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IDENTIFICAÇÃO DAS DEFORMIDADES DENTÁRIAS EM FÓSSEIS DE TUBARÕES DA FORMAÇÃO CALUMBI (CRETÁCEO SUPERIOR), BACIA SERGIPE-ALAGOAS E POSSÍVEIS CAUSAS ASSOCIADAS

Tatiana Menezes da Silva

Orientador: Dr. Alexandre Liparini Campos

DISSERTAÇÃO DE MESTRADO

Programa de Pós-Graduação em Geociências e Análise de Bacias

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por:

Tatiana Menezes da Silva
(Tecnóloga, Faculdade Pio Décimo-2015)

DISSERTAÇÃO DE MESTRADO

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BANCA EXAMINADORA:

Dr. Alexandre Liparini Campos [Orientador – UFS]

Dra. Maria Lúcia Góes de Araújo [Membro Externo]

Dra. Paula Dentzien Dias Francischini [Membro Externo – FURG]

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DEDICATÓRIA

Dedico este trabalho primeiramente a Jeová, aos meus pais, meu esposo, minhas irmãs, meus sobrinhos, meus cunhados e aos meus amados e preciosos filhos (Laudiclayton e Laudisley).

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"Talvez não tenha conseguido fazer o meu melhor, mas lutei para que o melhor fosse feito. Não sou o que deveria ser, mas graças a Deus, não sou o que era antes".

Martin Luther King

RESUMO

O Oceano Atlântico Sul foi formado ao longo do período Cretáceo e parte de sua história é preservada na sub-bacia sedimentar de Sergipe. Uma de suas formações geológicas mais recentes é a Formação Calumbi (Campaniano ao Recente). O Calumbi-1 (CAL01) é um dos afloramentos dessa unidade, localizado a 1 km ao sul do entroncamento entre a estrada Calumbi e da Ferrovia Centro Atlântica, em Nossa Senhora do Socorro, Sergipe. O CAL01 possui uma diversidade de registros fósseis, incluindo dentes de tubarões. Através dos dentes fossilizados é possível identificar e classificar tais organismos estudando a sua morfologia, e também inferir sobre a preferência alimentar desses seres. Através da morfologia, também é possível reconhecer dentes patológicos. Portanto, o objetivo desta pesquisa foi comparar e descrever dentes fósseis de tubarões com indicações de anomalias dentárias. Os objetivos específicos foram apresentar as possíveis causas associadas à anomalia e a frequência de deformidades dentárias por gênero e/ou espécie identificada. O material aqui descrito está alojado no Laboratório de Paleontologia da Universidade Federal de Sergipe (LPUFS), sendo proveniente de coletas realizadas durante anos de estudos no CAL01. Foram analisados 2.116 dentes fósseis, sendo que 0,75% apresentaram deformidades dentárias. Observou-se que 16 dentes de *Squalicorax pristodontus*, *Squalicorax kaupi*, *Cretolamna appendiculata* e *Serratolamna serrata* (combinadas) tinham alguma anomalia como ausência do sulco nutritivo, cúspides laterais não desenvolvidas, inversão de polaridade, cúspide arredondada, cúspide curvada, ausência de cúspide, coroa reduzida, dentículos extranumerários, concavidade basal profunda e formato assimétrico. As causas mais prováveis reconhecidas para tais anomalias foram doenças, tipo de dieta, mutações genéticas ou deficiências nutricionais, sendo as mais recorrentes, para os dentes analisados, relacionadas à dieta durofágica, provocando ferimentos nos tecidos formadores dos dentes.

Palavras-chave: Morfologia; Anomalia; Registro fóssil; Deformação.

ABSTRACT

The South Atlantic Ocean was formed during the Cretaceous period and part of its history is preserved in the Sergipe sub-basin. One of its most recent geological formations is the Calumbi Formation (Recent Campanian). The Calumbi-1 (CAL01) is one of the outcrops of this unit, located 1 km south of the junction between the Calumbi road and the Ferrovia Centro Atlântica, in Nossa Senhora do Socorro, Sergipe. CAL01 has a diversity of fossil records, including shark teeth. Through the fossilized teeth it is possible to identify and classify these organisms by studying their morphology, and also to infer about the food preference of these beings. Through morphology, it is also possible to recognize pathological teeth. Therefore, the objective of this research was to compare and describe fossil teeth of sharks with indications of dental anomalies. The specific objectives were to present the possible causes associated to the anomaly and frequency of dental deformities by gender and / or identified species. The material described here is housed in the Laboratory of Paleontology of the Federal University of Sergipe (LPUFS), and comes from collections made during years of studies in the CAL01. 2,116 fossil teeth were analyzed, and 0.75% presented dental deformities. It was observed that 16 teeth of *Squalicorax pristodontus, Squalicorax kaupi, Cretolamna appendiculata* and *Serratolamna serrata* (combined) had some anomaly such as absence of nutritive sulcus, undeveloped lateral cusps, reversal of polarity, rounded cusp, curved cusp, absence of cusp, crown reduced, supernumerary denticles, deep basal concavity and asymmetrical shape. The most probable causes for such anomalies were diseases, type of diets, genetic mutations or nutritional deficiencies, being the most frequent for the analyzed teeth, related to the durofagy diet, causing injuries in the tissues forming the teeth.

Keywords: Morphology; Anomaly; Fossil record; Deformation.

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INTRODUÇÃO

O período Cretáceo foi marcado por diversas modificações no planeta, como o surgimento das primeiras flores, a extinção dos dinossauros não avianos, o aparecimento dos primeiros mamíferos placentários e marsupiais, a diversificação das aves, a irradiação de inúmeros grupos de tubarões, a fragmentação de Gondwana, com subsequente formação de diversas bacias sedimentares (Aquino & Lana, 1990; Zalán, 2004; Favretto, 2010; Gonzalez, 2005).

A Bacia Sergipe-Alagoas representa uma entre as diversas bacias sedimentares marginais brasileiras desenvolvidas pela separação de Gondwana, ao longo do Mesozoico, especialmente ativa no período Cretáceo (Aquino & Lana, 1990; Souza-Lima, 2001). Uma das formações geológicas mais recentes da Bacia Sergipe-Alagoas é a Formação Calumbi (Campaniano ao Recente), cuja porção emersa se encontra próxima à costa sergipana, em uma faixa estreita de cerca de 17 km, nos arredores da Grande Aracaju. Suas rochas expostas datam do Neocretáceo (Campaniano ao Maastrichtiano – 84 a 66 milhões de anos). A Formação Calumbi possui alguns afloramentos, dentre eles o afloramento Calumbi-1 é, até o momento, o mais fossilífero desta formação.

O afloramento Calumbi-1 possui uma diversidade de registros fósseis de moluscos (bivalves, gastrópodes, amonoides), fragmentos de crustáceos, espinhos, dentes e ossos cranianos de peixes ósseos, além de dentes e vértebras de elasmobrânquios (*Hexanchus* cf. *H. microdon*, *Odontaspis*, *Cretolamna appendiculata*, *Serratolamna serrata*, *Odontaspis* cf. *O. hardingi*, *Carcharias*, *Squalicorax kaupi*, *Squalicorax pristodontus*, *Sclerorhynchidae* aff. *Ischyrhiza*, *Rhinobatos* sp) (Souza-Lima, 2001; Fernandes, 2016). A abundância de registros fósseis e a diversidade encontrada no Afloramento Calumbi-1, pode estar relacionado aos traços paleoambientais do Período Cretáceo como mares profundos, variações na salinidade e temperatura (Souza-Lima, 2001; Fernandes, 2016; Welton & Farish, 1993). A abundância relativamente alta de dentes de tubarões neste afloramento pode ser explicada pela composição química dos mesmos, ricos em fluorapatita e hidroxiapatita, como também pela própria biologia destes animais, que apresentam fileiras de dentes com substituição ilimitada dos mesmos. Um tubarão pode produzir durante a vida centenas e até milhares de dentes (Becker et al., 2000; Vuuren et al., 2015).

No que diz respeito à dentição dos tubarões, anatomicamente se considera que a atividade alimentar em elasmobrânquios atende a mecanismos altamente especializados combinados a um sistema sensorial potencialmente desenvolvido e único, a exemplo do aparato buco-mandibular modificado para aumentar a plasticidade e eficiência da mordida. Da mesma maneira, apresentam dentições especializadas em funções de variados modos de alimentação (Mota & Wilga, 1995; Mota & Wilga, 2001; Wilga et al., 2007). Segundo Silva *et al*. (2007) é possível identificar e classificar vertebrados através do estudo da morfologia dos dentes fossilizados, inclusive inferir sobre a preferência alimentar desses seres. O exemplo de tubarões com dentes pequenos com cúspides laterais curtas costumam ser eficientes para agarrar e esmagar, ou seja, cortam e quebram os ossos suas presas. Enquanto tubarões com dentes serrilhados com extremidades cortantes ou com raiz achatada são adaptados a agarrar e cortar pedações de carne de suas presas. Já dentes pontiagudos, com bordas em forma de lâmina, lisos e curvados costumam a cortar e perfurar as presas (Becker et al., 2000; Silva et al., 2007).

Dentes de tubarões atuais ou extintos, com formatos irregulares ou fora dos padrões normais observados na faixa de variação morfológica da espécie são considerados patológicos (Gudger, 1937; Becker et al., 2000). Gudger (1937) descreveu e classificou dentes patológicos de tubarões atuais, que apresentam curvaturas e rugosidades anormais, cúspides extranumerárias ou perfurações e dobras não usuais. As descrições de Gudger (1937) embasaram trabalhos subsequentes sobre patologias dentárias em dentes de tubarões fósseis (i.e., Johnson, 1987; Gottfried, 1993; Shimada, 1997; Becker *et al*., 2000).

Dentes de tubarões de espécies atuais podem apresentar alguma anomalia devido ao tipo de alimentação, lesão no tecido dentário, mutação genética, doenças, deficiências nutricionais ou danos causados pela alimentação (Balbino and Antunes, 2007; Becker et al., 2000; Shimada, 1997). Fatores tafonômicos, que atuam *post mortem*, tal como litificação, retrabalhamento dos dentes soltos por ondas, fratura ou quebra dos dentes também podem alterar os aspectos naturais de um dente (Whitenack & Motta, 2010; Araújo-Júnior et al., 2013; Behrensmeyer, 1991), porém tais feições não serão avaliadas no presente estudo.

Fernandes (2016) apresenta de maneira preliminar alguns dentes de tubarões fósseis anormais coletados no Afloramento Calumbi 1. Nesta pesquisa pretende-se classificar e descrever estes e outros dentes patológicos a fim de se entender as causas que poderiam ter levado a esse tipo de fossilização. As hipóteses a serem trabalhadas são a que as deformidades em dentes de tubarões (1) podem ter ocorrido em vida quando ainda fixados à arcada (patologias ou anomalias decorrentes da alimentação), ou (2) pela deterioração causada pelo decorrer do tempo após sua queda da arcada, mas antes de seu soterramento (processos bioestratinômicos, como intemperismo, abrasão/transporte); ou (3) a processos fóssildiagenéticos, como quebra/deformação dos dentes causada pelo peso dos sedimentos que se depositaram sobre eles ao longo do tempo (Becker et al., 2000). No presente trabalho, nosso objeto se restringirá apenas àqueles dentes caracterizados como pertencentes ao primeiro grupo descrito acima (i.e., deformidades estabelecidas na formação dentária, quando o animal ainda se encontrava vivo).

Tendo em vista que as identificações dos fósseis de tubarões são geralmente feitas apenas através dos dentes, a busca por um melhor entendimento das patologias dentárias de tubarões fósseis se justifica por auxiliar no reconhecimento de feições anômalas, não diagnósticas, além de permitir a interpretação das possíveis causas que levariam às deformidades dentárias.

Considerando-se a abundância e excepcional qualidade de afloramentos da seção marinha cretácea da Bacia Sergipe-Alagoas, quando comparada às demais bacias sedimentares costeiras do Brasil, nota-se que o conhecimento da paleoictiofauna marinha desta bacia é ainda escasso, com especial atenção para os registros da Fm. Calumbi. Embora estudada há mais de um século, ainda há muito a ser feito, havendo, sem dúvidas, um grande potencial de descobertas que proporcionarão elucidar ainda mais a história geológica e paleobiogeográfica do Oceano Atlântico Sul (Souza-Lima et al., 2002b).

OBJETIVOS

Diante deste cenário o objetivo desta pesquisa foi comparar e descrever dentes fósseis de tubarões com indicações de anomalias dentárias. Tendo como objetivos específicos descrever as causas das anomalias e relatar a frequência de deformidades dentárias por gênero e/ou espécies.

BACIA SERGIPE-ALAGOAS

Situada a leste da região nordeste a Bacia Sergipe-Alagoas (Fig. 1) localiza-se na margem do nordeste continental brasileiro e abrangendo os estados de Sergipe e Alagoas, possui área com cerca de 44.370 km^2, sendo aproximadamente 31.750 km^2 em mar (Figueiredo, 2014; Feijó, 1994).

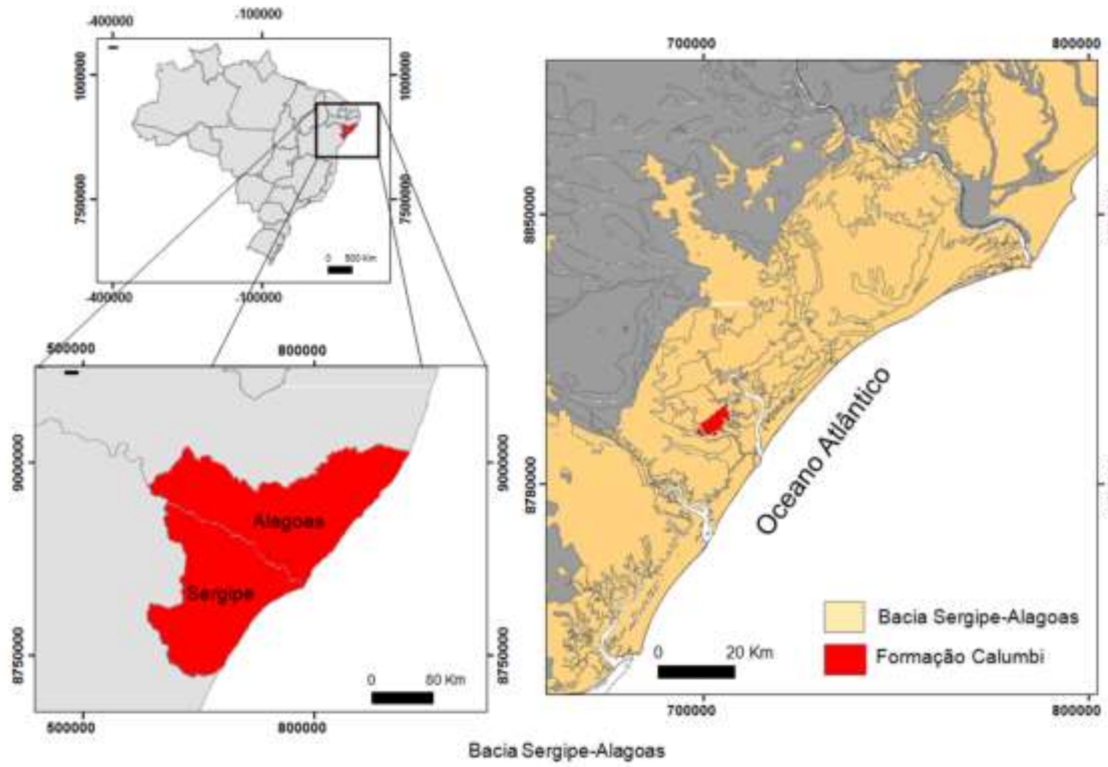

FIGURA 1. Mapa de localização da Formação Calumbi na Bacia Sergipe-Alagoas, em Nossa Senhora do Socorro no estado de Sergipe.

A Bacia Sergipe-Alagoas representa uma entre as diversas bacias sedimentares geradas pela separação do continente Gondwana, ao longo do mesozoico, especialmente ativa no período Cretáceo (Souza-Lima et al., 2002b).

O surgimento da Bacia Sergipe-Alagoas está relacionado às modificações na paleogeografia que ocorreram durante o Mesozoico, e que está correlacionada à separação do supercontinente Gondawna. Uma dessas mudanças foi o desenvolvimento do rifteamento que ocasionou a formação do Atlântico Sul (Cruz, 2008). A Bacia Sergipe-Alagoas apresenta depósitos sedimentares em todos os estágios evolutivos (Sinéclise Paleozoica, Pré-rifte, Rifte, Transicional e Drifte), sendo uma das bacias sedimentares mais completas das margens leste e sudeste brasileiro (Souza-Lima, 2001; Campos Neto et al., 2007; Cruz, 2008; Feijó, 1994).

O oceano Atlântico Sul se formou ao longo do período Cretáceo e parte de sua história se encontra preservada na sub-bacia sedimentar de Sergipe. A Formação Calumbi (Campaniano ao Recente) é uma das formações geológicas mais recentes, cuja porção emersa aflora próxima à costa sergipana, em uma faixa estreita de cerca de 17 km, nos arredores da Grande Aracaju (Bizzi et al., 2003; Figueiredo, 2014; Souza-Lima, 2001). Suas rochas expostas datam do Neocretáceo (Campaniano a Maastrichtiano – 84 a 66 Ma).

A Fm. Calumbi encontra-se “depositada discordantemente (discordância pré-Calumbi) sobre a rampa carbonática Cotinguiba ou sobre as rochas da formação Riachuelo” (Souza-Lima, 2001, p. 11). Souza-Lima (2001) demonstrou que para Fm. Calumbi há registros de dentes e vértebras de elasmobrânquios, além de espinhos, dentes e ossos cranianos de peixes ósseos. “Das formas descritas, várias têm caráter cosmopolita, refletindo o completo estabelecimento de circulação oceânica profunda ao final do Cretáceo” (Souza- Lima et al. 2002a, p. 3).

ÁREA DE ESTUDO

O afloramento Calumbi-1 (Fig.2) está localizado aproximadamente a 1 km ao sul do entroncamento entre a estrada Calumbi e a Ferrovia Centro Atlântica, sobre o rio do Sal, no povoado Calumbi, município de Nossa Senhora do Socorro, Sergipe, (10º52’52”S, 37º07’07”W, DATUM WGS84) (Figueiredo, 2014; Souza-Lima, 2001).

FIGURA 2. Visão geral do afloramento Calumbi-1.

METODOLOGIA E MÉTODOS

Amostragem e preparação do material coletado

Foram analisados nesta pesquisa dentes fósseis de tubarões isolados tanto totalmente preservados, quanto parcialmente preservado ou fragmentados, totalizando 2.116 dentes oriundos de duas amostragens distintas. O acervo encontra-se tombado no Laboratório de Paleontologia da Universidade Federal de Sergipe sob o acrônimo LPUFS.

A primeira amostra pertencente ao acervo do LPUFS é proveniente de coletas realizadas no afloramento Calumbi-1 durante anos de estudos anteriores, por diferentes pesquisadores. Esses dentes já haviam sido preparados e triados. A maior parte desses dentes estava identificada nos gêneros *Serratolamna, Squalicorax, Cretolamna, Odontaspis* e *Charcarias.* Porém para este estudo os dentes que já haviam sido identificados foram revisados e reavaliados quanto a sua identificação.

Na segunda amostra o material foi proveniente de uma coleta realizada em 27/09/2016 no afloramento Calumbi-1. Foram coletadas amostras de blocos superficiais expostos na superfície do afloramento, em diferentes níveis (i.e., superior, médio e inferior). As rochas foram conduzidas e acomodadas no laboratório do Núcleo de Petróleo e Gás da UFS (NUPEG) para subsequente preparação.

As técnicas empregadas para a preparação do material tiveram como finalidade dissociar o sedimento dos fósseis, sendo para tais submetidos às seguintes etapas (Fig. 3): imersão em recipientes com água por 2-3 dias para o amolecimento dos blocos e subsequente dissociação dos dentes dos sedimentos; peneiramento do material com malhas de 10 mm e 5 mm; lavagem e colocação de todo material peneirado em bandejas para secagem ao ar livre; triagem, com separação dos dentes de outros fósseis e grãos sedimentares; e por fim, visualização e identificação dos dentes (Gresele et al., 1993; Goellner & Malabarba, 2010).

FIGURA 3. Preparação do material: A. blocos superficiais; B. amolecimento; C. peneiramento e lavagem; D. secagem, triagem e separação.

Os critérios adotados para determinação do grau de preservação dos dentes fósseis foram classificados conforme sua integridade física. Quando sua preservação representava mais de 90% de integridade de sua estrutura original eram considerados totalmente preservados; parcialmente preservados (de 50% a 90%); e fragmentado (< 50%) (Araújo-Júnior et al., 2013; Behrensmeyer, 1991).

Após a triagem dos dentes, os mesmo foram identificados em nível de gênero ou espécie com base na literatura disponível (i.e., Balbino & Antunes, 2007; Becker et al., 2000; Becker & Chamberlain, 2012; Shimada, 1997, Shimada, 2002; Johnson, 1987; Gudger, 1937). Assim foi possível associar especificamente ou genericamente as possíveis anomalias encontradas. Para auxiliar na identificação da posição dentária de cada dente dentro na arcada foi feita, de forma tentativa, a montagem das séries dentárias artificiais das espécies/gênero estudados, conforme apresentado por Welton & Farrish (1993).

Para diferenciar as diversas formas e tamanhos de dentes alguns termos anatômicos foram utilizados para descrever linhas dentárias como: sinfisial, anterior, intermediário, lateral, posterior, superior, proximal, distal, parasinfisial, mesial e medial, para descrever linhas dentárias (Welton; Farrish, 1993; Applegate, 1965).

Para construção das séries dentárias utilizou como base o tamanho, forma e posição do dente em relação ao sinfisial.

Identificação e reconhecimento de dentes anômalos

Segundo Silva et al. (2007) é possível identificar e classificar vertebrados através do estudo da morfologia dos dentes fossilizados, inclusive inferir sobre a preferência alimentar desses seres. Por exemplo, os tubarões com dentes serrilhados são considerados grandes predadores nos ecossistemas marinhos. As espécies com este tipo de dentição possuem uma força maior na mordida e são adaptados para rasgarem o alimento (Becker & Chamberlain, 2012; Lucifora et al., 2001; Mota & Wilga, 1995; Mota & Wilga, 2001; Wilga et al., 2007).

Os tubarões com dentes estreitos, compridos e pontiagudos tem preferência por dietas piscívoras. Os dentes dessas espécies são adaptados para agarrar as presas, ou seja, perfurar os alimentos (Becker & Chamberlain, 2012; Lucifora et al., 2001; Tricas et al., 1997; Mota & Wilga, 1995; Mota & Wilga, 2001; Wilga et al., 2007).

Através da morfologia, além de identificar a preferência alimentar é possível reconhecer dentes patológicos.

Becker et al. (2000) definem dentes patológicos como sendo aqueles que apresentam variações morfológicas em diversos níveis sendo inexplicável através da heterodontia, variações ontogenética ou dimorfismo sexual.

Dentes de tubarões atuais ou extintos, com formatos irregulares ou fora dos padrões normais observados na faixa de variação morfológica da espécie como dentes com raiz e cúspides longos ou curtos, cúspides extras numerais, ranhuras no esmalte do dente, coroa enrugada, ápice do dente arredondado, ausência de cúspides e sulco nutritivo, cúspide com curvatura distinta daquelas dos dentes considerados normais são classificados como patológicos (Gudger, 1937; Becker et al., 2000; Purdy, 2006).

Gudger (1937) descreve e classifica dentes patológicos de tubarões atuais, que apresentam curvaturas e rugosidades anormais, cúspides extranumerárias ou perfurações e dobras não usuais. As descrições de Gudger (1937) embasaram trabalhos subsequentes sobre patologias dentárias em dentes de tubarões fósseis (e.g., Johnson, 1987; Gottfried, 1993; Shimada, 1997; Becker et al., 2000).

Quantificação a partir dos dentes isolados

Becker et al. (2000) descreveram duas maneiras para calcular a frequência de dentes deformados em uma população: o método "animal inteiro" e método "dentes isolados".

O método "animal inteiro" consiste em uma contagem em mandíbulas com a dentição completa que exibem dentes anormais e compará-los com mandíbulas que apresenta todas as dentições normais. Já o método "dentes isolados" consiste em relacionar o número de dentes anormais e compará-los com o número de dentes normais da mesma amostra (Becker et al., 2000). Porém, deve-se atentar para que apenas em algumas situações específicas os resultados entre os dois métodos são comparáveis (Becker et al., 2000). Comparações entre contagens feitas pela mesma metodologia estão menos sujeitas a interpretações equivocadas.

Outro fato é que quando os estudos são baseados em mandíbulas inteiras a pesquisa não leva em conta os dentes que os tubarões perdem durante toda vida, enquanto dentes fósseis isolados são baseados numa amostragem, em princípio, que inclui uma amostra de todos os dentes produzidos pelos tubarões ao longo de sua vida. Assim a amostragem de dentes fósseis (dentes isolados) é provavelmente baseada em um número menor de dentes de um número maior de espécimes, ao passo que as contagens em espécies atuais (animal inteiro) centram em um número maior de dentes de um número menor de espécimes (Becker et al., 2000).

Considerando as duas abordagens acima, o método “dentes isolados” é o mais adequado para ser aplicado no presente estudo para quantificar a frequência de deformidades em dentes fósseis de tubarões, pois os dentes estudados nesta pesquisa foram coletados dissociados.

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CAPÍTULO II – ARTIGO

ARTIGO SUBMETIDO À JOURNAL OF VERTEBRATE PALEONTOLOGY

DENTAL DEFORMITIES IN SHARK FOSSILS FROM THE CALUMBI FORMATION (UPPER CRETACEOUS), SERGIPE-ALAGOAS BASIN, AND POSSIBLE ASSOCIATED CAUSES

TATIANA MENEZES DA SILVA*[1] and ALEXANDRE LIPARINI[1]
[1]PIBi-Lab Laboratório de Pesquisas Integrativas em Biodiversidade, Programa de Pós-Graduação em Geociências e Análise de Bacias-PGAB/ Universidade Federal de Sergipe-UFS, Av. Marechal Rondon, s / n - Jd. Rosa Elze, 49100-000, São Cristóvão, Sergipe, Brasil. E-mail: tatisilva0083@gmail.com, alexandreliparini@yahoo.com.br.

ABSTRACT- The Sergipe-Alagoas Basin was formed during paleogeographic modifications generated by the fragmentation of Gondwana in the Mesozoic era. The Calumbi Formation is one the most recent geological formations there, and the Calumbi-1 outcrop (CAL01) geological unit contains a high diversity of fossil records, including shark teeth. Those fossil teeth allow the identification and classification of those chondrichthyes, and studies of their morphology allow inferences concerning their feeding preferences. The current study sought to compare and describe fossil shark teeth showing dental anomalies, their frequencies according to the genus and/or species, and suggest possible causes associated with those anomalies. The materials described here were collected over numerous years during studies of CAL01, and are currently deposited in the Paleontology Laboratory at the Federal University of Sergipe (LPUFS), Brazil. We analyzed 2,116 fossil teeth, of which 0.75% demonstrated dental deformities. A total of 16 of those teeth, belonging to the species *Squalicorax pristodontus*, *Squalicorax kaupi*, *Cretalamna appendiculata*, and *Serratolamna serrata*, demonstrated some type of anomaly, such as the absence of a nutrition fissure, undeveloped lateral cusps, polarity inversion, rounded cusps, curved cusps, absent cusps, reduced crowns, extra cusplets, a deep basal concavity, and asymmetrical shapes. The most probable and principally recognized cause of those anomalies is associated with a durophagous diet causing damage to teeth-forming tissues.

INTRODUCTION

The Sergipe-Alagoas Basin (Fig. 1) represents one of many sedimentary basins formed by the fragmentation of Gondwana during the Mesozoic, especially during the Cretaceous period (Aquino & Lana, 1990; Souza-Lima, 2001). One of the most recent formations in that group is the Calumbi formation (Campanian to recent), whose emergent portion is found along the coast of Sergipe State, in a narrow strip approximately 17 km wide, near the city of Aracaju. The exposed rocks there date to the Neocretaceous period (Campanian to Maastrichtian – 84 to 66 million years bp).

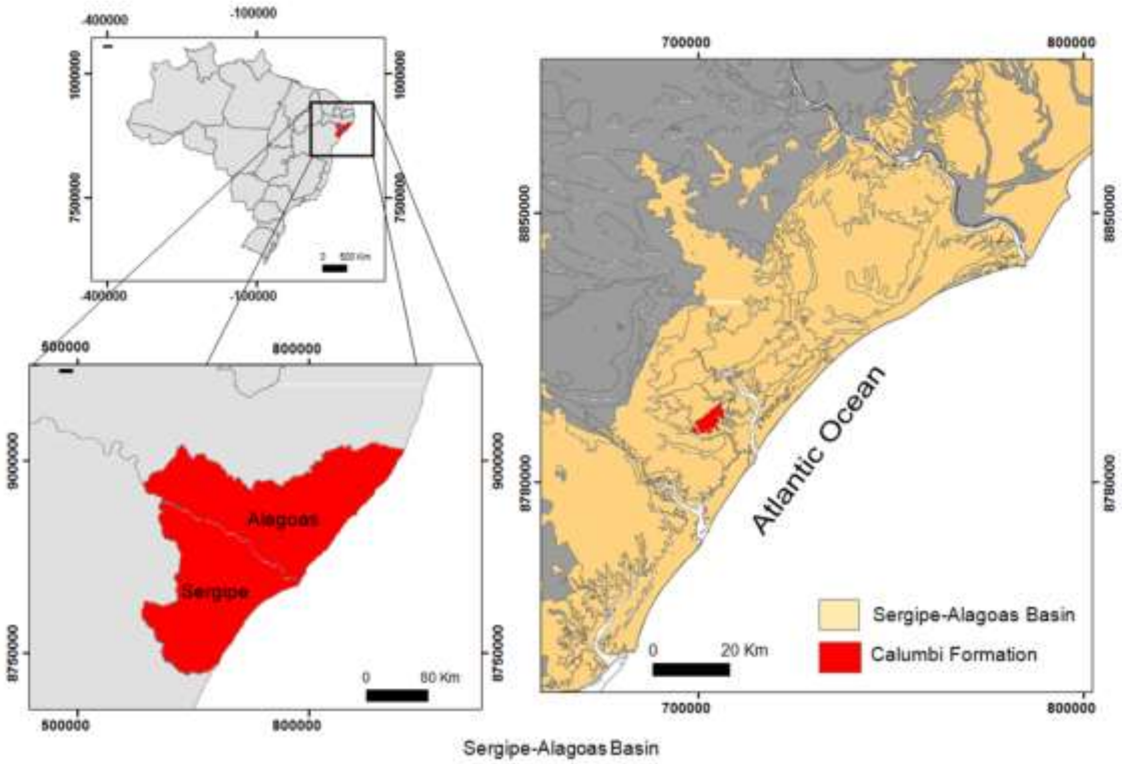

FIGURE 1. Map demonstrating the location of the Calumbi Formation in the Sergipe-Alagoas Basin, in the municipality of Nossa Senhora do Socorro, Sergipe State, Brazil.

The Calumbi Formation shows a number of outcrops, including the Calumbi-1 outcrop, which demonstrates a high diversity and density of fossil records, including elasmobranch teeth and vertebra (Souza-Lima, 2001; Fernandes, 2016). Morphological studies of those teeth can identify and classify those vertebrates, allow inferences concerning their feeding preferences, and identify tooth anomalies. Dental anomalies are considered rare among sharks (Becker et al., 2000).

The causes of tooth deformities can be related to shark feeding behaviors, lesions to dental tissues, genetic mutations, illnesses, nutritional deficiencies, or damage during feeding (Balbino & Antunes, 2007; Becker et al., 2000; Shimada, 1997). Posterior taphonomic alterations, such as lithification, the transport of loose teeth by ocean currents, and fractures or other mechanical damage, can also alter the natural aspects of a tooth (Whitenack & Motta, 2010; Araújo-Júnior et al., 2013; Behrensmeyer, 1991).

The possibilities that must be considered when examining shark teeth deformities are that they: (1) may have occurred during the life of the animal, when still attached to the dental arch (pathologies or anomalies resulting from feeding); (2) represent deterioration over time, after becoming detached from the dental arch, but before being buried (biostratinomic processes, such as erosion, abrasion/transport); or

(3) represent fossil-diagenetic processes, such as breakage/deformation caused by the weight of the sentiments deposited over them over time (Becker et al. 2000). The present work was restricted to teeth characterized as representing the first above-describe group (i.e., deformities established during tooth formation, when the animal was still alive).

In light of the fact that shark fossil identifications are generally based only on their teeth, the study of dental pathologies will be useful for recognizing anomalous non-diagnostic features, and interpreting possible causes of those dental deformities.

In spite of the abundance and exceptional quality of Cretaceous marine outcrops in the Sergipe-Alagoas Basin, as compared to other sedimentary basins along the Brazilian coast, our knowledge of the marine paleo-ichthyofauna preserved there is still quite limited, especially in terms of the Calumbi Formation. Although it has been studied for more than a century, the basin still has the potential for important new discoveries that would help to further elucidate the geological and paleobiogeographic history of the southern Atlantic Ocean (Souza-Lima et al., 2002).

As such, we sought to compare and describe fossil shark teeth showing dental anomalies, with the specific objectives of determining the frequencies of dental deformities per genus and/or species and ascribing probable causes to those anomalies.

Abbreviations—CAL01, Calumbi 1**; LPUFS,** Paleontology Laboratory of the Federal University of Sergipe; **NUPEG,** Petroleum and Gas Nucleus of the Federal University of Sergipe; **UFS,** Federal University of Sergipe.

MATERIALS AND METHODS

We analyzed 2,116 isolated fossil shark teeth from two distinct collections held at UFS in the LPUFS.

The first collection contained 1,922 teeth derived from the Calumbi-1 outcrop (10.88288° S, 37.11738° W) that had been collected by different researchers during previous studies and were prepared and later classified as belonging to the genera Serratolamna, Squalicorax, Cretalamna, Odontaspis, and Charcarias; we nonetheless reviewed and reevaluated them in terms of their identifications.

The second collection analyzed contained 194 teeth encountered during a field excursion undertaken on 27/09/2016 to the Calumbi-1 outcrop. We collected samples from superficial layers at different levels (i.e., superior, medium, and inferior). The extracted blocks were then transported to the NUPEG for preparation.

The techniques used to prepare the material were designed to disassociate the fossil sediments, and involved (Fig. 2): softening the blocks by immersing them in water for 2-3 days; sifting the material through 10 mm and 5 mm sieves; washing all of the materials retained in either sieve; drying the residual cleaned material in the open-air. The cleaned material was then separated and classified, and the teeth identified (Gresele et al., 1993; Goellner; Malabarba, 2010).

We classified the fossil teeth according to their physical integrities: Totally Preserved – when more than 90% of their original structures were intact; Partially Preserved (between 50% and 90%); and Fragmented (< 50%) (Araújo-Júnior et al., 2013; Behrensmeyer, 1991).

FIGURE 2. Preparation of the material: **A**, extracted surface blocks; **B**, softening; **C**, sieving and washing; **D**, drying, classification, and separation.

After classifying the teeth, they were identified to the genus or species level based on the published literature (i.e., Balbino & Antunes, 2007; Becker et al., 2000; Becker & Chamberlain, 2012; Shimada, 1997; Shimada, 2002; Johnson, 1987; Gudger, 1937), which allowed any anomalies encountered to be associated with specific taxa. To aid in determining the position of each tooth within the dental arch, we mounted artificial tooth sets of the species/genera studied, following Welton & Farrish (1993).

RESULTS

The first collection was composed of 1,922 fossil shark teeth and the second (after classification) comprised 194 teeth, including totally preserved, partially preserved, and fragmented teeth (total 2,116). Evaluations of the physical integrity of the teeth to determine their degrees of preservation (following Araújo-Júnior et al., 2013; and Behrensmeyer, 1991) classified 190 teeth as totally preserved, 346 as partially preserved, and 1,580 as fragmented (Table 1).

TABLE 1. Degrees of physical integrity of the fossil shark teeth by taxonomic group.

Species	Totally preserved Teeth (>90%)	Partially preserved Teeth (50% a 90%)	Fragmented Teeth (< 50%)
Archaeolamna kopingensis	1	--	--
Carcharias sp.	24	44	--
Cretalamna appendiculata	5	19	--
Cretoxyrhina sp.	1	9	--
Echinorhinus sp	--	2	--
Odontaspis sp.	54	59	--
Pseudocorax sp.	4	4	--
Mitsukurina sp.	1	--	--
Serratolamna serrata	62	86	--
Squalicorax kaupi	13	1	--
Squalicorax pristodontus	9	3	--
Squalicorax sp.	--	22	--
Undetermined	16	97	1,580
Total	190	346	1,580

The genera identified from the complete or partial teeth included: †*Archaeolamna* Siverson, 1992, †*Serratolamna* Landemaine, 1991, †*Cretalamna* Glickman, 1958, *Carcharias* (Rafinisque, 1810), †*Cretoxyrhina* (Glickman, 1958), *Echinorhinus* (Gill 1864), *Odontaspis* Agassiz, 1838, †*Pseudocorax* Priem, 1897, †*Mitsukurina* (Jordan, 1898) and †*Squalicorax* Whitley, 1939 – totaling 423 teeth identified to the generic level. Only four of the above mentioned genera could be identified to the species level: *Archaeolamna kopingensis* (Davis, 1890); *Serratolamna serrata* (Agassiz, 1843); *Cretalamna appendiculata* (Agassiz, 1843); and *Squalicorax kaupi* (Agassiz, 1843) and *Squalicorax pristodontus* (Agassiz, 1843).

Of the total of 2,116 teeth analyzed, 113 (classified in Table 1 as undetermined [among the totally or partially preserved specimens that]) could not be identified due to the lack of reference materials for comparisons. A total of 1,580 other teeth were fragmented and could not be identified due to their low level of integrity.

After analyzing and classifying the teeth according to their degrees of preservation it was possible to identify them and describe any anomalies. The teeth of four species belonging to three distinct genera (Cretalamna appendiculata, Serratolamna serrata, Squalicorax kaupi, and Squalicorax pristodontus) demonstrated some type of anomaly (Table 2). After identifying the teeth that demonstrated those anomalies, it was possible to calculate the frequency of deformities within the total sample and by species.

TABLE 2. Anomalies identified by species.

Species	Anomalies
Cretalamna appendiculata	Undeveloped lateral cusps Absence of a nutrition fissure
Serratolamna serrate	Lateral cusp absent Fissures indicate cusp divisions Cusps not defined Cusps reduced Polarity inversion Medial cusp rounded Curved cusp on lingual side
Squalicorax kaupi	Asymmetrical shape Deep basal concavity
Squalicorax pristodontus	Extra cusplet on proximal portion Cusp reduced

Of the 2,116 fossil shark teeth examined, 16 (0.75%) demonstrated some type of anomaly. Table 3 indicates which species demonstrated some type of dental anomaly, the numbers of such teeth from each species, and their anomaly frequency.

TABLE 3. Total number of teeth analyzed, and their anomaly frequency.

Species	Numbers of teeth in the collection	Numbers of teeth showing anomalies	Anomaly frequency in % for each species
Archaeolamna kopingensis	1	--	--
Carcharias sp.	68	--	--
Cretalamna appendiculata	24	2	8.33
Cretoxyrhina sp.	10	--	--
Echinorhinus sp.	2	--	--
Odontaspis sp.	113	--	--
Pseudocorax sp.	8	--	--
Mitsukurina sp.	1	--	--
Serratolamna serrate	148	11	7.43
Squalicorax kaupi	14	1	7.14
Squalicorax pristodontus	12	2	16.66
Squalicorax sp.	22	--	--
Indeterminate	1,693	--	--
Total	2,116	16	0.75

The percentage of anomalies per species was higher than 1% in the present study, which was greater than that reported by Becker et al. (2000) for pathological deformities in living and fossil chondrichthyan teeth.

Serratolamna serrata demonstrated a considerably greater absolute number of anomalous teeth (and the greatest number of teeth in the sample) than the other species.

Dental Deformities and their Descriptions

A total of six shark genera (*Echinorhinus* sp., *Mitsukurina* sp., *Hexanchus* sp., *Cretoxyrhina* sp., *Odontaspis* sp., and *Carcharias* sp.) and five species (Squalicorax *pristodontus*, *Squalicorax kaupi*, *Serratolamna serrata*, *Cretalamna appendiculata*, and *Archaeolamna kopingensis*) were identified and examined.

Some of the teeth analyzed here demonstrated morphological variations that diverged from the standard morphologies described for their respective species (Case et al., 2017; Underwood & Mitchell, 2000; Souza-Lima, 2001; Gudger, 1937; Becker et al., 2000). Welton & Farish (1993) reported that most tooth pathologies are not immediately recognized, but at least one species could be identified based on the type of tooth anomaly.

SYSTEMATIC PALEONTOLOGY

Family ANACORACIDAE Casier, 1947
Genus *Squalicorax* Whitley 1939
Squalicorax kaupi (Agassiz, 1843)

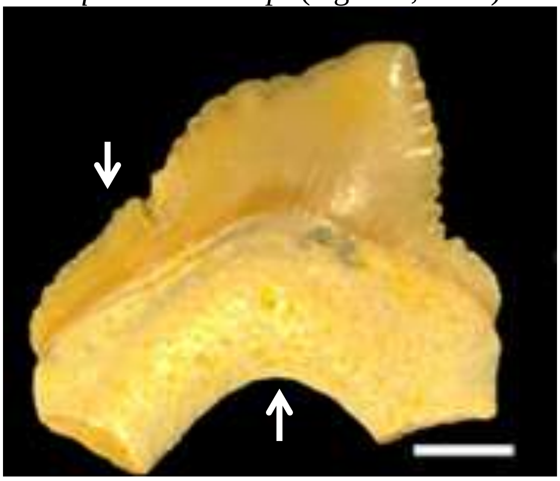

FIGURE 3. Tooth of *Squalicorax kaupi* demonstrating anomalies; lingual view. LPUFS 5780. Asymmetrical shape of the proximal portion and a deep basal concavity. Scale bar equals 2 mm.

Material analyzed—LPUFS 5780.

General description of non-anomalous teeth—*Squalicorax kaupi* teeth are composed of a distally inclined median cusp, crown crescent shaped and tall, lingual face protuberant, labial face planar, root crescent-shaped, with the presence of nutrient foramen. Proximal and distal portions uniformly covered by a single row of serrations.

The distal cutting edge moderately vertical and straight, the edges of the cusp show serrations that decrease in size towards the apex and the base of the crown. Root considerably tall and protuberant on the lingual face, absence of a nutrition fissure, root with various foramen on the labial and lingual faces. Basal concavity superficial (Case et al., 2017; Schwimmer, 1997; Shimada & Cicimurri, 2005; Souza-Lima, 2001; Welton & Farish, 1993).

Anomalies—Asymmetrical shape of the proximal portion and a deep basal concavity (Fig. 3).

Squalicorax pristodontus (Agassiz, 1843)

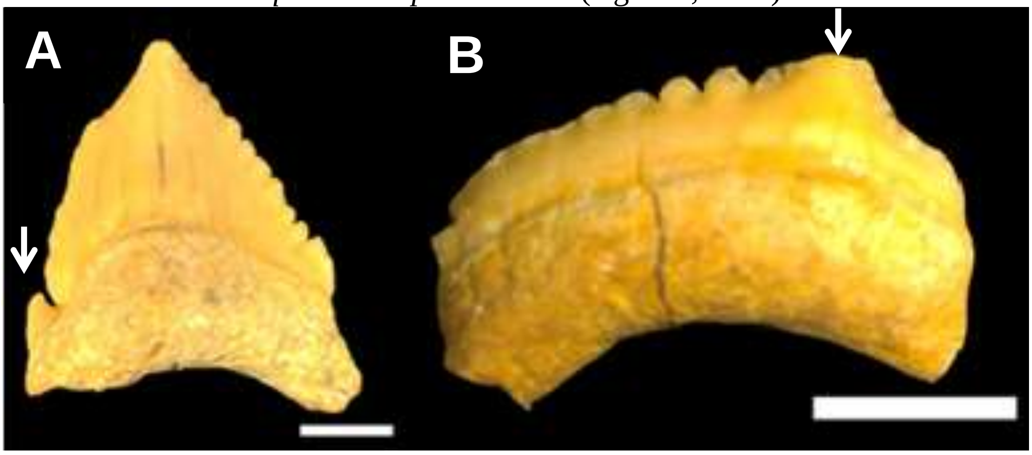

FIGURE 4. *Squalicorax pristodontus* tooth showing abnormalities; lingual view. **A**, LPUFS 5765. Extra cusptlet; **B**, LPUFS 5763. Crown apex near the root. Scale bar equals 2 mm.

Material analyzed—LPUFS 5765 and LPUFS 5763.

General description of non-anomalous teeth— The teeth are composed of a single distally inclined cusp covered by serrations, lingual face convex and labial face planar. Distal and proximal portions form a line in the shape of an almost continuous cutting edge. Cusp apex rounded. Root tall in lingual view, being two thirds taller than the tooth crown in some teeth. Peak of the median cutting edge slightly obtuse. The edge of the distal portion of the main cusp quite straight and perpendicular. Root bilobate and tall, slightly protuberant, with numerous nutrition foramen of various sizes on both faces. The labial face of the crown with multiple shallow nutrition fissures medially, above the crown foot. Basal concavity slightly rounded (Becker and Chamberlain, 2012; Case et al., 2017; Schwimmer, 1997; Shimada & Cicimurri, 2005; Shimada & Cicimurri, 2006; Souza-Lima, 2001; Welton & Farish, 1993).

Anomalies: —Tooth LPUFS 5765 (Fig. 4A) demonstrates a peculiarity, with the presence of an extra cusptlet on the portion proximal to the root. Specimen LPUFS 5763 (Fig. 4B) differs from the normal teeth of this species by having a short crown apex, and a smaller cusp that is proportional to the serration.

Family SERRATOLAMNIDAE Landemaine, 1991
Genus *Serratolamna* Landemaine, 1991
Serratolamna serrata (Agassiz, 1843)

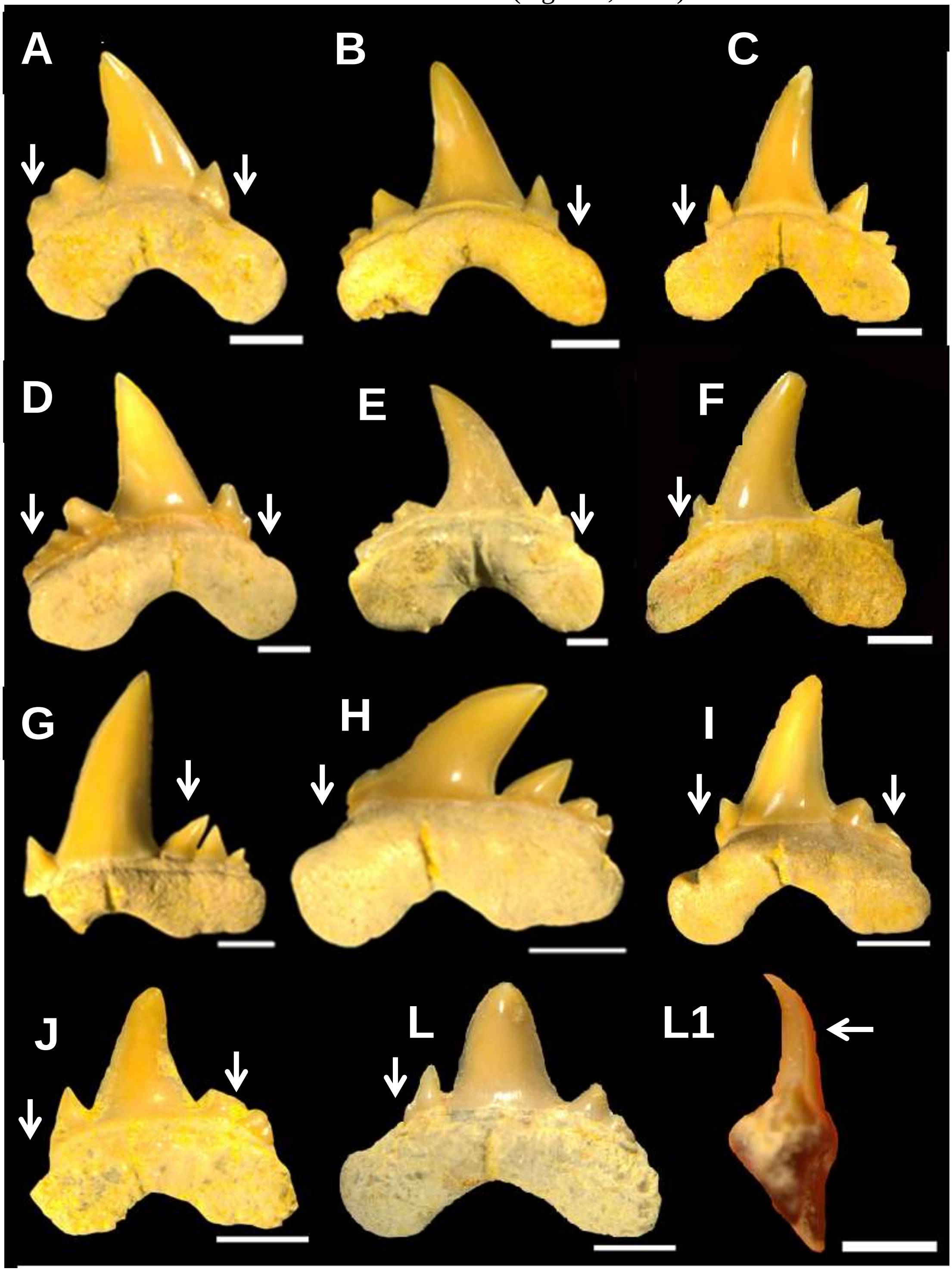

FIGURE 5. *Serratolamna serrata* teeth showing anomalies; lingual view. **A**, LPUFS 5781, absence of lateral cusps; **B**, LPUFS 5784, absence of lateral cusps; **C**, LPUFS 5785, absence of lateral cusps; **D**, LPUFS 5782, absence of lateral cusps; **E**, LPUFS 5788; **F**, LPUFS 5786 **G**, LPUFS 5764, polarity inversion; **H**, LPUFS 5783, absence of lateral cusps; **I**, LPUFS 5787, absence of lateral cusps; **J**, LPUFS 5789, absence of lateral cusps. **L**, LPUFS 5773, absence of lateral cusps. Lateral view; **L1**, LPUFS 5773, curved cusp. Scale bar equals 2 mm.

Material analyzed—LPUFS 5764; LPUFS 5773; LPUFS 5781; LPUFS 5782; LPUFS 5783; LPUFS 5784; LPUFS 5785; LPUFS 5786; LPUFS 5787; LPUFS 5788; LPUFS 5789.

General description of non-anomalous teeth—Crown composed of a median cusp inclined towards the proximal portion, demonstrating two to three erect lateral cusps on the proximal and distal portions. Lingual face protuberant and labial face planar. Crown base ample, median cusp long and triangular. Lateral cusps nearest the median cusp significantly larger than the other lateral cusps. Root separated into two lobes by an asymmetrical semicircular chamfer. Apex of the median cusp sharp. Lingual face of the root cut by a nutrition fissure, with a central foramen that extends throughout the root as a shallow basal V-shaped concavity (Case et al., 2017; Souza-Lima, 2001; Underwood & Mitchell, 2000, Welton & Farish, 1993; Shimada & Brereton, 2007).

Anomalies—The teeth show abnormalities such as the absence of other cusps in the proximal region, grooves in the proximal portion that indicate unformed cusp divisions, undefined cusps in the distal portion and/or small cusps (Fig. 5A, B, C, D, E, F, H, I, J and L). Polarity inversion in the first distal cusp (Fig. 5G). Median cusp rounded on the lingual face (Fig. 5C, F, I, J and L). Cusp curved on lingual portion (Fig. 5C, F, I, J and L).

Family CRETOXYRHINIDAE Glickman, 1958
Genus *Cretolamna* Gluckman, 1958
Cretolamna appendiculata (Agassiz, 1843) †

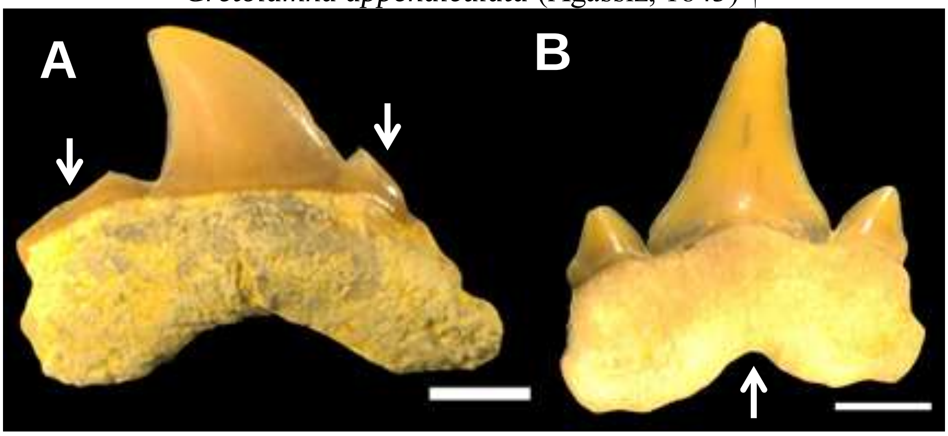

FIGURE 6. *Cretalamna appendiculata* teeth showing anomalies; lingual view. **A**, LPUFS 5780, undeveloped lateral cusps; **B**, LPUFS 5791, absence of a nutrition fissure. Scale bar equals 2 mm.

Material analyzed—LPUFS 5780; LPUFS 5791.

General description of non-anomalous teeth—Teeth composed of a robust and triangular median cusp and a pair of lateral cusps. Cusps wide, tall, and erect. Labial face planar and lingual face slightly convex. Distal, proximal, and median cusps with sharp edges, median cusp inclined towards the distal portion. Median crown larger than the width of the tooth. Root region well-defined, separated by two U-shaped root lobes on the upper teeth, V-shaped on lower teeth. With nutrition fissure and foramen in central lingual view, large basal root concavity (Shimada, 2007; Souza-Lima, 2001; Welton & Farish, 1993, Siverson, 1992).

Anomalies—Undeveloped lateral cusps (Fig. 6A). Absence of a nutrition fissure (Fig. 6B).

DISCUSSION

Tooth Deformation Frequencies

Studies examining dental abnormalities in sharks have found that they are quite rare (less than 1% of all teeth) (Becker et al., 2000; Johnson, 1987). Johnson (1987), for example, analyzed 51,400 isolated fossil shark teeth (from *Orthacanthus texensis, Orthacanthus platypternus, Barbclabornia luedersensis,* and *Xenacanthus slaughteri*), and reported that only 0.06% demonstrated some type of pathology. Becker et al. (2000) reported that among the 90,000 modern and fossil shark teeth they examined (200 mandibles), only 12 (0.013%) demonstrated some type of deformity; among the 10,000 fossil shark teeth that the same group examined *(Squalicorax kaupi, Squalicorax pristodontus, Archaeolamna kopingensis, Scapanorhynchus texanus*, *Brachyrhizodus wichitaensis,* and *Paranomotodon* sp.) only 0.09% (9 teeth) showed anomalies.

Hubbell (1996) examined 123 white shark mandibles and found only 10 specimens demonstrated anomalous teeth (the "entire animal" method yielded a frequency of 8.13%, the “isolated teeth” method generated a percentage of 0.25%). Another study by Hubbell (1996) reported examining 13,151 fossil teeth of *Carcharodon carcharias,* with 0.25% showing deformities.

Although we report here anomalies in only four species (Table 3), deformed teeth represented 0.75% of the total sample. That percentage is almost 12 times greater than that reported by Johnson (1987) (0.06%) who examined *Xenacanthus* teeth from the Permian period, and almost 8 times greater (0.09%) than that reported by Becker et al. (2000) for fossil teeth from the Upper Cretaceous period. The frequency of deformities closest to the 0.75% found here was 0.25%, reported by Hubbell (1996) among white sharks.

As such, the frequencies of dental deformities per species reported here are considerably greater than those of other studies. Becker et al. (2000) examined 6,727 teeth from *Squalicorax kaupi*, and only 0.015% (1 tooth) demonstrated any deformity, while of the 652 teeth of *Squalicorax pristodontus* examined, only 0.15% (1 tooth) demonstrated an abnormality. Although researchers have generally shown that less than 1% of the teeth of any species demonstrate deformities, of the 14 teeth of *Squalicorax kaupi* we examined here, 7.14% demonstrated some type of abnormality. That frequency was even higher in *Squalicorax pristodontus*, as of the 12 teeth identified for that species, 16.66% demonstrated some abnormality.

The teeth of *Squalicorax pristodontus* studied here demonstrated a considerably higher frequency of abnormalities when compared to the 0.15% rate reported by Becker et al. (2000). Likewise, the abnormality frequency reported by those same authors in *Squalicorax kaupi* was 0.015%, well below that found in the present work.

One factor influencing the unusually high percentage of abnormal teeth as compared to other studies is the reduced numbers of teeth reported here. While Becker et al. (2000) examined 7,379 teeth from *Squalicorax kaupi* and *Squalicorax pristodontus*, we examined a total of only 26 from those same two species. If our sample of *Squalicorax* teeth had been larger, the percentages would most likely have been more similar.

The high percentages of anomalous teeth we found for *Squalicorax kaupi*, *Serratolamna serrata,* and *Cretalamna appendiculata* are similar to those obtained by Hubbell (1996) using the “entire animal” methodology. As such, one possible hypothesis is that the fossil teeth we examined were derived from only a single original dental arch from each of those animals, backspace; that probability is heightened by the fact that, while those teeth were unattached, they were all collected within an area of no more than 2 m^2.

Causes of the Deformities

Hubbell (1996) reported observing deformities in *Carcharodon carcharias* and *Carcharodon megalodon* teeth such as: curved teeth; divided teeth; an orifice in the center of the crown; and wrinkled and/or twisted teeth. Those abnormalities were apparently caused by a spine from a stingray provoking lesions in the gengival tissue. Those abnormalities were similar to some dental specimens encountered in the present study.

Figure 3 shows an abnormal *Squalicorax kaupi* tooth demonstrating an asymmetrical shape in the proximal portion and a deep basal concavity. Deformities in *Squalicorax kaupi* were reported by Becker et al. (2000), including a disconected distal notch. The deformities reported by Becker et al. (2000) appear to have resulted from behavioral patterns and dietary preferences for spiny prey that could cause damage to the tissues of developing teeth.

Becker and Chamberlain (2012) described the lesions on *Squalicorax kaupi* and *Squalicorax pristodontus* teeth resulting from feeding on animals with hard exoskeletons that provoked breakage of the apices of the median teeth. Balbino & Antunes (2007) observed an inclined crown and other anomalies in *Carcharocles megalodon*, such as the absence of enamel near the root of a tooth and asymmetrical teeth.

Figure 4 shows two teeth from *Squalicorax pristodontus* with dental deformities. Tooth LPUFS 5765 (Fig. 4A) shows an extra cusplet near the root. Bemis et al. (2015) observed similar anomalies in *Carcharodon carcharias*, such as the presence of serrated lateral cusps near the basal border of the central cusp (while that tooth normally shows a central cusp covered with serrations reaching the basal concavity). Lines of abnormal and supernumerary serrations, as well as serration lines forming a "Y" have been observed in *Edestus* and *Carcharocles megalodon* – malformations believed to have been caused by trauma from a hard object (Itano, 2013). The cause of the deformity reported by Itano (2013), i.e., trauma from a hard object, may likewise have caused the deformity seen on tooth LPUFS 5756 (Fig. 4A), a row of abnormal serrations. Similar types of dental abnormalities were reported by Balbino & Antunes (2007), who described a coalesced tooth in *Squalicorax pristodontus* that clearly had a single root but two crowns. The crowns had almost normal median cusps, except for a visible shortening of the distal portion; the line of serrations showed size irregularities. Those authors noted that the deformities may have been caused by biting hard objects. Another abnormality observed in *Squalicorax pristodontus* was a fold along the median edge (Becker et al., 2000).

There have been no previous studies of dental deformities in the species *Serratolamna serrata* and *Cretalamna appendiculata*, but dental abnormalities similar to those reported here have been observed in other shark species.

The teeth of *Serratolamna serrata* (Fig. 5) demonstrated abnormalities such as a single proximal lateral cusp (while a normal tooth has two or three pairs of lateral cusps), groves that normally mark cusp divisions were not formed, and the presence of undefined cusps on the distal portion of the tooth and/or reduced cusps (Fig. 5A, B, C, D, E, F, I, J and L). Figure 5H shows a tooth without lateral cusps on the proximal portion. Figure 4B shows a *Squalicorax pristodontus* tooth with similar abnormalities; the apex of the crown near the root, and an abnormally small cusp near the root.

Johnson (1987) noted the absence of intermediate cusps in *Xenacanthus*. Vuuren et al. (2015) described abnormalities in *Carcharias taurus* teeth such as reduced median and proximal cusps, smaller than normal crowns, poorly defined lateral cusps, and a median cusp with an inclined apex. The abnormalities reported by Lucifora & Menni (2001) for *Carcharias taurus* were similar to the deformities described here for *Serratolamna serrata*, including an inverted cusp similar to a polarity inversion (Fig. 5G), a hook-shaped tooth identical to a curved cusp (Fig. 5C, F, I, J and L), lateral cusps absent, and small teeth similar to the poorly defined cusps on the distal portion and/or reduced cusps (Fig. 5 except Fig. 5G; Fig. 6B).

Cusp inversion was observed in *Triakissemi fasciata, Carcharhinus amblyrhynchos*, *Galeorhinus opterus, Notorhynchus maculatus,* and *Triaenodon obesus* (Reif, 1980); although polarity inversion has been described in different species, that malformation is similar to the deformity encountered the present study with tooth LPUFS 5764 from *Serratolamna serrata* (Fig. 5G). Reif (1980) noted that polarity inversions are only visible after the fifth row of teeth, and they represent anomalies related to lesions of the dental tissue and/or wounds. Shimada (1997) described dental abnormalities in *Cretoxyrhina mantelli* such as a curved cusp, wrinkles and/or vertical folding of the labial portion of the crown region, and excessive dentine. Inclined and folded cusps, and twisted cusps and roots were observed in *Carcharoides totusserratus*; a twisted crown was also reported for *Negaprion* (Balbino & Antunes, 2007). Becker el al. (2000) reported a folded lingual cusp and teeth with abnormal root growths in *Carcharhinus leucas*, the absence of a lateral cusp and a compressed principal cusp in *Archaeolamna kopingensis,* and a cusp folded along the lingual face in *Scapanorhynchus texanus* – similar to the anomaly classes discussed in the present paper.

The anomaly reported by Becker et al. (2000) in *Paranomotodon* sp., as a dislocation of the nutrition fissure and twisted cusp, was similar to that reported in the present study (a superficial and almost imperceptible nutrition fissure [Fig. 6B]). Figure 6A shows reduced and/or undeveloped lateral cusps, deformities similar to those described by Vuuren et al. (2015) and Lucifora & Menni (2001) for *Carcharias taurus* teeth (poorly defined lateral cusps and reduced cusps).

Dental anomalies, including the presence of a cusplet, were described for the first time in *Squalicorax pristodontus* and, even though they are distinct species, the anomalies were similar to those seen in *Carcharodon carcharias.*

Dental deformities in *Serratolamna serrata* and *Cretalamna appendiculata* are described here for the first time, although those types of abnormalities have previously observed been in other shark species.

CONCLUSION

The frequencies of dental deformities observed in the present work corroborated a study by Becker et al. (2000) that showed dental deformities generally represent less than 1% of any sample, so that dental abnormalities are reasonably rare in sharks. Deformity frequencies per species in the present work, however, yielded percentages greater than 1%. One possible explanation for that result is the relatively small sample size we considered. Another possible explanation is that our sampling may have examined only a single individual, as the anomaly frequency seen in Serratolamna serrata was similar to that observed with intact individuals (and different from calculations considering isolated teeth). That hypothesis, however, will need to be explicitly tested.

In relation to the causes of those anomalies, studies of the teeth of modern sharks have reported anomalies essentially identical to those described here and mainly associated with lesions that resulted in damage to dental tissues.

It was possible to identify numerous anomalous characteristics in the teeth analyzed in the present work, and the causes of those anomalies appeared to be related to the pathological effects of a durophagous diet. A detailed examination of the complete fossil fauna associated with the same outcrop (Calumbi 1) could sustain that hypothesis.

As such, the present research provided a more detailed understanding of the Sergipe sedimentary sub-basin, information concerning anomalous dental characteristics, and the possible causes of those deformities in fossil shark teeth.

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CAPÍTULO III – CONCLUSÃO

CONCLUSÃO

Analisando a frequência de deformidades com base na amostra, esta pesquisa corrobora com o estudo realizado por Becker et al. (2000), que a frequência de dentes que apresentaram deformidades dentárias em uma determinada amostra representa menos de 1%, sendo consideradas anormalidades dentárias como componente raro em tubarões. Quando analisado a frequência de deformidades por espécie esta pesquisa apresenta percentual maior que 1%, a explicação para um percentual elevado esta no tamanho amostral analisado neste estudo.

Com relação às causas das anomalias, estudos descrevendo dentes de tubarão existentes relatam anomalias como as descritas aqui. Esses estudos associam a ocorrência de anomalias com mutações genéticas, doenças no tecido embrionário, deficiências nutricionais ou lesões, que podem resultar em danos marcantes ao tecido dentário, levando a malformações dentárias.

Nesta pesquisa os dentes analisados possibilitaram identificar caracteres anômalos, e que as causas das anomalias estão relacionadas a efeitos patológicos ocasionados por dieta durofagia, que ocasionaram danos na mandíbula prejudicando a formação de dentes normais. Diante disso, esta pesquisa é relevante para sub-bacia sedimentar de Sergipe, lançando um novo visual para o reconhecimento de caracteres anômalo e as possíveis causas dessas deformidades em dentes fósseis de tubarões.

ANEXO I - NORMAS DA REVISTA JOURNAL OF VERTEBRATE PALEONTOLOGY

GUIDE TO MANUSCRIPT PREPARATION
FOR THE
JOURNAL OF VERTEBRATE PALEONTOLOGY

Adherence to the Guide to Manuscript Preparation provided here is mandatory. Do not rely on older issues of the Journal of Vertebrate Paleontology (JVP) as a style guide.

All manuscripts must be submitted electronically through the ManuscriptCentral/ScholarOne manuscripts submission site at https://mc.manuscriptcentral.com/jvp. For assistance with this process, please use the help tools provided through links at the web site.

Note also that strict adherence to the file-format, resolution, and size requirements for figures is absolutely essential for final acceptance to JVP.

Note also that JVP has stricter requirements for data sharing and open access to data than those posted on the journal web page, which are those imposed by the publishers, Taylor & Francis, on all their journals.

MANUSCRIPTS

Manuscript Categories

The Journal publishes two categories of papers: Articles and Short Communications. Authors must indicate during submission in which category they wish their manuscript to be considered.

The JVP no longer publishes book reviews. Book reviews should be submitted to the Society of Vertebrate Paleontology Newsletter.

Monographs can be considered for publication as supplements to the Journal; consult the Monographs Editor prior to submission.

Articles—Manuscripts intended as Articles (papers of 6 or more printed pages in the Journal) must not exceed 100 pages of double-spaced typescript including references, tables, and appendices at US Letter (21.5 by 28.0 cm; 8.5 by 11.0 in) or A4 (21.0 by 29.7 cm) page size. Longer manuscripts, or ones with an unusually large number of figures or tables, may be considered, but the Senior Editors must be consulted prior to submission. The manuscript should not exceed a ratio of approximately 1:3 between the number of figures plus tables and the number of typescript pages exclusive of references and captions. Submission of a color figure suitable for use on the cover of the journal is encouraged, but use of a submitted figure cannot be guaranteed.

Short Communications—Shorter manuscripts, usually not more than about 12–13 manuscript pages (approximately 4000–4200 words) long and with two to three small figures, are published as Short Communications. Short Communications do not have a published abstract, though an abstract and a plain-language summary are required as part of the on-line submission process.

Manuscript Requirements

The main text document for all submissions should have its contents arranged in the following order: title page, abstract (no abstract for Short Communications), main text, acknowledgments, literature cited, and figure captions. A short checklist:

- All typescript pages, including references, figure captions, tables, and appendices, must be double-spaced.
- All pages must be numbered. Leave at least 25 mm (1 in) margins on all sides of each page.
- **Do not use** two or more spaces after periods or colons anywhere in the manuscript.
- Type must be 12-point font size, Times New Roman is recommended.
- The right margin must not be justified. This combination of margins, double spacing and type size should yield about 26 lines per page.

Manuscripts must conform to the mandatory provisions of the Fourth Edition (1999) of the International Code of Zoological Nomenclature (ICZN, available on-line at iczn.org). New taxon names must be registered in ZooBank (ZooBank.org). Instructions on how to do this **will be provided with the proofs**. Sections on systematic paleontology should include, where appropriate and in that order, synonymy, holotype or type species, hypodigm, etymology, occurrence or distribution, diagnosis, description, and discussion or remarks. Each of these sections should be started as a tertiary heading (see below). All new taxa must be so designated (e.g., gen. et sp. nov.) and accompanied by an etymology including intended gender of the name and a concise differential diagnosis, written in telegraphic style and specifying the apomorphies of the taxon if known. Taxon definitions (node-, stem-, or apomorphy-based) are an accepted but not mandatory part of the Systematic Paleontology section.

Specific reference must be made to every illustration in the main text. Figures should be numbered in the order they are cited. Cite figure number (e.g., Fig. 3A-C) rather than specimen number to support descriptive statements. The specimen number must be included in the figure caption. All specimens used in diagnostic descriptions, in illustrations, or in taxonomic discussions must be properly curated and reposited in a recognized public or private, non-profit institution. All material mentioned in a paper must fulfill the criteria set out within the Society's Bylaw on Ethics (available at http://vertpaleo.org/the-Society/Governance-Documents/Bylaw-on-Ethics-Statement.aspx).

If a manuscript includes a phylogenetic analysis, special requirements apply. These can be found here. In addition, for the sake of transparency and to enhance collaboration, we also strongly recommend uploading the dataset, character descriptions and accompanying images to a suitable online repository (MorphoBank, http://www.morphobank.org) is recommended), although this is not a mandatory requirement for publication. Similarly, data sets supporting statistical analyses should also be uploaded as Supplementary Data for the benefit of reviewers, and readers. Such supplementary files must be submitted and available to the reviewers along with the main manuscript files. If you are not sure about the disposition of particular data sets, contact the Senior Editors about whether or not they will be published in JVP or placed on the web page.

All raw data necessary for validating anatomical descriptions must be included as supplementary material, uploaded to a freely publicly accessible data repository whose appropriateness will be determined at the discretion of the editors. These data include but are not limited to raw (i.e., unsegmented) x-ray or optical image stacks. Authors are permitted to crop tomographic slices to the reported feature(s) of interest provided they include the correct scaling/pixel size for the newly cropped image. Examples include providing raw CT scans of endocranial, nasal, or inner ear cavities rather than simply providing segmented 3D models. Statements to the effect of "Data are available upon request from the authors" are not permitted in JVP.

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Manuscript Submission

All manuscripts must be submitted via the Journal's on-line submission site at ScholarOne Manuscripts: https://mc.manuscriptcentral.com/jvp. Submit the main document as one file (includes title page, body of manuscript, literature cited, and figure captions). Submit the main text, as well as each table, appendix, or supplementary data file as a separate MS Word or RTF file. (See here for instructions on formatting 3D images as supplementary files.) Provide an abstract in the main document file for Articles, and provide both abstract and plain-language summary in the requested place on the submission web site for all manuscripts. Submit each figure as a separate file. Figures should be LZW compressed, gray-scale (unless color publication is intended), 600 dpi TIFF files (see detailed guidelines here). The submission web site will create pdf versions of most figure files, and a combined pdf file of text and figures for review purposes only. Upon completion of the submission process, an automated email acknowledgment will be sent to the corresponding author and to all co-authors whose email addresses have been entered correctly, and further communication concerning the manuscript will be via email.

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Manuscripts are processed by a Senior Editor and assigned to a member of the Editorial Board who manages the review process. Possible decisions include Accept, Minor Revision, Moderate Revision, Major Revision and Reject. A rejected manuscript is normally not eligible for revision and resubmission to JVP. A manuscript in need of Major Revision or Moderate Revision may be resubmitted, but only after fundamental changes are made, which may include new data collection, new analysis, extensive changes to text, and new or revised figures. In the case of Major Revision or Moderate Revision, the manuscript will normally undergo a full review process upon resubmission and there is no guarantee of eventual acceptance. After Minor Revision, the Editor may or may not decide to consult with one or more of the original referees. After decisions of Minor Revision, Moderate Revision, and Major Revision, there is a time limit for resubmission, after which a manuscript will be considered withdrawn. Consult the decision letter from the Editor for details of necessary changes. The revision deadline (date) can be found on the manuscript page on the website. If your revision is expected to exceed this date, request an extension to the deadline from your editor.

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FORMATTING YOUR MANUSCRIPT

A guide to some issues of style is provided here

USE THE FOLLOWING EXAMPLE AS A GUIDE BUT SEE ALSO HERE:

TITLE PAGE

Osteology and relationships of the Early Permian pelycosaur *Sphenacodon ferox* Marsh, 1878

MARTHA T. THOMPSON[1,*] and T. JOHN SMITH[2]

[1]Quaternary Sciences Program, and Department of Geology, Northern Arizona University, Flagstaff, Arizona 86011 U.S.A., doodaa@Arizona.com;

[2]University of Toronto in Mississauga, 3359 Mississauga Road, Mississauga, Ontario, L5L 1C6, Canada, jpq@uknow.ca

* For Short Communication—addresses as for Articles but run together and flush left, following authors' names:

MARTHA T. THOMPSON[1] and T. JOHN SMITH,[2] [1]Quaternary Sciences Program and Department of Geology, Northern Arizona University, Flagstaff, Arizona 86011 U.S.A., doodaa@arizona.com; [2]University of Toronto in Mississauga, 3359 Mississauga Road, Mississauga, Ontario, L5L 1C6, Canada, jqp@uknow.ca

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4

ABSTRACT

ABSTRACT—An informative abstract is required for Articles. Short Communications do not have an abstract in the main text file, but an abstract must be entered separately during web submission because it is used to help reviewers decide whether they are willing to review the manuscript. The abstract for Articles must be formatted as in this example and must begin on a new page. It should summarize the main facts, ideas, and conclusions of the Article, and not simply list the topics discussed, but it **must not exceed 250 words**. Include all new taxonomic names for referencing purposes. Abbreviations that are not listed in the Details of Style for Text (provided here) should be avoided. Literature citations are normally not allowed in the abstract.

ALTERNATE-LANGUAGE SUMMARY

A non-English-language summary may be added to the standard abstract in exceptional cases. Permission to have such a category comes from the Senior Editor. The summary should be an exact translation of the English abstract, placed after the Abstract and before the beginning of the text.

Please note that the Journal of Vertebrate Paleontology does not employ Key Words.

HEADINGS

There are three types of headings (or headers) as per the following examples.

PRIMARY HEADING

Text or secondary heading follows after a blank line. Do not write the primary heading in small caps. A blank line precedes the primary heading.

The Systematic Paleontology section requires some specific formatting. See here for examples.

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Text, if any, follows on the next line, indented. A blank line precedes the secondary heading. Use Title Capitalization (Capitalize the Important Words), not sentence capitalization. Do not cite figures or tables within headings.

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All paragraphs in running text should be indented.

Citation of References in Text, Basic (see here for alternatives)

(Smith et al., 1973)

Abbreviations

There can be separate 'Institutional Abbreviations' and 'Anatomical Abbreviations,' each beginning with a tertiary heading. The list should be ordered alphabetically by abbreviation. Note that the abbreviation is in bold but the punctuation is not. Examples:

Institutional Abbreviations—AMNH, American Museum of Natural History, New York; **MCZ**, Museum of Comparative Zoology, Harvard University.

Anatomical Abbreviations—a, articular; **prz**, prezygapophysis; **z**, zygantrum.

List anatomical abbreviations either in a separate section as in this example, especially when captions are used in multiple figures, or else in the figure captions, but not in both places. If listing them in figure captions, include all abbreviations for a given figure within its caption; do not refer the reader to another caption.

ACKNOWLEDGMENTS

Note the spelling of this heading with no 'E' after the 'G'. Avoid long and unnecessarily flowery acknowledgments. Use initials for all individuals being thanked, except to begin a sentence; avoid using titles such as Dr. or Prof.; use initials to distinguish among authors of the manuscript, and abbreviations for institutions listed in the manuscript text. Consider thanking the reviewers, including those remaining anonymous, and the Editor who handled the manuscript. Use active voice and concise language, as in this example: "I/We thank A. Able, B. Baker, and C. Charles for capable field assistance, and D. Delta for assisting EFG during a collections visit to the AMNH. Editor B. Careful and reviewers A. Positive and O. Negative made constructive suggestions for improvement of the manuscript. NSF grant 12345 to H.I.J. supported this research."

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Double-space all entries; make first line flush left, then use hanging indent for remainder of citation:

Sues, H.-D., E. Frey, D. M. Martill, and D. M. Scott. 2002. *Irritator challengeri*, a spinosaurid (Dinosauria: Theropoda) from the Lower Cretaceous of Brazil. Journal of Vertebrate Paleontology 22:535–547.

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Submitted/accepted line in Roman type appears as the very last line of the article immediately after the Literature Cited (flush left):

Submitted August 12, 2006; revisions received Month DD, YYYY; accepted Month DD, YYYY. [dates left blank, to be completed by the editors]

Further examples and formatting specifics are provided here

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File Format and Resolution

Submit all image files at final resolution, which is 600 dpi (236 pixel/cm) or better. The online system will automatically generate a combined pdf file. Name each figure file with author and figure number (e.g., SmithetalFig2.tif).

Remove color depth from grayscale images (see above) unless intending to pay for color printing and compress TIFFs using LZW compression to reduce file size without loss of quality. Do not submit jpg files. It is highly recommended to keep lettering in a separate layer, if possible (this makes correction of spelling or other errors easier). The resulting file should be between 0.5 MB and 10 MB in size, depending on contents and dimensions of the figure.

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The journal has a full-color cover format and we encourage authors to submit potential cover art with the post-review draft of their manuscript if they believe that their article is an appropriate candidate.

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The art should be submitted in landscape format, in color, 600 dpi, 168 mm (6.6 in, 3969 pixels) wide, and no more than 140 mm (5.5 in, 3307 pixels) tall. Final choice of Cover Article will be made by the editorial team led by the Senior Editors. Art that is not chosen for the cover of the journal could be made available as supplementary online data at the author's discretion.

Figure Captions

These should begin with 'FIGURE' in all caps. There is a period after the figure number. Follow the example below.

FIGURE 5. Theropod skull bones in lateral view. **A**, dentary of *Allosaurus fragilis* (after Madsen, 1976); **B**, maxilla of same; **C**, dentary of *Carcharodontosaurus*, AMNH 1956. **Abbreviations**: **a**, articular; **af**, ascending facet; **rt**, recurved teeth. Scale bar equals 5 cm. [planned for column, 2/3 page width, page width]

- Note what is in bold (the punctuation is not).
- Follow the punctuation conventions exactly.
- Spell out 'equals.'
- Note that the items in the abbreviations are listed alphabetically based on the abbreviation.
- Include a notation in square brackets at the end of each caption specifying the planned printed size of the figure "[planned for column width] or [planned for 2/3 page width] or [planned for page width]." In case the figure contains a stereo pair and requires a different size than page or column width, mention this within the square brackets [stereo pair; print exact size].

TABLES

All tables must be cited in the text and the tables must be numbered in the order in which they are cited in the text, even if there is only one table (i.e., Table 1). Tables with their captions should be comprehensible without reference to the text. Foldouts are not acceptable, but tables and charts can be reproduced to cover facing pages. The heading/caption for the table should appear in the table file, above the table, not in a list at the end of the manuscript document. Use 'TABLE' (all caps), flush left, in the table heading, with a period after the table number, as in this example:

TABLE 2. This is the caption of the table.

If a table continues on a second page, begin the next page with "TABLE 1. (Continued)". Do not use vertical lines in any table. Use only those few, black, horizontal lines (usually three) found in recently published examples in JVP. Tables should not use bold face.

Never use spaces for aligning numbers or text; use of tabs for aligning columns is discouraged; instead, use the table function of the word processor. Double-space everything even if this means that a table extends to more than one manuscript page.

Submit each table as a separate file (labeled, e.g., 'Author.Table1.doc').

APPENDICES

Appendices appear following the literature cited in the print and pdf versions of an article, and should be less than e.g., four manuscript pages in length. More extensive information (e.g., faunal lists, character lists, specimen lists, etc.) should be included as supplementary data (see below for details). Material for an appendix should be double-spaced and submitted as a separate file or files. An appendix or appendices (use Arabic numbers, beginning with 1) must be referred to in the text and/or in the tables/figures.

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Supplementary material (on-line only content) is supporting material that cannot be included in the printed version for reasons of space. JVP requires that all data files needed to replicate phylogenetic or statistical analyses published in the journal be made accessible to the reader. For phylogenetic analyses, see specific details below. This will enable others to replicate the research without the need to obtain such files directly from the author and will improve the accessibility and stewardship of information, as well as transparency.

Format the supplementary data file similarly to the published article, including title page with title, authors, and 'Journal of Vertebrate Paleontology,' and on following pages use text headings, figures, tables, and appendices as necessary. Each such file should be self-contained; if literature is cited within the supplementary data, the file must contain its own literature-cited section. The published article must not contain references that are cited only in the supplementary data. If a supplementary file contains tables, figures, or appendices, use Table S1, S2, Figure S1, S2, Appendix S1, etc., to prevent confusion with tables or figures in the main article. Each supplementary data file must be cited at the appropriate place in the text of the main manuscript (e.g., Supplementary Data 1) and be submitted as a separate file with the same name (e.g., 'supplementary_data_1.doc').

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- Do not use underlining anywhere in the manuscript.
- Use single quotes for select wording and connotations: 'big' versus 'small,' ....it looks like an inverted 'bell' ...it seems to be a form of 'bovid.'
- Use double quotes for actual quotations from the literature: ...as noted by Beard (1942:23) "the skull is twice as long as wide," or for non-monophyletic taxa when used formally as part of a name, "Pelycosauria."
- Always provide the page number for quotations: ...as noted by Beard (1942:23), "the skull is twice as long as wide," There is no space between the colon and the page number or figure reference.
- Do not use a page number in a citation unless you are providing a quotation or unless there is ambiguity with various statements made by an author: The skull was stated as being large (Frank, 1928:35) but later indicated to be relatively small (Frank, 1928:52).
- Do not use the apostrophe with numbers or acronyms: use 1950s not 1950's; NALMAs not NALMA's.
- Use English standards for decimal notation: 1,583,400.21.
- Mammalian teeth: lower teeth in lower case, i1, c1, p1–2, dp2, Rm3; upper teeth in upper case, I1, C1, P1, LDP2, M2–3. This does not have to be stated in the Materials and Methods section.
- Use comparative anatomical terminology, not medical anatomical terminology, e.g., 'dorsal' rather than 'superior.'
- Use metric throughout; include Imperial system in parentheses only if absolutely necessary. Abbreviations: m, meter; mm, millimeter; cm, centimeter; km, kilometer; μm, micron (not μ), micron or micrometer if spelled out; mi, mile; ft, feet; in, inch; gal, gallon; l, liter (spell out if without prefix: 3 ml and 1.2 g/ml, but 3 liters and 1.2 g/liter); ml, milliliter; g, gram (not gm); kg, kilogram; mg, milligram. Separate the unit from the numerical quantity by a space (e.g. 3.2 m, 0.5 g).
- If it is necessary to use mathematical symbols (+, -, =, '), separate with spaces before and after (e.g., CI = 0.63).
- Hyphens, en dashes, and em dashes are used in different situations. The hyphen (-) is used between parts of a compound word, as in 're-interpretation' or 'the basal-most taxon.' The en dash (–) is used for a range of values, as in 'pp. 33–44,' 'Figs. 5–7,' 'Triassic–Jurassic,' and '2–7 hemal arches.' The em dash (—) is used in running headers and in tertiary headings, such as **Diagnosis**—Skull large; etc., to indicate missing values in tables, and to emphasize parenthetical phrases, as in 'The skull—the only element preserved—is extremely wide.' Do not separate any hyphen or dash from the words around it by spaces.
- Spell out 'Figure' when part of a sentence; abbreviate as 'Fig.' when citing a figure in parentheses.
- Do not cite anatomical abbreviations within the text (e.g., Fig. 3:pt); they should be in the figure caption or in Abbreviations instead.
- Accepted abbreviations are: aff.; ca.; cf.; e.g.; etc.; i.e.; no. for number (not #); Ma not Mya for megannum; M.A.; M.Sc.; Ph.D., P.O.; viz; vs. (or versus). In a sentence, e.g. and i.e. should be followed by commas, ca. and cf. should not, as in: Diversity includes ca. nine families, e.g., Mustelidae, Felidae, and Canidae.
- The 'sister group' (but 'sister-group relationship'); 'crown group'; 'ingroup'; 'outgroup'; 'stem group'; 'total group'; 'anterodorsal', 'posteroventral,' etc. (rather than 'antero-dorsal'); 'basal-most' or 'anterior- most' item; 'cheek tooth' not 'cheektooth'; 'co-ossified,' not 'coossified'; 'cross-section' and 'cross-sectional view'; 'field

work' rather than 'fieldwork'; 'fishes'; 'forelimb' but 'hind limb.'

- Latin phrases are not italicized: Examples: a priori; gen. et sp. nov.; incertae sedis; in vivo; in vitro; M. supracoracoideus anterior; nomen dubium; per se; sensu; sensu lato; sensu stricto.
- Avoid single-sentence paragraphs.
- When providing a numbered sequence of items in one sentence, preceded by a colon, do so in the following style: "Explanations for the extinctions include: (1) climate; (2) temperature only (see Graham, 1956); and (3) predation by carnivorans."
- When citing a reference within a parenthetical phrase, avoid nested brackets by using the following style when the phrase is not complicated: "…there are three centra (four according to Smith, 2006) inthe…"
- When nested brackets are unavoidable, use outer parentheses and inner square brackets, i.e., (text[text]).

COMMON ERRORS TO AVOID

- Names of higher taxa are plural for purposes of grammar, as in "The Squamata *are* a taxon that includes snakes and lizards." Contrast this to the following: "The taxon Squamata *includes* snakes and lizards." Here, the subject of the sentence is the word 'taxon,' and the associated verb is singular.
- Terms such as 'available' and 'valid' have particular meanings under ICZN and should be avoided unless the specific meaning is intended.
- A comma separates the name of a taxonomic authority from the date of publication, and commas surround the date when a taxonomic authority is used in a sentence, as in, "…the species *Esox lucius* Linnaeus, 1758, is the…"
- Never cite a reference in brackets immediately after the name of a species unless you intend it as a taxonomic authority: "*Hensodon spinosus* (Hennig, 1907)" means that Hennig named this species in a different genus; see ICZN Article 51.
- A citation in brackets is acceptable after a generic or other higher taxonomic name because a taxonomic authority for a genus or higher taxon is never in brackets: contrast "…as in *Esox* Linnaeus, 1758" [authority] with "…as in *Esox* (Schmidt, 1875)" [ordinary citation].
- 'Upper' and 'lower' refer to rock or time-stratigraphic units; 'late' and 'early' refer to time. Use lower case when the age constraints are not known, generalizations are made, or when no formal subdivision exists. Use upper case only where mandated by current USGS recommendations—'Early/Lower Cretaceous', 'Middle Devonian' (for periods/systems and epochs/series), but 'late/upper Miocene,' 'middle Eocene,' 'early Paleozoic,' 'early/lower Albian,' and 'early/lower Tortonian' (for stage/age/informal subdivision of stage/age/epoch/series).
- 'Runs' implies motion; use 'extends,' 'connects,' 'projects': 'the lamina extends between the two…'.
- Avoid overuse of weak words such as 'suggests,' 'appears,' 'appears to be,' 'probably,' 'may be.' Use stronger words: 'indicates,' 'implies,' 'shows,' 'illustrates,' 'proposes.' If you know something to be true, then state it.
- 'Show' is often overused: 'The occipital condyle shows damage…'; write instead '…the occipital condyle is damaged.'
- 'Possess' is often overused: 'The femur possesses a protrusion...'; use the simpler 'has' if possible.
- Avoid words that incorrectly imply 'time' such as: 'since,' 'while,' 'frequently'; instead use 'because,' 'whereas,' 'many.'
- Don't use 'oval-shaped,' 'square-shaped,' triangular-shaped,' etc., when 'oval,' 'square,' or 'triangular' is meant.
- Use 'farther' when the meaning involves physical distance, 'further' to indicate a greater degree or additional point.
- "The crest on the bone is well developed" (note the correct absence of the hyphen), but, "The bone has a well-developed crest" (hyphen required); "…the small, water-worn tooth…" but "the thin, laterally expanded arch."
- Rocks do not 'outcrop'; rocks do 'crop out.'
- Capitalization with multiple proper names: 'Mississippi River' vs 'Mississippi and Missouri rivers'; also counties, formations, oceans, states, etc.
- Comma and period inside closing quotation marks, as in "…is long and thin," and "…is short and thick." Colon and semicolon outside quotation marks: "…include the following 'orders': Rodentia and Lagomorpha…" and "…the so-called 'palatine'; however, it…"
- 'As' implies a comparison: red as a rose. 'Because' implies the result of some action. "The skull is unknown as it is missing" should be "The skull is unknown because it is missing."
- Use "the blade of the scapula…" or "the scapular blade…" rather than "the scapula's blade…" because inanimate objects cannot possess.
- 'Which' is used to describe, and its phrase is normally set off by commas, whereas 'that' defines a situation and is normally used without surrounding commas: "... the basipterygoid process, which is small, is rugose..." versus "... the events that affected dinosaur communities were many..."
- 'However' is often over-used. Avoid the common error of linking two independent/principal clauses by 'however' or 'therefore' without the required semicolon or period. "The pelvis is large, however, the ilium is small" [incorrect] should be "The pelvis is large; however, the ilium is small" or, "The pelvis is large. However, the ilium is small."
- Avoid overuse of the semicolon. Consider if a colon or period would be better.

Return to main text

SYSTEMATIC PALEONTOLOGY EXAMPLES

There now are three different ways to provide your hierarchy: a traditional Linnean ranked hierarchy, an unranked classification with ranked lower levels, and an unranked monophyletic hierarchy. Examples of each type are:

Ranked Hierarchy

Order PYCNODONTIFORMES Berg, 1937
Family COCCODONTIDAE Berg, 1937

HENSODON SPINOSUS (Hennig, 1907)
(Figs. 2–4)

Mesodon spinosum Hennig, 1907:364, fig. 3 (original description).
Mesodon spinosus Hennig, 1907: Steinmann, 1928:56, fig. 14 (emended spelling).
Hensodon spinosus (Hennig, 1907): Kriwet, 2004:526, figs. 1–3, 5–9 (new combination).

Diagnosis—Diagnosis should be differential. Apomorphies of taxon specified if known. Telegraphic style (no verbs, no articles) strongly encouraged in diagnoses. Example—Apomorphies of taxon: orbit large, longer than deep; mandible shallow, flared posteriorly; mental foramen opening below second premolar. Differing from *Alphus brevis* in: incisors spatulate; diastema between I1 and C1.

- Note in the above that ranks are provided, in upper and lower case.
- All taxonomic names are written in all capital letters and centered (do not use large and small caps).
- Unranked taxa may be inserted between ranked taxa in the hierarchy.
- Generic and specific names are in italics and all caps.
- There is no comma between the taxon and the author but there is a comma between the author and the year of publication.
- All cited taxonomic authorities must be in the Literature Cited, including those in the synonymy. Follow guidelines in ICZN (1999) for citation of taxonomic authorities.
- The synonymy should be formatted as in the above example (left justified, with hanging indent if an entry continues on a new line). Leave vertical space above and below the synonymy to set it off from the taxonomic headings and the following text.
- The punctuation within the synonymy is important. The first line illustrates a first use of a taxonomic name (original description). In the second and third lines of the synonymy, the colon is used to set off the taxonomic name used, with appropriate authority, from a citation of the author who used it in this way. Spell out multiple authors, rather than using 'et al.' Cite only the first page establishing the usage, but list all figures.
- If diagnosing a new, monotypic genus, with separate listings for the genus and the species, the generic diagnosis should be, "As for type and only species." The full diagnosis is then provided for the new species. An alternative is a combined description of both taxa ("gen. et sp. nov.") as in the following examples, which would require just one diagnosis.
- Richter's signs are acceptable in synonymy lists, but cite Matthews, S. C. 1973. Notes on open nomenclature and synonymy lists. Palaeontology 16:713–719, in the text.

Unranked Hierarchy

REPTILIA SQUAMATA Oppell, 1811
TEIIDAE Gray, 1827

BISCUSPIDON NUMEROSUS, gen. et sp. nov.
(Figs. 2–4)

Monophyletic Hierarchy

REPTILIA sensu Gauthier, Estes, and de Queiroz, 1988

SQUAMATA sensu Estes, de Queiroz, and Gauthier, 1988
SCLEROGLOSSA sensu Estes, de Queiroz, and Gauthier, 1988 TEIIDAE Estes, de Queiroz, and Gauthier, 1988

BISCUSPIDON NUMEROSUS, gen. et sp. nov. (Figs. 2–4)

- You may add 'sensu Author, date' if there is a particular phylogenetic definition of a traditional Linnean name. The binomen is equivalent to the genus and species for purposes of conformity with ICZN and must be italicized. Both the genus and species must be declared as new when applicable. Family-group and binomial names are regulated by the ICZN and must be correctly formed. Do not use regulated endings (-oidea, -idae, -inae, -ini, -ina) for new, unranked taxa.

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TITLE PAGE SPECIFICS

Title

- Title of the paper should be in upper and lower case (so-called Sentence capitalization), in lightface (not bold), centered for Articles, and flush left for Short Communications. The title will be used as is (in Sentence capitalization) for the Table of Contents on the back of the journal, but it will be converted by the copy editor to all upper case for use on the first page of the article within the journal.
- The name of a new taxon may appear in the title.
- Taxonomic names listed in titles and abstracts should be separated by commas. The most inclusive taxon name will go first (i.e., Mammalia, Carnivora, Canidae).
- Names of genus- or species-group taxa or equivalent must be in italics.
- Avoid titles that include a subtitle set off by a colon, that are constructed as multiple sentences, or that are excessively long. Do not end the title with a period.

Author names

- Author names are all caps and centered for Articles, but flush left for Short Communications.
- Full first names are preferred (GEORGE G. SIMPSON), but initials are acceptable (G. G. SIMPSON). Be consistent.
- Denote author address by superscript number: T. JOHN SMITH[2] (the superscript appears immediately after any punctuation (usually a comma) that follows an author's name: GEORGE G. SIMPSON,[1,‡] ALFRED S. ROMER,[*,2] and WILLIAM K. GREGORY[3]
- Clearly denote corresponding author with a superscript asterisk (see above example), and provide [*]Corresponding author as a footnote.
- For current address different from address where work was done, denote with superscript dagger and provide footnote: [‡]Current address: Department of….
- For Article—provide complete postal address and postal codes for all authors; spell out all; use upper and lower case; center; separate addresses with semicolon and new line; provide email address; omit period at end of last address

Addresses

- Use country names for all affiliations (United Kingdom, Russia, Australia); spell out name (exception: use U.S.A.).
- Spell out names of states and provinces.

Running header

- Provide a running header, all caps, containing authors' names and brief title, separated by em dash without spaces

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SPECIFICS OF CITATIONS

Citation of references in text

- For three or more authors use 'et al.', but spell out all authors if taxonomic authority (use initials if two names with same date).
- For personal communications, author must obtain written permission from the person being cited, such as signed copy of page where cited, or email quoting passage and giving permission.

- No space between year/colon and page number or figure, table, and plate designation: (Smith, 1972:16; Smith, 1974:fig. 1). Use lower case for 'fig.', 'pl.', and 'table' in citations of other people's work and in synonymies.
- Order of references cited in parentheses is, first, chronological, in order of first publication by a particular author, then alphabetical in the case of different authors with first publication in the same year: (Hibbard, 1947; Albertson, 1953; Hibbard and Taylor, 1965) (Lund, 1976, 1992, 2003; Lund and Janvier, 1986; Lund and Lund, 1986, 1987; Lund and Youngman, 1994; Lund et al., 1998, 2002).

Citation of references in text: additional examples

(Smith, 1972a, 1972b, 1972c, 1976) (Smith, 1972:16)
(Smith, 1972; Smith, Jones, and Lee, 1973; Jones and Lee, 1975) (Smith, Jones, and Lee, 1973; Smith, Lee, and Jones, 1973)
If more than three authors with same first author and same year of publication, then: (Smith, Jones, et al., 1973; Smith, Lee, et al., 1973)
(Smith, 1972:12–15, 1974)
(Smith, 1972:fig. 1, table 4)
(Smith, 1972:table 3)
...Smith's (1972) figure 3... (pers. comm., April, 2004) (unpubl.)
(Smith in Jones, 1781)

Literature cited: general rules

- Last name first only for the first author, then typical style of first-name initial, middle-name initial, then last name; note use of comma before 'and'; see above example.
- Personal communications, submitted manuscripts, manuscripts in preparation, manuscripts under review, and field notes are **not** permitted in the Literature Cited; instead, cite these in text; e.g., '(pers. comm.)' or, if it is the author's own work, '(pers. observ.)' or '(unpubl. data)'; '(field notes of G. G. Simpson,1933, AMNH).'
- All citations and taxonomic authorities, including those in the Systematic Paleontology section and figure captions, or within figures and tables, must be included in the Literature Cited. References cited only in on-line supplementary data should not be in the Literature Cited.
- Primary order is by first author and by date. Secondary sort is by number of co-authors (two-authored references, then three-authored references, then four, and so forth). Within that sort, ordering is by alphabetization of junior authors, then by date (oldest first):
  Lund, R. 1984.
  Lund, R. 1985a.
  Lund, R. 1985b.
  Lund, R., and P. Janvier. 1986.
  Lund, R., and C. Poplin. 1985.
  Lund, R., and C. Poplin. 1986.
  Lund, R., and R. Zangerl. 1984.
  Lund, R., C. Poplin, and E. Grogan. 1995.
  Lund, R., E. Grogan, C. Poplin, and R. Zangerl. 1985.

- Authors must verify that all references cited in the text (including taxonomic authorities) appear in the Literature Cited section, and that all citations in the Literature Cited section are cited in the text and/or table/figure captions.

Author styles, additional examples

- Sues, H.-D.
- Thompson, W. A., III
- Smith, L. L., Jr.
- Use commas between all authors, and separate authors' initials by a space.
- Repeat author names, as shown above with the examples of 'Lund'.
- Do not use full names, just last names and initials.

Journal Article Examples

Author, I. 2002. Article title in sentence capitalization: subtitle, if any, beginning in lower case after colon or em dash. Always Spell Out Journal Name 25:152–159. [No spaces between colon, numbers, or en dash; no comma after journal name.]

Damiani, R. 2004. Cranial anatomy and relationships of *Microposaurus casei*, a temnospondyl from the Middle Triassic of South Africa. Journal of Vertebrate Paleontology 24:533–541.

- Use issue number only if each issue begins with page one: 25(6):1–23.

- Avoid including the leading article of journal names such as: ~~The~~ Journal of Ecology.
- Use italics for genus or species in titles.
- Separate page numbers by en dash (–), not hyphen (-)

Hou, L. 2002. [A late Pleistocene lizard from Inner Mongolia]. Vertebrata PalAsiatica 50:88–95. [Chinese]
Chen, G. 1991. A new genus of Caprini (Bovidae, Artiodactyla) from upper Pliocene of Yushe, Shansi. Vertebrata PalAsiatica 29:230–239. [Chinese 230–236; English 237–239]

- The square brackets indicate that the article is solely or primarily in a non-English language, Chinese in this example.
- Some journals publish a full-text English translation following the article in its original language; if both languages are used, provide both citations.

Henkel, S., and B. Krebs. 1969. Zwei Säugetier-Unterkiefer aus der Unteren Kreide von Uña (Prov. Cuenca, Spanien). Neues Jahrbuch für Geologie und Paläontologie, Monatshefte 1969:449–463.
Geraads, D. 1994. Les gisements de mammifères du Miocène supérieur de Kemiklitepe, Turquie: 4. Rhinocerotidae. Bulletin du Muséum national d'Histoire naturelle, Paris 4 sér. 16:81-95.

- For foreign-language titles and names of institutions or journals in non-English-speaking countries, use the accents and capitalization conventions of the foreign language, as in the above examples.
- Titles and journal names presented in their original language **do not** require identification of the language in square brackets, but **do** indicate if an English abstract is available..

Books, Dissertations, and Theses

Vrba, E. S., and G. B. Schaller (eds.). 2000. Antelopes, Deer, and Relatives: Fossil Record, Behavioral Ecology, Systematics, and Conservation. Yale University Press, New Haven, Connecticut, 341 pp.
Schatzinger, R. A. 1975. Later Eocene (Uintan) lizards from the greater San Diego area, California. M.Sc. thesis, San Diego State University, San Diego, California, 212 pp.
Saysette, J. E. 1999. Postcranial estimators of body mass in pecorans with emphasis on *Capromeryx* (Mammalia: Artiodactyla). Ph.D. dissertation, Colorado State University, Fort Collins, Colorado, 192 pp.

- Book titles are title capitalized, but thesis titles are sentence capitalized.
- Spell out everything except given names, 'eds.' and 'pp.'
- Repeat the city or country if the name is a part of the publisher or university: The University of Chicago Press, Chicago, Illinois.
- Spell out cities, states, countries (except for U.S.A.): Australian Museum, Sydney, New South Wales, Australia.
- Use 'thesis' for bachelors' or masters' degrees and 'dissertation' for doctoral degrees.

Articles in Books or Large Works

Emry, R. J., P. R. Bjork, and L. S. Russell. 1987. The Chadronian, Orellan, and Whitneyan North American Land Mammal Ages; pp. 118–152 in M. O. Woodburne (ed.), Cenozoic Mammals of North America. University of California Press, Berkeley, California.
Emslie, S. D., and N. J. Czaplewski. 1999. Two new fossil eagles from the late Pliocene (late Blancan) of Florida and Arizona and their biogeographic implications; pp. 185–198 in S. L. Olson (ed.), Avian Paleontology at the Close of the 20th Century: Proceedings of the 4th International Meeting of the Society of Avian Paleontology and Evolution, Washington, D.C., 4–7 June 1996. Smithsonian Contributions to Paleobiology 89.

Volumes in Edited Series

Stahl, B. J. 1999. Chondrichthyes III: Holocephali; in H.-P. Schultze (ed.), Handbook of Paleoichthyology, Volume 4. Verlag Dr. Friedrich Pfeil, München, 164 pp.

Articles In Press

Zhang, J.-Y. In press. New fossil osteoglossomorph from Ningxia, China. Journal of Vertebrate Paleontology.

- For in-press book or article in edited book or series, see examples above.

Articles as Abstracts in Symposium or Conference Proceedings

Nydam, R. L. 2002. Advances in our understanding of the polyglyphanodontine lizards of North America. Journal of Vertebrate Paleontology 22(3, Supplement):93A.

Software, Maps, Web Sites, and Web-based Articles

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Swofford, D. A. 2003. PAUP* 4.0. Sinauer Associates, Sunderland, Massachusetts.
Izett, G. A., and J. G. Honey. 1995. Geologic map of the Irish Flats NE Quadrangle, Meade County, Kansas, U.S. 1:24,000. U. S. Geological Survey. Geological Survey Miscellaneous Investigations Series Map I- 2498.
Scotese, C. R. Plate tectonic maps and continental drift animations: Late Permian. Paleomap Project, Department of Geology, University of Texas at Arlington. Available at www.scotese.com. Accessed November 8, 2004.
Janvier, P. 1997. Craniata. Tree of Life Web Project. Available at www.tolweb.org/Craniata/14826. Accessed November 30, 2006.

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PHYLOGENETIC ANALYSES: BEST PRACTICES

RUNNING ANALYSES, REPORTING, AND PRESENTING RESULTS

Materials and methods

- Include the size of the matrix (number of characters, number of taxa)
- Include a brief description of the matrix, if it is based on another matrix, if it is new, etc.
- Include the name of the software that you used to build the matrix
- We recommend using Mesquite or MorphoBank and saving the matrix as a Nexus file (specifying the precise format), such that all characters, character states and taxa are in a single file. You must ensure consistency in these respects between the number of characters and taxa in the manuscript and in the Supplementary file.
- Check for uninformative characters
- Taxa: use only species-group taxa as terminals and avoid using genera, families, clades etc. as terminals. If a single specimen is used for scoring, indicate which one it is; in case you use one taxon as representative of a clade (e.g., for the outgroup) please indicate which taxon the scoring is based on.
- Avoid chimaeric terminals
- Do not use an hypothetical outgroup with all 0s

Phylogenetic analysis: Provide a detailed methodology of the analysis

Specify the software and version used to perform the analysis (e.g., PAUP*, TNT), what kind of search you have done (e.g., exact or heuristic search); if you carried out a heuristic search, which kind of algorithm you used (e.g., TBR, SPR), how many replicates, how many hits on the shortest tree, how many trees held per replicate; calculate branch support using Bremer (or Decay Index), bootstrap or jackknife; report if you calculate a consensus tree and what kind of consensus tree you report.

Exact searches: For matrices comprising fewer than 25 taxa.

Heuristic searches: For matrices comprising more than 25 taxa. A heuristic parsimony analysis consists of two main processes: tree building, followed by branch swapping. One round of tree building followed by branch swapping can be called a replicate.

The two most common programs PAUP* and TNT approach these two parts a little differently. Report these appropriately.

- PAUP*: A typical heuristic search strategy in PAUP* consists of numerous (e.g., 10,000) replicates consisting of building a starting tree using random addition sequence (RAS) followed by tree bisection and reconnection branch swapping (TBR) keeping all the shortest trees in each replicate (summarized as RAS+TBR)
- A typical heuristic search strategy in TNT typically consists of fewer replicates (e.g., 1,000) of building a starting tree (Wagner tree) using RAS, but holding only a few of the shortest trees per replicate. Once all the replicates are done additional rounds of TBR are needed (swapping on the trees in RAM) to find the final set of most parsimonious trees. If this is not done your analysis will undersample the set of most parsimonious trees. [summarized as ((RAS + TBR) + TBR)]

Additionally for parsimony analysis,

- Are there characters with ordered/additive character states? If yes, which ones? Include the ordering in the nexus file.
- Do the characters have the same weight? If not, explain why.
- If implied weights have been used, specify how the k value was calculated (Maximum parsimony specific)
- If constraints have been used, specify the methodology and from which paper you took the topology (if applicable) and include the constraints, preferably in the Nexus file.
- If a script is used in the phylogenetic analysis be sure that it is available in a published paper. If it is a new script, it should be uploaded as supplementary material. The results of the script should be also added as supplementary

material (see below).

Bayesian inference analyses:

Specify the software and version used to perform the analysis (e.g., MrBayes, RevBayes, BEAST). Specify the model used (e.g., the Markov k-state variable model: Mkv) and whether a gamma rate variation parameter was used (recommended). Was your data partitioned? How long did you run your MCMC chain? How was convergence assessed (split frequency cut-off value? ESS value?). What kind of summary tree are you presenting? Report the posterior probabilities on the summary tree. If more complex models are used (as in BEAST) be sure to provide details on all the model specifications and priors used. In the case of RevBayes, for more complex models please consider providing as supplementary information an image of the graphical model.

Results

Maximum parsimony—report:

- Length of the tree/s, consistency index (CI), retention index RI (rescaled consistency index, RCI, is not required). Homoplasy index should not be reported: it is 1-CI.
- Number of most parsimonious trees (MPTs)
- If a consensus tree was calculated, which kind of consensus is it?
- Support values for all nodes (preferably on the figure)
- When referring to synapomorphies please report unambiguous, common synapomorphies (common to both ACCTRAN and DELTRAN optimizations); otherwise please specify.

MAKING YOUR DATA AND ANALYSIS METADATA AVAILABLE

Parsimony Analysis

Supplementary material should include the following files.

- **Full** matrix in .nex or .tnt format (without the trees) [mandatory; do not just provide added/modified taxa/characters)]
- README file including all the steps needed to replicate the primary phylogenetic analysis and any sensitivity or secondary analyses that were conducted [mandatory].
- Detailed information on the character/taxon sampling (description of characters; changes from previous matrices; specimens used to score; relevant literature; figures of character states; photographs of specimens) [optional]
- Sets of MPTs for all analyses in .tre or .ctf format [mandatory]
- List of common synapomorphies in .pdf or .txt format [optional]
- In case of constrained analysis the tree used to constrain and which nodes were constrained [mandatory]
- If scripts were used please provide the results of the scripts in a single .pdf or .docx file [optional]

Bayesian Analysis

Please provide as Supplementary Material all files used to perform analyses. In the case of MrBayes, best practice is to embed commands within the included nexus file.

Appendix

Matrices printed as an Appendix are not longer accepted, instead provide the .nex or .tnt file as Supplementary Material (see above)

We strongly urge authors to upload their matrices, results, and any other relevant files to MorphoBank.

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ANEXO II - COMPROVANTE DE SUBMISSÃO DO ARTIGO

Journal of Vertebrate Paleontology

Home

Author

Review

Submission Confirmation

Print

Thank you for your submission

Submitted to	Journal of Vertebrate Paleontology
Manuscript ID	JVP-2019-0069
Title	Dental deformities in shark fossils from the Calumbi formation (Upper Cretaceous), Sergipe-Alagoas basin, and possible associated causes
Authors	Silva, Tatiana Liparini, Alexandre
Date Submitted	18-May-2019

Author Dashboard