus coloradoensis* n. sp.- Murray and Chronic, pp. 605, 607, pl. 72, figs. 11-13.

1990. *Diplognathodus* sp.- Merino Rodo and Blanco Rojas, fig. 3d–e.

1996. *Diplognathodus coloradoensis* (Murray and Chronic).- Lemos and Medeiros, pl. 1, fig. 6.

2005. *Diplognathodus coloradoensis* (Murray and Chronic).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 2K-L.

2005. *Diplognathodus coloradoensis* (Murray and Chronic).- Scomazzon and Lemos, fig. 2A-B.

2009. *Diplognathodus coloradoensis* (Murray and Chronic).- Nascimento, Lemos and Scomazzon in Nascimento et al., fig. 4H.

2010b. *Diplognathodus coloradoensis* (Murray and Chronic).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5L.

Material: Nineteen P1 elements MP-M 926, 951–954, 1005, 1006, 1065, 1241, 1244–1246, 1304 and 1329 from the Itaituba Formation (Table 1).

Remarks: The holotype shows the oral depression with a lower denticle. Adjacent to the depression is the laterally wider denticle of the free blade. Denticles of the carina with isolated tips, and the two dorsal teeth larger, are dorsally inclined. The elements studied by Bender (1980) from the Canadian Arctic Archipelago show the fused carina teeth and the straight dorsal margin finishing before the expanded basal cavity. Merrill (1973) remarked on the probable evolution from a fully denticulate ancestor towards the fusion of the carina denticles into a spatula-like ridge.

Occurrence: Occurs from the Asatauian to the lower Solontsovian horizons in the South Urals, including the Bashkirian/Moscovian boundary (Nemirovskaya and Aleeksev, 1995). The species is in the Aegiranum Marine Band (base of the Bolsovian) in Belgium. It occurs in the Moscovian from the K_9 Limestone to the N_2 Limestone (Kashirian to Myachkovian) in the Donets Basin after Nemyrovska et al. (1999), and from the Vereian to Myachkovian in the Moscow Basin (Goreva and Aleeksev, 2001). In South America, this species is present in the Brazilian Itaituba Formation and the Bolivian Huarachani-Pacobamba section (Merino Rodo and Blanco Rojas, 1990)

Diplognathodus ellesmerensis Bender, 1980

Fig. 2 (13)

1980. *Diplognathodus ellesmerensis* n. sp.- Bender, pp. 9-10, pl. 4, figs. 5-7, 11, 15-21, 23-25.

1990. *Diplognathodus ellesmerensis* Bender.- Merino Rodo and Blanco Rojas, fig. 3f (only).

2005. *Diplognathodus ellesmerensis* Bender.- Scomazzon and Lemos, fig. 2E (only).

2010b. *Diplognathodus coloradoensis* (Murray and Chronic).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5M.

Material: Twenty one P1 elements MP-M 931, 939–943, 1007, 1059, 1061, 1064, 1203–1206, 1253, 1267–1269, 1272 and 1283 (five of them poorly preserved) from the Itaituba Formation (Table 1).

Remarks: Bender (1980) related *D. ellesmerensis* with *D. orphanus*. *D. ellesmerensis* have a larger basal cavity, a more distinct notch and denticulation than *D. orphanus*. This notch separates the ventral blade from the dorsal carina developed on the subelliptical cup. The notch consists of two to four fine denticles. The long axis of denticles converges orally. The large dorsal denticles are rounded and varying in number from 4 to 6. The third denticle from the dorsal tip is usually higher and the long axis of the dorsal denticles diverges orally. Qi et al. (2013) restricted the main characteristics of this species: the tips of the blade denticles fan out at the same level, the most dorsal denticle points towards the dorsal end, the denticulate "spatula" (dorsal portion) arches rather than delineates a lat aboral surface, and the cup is laterally flattened. The strict application of these characteristics will exclude from the species a few specimens of the original description in Bender (1980), since flattening is uncommon (see oral view of the holotype in pl. 4, figs. 23–25) and the flat aboral margin sometimes occurs in the illustrated variation.

Occurrence: *D. ellesmerensis* first occurred in the K_3 Limestone (Lozovian Horizon), above other possible index species for the Moscovian occurring in the Donets Basin (Nemyrovska, 1999). It is found in the L_4^1 Limestone in the Izvarino section, Kashirian (Fohrer et al., 2007). In South America, it occurs in the Bolivian Huarachani-Pacobamba section (Merino Rodo and Blanco Rojas, 1990) and the upper part of the Itaituba Formation in the Amazonas Basin.

Diplognathodus orphanus (Merrill, 1973)

Fig. 2(14–15)

1973. *Spathognathodus orphanus* n. sp.- Merrill. p. 309, pl. 3, figs. 45-46.

1992a. *Diplognathodus orphanus* (Merrill).- Lemos, pl. 4, fig. 6.

1992b. *Diplognathodus orphanus* (Merrill).- Lemos, pp. 127-128, pl. 3, fig. 4 (only).

1996. *Diplognathodus orphanus* (Merrill).- Lemos and Medeiros, pl. 1, fig. 5.

2005. *Diplognathodus orphanus* (Merrill).- Scomazzon and Lemos, fig. 2D (only).

2010b. *Diplognathodus orphanus* (Merrill).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5N.

Material: Twenty four elements MP-M 924–925, 933, 971, 972, 1026, 1027, 1048, 1258–1261, 1265, 1266, 1292, 1294, 1298, 1318 and 1326 from the Itaituba Formation (Table 1).

Remarks: Qi et al. (2013) considered a wider concept for this species than did other authors. They included a morphotype bearing a denticulate dorsal carina (“spathula”) that slopes towards the dorsal part, and which they differentiated as *D.* aff. *orphanus*. A transitional morphology between *D.* aff. *orphanus* and *D. ellesmerensis* (*D. orphanus* sensu lato) shows the same characteristics as *D. ellesmerensis*, except for the laterally flattened cup. A few elements in the Amazonian samples seem to be similar to this transitional morphotype (sample 5.5 m in the Calminas quarry)

Occurrence: Asatauian to the lower Imendyashevian horizons in the South Urals, including the Bashkirian/Moscovian boundary (Nemirovskaya and Aleeksev, 1995). In South America, *D. orphanus* is known from the Amazonas and Solimões basins (Lemos, 1992b) and the Bolivian Lake Titicaca region (Sakagami and Mizuno, 1994).

Diplognathodus aff. *orphanus* (Merrill, 1973)

Fig. 2(16–19)

1989. *Diplognathodus orphanus* (Merrill).- Whiteside and Grayson, pl. 1. fig. 6.

1990. *Diplognathodus ellesmerensis* Bender.- Merino Rodo and Blanco Rojas, fig. 3e (only).

1992b. *Diplognathodus orphanus* (Merrill).- Lemos, pp. 127-128, pl. 3, fig. 5 (only).

2005. *Diplognathodus orphanus* (Merrill, 1973).- Scomazzon and Lemos, fig. 2C (only).

2005. *Diplognathodus ellesmerensis* Bender.- Scomazzon and Lemos, fig. 2F (only).

2009. *Diplognathodus orphanus* (Merrill).- Nascimento, Lemos and Scomazzon in Nascimento et al., fig. 4G.

Material: Twenty three elements MP-M 929, 930, 934–938, 944, 1057, 1058, 1062, 1273, 1280–1282, 1285, 1286, 1288 and 1290 from the Itaituba Formation, well 1-CM-2-PA (samples 3 and 4) and Calminas quarry (sample 5.5).

Remarks: Short elements with a relatively expanded basal cavity. A single incipient notch is at the ventral end of the carina and at the position of the first denticle. The carina consists of 4-6 denticles, usually separated from the contiguous ones. The free blade is usually short and formed by between 3 and 7 teeth. A high and wide tooth is located proximally right at the dorsal beginning of the blade. The typical specimens of *D. orphanus* show higher teeth in the middle of the free blade, although the incipient notch can be present in some elements (see Merrill, 1973, pl. 47, figs. 49 and 52). The aboral margin is straight or slightly convex, whereas it is convex in *D. ellesmerensis*. The narrow basal cavity and the flattening cup in many of the studied specimens are similar to those shown in *D. ellesmerensis*. Some specimens with two small denticles at the position of the notch are included in *D.*

ellesmerensis in spite of the high first tooth being at the free blade. It suggests a relation between the two taxa.

The elements identified as *D. ellesmerensis* in Cardoso (2010, figs. 41, 43; Appendix A, figs. 9 and 10) from the Itaituba Formation are included in *D.* aff. *orphanus*. An element close to *D. orphanus* illustrated as *D. coloradoensis* by Savage and Barkeley (1985, fig. 12.13 to 12.16) shows a large proximal tooth at the blade. Nevertheless, it shows a wider cup and a higher number of teeth in the blade (7) than the tiny Brazilian elements.

Occurrence: Occurs in a few samples in the lowermost range of *D. ellesmerensis* in the Amazonas Basin, and is illustrated by Merino Rodo and Blanco Rojas (1990) from the Bolivian Huarachani-Pacobamba section.

Diplognathodus iowensis Swade, 1985

Fig. 2(20–21)

1985. *Diplognathodus iowensis* n. sp.- Swade, pp. 65-66, fig. 19.

Material: Four P1 elements MP-M 1084–1087 from the Nova Olinda Formation in well 9-FZ-2-AM (core sample 19).

Remarks: The presence of discrete denticles and the short platform are characteristics similar to the specimens illustrated by Swade (1985) from Iowa (USA). Four or five teeth form the ventral blade, the second proximal being higher than the other ones. Teeth of the carina outline a convex curve that may be broken by some higher denticles towards the dorsal part. An incipient notch is located before the ventral high teeth in some specimens. *Diplognathodus moorei* (von Bitter, 1972) shows a shorter platform than Amazonian specimens. One or two small teeth are located between the higher ventral teeth of the blade and the relatively high ones on the dorsal carina.

Occurrence: Swade (1985) reported this species from the lower and upper Ford Scott and the Lost Branch cyclothems, where it dominates the fauna of the Cooper Creek Limestone, in Desmoinesian beds from south-central Iowa.

Genus **Idiognathodus** Gunnell, 1931

Type species: *Idiognathodus claviformis* Gunnell, 1931

Idiognathodus aff. *claviformis* Gunnell, 1931

Fig. 2 (24)

Material: One large P1 element MP-M 1032 (core sample 4, well 2-PE-1-AM).

Description: Element with prominent lobes. The rostral lobe has a straight ventral margin, bordered by a row of strong nodes. The lobe is ornamented by nodes. The caudal lobe is triangular and the ventral margin supports a row of strong nodes. Several rows of nodes are parallel to the rostral ridges, which are low and consist of aligned nodes. The triangular tongue is ornamented by discontinuous ridges with a middle node at the position of the carina. Rostral ridges are undeveloped and replaced by rows of nodes. These ridges do not extend to the ventral blade.

Remarks: Element similar to *Idiognathodus claviformis* Gunnell, 1931 from the Putnam Hill Member in Ohio illustrated by Merrill (1974, pl. 1, fig. 6, only). As the Amazonian specimen, it shows discontinuous transverse ridges on a triangular tongue and short ventral adcarinal ridges converging dorsally toward the carina. Both have lobes ornamented by large nodes without defined orientation. The North American element shows a longer outer lobe reaching to the dorsal half of the platform, whereas the lobe is restricted to the ventral half in the studied element.

Idiognathodus claviformis holotype is from the Coal City cyclothem in the upper Desmoinesian and requires a detailed study to characterize it (Lambert et al., 2003b). The concept of *I. claviformis* is restricted to a short, wide morphotype, characterized by an oral surface with irregular nodes and ridges on the ventral part of the platform, transverse ridges on the dorsal part, and a blunt dorsal tip (Barrick and Walsh, 1999).

Occurrence: Upper part of the Itaituba Formation. The morphotype from the Putnam Hill Member is in North America Desmoinesian beds (Merrill, 1974).

Idiognathodus amplificus Lambert, 1992

Fig. 2(22–23)

1992. *Idiognathodus amplificus* n. sp.- Lambert, p. 114, pl. 2, figs. 1-12.

Material: Two P1 elements MP-M 989 and 994 from well 1-FZ-1-AM (sample 25).

Remarks: The presence of disrupted transverse ridges on the dorsal part of the platform and the incipient lobes ornamented by few nodes are characteristics described in the original material from Iowa studied by Lambert (1992). The accessory lobes drape around the distal ventral portion of the platform, especially in sinistral elements. Dextral elements have less developed accessory lobes that do not extend dorsally. The platform of *Idiognathodus amplificus* is narrow, with a pointed dorsal tip and relatively flat transverse ridges. The carina is minor to absent; the adcarinal ridges are short and terminate abruptly at the ventral-most transverse ridge.

Occurrence: The species is used to correlate lower Desmoinesian strata in North America (Lambert, 1992; Ritter et al., 2002). It ranges from the McCurtain cyclothem to the Inola cyclothem in the lower half of the Cherokee Group of the Northern American

Midcontinent (Heckel, 2013). Brazilian specimens were recovered from the upper beds of the Itaituba Formation.

Idiognathodus crassadens Stamm and Wardlaw, 2003

Fig. 2(25–29)

2003. *Idiognathodus crassadens* n. sp.- Stamm and Wardlaw, p. 114, pl. 3, figs. 1-12; pl. 4, figs. 8-9.

Material: Twelve P1 elements MP-M 1090–1092, 1095-1101 from core sample 19. Two specimens (MP-M 1113–114) are considered a close morphotype from core sample 27 (well 9-FZ-2-AM). Both samples are in the Nova Olinda Formation.

Remarks: The specimens show the typical sub-symmetrical platform, with irregular transverse ridges and denticles. The stout, irregular denticles in the inner lobe are only present in several Amazonian specimens. The two elements from core sample 27 are considered *I.* aff. *crassadens*. They have rostral ridges located at the margins of the platform and some nodes differentiated in the largest element (Fig. 3(1–2)). The dorsal platform is high and forms a convex upper curve, but transverse ridges are disrupted and interrupted by the carina. These elements are similar to several specimens of *Idiognathodus* sp. D Boardman, Heckel and Marshall, 2004 (figs. 23.24-26, 28, 29 and 31).

Occurrence: The typical *I. crassadens* is collected from the Tiawah and Russell Creek limestones (Boardman et al., 2004), which are equivalent to the Verdigris Limestone in the upper part of the Cherokee Group (Stamm and Wardlaw, 2003). The morphotype *Idiognathodus* sp. D occurs at the upper Boggy Formation (Cherokee Group) in northeastern Oklahoma and southern Kansas (Boardman et al., 2004).

Idiognathodus ignisitus Stamm and Wardlaw, 2003

Fig. 3(3–5)

2003. *Idiognathodus ignisitus* n. sp.- Stamm and Wardlaw, p. 116, pl. 1, figs. 1-15.

Material: Two sinistral and four dextral elements from well 1-RX-6-AM (sample 10, MP-M 1140–1141, 1143, 1148) and well 9-FZ-2-AM (sample 19, MP-M 1093–1094). Another two dextral elements are considered as probably belonging to this species (MP-M 1109–1110, sample 27, well 9-FZ-2-AM). All samples come from beds in the Nova Olinda Formation.

Remarks: The sinistral elements show a wider platform than does the dextral one, as in the material described by Stamm and Wardlaw (2003). These authors indicated that the species evolved from *I. obliquus* through the wide sinistral elements, the rounder dorsal end, and the narrowing of lobes. The dextral elements are narrow. The Amazonian specimens show interruptions in the transverse ridges of the dorsal platform, whereas those described by Stamm and Wardlaw (2003) only usually have the more dorsally located transverse ridges broken. Two elements from sample 27 are assigned to *I.* cf. *ignisitus* because they show a long row of nodes on the long and narrow rostral lobe, whereas the shorter, wider caudal lobe supports two rows (Fig. 3(6–7)). The rostra are composed of two ridges with a sinusoidal disposition: the narrower area is at the dorsal end, but ridges curve outwards on the tongue. This pattern only occurs in some elements of the type material from Utah (Stamm and Wardlaw, 2003, pl. 1, figs. 12, 13 and 15). The Amazonian elements has a concave tongue with a depressed longitudinal, central area that differentiates them from the North American material, where the more dorsal transverse ridges are only interrupted in some elements (Stamm and Wardlaw, 2003, pl. 1, figs. 1-5, 7-8). *I.* cf. *ignisitus* are close to *Idiognathodus* sp. A Boardman et al. (2004, fig. 3.6-7, 20-22) and *I. podolskiensis* (fig. 2.1), although the

Amazonian elements have a long rostral row of nodes. This row of nodes is present in a few elements in the variability of the upper Atokan *Idiognathodus gibbus* Lambert, 1992, although this species develops a smaller caudal lobe and a more concave tongue than *I.* cf. *ignisitus*. Finally, *I. ignisitus* may be a junior synonym of *Idiognathodus mundulus* Youngquist and Downs (1949, p. 167, pl. 31, figs. 16-17), though a detailed description and re-illustration of type material is necessary to confirm this, and our concept of this species follows that developed by Stamm and Wardlaw (2003).

Occurrence: The type material is from the Verdigris cyclothem, according to Barrick et al. (2013). *I. ignisitus* comes from the Upper Tiawah cyclothem (Heckel, 2013), whereas *I. mundulus* occurs in the Verdigris cyclothem.

Idiognathodus incurvus Dunn, 1966

Fig. 3(8–9)

1966. *Idiognathodus incurvus* n. sp.- Dunn, p. 1301, pl. 158, figs. 2, 3.

2009. *Idiognathodus incurvus* Dunn.- Nascimento in Nascimento et al., fig. 4B, C and E?.

2010b. *Idiognathodus incurvus* Dunn.- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5B (only).

Material: Twelve elements MP-M 945, 1011–1013, 1028, 1044–1045, 1123, 1257, 1263, 1271, 1272,1314 and 1316, 1324 (six doubtful small elements) from the Itaituba Formation (Table 1).

Remarks: The long axis of the conodont curves towards the caudal side near the dorsal end. The rostral margin of the platform is strongly convex, whereas the caudal margin is straight to slightly concave. Hence, the dorsal end is caudally curved, whereas the oral surface is flat. The tongue of the platform has a shallow trough or concavity extending from the dorsal tip to approximately the mid-point of tongue. The lobes are composed of 2 or 3 rows of nodes located on both sides of the ventral part of the platform. The caudal ridge is well developed, the rostral ridge being shorter than the caudal.

Grayson et al. (1989) used the *I. incurvus* Complex for a wide range of morphological variability broadening the original concept of Dunn (1966). The main characteristic is the ventral projections of the adcarinal ridges forward the free blade forming a downward extension. This concept seems to include morphotypes that other authors consider descendants of *I. incurvus* (Barrick et al., 2004).

Occurrence: *I. incurvus* is described in the uppermost Bashkirian of the Donets Basin (Nemyrovska, 1999) and ranges through the North American Atokan beds (Barrick et al., 2004).

Idiognathodus itaitubensis nov. sp.

Fig. 4(1-16)

1974. *Idiognathodus* cf. *delicatus* Gunnell.- Merrill, pl. 1, figs. 14-16 (only).

1984. *Idiognathodus delicatus* Gunnell.- Grayson, pl. 1, fig. 1, pl. 3, figs. 2; pl. 4, figs. 7-8 (only).

1984. *Streptognathodus* sp. aff. *S. wabaunsensis* Gunnell.- Grubbs, pp. 71–72, pl. 1, figs. 8–11.

1985. *Idiognathodus* sp. A.- Grayson, Trice and Westergaard, pl. 1, figs. 52, 56.

1985. *Idiognathodus suberectus* Dunn.- Rocha Campos and Archangelsky, pl. 5, fig. 20.

1990. *Idiognathodus incurvus* Dunn.- Grayson, pl. 4, figs. 4-5 (only).

1992a. *Idiognathodus suberectus* Dunn.- Lemos, pl. 2, figs. 2a-c.

1992a. *Streptognathodus expansus* Igo and Koike.- Lemos, pp. 81-82, pl. 3, fig. 4 (only).

1998. *Idiognathodus incurvus* Dunn.- Rexroad, Brown, Devera and Suman, pl. 1, figs. 20, 23, 24, 27, 28, 29, 30, 31.

2004. *Idiognathodus incurvus* Dunn descendants.- Barrick, Lambert, Heckel and Boardman, pl. 2, figs. 3 and 5 (only).

2004. *Idiognathodus podolskiensis*.- Boardman, Heckel and Marshall, fig. 2.1, 3.

2004. *Idiognathodus* n. sp. B nomen nudum.- Boardman, Heckel and Marshall, fig. 2.2, 16.

2009. *Idiognathodus incurvus* Dunn.- Nascimento et al., fig. 4C.

2009. *Idiognathodus incurvus* Dunn.- Lucas, Krainer and Barrick, fig. 14.6-7.

Derivation of the name: From the Itaituba Formation, where it was collected.

Holotype: Specimen MPM-974 (Fig. 4(7) and seven specimens MP-M 973, 975–976, 978–980 and 990 are paratypes (Fig. 4(6, 8–13).

Material: Twenty seven (four poorly preserved) P1 elements MP-M 946–948, 950, 973–988, 990, 991, 993, 1013, 1049, 1076–1077, 1105–1107, 1117, 1119, 1130–1135, 1188 from the Itaituba and Nova Olinda formations (Table 1).

Type Locality and horizon: Sample from core 25 in well 1-FZ-1-AM, included in the upper part of the Itaituba Formation (geographic coordinates 03º 43' 35.4" S and 58º 57' 03.1" W).

Diagnosis: P1 element with a sub-rhomboidal field of transverse ridges, which show a longitudinal depression usually interrupting these ridges. Carina and rostra ridges are at or close to the mid-point of the platform. Adcarinal grooves extend ventrally to reach to the blade, particularly the caudal one. Incipient rostral lobe usually supports a few nodes, whereas the caudal one being wider, is ornamented by one or more rows of nodes.

Description: The elements have a curved platform where the outline changes due to the caudal lobe protruding. A very characteristic twofold sinusoidal disposition is visible from the rostra ridges and the margins of the tongue. It is poorly developed only in smaller specimens, which are similar to the *Idiognathodus sinuosus* morphology. The carina and the rostra ridges often correspond to larger nodes on the margins and central part of the proximal tongue. The latter supports a field of transverse ridges (between seven and thirteen), usually interrupted (or depressed) in the subcentral to caudal portion. Thus, a short eccentric to central trough may be present. The oral surface of the tongue is more or less concave, with a longitudinal depression. The rostral lobe is not differentiated from the platform and supports one node or a row of 3 to 4 nodes. None develop in the smallest size elements. The rostral lobe shows a lower platform margin than the caudal lobe. The latter is prominent and usually bears a row of nodes, or a second row of nodes in larger specimens, bears. The largest elements include a third row of two nodes adjacent to the margin. Lobe ornamentation seems to increase in elements from younger beds.

The rostra ridges are well developed and project outwards away from the free blade, particularly the caudal one. The element from the lower beds (sample 34, well 1-FZ-1-AM) shows a caudal lobe differentiated and ornamented by one or two rows of a few nodes each and a less curved sinusoidal disposition for rostra ridges and the tongue (Fig. 4(15)). The protruding adcarinal extensions are situated a short distance along the free blade.

Remarks: The new species is very closely related to *I. incurvus* Dunn (1996), in fact it closely resembles those North American elements illustrated as “*I. incurvus* descendents” by Barrick et al. (2004). Typical specimens of *I. incurvus* do not show the sinusoidal and rhomboidal tongue, a triangular tongue being present in its place. The ventral margin of the rostral platform is straight as it is in the new species, and ornamentation of the rostral margin is poorly differentiated from the rostral ridge, since this rostral part of the platform is at the same height as the caudal one (no lower). The typical elements of *I. incurvus* show a shallow longitudinal depression along the dorsal half of the tongue, which becomes longer and deeper in *I. itaitubensis*. One element from sample 34 (Fig. 4(15)) shows a higher rostral lobe, carina and rostral ridges replaced dorsally by rows of nodes and a concave tongue where transverse ridges consist of short segments or nodes, as in *I. klapperi*.

Another closely related species is *Idiognathodus ellisoni* Clark and Behnken, 1971. It shows long adcarinal ridges extending ventrally to the free blade and converging dorsally toward the carina, they do in *I. itaitubensis*. A middle trough or depressed area occurs in the tongue and becomes shallower in large specimens. It differs from *I. itaitubensis* in having shorter lateral lobes, which are ornamented by strong nodes on flat oral surfaces. These surfaces are distally curved and decrease in height toward the margins in *I. itaitubensis*.

Idiognathodus sp. A Grubbs, 1984 shows some widely spaced, oblique transverse ridges on the tongue. The ridges have differentiated nodes at the location of the carina in the ventral part of the tongue (Fig. 3(21).

Idiognathodus covandogae Méndez, 2006 is a related morphology, probably younger than most of the studied elements. It shows the subcentral depression of the tongue, but no interruption of the transverse ridges. The platform is slender and adcarinal extensions are somewhat longer than those of *I. itaitubensis*. The rostral lobe is located at a similar height to the caudal one, and the carina and rostra ridges are limited to the ventral half of the platform.

Occurrence: Upper part of the Itaituba Formation to the lower part of the Nova Olinda Formation in the Amazonas Basin (Moscovian) and the Solimões Basin. The specimens from Oklahoma described by Grubbs (1984) were collected in upper Atokan to basal Desmoinesian beds.

Idiognathodus izvaricus Nemyrovska, 2007

Fig. 3(10–12)

2007. *Idiognathodus izvaricus* n. sp.- Nemyrovska in Fohrer et al., p. 9, figs. 13.3–13.17, 14.1–14.20.

Material: Eight P1 elements MP-M 967–969, 994, 1008, 1051, 1116 and 1120 (Table 1).

Remarks: Specimens show transverse ridges as in Morphotype 1 differentiated by Nemyrovska in Fohrer et al. (2007). Two elements have one node at the rostral margin, and a few nodes or radial transverse ridges in the small caudal lobe. The P1 element from sample 16 (well 2-MN-1-AM) (Fig. 3(12)) is close to *I. rectus* Youngquist and Downs, 1949 from North America. However, the straight longitudinal platform and, particularly, the ventrally extended adcarinal grooves and carina, which reach the mid platform, are more dorsally extended that in *I. rectus*. Small elements from sample 10 with long carina and poorly developed lobes resemble Morphotype 2 of Nemyrovska in Fohrer et al. (2007). *Idiognathodus izvaricus* Morphotype 1 is close to ‘*Streptognathodus*’ *parvus* Dunn, 1966 in having a poorly developed lobe and the transversely ridged posterior platform, but differs from the latter in the former’s more advanced shape of the ventral margin of the platform, the dorsally located caudal lobe, and the occurrence of a rostral lobe in some specimens.

Occurrence: The upper half of the Lozovaian to the base of the Lomovatkaian (lower Moscovian), which is $C2^6$ (L) suite and the base of the $C2^7$ (M) suite (Fohrer et al., 2007). It occurs in the upper part of the Itaituba Formation and the lower part of the Nova Olinda Formation.

Idiognathodus cf. *klapperi* Lane and Straka, 1974

Fig. 3(13)

Material: Two fragments of P1 elements from wells 1-CM-2-PA (sample 1, MP-M 923) and 2-CP-2-PA (sample 21, MP-M 958) from the Itaituba Formation.

Remarks: Lane and Straka (1974) considered the discontinuous transverse ridges in the tongue of the P1 element as the prevalent characteristic of this species, but Grayson et al. (1990) widely extended the concept of this species. They considered that the adcarinal ridges are within the platform and both extend ventrally about the same distance. The lateral lobes are well developed in mature specimens, the rostral lobe shows an elaborated rostral margin, and isolated nodes are situated at the ends of the adcarinal ridges.

A few specimens of *I. incurvus* previously illustrated from the Amazonas Basin are tentatively assigned here to *I. klapperi* (Nascimento et al., 2005, figs. 2A?, F; Nascimento et al., 2010b, fig. 5A, only).

Occurrence: Occurs rarely in the upper Morrowan and lower Atokan (Grayson, 1990; Barrick et al., 2004).

Idiognathodus cf. *obliquus* Kossenko and Kozitskaya, 1978 in Kozitskaya et al.

Fig. 3(15–16)

Material: Eight small or broken elements MP-M 1072–1073, 1075–1076, 1078–1080, 1102, 1104 from wells 1-FZ-1-AM (sample 17) and 9- FZ-2-AM (sample 27) in the Nova Olinda Formation.

Remarks: Some poorly preserved elements may be included in this species, since they show many transverse ridges developed in the dorsal platform and clearly oblique to the margins. The dextral element is more strongly curved than the sinistral pair when wiewed orally, as Ritter et al. (2002) indicated and, consequently, oblique transversal ridges are more developed in the former. Small elements have a concave oral surface. The rostral lobe may be long and composed of a few rows of nodes.

Occurrence: *I. obliquus* occurs in the North American lower Desmoinesian (Lambert, 1992; Ritter et al., 2002; Heckel, 2013). It is common in the Moscovian, from the Kashirian to basal Podolskian in the Moscow Basin (Goreva and Alekseev, 2001) and the Podolskian to lower Myachkovian in the Donets Basin (Nemyrovska et al, 1999).

Idiognathodus podolskiensis Goreva, 1984

Fig. 3 (17–18)

1984. *Idiognathodus podolskiensis* n. sp.- Goreva, p. 108, pl. 2, figs. 23-27.

2004. *Idiognathodus podolskiensis* Goreva.- Boardman, Heckel and Marshall, figs. 3.3–5).

Material: Seven P1 elements from well 9-FZ-2-AM (sample 27; MP-M 1108, 1111, 1112 and 1115) and 1-RX-6-AM (sample 10, MP-M 1142, 1144 and 1145) in the lower part of the Nova Olinda Formation.

Remarks: *I. podolskiensis* resembles *I. obliquus*, but can be distinguished from the latter by the depressed dorsal part of the ribbed platform (Nemyrovska et al., 1999). Amazonian elements are poorly preserved and support mineral overgrowth. They show the characteristic depressed field of transverse ridges, particularly in small and middle sized specimens. The rostra ridges are well developed, especially the flaring caudal ridge. Two long, moderately prominent accessory lobes are found on either side of the platform. The rostral is narrow and similar to middle-sized elements from Alekseev and Goreva, 2001, pl. 18, figs. 4 and 7). Elements closely resemble several specimens of *I. podolskiensis* from the North American Inola Limestone illustrated by Boardman et al. (2004).

*Idiognathodus itaitubensis s*hows a similar rostral lobe, but shorter and lower than that of *I. podolskiensis*. Furthermore, the sinusoidal disposition of the rostral ridges and its continuity in the margins of the tongue is not present in *I. podolskiensis*, in which the outline of the tongue is subrectangular to subtriangular.

Occurrence: The taxon occurs in the *N. medexultimus*–*I. podolskiensis* and *N. inaequalis* zones (Podolskian–lower Myachkovian) of the Moscow Syneclise (Goreva and Alekseev, 2001). A close morphotype is reported from the North American Desmoinesian Sam Creek to Inola cyclothems (Barrick et al., 2013; Heckel, 2013).

Idiognathodus cf. *praeobliquus* Nemyrovska, Perret-Mirouse and Alekseev, 1999

Fig. 3(19)

Material: Two elements from wells 2-CP-PA (core sample 2, MP-M 949) and 1-FZ-1AM (sample 34, MP-M 1010) in the upper part of the Itaituba Formation.

Remarks: P1 element with moderately broad, lanceolate, slightly asymmetrical, caudally curved dorsal platform. Two unequal lobes are developed, the rostral being less prominent than in *I. obliquus*, to which it probably gave rise (Nemyrovska et al., 1999). Consequently, it has a more symmetrical platform than *I. obliquus*. The transverse ridges of the dorsal platform are oblique, but less so than in *I. obliquus*. Furthermore, the latter species has an asymmetrically arched platform in lateral view. *I. praeobliquus* shows an advanced ventral margin of the platform, with well developed rostra projecting outwards towards the free blade from the ventral platform margin.

The Amazonian elements have a similar disposition to *I. itaitubensis* nov. sp., but with a flat or slightly depressed oral surface of the tongue. Furthermore, they develop lateral lobes, forming a more symmetrical platform. In any case, the transverse ridges are slightly contorted in the central platform by the presence of the slight depression. The rostral lobe is incipient and ornamented by nodes as high as those in the caudal lobe. The material type illustrated shows a higher number of transverse ridges and a stronger curvature of the platform than do the Amazonian specimens. They are similar to North American *I. praeobliquus* in Boardman et al. (2004), where some elements show a concave oral surface of the ribbed platform.

Occurrence: *I. praeobliquus* is present in the Kashirian beds of the Moscow basin (Alekseev and Goreva, 2013). It occurs in the upper part of the C_2^5 (K) Suite (Vereian) in the Donets Basin and reaches the lower part of the C_2^7 (M) Suite (lower Podolskian) according to Nemyrovska et al. (1999) and Fohrer et al. (2007). A similar morphotype (*I.* cf. *praeobliquus*) is present in the Atokan beds of Iowa and the Desmoinesian McCurtain cyclothem of the Cherokee Group in Oklahoma (Boardman et al., 2004; Barrick et al., 2013).

Idiognathodus rectus Youngquist and Downs, 1949

Fig. 3(20)

1949. *Idiognathodus rectus* n. sp.- Youngquist and Downs, pp. 167-168, pl. 30, figs. 21-23 (holotype re-illustrated in Barrick, Lambert, Heckel, Roscoe and Boardman, 2013, pl. 2, fig. 8).

Material: On element MP-M 1103 of medium sized in well 1-FZ-1-AM (core sample 27, Nova Olinda Formation).

Remarks: The platform and blade are exceptionally straight. The former is ornamented by transverse ridges. The element is longer and shows a more extended tongue than does the holotype. The Amazonian elements closely resemble small elements of *I. robustus* Kossenko and Kozitskaya, 1978 in Stamm and Wardlaw (2003), although we consider they belong to *I. rectus*. This species has a straight, relatively symmetrical oval platform with minimal lobes, and coarse transverse ridges, whereas the morphotype close to *I. robustus* has a platform that is slightly bent caudally and a shorter ventral extension of adcarinal ridges, in accordance with Barrick et al. (2013).

Occurrence: *I. rectus* is a species abundant in the *I. rectus*/*I. iowaensis* Zone of Barrick et al. (2013), which encompasses the middle and Upper Cherokee Group in the middle Desmoinesian of North America. Heckel (2013) extended it from the Inola cyclothem to, probably, the Bevier cyclothem.

Idiognathodus cf. *sinuosus* Ellison and Graves, 1941

Fig. 13(14)

Material: Four small specimens and fragments from wells 2-MN-1-AM (sample 24, MP-M 1124), 1-TR-1-AM (sample 14, MP-M 1053) and the Calminas quarry (samples 5.02 and 5.5, MP-M 1289 and 1317) in beds of the Itaituba Formation.

Remarks: Sinistral and dextral elements of this taxon are *Idiognathodus humerus* and *I. sinuosus*, respectively (Dunn, 1970). The dextral element has developed a caudal ridge that borders the small ornamented caudal lobe. The rostral margin is high and corresponds to the rostral wall parallel to the carina. One to several nodes may be at the margin, at the location of the rostral lobe. The platform is curved, with a flat to concave tongue. The caudal lobe is parallel to the carina and incipient to protruding. The small size and bad preservation prevents accurate identification of the Amazonian specimens. Some elements could well correspond to immature stages on the growth of younger related species.

Occurrence: *I. sinuosus* is a Morrowan North American species that reaches the Atokan (Lane and Straka, 1974; Grayson, 1990). It is in the Prikamian Horizon of the Donets Basin (Nemyrovska, 1999) and the Askynbashian Horizon of the South Urals, indicating a range from the middle Bashkirian to the lowermost Moscovian in the Moscow, Donets and South Urals basins.

Idiognathodus nov. sp. 1

Fig. 3(22–23)

Material: Two elements MP-M 959–960 from sample 21 in well 2-CP-2-PA.

Diagnosis: P1 element with a long carina and narrow adcarinal troughs, only deep in the ventral portion of the platform. Two rows of transverse ridges are located on both margins of the platform. Transverse ridges are subdivided into two wider rows of nodes at the ventral part of the caudal platform where a lateral lobe is incipient.

Description: The P1 elements have a subsymmetrical platform without lobe development, except a short caudal lobe, slightly wider than the caudal platform. Only the caudal lobe shows two differentiated rows of nodes aside from the carina and consequently, a short caudal rostra ridge occurs. The rest of the platform margins are ornamented by short transverse ridges, which are similar, or higher than the central carina. The rostral margin supports one to a few nodes. Narrow adcarinal troughs only occur at the ventral platform, and the carina is composed of isolated nodes aligned with the transverse ridges in the dorsal platform. The carina reaches the dorsal end of the platform.

Remarks: The ornamentation distribution is similar to *I. klapperi*, although lobes are not developed. The elements are similar to the specimen illustrated as *Idiognathodus* spp. by Higgins (1975, pl. 17, fig. 8).

Occurrence: Lower part of the Itaituba Formation. Specimens related to the Amazonian ones were collected in the English Yeadonian (late Bashkirian), according to Higgins (1975).

Genus *Streptognathodus* Gunnell, 1933

Type Species: *Streptognathodus excelsus* Stauffer and Plummer, 1932

Remarks: After diagnosis from the species type, Ellison (1941, 1972) gave a revised diagnosis for *Streptognathodus*. This genus differs from *Idiognathodus* in having a deep medial trough between the parapets. This trough may be crossed by the carina along most of its length. Consequently, only a few continuous transverse ridges can be developed. Barrick and Boardman (1989), Barrick et al. (1999) considered the Bashkirian-early Moscovian streptognathodids as derived from *Idiognathodus* and unrelated to the younger middle Missourian (Kasimovian) species of true *Streptognathodus*. Several authors included all of them in *Idiognathodus*, since elements of the apparatuses other that P1 ones are similar (Baesemann, 1973; Merrill and von Bitter, 1976). Furthermore, part of the separate derivation of older species with morphology of '*Streptognathodus*' in the later part of the Desmoinesian is included in the genus *Swadelina* Lambert, Heckel and Barrick, 2003a. Nemyrovska (2011) incorporated in this new genus some species of late Moscovian from east Europe that could be derived from '*Stretognathodus*' *transitivus*, or from *Idiognathodus izvaricus*, according to Nemyrovska (in Fohrer et al., 2007). Here, older Bashkirian streptognathids remain as '*Streptognathodus*', waiting for their phyllogenetic relationship to be clarified.

Streptognathodus firmus Kozitskaya, 1978

Fig. 3(24–25)

1978. *Streptognathodus firmus* n. sp.- Kozitskaya in Kozistkaya, Kossenko, Lipnygov and Nemirovskaya, pl. 28, figs. 1-6.

Material: One broken sinistral P1 element MP-M 1183 from well 9-FZ-2-AM (sample 7) and another poorly preserved MP-M 1118 from well 9-FZ-28-AM (core sample 183) in the upper part of the Nova Olinda Formation.

Description: One element has nodes on the parapets and a long carina, which reaches the dorsal end of the platform. The caudal parapet longer than the rostral and the ventral end located more ventrally than that of the rostral parapet. Another specimen is a broken sinistral element where only the dorsal part is preserved, and consequently the determination is doubtful. It is a probably a specimen where the carina grades dorsally to isolated nodes. The carina reaches close to the dorsal margin of the platform. The transverse ridges on the parapets are very short, perhaps in relation to the deep adcarinal troughs and small size of the element.

Occurrence: *Streptognathodus firmus* occurs in the Kasimovian of the Donets Basin and Dnieper-Donets Depression and the Gzhelian of Timan, according to Kozitskaya et al. (1978). Barrick et al. (2004) indicated a range from the late Missourian to the middle Virgilian in Midcontinent North America.

Streptognathodus sp.

Fig. 3 (26–27)

Material: Two elements MP-M 1128–1129 and one fragment MP-M 1197 from core sample 4 in well 1-NO-1-AM.

Description: Elements with a sub-symmetrical platform, slender and with the widest part close to the ventral end. Platform supports two long parapets, the caudal slightly higher and longer than the rostral. The ornamentation of the parapets consists of strong nodes, which cause shallow, narrow adcarinal troughs. The nodes are fused to the carina to form a transverse ridge at the dorsal end of the platform. The carina is only higher than the parapets at this dorsal end.

Occurrence: This occurs in the upper part of the Nova Olinda Formation.

'*Streptognathodus*' *expansus* Igo and Koike, 1964

Fig. 5(1–2)

1964. *Streptognathodus expansus* n. sp.- Igo and Koike, p. 189, pl. 28, fig. 14.

1966. *Streptognathodus suberectus* n. sp.- Dunn, p. 1303, pl. 157, figs. 4-6.

1992a. *Streptognathodus expansus* Igo and Koike.- Lemos, pp. 81-82, pl. 3, fig. 5 (only).

1992a. *Idiognathodus suberectus* Dunn.- Lemos, pp. 80-81, pl. 3, fig. 7.

1992a. *Streptognathodus expansus* Igo and Koike.- Lemos, pp. 81-82, pl. 4, figs. 7-8

Material: Seven P1 elements from well 2-MN-1-AM (sample 24, MP-M 1122) and the Calminas quarry (samples 6.6, 14.2, 14.6 and 14.8; MP-M 1071, 1296, 1209, 1300, 1310 and 1327).

Remarks: Dunn (1970) suggested that the sinistral element of *Streptognathodus expansus* and the dextral element of *Streptognathodus suberectus* are part of the same apparatus, based on the similar stratigraphic occurrences. Proctor (1991, unpublished) assumed this reconstruction and identified three morphotypes in the Dimple Limestone (North America) showing an increase on the complexity of dextral elements. Qi et al. (2013) described a primitive form of *S. expansus* in the Dizazinshang section that Qi et al. (2011) had informally named ‘*S. preexpansus*’.

Occurrence: *S. expansus* is an upper Bashkirian species that has its first occurrence in the *I. sinuosus* Zone, according to Lane and Straka (1974). It disappears in the *I. tuberculatus*-*I. fossatus* Zone or below the occurrence of *D. marginodosus* and *I. incurvus* in the Donets

Basin (Nemyrovska, 1999). It ranges over an equivalent interval of the South Urals, between the Askynbashian and the Tashastian horizons (Nemirovskaya and Alekseev, 1995; Kulagina et al., 2001). It occurs in the Monte Alegre and Itaituba formations in the Amazonas Basin (Lemos and Medeiros, 1996; own data), and the upper range seems to be similar in South China, where it reaches the lower Moscovian (Qi et al, 2013).

‘*Streptognathodus*’ *parvus* Dunn, 1966

Fig. 5(4)

1966 *Streptognathodus parvus* n. sp.- Dunn, pp. 1302-1303, pl. 158, figs. 9-10.

1992a. *Streptognathodus parvus* Dunn.- Lemos, p. 81, pl. 2, figs. 3-5.

Material: Four elements and two more poorly preserved (MP-M 903, 1043, 1046, 1125 and 1329) from wells 1-AM-9-AM (core sample 9), 2-MN-1-AM (sample 24), 2-SA-1-AM (sample 10) and the Calminas quarry (sample 14.8).

Remarks: The largest element shows a small node located on the middle slope of the rostral margin. Two or three nodes are located at the incipient step of the caudal lobe.

Occurrence: The $C_2$2(G) to C_2^5 (K) suites (Cheremshanian to the lower Lozovian horizons) of the upper Bashkirian to the lower Moscovian in the Donets Basin or *S. expansus* to *D. donetzianus* zones after Nemyrovska (1999). It occurs in the Tashastian to the Asatauian horizons in the South Urals of the upper Bashkirian (Nemirovskaya and Alekseev, 1995; Kulagina et al., 2001). Dunn (1966) reported it from North American localities with *I. sinuosus*. It occurs in the Monte Alegre and Itaituba formations of the Amazonas Basin (Lemos and Medeiros, 1996; own data) and in the Solimões Basin (Lemos, 1992a).

Genus **Neognathodus** Dunn, 1970

Species type: *Polygnathus bassleri* Harris and Hollingsworth, 1933

Neognathodus bassleri (Harris and Hollingsworth, 1933)

Fig. 5(4)

1933. *Polygnathus bassleri* n. sp.- Harris and Hollingsworth, p. 198, pl. 1, figs. 13a-e (re-illustrated in Barrick, Lambert, Heckel and Boardman, 2004, pl. 1, fig. 11).

1992a. *Neognathodus bassleri* (Harris and Hollingsworth).- Lemos, pp. 84, 86, pl. 3, fig. 2a-b.

Material: Two elements from the Monte Alegre and Itaituba formations in wells 1-AM-7-AM (sample 9, MP-M 1165) and 2-CA-1-AM (sample 6, MP-M 917).

Remarks: According to Merrill (1972), *Neognathodus bassleri* has wide platforms with widely flaring parapets, generally higher than the carina (Lane, 1967), which does not usually extend to the dorsal junction of the parapets. Later forms are narrower, more symmetrical, but still retain high and somewhat flaring parapets (Lane, 1967; Grayson, 1984).

Occurrence: *N. bassleri* is an upper Morrowan species in North America (Barrick et al. 2013), where it is very common. It occurs in the Monte Alegre and Itaituba formations of the Amazonas Basin.

Neognathodus asymmetricus (Stibane, 1967) sensu Barrick, Lambert, Heckel and Boardman, 2004

Fig. 5(6–8)

2004. *Neognathodus asymmetricus* Stibane.- Barrick, Lambert, Heckel and Boardman, pl. 1, fig. 1 (re-illustrated in Barrick, Lambert, Heckel, Roscoe and Boardman, 2013, pl. 1, fig. 3).

Material: Four elements MP-M 1051, 1146, 1147 and 1183 from well 1-RX-6-AM (core samples 10, 16 and 24).

Remarks: Stamm and Wardlaw (2003) included the species of Merrill's (1972) *N. medadultimus* and *N. medexultimus* in *N. asymmetricus* (Stibane, 1967), since morphologies correspond to different growth stages in their samples. Barrick et al. (2004, 2013) confirmed this synonym in North American collections. However, both morphotypes could have been different species. The Colombian material type includes a holotype with distinct morphology and sample provenance with respect to others specimens whose morphology is close to that described in North America. The holotype (Stibane, 1967, pl. 36, figs. 11-13) shows high parapets with a crenulated margin, and deep adcarinal troughs. The carina is high in its ventral portion, then becoming lower and finally disappearing before the dorsal tip. The platform outline is biconvex, although the caudal margin is slightly sinuous to straight. Other specimens from the Páramo de Sumapaz (sample 95) distinct from the holotype of *N. asymmetricus* (Stibane, 1967, pl. 36, figs. 14-18), show lower parapets and a reduced rostral half of the platform and seem to be similar to *N. medexultimus* Merrill, 1972.

Two Amazonian specimens are similar to the morphotype *N. medadultimus* and show a shorter development of the rostral parapet, which begins slightly more dorsally than the caudal parapet (Fig. 5(8)). Another two younger elements have both parapets finishing slightly before the dorsal tip of the platform. The carina protrudes from beyond the platform and short transverse ridges are formed by lateral nodes (Fig. 5(6)). This characteristic occurs in *N. roundyi* (Gunnell, 1931), a probable descendant in which the rostral parapet is less developed.

Occurrence: In South America, this species is known from the Colombian Cordillera Oriental (Stibane, 1967), the Bolivian Titicaca region (Sakagami and Mizuno, 1994) and the Nova Olinda Formation in the Amazonas Basin. *Neognathodus asymmetricus* in the sense of Barrick et al. (2004) is a Desmoinesian species with a probable occurrence at the Sam Creek cyclothem (Boardman et al. 2004) and a range from the Inola cyclothem to the Fleming cyclothem (Barrick et al., 2013).

Neognathodus bothrops Merrill, 1972

Fig. 5(9)

1972. *Neognathodus bothrops* n. sp.- Merrill, p. 823, pl. 1, figs. 8-13 (only).

Material: Two P1 elements and two probable ones (MP-M 998–999, 1001–1002) from well 1-FZ-1-AM (core sample 25, upper part of the Itaituba Formation).

Remarks: *N. bothrops* has a relatively symmetrical P1 element and an outline more oval than *N. colombiensis*. Typical elements show a smooth to slightly crenulated area at the ventral end of the parapets. The carina is sub-central and slightly shifted towards the rostral parapet. Both parapets are fused to the dorsal end of the carina, but a pointed tip of the carina is already visible. *N.* '*bothrops*' Grayson, 1990, nomen nudum has a more asymmetrical platform, with a narrow rostral part ornamented by short transverse ridges and flared caudal platform supporting longer and radial ridges (Grayson, 1990, pl. 4, figs. 17-19). Barrick et al. (2013) indicated that this species included some morphotypes integrated in the temporal sequence of Grayson (1990) from *Neognathodus* '*pre-bothrops*' nomen nudum, *N.* '*bothrops*' nomen nudum and *N. bothrops*.

Occurrence: *N. bothrops* occurs in the Atokan to lower Desmoinesian (Merrill, 1972; Barrick et al. 2013). In the Moscow basin, it is present from the basal Kashirian Russian Horizon in the Moscow Basin (Alekseev and Goreva, 2013).

Neognathodus colombiensis (Stibane, 1967)

Fig. 5(10–12)

1967. *Streptognathodus colombiensis* n. sp.- Stibane, pp. 336-337, pl. 36, figs. 1-10.

Material: Five elements MP-M 995–996, 1000, 1003–1004 from drilling hole 1-FZ-1-AM (core sample 25).

Remarks: Elements with a sub-symmetrical platform, relatively flat and with a triangular outline. They are ornamented by transverse ridges that may extend to the carina, and adcarinal troughs are short and shallow.

They are ventrally differentiated in North American illustrated specimens (Barrick et al., 2004, pl. 1, fig. 10) from the Seville Limestone (Illinois). This characteristic could be insufficient to differentiate this morphotype from the specimens from our material and the illustrated elements of Stibane (1967) since it is not present in the specimens designated *Neognathodus* sp. A from the Seville Limestone in Merrill and King (1971, pl. 76, figs. 7-10). The carina protrudes from the expanded platform and at the same height as or higher than the lateral parapets. Barrick et al. (2013) included the sequence of Grayson (1990) of *N.* '*pre-bothrops*', *N.* '*bothrops*' and *N. bothrops* Merrill in *N. colombiensis*, but all these morphotypes should be subjected to an exhaustive revision to characterize the variability of these species.

Occurrence: Nevado River in the Colombian northern Andes (Stibane, 1967) and the Seville Limestone in Illinois (Barrick et al, 2004) in beds considered to be from the late

Atokan to the early Desmoinesian (*N. colombiensis* Zone). Studied specimens come from the upper beds of the Itaituba Formation.

Neognathodus inaequalis Kozitskaya and Kossenko, 1978

Fig. 5(13)

1978. *Neognathodus inaequalis* n. sp.- Kozitskaya and Kossenko in Kozitskaya et al., p. 74, pl. 20, figs. 1-8.

2003. *Neognathodus intrala* n. sp.- Stamm and Wardlaw, p. 119, pl. 4, figs. 5 and 11; pl. 5, figs. 1-7.

Material: Two elements MP-M 1088–1089 from well 9-FZ-2-AM (sample 19, Nova Olinda Formation).

Remarks: The specimens show a symmetrical platform. This symmetry is greater than that of North American *N. intrala* Stamm and Wardlaw (2003), but the smallest elements show moderate asymmetry. The carina decreases in height from the middle platform to the dorsal part, where it is similar in height to, or lower than the lateral parapets. The margin of the rostral parapet is smoother than the caudal one or is widely crenulated. Adcarinal grooves developed at the ventral portion and may be extended dorsally. *Neognathodus intrala* morphotype seems to be included in the variation of *N. inaequalis,* although this should be confirmed.

Occurrence: *N. inaequalis* ranges from the upper Podolskian to the lower Myachkovian regional stages (Moscovian) in the Moscow Basin, according to Goreva and Alekseev (2001). *N. intrala* is associated with *N. roundyi* in the middle to upper Desmoinesian of North America (Barrick et al., 2013).

Neognathodus symmetricus (Lane, 1967)

Fig. 5(14–16)

1967. *Gnathodus bassleri symmetricus* n. subsp.- Lane, pp. 935-936, pl. 120, figs. 1, 13, 14 and 17; pl. 121, figs. 6 and 9 (holotype re-illustrated in Barrick, Lambert, Heckel and Boardman, 2004, pl. 1, fig. 7).

1992a. *Neognathodus symmetricus* (Lane).- Lemos, pp. 87, pl. 3, fig. 1 (re-illustrated in Lemos and Medeiros, 1996, fig. 2a-b).

Material: Forty one P1 elements MP-M 895, 897–899, 903–906, 910, 918, 1031, 1035–1037, 1152–1161, 1166–1171, 1175, 1178–1180, 1182, 1185, 1200, 1262, 1336 (eleven very small or poorly preserved) from the Monte Alegre and Itaituba formations (Table 1).

Remarks: Many studied P1 elements are small in size, but larger elements resemble closely to North American elements, as the type material, and are differentiated from morphology described in Sanz-López and Blanco-Ferrera (2012) from the Pyrenees.

Occurrence: Early morphotype from Sanz-López and Blanco-Ferrera (2012) occurs in lower Bashkirian beds with Kinderscoutian ammonoids or in the equivalent to the Ammonoid H1 Zone in South Urals (Kulagina et al., 2001). The species reaches the uppermost Bashkirian in the southern Urals (Kulagina et al., 2001). The North American type material, however, ranges from the *N. symmetricus* Zone in the middle Morrowan, from a bed below the first occurrence of ammonoid *Cancelloceras* Ruzhencev and Bogoslovskaya (Lane 1967; Lane and Straka 1974).

Neognathodus uralicus Nemirovskaya and Aleeksev, 1995

Fig. 5(23)

1995. *Neognathodus uralicus* n. sp.- Nemirovskaya and Aleeksev, p. 118, pl. 4, figs. 1, 5.

Material: One element (MP-M 1054) from well 1-UA-1-AM (core sample 16, Itaituba Formation).

Remarks: This species differs from *N. asymmetricus* in the ventral width of the platform, with strong parapets. The rostral parapet is short and the dorsal carina is prominent in the half where the rostral parapet is missing. The ornamentation is stronger than in *N. tsnensis*, with wide transverse ridges meeting the carina in the dorsal part of the caudal platform.

Occurrence: Solontsovian to lower Imendyashevian horizons in the Moscovian of Askyn section, South Urals (Nemirovskaya and Aleeksev, 1995), or from the uppermost Bashkirian to lower Moscovian at the Basu section (Kulagina et al., 2009). In the American southern Midcontinent, *N. uralicus* is common in the Atokan *N. atokaensis* Zone of Barrick et al. (2013).

Neognathodus sp. 1 Nemyrovska, 1999

Fig. 5(17–19)

1972. *Neognathodus bassleri bassleri* (Harris and Hollingsworth).- Merrill, pl. 1, fig. 17 (only) (re-illustrated in Merrill, 1974, pl. 1, fig. 20).

1999. *Neognathodus* sp. 1.- Nemyrovska, 1999, pl. 5, figs. 15-116, 17?, 19 and 20.

Material: Five elements from wells 1-AM-7-AM (sample 9, MP-M 1163–1165), 1-AM-9-AM (sample 2, MP-M 896) and 2-CA-1-AM (sample 6, MP-M 915–916).

Description: The platform is small, symmetrical, and moderately wide. The carina is short and low and it ends half way along the platform. Two or three small nodes may replace the dorsal carina.

Remarks: The species is close to *N. bassleri*, but the platform is less ornamented and the carina is ending in the dorsal platform. It seems to be close to the holotype of *Neognathodus asymmetricus* illustrated by Stibane (1967, pl. 36, figs. 11-13), which is clearly distinct to another one morphology corresponding to the rest of elements (figs. 14-18). The holotype show high parapets with a crenulated margin, deep adcarinal troughs and a carina high in its ventral portion, then becoming lower and disappear before the dorsal tip. The platform outline is biconvex, although the caudal margin is slightly sinuous to straight.

Occurrence: Reported from the Lower Mercer Member in Ohio (Merrill, 1972, 1974) and the upper Bashkirian limestones G_1^2-H_5^1 in the Donets Basin (Nemyrovska, 1999).

Neognathodus sp. A Grayson, 1984

Fig. 5(21)

1984. *Neognathodus* n. sp. A.- Grayson, pp. 51-52.

1992. *Neognathodus* sp. C.- Grayson in Sutherland and Grayson, pl. 2, fig. 22.

1992a. *Neognathodus roundyi* (Gunnell).- Lemos, pp. 86-87, pl. 1, fig. 3.

2005. *Neognathodus roundyi* (Gunnell).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 2.D-E, H.

2010b. *Neognathodus medadultimus* Merrill.- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5E.

2010b. *Neognathodus roundyi* (Gunnell).- Nascimento, Scomazzon and Lemos in Nascimento et al., fig. 5G.

Material: One element MP-M 1030 from the Itaituba Formation (sample 10, well 2-PC-1-AM).

Description: Specimen with a long caudal parapet, which reaches the dorsal tip, and a rostral platform ornamented by several nodes on the ventral part. A trough is located between the row of the nodes and the carina. The nodes of the carina are laterally expanded in the dorsal part of the platform.

Remarks: Grayson (1984) remarked that the caudal parapet is high and ornamented by prominent transverse ridges, whereas the rostral margin is distinctly lower than the caudal one, and semicircular in oral view. Ornamentation may be absent on the rostral margin, or it consists of a row of nodes running parallel to the rostral margin or of transverse ridges that are sub-perpendicular to the carina.

Occurrence: This morphotype occurs in the lower part of the Itaituba Formation and is described from the upper part of the Wapanucka Limestone in the Morrowan to Atokan beds, where it is found together with *Idiognathodus incurvus* (Sutherland and Grayson, 1992).

5. Discussion and conclusions

Conodont faunas from the Carboniferous part of the Tapajós Group in the Amazonas Basin show a high diversity. Nowadays, they constitute the widest of those described from the Lower–Middle Pennsylvanian in South America. In this time, warm-water carbonates and evaporites were being deposited in the Amazonas Basin in relation to the drift of western Gondwana to lower latitudes (Isaacson and Díaz Martínez, 1995; Iannuzzi and Rösler, 2000). Glacial and glacial influenced deposits are known in the southern part of South America, suggesting a severe climate gradient along the Gondwanan western margin (Limarino and Spalletti, 2006; Grader et al. 2008).

High resolution sampling from wells of the Amazonas Basin should provide results similar to classical areas such as those in North America and a very-accurate conodont biostratigraphy. The subsurface sampling has given slow results, but some studied beds of the upper part of the Itaituba Formation and the Nova Olinda Formation yield significant and diverse conodont associations, showing that a better knowledge may be obtained in accordance with the higher sampling density.

Abundant conodont associations from the Amazonas Basin include a large number of cosmopolitan conodont species of the genera *Declinognathodus, Idiognathoides,* '*Streptognathodus*', *Neognathodus* and *Diplognathodus* (Table 1). With respect to the genus *Idiognathodus,* many species have been regarded as being the same as the North America Midcontinent area (*I. amplificus*, *I. crassadens*, *I. ignisitus*, *I. klapperi* and *I. rectus*). This confirms the known connection of the Amazonas Basin with the Midcontinent–Andean Realm after Ross (1967), as previous studies of the Bashkirian–Moscovian have indicated (Ross and Ross, 1985; Lemos, 1992a, 1992b, Altiner and Savini, 1995; Meyerhoff et al., 1996; Lemos and Medeiros, 1996, Nascimento et al., 2009). The new species, *I. itaitubensis,* probably descends from upper Bashkirian *I. incurvus,* a common species in the North American Atokan Stage. It is also close to the younger Upper Pennsylvanian–lower Permian? *I. ellisoni,* described in the Midcontinet-Andean Realm (Suárez Riglos et al., 1987).

Some species, such as *Idiognathodus izvaricus*, *I.* cf. *obliquus*, *I. praeobliquus*, *I. podolskiensis,* are typical Tethyan or Uralian taxa (Eurasian–Arctic Realm after Ross, 1967). Except *I. izvaricus,* others have also been reported from North America (Barrick et al., 2013, and references therein), where they could have migrated from the Tethys area through the primary route of the Arctic or Uralian-Franklinian Province (Ross, 1967; Groves et al., 2007; Davydov, 2014, and references therein included) (Fig. 6(1)). Nevertheless, the new occurrence of *I. izvaricus* in the Moscovian of the Amazonas Basin, far away the known occurrence in the Donets and Moscow basins, brings back the discussion on an intermittent second marine connection between the western Palaeo-tethys Ocean and the marine basins of South America. An occasional connection was previously suggested on the basis of the presence of a few Morrowan and upper Atokan foraminifers in the Amazonas Basin and Bolivia (such as *Plectostaffella jakhensis* Reitlinger and *Asselodiscus* Mamet and Pinard). These taxa are known in the Eurasian-Arctic Realm, but not in the sub-Arctic North America (Altiner and Savini, 1995; Baesemann et al., 1998; Wood et al., 2002). It was suggested anew on the basis of palaeobiogeographical relationships among poriferan and coral associations of the Palaeo-tethys and Panthalassa oceans during the Moscovian (García-Bellido and Rodríguez, 2005) and of brachiopod faunas from western Argentina (Taboada, 2010, and references therein). Probable seaways for migration from North Africa and Western Europe were proposed on the basis of the incomplete closure of the Rheic Ocean or directly from North Africa to Amazonian seaway (Baesemann et al, 1998; Vai, 2003) (Fig. 6(2–3)). In this way, the upper part of the Itaituba Formation, where *I. izvaricus* occurs, corresponds to a highstand interval characterized by the widest distribution of marine carbonates passing over the Purus and Gurupá margins of the Amazonas Basin (Matsuda et al., 2004). The suggestion of probable migration of faunas is in line with the interpretation of the neodymium isotopic composition analyzed in carbonate rocks, conodonts and brachiopod shells from the Itaituba and the Nova Olinda formations by Scomazzon (2004) and Scomazzon et al. (2005). These authors argued in favour of an incoming of seawater masses in the Amazonas Basin from the Palaeo-tethys Ocean, instead of a single Panthalassa Ocean provenance.

The Amazonas seaway must have been closed in the upper part of the Nova Olinda Formation, because it was a restricted basin with frequent evaporite precipitation in the upper part of the Fazendinha Member, whereas prevailing continental sedimentation with rare marine beds occurred during the Arari Member (Cunha et al., 2007). The scarce

Streptognathodus and *Adetognathus* specimens studied suggest low diversity and abundance Upper Pennsylvanian and probable lower Permian associations in comparison with those richer in conodonts described in open marine conditions from the Bolivian sub-basins (Suárez Riglos et al., 1987; Grader et al., 2008).

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References

Alekseev , A.S., Goreva, N.V., 2001. [Description of new characteristic taxa, Chapter 9, Conodonta], in: Makhlina, M.Kh. et al. (Eds.), [Middle Carboniferous of Moscow Syneclise (southern part).Volume 2. Biostratigraphy]. Paleontologicheskiy Institut Rossiiskoy Akademii Nauk, Moscow, pp. 113–140 (in Russian).

Alekseev , A.S., Goreva, N.V., 2013. The conodont *Neognathodus bothrops* Merrill, 1972 as the marker for the lower boundary of the Moscovian Stage (Middle Pennsylvanian), in: Lucas, S.G., DiMichele, W.A., Barrick, J.E., Schneider, J.W., Spielman, J.S. (Eds.), The Carboniferous–Permian Transition. New Mexico Museum of Natural History and Science, Bulletin 60, pp. 1–6.

Altiner, D., Savini, R.R., 1995. Pennnsylvanian foraminifera and biostratigraphy of the Amazonas and Solimões basins (north Brazil). Revue de Paléobiologie 14, 417–453.

Araújo, J.S., Rocha-Campos, A.C., 1969. Conodonts from the Itaituba Formation (Pennsylvanian) at well PEST-2-AM Amazon Basin. Ciência e Cultura 21, 221–228.

Austin, R.L., Rhodes, F.H.T., 1981. Family Cavusgnathidae, in: Clark, D.L. et al. (Eds.), Conodonta. Treatise on Invertebrate Paleontology, Part W (Miscellanea), Supplement 2. Geological Society of America and University of Kansas, p. 158.

Baesemann, J.F., 1973. Missourian (Upper Pennsylvanian) conodonts of northeastern Alaska. Journal of Paleontology 47, 689–710.

Baesemann, J.F., Brenckle, P.L., Gruzlovic, P.D, 1998. Composite standard correlation of the Mississippian-Pennsylvanian (Carboniferous) Lisburne Group from Prudhoe Bay to the eastern Arctic National Wildlife Refuge, North Slope, Alaska, in: Clough, J.G., Larson, F. (Eds.), Short notes on Alaska geology 1997: Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, Professional Report 118, pp. 23–36.

Barrick , J. E., Boardman, D.R., 1989. Stratigraphic distribution of morphotypes of *Idiognathodus* and *Streptognathodus* in Missourian-lower Virgilian strata, north-central Texas, in: Boardman, D.R., Barrick, J.E., Cocke, J.M., Nestell, M.K. (Eds.), Late Pennsylvanian chronostratigraphic boundaries in north-central Texas: Glacial-eustatic events, biostratigraphy, and paleoecology, a guidebook with contributed papers, pt. II, Contributed papers, Texas Tech University, Lubbock. Studies in Geology 2, pp. 167–188.

Barrick, J.E., Heckel, P.H., Boardman, D.R., 1999. Evolutionary patterns in Late Pennsylvanian *Idiognathodus* and *Streptognathodus* and implications for chronostratigraphic boundary characterization and recognition, in: Heckel, P.H. (Ed.), Guidebook, Fieldtrip #8, XIV International Congress on the Carboniferous-Permian. Kansas Geological Survey, Lawrence, Open File Report 99–27, pp. 178–185.

Barrick , J.E., Lambert , L.L., Heckel , P.H., Boardman, D.R., 2004. Pennsylvanian conodont zonation for Midcontinent North America. Revista Española de Micropaleontologia 36, 231–250.

Barrick, J.E., Lambert, L.L., Heckel, P.H., Rosscoe, S.J., Boardman, D.R., 2013. Midcontinent Pennsylvanian conodont zonation. Stratigraphy 10, 55–72.

Barrick J.E., Walsh, T.R., 1999. Some older North American types of *Idiognathodus* and *Streptognathodus*, in: Heckel, P.H. (Ed.), Guidebook, Fieldtrip #8, XIV International Congress on the Carboniferous–Permian. Kansas Geological Survey, Lawrence, Open File Report 162–169, pp. 99–27.

Bender, K.P. 1980. Lower and Middle Pennsylvanian conodonts from the Canadian Artic Archipelago. Geological Survey of Canada 79, 1–24.

Boardman, D.R., Heckel, P.H.., Marshall, T.R., 2004. Preliminary report on lower Desmoinesian (mid-Moscovian) conodonts from lower and middle Cherokee Group of southern Midcontinent North America. Newsletter on Carboniferous Stratigraphy 22, 41–47.

Campanha, V.A., Rocha-Campos, A.C., 1979. Alguns microfósseis da Formação Piauí (Neocarbonífero), bacia do Parnaíba. Boletim IG, Instituto de Geociências Universidade de São Paulo, 10, 57–67.

Caputo, M.V., Melo, J.H.G., Streel, M., Isbell, J.L., 2008. Late Devonian and Early Carboniferous glacial records of South America, in: Fielding, C.R., Frank, T.D., Isbell, J.L.

(Eds.), Resolving the Late Paleozoic Ice Age in Time and Space: Geological Society of America Special Paper 441, pp. 161–173.

Cardoso, C.N., 2010. Análise cronoestratigráfica baseada em conodontes da Formação Itaituba (Pedreira Calminas), Atokano da Bacia do Amazonas-Brasil. Dissertação Mestrado em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre (unpublished).

Cardoso, C.N., Sanz-López, J., Blanco-Ferrera, S., Lemos, V.B. and Scomazzon, A.K., 2015. Frasnian conodonts at high palaeolatitude (Amazonas Basin, North Brazil). Palaeogeography, Palaeoclimatology, Palaeoecology 418, 57–64.

Cardoso, C.N., Sanz-López, J., Blanco-Ferrera, S., Lemos, V.B. Scomazzon, A.K., submitted. Conodont colour alteration index and upper Paleozoic thermal history of the Amazonas Basin, Brazil. Journal of South American Earth Sciences.

Clark, D.L., Behnken, F.H., 1971. Conodonts and biostratigraphy of the Permian, in: Sweet W.C., Bergstrom, S.E. (Eds.), Symposium on conodont biostratigraphy. Geological Society of America Memoir 127, pp. 415-439.

Cunha, P.R.C., Gonzaga, F.G., Coutinho, L.F.C., Feijó, F.J., 1994. Bacia do Amazonas. Boletim de Geociências da Petrobras, 8, 47–55.

Cunha, P.R.C., Melo, J.H.G., Silva, O.B., 2007. Bacia do Amazonas. Boletim de Geociências da Petrobras 15, 227–251.

Davydov, V., 2014. Warm water benthic foraminifera document the Pennsylvanian–Permian warming and cooling events – The record from the Western Pangea tropical shelves. Palaeogeography, Palaeoclimatology, Palaeoecology 414, 284–295.

Dunn, D.L., 1965. Late Mississippian conodonts from the Bird Spring Formation in Nevada. Journal of Paleontology 39, 1145–1150.

Dunn, D.L., 1966. New Pennsylvanian platform conodonts from southwestern United States. Journal of Paleontology 40, 1294–1303.

Dunn, D.L., 1970. Middle Carboniferous conodonts from western United States and phylogeny of the platform group. Journal of Paleontology, 44, 312–342.

Dzik, J., 1976. Remarks on the evolution of Ordovician conodonts. Acta Palaeontologica Polonica 21, 395–455.

Ellison, S.P., 1941. Revision of the Pennsylvanian conodonts. Journal of Paleontology 15, 107–143.

Ellison, S.P., 1972. Conodont taxonomy in the Pennsylvanian. Geologica et Paleontologica SB1, 127–146.

Ellison, S., Graves, R. W. Jr, 1941. Lower Pennsylvanian (Dimple Limestone) conodonts of the Marathon Region, Texas. Bulletin of the Missouri University, School of Mines and Metallurgy 14, 1–21.

Fohrer, B., Nemyrovska, T.I., Samankassou, E. Ueno, K., 2007. The Pennsylvanian (Moscovian) Izvarino section, Donets Basin, Ukraine: A multidisciplinary study on microfacies, biostratigraphy (conodonts, foraminifers, and ostracodes), and paleoecology. Journal of Paleontology 81, 1–85.

Fúlfaro, V.J. 1965. Conodontes do Calcário Itaituba do Carbonífero do Rio Tapajós, Estado do Pará. Boletim da Sociedade Brasileira de Geologia 14, 29–40.

García-Bellido, D.C., Rodríguez, S., 2005. Palaeobiogeographical relationships of poriferan and coral assemblages during the late Carboniferous and the closure of the western Palaeotethys Sea–Panthalassan Ocean connection. Palaeogeography, Palaeoclimatology, Palaeoecology 219, 321–331.

Gonzaga, F.G., Gonçalves, F.T.T., Coutinho, L.F.C., 2000. Petroleum geology of the Amazonas Basin, Brazil: modelling of hydrocarbon generation and migration, in: Mello, M.R., Katz, B.J. (Eds.), Petroleum systems of South Atlantic margins. American Association of Petroleum Geologists Memoir 73, pp. 159–178.

Goreva, N.V., 1984. [Conodonts of the Moscovian Stage of the Moscow Syneclise], in: Menner, V.V. (Ed.), [Paleontological characteristics of the types and keys sections of the Moscow Syneclise]. Moskow University Publications House, pp. 44–102 (in Russian).

Goreva, N.V., Alekseev , A.S., 2001. [Biostratigraphic characteristics of Moscovian Stage on different fossil groups, Chapter 2, Conodonta], in: Makhlina, M.Kh. et al. (Eds.), [Middle Carboniferous of Moscow Syneclise (southern part).Volume 2]. Biostratigraphy. Paleontologicheskiy Institut Rossiiskoy Akademii Nauk, Moscow, pp. 33–54 (in Russian).

Grader, G.W., Isaacson, P.E., Díaz-Martínez, E., Pope, M.C., 2008. Pennsylvanian and permian sequences in Bolivia: Direct responses to Gondwana glaciation, in: Fielding, C.R., Frank, T.D., Isbell, J.L. (Eds.), Resolving the Late Paleozoic Ice Age in time and space. Geological Society of America Special Paper 441, pp. 143–159.

Grayson, R.C., 1984. Morrowan and Atokan (Pennsylvanian) conodonts from the eastern margin of the Arbuckle Mountains, southern Oklahoma, in: Sutherland, P.K., Manger, W.L. (Eds.), The Atokan Series (Pennsylvanian) and its boundaries – a symposium. Bulletin Oklahoma Geological Survey 136, Norman, pp. 41–61.

Grayson, R.C., 1990. Canyon Creek: a significant exposure of a predominantly mudrock succession recording essentially continuous deposition from the late Devonian through the Middle Pennsylvanian, in: Ritter, S.M. (Ed.), Early and Middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma. Oklahoma Geological Survey. Guidebook 27, Norman, pp. 85–114.

Grayson, R.C., Merrill, G.K., Lambert, L.L., 1990. Carboniferous gnathodontid conodont apparatuses: evidence of a dual origin for Pennsylvanian taxa. Courier Forschungsinstitut Senckenberg 118, 353–396.

Grayson, R.C., Merrill, G.K., Lambert, L.L., Turner, J., 1989. Phylogenetic basis for species recognition within conodont genus *Idiognathodus*, applicability to correlation and boundary placement, in: Boardman, D.R., Barrick, J.E., Cocke, J.M., Nestell, M.K. (Eds.), Late Pennsylvanian chronostratigraphic boundaries in north-central Texas: Glacial–eustatic events, biostratigraphy, and paleoecology, a guidebook with contributed papers, pt. II, Contributed papers, Texas Tech University, Lubbock, Studies in Geology 2, pp. 75–94.

Grayson, R.C., Trice, E.L., Westergaard, E.H., 1985. Significance on some middle Atokan to early Missourian conodont faunas from the Llano Uplift and Colorado River Valley, Texas. Southwest section APPPG 1985 Transactions, Forth Worth, pp. 117–131.

Groves, J.R., Kulagina, E.I., Villa, E., 2007. Diachronous appearances of the Pennsylvanian fusulinid *Profusulinella* in Eurasia and North America. Journal of Paleontology 81, 227–237.

Grubbs, R.K., 1984. Conodont platform elements from the Wapanucka and Atoka formations (Morrowan–Atokan) of the Mill Creek Syncline central Arbuckle Mountains, Oklahoma, in: Sutherland, P.K., Manger, W.L. (Eds.), The Atokan Series (Pennsylvanian) and its boundaries–A symposium. Oklahoma Geological Survey 136, Norman, pp. 65–79.

Gunnell, F.H., 1931. Conodonts from the Fort Scott Limestone of Missouri. Journal of Paleontology 15, 242–252.

Gunnell , F.H., 1933. Conodont and fish remains from the Cherokee, Kansas City, and Wabaunsee groups of Missouri and Kansas. Journal of Paleontology 7, 261–297.

Harris, R.W., Hollingsworth, R.V., 1933. New Pennsylvanian conodonts from Oklahoma. American Journal of Science 25, 193–204.

Harlton, B.H., 1933. Micropaleontology of the Pennsylvanian Johns Valley Shale of the Ouachita Mountains. Journal of Paleontology 7, 3–29.

Heckel, P.H., 2013. Pennsylvanian stratigraphy of Northern Midcontinent Shelf and biostratigraphic correlation of cyclothems. Stratigraphy 10, 3–39.

Henderson, C.M., Schmitz, M., Crowley, J., Davydov, V. 2009. Evolution and geochronlogy of the *Sweetognathus* lineage from Bolivia and the urals of Russia; biostratigraphic problems and implications for Global Stratotype Section and Pont (GSSP) definion. Permophyles 53 Supplement 1, 20–21.

Higgings, A.C., 1975. Conodont zonation of the late Viséan - early Westphalian strata of the south and central Pennines of northern England. Bulletin of the Geological Survey of Great Britain 53, 1–127.

Horowitz, A.S., Rexroad, C.B., 1982. An evaluation of statistical reconstructions of multielement conodont taxa from middle Chesterian rocks (Carboniferous) in southern Indiana. Journal of Paleontology 56, 959–969.

Iannuzzi, R., Rösler, O., 2000. Floristic migration in South America during the Carboniferous: phytogeographic and biostratigraphic implications. Palaeogeography, Palaeoclimatology, Palaeoecology 161, 71–94.

Igo, H., Koike, T., 1964. Carboniferous conodonts from the Omi Limestone, Niigata Prefecture, central Japan. Palaeontological Society of Japan, Transaction and Proceedings, New series 53, 179–193.

Issacson, P.E., Díaz Martínez, E., 1995. Evidence for a Middle–Late Paleozoic foreland basin and significant paleolatitudinal shift, Central Andes, in: Tankard, A.J., Suárez, R., Welsink, H.J. (Eds.), Petroleum basins of South America. American Association of Petroleum Geologists Memoir 62, pp. 231–249.

Jeppsson, L., Anehus, R., 1995. A buffered formic acid technique for conodont extraction. Journal of Paleontology 69, 790–794.

Jeppsson, L., Anehus, R., Fredholm, D., 1999. The optimal acetate buffered acetic acid technique for extracting phosphatic fossils. Journal of Paleontology 73, 964–972.

Kozitskaya, R.I., Kossenko Z.A., Lipnjagov, O.M., Nemirovskaya, T.I., 1978. [Carboniferous conodonts of the Donets Basin]. Izdatel’stvo (Naukova Dumka), Kiev (in Russian).

Kozur, H., 1975. Beitäge zur Conodontenfauna des Perm. Geologica et Paläontologica 5, 1–44.

Kulagina, E.I., Pazukhin, V.N, Davydov, V.I., 2009. Pennsylvanian biostratigraphy of the Basu River section with emphasis on the Bashkirian-Moscovian transition, in: Puchkov, V.N., Kulagina, E.I., Nikolaeva, S.V., Kochetova, N.N. (Eds.), Carboniferous type sections in Russia and potential global stratotypes. Proceedings of the International Field Meeting “The historical type sections, proposed and potential GSSPs of the Carboniferous in Russia.” Southern Urals Session. Ufa–Sibai, 13–18 August, 2009. Ufa-Design Polygraph Service, Ltd., pp. 42─63.

Kulagina, E.I., Pazukhin, V.N., Kochetova, N. M., Sintsyna, Z. A., Kochetova, N. N., 2001. [The stratotype and key sections of the Bashkirian stage (Carboniferous) in the Southern Urals]. Ufa, Gilem, (imprint) (in Russian).

Lambert, L.L., 1992. Atokan and basal Desmoinesian conodonts from central Iowa, reference area for the Desmoinesian Stage, in: Sutherland, P.K. and Manger, W.L. (Eds.), Recent advances in Middle Carboniferous biostratigraphy. Oklahoma Geological Survey, Norman, Circular 94, pp. 111–123.

Lambert, L.L., Heckel, P. H. Barrick, J.E., 2003a. *Swadelina* new genus (Pennsylvanian Conodonta), a taxon with potential chronostratigraphic significance. Micropaleontology 49, 151–158.

Lambert , L.L., Heckel, P.H., Barrick, J.E., 2003b. New insights on the locality and material for the first Pennsylvanian conodont paper published in North America [abstract]. Geological Society of America, Abstracts with Programs 35(2), 5.

Lane, H.R., 1967. Uppermost Mississippian and lower Pennsylvanian conodonts from the type Morrowan region, Arkansas. Journal of Paleontology 41, 920–943.

Lane, H.R., Straka, J.J. II, 1974. Late Mississipian and Early Pennsylvanian conodonts Arkansas and Oklahoma. Special Paper of the Geological Society of America 152, 1–144.

Lemos, V.B., 1990. Assembléia de Conodontes do Carbonífero da Bacia do Amazonas. Ph.D. thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre (unpublished).

Lemos, V.B., 1992a. Conodontes do Carbonífero das Bacias do Amazonas e Solimões. Taxonomia – Parte I. Pesquisas 19, 75–93.

Lemos, V.B., 1992b. Conodontes do Carbonífero das Bacias do Amazonas e Solimões. Taxonomia – Parte II. Pesquisas 19, 120–131.

Lemos, V.B., Medeiros, R.A., 1989. Transgressões e regressões cíclicas e ocorrência de conodontes no Morrowano e Atokano na Bacia do Amazonas. Anais do Simpósio de marcos estratigráficos, Curitiba, 2, 961–969.

Lemos, V.B., Medeiros, R.A., 1996. O Limite Morrowano/Atokano na Bacia do Amazonas, Brasil, com base em conodontes. Boletim de Geociências da Petrobrás 10, 165–173.

Lemos, V.B., Scomazzon, A.K., 2001. The Carboniferous biochronostratigraphy of the Amazonas Basin, Brazil, based on conodonts, in*:* Melo, J.H.G., Terra, G.S.T. (Eds.), Workshop Correlação de Sequências Paleozóicas Sul-Americanas, Rio de Janeiro, pp. 131–138.

Limarino, C.O., Spalletti, L.A., 2006. Paleogeography of the upper Paleozoic basins of southern South America: An overview. Journal of South American Earth Sciences 22, 134–155.

Lucas, S.G., Krainer, K., Barrick, J.E., 2009. Pennsyklvanian stratigraphy and conodont biostratigraphy in the Cerros de Amado, Socorro County, New Mexico. New Mexico

Geological Society Guidebook, Socorro, 60th Field Conference, Geology of the Chupadera Mesa Region, 182–211.

Matsuda, N.S., Dino, R., Wanderley Filho, J.R., 2004. Revisão litoestratigráfica do Grupo Tapajós, Carbonífero Médio – Permiano da Bacia do Amazonas. Boletim de Geociências da Petrobras 12, 435–441.

Matsuda, N.S., Winter, W.R., Wanderley Filho, J.R., Cacela, A.S.M., 2010. O Paleozóico da borda sul da Bacia do Amazonas, Rio Tapajós - Estado do Pará. Boletim de Geociências da Petrobras 18, 123–152.

Méndez, C.A., 2006. Upper Moscoviasn–middle Kasimovian conodonts (Pennsylvanian, Carboniferous) from the Las Llacerias Section (Cantabrian Zone, north Spain). Geobios 39, 245–254.

Merino Redo, D., Blanco Rojas, J., 1990, Conodontos de la Formación Copacabana (Carbonífero superior-Pérmico inferior) en la sección de Huarachani-Pacobamba: Departamento de La Paz, Bolivia. Revista Técnica de Yacimientos Petrolíferos Fiscales Bolivianos 11, 109–116.

Merrill, G.K., 1972. Taxonomy, phylogeny, and biostratigraphy of *Neognathodus* in Appalachian Pennsylvanian rocks. Journal of Paleontology 46, 817–829.

Merrill, G.K., 1973. Pennsylvanian non platform conodont genera, I: *Spathognathodus*. Journal of Paleontology 47, 289–314.

Merrill, G.K., 1974. Pennsylvanian conodont localities in northeastern Ohio. Division of Geological Survey, Ohio Department of Natural Resources, Columbus, Guidebook 3, 1–28.

Merrill, G.K., King, C.W., 1971. Platform conodonts from the lowest Pennsylvanian rocks of north-western Illinois. Jounal of Paleontology 45, 645–664.

Merrill, G.K., von Bitter, P.H., 1976. Revision of conodont biofacies nomenclature and interpretations of environmental controls in Pennsylvanian rocks of eastern and central North America. Royal Ontario Museum, Life Science Contributions 108, 1–46.

Meyerhoff, A.A, Boucot, A.J., Meyerhoff Hull, D., Dickins, J.M., 1996. Phanerozoic faunal and floral realms of the Earth: The intercalary relations of the Malvinokaffric and Gondwana Faunal Realms with the Tethyan Faunal Realm. Geological Society of America Memoir 189, 1–69.

Murray, F.N., Chronic, J. 1965. Pennsylvanian conodonts and other fossils from insoluble residues of the Minturn Formation (Desmoinesian), Colorado. Journal of Paleontology 39, 594–609.

Nascimento, S., Lemos, V.B., Scomazzon, A.K., Moutinho, L.P., Matsuda, N.S., Silva, C.P., 2010a. First occurrence of *Ellisonia, Gondolella* and *Ubinates* (conodonts) in Itaituba Formation, Pennsylvanian of Amazonas Basin, Brazil. Gaea –Journal of Geoscience 6, 56–62.

Nascimento, S., Scomazzon, A.K., Moutinho, L.P., Lemos, V.B, Matsuda, N.S., 2005. Conodont biostratigraphy of two calcareous quarries - Lower Itaituba Formation, Atokan Age, Amazonas Basin, Brazil. Revista Brasileira de Paleontologia 8, 193–202.

Nascimento, S., Smaniotto, L.P., Souza, P.A., Lemos, V.B., Scomazzon, A.K., 2009. Biochronostratigraphy (conodonts and palynology) from selected strata of the Itaituba Formation, Pará State, Brazil. Pesquisas em Geociências 36, 37–47.

Nascimento, S., Scomazzon, A.K., Lemos, V.B., Moutinho, L.P., Matsuda, N.S., 2010b. Bioestratigrafia e paleoecologia com base em conodontes em uma seção de carbonatos marinhos do Pensilvaniano inferior, Formação Itaituba, borda sul da Bacia do Amazonas, Brasil. Pesquisas em Geociências 37, 243–256.

Nemirovskaya, T.I., 1978. [Biostratigraphy of the Serpukhovian and Bashkirian of Donbas by conodonts]. Tektonika i stratigrafia (Naukova Dumka) 14, 83–91 (in Russian).

Nemirovskaya, T.I., Alekseev, A.S., 1995. The Bashkirian conodonts of the Askyn section, Bashkirian Mountains, Russia. Bulletin de la Société Belge de Géologie 103, 109–133 (imprinted in 1994).

Nemyrovska, T.I., 1999. Bashkirian conodonts of the Donets basin, Ukraine. Scripta Geologica 119, 1–115.

Nemyrovska, T.I., 2011. Late Moscovian (Carboniferous) conodonts of the genus *Swadelina* from the Donets Basin, Ukraine. Micropaleontology 57, 491–505.

Nemyrovska , T.I., Perret-Mirouse, M.F., Alekseev, A.S., 1999. On Moscovian (Late Carboniferous) conodonts of the Donets Basin, Ukraine. Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen 214, 169–194.

Neves, C.A.O., 1990. Prospectos potenciais e áreas prioritárias para exploração na Bacia do Amazonas. Boletim de Geociências da Petrobras 4, 95–103.

Playford, G., Dino, R., 2000a. Palynostratigraphy of upper Palaeozoic strata (Tapajós Group), Amazonas Basin, Brazil: Part one. Palaeontographica Abteilung B 225, 1–46.

Playford, G., Dino, R., 2000b. Pa1ynostratigraphy of upper Pa1aeozoic strata (Tapajós Group), Amazonas Basin, Brazil: Part two. Palaeontographica Abteilung B 225, 87–145.

Playford, G., Dino, R., 2005. Carboniferous and Permian pa1ynostratigraphy, in: Koutsoukos, E.A.M. (Ed.), App1ied Stratigraphy, chapter 5, Springer, Dordrecht, pp. 101–121.

Proctor, D.D., 1991. Conodont fauna of the Dimple Limestone (late Morrowan-early Atokan, early Pennsylvanian) in the Marathon Basin, Texas. Ph.D. thesis, Texas Tech University (unpublished).

Purnell, M.A., Donoghue, P.J., Aldridge, R.J. 2000. Orientation and anatomical notation in conodonts. Journal of Paleontology 74, 113–122.

Qi, Y., Lambert, L.L., Nemyrovskaya, T., Wang, X.D., Hu, K., Wang, Q., 2013. Multiple transitional conodont morphologies demonstrate depositional continuity in the Bashkirian–Moscovian boundary interval, Naqing section, Guizhou, South China. New Mexico Museum of Natural History and Science Bulletin 60, 329–336.

Qi, Y., Wang, X., La,mbert, L.L., Barrick, J.E., Wang, Z., Hu, K., Wang, Q., 2011. Three new potential levels for the Bashkirian–Moscovian boundary in the Naqing section based on conodonts. Newsletter on Carboniferous Stratigraphy 29, 61–64.

Rexroad , C.B., Brown , L.M., Devera , J., Suman , R.J., 1998. Conodont biostratigraphy and paleoecology of the Perth Limestone Member, Staunton Formation (Pennsylvanian) of the Illinois Basin, U. S. A. Palaeontologica Polonica 58, 247–259.

Ritter, S.M., 1986. Taxonomic revision and phylogeny of post-Early Permian crisis *bisselli* – *whitei* Zone conodonts with comments on late Paleozoic diversity. Geologica et Palaeontologica 20, 139–165.

Ritter , S.M., Barrick , J.E., Skinner , M.R., 2002. Conodont sequence biostratigraphy of the Hermosa Group (Pennsylvanian) at Honaker Trail, Paradox basin, Utah. Journal of Paleontology 76, 495–517.

Rocha-Campos, A.C., Archangelsky, S., 1985. South America, in: Martínez Díaz, C., Wagner, R.H., Winkler Prins, C.F., Granados, L.F. (Eds.), The Carboniferous of the World II, Australia, Indian subcontinent, South Africa, South America & North Africa. Instituto Geológico y Geominero de España, Madrid, IUGS Publication 20, pp. 175–297.

Ross, C.A., 1967. *Eoparafusulina* from the Neal Ranch Formation (Lower Permian), west Texas. Journal of Paleontology 41, 943–946.

Ross, C.A., Ross, J.R.P., 1985. Late Paleozoic depositional sequences are synchronous and worldwide. Geology 13, 194–197.

Sakagami, S., Mizuno, Y., 1994. Discovery of middle Pennsylvanian fusulinids and conodonts from the Copacabana Group in the Lake Titicaca region, Bolivia. Proceedings of the Palaeontological Society of Japan 174, 484–494.

Sanz-López, J., Blanco-Ferrera, S., 2012. Lower Bashkirian conodonts from the Iraty Formation in the Alduides-Quinto Real Massif (Pyrenees, Spain). Geobios 45, 397–411.

Sanz-López, J,. Blanco-Ferrera, S., 2013. Early evolution of *Declinognathodus* close to the Mid-Carboniferous boundary interval in the Barcaliente type section (Spain). Palaeontology 56, 927–946.

Sanz-López, J., Blanco-Ferrera, García-López, S., Sánchez de Posada, L.C., 2006. The Mid-Carboniferous boundary in Northern Spain: difficulties for correlation of the Global Stratotype Section and Point. Rivista Italiana di Paleontologia e Stratigrafia 112, 3–22.

Savage, N.M., Barkeley, S.J., 1985. Early to Middle Pennsylvanian conodonts from the Klawak Formation and the Ladrones Limestone, southeastern Alaska. Journal of Paleontology 59, 1451–1475.

Scomazzon, A.K., 1999. Refinamento bioestratigráfico com base em Conodontes, no Pensilvaniano da Bacia do Amazonas – Região do Tapajós. Dissertação de Mestrado, Universidade Federal do Rio Grande do Sul, Porto Alegre (unpublished).

Scomazzon, A.K., 2004. Estudo de conodontes em carbonatos marinhos do Grupo Tapajós, Pensilvaniano inferior a médio da Bacia do Amazonas com aplicação de isótopos de Sr e Nd neste intervalo. Ph.D. thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre (unpublished).

Scomazzon, A.K., Koester, E., Moutinho, L.P., Matsuda, N.S., Nascimento, S., Lemos, V.B., 2005. Sr and Nd isotopic analysis in fossils and carbonatis rocks of the Iaituba and Nova Olinda formations, Pennsylvanian of Amazonas Basin. Gondwana 12, Geological and biological heritage of Gondwana, Mendoza, Argentina, Academia Nacional de Ciencias, Abstracts, 237.

Scomazzon, A.K., Lemos, V.B., 2005. *Diplognathodus* occurrence in the Itaituba Formation, Amazonas Basin, Brazil. Revista Brasileira de Paleontologia 8, 203–208.

Scotese, C.R. 2002. Paleomap website: http://www.scotese.com, chris@scotese.com.

Stamm , R.G., Wardlaw , B.R., 2003. Conodont faunas of the late Middle Pennsylvanian (Desmoinesian) Lower Kittanning cyclothem, U.S.A, in: Cecil, C.B., Edgar, N.T. (Eds.), Climate controls on stratigraphy. SEPM (Society for Sedimentary Geology), Tulsa, Special Publication 77, pp. 95–121.

Stauffer, C.R., Plummer H.J., 1932. Texas Pennsylvanian conodonts and their stratigraphic relations. University of Texas Bulletin 3201, 13–50.

Stibane , F. R., 1967. Conodonten des Karbons aus den nordlichen Andeen Sudamerikas. Neues Jahrbuch für Geologie und Paläeontologie 128, 329–340.

Stibane, F., Forero, A., 1969. Los afloramientos del Paleozoico de La Jagua (Huila) y Río Nevado (Santander del Sur). Geología Colombiana 6, 31–66.

Suárez Riglos, M., Hünicken, M.A., Merino Redo, D.A., 1987. Conodont biostratigraphy of the Upper Carboniferous–Lower Permian rocks of Bolivia, in: Austin, R.L. (Ed.), Conodonts: Investigative Techniques and Applications. British Micropalaeontological Society, Ellis Horwood Publishers, London, pp. 317–325.

Sutherland, P.K., Grayson, R.C., 1992. Morrowan and Atokan (Pennsylvanian) biostratigraphy in the Ardmore basin, Oklahoma, in: Sutherland, P.K., Manger, W.L. (Eds.), Recent advances in middle Carboniferous biostratigraphy – a symposium. Oklahoma Geological Survey Circular 94, Norman, pp. 81–99.

Swade, J.W., 1985. Conodont distribution, paleoecology, and preliminary biostratigraphy of the Upper Cherokee and Marmaton Groups (upper Desmoinesian, middle Pennsylvanian) from two cores in south-central Iowa. Iowa Geological Survey, Iowa, Technical Information Series 14, 1–71.

Taboada, A.C., 2010. Mississippian-Early Permian brachiopods from western Argentina: Tools for middle- to high-latitude correlation, paleobiogeographic and paleoclimatic reconstruction. Palaeogeography, Palaeoclimatology, Palaeoecology 298, 152–173.

Tengan, C., Shimabukuro, S., Rocha Campos, A.C., 1976. Conodontes Carboniferos do Poço FB-ST-1-AM, bacia do Amazonas, Brasil. XXIX Congresso Brasileiro de Geologia, Ouro Preto, Resumos, 365.

Vai, G.G., 2003. Development of the palaegeography of Pangaea from Late Carboniferous to Early Permian. Palaeogeography, Palaeoclimatology, Palaeoecology 196, 125–155.

von Bitter, P.H., 1972. Environmmental control of conodont distribution on the Shawnee Group (Upper Pennsylvanian) of eastern Kansas. The University of Kansas Paleontological Contributions 59, 1–105.

von Bitter, P.H., Merrill, G.K., 1983. Late Paleozoic species of *Ellisonia* (Conodontophorida). Royal Ontario Museum, Life Sciences Contribution 136, 1–57.

von Bitter, P.H., Merrill, G.K., 1990. Effects of variation of the speciation and phylogeny of *Diplognathodus*. Courier Forschungsinstitut Senckenberg 118, 105–129.

Wanderley Filho, J.R., Eiras, J.F., Cunha, P.R.C., van der Ven, P.H., 2010. The Paleozoic Solimões and Amazonas basins and the Acre foreland basin of Brazil, in: Hoorn, C., Wesselingh, F.P. (Eds.), Amazonia, landscape and species evolution. Blackwell Publishing, Chichester, pp. 30–37.

Whiteside, J.R., Grayson, R.C. 1989. Carboniferous conodont faunas, northern Ouachita Mountains, Oklahoma, in: Suneson, N.H., Campbell, J.A., Tilford, M.J. (Eds.), Geology and resources of the Frontal belt of the western Ouachita Mountains, Oklahoma. Guidebook for Field Trip No. 2, September, 27–28, 1989, American Association of

Petroleum Geologists, Mid-Continent Section Meeting, Oklahoma City. Oklahoma Geological Survey Special Publication 90-1, pp. 149–167.

Wood, G.D., Groves, J.R., Wahlman, G.P., Brenckle, P.L., Alemán, A.M. 2002. The paleobiogeographic and biostratigraphic significance of fusulinacean and smaller foraminifers, and palynomorphs from the Copacaban Formation (Pennsylvanian–Permian), Madre de Díos Basin, Peru, in: Hills, L.V., Henderson, C.M., Bamber, E.W. (Eds.), Carboniferous and Permian of the World. Canadian Society of Petroleum Geologists Memoir 19, pp. 630–664.

Youngquist, W., Downs, R.H., 1949. Additional conodonts from the Pennsylvanian of Iowa. Journal of Paleontology 23, 161–171.

Figure Captions

Fig 1. Map of the Amazonas Basin showing marginal Paleozoic outcrop belts (modified from Matsuda et al., 2010) and location of wells and quarries: (**1**) 2-AL-1-PA, (**2**) 1-AM-1-AM, (**3**) 1-AM-6-AM, (**4**) 1-AM-7-AM, (**5**) 1-AM-9-AM, (**6**) 2-CA-1-AM, (**7**) 1-CM-2-PA, (**8**) 2-CP-2-PA, (**9**) 1-FZ-1-AM, (**10**) 9-FZ-2-AM, (**11**) 9-FZ-28-AM, (**12**) 2-MN-1-AM, (**13**) 2-MS-4-AM, (**14**) 1-NO-1-AM, (**15**) 1-PB-1-PA, (**16**) 2-PC-1-AM, (**17**) 2-PE-1-AM, (**18**) 2-PE-2-AM, (**19**) 1-RX-1-AM, (**20**) 1-RX-6-AM, (**21**) 2-SA-1-AM, (**22**) 1-TR-1-AM, (**23**) 1-UA-1-AM, (**24**), and Calminas quarry.

Fig 2. P1 elements of several conodont genera from the Tapajós Group in the Amazonas Basin. Scale bar is 200 µm. **1–2.** *Adetognathus lautus* (Gunnell, 1933) from the Itaituba Formation. 1: sinistral P1 element, MP-M 902, sample 3 in well 1-AM-9-AM; 2: dextral P1 element, MP-M 970, sample 19 in well 1-FZ-1-AM. **3.** *Adetognathus flexus* (Ellison, 1941) from the Nova Olinda Formation, sinistral P1 MP-M 1127 element, sample 4, well 1-NO-1-AM. **4.** *Declinognathodus* cf. *marginodosus* (Grayson, 1984) from the Monte Alegre Formation. MP-P 1184, sample 19 of well 1-UA-1-AM. **5–6.** DE *Idiognathoides sinuatus* Harris and Hollingsworth, 1933 from the Itaituba Formation in well 2-CP-2-PA. 5: MP-M 964, sample 22; 6: MP-M 957, sample 21. **7–8.** *Idiognathoides corrugatus* (Harris and Hollingsworth, 1933) from the Itaituba Formation. 7: MP-M 921, sample 1 in well 1-CM-02-PA; 8: MP-M 1052, sample 13 in well 1-TR-1-AM. **9**. *Idiognathoides ouachitensis* (Harlton, 1933), MP-M 1014-1016 from the Itaituba Formation, sample 34 in well 1-FZ-1-AM. **10–11**. *Rachistognathus muricatus* (Dunn, 1965), MP-M 1073 and MP-M 1073, broken specimens from the Monte Alegre Formation, sample 10 in well 1-AM-9-AM. **12.** *Diplognathodus coloradensis* (Murray and Chronic, 1965), MP-M 951, Itaituba Formation, sample 5 in well 2-

CP-2-AM. **13**. *Diplognathodus ellesmerensis* Bender, 1980. MP-M 940, Itaituba Formation, sample 3 in well 1-CM-2-PA. **14–15**. *Diplognathodus orphanus* (Merrill, 1973) from the Itaituba Formation. 14a,b: MPM-M 1326, oral an lateral view of a transitional element to *D. ellesmerensis* from sample 5.5 m in Calminas quarry; 15: MP-M 1026, sample 34 in well 1-FZ-1-AM. **16–19**. *Diplognathodus* aff. *orphanus* (Merrill, 1973), MP-M 938, 936, 934 and 929, Itaituba Formation, sample 3 in well 1-CM-2-PA. **20–21**. *Diplognathodus iowensis* Swade, 1985. MP-M 1086 and 1087, Nova Olinda Formation, sample 19 in well 9-FZ-2-AM. **22–23**. *Idiognathodus amplificus* Lambert, 1992. MP-M 989 and 994, Itaituba Formation, sample 25 in well 1-FZ-1-AM. **24**. *Idiognathodus* aff. *claviformis* Gunnell, 1931. MP-M 1032, Itatiuba Formation, sample 4, well 2-PE-1-AM. **25–29**. *Idiognathodus crassadens* Stamm and Wardlaw, 2003. MP-P 1090, 1091, 1101, 1092 and 1095 from the Nova Olinda Formation, sample 19, well 9-FZ-2-AM.

Fig 3. *Idiognathodus* and *Streptognathodus* P1 elements from the Amazonas Basin. Scale bar is 200 µm. **1–2**. *Idiognathodus* aff. *crassadens* Stamm and Wardlaw, 2003. MP-M 1113 and 11141, Nova Olinda Formation, sample 27, well 9-FZ-2-AM. **3–5**. *Idiognathodus ignisitus* Stamm and Warrdlaw, 2003. MP-M 1141, 1140 and 1143, Nova Olinda Formation, sample 10, well 1-RX-6-AM. **6–7**. *Idiognathodus* cf. *ignisitus* Stamm and Warrdlaw, 2003. MP-M 1109–1110, Nova Olinda Formation, sample 27, well 9-FZ-2-AM. **8–9**. *Idiognathodus incurvus* Dunn, 1966 from the Itaituba Formation. MP-M 1044, sample 10 in well 2-SA-1-AM; 9: MP-M 1271, from sample 5.5 m in Calminas quarry. **10–12**. *Idiognathodus izvaricus* Nemyrovska, 2007. 10: MP-M 1008, Itaituba Formation, sample 34 in well 1-FZ-1-AM; 11: MP-M 994, Itaituba Formation, sample 25 in well 1-FZ-1-AM; 12: MP-M 1120, Nova Olinda Formation, sample 16, well 2-MN-1-AM. **13**. *Idiognathodus* cf. *klapperi* Lane and Straka, 1974. MP-M 923, Itaituba Formation sample 1, well 1-CM-2-PA. **14.** *Idiognathodus* cf.

sinuosus Ellison and Graves, 1941. MP-M 1119, Itaituba Formation, sample 14, well 1-TR-1-AM. **15–16**. *Idiognathodus* cf. *obliquus* Kossenko and Kozitskaya, 1978 from the Nova Olinda Formation. 15: MP-M 1102, sample 27, well 9-FZ-2-AM; 16: MP-M 1080, sample 17, well 1-FZ-1-AM. **17–18**. *Idiognathodus podolskiensis* Goreva, 1984. MP-M 1108 and 1111, Nova Olinda Formation, sample 27, well 9-FZ-2-AM. **19.** *Idiognathodus* cf. *praeobliquus* Nemyrovska, Perret-Mirouse and Alekseev, 1999. MP-M 949, Itaituba Formation, sample 2, well 2-CP-2-PA. **20**. *Idiognathodus rectus* Youngquist and Downs, 1949. MP-M 1103, Nova Olinda Formation, sample 27, well 1-FZ-1-AM. **21**. *Idiognathodus* sp. A Grubbs, 1984. MP-M 1025, Itaituba Formation, sample 34 in well 1-FZ-1-AM. **22–23**. *Idiognathodus* nov. sp. 1. MP-M 959–960, Itaituba Formation, sample 21, well 2-CP-2-PA. **24–25**. *Streptognathodus firmus* Kozitskaya, 1978 from the Nova Olinda Formation. 23: MP-M 1183, sample 7, well 9-FZ-2AM; 24: MP-M 1118, sample 183, well 9-FZ-28-AM. **26–27**. *Streptognathodus* sp. MP-M 1128–1129, Nova Olinda Formation, sample 4, well 1-NO-1-AM.

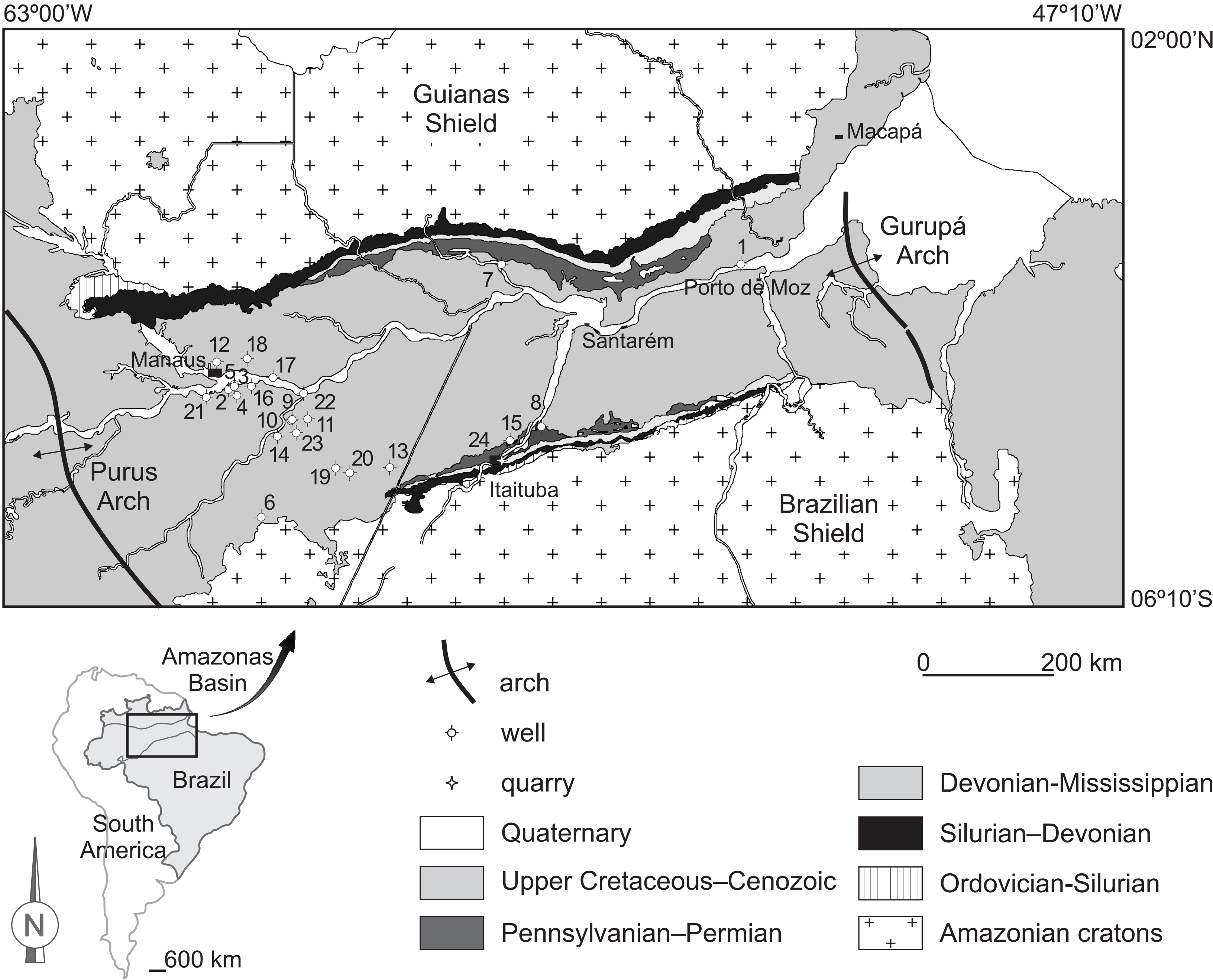
Fig 4. P1 elements of *Idiognathodus itaitubensis* nov. sp. All specimens come from the Itaituba Formation, except 5 and 16 from the Nova Olinda Formation. Scale bar is 200 μm. **1–2.** MP-M 948 and 950, sample 2, well 2-CP-2-PA. **3–4.** MP-M 955–956, sample 5, well 2-CP-2-PA. **5.** MP-M 1049, sample 16, well 1-RX-6-AM. **6–14.** MP-M 973– 976, 978–980 and 990–991, sample 25, well 1-FZ-1-AM; 7 is holotype and 6 and 8–13 are paratypes. **15.** MP-M 1013 from sample 34 in well 1-FZ-1-AM. **16.** MP-M 1119, sample 16, well 2-MN-1-AM.

Fig 5. P1 elements of '*Streptognathodus*' and *Neognathodus* from the Amazonas Basin. Scale bar is 200 μm. **1–2.**: '*Streptognathodus*' *expansus* Igo and Koike, 1964 from the Itaituba Formation. 1: MP-M 1122, sample 24, well 2-MN-1AM; 2: MP-M 1296, sample 6.6 m in Calminas quarry. **3**.'*Streptognathodus*' *parvus* Dunn, 1966. MP-M 1046, Itaituba Formation, sample 10, well 2-SA-1-AM. **4**. *Neognathodus bassleri* (Harris and Hollingsworth, 1933). MP-M 1165, Itaituba Formation, sample 9, well 1-AM-7-AM. **5**. *Neognathodus* cf. *askynensis*. MP-M 900, Itaituba Formation, sample 2 of well 1-AM-9-AM. **6–8**. *Neognathodus asymmetricus* (Stibane, 1967) sensu Barrick et al., 2004 from the Nova Olinda Formation, well 1-RX-6-AM. 6–7: MP-M 1146–1147, sample 10; 8: MP-M 1051 from sample 16. **9**. *Neognathodus bothrops* Merrill, 1972. MP-M 998, Itaituba Formation, sample 25, well 1-FZ-1-AM. **10–12**. *Neognathodus colombiensis* (Stibane, 1967). MP-M 1004, 1000 and 996, Itatituba Formation, sample 25, well 1-FZ-1-AM. **13**. *Neognathodus inaequalis* Kozitskaya and Kossenko, 1978. MP-M 1088, Nova Olinda Formation, sample 19, well 9-FZ-2-AM. **14–16**. *Neognathodus symmetricus* (Lane, 1967) from the Monte Alegre Formation. 14: MP-M 1160, sample 9, well 1-AM-7-AM; 15: MP-M 1166, sample 10, well 1-AM-9-AM; 16: Mp-M 1153, sample 3, well 1-AM-6-AM. **17–19**. *Neognathodus* sp. 1 Nemyrovska, 1999. 17: MP-M 1163–1164, Monte Alegre Formation, sample 9, well 1-AM-7-AM; 19: MP-M 915, Itaituba Formation, sample 6, well 2-CA-1-AM. **20**. *Neognathodus* nov. sp. 1, MP-M 919, Itaituba Formation, sample 6, well 2-CA-1-AM. **21**. *Neognathodus* sp. A Grayson, 1984. MP-M 1030, Itaituba Formation, sample 10, well 2-PC-1-AM. **22**. *Neognathodus tsnensis* Alekseev and Gerelzezeg, 2001. MP-M 997, Itaituba Formation, sample 25, well 1-FZ-1-AM. **23**. *Neognathodus uralicus* Nemirovskaya and Aleeksev, 1995. MP-M 1054, sample 16, well 1-UA-1-AM.

Fig. 6. Pennsylvanian worldwide palaeogeography redrawn from Scotese (2000), showing the primary migratory path normally accepted from the Palaeo-tethys Ocean (Eurasian–Arctic Realm) to the east part of the Panthalassic Ocean (Midcontinent–Andean Realm) (**1**) and the speculative connection through North Africa after Vai (2003) (**2**) and Baesemann et al. (1998) (**3**).

Table 1. Distribution of studied conodonts in localities and samples of the Itaituba (I), Monte Alegre (MA) and Nova Olinda (NO) formations.

Figure 1


63º00'W
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Manaus
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South America
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arch
well
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Pennsylvanian–Permian
Devonian-Mississippian
Silurian–Devonian
Ordovician-Silurian
Amazonian cratons

Figure 2

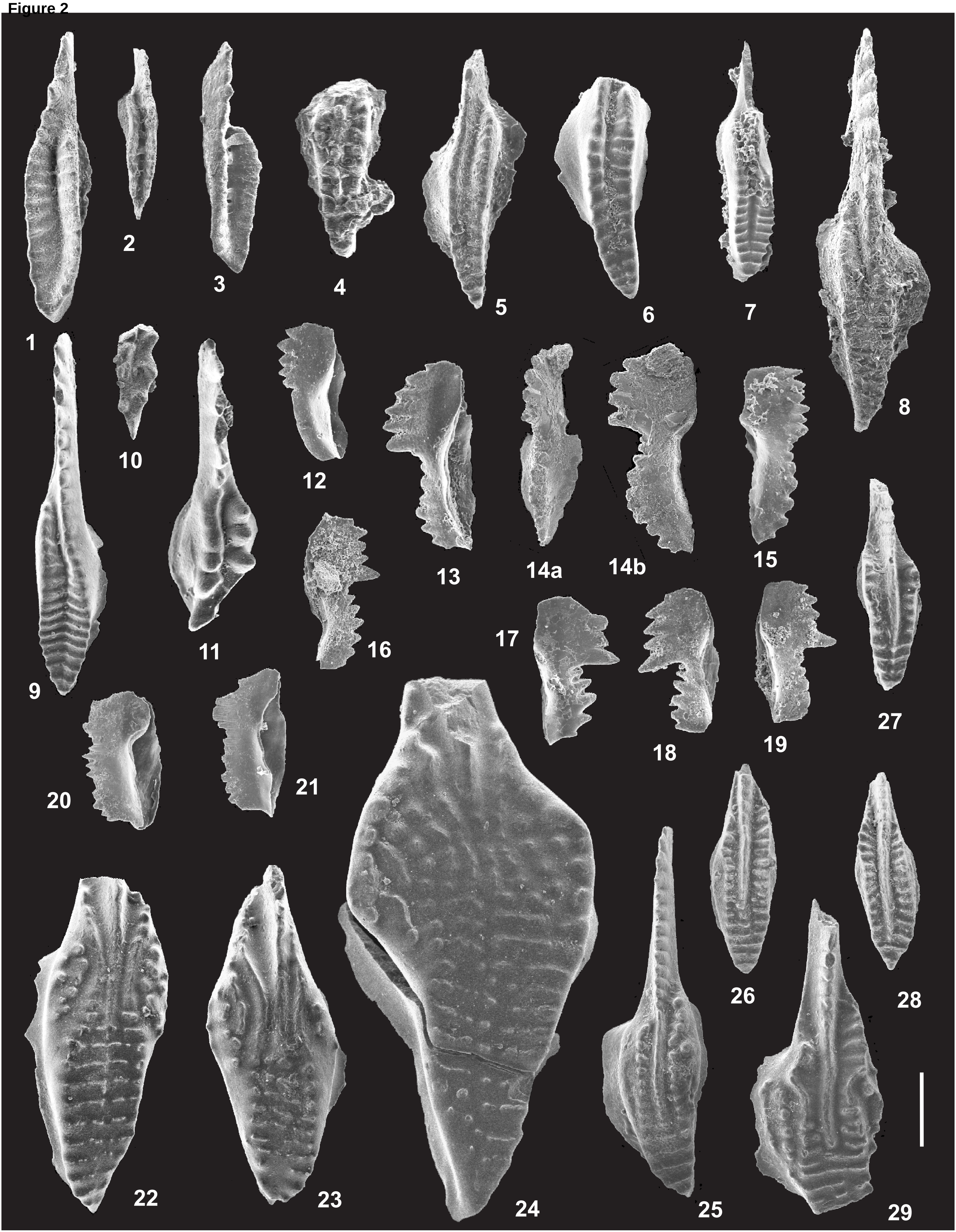
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Figure 3

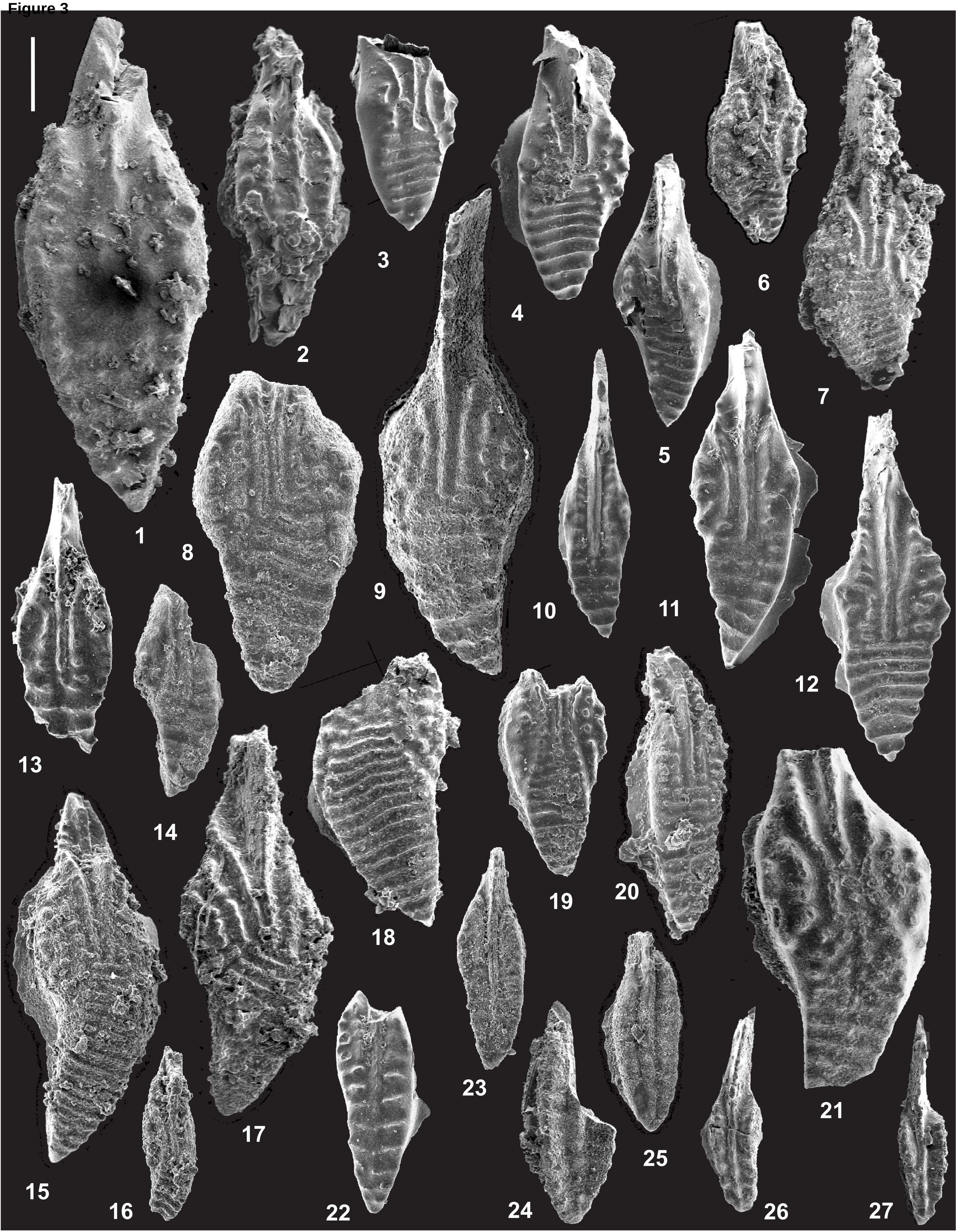

Figure 4

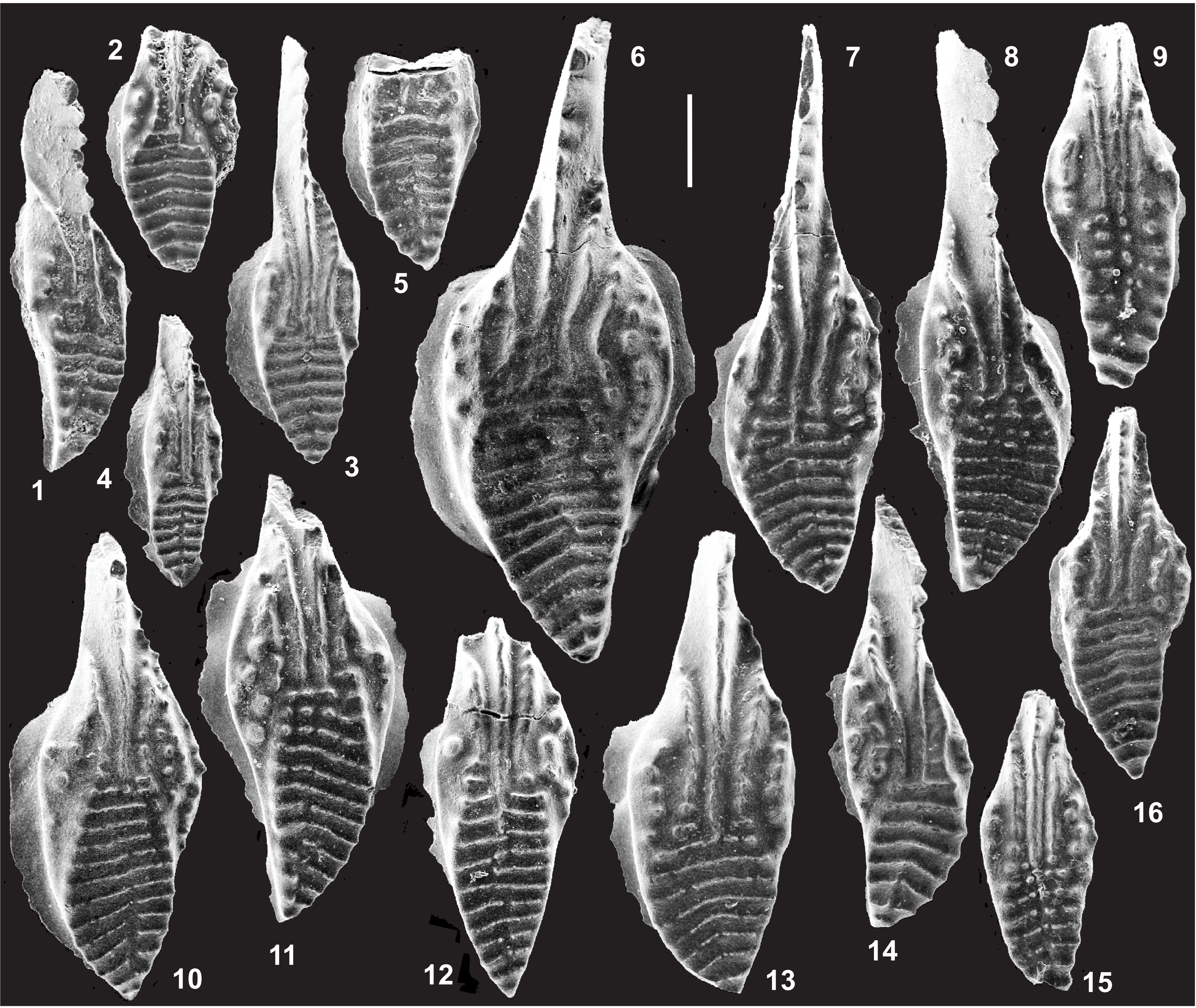

Figure 5

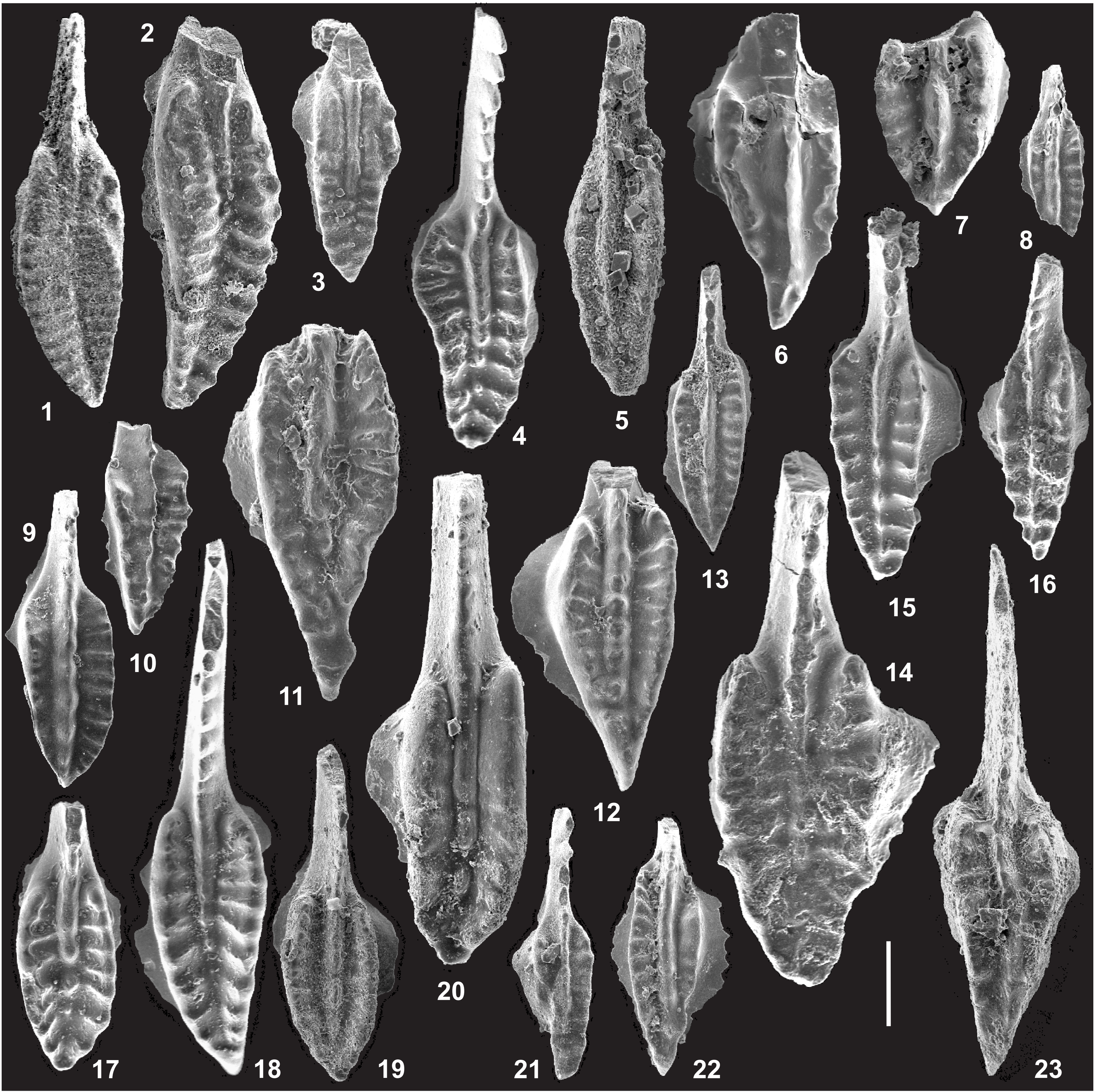

Figure 6

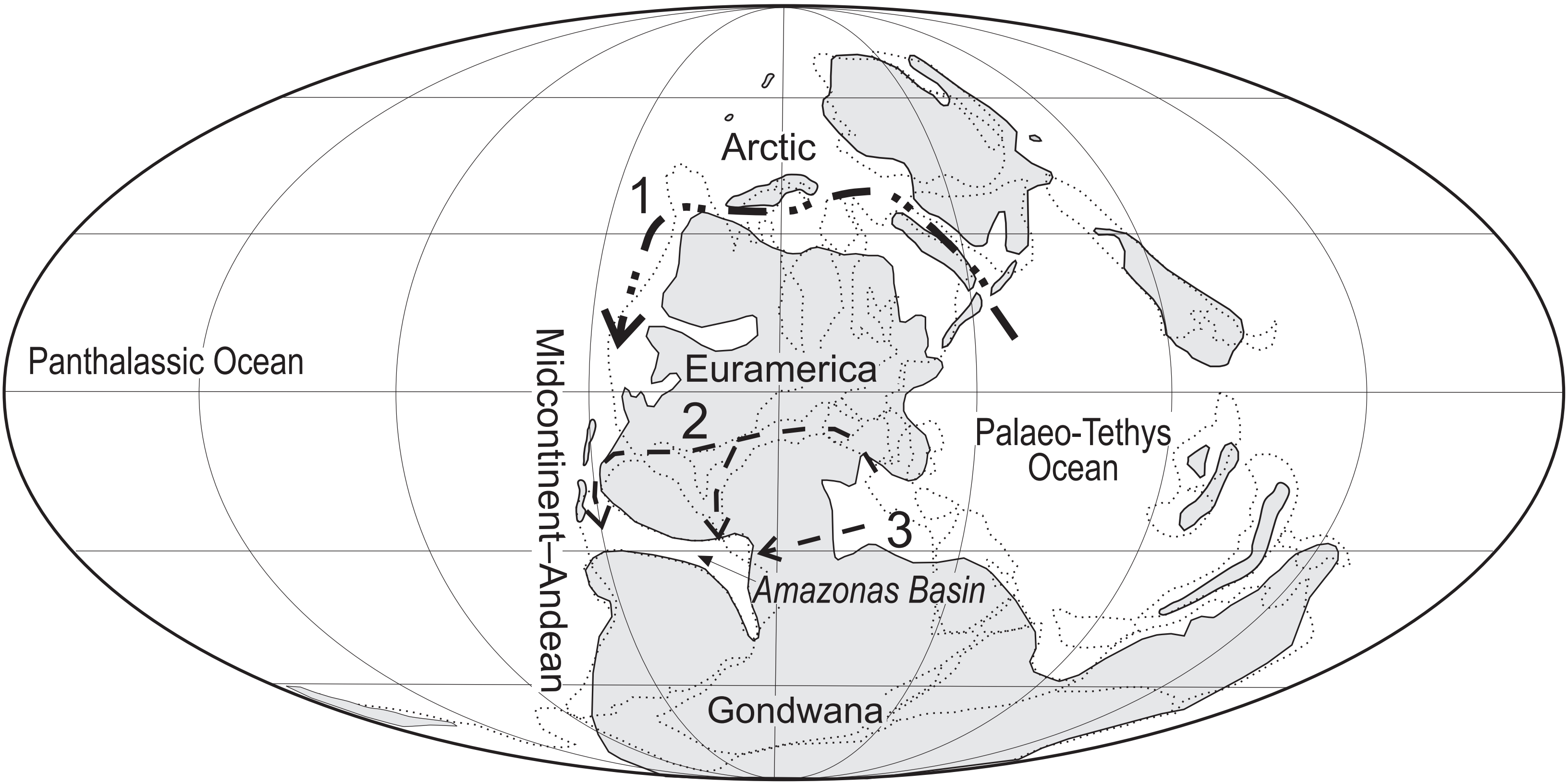
Arctic
1
Panthalassic Ocean
Euramerica
Midcontinent–Andean
2
Palaeo-Tethys
Ocean
3
Amazonas Basin
Gondwana

Table 1

locality reference	well/outcrop	depth (m)	conodonts sample	*Adetognathus lautus* (Gunnell, 1933)	*Adetognathus flexus* (Ellison, 1941)	*Adetognathus* sp.	*Declinognathodus* cf. *marginodosus* (Grayson, 1984)	*Diplognathodus coloradensis* (Murray & Chronic, 1965)	*Diplognathodus ellesmerensis* Bender, 1980	*Diplognathodus* cf. *ellesmerensis* Bender, 1980	*Diplognathodus orphanus* (Merrill, 1973)	*Diplognathodus* aff. *orphanus* (Merrill, 1973)	*Diplognathodus iowensis* Swade, 1985	*Diplognathodus* sp.	*Ellisonia latilaminata* von Bitter & Merrill, 1983	*Ellisonia* sp.	*Hindeodus* sp.	*Idiognathodus amplificus* Lambert, 1992	*Idiognathodus* aff. *claviformis* Gunnell, 1931	*Idiognathodus crassadens* Stamm & Wardlaw, 2003	*Idiognathodus* aff. *crassadens* Stamm & Wardlaw, 2003	*Idiognathodus ignisitus* Stamm & Wardlaw, 2003	*Idiognathodus* cf. *ignisitus* Stamm & Wardlaw, 2003	*Idiognathodus incurvus* Dunn, 1966	*Idiognathodus* cf. *incurvus* Dunn, 1966	*Idiognathodus itaitubensis* nov. sp.	*Idiognathodus izvaricus* Nemyrovska, 2007	*Idiognathodus* cf. *klapperi* Lane & Straka, 1974	*Idiognathodus* cf. *obliquus* Kossenko & Kozitskaya, 1978	*Idiognathodus podolskensis* Goreva, 1984	*Idiognathodus* cf. *praeobliquus* Nemyrovska et al., 1999	*Idiognathodus rectus* Youngquist & Downs, 1949	*Idiognathodus* cf. *sinuosus* Ellison & Graves, 1941	*Idiognathodus* sp. A Grubbs, 1984	*Idiognathodus* nov. sp. 1	*Idiognathodus* sp.	*Idiognathoides corrugatus* (Harris & Hollingsworth, 1933)	*Idiognathoides lanei* Nemirovskaya, 1978	*Idiognathoides ouachitensis* (Harlton, 1933)	DE *Idiognathoides sinuatus* Harris & Hollingsworth, 1933	*Idiognathoides* sp.	*Idiopriniodus* sp.	*Neognathodus* cf. *askynensis* Nemirovskaya & Alekseev, 1995	*Neognathodus asymmetricus* (Stibane, 1967)	*Neognathodus bassleri* (Harris & Hollingsworth, 1933)	*Neognathodus bothrops* Merrill, 1972	*Neognathodus* cf. *bothrops* Merrill, 1972	*Neognathodus colombiensis* (Stibane, 1967)	*Neognathodus inaequalis* Kozitskaya & Kossenko, 1978	*Neognathodus symmetricus* (Lane, 1967)	*Neognathodus* cf. *symmetricus* (Lane, 1967)	*Neognathodus tsnensis* Alekseek & Gerelzezeg, 2001	*Neognathodus uralicus* Nemirovskaya & Aleeksev, 1995	*Neognathodus* sp. 1 Nemyrovska, 1999	*Neognathodus* sp. A Grayson 1984	*Neognathodus* nov. sp. 1	*Rachistognathus muricatus* (Dunn, 1965)	*Streptognathodus firmus* Kozitskaya, 1978	*Streptognathodus* sp.	*Streptognathodus' expansus* Igo & Koike, 1964	*Streptognathodus' parvus* Dunn, 1966	unidentified element
1	2-AL-1-PA	1933–1935	34 (I)	1																																																									
2	1-AM-1-AM	1153-1157.7	4 (MA)																																														1												
3	1-AM-6-AM	1100–1103	3 (MA)																																														1												
		1103–1106	4 (MA)																																														3												
4	1-AM-7-AM	1175–1178	9 (MA)	1																																									1					4				3								
5	1-AM-9-AM	1081–1085.5	2 (I)	1																																							1							3	1			1								
		1085.5–1088	3 (I)	1																																																									
		1088–1090.5	4 (I)			1																																																							
		1100–1102.5	9 (I)																																	2					1								4	1										1	1
		1102.5–1105	10 (MA)	3																																														6							3					
		1105–1106.5	11 (MA)																																														1												1
		1106.5–1110	12 (MA)	3																																														2												
		1110–1112.5	13 (MA)																																														1												
		1112.5–1115.5	14 (MA)																																														1												
		1115.5–1117.5	15 (MA)																																															1											
		1119–1123	17 (MA)			1																																		1																					
6	2-CA-1-AM	327–330	2 (I)																																			1	2																						1
		380–381.5	3 (I)																																				1																						
		538–542	6 (I)																																									1						1			2		1						1
7	1-CM-2-PA	170.5–175	1 (I)				3	4		6																1									1		1	1																						
		179–183	3 (I)	2					6		1	8																										1																							
		183-186	4 (I)								1	1																										1																							
8	2-CP-2-PA	633–638.5	2 (I)																					1	4					1																														
		650.5–654.5	5 (I)				4																	3																																				
		665–669	21 (I)				5																			1							2		2	1	4	2																					1	
		802–806.5	22 (I)				4																															5																					
9	1-FZ-1-AM	1669–1673	17 (NO)																						2			6							2																										1
		1923.5–1926.5	19 (I)	1							1																3																																			
		1943–1946	25 (I)				1										2								3	1																		2	2	5				1									
		1963–1966	31 (I)												1																																														1
		1973–1976	34 (I)					1		2														1	1	1	1				1			1				3	1																					
		2005–2010	40 (I)										2										1																																				
		2051–2056	41 (I)																																			cf.																						
10	9-FZ-2-AM	1062–1068	7 (NO)																																1																					1				
		1183–1201	19 (NO)									4						12		2																												2													
		1648.5–1666	27 (NO)																	2		2			3			2	4		1				1																										1
		1680–1691	29 (NO)																							1																																		
		1834–1846	31 (NO)																						cf.																																			
11	9-FZ-28-AM	1003.5	183 (NO)																																																						1				
		1085–1103	190 (NO)																																																										1
12	2-MN-1-AM	509.5–515	11 (NO)																																																										1
		530–534.5	16 (NO)																						1	1																																		
		816–819	23 (I)																																				1																						
		867–871.5	24 (I)																					1							1																										1	1	
13	2-MS-4-AM	974.5–976.8	5 (I)																																																										1
14	1-NO-1-AM	950–956	2 (NO)																																																										1
		960–966	4 (NO)		1																																																					3			
		970–976	6 (NO)																																																										1
15	1-PB-1PA	205–210	8 (MA)	1																																													1												
16	2-PC-1-AM	618.5–621.5	4 (NO)																						3																																			
		1060–1062	10(I)																																																			1							
		1137.5–1140	21(I)																																														1												
17	2-PE-1-AM	810–812	2 (NO)																						3																																			
		926–929	4 (I)															1																																										
18	2-PE-2-AM	815–818.5	2 (I)	1																																1																									
		818.5–821	3 (I)																																															3											
		828–831.5	6 (I)																																															1											
19	1-RX-1-AM	1553.5–1555	71 (NO)																						cf.																																			1
20	1-RX-6-AM	1558.7–1590.4	10 (NO)																		4				cf.				3													2																		
		1689–1693	16 (NO)																						cf.	1																1																		
		1696–1699	18 (NO)																																																										4
		1699–1703.1	19 (NO)																																																										6
		1925–1927	21 (NO)																																																										1
		1947–1950	24 (NO)																																								1																		
21	2-SA-1-AM	1116–1121	10 (I)	1							1												2																3																				2	
22	1-TR-1-AM	1682–1686.5	5 (NO)																																																										1
		2019.5–2014	13 (I)																																	1																									
		2051.5–2055	14 (I)																													1																													
23	1-UA-1-AM	2423–2426	8 (NO)			1																																																							1
		2552–2555	12 (I)																																																											
		2710–2713.5	16 (I)																																																		1									
		2856–2859.5	19 (MA)				1																												1														1												
24	Calminas quarry	15.35 m (I)																																																												
			14.8 m (I)	1				1						1										1														1		1																		1	1	
			14.6 m (I)																																																								1		
			14.2 m (I)											1																										1																				1		4
			10.2 m (I)											1			1																						1		1																					
			8.7 m (I)											1																																																
			7.05 m (I)					1																																																					
			7.0 (I)																																																											
			6.6 m (I)	1							2			1																																														3		1
			6.5 m (I)																																																										2
			5.85 m (I)						1																																																				
			5.5 m (I)	1					2	5	4	14		5		1								1								1			1	1														1										8
			5.02 m (I)						2		1			1										2									1																			2										1
			4.7 m (I)								5				1										1																1																						1
			4.0 (I)																																																											
			2.0 (I)																																																											
			1.0 (I)																																																											
			0.0 m (I)																																																											

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 ADMINISTRATOR NOTICE: The query to URIBL was blocked. See
 http://wiki.apache.org/spamassassin/DnsBlocklists#dnsbl-block for more
 information. [URIs: elsevier.com] -0.0 SPF_PASS              SPF: sender
 matches SPF record 0.8 BAYES_50             BODY: Bayes spam probability is
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Cardoso, C.N., Sanz-López, J., Blanco-Ferrera, S., Lemos, V.B. Scomazzon, A.K., 2015b. ***Conodont colour alteration index and upper Paleozoic thermal history of the Amazonas Basin, Brazil***. Journal of South American Earth Sciences, 64, 139-151.

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Conodont color alteration index and upper Paleozoic thermal history of the Amazonas Basin, Brazil

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Contact metamorphism

ABSTRACT

The conodont color alteration index (CAI) was determined in elements from core samples of the Frasnian Barreirinha Formation (one well) and of the Pennsylvanian–Permian Tapajós Group (twenty three wells and one limestone quarry) in the Amazonas Basin. The thermal history of the basin is analyzed using the CAI value distribution represented in maps and stratigraphic sections through correlation schemes, and in conjunction with previously published data. The pattern of palaeotemperatures for CAI values of 1.5–3 is coincident with organic matter maturation under a sedimentary overburden providing diagenetic conditions in the oil/gas window. Locally, conodonts show metamorphism (CAI value of 6–7) in relation to the intrusion of diabase bodies in beds including high geothermal gradient evaporites. Microtextural alteration on the surface conodonts commonly shows several types of overgrowth microtextures developed in diagenetic conditions. Locally, recrystallization in conodonts with a high CAI value is congruent with contact metamorphism in relation to Mesozoic intrusions. The CAI values of 1.5 or 2 observed close to the surface in several areas of the basin may be interpreted in relation to a high thermal palaeogradient derived from the magmatic episode or/and to the local denudation of the upper part of the Paleozoic succession prior to this thermal event.

1. Introduction

The conodont color alteration index (CAI) allows us to determine maximum palaeotemperatures affecting rocks and gives evidence to establish the thermal history of a basin, particularly for rocks between diagenetic and lower metamorphism grades (Epstein et al., 1977; Rejebian et al., 1987). It is an important implement in economic geology, because it is used to explore the hydrocarbon potential and the influence of hydrothermal activity in Paleozoic to Triassic basins. Evaluation of the oil source potential in the intracratonic Amazonas Basin stemmed from the creation of Brazilian oil Company (Petrobras). Subsurface study led to the discovery of a few oil and gas reservoirs or evidences in the Paleozoic rocks covered by a minor thickness of Mesozoic–Cenozoic strata. Gonzaga et al. (2000) evaluated the oil source potential on the basis on geochemical methods, including elemental and visual kerogen analysis of oil, gas and rock, rock–Eval pyrolysis, gas chromatography and mass spectrometry. The same authors suggested a thermal evolution of the basin, integrating data from the spore coloration index, vitrinite reflectance and fluorescence, T max and sterane isomerization ratios. With this background, CAI values in Paleozoic conodonts from samples of the Amazonas Basin were preliminarily analyzed (Rocha Campos et al., 1988; Scomazzon, 2004; Nascimento, 2008; Cardoso, 2010; Cardoso et al., 2012), although conodont color was compared with published color charts rather than a standard slide of conodonts. The pioneering study of Rocha Campos et al. (1988) determined CAI values ranging from 1 to >5 and related them to overburden due to the Paleozoic rocks. Some inconsistent results with respect to the Paleozoic sedimentary thickness could be caused by uplift and local erosion of the sedimentary succession or, more probably, by younger heating associated with intrusion emplacement. The more recent studies confirmed the range of variation of the CAI value and separated them into two clusters, 1.5–2 and 4–5. Apart from the CAI value, Nascimento (2008) studied the conodont texture, from a prevailing smooth but locally sugary to a granular texture, which the author locally associated with fluid activity. Later,

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Cardoso (2010), Cardoso et al. (2012) illustrated textures and microtextures (in the sense of Blanco-Ferrera et al., 2011) developed on many of the studied conodonts, in spite of their low CAI values, indicating diagenetic conditions.

The aim of the present study is to apply the CAI determination to the Amazonas Basin through analysis of eighty-six available samples from twenty-three wells and an outcrop. Their variation is analyzed on a simplified geological map and cross-sections for different Paleozoic lithostratigraphic units. The CAI values are complemented by the changes observed on the conodont surface through the study of texture and microtexture; all these data are then integrated into the basin tectonothermal history.

2. Geological setting

The Amazonas Basin is an intracratonic, east–west elongated syneclise in northern Brazil, bounded to the north and south, by the Precambrian Guianas and Central Brazil shields, respectively (Fig. 1). The Amazonas Basin is separated from the Solimões Basin by the Purus Arch in the west, and from the Marajó Basin by the Gurupá Arch in the east, transverse structures that conditioned its sedimentation and filling (Fig. 2). It is mostly filled by Paleozoic rocks and occupies an area of 500,000 km^2 in the Amazonas, Pará, and Amapá states (Gonzaga et al., 2000). Despite its large dimensions, Paleozoic rocks are rarely seen in outcrops there due to the widespread overlying Mesozoic and Cenozoic sedimentary cover and the dense Amazonian rainforest. Consequently, the study of the Amazonian rocks is mostly based on subsurface wells and seismic data. The Paleozoic succession extends for more than 5000 m in the deeper central basin, whereas the thickness decreases towards relatively shallow ramps, the so-called North and South Platforms (Fig. 2; Neves, 1990; Cunha et al., 1994; Gonzaga et al., 2000; Wanderley-Filho et al., 2010). Interaction between normal NE–SW trending faults and NW–SE trending transfer faults subdivided the basin into a series of long segments with ENE–WSW orientation, which alternate with shorter segments of E–W trend (Wanderley-Filho et al., 2005, 2010).

Paleozoic strata consist of several sequences limited by regional unconformities (Neves, 1990; Cunha et al., 1994, 2007; Matsuda et al., 2004; and the papers cited therein). The oldest sequence comprises the Upper Ordovician–Lower Devonian Trombetas Group including up 1100 m of glacial and marine strata. It includes the Silurian Pitinga Formation, which contains a hydrocarbon source rock in the basal part (Carozzi, 1979; Gonzaga et al., 2000). It is followed by up to 1320 m of upper Emsian–Tournaisian strata making up the Urupadi and Curuá groups. The Upper Devonian–Mississippian Curuá Group contains up to 75 m of shales rich in organic matter at the lower part of the Barreirinha Formation (Frasnian–middle Famennian). The high content in type II organic matter makes it the main hydrocarbon source rock interval of the Amazonas Basin (Carozzi, 1979; Gonzaga et al., 2000).

A regional unconformity exists at the base of the Pennsylvanian–Permian Tapajós Group, which reaches up to 2800 m in thickness. The older 5–140 m corresponds to the Monte Alegre Formation, which consists of fluvial to aeolian sandstones, marine littoral to lacustrine siltstone to shales. A Bashkirian age is considered on the basis of the conodont, foraminifer and palynoflora content (Lemos, 1992a, b; Altiner and Savini, 1995; Playford and Dino, 2000, 2005). Adjacent to and above the Monte Alegre Formation, the Itaituba Formation consists of up 420 m of marine

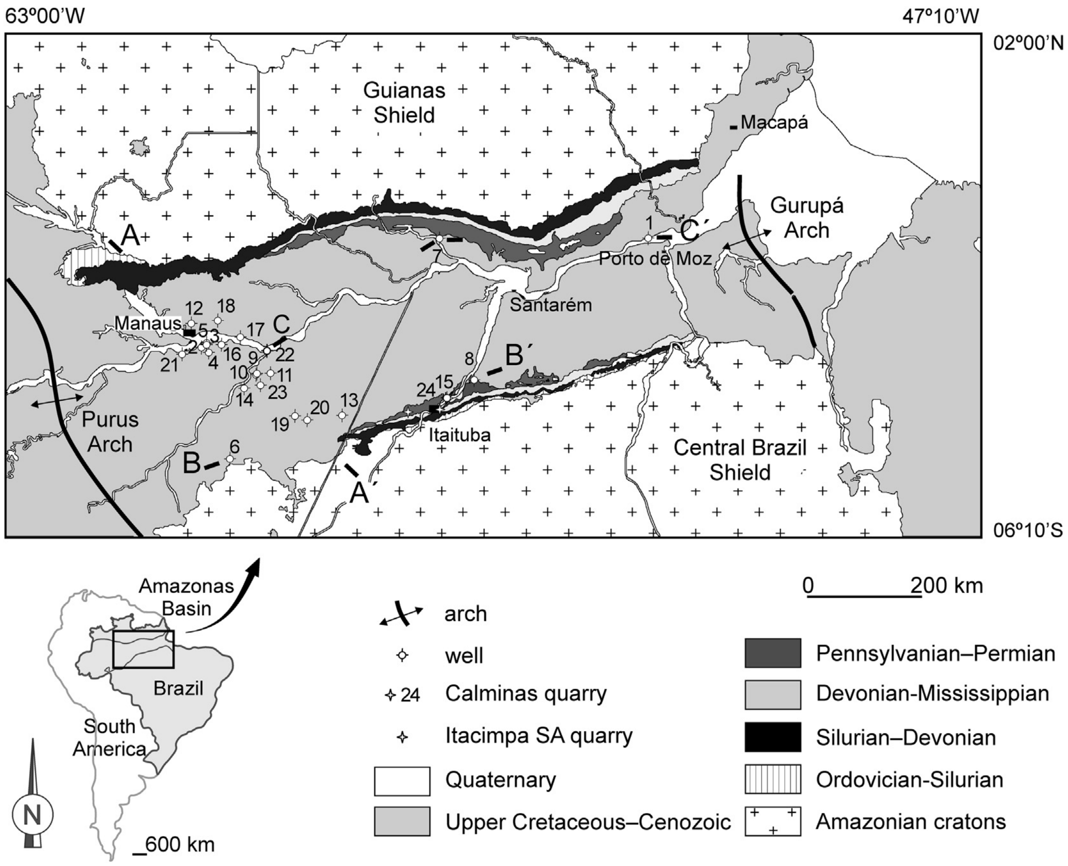

Fig. 1. Map of the Amazonas Basin showing marginal Paleozoic outcrop belts (modified from Matsuda et al., 2010) and location of the studied wells and quarries (numbers 1–24 in accordance with the list included in Table 1). Location of the cross-sections A–A′ of Fig. 3, B–B′ and C–C′ of Fig. 4.

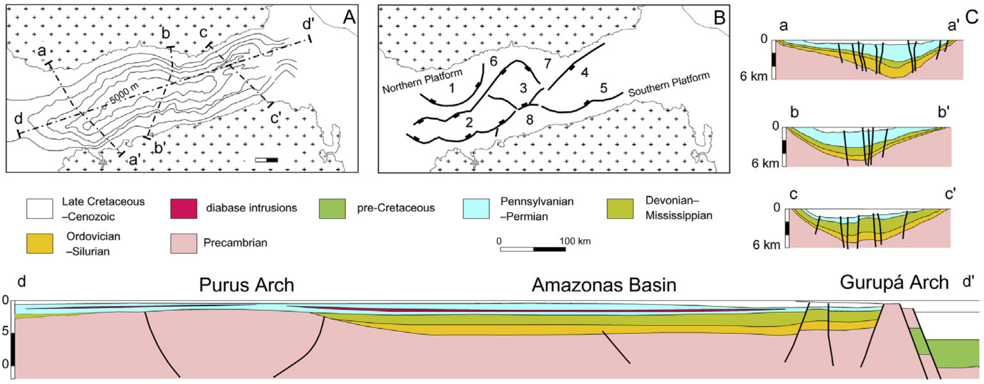

Fig. 2. **A**, Contour map of the Precambrian basement depth in the Amazonas Basin after Gonzaga et al. (2000) with the location of geological cross sections. **B**, tectonic scheme with half-grabens (1, Manaus; 2, Abacaxis; 3, Oriximiná, 4, Monte Alegre; and 5, Tucumá), and platforms (6, Manaus; 7, Cuminá; and 8, Mamuru), according to Coutinho and Gonzaga (1996). C, a–a′ to c–c′, and d–d′, geological cross sections according to Gonzaga et al. (2000) and Wanderley-Filho et al. (2005), respectively.

carbonate beds grading upward to shales, sandstone and anhydrites. The Itaituba Formation shows a gradational upper boundary with the Nova Olinda Formation, which consists of up to 1200 m of hypersaline marine with sabkha deposits (anhydrite and halite). A probable Bashkirian to Moscovian, Gzhelian or early Permian age is considered on the basis of conodonts, foraminifers and miospores (Lemos, 1990, 1992a, b; Altiner and Savini, 1995; Playford and Dino, 2005). The overlying Andirá Formation is composed of Permian red beds, up to 700 m thick (Playford and Dino, 2000; Cunha et al., 2007).

The Paleozoic sedimentation ended in an episode of transcurrent deformation in the Permian–Triassic (Santos et al., 2011) and later, a complex of diabase sills and dikes intruded in significant volumes throughout the basin. It corresponds to the magmatic Penatecaua episode, dated at Late Triassic to Early Jurassic (204–179 Ma according to Santos et al., 2002; Wanderley-Filho et al., 2005). This episode is tholeiitic in nature and consists of a mid-oceanic ridge basal (MORB) type quartz diabase that formed during the opening of the Central Atlantic Ocean (Almeida, 1986; Gonzaga et al., 2000; Cunha et al., 2007; Wanderley-Filho et al., 2010). The intrusive bodies are mainly sills, about 500 m in thickness (maximum 915 m), hundreds of kilometers in extent, and which reached temperatures close to 1000 °C, according to Wanderley-Filho et al. (2006). They were mainly emplaced in the evaporite rocks of the Nova Olinda Formation in the western part of the basin whereas they are found at all levels of the sedimentary sequence in the eastern part (Mosmann et al., 1986; Gonzaga et al., 2000).

An erosive hiatus spanning the Triassic–Early Cretaceous is largely explained by the fact that Late Cretaceous uplift occurred, according apatite fission track studies (Neves, 1990). This uplift seems to be associated with the inversion of structures, development of asymmetric folds and northeast-trending faults, all of them of the so-called Juruá transpressional tectonic event, which relates to the opening of the Equatorial Atlantic Ocean. Deformation contributed to the remobilization of hydrocarbon and to the formation of structural traps (Neves, 1990). Deposition of lacustrine and fluvial systems (Alter do Chão Formation) with drainage towards the Pacific Ocean and the Caribbean Sea occurred during the Late Cretaceous. It only locally exceeds 400 m in thickness in the central part of the Amazonas Basin and increases westwards, in the Peruvian Basin. The Cenozoic is represented by a thin layer of continental deposits near the Purus Arch in the west, and approximately 1000 m thick succession at the easternmost boundary with the Marajó Basin (Mosmann et al., 1986). Some structures show reactivation in relation to the Andean Cordillera formation and late Paleogene to Holocene deformation of Cenozoic sediments due to transpressional and transtensional structures (Neves, 1990; Gonzaga et al., 2000; Santos et al., 2011).

3. Material and methods

Seventy six samples (0.3–0.5 kg each one) of limestone, shale, siltstone, sandstone, mudstone and dolomite rocks from twenty three PETROBRAS drilled wells and twelve samples from the Calminas limestone quarry outcrop (Fig. 1) were processed using buffered solutions of acetic acid following the methodology of Jeppsson and Anehus (1995) and Jeppsson et al. (1999). The study of the color alteration index of the conodonts in this work is restricted to available core samples in each well (Figs. 3–4; Table 1). The samples come between few hundred meters above sea level to 3000 m below it. The Calminas quarry section reaches 18 m thick. One sample comes from the Frasnian Barreirinha Formation (Cardoso et al., 2015) and the rest range from the Pennsylvanian to probable lower Permian recorded between the Monte Alegre and the Nova Olinda formations.

The CAI values of one thousand six hundred and ninety conodonts of the Amazonas Basin were determined through conodont color using a standard slide kindly provided by Anita Harris (US Geological Survey, recently deceased). The value was measured both in slender and/or immature and in large and/or mature specimens, and from different lithologies. Consequently, results must take in account the variation in values associated with conodont size and lithology. The methodology used for determining CAI is described in García-López et al. (1997) and Bastida et al. (1999). At each locality, the CAI value was used in schemes of correlation between the stratigraphic sections and also for contouring the CAI data on isograd maps. For maturation/metamorphism zonation purposes, the terms defined by García-López et al. (2001): diacaizone ($\mathrm{CAI} < 4$), ancaizone ($4 \leq \mathrm{CAI} \leq 5.5$) and epicaizone ($\mathrm{CAI} > 5.5$) are used.

Temperature ranges of the CAI values were obtained from the Arrhenius plot presented by Rejebian et al. (1987). Heating times are discussed further on in the text.

Conodont texture and the variation in the CAI values within a sample, and among neighboring samples, may help to distinguish grades and types of diagenesis and metamorphism. Hence, about three hundred specimens with different surface alteration were observed under the scanning electronic microscope. Microtextures were differentiated in accordance with Blanco-Ferrera et al. (2011), Sanz-López and Blanco-Ferrera (2012). Nevertheless, the CAI, textural and microtextural features must be compared with

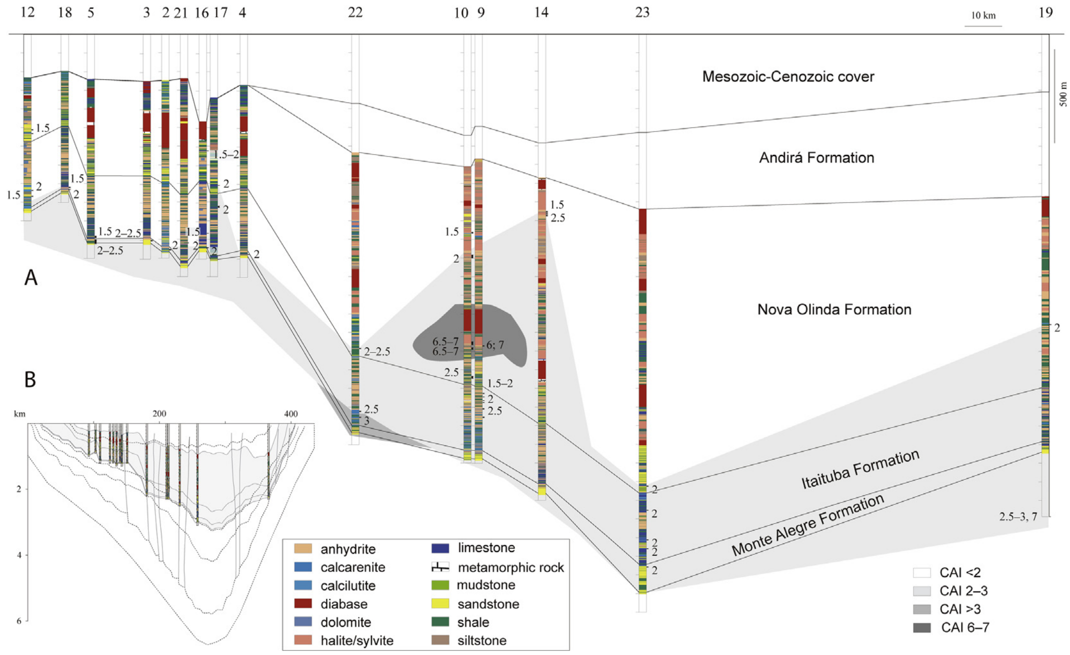

Fig. 3. **A**, Simplified logs of the Petrobras drilled wells with the location of the core samples and the CAI values 1 to 7 along the cross-section A–A'. Location of the cross-section and the drilling holes in Fig. 1. **B**, Position of the logs of the Monte Alegre, Itaituba and Nova Olinda formations (dashed grey) in the cross section a–a′ of Fig. 2C.

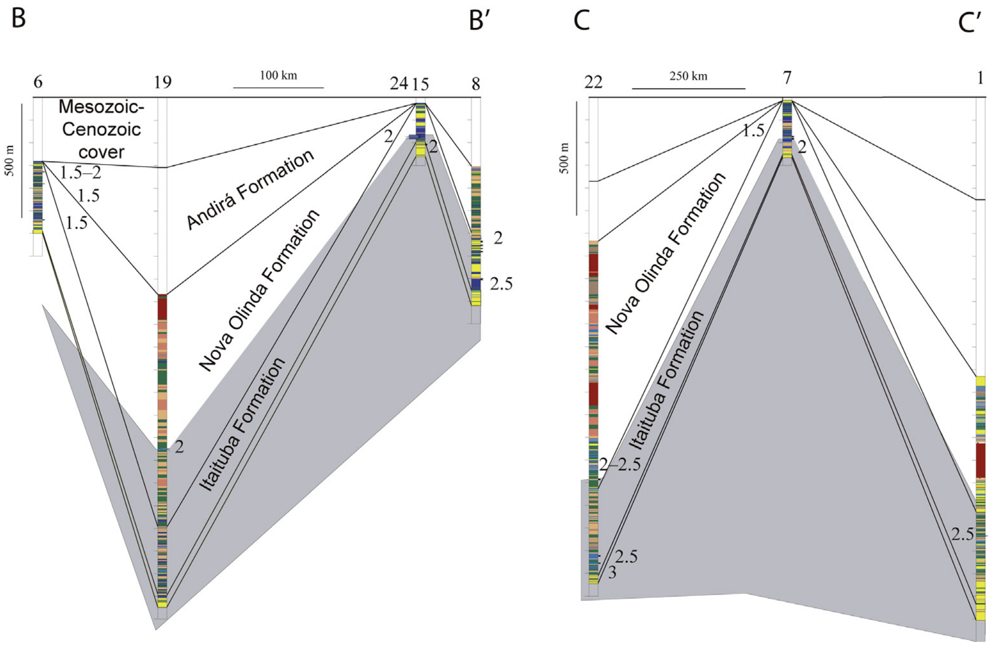

Fig. 4. Simplified logs of the Petrobras drilled wells with the location of the core samples and the CAI values 1.5 to 3 along the cross-section B–B′ and C–C′. Location of the cross-sections and the drilling holes in Fig. 1. Legend is in Fig. 3.

caution, since conodonts were recovered from distinct lithologies.

The studied specimens are stored in the repository of the Laboratório de conodontes, Universidade Federal do Rio Grande do Sul (Porto Alegre, Brazil) with the abbreviated catalog notation MP-M 895 to MP-M 1347.

4. Results

The CAI value for each sample was used to correlate CAI fields between the stratigraphic sections obtained from the wells and to analyze five map schemes of CAI isolines for the Barreirinha, Monte Alegre, lower and upper parts of the Itaituba and Nova Olinda formations (Fig. 5A–E).

The core sample of the Barreirinha Formation (well 19, Fig. 5A) contains a few conodonts with a CAI value of 2.5 and 3, and other ones with an anomalous value of 7 (Table 1). Thirteen conodont core samples from the Monte Alegre Formation show prevailing CAI value of 2 (Fig. 5B, Table 1), varying from 1.5 to 2 (wells 4, 15 and 23), to 2 (wells 2, 4 and 23), 2–2.5 (well 3) and 1.5 to 3 (well 5). Value 2.5 (well 8) shows shift eastwards of the maturation grade

Table 1
Conodont color alteration index (CAI) values and palaeotemperatures inferred from the CAI Arrhenius plot (Epstein et al., 1977; Rejebian et al., 1987) for the studied samples, and corresponding stratigraphic unit, stage, CAI (number) of conodonts, mode of CAI for sample, textures and microtextures.

Locality	Well/ outcrop	Formation	Core/ sample	Depth (m)	Lithology	CAI of conodonts	CAI mode	Temperature range °C	Texture (stereoscopic microscope)	Microtextures (SEM)
1	2-AL-1-PA	Itaituba (Upper)	34	1933–1935	Limestone	2.5 (1)	2.5	70–115	Bright smooth; bright and dusty sugary; mineral overgrowth; bleached; patina	
2	1-AM-1-AM	Monte Alegre	4	1153–1157.7	Limestone/ shale	2 (3)	2	45–75	Large free blade: dusty sugary; organic matter	External cast, irregular envelope
3	1-AM-6-AM	Monte Alegre	3	1100–1103	Sandstone	2 (3 free blade); 2.5 (4 platform)	2–2.5	60–100	Platforms: bright sugary; mineral overgrowth; mineral coating; bleached; organic matter	Original ornamentation; small crystal, external casts; irregular envelope
			4	1103–1106	Sandstone	2 (2 small); 2.5 (12 large specimens)	2.5	60–100	large specimens: bright sugary; minerals overgrowth; bleached	External cast, irregular envelope
4	1-AM-7-AM	Monte Alegre	9	1175–1178	Limestone/ siltstone	2 (26)	2	45–75	Bright smooth; bright and dusty sugary; minerals overgrowth; minerals coating; bleached; grey and white patina	Original, incipient small crystal; corrosion; irregular envelope
5	1-AM-9-AM	Itaituba (Lower part)	2	1081–1085.5	Shale	1.5 (85)	1.5	<40–50	Incipient dusty sugary; mineral overgrowth developed just on platforms on parapets and grooves, and the basal cavity	Large crystal, external cast; irregular envelope, dolomite pseudomorphs
			3	1085.5–1088	Shale	2 (5)	2	<40–75	Bright smooth and incipient dusty sugary	Small crystal to large crystal; irregular envelope
			4	1088–1090.5	Limestone	1.5 (1)	1.5	<40–50	Slender platform fragment: bright smooth; incipient dusty sugary; mineral overgrowth	
			9	1100–1102.5	Mudstone	1.5 (16); 2 (10 larger specimens)	1.5–2	<40–50	Bright smooth and/or bright sugary; mineral overgrowth on carina and transverse ridges; full mineral coating	Small crystal; irregular envelope with dolomite
		Monte Alegre	10	1102.5–1105	Mudstone	1.5 (28); 2 (30 large)	1.5–2	<40–75	Bright smooth and/or incipient bright sugary; mineral overgrowth on carina and basal cavity	Small crystal, external casts; irregular envelope
			11	1105–1106.5	Mudstone/ limestone	1.5 (3); 2 (4)	1.5–2	<40–75	Bright smooth; incipient bright sugary; mineral overgrowth on carina and base of teeth	Small crystal: irregular envelope
			12	1106.5–1110	Shale	2 (8)	2	45–75	Bright smooth; bright sugary; mineral overgrowth on grooves and along the carina; organic matter	Small crystal: irregular envelope
			13	1110–1112.5	Shale	2.5 (2)	2.5	70–115	Large specimens: bright smooth; bright sugary; grey patina on transverse ridges; organic matter	Small crystal; corrosion
			14	1112.5–1115.5	Shale	2 (1)	2	45–75	Bright sugary	
			15	1115.5–1117.5	Siltstone	3 (2)	3	108–188	large specimens: bright sugary; mineral overgrowth	Small crystal; corrosion; irregular envelope
			17	1119–1123	Shale/ sandstone	2.5 (2)	2.5	70–115	Bright smooth; bright sugary	
6	2-CA-1-AM	Itaituba (Upper part)	2	327–330	Limestone	1.5 (6 slender); 2 (6 large)	1.5–2	<40–75	Bright smooth; bright sugary; mineral coating; organic matter coating	Original ornamentation, corrosion, irregular envelope
			3	380–381.5	Limestone	1.5 (2)	1.5	<40–50	Sugary; minerals overgrowth; grey patina	Corrosion, irregular envelope
		Itaituba (Lower)	6	538–542	Sandstone/ limestone	1.5 (13); 2 (4)	1.5	<40–50	Bright smooth; bright sugary; mineral overgrowth; bleached; grey patina	External cast, large crystal, irregular envelope
7	1-CM-2-PA	Itaituba (Lower part)	1	170.5–175	Limestone/ shale	1.5 (46)	1.5	<40–50	Bright smooth; bright and dusty sugary; mineral overgrowth; mineral coating; grey patina	Original ornamentation, irregular envelope, external cast
			3	179–183	Limestone	1.5 (66); 2 (4)	1.5	<40–50	Bright smooth; bright sugary; mineral coating	Original ornamentation, small crystal, external cast; irregular envelope
			4	183–186	Limestone	2 (13)	2	<40–75	Bright sugary; minerals overgrowth; mineral coating	Small crystal, irregular envelope
8	2-CP-2-PA	Itaituba (Upper part)	2	633–638.5	Shale/ sandstone	2 (18)	2	45–77	Very large specimens: bright smooth; mineral coating; grey patina	Original ornamentation, small crystal, corrosion; irregular envelope
			5	650.5–654.5	Limestone	1.5 (61); 2 (20)	1.5–2	<40–50	Bright smooth; organic matter	Small crystal, external cast, large crystal; irregular envelope
			10	665–669	Mudstone	2 (7)	2	45–77	Bright smooth; bright sugary; mineral overgrowth; grey patina	
		Itaituba (Lower part)	18	779–783.5	Sandstone	2.5 (1)	2.5	70–115	Sugary	
			21	799–801	Siltstone/ Limestone	2.5 (24)	2.5	70–115	Bright smooth; bright sugary; mineral overgrowth; bleached; grey patina	Corrosion, irregular envelope
			22	802–806.5	Limestone	2.5 (18)	2.5	70–115	Bright smooth; bright sugary; mineral overgrowth; mineral coating; organic matter	Irregular envelope

(*continued on next page*)

Table 1 (*continued*)

Locality	Well/ outcrop	Formation	Core/ sample	Depth (m)	Lithology	CAI of conodonts	CAI mode	Temperature range °C	Texture (stereoscopic microscope)	Microtextures (SEM)
9	1-FZ-1-AM	Nova Olinda	17	1669−1673	Shale	6 (48); 7 (3 ramiforms)	6	420−720	Bright and dusty sugary; mineral overgrowth; mineral coating; grey patina; bleached:	Large crystal; irregular envelope; granular
		Itaituba (Upper part)	19	1923.5−1926.5	Siltstone	1.5 (15); 2 (24)	1.5−2	<40−75	Bright sugary	External cast, large crystal; irregular envelope
			25	1943−1946	Shale	2 (313)	2	45−77	Bright smooth; bright and dusty sugary; mineral overgrowth; grey patina, sometimes on nodes; scattered organic matter	External cast, small crystal; corrosion; irregular envelope
			31	1963−1966	Siltstone	2 (4)	2	45−77	Bright sugary; mineral coating; organic matter	External cast, incipient large crystal; irregular envelope
			34	1973−1976	Shale	2 (91)	2	45−77	Bright smooth; bright and dusty sugary; mineral coating; grey patina; scattered organic matter	Original, small crystal, external cast; corrosion; irregular envelope
			40	2005−2010	Limestone/ siltstone	2.5 (1)	2.5	70−115	Bright sugary; mineral coating on basal cavity	Original, small crystal; irregular envelope
			41	2051−2056	Limestone	2.5 (1)	2.5	70−115	Mineral coating; organic matter	Irregular envelope
10	9-FZ-2-AM	Nova Olinda	7	1062−1068	Limestone	1.5 (7)	1.5	<40−52	Bright and dusty sugary; mineral overgrowth; mineral coating; organic matter	Large crystals, irregular envelope, pseudomorphs
			19	1183−1201	Siltstone	2 (86)	2	45−77	Bright smooth; bright sugary; mineral overgrowth; mineral coating; organic matter	Original, small crystal, external casts,; irregular envelope
			27	1648.5−1666	Siltstone	6.5−7 (78)	6.5−7	550−720	Dusty sugary; mineral overgrowth; intensely bleached; grey patina	Irregular envelope, granular
			29	1680−1691	Shale	6.5−7 (2)	6.5−7	550−720	Dusty sugary; mineral overgrowth; intensely bleached; grey patina	Irregular envelope; granular
			31	1834−1846	Shale/ siltstone	2.5 (3)	2.5	68−118	Bright and dusty sugary; organic matter	Irregular envelope
11	9-FZ-28-AM	Nova Olinda	183	1003.5	−	1.5 (1)	1.5	<40−50	Coarse bright and dusty sugary; incipient mineral overgrowth; organic matter	Large crystal, external cast; irregular envelope
			190	1085−1103	−	1.5 (1)	1.5	<40−50	Bright smooth; bright sugary; mineral overgrowth; organic matter	
12	2-MN-1-AM	Nova Olinda	11	509.5−515	Sandstone	1.5 (2)	1.5	<40−50	Bright and dusty sugary; mineral overgrowth; mineral coating on basal cavity; organic matter	
			16	530−534.5	Siltstone/ limestone	1.5 (3)	1.5	<40−50	Original surface	Small crystal; irregular envelope
		Itaituba (Lower)	23	816−819	Limestone	2 (2)	2	45−77	Bright and dusty sugary; organic matter	Large crystal; irregular envelope
			24	867−871.5	Siltstone/ shale	1.5 (11)	1.5	<40−50	Bright sugary; mineral overgrowth	Small crystal, external cast: irregular envelope
13	1-MS-4-AM	Itaituba	5	974.5−976.8	−	2 (1)	2	45−77	Bright smooth; bright sugary	
14	1-NO-1-AM	Nova Olinda	2	950−956	Siltstone	1.5 (2)	1.5	<40−50	Bright and dusty sugary	Large crystal
			4	960−966	Shale	2 (1); 2.5 (11)	2.5	68−118	Bright sugary; grey patina	External cast, large crystal; irregular envelope
			6	970−976	Shale	2.5 (1)	2.5	68−118	Bright and dusty sugary	
15	1-PB-1-PA	Monte Alegre	8	205−210	Sandstone	2 (3)	2	45−77	Dusty sugary; mineral overgrowth; bleached	External cast, large crystals
16	2-PC-1-AM	Nova Olinda	4	618.5−621.5	Limestone	1.5 (2); 2 (9)	2	<40−50	Bright smooth; mineral overgrowth	Original ornamentation; small crystal, external cast; irregular envelope
		Itaituba (Lower)	10	1060−1062	Limestone	1.5 (8)	1.5	<40−50	Slender specimens: Bright smooth; bright sugary	Small crystal, external cast; irregular envelope
			21	1137.5−1140	Shale	2 (4)	2	45−77	Bright smooth; bright sugary; grey patina	Small crystal, external cast; irregular envelope
17	2-PE-1-AM	Nova Olinda	2	810−812	Limestone	2 (13); 7 (2 bleached)	2	−	Bright smooth; bright and dusty sugary; mineral overgrowth; bleached; white patina	Small crystal; irregular envelope
		Itaituba (Lower)	4	926−929	Shale/ limestone	2 (5)	2	45−77	Bright smooth; bright sugary	Small crystal
18	2-PE-2-AM	Itaituba	2	815−818.5	Limestone	1.5 (5)	1.5	<40−50	Bright smooth; bright sugary; incipient mineral overgrowth	Small crystal; irregular envelope
			3	818.5−821	Limestone	1.5 (2); 2 (3)	1.5−2	<40−50	Bright and dusty sugary; well developed mineral overgrowth	Irregular envelope
			6	828−831.5	Dolomite	2 (1)	2	45−77	Bright smooth; bright and dusty sugary; organic matter	Irregular envelope
19	1-RX-1-AM	Nova Olinda	71	1553.5−1555	Shale	2 (1)	2	45−77	Bright sugary; grey patina	Original ornamentation; corrosion
		Barreirinha	124		Shale			70−180		

Table 1 (*continued*)

Locality	Well/ outcrop	Formation	Core/ sample	Depth (m)	Lithology	CAI of conodonts	CAI mode	Temperature range °C	Texture (stereoscopic microscope)	Microtextures (SEM)
				2573.5–2578		2.5 (1); 3 (1); 7 (11 bleached)	2.5–3		Bright and dusty sugary; white patina; dissolution and bleached	Original ornamentation; small crystal; corrosion
20	1-RX-6-AM	Nova Olinda	10	1588.7–1590.4	–	2 (78); 6.5 (1 full bleached)	2	–	Bright smooth; bright sugary; mineral overgrowth; organic matter; bleached; white patina	Small crystal; irregular envelope
		Itaituba	16	1689–1693	–	2 (14)	2	45–77	Bright smooth; bright sugary; mineral overgrowth on the adcarinal grooves	Small crystal; dissolution; irregular envelope
			18	1696–1699	–	2.5 (4)	2.5	68–118	Bright and dusty sugary; minerals overgrowth; white patina; organic matter	
			19	1699–1703.1	–	2 (5); 6.5 (1 full bleached)	2	–	Bright smooth; bright sugary; organic matter; bleached; white patina	
			21	1925–1927	–	2 (2)	2	45–77	Dusty sugary; incipient mineral overgrowth; organic matter	
		Monte Alegre	24	1947–1950	–	2 (3)	2	45–77	Bright smooth; bright sugary; mineral overgrowth; organic matter	Small crystal; irregular envelope
21	2-SA-1-AM	Itaituba (Lower)	10	1116–1121	Shale	2 (33)	2	45–77	Bright sugary; mineral overgrowth; grey patina; organic matter	Small crystal; dissolution; irregular envelope
22	1-TR-1-AM	Nova Olinda	5	1682–1686.5	Limestone	2 (1); 2.5 (1)	2–2.5	45–118	Sugary	Original ornamentation; external cast; irregular envelope
		Itaituba (Lower part)	13	2019.5–2024	Limestone	2.5 (1)	2.5	68–118	Bright sugary; mineral overgrowth; grey patina	External cast, large crystal; irregular envelope
			14	2051.5–2055	Limestone	3 (1)	3	108–188	Bright sugary; mineral overgrowth	Small crystal; irregular envelope
23	1-UA-1-AM	Nova Olinda	8	2423–2426	Sandstone	2 (5)	2	45–77	Bright sugary	External cast, irregular envelope
		Itaituba (Upper)	12	2552–2555	Shale/ limestone	2 (1)	2	45–77	Bright sugary	
		Itaituba (Lower part)	16	2710–2713.5	Limestone	2 (1)	2	45–77	Bright and dusty sugary; mineral overgrowth; grey patina	External cast, irregular envelope
			17	2757.5–2761	Limestone	2 (5)	2	45–77	Bright sugary; mineral overgrowth; one bleached specimen	
		Monte Alegre	19	2856–2859.5	Sandstone	2 (4)	2	45–77		External cast, small crystal; irregular envelope
24	Calminas quarry	Itaituba (Lower part)	14.80		Limestone	2 (27 small); 2.5 (11 large specimens)	2.14	45–77	Bright and dusty sugary; grey patina	External cast, large crystal; irregular envelope
			14.20		Limestone	2 (12)	2	45–77	Slender specimens: dusty sugary	External cast, large crystal; irregular envelope
			10.20		Dolomite	2.5 (2)	2.5	70–115	Middle-sized specimens: coarse bright and dusty sugary; organic matter	External cast, large crystal
			7.05		Limestone	7 (1)		–	Slender free blade: bright sugary; leached organic matter; full bleached	Small crystal; irregular envelope
			6.60		Limestone	2 (3)	2	45–77	Bright and dusty sugary; mineral overgrowth as crystals; patina	Original ornamentation; irregular envelope
			6.50		Limestone	2.5 (2)	2.5	70–115	Middle-sized specimens: bright and dusty sugary; grey patina	
			5.85		Mudstone	2 (4)	2	45–77	Slender specimens: bright and dusty sugary; incipient mineral overgrowth	Small crystal, large crystal; external cast; irregular envelope
			5.50		Mudstone	2 (94)	2	45–77	Bright and dusty sugary; mineral overgrowth well developed in some specimens; grey and white patina; organic matter	Original ornamentation; large crystal, external cast; irregular envelope
			5.02		Dolomite	2 (17)	2	45–77	Slender specimens: bright and dusty sugary; mineral overgrowth; grey and white patina	External cast; irregular envelope
			4.70		Dolomite	2 (16)	2	45–77	Slender specimens: coarse bright and dusty sugary; mineral overgrowth well developed in some specimens	Irregular envelope

with respect to older formations.

CAI value distribution in the Itaituba Formation is subdivided into twenty samples for the lower and fourteen for the upper part, since the number of samples and the variation in value make it possible (Fig. 5C and D). The distribution of the lower part of the formation supplements the data from the very thin Monte Alegre Formation. A CAI value below 2 occurs in the western and northern part of the basin (wells 5–8, 12, 16 and 17; Fig. 5C). The CAI value increases to 2 (or 2–2.5) to the east and south of Manaus city (Fig. 1, wells 17, 21 and 23) and at the southern platform (Fig. 1, Calminas outcrop 24 and well 8). It is a slightly higher CAI value than 1.5 to 2 and the vitrinite reflectance range of 0.38%–0.70% (which should be equivalent to CAI 1) from the neighboring Itacimpa SA cement Company (Fig. 1), according to Nascimento (2008) and Oda et al. (2006). The value 2.5 (wells 1, 8 and 9), exceptionally as high as to 3 (well 22), is observed in the deep central part of the basin (>2 km thick; Figs. 1, 3 and 4C). One conodont element from the Calminas quarry (24) shows an abnormally high value of 7.

The upper part of the Itaituba Formation yields conodonts with a CAI value below 2 in a similar area to the lower part (well 6 and 8),

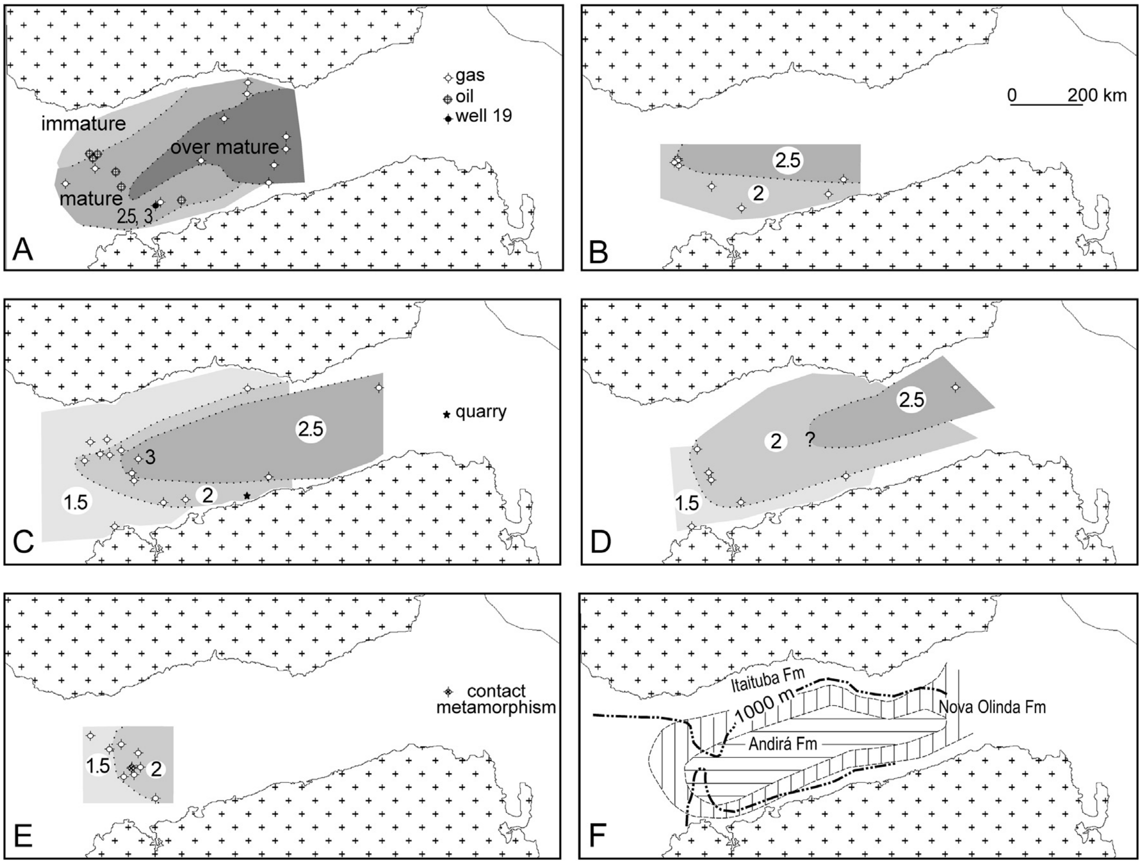

Fig. 5. Sketches of distribution of the CAI values in the Amazonas Basin. **A**, location of well 19 and CAI value 2.5 and 3 determined in the core sample of the Barreirinha Formation. Distribution of the belts of organic matter maturation (immature, mature and over-mature) for the Barreirinha Formation after Neves (1990) and oil and gas occurrences known in the Amazonas Basin (Neves, 1990; Gonzaga et al., 2000). **B**, distribution of isoline between the CAI value of 2 and 2.5 in accordance with the conodonts studied in the Monte Alegre Formation. **C**, distribution of isolines between the CAI values from 1.5, 2 and 2.5 in the lower part of the Itaituba Formation and location of the well where CAI reaches 3. **D**, distribution of isolines of CAI values of 1.5, 2 and 2.5 in the upper part of the Itaituba Formation. **E**, distribution of isolines for the CAI values of 1.5 and 2 in the Nova Olinda Formation and wells where contact metamorphism occurs. **F**, distribution of the different formations of the Tapajós Group preserved just below the cover and estimation of the line corresponding to eroded gaps of around 1000 m in thickness interpreted from the CAI values.

but the isoline of CAI 2 moves slightly eastward (wells 8, 9 and 23; Fig. 5D). Furthermore, a high value of 2.5 is noted at the well located at the eastern part of the Amazonas Basin (well 1).

Twenty core samples from eleven wells are studied in the Nova Olinda Formation (Fig. 5E). This formation shows CAI values lower than 2 (1.5) to the western part of the basin (wells 12 and 16). The isoline of 2 indicates a location approximately coincident with the upper part of the Itaituba Formation (wells 10, 17, 19, 20, 22 and 23). Furthermore, a sharp increment from 1.5 to 2.5 occurs at shallow depth in well 14, and three core samples show anomalous CAI values of 6 or 7 (wells 9, 10 and 17).

The surface texture of conodonts is rarely bright and smooth, but is usually bright to dull sugary with mineral overgrowth or sometimes a very widespread coating (Table 1). Occasionally, particularly in samples from the Monte Alegre Formation, conodonts show an impregnation of organic matter, which seems to be in relation to the role often played as hydrocarbon storage rock of this unit (Neves, 1990). Bleach and grey to white patina occasionally occur.

Unaltered microtexture is observed in a few specimens and the development of overgrowth microtextures is very common, sometimes with a corrosion pre-dating the overgrowth (Fig. 6A and B). Small crystal microtexture occurs incipiently in conodonts from limestone and fine-grained rocks of the studied formations (Fig. 6B–Bb, D). External cast microtexture is observed in sandstone beds of the Monte Alegre Formation but also in other lithologies of the different formations (Fig. 6C–F). Large crystal microtexture is incipiently (Fig. 6D–E) to strongly developed in samples from dolostone, bioclastic limestone and shales associated with evaporites (Fig. 6G–I). Irregular envelope microtexture is common, sometimes associated with pseudomorph dolomite crystal, and becomes more strongly developed in beds interbedded with evaporites (Fig. 6A, B, G and I). Abnormally high values of CAI together with a prevailing low value (wells 17, 19 and outcrop 24) are linked to strong dissolution and loss of organic matter, and occasionally to rounded and wasted conodonts. Granular microtexture occurs in samples of the Nova Olinda Formation with CAI 6 to 7 (Fig. 7A–C). The granules are apatite crystal with rounded edges.

5. Discussion

The CAI values from the Barreirinha, Monte Alegre, Itaituba and Nova Olinda formations are mostly between 1.5 and 3, an interval included in the diacaizone in the sense of García-López et al. (2001), or diagenetic conditions. This indicates that organic matter maturation is in the oil window (heavy to light oil and wet gas) in accordance with several authors (Legall et al., 1981; Nowlan and Barnes, 1987) and the occurrence of hydrocarbon source rocks and known reservoirs in the Amazonas Basin (Fig. 5A). Conodonts of CAI value 1 (immature conditions) are not observed in the studied rocks, although it could occur if we take into account the

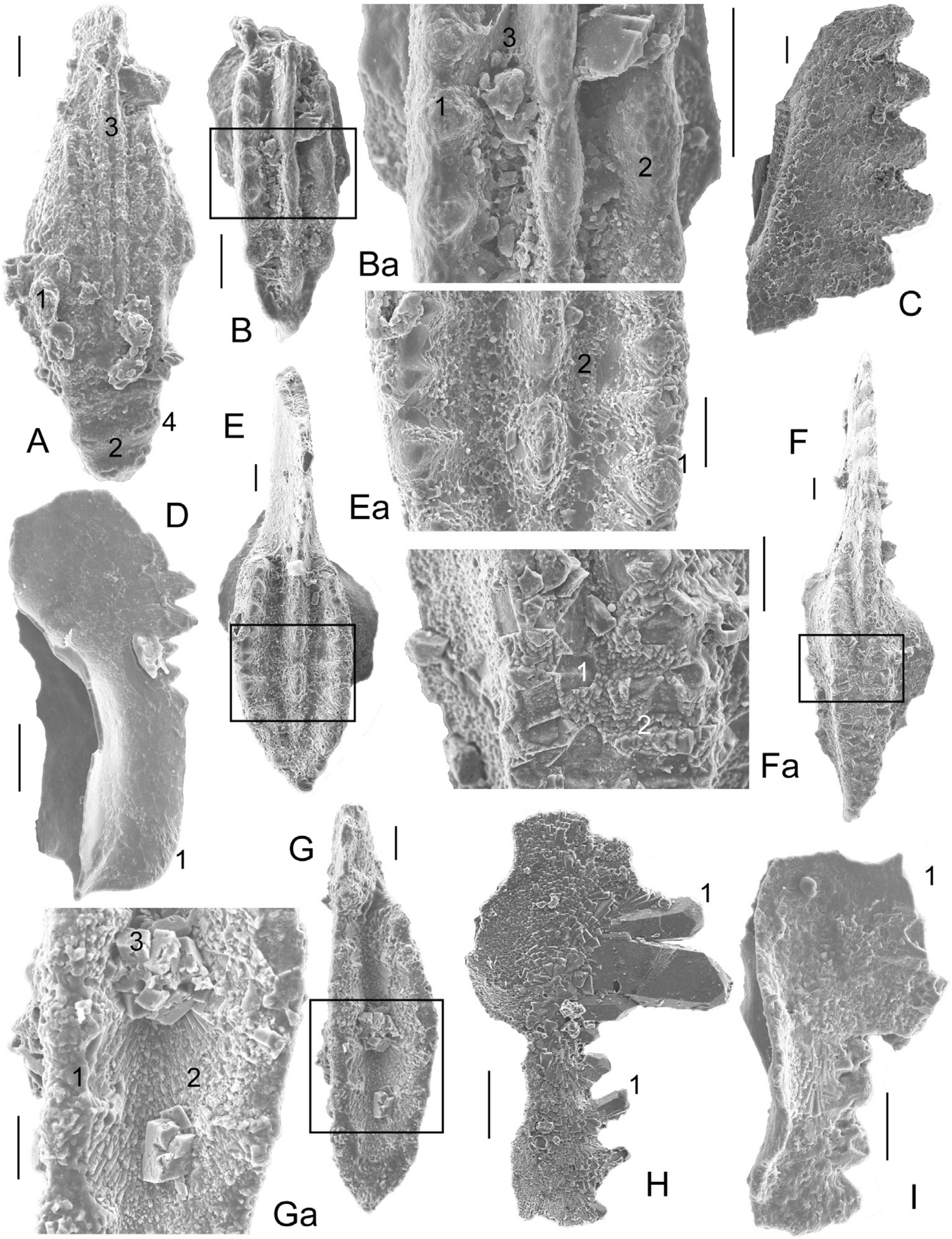

Fig. 6. Microtextures on P1 conodont elements from the Itaituba Formation in diagenetic conditions; bar scale is 50 microns. **A**, '*Streptognathodus*' cf. *parvus* from well 21 (MP-M 1043, core sample 10), where an irregular, partial heterogeneous cover of crystals (**1**, irregular envelope microtexture) is developed on small anhedral or subhedral apatite crystals (**2**, small crystal microtexture) and on the dissolution of a toothless carina inverted as a central groove (**3**) and also on several excavated transverse ridges of the tongue (**4**). **B**, oral view and detail (**Ba**) of *Neognathodus symmetricus* (well 5, core sample 9, MP-M 905), small crystal microtexture (**1**) is developed on the original ornamentation of nodes (**2**) and irregular envelope microtexture fills adcarinal troughs (**3**). **C**, lateral view of *Diplognathodus* sp. fragment (sample 10.2, Calminas quarry, MP-M 1305) with an irregular net of polygons defined by apatite walls (external cast microtexture) and developed on the surface and broken edge of conodont. **D**, External cast microtexture developed on the surface of *Diplognathodus coloradensis* (well 8, sample 5, MP-M 954), including teeth of the free blade with original ornamentation, with common small crystal microtexture and local columnar crystals of the large crystal microtexture (**1**). **E**, oral view and detail (**Ea**) of *Neognathodus symmetricus* (well 6, core sample 6, MP-M 915) with external cast microtexture, plates on nodes (**1**), and blocky to small columnar crystals in several casts (**2**) of incipient large crystal microtexture. **F**, oral view of detail (**Fa**) of *Idiognathoides corrugatus* (drill hole 22, core sample 13, MP-M 1052) with development of external cast microtexture (**1**) and locally blocky crystals of the large crystal microtexture (**2**). G, oral view and detail (**Ga**) of *Adetognathus lautus* (well 5, core sample 2, MP-M 901) with wide development of large crystal microtexture, apatite plates on the nodes of parapets (**1**) and fans of columnar crystals on the slopes (**2**); irregular envelope microtexture consists of isolated pseudomorph dolomite crystals (**3**). **H**, lateral view of *Diplognathodus* cf. *ellesmerensis* (Calminas quarry, sample 5.5, MP-M 1269) with a radial disposition of fans of columnar apatite crystals from the middle platform to the margins (large crystal microtexture); large acicular apatite crystals are on the denticles of the carina–blade (**1**) (large denticular crystal microtexture after Sanz-López and Blanco-Ferrera, 2012). I, lateral view of *Diplognathodus* sp. (core sample 5.5, MP-M 1060, Calminas quarry), where columnar crystals (large crystal microtexture) are covered by small crystals forming a thin envelope that fills the space between blade denticles (**1**).

local occurrence of low maturation index at shallow depth (<0.65% Ro at 1500 m in well B in Gonzaga et al., 2000). Nevertheless, the summary of vitrinite reflectance values and thermal alteration index from Mosmann et al. (1986) seems to indicate slightly lower organic maturation than the CAI data studied here, particularly for the western part of the basin.

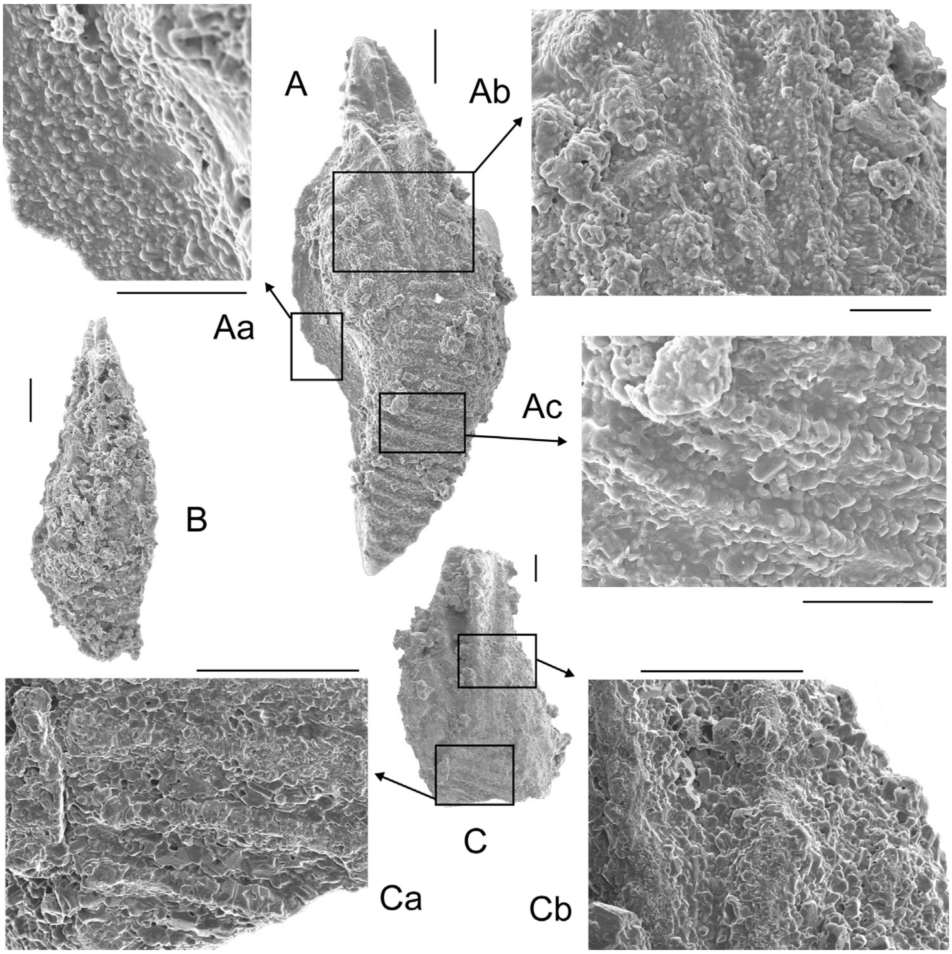

Fig. 7. Microtextures on P1 conodont elements from contact metamorphism conditions in rocks of the Nova Olinda Formation; bar scale is 50 microns. **A**, oral view of *Idiognathodus* cf. *obliquus* (well 10, core sample 27, MP-M 1102) and details of the granular microtexture in the caudal expansion of the basal cavity (**Aa**); the proximal area with longitudinal and transverse ridges, and node ornamentation on the lobes (**Ab**), and the transverse ridges on the tongue with recrystallizated granules (**Ac**). B, oral view of *Idiognathodus* sp. with an irregular envelope microtexture of silicates (well 9, core sample 17, MP-M 1073). **C**, fragment of *Idiognathodus* cf. *obliquus* (well 9, core sample 17, MP-M 1077) with granular microtexture on the tongue (**Ca**) and the nodes of the rostral lobe (**Cb**).

The organic matter maturation and the main phase of petroleum generation and expulsion are related to the overburden effect of the sedimentary pile accumulated during the Carboniferous and Permian (Gonzaga et al., 2000). Assuming sedimentary burial during the Paleozoic as the main process in the maturation, the CAI values indicate palaeotemperatures between less than 40 °C and about 180 °C. This range depends on the heating time being considered. A long heating time (286 Ma for the Barreirinha Formation and 208–232 for different units of the Tapajós Group) is inferred through the difference between the average age of sedimentation of each lithostratigraphic unit and the uplift prior to the Late Cretaceous sedimentation (98 Ma). Shorter times are obtained (117 Ma for the Barreirinha Formation and between 48 and 63 Ma for the Tapajós Group) if uploading of the Paleozoic basin began in late Permian (258 Ma), as is supported by the cooling trend indicated by apatite fission track data (Pina et al., 2014). An intermediate time span is also acceptable if the main uplift occurred in the Early Triassic/Jurassic in relation to the eastward formation of the Marajó Basin and local sill intrusions. The high part of the temperature range (shorter heating time) is likely to be more realistic if we accept that the Carboniferous–Permian maturation and the main phase of petroleum generation and expulsion were completed in the Early Triassic (Gonzaga et al., 2000).

The highest studied CAI value (2.5 or 3) occurs in the Barreirinha Formation and in a few samples of the Monte Alegre and the lower part of the Itaituba Formation in the deep part of the basin. Rock maturity reaches Ro > 1.4% in the depocenter of the basin, according to Gonzaga et al. (2000), which correlates with a CAI value of 3 (Epstein et al., 1977). The CAI value between 2.5 and 3 has been associated with rocks containing heavy to light oil and wet gas, but also with dry gas (Nowlan and Barnes, 1987). It agrees with the location of the studied sample from the Barreirinha Formation in the mature oil belt inferred for the basin through vitrinite reflectance and thermal alteration index (Fig. 5A; Neves, 1990; Mosmann et al., 1986). Except for the well 22, a CAI value of 3 has been rejected here for palaeotemperature determination proposes. This value was measured on large conodonts or is associated with a wide variation among closely recovered samples. It is noted particularly in the Monte Alegre Formation drilled in well 5, where values vary between 1.5 and 2 and 3 among seven core samples along 20.5 m. The higher value occurs in conodonts obtained from shale and sandstone (2.5–3) with respect to limestone and mudstone (1.5–2). The different lithology has an associated distinct thermal conductivity and porosity, and the variation in the CAI value in relation to the host-rock is widely known and estimated from half to one unit of CAI (Epstein et al., 1977; Mayr et al., 1978; Legall et al., 1981; Belka, 1990; Burnett et al., 1994; Helsen, 1997). Fluid activity from an early diagenesis agrees with the common textural changes observed in the conodonts showing low CAI values in a similar way to other basins with very different tectonothermal history, but where phosphate was also removed at shallow depth (Blanco-Ferrera et al., 2011).

The studied samples of the Tapajós Group are located particularly in the western part of the Amazonas Basin and distribution of the CAI isolines shows a trend approximately coincident with the map of depth of the Precambrian basement (Fig. 2A), the known distribution of the mature areas for hydrocarbons (Fig. 5A) and the isopach map of the distribution of the preserved Paleozoic succession (Mosmann et al., 1986; Neves, 1990; Gonzaga et al., 2000). The CAI 2 isoline is in the Nova Olinda Formation at the depocenter of the basin, but moves downwards to the lower part of the Itaituba Formation in the wells located in the basin margins and associated with the decreasing sedimentation thickness (Figs. 3–4, 8A). It agrees with results derived from other maturation indices, indicating that maturation zones are more or less parallel to the basin margins and increase from immature to over-mature zones from the margin to the central depocenter (Fig. 5A; Gonzaga et al., 2000).

Upper Cretaceous and Cenozoic deposits seem to reach an insufficient thickness to increase the previously attained CAI value (less than 500 m in the deeper part of the basin, according to Mosmann et al., 1986) and can be thinner than several diabase bodies (900 m). Only the easternmost well 1cut a thick cover of 1230 m that agrees with the CAI value of 2.5 if we accept a current, mean surface temperature of 26.7 °C and a geothermal gradient of <20 to 30 °C/km (Meister, 1973). Nevertheless, this value of 2.5 is located in the eastern part of the Amazonas Basin, an over-mature zone in which overheating was caused by abundant intrusive sills and dykes along the entire sedimentary pile (Gonzaga et al., 2000).

The CAI value of 4 or 5 is not present in the studied samples, although Rocha Campos et al. (1988) reported it in the central part of the basin. Among samples with a CAI value higher than 5 (from 6 to 7), two groups of conodonts are differentiated. A first group corresponds to a few bleached elements with strong corrosion and a high CAI value associated with other lower CAI values. Rejebian et al. (1987) described this variation in natural conodonts, and others experimentally processed in the laboratory, when heating is associated with fluids under pressure. The corrosion observed in conodonts with an abnormally high CAI value from the Barreirinha, Itaituba and Nova Olinda formations indicates a strong leaching of conodont organic matter.

The second group of conodonts with values between 6 and 7 (Table 1, sample 15 in well 9, samples 27 and 29 in well 10) are associated with granular microtexture due to apatite recrystallization in the Nova Olinda Formation. Contact metamorphism due to diabase sill and dyke intrusions explains reasonably well CAI values and conodont microtextures in a core containing anhydrite beds about 50 m below a diabase sill of 120 m in thickness. Previously, Rocha Campos et al. (1988) interpreted heating by contact metamorphism as a way of explaining the wide variation of CAI values (from 1 to 1.5 to >5) in a well (FB-1-AM), and Gonzaga et al. (2000) proved this through vitrinite reflectance determinations close to igneous intrusions in two other wells. The local effect of diabase intrusions affects a few hundred meters of the host-rock with inversion in the maturation grade, particularly in the evaporite rocks of the Nova Olinda Formation of the western part of the basin (Mosmann et al., 1986). Evaporite units are highly conductive rocks and vitrinite reflectance proved the thermal effect in the host-rock reached 1.5 times the thickness of sill in the neighboring Solimões Basin (Eiras, 1998). Furthermore, the extensive bodies of sills, together with thick evaporite strata, where these bodies are often intruded, form a seal for hydrocarbon accumulation (Milani and Zalán, 1999; Gonzaga et al., 2000). Palaeotemperatures are here estimated at between 420 and 720 °C for a heating time of between 1000 years and 1 Ma, although the highest temperature (short heating) is likely to be closer to reality.

A point for discussion is the occurrence of CAI values of 1.5 and 2 at shallow depth or at the surface, particularly towards the north and south platforms (Cuminá and Mamuru), where current geothermal gradient is higher than in the central part of the basin (<26 to 30 °C/km with respect to < 17 and 20 °C/km after Meister, 1973; Zembruscki and Kiang, 1989). Local denudation of a part of the Pennsylvanian–Permian succession, particularly at the margins of the basin (up to 1.8 km) with the consequent reduction of the Amazonas Basin extension was suggested on the basis of other thermal maturity indices different from the CAI (Nunn and Aires, 1988; Gonzaga et al., 2000). An estimation of the overburden depth necessary to obtain the CAI values suggests local erosion of about 1000 m of the Tapajós Group in the north and south marginal areas, where Cretaceous strata may directly overlie the Itaituba Formation (Fig. 5F; Appendix A). A schematic diagram derived from the cross-sections (Figs. 3 and 4) suggests a denudation of 1500 m at the southern margin (Fig. 8B), or lower if the geothermal gradient was higher in the marginal area than in the central basin (Fig. 8C). Erosion decreases towards the central part of the basin, where the Nova Olinda and Andirá formations are preserved below Cretaceous–Cenozoic strata. The estimation of erosion calculated on the basis of the CAI value indicates a greater complexity than just gaps increasing towards the basin margins (Fig. 5F), and several

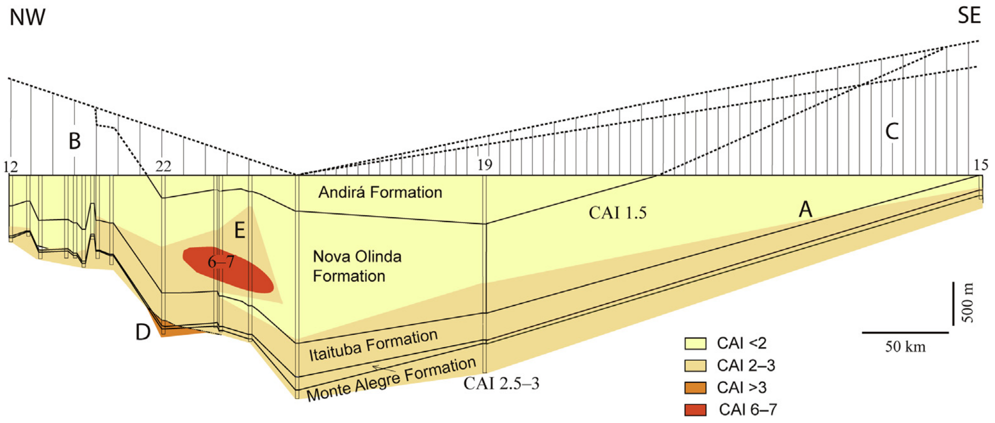

Fig. 8. Location of the isolines for CAI 2 and 3 and the area with CAI values of 1.5 and 6–7 in a scheme that links cross-sections A–A′ and B–B′ of Fig. 1. Isoline of CAI 2 is in the Nova Olinda Formation in the central part of the basin and shifts to the basal part of the Itaituba Formation located in the south margin (**A**). An eroded gap is inferred at the margins of the basin, assuming a geothermal gradient that is homogeneous in the basin (**B**) or higher in the southern margin (**C**). Location of CAI value of 3 (**D**) and others higher than 2 (**E**) in the area with CAI values of 6–7 associated with diabase sills.

CAI values are difficult to explain. This is the case of the value of 3 at shallow depth in well 22, and particularly the value of 2.5 in well 14 (Fig. 3, Table 1). The latter is close to wells with contact metamorphism due to the diabase intrusion (Fig. 8D–E). It suggests that a heating event, probably related to the overheating by intrusive bodies and generated from the basement of the basin, may be overimposed on the sedimentary burial, as Gonzaga et al. (2000) considered for the over-mature zone with abundant intrusions in the eastern part of the Amazonas Basin. In the western part, maturation may be extended if the heating time increases beyond intrusive emplacement and the heat transport is influenced by hydrodynamic movements through outcropping formations and faults, as Zembruscki and Kiang (1989) described in order to explain the current geothermal gradient. Another possible explanation for the locally higher maturation may be the abundant high conductivity evaporite rocks (BjØrlykke, 2010) and the migration and petroleum expulsion from the central basin towards its margins. These processes should be put to the test through a detailed study of samples from older rocks than those in the Tapajós Group.

6. Conclusions

The color alteration index of conodonts has been shown to be a valid palaeothermal index in the Amazonas Basin. In the tectonothermal history of the basin, sedimentary burial is the main process involved in the maturation of organic matter during the Pennsylvanian–Permian time. A CAI value of 3, close to the boundary heavy–light oil and wet gas/dry gas boundary seems to be located at a depth of 2.5–3 km. A complex diagenetic history is illustrated by the wide and extensive development of conodont apatite overgrowth microtextures at the CAI values between 1.5 and 3. The high temperature Mesozoic thermal event associated with igneous activity is locally recorded by high CAI values (6–7) and recrystallization is observed in surface texture of the conodonts. Denudation of the margins of the basin serves to explain relatively high CAI values at shallow depth, although heating beyond the igneous thermal event and widely extended through fluid migration and/or highly conductive evaporite rocks should be considered.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jsames.2015.10.007.

References

Almeida, F.F.M. de, 1986. Distribuição regional e relações tectônicas do magmatismo Pós-Paleozóico no Brasil. Rev. Bras. Geociênc. 16, 325–349.

Altiner, D., Savini, R.R., 1995. Pennsylvanian foraminifera and biostratigraphy of the Amazonas and Solimões basins (north Brazil). Rev. Paléobiol. 14, 417–453.

Bastida, F., Brime, C., García-López, S., Sarmiento, G.N., 1999. Tectono-thermal evolution in a region with thin skinned tectonics: the western nappes in the Cantabrian Zone (Variscan belt of NW Spain). Int. J. Earth Sci. 88, 38–48.

Belka, Z., 1990. Thermal maturation and burial history from conodont color alteration data, Holy Cross Mountains, Poland. Cour. Forchungsinstitut Senckenberg 118, 241–251.

Blanco-Ferrera, S., Sanz-López, J., García-López, S., Bastida, F., Valín, M.L., 2011. Conodont alteration and tectonothermal evolution of a diagenetic unit in the Iberian Variscan belt (Ponga-Cuera unit, NW Spain). Geol. Mag. 148, 35–49.

BjØrlykke, K., 2010. Heat transport in sedimentary basins. In: BjØrlykke, K. (Ed.), Petroleum Geoscience: from Sedimentary Environments to Rock Physics. Springer-Verlag Berlin, Heidelberg, pp. 253–257.

Burnett, R.D., Higgins, A.C., Austin, R.L., 1994. Carboniferous–Devonian conodont CAI in England, Wales and Scotland. The pattern and its interpretation: a synoptic review. Cour. Forchungsinstitut Senckenberg 168, 267–280.

Cardoso, C.N., 2010. Análise cronoestratigráfica baseada em conodontes da Formação Itaituba (Pedreira Calminas), Atokano da Bacia do Amazonas-Brasil. Dissertação Mestrado em Geociências, Instituto de Geociências, Pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Cardoso, C.N., Lemos, V.B., Scomazzon, A.K., 2012. Alterações de cor e texturais/microcristalinas em conodontes - importante ferramenta no estudo da geotermometria. In: Anais do Congresso Brasileiro de Geologia 46, Congresso de Geologia dos Países de Lingua Portuguesa 1 Santos, São Paulo, CD-ROM Sociedade Brasileira de Geologia.

Cardoso, C.N., Sanz-López, J., Blanco-Ferrera, S., Lemos, V.B., Scomazzon, A.K., 2015. Frasnian conodonts at high palaeolatitude (Amazonas Basin, north Brazil). Palaeogeogr. Palaeoclimatol. Palaeoecol. 418, 57–64.

Carozzi, A.V., 1979. Petroleum geology in the paleozoic clastics of the Middle Amazon Basin, Brazil. J. Pet. Geol. 2, 55–74.

Coutinho, L.F.C., Gonzaga, F.G., 1996. Evolução tectonosedimentar e termomecânica da Bacia do Amazonas. Anais do 39 Congresso de Geologia. Salvador 5, 342–346.

Cunha, P.R.C., Gonzaga, F.G., Coutinho, L.F.C., Feijó, F.J., 1994. Bacia do Amazonas. Bol. Geociênc. Petrobras 8, 47–55.

Cunha, P.R.C., Melo, J.H.G., Silva, O.B., 2007. Bacia do Amazonas. Bol. Geociênc. Petrobras 15, 227–251.

Eiras, J.F., 1998. Cenário geológico nas bacias sedimentares no Brasil: Tectônica, sedimentação e sistemas petrolíferos da Bacia do Solimões, Estado do Amazonas. In: Searching for Oil and Gas in the Land of Giants Buenos Aires, 1998. Anais, Buenos Aires, Schlumberger, pp. 23–31.

Epstein, A.G., Epstein, J.B., Harris, L.D., 1977. Conodont color alteration-an index to organic metamorphism. U. S. Geol. Surv. Prof. Pap. 995, 1–27.

García-López, S., Brime, C., Bastida, F., Sarmiento, G.N., 1997. Simultaneous use of thermal indicators to analyse the transition from diagenesis to metamorphism: an example from the Variscan Belt of northwest Spain. Geol. Mag. 134, 323–334.

García-López, S., Bastida, F., Aller, J.A., Sanz-López, J., 2001. Geothermal paleogradients and metamorphic zonation from the conodont color alteration index (CAI). Terra Nova 13, 79–83.

Gonzaga, F.G., Gonçalves, F.T.T., Coutinho, L.F.C., 2000. Petroleum geology of the Amazonas Basin, Brazil: modelling of hydrocarbon generation and migration. In: Mello, M.R., Katz, B.J. (Eds.), Petroleum Systems of South Atlantic Margins, 73. American Association of Petroleum Geologists Memoir, pp. 159–178.

Helsen, S., 1997. The influence of host-rock composition on the color alteration of Namurian conodonts from Belgium. Geol. Mijnb. 75, 373–378.

Jeppsson, L., Anehus, R., 1995. A buffered formic acid technique for conodont extraction. J. Paleontol. 69, 790–794.

Jeppsson, L., Anehus, R., Fredholm, D., 1999. The optimal acetate buffered acetic acid technique for extracting phosphatic fossils. J. Paleontol. 73, 964–972.

Legall, F.D., Barnes, C.R., Macqueen, R.W., 1981. Thermal maturation burial history and hotspot development, Paleozoic strata of southern Ontario-Quebec, from conodont and acritarch color alteration studies. Bull. Can. Pet. Geol. 29, 492–539.

Lemos, V.B., 1990. Assembléias de conodontes do carbonífero da Bacia do Amazonas (Tese Doutorado em Ciências). Universidade Federal do Rio Grande do Sul, Porto Alegre.

Lemos, V.B., 1992a. Conodontes do Carbonífero das Bacias do Amazonas e Solimões. Taxonomia – Parte I. Pesquisas 19, 75–93.

Lemos, V.B., 1992b. Conodontes do Carbonífero das Bacias do Amazonas e Solimões. Taxonomia – Parte II. Pesquisas 19, 120–131.

Matsuda, N.S., Dino, R., Wanderley Filho, J.R., 2004. Revisão litoestratigráfica do Grupo Tapajós, Carbonífero Médio – Permiano da Bacia do Amazonas. Bol. Geociências Petrobras 12, 435–441.

Matsuda, N.S., Winter, W.R., Wanderley Filho, J.R., Cacela, A.S.M., 2010. O Paleozóico da borda sul da Bacia do Amazonas, Rio Tapajós - Estado do Pará. Bol. Geociências Petrobras 18, 123–152.

Mayr, U., Uyeno, T.T., Barnes, C.R., 1978. Subsurface stratigraphy, conodont zonation, and organic metamorphism of the lower Paleozoic succession, Bjorne

Peninsula, Ellesmere Island, District of Franklin. Pap. Geol. Surv. Can. 78, 1A, 393–398.

Meister, E.M., 1973. Gradientes geotérmicos nas bacias sedimentares brasileiras. Bol. Técnico Petrobras 16, 221–232.

Milani, E.J., Zalán, P.V., 1999. An outline of the geology and petroleum systems of the Paleozoic interior basins of South America. Episodes 22, 199–205.

Mosmann, R., Falkenhein, F.U.H., Gonçalves, A., Nepomuceno Filho, F., 1986. Oil and gas potential of the Amazon Paleozoic basins. In: Halbouty, M.T. (Ed.), Future Petroleum Provinces of the World, vol. 40. American Association of Petroleum Geologists Memoir, pp. 207–241.

Nascimento, S., 2008. Conodontes e a cronoestratigrafia da base da seção pensilvaniana, na Região de Itaituba, Porção Sul da Bacia do Amazonas, Brasil (Tese Doutorado em Ciências). Programa de Pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Neves, C.A.O., 1990. Prospectos potenciais e áreas prioritárias para exploração na Bacia do Amazonas. Bol. Geociências Petrobras 4, 95–103.

Nowlan, G.S., Barnes, C.R., 1987. Application of conodonto color alteration indices to regional and economic geology. In: Austin, R.L. (Ed.), Conodonts: Investigative Techniques and Applications. British Micropaleontological Society Series, Ellis Horwood, Chichester, pp. 188–202.

Nunn, J.A., Aires, J.R., 1988. Gravity anomalies and flexure of the lithosphere in the middle Amazon Basin, Brazil. J. Geophys. Res. 93, 415–428.

Oda, H., Matsuda, N.S., Matsumoto, R., Nishikawa, S., Minori, A., Moutinho, L.P., Nascimento, S., Scomazzon, A.K., 2006. Coal properties and trace elements of the coal of Lower Pennsylvanian intracratonic Amazon Basin – northern Brazil. In: Takano, O., Kano, K., Hoyanagi, K. (Eds.), 17th International Sedimentological Congress, Fukuoka, Abstract, O-055.

Pina, A.C.M., Moura, C.A.V., Vignol-Lelarge, M.L., 2014. Termocronologia por traços de fissão em apatita em rochas ígneas do embasamen-to e sedimentar da Bacia do Amazonas, na região de Itaituba, PA, Brasil. Pesqui. em Geociências 41, 39–50.

Playford, G., Dino, R., 2000. Pa1ynostratigraphy of upper Pa1aeozoic strata (Tapajós Group), Amazonas Basin, Brazil: Part two. Palaeontogr. Abt. B 225, 87–145.

Playford, G., Dino, R., 2005. Carboniferous and Permian pa1ynostratigraphy. In: Koutsoukos, E.A.M. (Ed.), App1ied Stratigraphy, Chapter 5. Springer, Dordrecht, pp. 101–121.

Rejebian, V.A., Harris, A.G., Huebner, J.S., 1987. Conodont color and textural alteration: an index to regional metamorphism and hydrothermal alteration. Bull. Geol. Soc. Am. 99, 471–479.

Rocha Campos, A.C., Pedrão, E., Lemos, V.B., 1988. Indices de alteração de cor de conodontes do Carbonifero da Bacia do Amazonas. In: IV Congreso Argentino de Paleontología y Bioestratigrafía, November 1986, Mendoza, Actas, vol. 3, pp. 235–236.

Santos, J.O.S., Hartmann, L.A., McNaughtonc, N.J., Fletcherc, I.R., 2002. Timing of mafic magmatism in the Tapajós province (Brazil) and implications for the evolution of the Amazon Craton: evidence from baddeleyite and zircon U–Pb SHRIMP geochronology. J. S. Am. Earth Sci. 15, 409–429.

Santos, T.B., Mancini, F., Rostirolla, S.P., Mesquita Barros, C.E., Salamuni, E., 2011. Registro da deformação pós-paleozóica na Bacia do Amazonas, região de Itaituba (PA). Rev. Bras. Geociências 41, 95–107.

Sanz-López, J., Blanco-Ferrera, S., 2012. Overgrowths of large authigenic apatite crystals on the surface of conodonts from Cantabrian limestones (Spain). Facies 58, 707–726.

Scomazzon, A.K., 2004. Estudo de conodontes em carbonatos marinhos do Grupo Tapajós, Pensilvaniano inferior a médio da Bacia do Amazonas com aplicação de isótopos de Sr e Nd neste intervalo (Ph.D. thesis). Universidade Federal do Rio Grande do Sul, Porto Alegre.

Wanderley-Filho, J.R., Melo, J.H.G., Fonseca, V.M.M., Machado, D.M.C., 2005. Bacia do Amazonas. Fundação Paleontológica Phoenix 82, 1–6.

Wanderley-Filho, J.R., Silva Travassos, W.A., Barbosa Alves, D., 2006. O diabásio nas bacias paleozóicas amazônicas – herói ou vilão? Bol. Geociências Petrobras 14, 177–184.

Wanderley-Filho, J.R., Eiras, J.F., Cunha, P.R.C., van der Ven, P.H., 2010. The Paleozoic Solimões and Amazonas Basins and the Acre Foreland Basin of Brazil. In: Hoorn, C., Wesselingh, F.P. (Eds.), Amazonia, Landscape and Species Evolution. Blackwell Publishing, pp. 30–37.

Zembruscki, S.G., Kiang, C.H., 1989. Gradiente geotérmico das bacias sedimentares brasileiras. Bol. Geociências Petrobras 3, 215–227.

Capítulo V – Considerações Finais

Conclusões

(I)

A ausência de conodontes nas faunas marinhas do Devoniano Inferior a médio dos reinos Malvinocáfrico e das Américas Orientais (Gondwana) é uma particularidade conhecida em grande parte da América do Sul, África do Sul, Antártida, Índia e Leste da Austrália. Este fato é contrastante com a sua abundância em faunas contemporâneas do Norte (Euramerica). Ao longo do intervalo Carbonífero-Permiano, as temperaturas mais frias associadas a períodos glaciais em latitudes altas influenciaram a evolução e restringiram a distribuição das faunas de conodonte, o que também parece ser verdadeiro para o Devoniano, quando os conodontes estavam majoritariamente restritos às latitudes baixas, cinturão tropical.

As ocorrências de conodontes do Devoniano da América do Sul são muito raras, sendo conhecidas a partir de poucos registros nas bacias do Gran Chaco e Madre de Dios na Bolívia e bacias do Solimões e Amazonas no Brasil. Esse é o primeiro relato em detalhe dos conodontes do Devoniano Superior da Bacia do Amazonas. A associação de conodontes estudada do Membro Abacaxis (Formação Barreirinha) é composta pelas espécies *Cryptotaxis* sp. A (Frasniano superior), *Mehlina gradata* (Frasniano inferior-Fameniano inferior), *'Ozarkodina'* aff. *Sannemanni* (Givetiano superior-Frasniano inferior), *Polygnathus* sp. e *Prioniodina* sp., inseridas nas ordens Prioniodinida e Ozarkodinida. As formas conservativas: *Mehlina*, ‘*Ozarkodina*’ e *Prioniodina*, têm homeomorfos no Siluriano, Devoniano Inferior e Carbonífero. Esses táxons são essencialmente generalistas/cosmopolitas, o que seria esperado de faunas pioneiras. Formas especialistas endêmicas também ocorrem, representadas por *Cryptotaxis* e *Polygnathus*.

Essa associação faunística indica que os folhelhos negros no testemunho número 124 do poço 1-RX-1-AM foram depositados provavelmente no Frasniano tardio, corroborando com a idade anteriormente atribuída por palinomorfos de Frasniano tardio à Fameniano médio.

Os conodontes oriundos do Devoniano Superior do norte do Brasil (Bacia do Amazonas e Bacia do Solimões) apresentam semelhanças com as faunas desse mesmo período da Bolívia, América do Norte central e Europa ocidental, sugerindo o intercâmbio de táxons entre estas regiões.

No momento da deposição do Membro Abacaxis, a Bacia do Amazonas estava posicionada próximo à paleolatitude 60ºS. A expansão máxima dos conodontes de latitude baixa em direção ao pólo dar-se-ia entre o Frasniano mais tardio e o início do Fameniano, durante o período de aquecimento máximo. Deste modo, aventa-se a influência de correntes marinhas mais quentes na América do Sul ou um gradiente de temperatura latitudinal mais brando no limite Frasniano-Fameniano, que permitissem a migração de táxons de regiões de latitude baixa para outras em latitude alta. Isto é consistente com a hipótese de que a redução do gradiente climático global, responsável pelo forte provincialismo faunístico do Devoniano inicial ao médio, estava em andamento possivelmente desde o Givetiano inicial até ao menos o início do Fameniano, permitindo o desenvolvimento de faunas cosmopolitas durante o Devoniano Superior, beneficiado também pela ampla inundação das plataformas durante o evento transgressivo Emsiano-Eifeliano. A migração de conodontes ocorreu através de uma conexão entre o Oceano Rheic em latitude inferior e as bacias Madre de Dios e Solimões, passando sob o Alto de Purus no Frasniano, alcançando a Bacia do Amazonas, ou a partir da principal abertura marinha na margem Nordeste da bacia. A presença de trilobitas malvinocáfricas (do tipo Boliviano) na fauna de braquiópodes do Reino das Américas Orientais (predomínio do tipo Apalachiano) na Formação Maecuru (Emsiano-Eifeliano da Bacia do Amazonas) reforçaria essa hipótese.

Posteriormente, o arrefecimento moderado da temperatura da água, entre o Fameniano médio e tardio, ocasionou a propagação de táxons característicos de água fria rumo às latitudes baixas antes do episódio glacial no Fameniano mais tardio, favorecida também pela ocorrência de evento transgressivo. A presença de *Cryptotaxis* na Bacia do Amazonas é uma ocorrência mais antiga (Frasniano), já que espécimes semelhantes são encontrados em faunas mais jovens (Fameniano da América do Norte), sugerindo uma possível origem ou refúgio desse táxon na América do Sul, posterior migração e chegada ao norte no momento mais frio.

A baixa diversidade faunística, contrastante com a alta diversidade de gêneros do Devoniano tardio em latitudes baixas, sugere que o ambiente representado pela Formação Barreirinha era inóspito para a maioria das espécies de conodontes. Além disso, a ocorrência desses espécimes está vinculada a um intervalo restrito no Membro Abacaxis da Formação Barreirinha, indicando que tais condições ambientais favoráveis à migração e desenvolvimento da fauna de conodontes no norte da América do Sul foram episódicas, o que pode ser observado também pelo registro limitado a dois intervalos na Formação Tomachi, Bacia Madre de Dios, Bolívia.

Portanto, pode-se constatar que a fauna da Bacia do Amazonas representa uma comunidade de água fria localizada em bacia de águas relativamente rasas em latitude alta. Assim, a extinção do limite Frasniano-Fameniano conhecida de latitudes baixas não se desenvolveu em domínios subpolares.

(II)

Em contrapartida, o registro de conodontes da Bacia do Amazonas é oriundo principalmente de intervalos de temperatura moderada, tal como a que prevaleceu no Pensilvaniano durante a sedimentação do Grupo Tapajós. Consequentemente, as faunas de conodontes pensilvanianas nesta bacia mostram uma alta diversidade e, atualmente, constituem o registro mais vasto do Pensilvaniano Inferior a Médio na América do Sul.

Cinquenta e oito táxons foram identificados a partir de amostras de afloramento e de subsuperfície das formações Monte Alegre, Itaituba e Nova Olinda – Grupo Tapajós, Bacia do Amazonas. Vinte e sete ocorrências referem-se a novas espécies identificadas para esta Época na bacia: 1. *Adetognathus flexus*; 2. *Declinognathodus* cf. *marginodosus*; 3. *Diplognathodus iowensis*; 4. *Idiognathodus aff. claviformis*; 5. *I. amplificus*; 6. *I. crassadens*; 7. *I.* aff. *crassadens*; 8. *I. ignisitus*; 9. *I.* cf. *ignisitus*; 10. *I. izvaricus*; 11. *I.* cf. *obliquus*; 12. *I. podolskiensis*; 13. *I.* cf. *praeobliquus*; 14. *I. rectus*; 15. *Idiognathodus* sp. A; 16. *Idiognathoides corrugatus*; 17. *I. lanei*; 18. *I. ouachitensis*; 19. *Neognathodus* cf. *askynensis*; 20. *N. asymmetricus*; 21. *N. colombiensis*; 22. *N. inaequalis*; 23. *N. tsnensis*; 24. *N. uralicus*; 25. *Neognathodus* sp. 1; 26. *Neognathodus* sp. A; 27. *Streptognathodus firmus*. Destas, vinte e três também são ocorrências inéditas para o Pensilvaniano da América do Sul, à exceção de *Idiognathoides corrugatus* e *I. ouachitensis*, os quais ocorrem na bacia brasileira do Solimões, *Neognathodus asymmetricus*, reconhecido na Colômbia e na Bolívia, e *N. colombiensis*, Colômbia.

Idiognathodus itaitubensis, nova espécie, é proposta para o Moscoviano inferior-médio, ocorrendo nas formações Itaituba superior à Nova Olinda inferior.

Através deste estudo, confirmou-se a afinidade previamente conhecida das faunas amazonenses com aquelas do Reino *Midcontinent-Andean*, principalmente por meio de espécies em comum de *Idiognathodus*. Propõe-se ainda uma possível conexão (marinha secundária intermitente) entre as bacias da América do Sul e o Oceano Paleotethys ocidental durante o Moscoviano, com base na ocorrência de *I. izvaricus* nas formações Itaituba e Nova Olinda, distante do registro conhecido nas bacias de Donets (Ucrânia) e de Moscow (Rússia).

(III)

O Índice de Alteração de Cor de conodontes (IAC) foi determinado em espécimes da Bacia do Amazonas oriundos das formações Barreirinha, Monte Alegre, Itaituba e Nova Olinda. A distribuição do valor de IAC na Formação Itaituba foi subdividida em porções inferior e superior, uma vez que o número de amostras e a variação no valor tornaram-na possível.

A Formação Barreirinha contém elementos com valor de IAC entre 2.5 e 3, associado a um valor anômalo de 7. Na Formação Monte Alegre, predomina o valor de IAC de 2, com algumas ocorrências de IAC variando entre 2-2.5 e 1.5-3. Um valor de IAC abaixo de 2 ocorre nas porções Oeste e Norte da bacia para a Formação Itaituba (inferior). O valor de IAC aumenta para 2 (ou 2-2.5) para Leste e Sul da cidade de Manaus e para a plataforma Sul. Os valores de 2.5 a excepcionalmente 3 são observados no depocentro da bacia. Além disso, há registro na plataforma Sul de um valor anômalo de 7. A Formação Itaituba (superior) contém espécimes com valor de IAC abaixo de 2 em uma área semelhante à da porção inferior, ao passo que um valor elevado de 2.5 é observado no extremo Leste da bacia. Na Formação Nova Olinda, há predomínio de valores baixos de IAC, até 2, e ocorrências de valores de IAC anômalos de 6 ou 7. Para Oeste na bacia, mostra valores de IAC de 1.5.

Nas rochas estudadas, não são observados conodontes com IAC de 1, vinculado a condições imaturas. Os valores de IAC das formações Barreirinha, Monte Alegre, Itaituba e Nova Olinda estão principalmente entre 1.5 e 3, intervalo associado a condições diagenéticas propícias à geração de hidrocarbonetos (óleo pesado a leve e gás úmido). Os valores mais elevados de IAC, 2.5 ou 3, ocorrem na parte profunda da bacia, na Formação Barreirinha e em algumas amostras das formações Monte Alegre e Itaituba (inferior). Este intervalo de IAC é associado a rochas contendo óleo pesado a leve e gás úmido, mas também gás seco, corroborando a localização da amostra estudada da Formação Barreirinha no cinturão de óleo maturo inferido para a bacia. A ocorrência de espécimes oriundos da Formação Monte Alegre apresentando impregnação por matéria orgânica parece estar relacionada à função desta unidade como rocha reservatório de hidrocarbonetos.

Na história tectono-termal da bacia, o soterramento sedimentar é o principal processo envolvido na maturação da matéria orgânica durante o intervalo Pensilvaniano-Permiano, no entanto valores mais altos de IAC, 4 ou 5, estão ausentes entre as amostras estudadas. Associados a valores de IAC inferiores, foram registrados valores anômalos, de 6 a 7, para as formações Barreirinha, Itaituba e Nova Olinda. Estas anomalias são produto de metamorfismo relacionado à intrusão de corpos de diabásio em camadas contendo evaporitos. Além disso, há duas ocorrências intrigantes de valores de IAC a profundidades rasas na Bacia do Amazonas: **(I)** valores de 1.5 e 2, ocorrendo também à superfície, e **(II)** valores de 2-2.5, 3. Um paleogradiente térmico elevado derivado de episódio magmático e/ou uma erosão de cerca de 1000m do Grupo Tapajós, antes deste evento térmico, nas áreas marginais Norte e Sul são sugeridos para elucidar a obtenção dos valores de IAC de 1.5 e 2, com uma possível denudação local de até 1500m na margem Sul. Ao passo que o registro de valores mais altos pode estar associado à sobreposição de um evento de aquecimento à sobrecarga sedimentar. Assim, um prolongamento do aquecimento (metamorfismo de contato) através do transporte de calor, seja por meio de falhas e formações aflorantes (migração de fluido) e/ou via unidades evaporíticas de condutividade alta, com expulsão e migração de petróleo do centro às margens da bacia, deve ser considerado.

A atividade de fluidos vinculada a uma diagênese inicial corrobora as alterações texturais comumente observadas em conodontes com valores de IAC baixos (sacarosa brilhante à opaca, sobrecrescimento de minerais, recobrimento mineral, (pátinas cinza a branca e *bleach*)). As texturas sacarosa brilhante a opaca e *bleach*, além das microtexturas de ornamentação original, cristal pequeno e corrosão, ocorrem nas quatro formações. As formações Monte Alegre, Itaituba e Nova Olinda contêm espécimes com texturas lisa e brilhante, sobrecrescimento de minerais, recobrimento mineral, pátina cinza, *smoke* e matéria orgânica. As microtexturas de cristal grande, molde externo e envelope irregular também estão presentes. Há presença de pátina branca nas formações Barreirinha, Monte Alegre, Itaituba (inferior) e Nova Olinda, ao passo que pseudomorfos de dolomita são observados nas formações Itaituba (inferior) e Nova Olinda. Barreirinha e Itaituba (inferior) registram microtexturas de dissolução, contudo, somente na Formação Nova Olinda ocorre espécimes com textura de superfície original e microtextura granular.

Os valores de IAC anômalos, registrados para as formações Barreirinha, Itaituba e Nova Olinda, em conjunto com um valor baixo predominante estão vinculados à forte dissolução, lixiviação da matéria orgânica dos espécimes e, ocasionalmente, corrosão. Dois grupos de conodontes, submetidos ao evento térmico mesozóico de alta temperatura associado com atividade ígnea, são diferenciados para as amostras que proveram valores de IAC de 6 a 7: **(I)** valor anômalo em conjunto com outros valores de IAC inferiores, *bleach* e forte corrosão; **(II)** espécimes apresentando microtextura granular (Formação Nova Olinda) vinculada à recristalização de apatita. O primeiro grupo caracteriza espécimes submetidos a aquecimento, associado a fluídos sob pressão, enquanto o segundo grupo, a metamorfismo de contato, através de intrusões de diabásio nas proximidades de unidades evaporíticas.

Considerando que a maturação da matéria orgânica no Carbonífero-Permiano e a principal fase de geração e expulsão de petróleo concluída no Triássico inicial estão relacionadas ao efeito de sobrecarga da pilha sedimentar acumulada até o Permiano, os valores de IAC indicam paleotemperaturas entre menos que 40ºC e, mais provável, cerca de 180ºC. Para as unidades intrudidas por *sills*, com intercalações de estratos evaporíticos espessos, as paleotemperaturas são aqui estimadas entre 420-720ºC para um intervalo de aquecimento entre 1000 anos e 1Ma, embora a temperatura mais alta (curto aquecimento) seja mais plausível. A distribuição das isolinhas de IAC para as amostras estudadas do Grupo Tapajós mostra uma tendência aproximadamente coincidente com os mapas de profundidade do embasamento pré-cambriano, de distribuição da sucessão paleozóica preservada e de áreas maturas para hidrocarbonetos.

Recomendações

A taxonomia e a sistemática permitiram o reconhecimento de 45 espécies de conodontes para a Bacia do Amazonas, sendo identificadas três espécies para a Formação Barreirinha; seis para a Formação Monte Alegre; 40 espécies para a Formação Itaituba, sendo 24 para a porção inferior e 16 para a porção superior; 13 espécies para a Formação Nova Olinda. Assim, uma amostragem de alta resolução em sucessões de subsuperfície para a Bacia do Amazonas provavelmente forneceria resultados semelhantes àqueles de áreas clássicas e uma bioestratigrafia de conodontes muito precisa.

Além disso, um melhor conhecimento a respeito da história tectono-termal da bacia, a partir de dados do Índice de Alteração de Cor (IAC) de conodontes, também poderia ser obtido frente a uma densidade de amostragem superior.

Capítulo VI – Referências Bibliográficas

Abelson, P. H. Organic constituents of fossils. In: Abelson, P. H. Paleobiochemistry, 1953-1954. **Annual report of the director of the Geophysical Laboratory. Carnegie Institute Washington Year Book**, n. 53, p. 97-101.

Aldridge, R. L.; Briggs, D. E. G.; Clarkson, E. N. K.; Smith, M. E. The affinities of conodonts-new evidence from the Carboniferous of Edinburgh, Scotland. **Lethaia**, v. 19, p. 279-291, 1986.

Aldridge, R. L.; Briggs, D. E. G.; Smith, M. R; Clarkson, E. N. K.; Clark, N. D. L. The anatomy of conodonts. **Philosophical Transactions of the Royal Society London**, v. 340, p. 405-421, 1993.

Aldridge, R. L.; Donogue, P. C. J. Conodonts: a sister group of hagfishes?. In: Jorgensen, J. M. *et al*. (Ed.). **The Biology of Hagfishes**. London: Chapman; Hilt, 1998. v. 2, p. 15-31.

Alekseev, A. S.; Goreva, N. V. Description of new characteristic taxa. In: Makhlina, M. Kh. *et al*. (Ed.). **Middle Carboniferous of Moscow Syneclise (southern part)**. Moscow: Paleontologicheskiy Institut Rossiiskoy Akademii Nauk, 2001. v. 2, chapter 9, p. 113-140 (in Russian).

Alekseev, A. S.; Goreva, N. V. The conodont *Neognathodus bothrops* Merrill, 1972 as the marker for the lower boundary of the Moscovian Stage (Middle Pennsylvanian). In: Lucas, S. G. *et al*. (Ed.). **The Carboniferous-Permian Transition**. New Mexico Museum of Natural History and Science, 2013. Bulletin 60, p. 1-6.

Almeida, F. F. M. Distribuição regional e relações tectônicas do magmatismo Pós-Paleozóico no Brasil. **Revista Brasileira de Geociências**, v. 16, p. 325-349, 1986.

Altiner, D.; Savini, R. R. Pennnsylvanian foraminifera and biostratigraphy of the Amazonas and Solimões basins (north Brazil). **Revue de Paléobiologie**, v. 14, p. 417-453, 1995.

Araújo, J. S.; Rocha-Campos, A. C. Conodonts from the Itaituba Formation (Pennsylvanian) at well PEST-2-AM Amazon Basin. **Ciência e Cultura**, v. 21, p. 221-228, 1969.

Armstrong, H. A. Numerical methods as a test of CAI temperature ranges. In: FOURTH EUROPEAN CONODONT SYMPOSIUM (ECOS IV), 1985. Southampton, Abstracts… Southampton: 1985. p. 2-3.

Austin, R. L.; Rhodes, F. H. T. Family Cavusgnathidae. In: Clark, D. L. *et al*. (Ed.). **Conodonta. Treatise on Invertebrate Paleontology**. Geological Society of America and University of Kansas, 1981. Part W (Miscellanea), Supplement 2, p. 158.

Baesemann, J. F. Missourian (Upper Pennsylvanian) conodonts of northeastern Alaska. **Journal of Paleontology**, v. 47, p. 689-710, 1973.

Baesemann, J. F.; Brenckle, P. L.; Gruzlovic, P. D. Composite standard correlation of the Mississippian-Pennsylvanian (Carboniferous) Lisburne Group from Prudhoe Bay to the eastern Arctic National Wildlife Refuge, North Slope, Alaska. In: Clough, J.G.; Larson, F. (Ed.). **Short notes on Alaska geology**. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys: Professional Report, 1998. p. 23-36.

Bardashev, I. A. Conodont stratigraphy of Middle Asian Middle Devonian. **Courier Forschungsinstitut Senckenberg**, v. 154, p. 31-83, 1992.

Barrick, J. E.; Boardman, D. R. Stratigraphic distribution of morphotypes of *Idiognathodus* and *Streptognathodus* in Missourian-lower Virgilian strata, north-central Texas. In: Boardman, D. R. *et al*. (Ed.). **Late Pennsylvanian chronostratigraphic boundaries in north-central Texas: Glacial-eustatic events, biostratigraphy, and paleoecology, a guidebook with contributed papers**. Contributed papers, Texas Tech University: Lubbock. Studies in Geology, 1989. Part II, p. 167–188.

Barrick J. E.; Walsh, T. R. Some older North American types of *Idiognathodus* and *Streptognathodus*. In: Heckel, P.H. (Ed.). **Guidebook, Fieldtrip 8, XIV International Congress on the Carboniferous–Permian**. Lawrence: Kansas Geological Survey, 1999. p. 162-169, p. 99-27 (Open File Report).

Barrick, J. E.; Heckel, P. H.; Boardman, D. R. Evolutionary patterns in Late Pennsylvanian *Idiognathodus* and *Streptognathodus* and implications for chronostratigraphic boundary characterization and recognition. In: Heckel, P.H. (Ed.). **Guidebook, Fieldtrip 8, XIV International Congress on the Carboniferous-Permian**. Lawrence: Kansas Geological Survey, 1999. p. 99-27, p. 178-185 (Open File Report).

Barrick, J. E.; Lambert, L. L.; Heckel, P. H.; Boardman, D. R. Pennsylvanian conodont zonation for Midcontinent North America. **Revista Española de Micropaleontologia**, v. 36, p. 231-250, 2004.

Barrick, J. E.; Lambert, L. L.; Heckel, P. H.; Rosscoe, S. J.; Boardman, D. R. Midcontinent Pennsylvanian conodont zonation. **Stratigraphy**, v. 10, p. 55-72, 2013.

Bassler, R.S. Classification and stratigraphic use of the conodonts. **Bulletin Geological Society of America**, v. 36, p. 218-220, 1925.

Bastida, F.; Brime, C.; García-López, S.; Sarmiento, G. N. Tectono-thermal evolution in a region with thin skinned tectonics: the western nappes in the Cantabrian Zone (Variscan belt of NW Spain). **International Journal of Earth Sciences**, *v.* 88, p. 38-48, 1999.

Belka, Z. Upper Visean conodonts from Orlej in the Cracow Upland: stratigraphical and paleothermal implications. **Acta Geologica Polonica**, v. 32, n. 1-2, p. 57-67, 1982.

______. Thermal maturation and burrial history from Conodont Colour Alteration data, Holy Cross Mountains, Poland. **Courier Forchung-Institut Senckenberg**, v. 118, p. 241-251, 1990.

Bender, K. P. Lower and Middle Pennsylvanian conodonts from the Canadian Artic Archipelago. **Geological Survey of Canada**, v. 79, p. 1-24, 1980.

Bischoff, G.; Ziegler, W. Die Conodontenchronologie des Mitteldevons und des tiefsten Oberdevons. **Abhandlungen des Hessischen Landesamtes fur Bodenforschung**, v. 22, p. 1-136, 1957.

BjØrlykke, K. Heat transport in sedimentary basins. In: BjØrlykke, K. (Ed.). **Petroleum Geoscience: from sedimentary environments to rock physics**. Springer-Verlag Berlin: Heidelber, 2010. p. 253-257.

Blanco-Ferrera, S.; Sanz-López, J.; García-López, S.; Bastida and F.; Valín, M. L. Conodont alteration and tectonothermal evolution of a diagenetic unit in the Iberian Variscan belt (Ponga-Cuera unit, NW Spain). **Geological Magazine**, v. 148, p. 35-49, 2011.

Boardman, D. R.; Heckel, P. H.; Marshall, T. R. Preliminary report on lower Desmoinesian (mid-Moscovian) conodonts from lower and middle Cherokee Group of southern Midcontinent North America. **Newsletter on Carboniferous Stratigraphy**, v. 22, p. 41-47, 2004.

Bond, D. P. G.; Wignall, P. B. The role of sea-level change and marine anoxia in the Frasnian-Famennian (Late Devonian) mass extinction. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 263, p. 107-118, 2008.

Bostick, N. H. Time as a factor in thermal metamorphism of phytoclasts (coaly particles). In: COMPTE RENDU, SEPTIÈME CONGRÈS INTERNATIONALES DE STRATIGRAPHIE ET DE GÉOLOGIE DU CARBONIFÈRE, 1971. Krefeld, **Anais**... Krefeld: 1973. v. 2, p. 183-193.

Boucot, A. J.; Johnson, J. G.; Talent, J. A. Early Devonian brachiopod zoogeography. **Geological Society of America Special Paper**, v. 119, p. 113, 1969.

Boucot, A. J. Devonian biogeography: An update. In: McMillan *et al*. (Ed.). **Devonian of the World**. Canadian Society of Petroleum Geologists, 1989. Memoir 14, v. 3, p. 211-223 (imprint 1988).

Brand, U. Global climatic changes during the Devonian–Mississippian: stable isotope biogeochemistry of brachiopods. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 75, p. 311-329, 1989.

Briggs, D. E. G.; Clarksoy, E. N. K.; Aldridge, R.L. The conodont animal. **Lethaia**, v. 16, p. 1-14, 1983.

Brime, C.; Garcia-Lopez, S.; Bastida, E.; Valin, M. L.; Sanz-Lopez, J.; Aller, J. Transition from diagenesis to metamorphism near the front of the variscan regional metamorphism (Cantabrian Zone, Northwestern Spain). **Journal of Geology**, v. 109, p. 363-379, 2001.

Burnett, R. D. Regional maturation patterns for Late Visean (Carboniferous, Dinantian) rocks of northern England based on mapping conodont colour. **Irish Journal of Earth Sciences**, v. 8, p. 165-186, 1987.

______. Physical and chemical changes in conodonts from contact-metamorphosed limestones. **Irish Journal of Earth Sciences**, v. 9, p. 79-119, 1988.

Burnett, R. D.; Higgins, A. C.; Austin, R. L. Carboniferous-Devonian Conodont CAI in England, Wales and Scotland. The pattern and its interpretation: a synoptic review. **Courier Forchung-Institut Senckenberg**, v. 168, p. 267-280, 1994.

Campanha, V. A.; Rocha-Campos, A. C. Alguns microfósseis da Formação Piauí (Neocarbonífero), Bacia do Parnaíba. **Boletim IG, Instituto de Geociências Universidade de São Paulo**, v. 10, p. 57-67, 1979.

Caputo, M. V. Late Devonian glaciation in South America. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 51, p. 291-317, 1985.

Caputo, M. V.; Melo, J. H. G.; Streel, M.; Isbell, J. L. Late Devonian and Early Carboniferous glacial records of South America. In: Fielding, C. R. *et al.* (Ed.). **Resolving the Late Paleozoic Ice Age in Time and Space**. Geological Society of America Special Paper, 2008. p. 161-173.

Cardoso, Cassiane Negreiros. Análise cronoestratigráfica baseada em conodontes da Formação Itaituba (Pedreira Calminas), Atokano da Bacia do Amazonas-Brasil. 2010. 163 f. Dissertação (Mestrado em Geociências) – Instituto de Geociências, Curso de Pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2010.

Cardoso, C. N.; Lemos, V. B.; Scomazzon, A. K. Alterações de cor e texturais/microcristalinas em conodontes - importante ferramenta no estudo da geotermometria. In: CONGRESSO BRASILEIRO DE GEOLOGIA, 46. CONGRESSO DE GEOLOGIA DOS PAÍSES DE LINGUA PORTUGUESA, 1., 2012. Santos, SP, **Anais**... São Paulo: Sociedade Brasileira de Geologia, 2012. 1 CD-ROM.

Cardoso, C. N.; Lemos, V. B.; Scomazzon, A. K. First occurrence of Devonian conodont elements in the Barreirinha Formation, Amazonas Basin, Northeast Brazil. In: Albanesi, G. L.; Ortega, G. (Ed.). **Conodonts from the Andes**. Asociación Paleontológica Argentina: Publicación Especial, 2013. p. 91-93.

Cardoso, C. N.; Sanz-López, J.; Blanco-Ferrera, S.; Lemos, V. B.; Scomazzon, A. K. Frasnian conodonts at high palaeolatitude (Amazonas Basin, north Brazil). **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 418, p. 57-64, 2015a.

Cardoso, C. N.; Sanz-López, J.; Blanco-Ferrera, S.; Lemos, V. B; Scomazzon, A. K. Conodont colour alteration index and upper Paleozoic thermal history of the Amazonas Basin, Brazil. **Journal of South American Earth Sciences**, v. 64, p. 139-151, 2015b.

Carozzi, A. V.; Alves, R. J.; Castro, J. C. Controle tectônico sedimentar dos carbonatos permo-carboníferos das formações Itaituba e Nova Olinda da Bacia do Amazonas. In: CONGRESSO BRASILEIRO DE GEOLOGIA, 26., 1972. Belém, **Anais**... Belém: Sociedade Brasileira de Geologia, 1972. v. 3, p. 47-64.

Carozzi, A. V. Petroleum geology in the Paleozoic clastics of the Middle Amazon Basin, Brazil. **Journal of Petroleum Geology**, v. 2, p. 55-74, 1979.

Chauffe, K. M. Phylogeny of the multielement conodont genera *Bactrognathus*, *Doliognathus* and *Staurognathus*. **Journal of Paleontology**, v. 59, p. 299-309, 1985.

Chauffe, K. M.; Nichols, P. A. Multielement conodont species from the Louisiana Limestone (Upper Devonian) of West-Central Illinois and Northeastern Missouri, U.S.A. **Micropaleontology**, v. 41, p. 171-186, 1995.

Clark, D. L.; Miller, J. F. Early evolution of conodonts. In: Robinson, R. A. (Ed.). **Treatise on invertebrate Paleontology**. Kansas: Geological Society of America and University Press, 1969. Part W, Supplement 2, p. 125-134.

Clark, D. L.; Behnken, F. H. Conodonts and biostratigraphy of the Permian. In: Sweet W.C.; Bergstrom, S.E. (Ed.). **Symposium on conodont biostratigraphy**. Geological Society of America Memoir, 1971. v. 127, p. 415-439.

Clark, D. L.; Sweet, W. C.; Bergström, S. M.; Klapper, G.; Austin, R. L.; Rhodes, F. H. T.; Müller, K. J.; Ziegler, W.; Lindström, M.; Miller, J. F.; Harris, A. G. Conodonta. In: Robinson, R. A. (Ed.). **Treatise on invertebrate Paleontology**. Kansas: Geological Society of America and University Press, 1981. Part W, supplement 2, p. 1-202.

Coutinho, L. F. C.; Gonzaga, F. G. Evolução tectonosedimentar e termomecânica da Bacia do Amazonas. In: CONGRESSO DE GEOLOGIA, 39., 1996. Salvador, **Anais**... Salvador: 1996. v. 5, p. 342-346.

Cunha, P. R. C.; Gonzaga, F. G.; Coutinho, L. F. C.; Feijó, F. J. Bacia do Amazonas. **Boletim de Geociências da Petrobras**, v. 8, p. 47-55, 1994.

Cunha, P. R. C.; Melo, J. H. G.; Silva, O. B. Bacia do Amazonas. **Boletim de Geociências da Petrobras**, v. 15, p. 227-251, 2007.

Davydov, V. Warm water benthic foraminifera document the Pennsylvanian–Permian warming and cooling events – The record from the Western Pangea tropical shelves. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 414, p. 284-295, 2014.

Di Pasquo, M., Amenábar, C. R., Noetinger, S. Middle Devonian microfloras and megafloras from western Argentina and Southern Bolivia: their importance in the palaeobiogeographical and palaeoclimatic evolution of western Gondwana. In: Königshof, P. (Ed.). **Devonian Change: case studies in palaeogeography and palaeoecology**. The Geological Society, London: Special Publication, 2009. p. 193-213.

Donoghue, P. C. J.; Purnell, M. A.; Aldridge, R. J.; Zhang, S. The interrelationships of ‘complex’ conodonts (Vertebrata). **Journal of Systematic Palaeontology**, v. 6, n. 2, p. 119-153, 2008.

Dunn, D. L. Late Mississippian conodonts from the Bird Spring Formation in Nevada. **Journal of Paleontology**, v. 39, p. 1145-1150, 1965.

______. New Pennsylvanian platform conodonts from southwestern United States. **Journal of Paleontology**, v. 40, p. 1294-1303, 1966.

______. Middle Carboniferous conodonts from western United States and phylogeny of the platform group. **Journal of Paleontology**, v. 44, p. 312-342, 1970.

Dzik, J. Remarks on the evolution of Ordovician conodonts. **Acta Palaeontologica Polonica**, v. 21, p. 395-455, 1976.

Eiras, J. F. Cenário geológico nas bacias sedimentares no Brasil: Tectônica, sedimentação e sistemas petrolíferos da Bacia do Solimões, Estado do Amazonas. In: SEARCHING FOR OIL AND GAS IN THE LAND OF GIANTS, 1998. Buenos Aires, **Anais**… Buenos Aires: Schlumberger, 1998. p. 23-31.

Ellison, S.; Graves, R. W. Jr. Lower Pennsylvanian (Dimple Limestone) conodonts of the Marathon Region, Texas. **Bulletin of the Missouri University, School of Mines and Metallurgy**, v. 14, p. 1-21, 1941.

Ellison, S. R. J. The composition of conodonts. **Journal of Paleontology**, v. 18, p. 133-140, 1944.

Ellison, S. P. Revision of the Pennsylvanian conodonts. **Journal of Paleontology**, v. 15, p. 107-143, 1941.

______. Conodont taxonomy in the Pennsylvanian. **Geologica et Paleontologica SB1**, p. 127-146, 1972.

Epstein, A. G.; Epstein, J. B.; Harris, L. D. Incipient metamorphism, structural anomalies, and oil and gas potential in the Appalachian basin determined from conodont color. In: ANNUAL MEETING, 1974. Miami Beach, **Anais**… Miami Beach: Geological Society of America Abstracts with Programs, 1974. v. 6, n. 7, p. 723-724.

Epstein, A. G.; Epstein, J. B.; Harris, L. D. Conodont color alteration – an index to diagenesis of organic matter. In: ANNUAL MEETING, 1975. Dallas, **Anais**… Dallas: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, 1975a. v. 2, p. 21-22.

Epstein, A. G.; Epstein, J. B.; Harris, L. D. Conodont color alteration - an index to organic metamorphism. United States Geological Survey open-file report, 1975b. v. 75, p. 379.

Epstein, A. G.; Epstein, J. B.; Harris, L. D. Conodont Color Alteration - an Index to Organic metamorphism**. US Geological Survey Professional Paper**, v. 995, p. 1-27, 1977.

Fohrer, B.; Nemyrovska, T. I.; Samankassou, E.; Ueno, K. The Pennsylvanian (Moscovian) Izvarino section, Donets Basin, Ukraine: A multidisciplinary study on microfacies, biostratigraphy (conodonts, foraminifers, and ostracodes), and paleoecology. **Journal of Paleontology**, v. 81, p. 1-85, 2007.

Fúlfaro, V. J. Conodontes do Calcário Itaituba do Carbonífero do Rio Tapajós, Estado do Pará. **Boletim da Sociedade Brasileira de Geologia**, v. 14, p. 29-40, 1965.

García-Bellido, D.C.; Rodríguez, S. Palaeobiogeographical relationships of poriferan and coral assemblages during the late Carboniferous and the closure of the western Palaeotethys Sea–Panthalassan Ocean connection. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 219, p. 321-331, 2005.

García-López, S.; Brime, C.; Bastida, F.; Sarmiento, G. N. Simultaneous use of thermal indicators to analyse the transition from diagenesis to metamorphism: an example from the Variscan Belt of northwest Spain. **Geological Magazine**, v. 134, p. 323-334, 1997.

García-López, S.; Bastida, F.; Aller, J. A.; Sanz-López, J. Geothermal paleogradients and metamorphic zonation from the conodont colour alteration index (CAI). **Terra Nova**, v. 13, p. 79-83, 2001.

Geitgey, J. E.; Carr, T. R. Temperature as factor affecting conodont diversity and distribution. In: Austin, R.L. (Ed.). **Conodonts: investigative techniques and applications**. British Micropalaeontological Society Series, Chichester: Ellis Horwood Limited, 1987. p. 241-255.

Gonzaga, F. G.; Gonçalves, F. T. T.; Coutinho, L. F. C. Petroleum geology of the Amazonas Basin, Brazil: modelling of hydrocarbon generation and migration. In: Mello, M. R.; Katz, B. J. (Ed.). **Petroleum systems of South Atlantic margins**. American Association of Petroleum Geologists Memoir, 2000. p. 159-178.

Goreva, N. V. Conodonts of the Moscovian Stage of the Moscow Syneclise. In: Menner, V. V. (Ed.). **Paleontological characteristics of the types and keys sections of the Moscow Syneclise**. Moskow University Publications House, 1984. p. 44-102 (in Russian).

Goreva, N. V.; Alekseev, A. S. Biostratigraphic characteristics of Moscovian Stage on different fossil groups. In: Makhlina, M. Kh. *et al*. (Ed.). **Middle Carboniferous of Moscow Syneclise (southern part)**. Moscow: Paleontologicheskiy Institut Rossiiskoy Akademii Nauk, 2001. v. 2, chapter 2, p. 33-54 (in Russian).

Grader, G. W.; Isaacson, P. E.; Díaz-Martínez, E.; Pope, M. C. Pennsylvanian and permian sequences in Bolivia: Direct responses to Gondwana glaciation. In: Fielding, C. R. *et al*. (Ed.). **Resolving the Late Paleozoic Ice Age in time and space**. Geological Society of America Special Paper, 2008. p. 143-159.

Grahn, Y.; Melo, J. E. G. Chitinozoan biostratigraphy of the Late Devonian formations in well Caima PH-2, Tapajos River area, Amazonas Basin, northern Brazil. **Review of Palaeobotany and Palynology**, v. 118, p. 115-139, 2002.

Grayson, R. C. Morrowan and Atokan (Pennsylvanian) conodonts from the eastern margin of the Arbuckle Mountains, southern Oklahoma. In: Sutherland, P.K.; Manger, W.L. (Ed.). **The Atokan Series (Pennsylvanian) and its boundaries**. Norman: Bulletin Oklahoma Geological Survey, 1984. v.136, p. 41-61. (a symposium).

Grayson, R. C.; Trice, E. L.; Westergaard, E. H. Significance on some middle Atokan to early Missourian conodont faunas from the Llano Uplift and Colorado River Valley, Texas. **Southwest section APPPG Transactions**, Forth Worth, p. 117-131, 1985.

Grayson, R. C.; Merrill, G. K.; Lambert, L. L.; Turner, J. Phylogenetic basis for species recognition within conodont genus *Idiognathodus*, applicability to correlation and boundary placement. In: Boardman, D. R. *et al.* (Ed.). **Late Pennsylvanian chronostratigraphic boundaries in north-central Texas: Glacial–eustatic events, biostratigraphy, and paleoecology, a guidebook with contributed papers**. Contributed papers, Texas Tech University, Lubbock, Studies in Geology, 1989. Part II, p. 75-94.

Grayson, R. C. Canyon Creek: a significant exposure of a predominantly mudrock succession recording essentially continuous deposition from the late Devonian through the Middle Pennsylvanian. In: Ritter, S. M. (Ed.). **Early and Middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma**. Norman: Oklahoma Geological Survey, Guidebook, 1990. p. 85-114.

Grayson, R. C.; Merrill, G. K.; Lambert, L. L. Carboniferous gnathodontid conodont apparatuses: evidence of a dual origin for Pennsylvanian taxa. **Courier Forschungsinstitut Senckenberg**, v. 118, p. 353-396, 1990.

Groves, J. R.; Kulagina, E. I.; Villa, E. Diachronous appearances of the Pennsylvanian fusulinid *Profusulinella* in Eurasia and North America. **Journal of Paleontology**, v. 81, p. 227-237, 2007.

Grubbs, R. K. Conodont platform elements from the Wapanucka and Atoka formations (Morrowan–Atokan) of the Mill Creek Syncline central Arbuckle Mountains, Oklahoma. In: Sutherland, P. K.; Manger, W. L. (Ed.). **The Atokan Series (Pennsylvanian) and its boundaries**. Norman: Bulletin Oklahoma Geological Survey, 1984. v. 136, p. 65-79. (a symposium).

Gunnell, F. H. Conodonts from the Fort Scott Limestone of Missouri. **Journal of Paleontology**, v. 15, p. 242-252, 1931.

______. Conodont and fish remains from the Cherokee, Kansas City, and Wabaunsee groups of Missouri and Kansas. **Journal of Paleontology**, v. 7, p. 261-297, 1933.

Hallam, A.; Wignall, P. B. **Mass extinctions and their aftermath**. New York: Oxford University Press, 1997. 328 p.

Harlton, B. H. Micropaleontology of the Pennsylvanian Johns Valley Shale of the Ouachita Mountains. **Journal of Paleontology**, v. 7, p. 3-29, 1933.

Harris, A. G.; Harris, L. D.; Epstein, J. B. **Oil and gas data from Paleozoic rocks in the Appalachian basin: maps for assessing hydrocarbon potential and thermal maturity (conodont color alteration isograd isopachs)**. United States of America: United States Geological Survey Miscellaneous Investigations Series, 1978, Map 1-917-E.

Harris, A. G. Color and alteration: an index to organic metamorphism in conodont elements. In: Robinson, R. A. (Ed.). **Treatise on invertebrate Paleontology**. Kansas: Geological Society of America and University Press, 1981. Part W, supplement 2, p. 1-202.

Harris, A. G.; Rexroad, C. B.; Liermann, R. T.; Askin, R. A. Evaluation of a CAI anomaly, Putman County, Central Indiana, U.S.A.: possibility of a Mississippi-Valley-type hydrothermal system. **Courier Forschungs Institute Senckenberg**, v. 118, p. 253-266, 1990.

Harris, A. G.; Stamm, N. R.; Weary, D. J.; Reperski, J. E.; Stamm, R. G.; Parker, R. A. **Conodont color alteration index (CAI) map and conodont-based age determinations for the Winchester 30'x 60' quadrangle and adjacent area, Virginia, West Virginia, and Maryland**. United States of America: United States Geological Survey Miscellaneous Investigations Series, 1994, Map MF-2239.

Harris, N. B.; Mnich, C. A.; Selby, D.; Korn, D. Minor and trace element and Re–Os chemistry of the Upper Devonian Woodford Shale, Permian Basin, west Texas: Insights into metal abundance and basin processes. **Chemical Geology**, v. 356, p. 76-93, 2013.

Harris, R. W.; Hollingsworth, R. V. New Pennsylvanian conodonts from Oklahoma. **American Journal of Science**, v. 25, p. 193-204, 1933.

Hass, W. H. Conodonts from the Chappel Limestone of Texas. **U.S. Geological Survey Professional Paper**, v. 294-J, p. 365-399, 1959.

Heckel, P. H.; Witzke, B. J. Devonian world paleogeography determined from distribution of carbonates and related lithic paleoclimatic indicator. In: House, M. R. *et al*. (Ed.). **The Devonian System**. Special Papers in Palaeontology, 1979. v. 23, p. 99-123.

Heckel, P. H. Pennsylvanian stratigraphy of Northern Midcontinent Shelf and biostratigraphic correlation of cyclothems. **Stratigraphy**, v. 10, p. 3-39, 2013.

Helms, J. Conodonten aus dem Saalfelder Oberdevon (Thüringen). **Geologie**, v. 8, p. 634-677, 1959.

Helsen, S.; Königshof, R. Conodont thermal alteration patterns in Paleozoic rocks from Belgium, northern France and western Germany. **Geological Magazine**, v. 131, n. 3, p. 369-386, 1994.

Helsen, S. The influence of host-rock composition on the colour alteration of Namurian conodonts from Belgium. **Geologie en Mijnbouw**, v. 75, p. 373-378, 1997.

Henderson, C. M.; Schmitz, M.; Crowley, J.; Davydov, V. Evolution and geochronlogy of the *Sweetognathus* lineage from Bolivia and the urals of Russia; biostratigraphic problems and implications for Global Stratotype Section and Pont (GSSP) definion. **Permophyles**, v. 53, supplement 1, p. 20-21, 2009.

Higgings, A. C. Conodont zonation of the late Viséan - early Westphalian strata of the south and central Pennines of northern England. **Bulletin of the Geological Survey of Great Britain**, v. 53, p. 1-127, 1975.

Hinde, G. J. On conodonts from the Chazy and Cincinnati group of the Cambro-Silurian and from the Hamilton and Genesee shale divisions of the Devonian in Canada and the United States. **Geological Society of London Quarterly Journal**, v. 35, p. 351-369, 1879.

Hood, A.; Gutjahr, C. C. M.; Heacock, R. L. Organic metamorphism and the generation of petroleum. **American Association of Petroleum Geologists Bulletin**, v. 59, n. 6, p. 986-996, 1975.

Horowitz, A. S.; Rexroad, C. B. An evaluation of statistical reconstructions of multielement conodont taxa from middle Chesterian rocks (Carboniferous) in southern Indiana. **Journal of Paleontology**, v. 56, p. 959-969, 1982.

Hünicken, M. A. Some paleogeographical aspects of South American conodonts and related forms. **Courier Forschungsinstitut Senckenberg**, v. 117, p. 29-49, 1989.

Hünicken, M. A.; de Melo, J. H. G.; Lemos, V. B. Devonian conodonts from the Upper Amazon Basin, Northwestern Brazil. In: McMillan, N.J. *et al*. (Ed.). **Devonian of the World**. Canadian Society of Petroleum Geologists, 1989. Memoir 14, v. 3, p. 479-483 (imprint 1988).

Iannuzzi, R.; Rösler, O. Floristic migration in South America during the Carboniferous: phytogeographic and biostratigraphic implications. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 161, p. 71-94, 2000.

Igo, H.; Koike, T. Carboniferous conodonts from the Omi Limestone, Niigata Prefecture, central Japan. **Palaeontological Society of Japan, Transaction and Proceedings, New series**, v. 53, p. 179-193, 1964.

Issacson, P. E.; Díaz Martínez, E. Evidence for a Middle–Late Paleozoic foreland basin and significant paleolatitudinal shift, Central Andes. In: Tankard, A. J. *et al*. (Ed.). **Petroleum basins of South America**. American Association of Petroleum Geologists, 1995. Memoir 62, p. 231-249.

Isaacson, P. E. Mid-Paleozoic biogeography of the Central Andes: endemic faunas, immigrants, and paleogeography. In: Díaz-Martínez, E.; Rábano, I. (Ed.). **European Meeting on the Palaeontology and Stratigraphy of Latin America, 4**. Madrid: Instituto Geológico y Minero de España, 2007. p. 213-218. (Cuadernos del Museo Geominero, 8).

Isaacson, P. E.; Díaz-Martínez, E.; Grader, G. W.; Kalvoda, J.; Babek, O.; Devuyst, F. X. Late Devonian–earliest Mississippian glaciation in Gondwanaland and its biogeographic consequences. **Palaeogreography, Palaeoclimatology, Palaeoecology**, v. 268, p. 126-142, 2008.

Jeppsson, L.; Anehus, R.; Fredholm, D. The optimal acetate buffered acetic acid technique for extracting phosphatic fossils. **Journal of Paleontology**, v. 73, p. 964-972, 1999.

Joachimski, M. M.; Breisig, S.; Buggisch, W.; Talent, J. A.; Mawson, R.; Gereke, M.; Morrow, J. M.; Day, J.; Weddige, K. Devonian climate and reef evolution: Insights from oxygen isotopes in apatite. **Earth and Planetary Science Letters**, v. 284, p. 599-609, 2009.

John, E. H.; Wignall, P. B.; Newton, R. J.; Bottrell, S. H. $\delta^{34}S_{CAS}$ and $\delta^{18}O_{CAS}$ records during the Frasnian-Famennian (Late Devonian) transition and their bearing on mass extinction models. **Chemical Geology**, v. 275, p. 221-234, 2010.

Johnson, J. G.; Klapper, G.; Sandberg, C. A. Devonian eustatic fluctuations in Euramerica. **Geological Society of America Bulletin**, v. 96, p. 567-587, 1985.

Kidder, D. L.; Worsley, T. R. Causes and consequences of extreme Permo-Triassic warming to globally equable climate and relation to the Permo-Triassic extinction and recovery. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 203, p. 207-237, 2004.

Kidder, D. L.; Worsley, T. R. Phanerozoic Large Igneous Provinces (LIPs), HEATT (haline Euxinic Acidic Thermal Transgression) episodes, and mass extinctions. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 295, p. 162-191, 2010.

Klapper, G.; Philip, G. M. Devonian conodont apparatuses and their vicarious skeletal elements. **Lethaia**, v. 4, p. 429-452, 1971.

Klapper, G.; Philip, G. M. Familial classification of reconstructed Devonian conodont apparatuses. **Geologica et Palaeontologica Special Volume**, v. 1, p. 97-105, 1972.

Klapper, G.; Johnson, J. G. Endemism and dispersal of Devonian conodonts. **Journal of Paleontology**, v. 54, p. 400-455, 1980.

Klapper, G. The Montagne Noire Frasnian (Upper Devonian) conodont succession. In: McMillan, N. J.; Embry, A. F.; Glass, D. J. (Ed.). **Devonian of the World**. Canadian Society of Petroleum Geologists, 1989. memoir 14, v. 3, p. 449-468 (imprint 1988).

Klapper, G.; Kuz'min, A. V.; Ovnatanova, N. S. Upper Devonian conodonts from the Timan-Pechora Region, Russia, and correlation with a Frasnian composite standard. **Journal of Paleontology**, v. 70, p. 131-152, 1996.

Königshof, P. Conodont colour alteration adjacent to a granitic intrusion, Harz Mountains. **Neues Jahrbuch Geologie und Paläontologie Monatshefte**, v. 2, p. 84-90, 1991.

______. Conodont deformation patterns and textural alteration in Paleozoic conodonts: examples from Germany and France. **Senckenbergiana lethaea**, v. 83, p. 149-156, 2003.

Kovacs, S.; Arkai, E. Conodont alteration in metamorphosed limestones from northern Hungary, and its relationship to carbonate texture, illite-crystallinity and vitrinite reflectance. In: Austin, R. L. (Ed.). **Conodonts: Investigative techniques and applications**. Chichester: British Micropaleontological Society Series, Ellis Horwood Limited, 1987. p. 209-230.

Kozitskaya, R. I.; Kossenko Z. A.; Lipnjagov, O. M.; Nemirovskaya, T. I. **Carboniferous conodonts of the Donets Basin**. Kiev: Izdatel’stvo (Naukova Dumka), 1978. 136 p. (in Russian).

Kozur, H. Beitäge zur Conodontenfauna des Perm. **Geologica et Paläontologica**, v. 5, p. 1-44, 1975.

Kroemmelbein, K. Devonian of the Amazonas Brazil. In: INTERNATIONAL SYMPOSIUM ON THE DEVONIAN SYSTEM. Calgary: Alberta Society of Petroleum Geologists, 1967. v. 2, p. 201-208.

Kulagina, E. I.; Pazukhin, V. N.; Kochetova, N. M.; Sintsyna, Z. A.; Kochetova, N. N. **The stratotype and key sections of the Bashkirian stage (Carboniferous) in the Southern Urals**. Gilem: Ufa, 2001. (imprint, in Russian).

Kulagina, E. I.; Pazukhin, V. N; Davydov, V. I. Pennsylvanian biostratigraphy of the Basu River section with emphasis on the Bashkirian-Moscovian transition. In: CARBONIFEROUS TYPE SECTIONS IN RUSSIA AND POTENTIAL GLOBAL STRATOTYPES, 2009. Ufa–Sibai, **Proceedings**… Ufa–Sibai: Ufa-Design Polygraph Service Ltd., 2009. p. 13-18, p. 42-63.

Lambert, L. L. Atokan and basal Desmoinesian conodonts from central Iowa, reference area for the Desmoinesian Stage. In: Sutherland, P. K.; Manger, W. L. (Ed.). **Recent advances in Middle Carboniferous biostratigraphy**. Oklahoma, Norman: Geological Survey, 1992. Circular 94, p. 111-123.

Lambert, L. L.; Heckel, P. H.; Barrick, J. E. *Swadelina* new genus (Pennsylvanian Conodonta), a taxon with potential chronostratigraphic significance. **Micropaleontology**, v. 49, p. 151-158, 2003a.

Lambert, L. L.; Heckel, P. H.; Barrick, J. E. New insights on the locality and material for the first Pennsylvanian conodont paper published in North America. **Geological Society of America**, v. 35(2), n. 5, 2003b. (Abstracts with Programs).

Lane, H. R. Uppermost Mississippian and lower Pennsylvanian conodonts from the type Morrowan region, Arkansas. **Journal of Paleontology**, v. 41, p. 920-943, 1967.

Lane, H. R.; Straka, J. J. II. Late Mississipian and Early Pennsylvanian conodonts Arkansas and Oklahoma. **Special Paper of the Geological Society of America**, v. 152, p. 1-144, 1974.

Legall, F. D.; Barnes, C. R.; McQueen, R. W. Thermal maturation, burial history and hotspot development, Paleozoic strata of Southern Ontario-Quebec, from conodont and acritarch colour alteration studies. **Bulletin Canadian Petroleum Geology**, v. 29, p. 492-539, 1982.

Lemos Valesca Brasil. **Assembléias de conodontes do carbonífero da Bacia do Amazonas**. 1990. 259 f. Tese (Doutorado em Ciências) - Instituto de Geociências, Curso de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 1990.

______. Conodontes do Carbonífero das Bacias do Amazonas e Solimões. Taxonomia – Parte I. **Pesquisas**, v. 19, p. 75-93, 1992a.

______. Conodontes do Carbonífero das Bacias do Amazonas e Solimões. Taxonomia – Parte II. **Pesquisas**, v. 19, p. 120-131, 1992b.

Lemos, V. B.; Medeiros, R. A. Transgressões e regressões cíclicas e ocorrência de conodontes no Morrowano e Atokano na Bacia do Amazonas. In: SIMPÓSIO DE MARCOS ESTRATIGRÁFICOS, 1989. Curitiba, **Anais**... Curitiba: 1989. v. 2, p. 961-969.

Lemos, V. B.; Medeiros, R. A. Conodontes do Carbonífero Inferior da Bacia do Amazonas. **Boletim de Geociências da Petrobrás**, v. 10, p. 55-60, 1996a.

Lemos, V. B.; Medeiros, R. A. O Limite Morrowano/Atokano na Bacia do Amazonas, Brasil, com base em conodontes. **Boletim de Geociências da Petrobrás**, v. 10, p. 165-173, 1996b.

Lemos, V. B.; Scomazzon, A. K. The Carboniferous biochronostratigraphy of the Amazonas Basin, Brazil, based on conodonts. In*:* Melo, J. H. G.; Terra, G. S. T. (Ed.). **Workshop Correlação de Sequências Paleozóicas Sul-Americanas**. Rio de Janeiro, 2001. p. 131-138.

Limarino, C. O.; Spalletti, L. A. Paleogeography of the upper Paleozoic basins of southern South America: An overview. **Journal of South American Earth Sciences**, v. 22, p. 134-155, 2006.

Lucas, S. G.; Krainer, K.; Barrick, J. E. Pennsyklvanian stratigraphy and conodont biostratigraphy in the Cerros de Amado, Socorro County, New Mexico. In: 60th Field Conference, Geology of the Chupadera Mesa Region, 2009. Socorro, **New Mexico Geological Society Guidebook**, 2009. p. 182-211.

Lüning, S.; Adamson, K.; Craig, J. Frasnian organic-rich shales in North Africa: regional distribution and depositional model. In: Arthur T. J. *et al*. (Ed.). **Petroleum geology of Africa: new themes and developing technologies**. Geological Society, London, 2003. p. 165-184. (Special Publication, 207).

Matsuda, N. S.; Dino, R.; Wanderley Filho, J. R. Revisão litoestratigráfica do Grupo Tapajós, Carbonífero Médio – Permiano da Bacia do Amazonas. **Boletim de Geociências da Petrobras**, v. 12, p. 435-441, 2004.

Matsuda, N. S.; Winter, W. R.; Wanderley Filho, J. R.; Cacela, A. S. M. O Paleozóico da borda sul da Bacia do Amazonas, Rio Tapajós – Estado do Pará. **Boletim de Geociências da Petrobras**, v. 18, p. 123-152, 2009.

Mayhew, P. J.; Jenkins, G. B.; Benton, T. G. A long-term association between global temperature and biodiversity, origination and extinction in the fossil record. **Proceedings of the Royal Society**, v. B, p. 1-7, 2007.

Mayr, U.; Uyeno, T. T.; Barnes, C. R. Subsurface stratigraphy, conodont zonation, and organic metamorphism of the lower Paleozoic succession, Bjorne Peninsula, Ellesmere Island, District of Franklin. **Paper of the Geological Survey of Canada**, v. 78-1A, p. 393-398, 1978.

Mei, S.; Henderson, C. M. Evolution of Permian conodont provincialism and, its significance in global correlation and paleoclimate implication. **Palaeogreography, Palaeoclimatology, Palaeoecology**, v. 170, p. 237-260, 2001.

Meister, E. M. Gradientes geotérmicos nas bacias sedimentares brasileiras. **Boletim Técnico da Petrobras**, v. 16, p. 221-232, 1973.

Melo, J. H. G. The Malvinokaffric Realm in the Devonian of Brazil. In: McMillan, N. J. *et al*. (Ed.). **Devonian of the World**. Canadian Society of Petroleum Geologists, 1989. Memoir 14, v. 1, p. 669-703 (imprint 1988).

Melo, J. H. G.; Loboziak, S. Devonian-Early Carboniferous miospore biostratigraphy of the Amazon Basin, northern Brazil. **Review of Palaeobotany and Palynology**, v. 124, p. 131-202, 2003.

Méndez, C. A. Upper Moscoviasn-middle Kasimovian conodonts (Pennsylvanian, Carboniferous) from the Las Llacerias Section (Cantabrian Zone, north Spain). **Geobios**, v. 39, p. 245-254, 2006.

Merino Redo, D.; Blanco Rojas, J. Conodontos de la Formación Copacabana (Carbonífero superior-Pérmico inferior) en la sección de Huarachani-Pacobamba: Departamento de La Paz, Bolivia. **Revista Técnica de Yacimientos Petrolíferos Fiscales Bolivianos**, v. 11, p. 109-116, 1990.

Merrill, G. K.; King, C. W. Platform conodonts from the lowest Pennsylvanian rocks of north-western Illinois. **Jounal of Paleontology**, v. 45, p. 645-664, 1971.

Merrill, G. K. Taxonomy, phylogeny, and biostratigraphy of *Neognathodus* in Appalachian Pennsylvanian rocks. **Journal of Paleontology**, v. 46, p. 817-829, 1972.

Merrill, G. K. Pennsylvanian non platform conodont genera, I: *Spathognathodus*. **Journal of Paleontology**, v. 47, p. 289-314, 1973.

______. **Pennsylvanian conodont localities in northeastern Ohio**. Columbus: Division of Geological Survey, Ohio Department of Natural Resources, 1974. Guidebook 3, p. 1-28.

Merrill, G. K.; von Bitter, P. H. Revision of conodont biofacies nomenclature and interpretations of environmental controls in Pennsylvanian rocks of eastern and central North America. **Royal Ontario Museum, Life Science Contributions**, v. 108, 1-46, 1976.

Meyerhoff, A. A; Boucot, A. J.; Meyerhoff Hull, D.; Dickins, J. M. Phanerozoic faunal and floral realms of the Earth: The intercalary relations of the Malvinokaffric and

Gondwana Faunal Realms with the Tethyan Faunal Realm. **Geological Society of America Memoir**, v. 189, p. 1-69, 1996.

Milani, E. J.; Victor Zalán, P. V. An outline of the geology and petroleum systems of the Paleozoic interior basins of South America. **Episodes**, v. 22, p. 199-205 1999.

Mishima, H.; Kakei, M.; Yasui, T.; Miyamoto, S.; Miake, Y.; Yanagisawa, T. Apatite crystal in hard tissue of conodont fossils. **Frontiers of Materials Science**, v. 2, p. 179-181, 2008.

Mosmann, R.; Falkenhein, F. U. H.; Gonçalves, A.; Nepomuceno Filho, F. Oil and gas potential of the Amazon Paleozoic basins. In: Halbouty, M. T. (Ed.). **Future petroleum provinces of the world**. American Association of Petroleum Geologists, 1986. memoir 40, p. 207-241.

Munsell Color Company. **Munsell soil color charts**. Baltimore: Munsell Color Company, 1971.

Murray, F. N.; Chronic, J. Pennsylvanian conodonts and other fossils from insoluble residues of the Minturn Formation (Desmoinesian), Colorado. **Journal of Paleontology**, v. 39, p. 594-609, 1965.

Nascimento, S.; Scomazzon, A. K.; Moutinho, L. P.; Lemos, V. B; Matsuda, N. S. Conodont biostratigraphy of two calcareous quarries - Lower Itaituba Formation, Atokan Age, Amazonas Basin, Brazil. **Revista Brasileira de Paleontologia**, v. 8, p. 193-202, 2005.

Nascimento, Sara. **Conodontes e a cronoestratigrafia da base da seção pensilvaniana, na Região de Itaituba, Porção Sul da Bacia do Amazonas, Brasil**. 2008. 246 f. Tese (Doutorado em Ciências) - Instituto de Geociências, Curso de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2008.

Nascimento, S.; Smaniotto, L. P.; Souza, P. A.; Lemos, V. B.; Scomazzon, A. K. Biochronostratigraphy (conodonts and palynology) from selected strata of the Itaituba Formation, Pará State, Brazil. **Pesquisas em Geociências**, v. 36, p. 37-47, 2009.

Nascimento, S.; Lemos, V. B.; Scomazzon, A. K.; Moutinho, L. P.; Matsuda, N. S.; Silva, C. P. First occurrence of *Ellisonia*, *Gondolella* and *Ubinates* (conodonts) in Itaituba Formation, Pennsylvanian of Amazonas Basin, Brazil. **Gaea – Journal of Geoscience**, v. 6, p. 56-62, 2010a.

Nascimento, S.; Scomazzon, A. K.; Lemos, V. B.; Moutinho, L. P.; Matsuda, N. S. Bioestratigrafia e paleoecologia com base em conodontes em uma seção de carbonatos marinhos do Pensilvaniano inferior, Formação Itaituba, borda sul da Bacia do Amazonas, Brasil. **Pesquisas em Geociências**, v. 37, p. 243-256, 2010b.

Neis, P. A. **Resultados Biocronoestratigráficos das Associações de Conodontes da Formação Itaituba, Carbonífero Superior (Pensilvaniano), da Bacia do Amazonas**. 1996. 138f. Dissertação (Mestrado em Geociências) - Instituto de Geociências, Curso de Pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 1996.

Nemirovskaya, T.I. Biostratigraphy of the Serpukhovian and Bashkirian of Donbas by conodonts. **Tektonika i Stratigrafia,** Kiev, v. 14, p. 83-91, 1978. (in Russian).

Nemirovskaya, T. I.; Alekseev, A. S. The Bashkirian conodonts of the Askyn section, Bashkirian Mountains, Russia. **Bulletin de la Société Belge de Géologie**, v. 103, p. 109-133, 1995 (imprinted in 1994).

Nemyrovska, T. I. Bashkirian conodonts of the Donets basin, Ukraine. **Scripta Geologica**, v. 119, p.1-115, 1999.

Nemyrovska, T. I.; Perret-Mirouse, M. F.; Alekseev, A. S. On Moscovian (Late Carboniferous) conodonts of the Donets Basin, Ukraine. **Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen**, v. 214, p. 169-194, 1999.

Nemyrovska, T. I. Late Moscovian (Carboniferous) conodonts of the genus *Swadelina* from the Donets Basin, Ukraine. **Micropaleontology**, v. 57, p. 491-505, 2011.

Neves, C. A. O. Prospectos potenciais e áreas prioritárias para exploração na Bacia do Amazonas. **Boletim de Geociências da Petrobras**, v. 4, p. 95-103, 1990.

Ngan, P. N. Conodonts from limestone pieces of the Late Paleozoic conglomerates in north-west Bulgaria. **Geologica Balcanica**, v. 9, p. 77-92, 1979.

Nicoll, R. S.; Druce, E. C. Conodonts from the Fairfield Group, Canning Basin, Western Australia. **Bulletin of the Bureau of Mineral resources, Geology and Geophysics**, v. 190, p. 1-134, 1979.

Nicoll, R. S. Conodont colour alteration adjacent to a volcanic plug, Canning Basin, western Australia. **Bureau of Mineral Resources Journal of Australian Geology and Geophysics**, v. 6, p. 265-267, 1981.

Nicoll, R. S.; Gorter, J. D. Conodont colour alteration, thermal maturation and the geothermal history of the Canning Basin, western Australia. Australian Petroleum Exploration Association, v. 24, n. 1, p. 243-258, 1984.

Nöth, S. Conodont color (CAI) versus microcrystalline and textural changes in Upper Triassic conodonts from Northwest Germany. **Facies**, v. 38, p. 165-174, 1998.

Nowlan, G. S.; Barnes, C. R. Application of conodont colour alteration indices to regional and economic geology. In: Austin, R. L. (Ed.). **Conodonts: Investigative techniques and applications**. Chichester: British Micropaleontological Society Series, Ellis Horwood, 1987. p. 188-202.

Nunn, J. A.; Aires, J. R. Gravity anomalies and flexure of the lithosphere in the middle Amazon Basin, Brazil. **Journal of Geophysical Research**, v. 93, p. 415-428, 1988.

Oda, H.; Matsuda, N. S; Matsumoto, R.; Nishikawa, S.; Minori, A.; Moutinho, L. P.; Nascimento, S.; Scomazzon, A. K. Coal properties and trace elements of the coal of Lower Pennsylvanian intracratonic Amazon Basin – Northern Brazil. In: INTERNATIONAL SEDIMENTOLOGICAL CONGRESS, 17., 2006. Fukuoka, **Abstract**… Fukuoka, 2006. O-055.

Over, D.J. Conodonts and the Devonian-Carboniferous boundary in the Upper Woodford Shale, Arbucle Mountains, south-central Oklahoma. **Journal of Paleontology**, v. 66, p. 293-311, 1992.

Over, D. J. ; de la Rue, S. ; Isaacson, P. E. ; Ellwood, B. Upper Devonian conodonts from black shales of the high latitude Tomachi Formation, Madre de Dios Basin, northeastern Bolivia. **Palaeontographica Americana**, v. 62, p. 89-95, 2009.

Over, D. J.; Evans, S. D.; Day, J.; Hasenmueller, N. R. The Devonian/Carboniferous boundary and the holotype of *Siphonodella sulcata* (Huddle, 1934) in the upper New Albany Shale, Illinois basin, southern Indiana. **Geological Society of America Abstracts with Programs**, v. 45, n. 7, p. 529, 2013.

Pereira, E.; Bergamaschi, S.; Rodrigues, R.; Pessôa de Souza, M. S. Silurian and Devonian world-wide flooding events in the Paraná Basin. In: PROBLEMS IN WESTERN GONDWANA GEOLOGY, WORKSHOP “SOUTH AMERICA - AFRICA CORRELATIONS: DU TOIT REVISITED”, I. Gramado, **Abstracts**… Gramado, 2007. p. 115-120.

Philippi, G. T. On the depth, time and mechanism of petroleum generation. **Geochimica et Cosmochimica Acta**, v. 29, p. 1021-1049, 1965.

Pietzner, H.; Vahl, J.; Werner, H.; Ziegler, W. Zur chemischen zusammensetzung und mikromorphologie der conodonten. In: Robinson, R. A. (Ed.). **Treatise on invertebrate Paleontology**. Kansas: Geological Society of America and University Press, 1968. Part W, supplement 2, p. 1-202.

Pina, A. C. M.; Moura, C. A. V.; Vignol-Lelarge, M. L. Termocronologia por traços de fissão em apatita em rochas ígneas do embasamento e sedimentar da Bacia do Amazonas, na região de Itaituba, PA, Brasil. **Pesquisas em Geociências**, v. 41, p. 39-50, 2014.

Playford, G.; Dino, R. Palynostratigraphy of upper Palaeozoic strata (Tapajós Group), Amazonas Basin, Brazil: Part one. **Palaeontographica Abteilung**, v. B 225, p. 1-46, 2000a.

Playford, G.; Dino, R. Palynostratigraphy of upper Palaeozoic strata (Tapajós Group), Amazonas Basin, Brazil: Part two. **Palaeontographica Abteilung**, v. B 225, p. 87-145, 2000b.

Playford, G.; Dino, R. Carboniferous and Permian palynostratigraphy. In: Koutsoukos, E. A. M. (Ed.). Springer, Dordrecht: Applied Stratigraphy, 2005. Chapter 5, p. 101-121.

Pollock, C. A. Lower Upper Devonian conodonts from Alberta, Canada. **Journal of Paleontology**, v. 42, p. 415-443, 1968.

Proctor, David Dickey. **Conodont fauna of the Dimple Limestone (late Morrowan-early Atokan, early Pennsylvanian) in the Marathon Basin, Texas**. 1991. Ph.D. thesis, Texas Tech University (unpublished).

Purnell, M. A.; Donoghue, P. J.; Aldridge, R. J. Orientation and anatomical notation in conodonts. **Journal of Paleontology**, v. 74, p. 113-122, 2000.

Qi, Y.; Wang, X.; Lambert, L. L.; Barrick, J. E.; Wang, Z.; Hu, K.; Wang, Q. Three new potential levels for the Bashkirian–Moscovian boundary in the Naqing section based on conodonts. **Newsletter on Carboniferous Stratigraphy**, v. 29, p. 61-64, 2011.

Qi, Y.; Lambert, L. L.; Nemyrovskaya, T.; Wang, X. D.; Hu, K.; Wang, Q. Multiple transitional conodont morphologies demonstrate depositional continuity in the Bashkirian–Moscovian boundary interval, Naqing section, Guizhou, South China. **New Mexico Museum of Natural History and Science Bulletin**, v. 60, p. 329-336, 2013.

Racki, G. Toward understanding Late Devonian global events: few answers, many questions. In: Over, D. J. *et al*. (Ed.). **Understanding Late Devonian and Permian-Triassic Biotic and Climatic Events: Towards an Integrated Approach**. Elsevier, 2005. p. 5-36.

Rejebian, V. A.; Harris, A. G.; Huebner, J. S. Conodont colour and textural alteration: An index to regional metamorphism and hydrothermal alteration. **Bulletin of the Geological Society of America**, *v.* 99, p. 471-479, 1987.

Rexroad, C. B.; Brown, L. M.; Devera, J.; Suman, R. J. Conodont biostratigraphy and paleoecology of the Perth Limestone Member, Staunton Formation (Pennsylvanian) of the Illinois Basin, U. S. A. **Palaeontologica Polonica**, v. 58, p. 247-259, 1998.

Richter, R.; Richter, E. Die Trilobiten der Weismes-Schichten am Hohen Venn, mit Bemerkungen über die Malvinocaffrische Provinz. **Senckenbergiana**, v. 25, p. 156-179, 1942.

Ritter, S. M. Taxonomic revision and phylogeny of post-Early Permian crisis *bisselli – whitei* Zone conodonts with comments on late Paleozoic diversity. **Geologica et Palaeontologica**, v. 20, p. 139-165, 1986.

Ritter, S. M.; Barrick, J. E.; Skinner, M. R. Conodont sequence biostratigraphy of the Hermosa Group (Pennsylvanian) at Honaker Trail, Paradox basin, Utah. **Journal of Paleontology**, v. 76, p. 495-517, 2002.

Rocha-Campos, A. C.; Archangelsky, S. South America. In: Martínez Díaz, C. *et al*. (Ed.). **The Carboniferous of the World II, Australia, Indian subcontinent, South Africa, South America & North Africa**. Madrid: Instituto Geológico y Geominero de España, IUGS Publication, 1985. p. 175-297.

Rocha Campos, A. C.; Pedrão, E.; Lemos, V. B. Indices de alteração de cor de conodontes do Carbonifero da Bacia do Amazonas. In: Congreso Argentino de Paleontología y Bioestratigrafía, IV., 1988. Mendoza, **Actas**… Mendoza, 1988. v. 3, p. 235-236.

Ross, C. A. *Eoparafusulina* from the Neal Ranch Formation (Lower Permian), west Texas. **Journal of Paleontology**, v. 41, p. 943-946, 1967.

Ross, C. A.; Ross, J. R. P. Late Paleozoic depositional sequences are synchronous and worldwide. **Geology**, v. 13, p. 194-197, 1985.

Rosscoe, S.; Barrick, J. E. Revision of *Idiognathodus* species from the Desmoinesian-Missourian (~Moscovian-Kasimovian) boundary interval in the Midcontinent Basin, North America. **Palaeontographica Americana**, nº 62, 2009.

Sakagami, S.; Mizuno, Y. Discovery of middle Pennsylvanian fusulinids and conodonts from the Copacabana Group in the Lake Titicaca region, Bolivia. **Proceedings of the Palaeontological Society of Japan**, v. 174, p. 484-494, 1994.

Sandberg, C. A. Conodont biofacies of Late Devonian *Polygnathus styriacus* Zone in western United States. In: Barnes, C. R. (Ed.). **Conodont paleoecology**. Geological Association of Canada Special Paper, 1976. v. 15, p. 171-186.

Sandberg, C. A.; Ziegler, W. Taxonomy and biofacies of important conodonts of Late Devonian *styriacus*-Zone, United States and Germany. **Geologica et Palaeontologica**, v. 13, p. 173-212, 1979.

Santos, J. O. S.; Hartmann, L. A.; McNaughtonc, N. J.; Fletcherc, I. R. Timing of mafic magmatism in the Tapajós Province (Brazil) and implications for the evolution of the Amazon Craton: evidence from baddeleyite and zircon U–Pb SHRIMP geochronology. **Journal of South American Earth Sciences**, v. 15, p. 409-429, 2002.

Santos, T. B.; Mancini, F.; Rostirolla, S. P.; Mesquita Barros, C. E.; Salamuni, E. Registro da deformação pós-paleozóica na Bacia do Amazonas, região de Itaituba (PA). **Revista Brasileira de Geociências**, v. 41, p. 95-107, 2011.

Sanz-López, J.; Blanco-Ferrera, S.; García-López, S.; Sánchez de Posada, L. C. The Mid-Carboniferous boundary in Northern Spain: difficulties for correlation of the Global Stratotype Section and Point. **Rivista Italiana di Paleontologia e Stratigrafia**, v. 112, p. 3-22, 2006.

Sanz-López, J.; Blanco-Ferrera, S. Lower Bashkirian conodonts from the Iraty Formation in the Alduides-Quinto Real Massif (Pyrenees, Spain). **Geobios**, v. 45, p. 397-411, 2012.

Sanz-López, J.; Blanco-Ferrera, S. Overgrowths of large authigenic apatite crystals on the surface of conodonts from Cantabrian limestones (Spain). **Facies**, v. 58, p. 707-726, 2012.

Sanz-López, J.; Blanco-Ferrera, S. Early evolution of *Declinognathodus* close to the Mid-Carboniferous boundary interval in the Barcaliente type section (Spain). **Palaeontology**, v. 56, p. 927-946, 2013.

Savage, N. M.; Barkeley, S. J. Early to Middle Pennsylvanian conodonts from the Klawak Formation and the Ladrones Limestone, southeastern Alaska. **Journal of Paleontology**, v. 59, p.1451-1475, 1985.

Schimmelmann, A.; Sessions, A. L.; Mastalerz, M. Hydrogen isotopic (D/H) composition of organic matter during diagenesis and thermal maturation. **Annual Review of Earth and Planetary Sciences**, v. 34, p. 501-533, 2006.

Scomazzon, Ana Karina. **Refinamento bioestratigráfico com base em Conodontes, no Pensilvaniano da Bacia do Amazonas – Região do Tapajós**. 1999. 142 f. Dissertação (Mestrado em Geociências) – Instituto de Geociências, Curso de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 1999.

______. **Estudo de conodontes em carbonatos marinhos do Grupo Tapajós, Pensilvaniano inferior a médio da Bacia do Amazonas com aplicação de isótopos de Sr e Nd neste intervalo**. 2004. 294 f. Tese (Doutorado em Geociências) – Instituto de Geociências, Curso de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2004.

Scomazzon, A. K.; Koester, E.; Moutinho, L. P.; Matsuda, N. S.; Nascimento, S.; Lemos, V. B. Sr and Nd isotopic analysis in fossils and carbonatics rocks of the Itaituba and Nova Olinda formations, Pennsylvanian of Amazonas Basin. In: GONDWANA, 12., 2005. Mendoza, **Abstracts**... Mendoza: Academia Nacional de Ciências, 2005. p. 328.

Scomazzon, A. K.; Lemos, V. B. *Diplognathodus* occurrence in the Itaituba Formation, Amazonas Basin, Brazil. **Revista Brasileira de Paleontologia**, v. 8, p. 203-208, 2005.

Scomazzon, A. K.; Moutinho, L. P.; Nascimento, S.; Lemos, V. B.; Matsuda, N. S. Conodont biostratigraphy and paleoecology of the marine sequence of the Tapajós Group, Early-Middle Pennsylvanian of Amazonas Basin, Brazil. **Journal of South American Earth Science**, v. 65, p. 25-42, 2016.

Scotese, C. R. Paleomap, 2002. Disponível em: <http://www.scotese.com>. Acessado em: jan. 2014.

Scott. A.J. Three new conodonts from the Louisiana Limestone (Upper Devonian) of western Illinois. **Journal of Paleontology**, v. 35, p. 1223-1227, 1961.

Silva, O. B.; Lemos, V. B. Controle dos Ciclos Sedimentares na Distribuição Estratigráfica dos Conodontes do Pensilvaniano (Fm. Itaituba) - Bacia do Amazonas.

In: SIMPÓSIO DE GEOLOGIA DA AMAZÔNIA, 5. 1996. Belém, **Anais**… Belém: Sociedade Brasileira de Geologia, 1996. p. 199-202.

Stamm, R. G.; Wardlaw, B. R. Conodont faunas of the late Middle Pennsylvanian (Desmoinesian) Lower Kittanning cyclothem, U.S.A. In: Cecil, C. B.; Edgar, N. T. (Ed.). **Climate controls on stratigraphy**. Tulsa: SEPM (Society for Sedimentary Geology), Special Publication, 2003. p. 95-121.

Stauffer, C. R.; Plummer H. J. Texas Pennsylvanian conodonts and their stratigraphic relations. **University of Texas Bulletin**, v. 3201, p. 13-50, 1932.

Stibane, F. R. Conodonten des Karbons aus den nordlichen Andeen Sudamerikas. **Neues Jahrbuch für Geologie und Paläeontologie**, v. 128, p. 329-340, 1967.

Stibane, F.; Forero, A. Los afloramientos del Paleozoico de La Jagua (Huila) y Río Nevado (Santander del Sur). **Geología Colombiana**, v. 6, p. 31-66, 1969.

Streel, M.; Caputo, M. V.; Loboziak, S.; Melo, J. E. Late Frasnian-Famennian climates based on playnomorph analyses and the question of the Late Devonian glaciations. **Earth-Science Reviews**, v. 52, p. 121-173, 2000.

Streel, M. West Gondwanan and Euramerican climate impact on early Famennian to latest Viséan miospore assemblages. **Newsletter of the Subcommission on Devonian Stratigraphy**, v. 22, p. 53-55, 2007.

______. Upper Devonian miospore and conodont zone correlation in western Europe. In: Königshof, P. (Ed.). **Devonian Change: case studies in palaeogeography and palaeoecology**. London: The Geological Society, Special Publication, 2009. p. 163-176.

Suárez Riglos, M.; Hünicken, M. A.; Merino Redo, D. A. Conodont biostratigraphy of the Upper Carboniferous-Lower Permian rocks of Bolivia. In: Austin, R. L. (Ed.). **Conodonts: Investigative Techniques and Applications**. London: British Micropalaeontological Society, Ellis Horwood Publishers, 1987. p. 317-325.

Sutherland, P. K.; Grayson, R. C. Morrowan and Atokan (Pennsylvanian) biostratigraphy in the Ardmore basin, Oklahoma. In: Sutherland, P. K.; Manger, W. L. (Ed.). **Recent advances in middle Carboniferous biostratigraphy**. Norman: Oklahoma Geological Survey, 1992. Circular 94, p. 81-99. (a symposium).

Swade, J.W. Conodont distribution, paleoecology, and preliminary biostratigraphy of the Upper Cherokee and Marmaton Groups (upper Desmoinesian, middle

Pennsylvanian) from two cores in south-central Iowa. Technical Information Series, Iowa Geological Survey, Iowa, v. 14, p. 1-71, 1985.

Sweet, W. C.; Bergström, S. M. Conodont provinces and biofacies of the Late Ordovician. In: Clark, D. L. (Ed.). **Conodont biofacies and provincialism**. Geological Society of America Special Paper, 1984. p. 69-87.

Sweet, Walter Clarence. **The Conodonta: morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum**. 1988. 212 f. Monographs on Geology and Geophysics, Oxford University Press, 1988.

Sweet, W. C.; Donoghue, P. C. J. Conodonts: past, present, future. **Journal of Paleontology**, v. 75, n. 6, p. 1174-1184, 2001.

Taboada, A. C. Mississippian-Early Permian brachiopods from western Argentina: Tools for middle- to high-latitude correlation, paleobiogeographic and paleoclimatic reconstruction. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 298, p. 152-173, 2010.

Teichmüller, M.; Teichmüller, R. Geological aspects of coal metamorphism. In: Murchison, D.; Westoll, T. S. (Ed). **Coal and coal-bearing strata**. New York: Elsevier Publishing Company, 1968. p. 233-267.

Tengan, C.; Shimabukuro, S.; Rocha Campos, A. C. Conodontes Carboniferos do Poço FB-ST-1-AM, Bacia do Amazonas, Brasil. In: CONGRESSO BRASILEIRO DE GEOLOGIA, XXIX., 1976. Ouro Preto, **Resumos**… Ouro Preto, 1976.

Thompson, J. B.; Newton, C. R. Late Devonian mass extinction: episodic climatic cooling or warming? In: McMillan, N.J. *et al*. (Ed.). **Devonian of the World**. Canadian Society of Petroleum Geologists, 1989. Memoir 14, v. 3, p. 29-34 (imprint 1988).

Vai, G. G. Development of the palaegeography of Pangaea from Late Carboniferous to Early Permian. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 196, p. 125-155, 2003.

Van Geldern, R.; Joachimski, M. M.; Day, J.; Jansen, U.; Alvarez, F.; Yolkin, E. A.; Ma, X. P. Carbon, oxygen and strontium isotope records of Devonian brachiopod shell calcite. **Palaeogreography, Palaeoclimatology, Palaeoecology**, v. 240, p. 47-67, 2006.

Vavrdová, M.; Isaacson, P. E. Late Famennian phytogeographic provincialism: Evidence for a limited separation of Gondwana and Laurentia. **Abhandlungen der Geologischen Bundesanstalt**, v. 54, p. 453-463, 1999.

von Bitter, P. H. Environmmental control of conodont distribution on the Shawnee Group (Upper Pennsylvanian) of eastern Kansas. **The University of Kansas Paleontological Contributions**, v. 59, p. 1-105, 1972.

von Bitter, P. H.; Merrill, G. K. Late Paleozoic species of *Ellisonia* (Conodontophorida). **Royal Ontario Museum, Life Sciences Contribution**, v. 136, p. 1-57, 1983.

von Bitter, P. H.; Merrill, G. K. Effects of variation of the speciation and phylogeny of *Diplognathodus*. **Courier Forschungsinstitut Senckenberg**, v. 118, p. 105-129, 1990.

Wanderley Filho, J. R.; Melo, J. H. G.; Fonseca, V. M. M.; Machado, D. M.C. Bacia do Amazonas. **Fundação Paleontológica Phoenix**, v. 82, p. 1-6, 2005.

Wanderley Filho, J. R.; Silva Travassos, W. A.; Barbosa Alves, D. O diabásio nas bacias paleozóicas amazônicas – herói ou vilão? **Boletim de Geociências da Petrobras**, v. 14, p. 177-184, 2006.

Wanderley Filho, J.R.; Eiras, J. F.; Cunha, P. R. C.; van der Ven, P. H. The Paleozoic Solimões and Amazonas basins and the Acre foreland basin of Brazil. In: Hoorn, C.; Wesselingh, F. P. (Ed.). **Amazonia, landscape and species evolution**. Chichester: Blackwell Publishing, 2010. p. 30–37.

Wardlaw, B. R.; Harris, A. G. Conodont-based thermal maturation of Paleozoic rocks in Arizona. **American Association of Petroleum Geologists Bulletin**, v. 68, p. 1101-1106, 1984.

Whiteside, J. R.; Grayson, R. C. Carboniferous conodont faunas, northern Ouachita Mountains, Oklahoma. In: Suneson, N. H. *et al*. (Ed.). **Geology and resources of the Frontal belt of the western Ouachita Mountains, Oklahoma**. Oklahoma City: American Association of Petroleum Geologists, 1989. n. 2, p. 27-28. (Mid-Continent Section Meeting, Oklahoma Geological Survey Special Publication, Guidebook for Field Trip).

Wirth, M. Zur Gleiderung des höheren Paläozoikums (Givet-Namur) im Gebiet des Quinto Real (Westpyrenäen) mit Hilfe von Conodonten. **Neues Jahrbuch für Geologie und Paläontologie Abhandlungen**, v. 127, p. 179-244, 1967.

Witzke, B. J.; Heckel, P. H. Paleoclimatic indicators and inferred Devonian paleolatitudes of Euramerica. In: McMillan, N. J. *et al*. (Ed.). **Devonian of the World**.

Canadian Society of Petroleum Geologists, 1989. memoir 14, v. 1, p. 49-63. (imprint 1988).

Wnuk, C. The development of floristic provinciality during the Middle and Late Paleozoic. **Review of Palaeobotany and Palynology**, v. 90, p. 5-40, 1996.

Wood, G. D.; Groves, J. R.; Wahlman, G. P.; Brenckle, P. L.; Alemán, A. M. The paleobiogeographic and biostratigraphic significance of fusulinacean and smaller foraminifers, and palynomorphs from the Copacaban Formation (Pennsylvanian–Permian), Madre de Díos Basin, Peru. In: Hills, L. V. *et al*. (Ed.). **Carboniferous and Permian of the World**. Canadian Society of Petroleum Geologists, 2002. memoir 19, p. 630-664.

Yardley, B. W. D. **Introdução à petrologia metamórfica**. Brasília: Editora Universidade de Brasília, 1994. 340 p.

Youngquist, W. L. Upper Devonian conodonts from the Independence Shale (?) of Iowa. **Journal of Paleontology**, v. 19, p. 355-367, 1945.

Youngquist, W.; Downs, R. H. Additional conodonts from the Pennsylvanian of Iowa. **Journal of Paleontology**, v. 23, p. 161-171, 1949.

Zembruscki, S. G.; Kiang, C. H. Gradiente geotérmico das bacias sedimentares brasileiras. **Boletim de Geociências da Petrobras**, v. 3, p. 215-227, 1989.

Ziegler, W. Conodontenfeinstratigraphische Untersuchungen an der Grenze Mitteldevon/Oberdevon und in der Adorfstufe. **Notizblatt des Hessischen Landesamtes Bodenforschung**, v. 87, p. 7-77, 1958.

Ziegler, W.; Lindström, M. Chemical and mineralogical properties. In: Robinson, R. A. (Ed.). **Treatise on invertebrate Paleontology**. Kansas: Geological Society of America and University Press, 1981. Part W, supplement 2, p. 1-202.

Ziegler, W.; Sandberg, C. A. *Palmatolepis* based revision of upper part of standard Late Devonian conodont zonation. In: Clark, D. L. (Ed.). **Conodont biofacies and provincialism**. Geological Society of America Special Paper, 1984. p. 179-194.

Ziegler, W.; Sandberg, C. A. The Late Devonian Standard Conodont Zonation. **Courier Forschungs-Institut Senckenberg**, v. 121, p. 1-115, 1990.