UNIVERSIDADE ESTADUAL PAULISTA
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Campus de Rio Claro

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BIVALVES DA FORMAÇÃO TACIBA, CISURALIANO, GRUPO ITARARÉ, BACIA DO PARANÁ, E SEU SIGNIFICADO BIOESTRATIGRÁFICO E PALEOAMBIENTAL NO CONTEXTO DA GLACIAÇÃO NEOPALEOZOICA NO GONDWANA CENTRAL

Tese de Doutorado elaborada junto ao curso de Pós-Graduação em Geociências - Área de concentração em Geologia Regional para obtenção de título de Doutor em Geociências.

Orientador: Prof. Dr. Marcello Guimarães Simões

Rio Claro - SP
2013

551.7 N518b

Neves, Jacqueline Peixoto
Bivalves da Formação Taciba, Cisuraliano, Grupo Itararé, Bacia do Paraná, e seu significado bioestratigráfico e paleoambiental no contexto da glaciação neopaleozóica no Gondwana central / Jacqueline Peixoto Neves. - Rio Claro, 2013
195 f. : il., figs., tabs., quadros, fots., mapas

Tese (doutorado) - Universidade Estadual Paulista, Instituto de Geociências e Ciências Exatas
Orientador: Marcello Guimarães Simões

1. Geologia estratigráfica. 2. Bioestratigrafia. 3. Bivalvia. I. Título.

Ficha Catalográfica elaborada pela STATI - Biblioteca da UNESP
Campus de Rio Claro/SP

AGRADECIMENTOS

Gostaria de agradecer a diversas pessoas que contribuíram de forma direta para a construção desta tese de doutoramento:

Ao meu orientador, Prof. Dr. Marcello Guimarães Simões, que muito me ensinou, não apenas em relação ao tema da presente tese, mas também no se fazer ciência com comprometimento e maturidade. Agradeço pela orientação quase que diária e por ter sido solícito sempre que precisei sanar minhas dúvidas. Agradeço também pelas oportunidades que me proporcionou, em diversos aspectos, ao longo dos anos de convívio.

Ao Prof. Dr. Luiz Eduardo Anelli, por sua contribuição em grande parte da pesquisa apresentada nesta tese, com especial atenção às análises taxonônicas do material estudado. Agradeço, pelas diversas vezes que me recebeu em São Paulo e por aquelas em que esteve em Botucatu, me auxiliando neste trabalho. Agradeço também por suas considerações e sugestões apresentadas, como membro da comissão examinadora de meu Exame Geral de Qualificação.

Ao Instituto de Geociências e Ciências Exatas da Universidade Estadual Paulista/*campus* Rio Claro, por tornar viável a concretização da presente tese.

Ao Laboratório de Paleozoologia Evolutiva, Departamento de Zoologia, Instituto de Biociências da Universidade Estadual Paulista/*campus* Botucatu, agradeço pela estrutura e instalações onde a pesquisa foi desenvolvida e também pela possibilidade de estudo do material pertencente à coleção científica desta Instituição.

Ao Instituto de Geociências da Univerdidade de São Paulo, em especial à Profa. Dra. Juliana de Moraes Leme Basso, prof. Dr. Luiz Eduardo Anelli e prof. Dr. Thomas Fairchild, pelo consentimento do empréstimo do material estudado, pertencente à coleção científica deste Instituto.

Ao Dr. Neil Landman, curador da coleção científica de Paleontologia de Invertebrados do American Museum of Natural History, New York, por consentir a consulta às amostras do material do Peru, que tanto contribuíram para gerar os resultados aqui apresentados. Bem como agradeço a Bushra Hussaini, assistente científica sênior da mesma instituição, pela extrema delicadeza com que me recebeu nesta oportunidade.

À Prof. Dra. Beatriz Aguirre-Urreta, curadora da coleção científica de Paleontologia do Departamento de Geologia da Universidade de Buenos Aires, por permitir a consulta do material da Formação Bonete, o qual forneceu essencial embasamento para as propostas aqui apresentadas. Agradeço também a Marian Tanuz, técnica desta coleção científica, por sua eficiência e disponibilidade em ajudar. Ainda agradeço ao Prof. Dr. Dario G. Lazo, pelo auxílio laboratorial fornecido durante minha estada nesta instituição.

Ao Prof. Dr. Luiz Carlos Weinschültz, por todo o auxílio no trabalho de campo na região de Mafra, SC, e por permitir o empréstimo do material proveniente da coleção científica do Cenpaleo, o qual foi muito importante para a construção dos resultados desta pesquisa.

Ao Prof. Dr. Joel Carneiro de Castro, por nos acompanhar em um dos trabalhos de campo nas localidades estudadas e também por estabelecer nosso contato com o Cenpaleo.

À Profa. Dra. Rosemarie Rohn Davies, por suas considerações e sugestões apresentadas, enquanto membro da comissão examinadora de meu Exame Geral de Qualificação.

Ao Prof. Dr. Norberto Morales, por ser solícito em diversos momentos que o procurei durante o desenvolvimento deste trabalho.

Ao Prof. Dr. Luiz Eduardo Anelli e Suzana Matos da Silva pela colocaboração em todos os trabalhos de campo. Bem como aos colegas: Juliana David, João Bondioli, Heitor Sartorelli e Filipe Santos pelo auxílio em situações que envolveram este trabalho.

À Rosângela, secretária da Pós-graduação do IGCE/UNESP, pela disposição em ajudar sempre que precisei. À Ivone Cardoso Gonzales e Marcelha Paes Landim por todo o auxílio durante as consultas ao material pertencente à coleção científica do IGc/USP.

À Juliana Ramos, Silvio César de Almeida, Hamilton Antonio Rodrigues, Flávio da Silva e Carolina Schultz Lopes, técnicos do Departamento de Zoologia, IBB-UNESP, onde a presente pesquisa foi desenvolvida, pelo auxílio geral em diversas oportunidades.

À Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), agência financiadora da presente pesquisa, obrigada.

Agradeço ainda às pessoas, não menos importantes, que indiretamente contribuíram para a construção da presente tese:

Érik Januário da Silva, pelo apoio incondicional do início ao final de meu doutoramento, pela confiança que me transmitiu em todos os momentos que precisei e pelas conversas diárias relacionadas ao desenvolvimento deste trabalho.

Meus queridos pais, irmãos e sobrinhos por sempre me incentivarem a seguir em busca de meus objetivos.

Bruna Fernandes Malta, a amiga de sempre, que me ouviu e aconselhou em diversos momentos desta etapa.

Aos meus sogros, que estiveram presente durante todo este processo, sempre solícitos em ajudar.

"The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when one contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day. Never lose a holy curiosity."

Albert Einstein

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RESUMO

Na região de Teixeira Soares, Estado do Paraná, a porção superior da Formação Taciba (~60m), Grupo Itararé, é dominada por conglomerados matriz-suportados, maciços a laminados, representando diamictitos polimíticos ressedimentados. Este é sucedido por arenitos finos a médios, com estratificação cruzada tabular e pavimentos de conchas, interpretados como depósitos litorâneos. Acima, ocorrem siltitos laminados e intensamente bioturbados com conchas articuladas, provavelmente depositadas em ambientes de plataforma interna. Para o topo, arenitos finos a muito finos/siltitos com estratificações cruzada de baixo ângulo e *hummocky*, e argilitos intercalados, incluindo conchas *in situ*, são interpretadas como tempestitos amalgamados de plataforma interna distal. Finalmente, siltitos maciços a laminados/argilitos ou folhelhos cinza escuro são inferidos como depósitos de plataforma externa (Folhelho Passinho), o qual é sucedido por sedimentos flúvio-deltáicos da Formação Rio Bonito. Esta sucessão de granodecrescência ascendente não apresenta clastos-caídos, e está associada à transgressão pós-glacial do Paleozoico Superior. Seis assembleias de bivalves foram reconhecidas, refletindo mudanças nos parâmetros paleoambientais. Dezenove espécies foram identificadas, incluindo quatro novas. *Myonia argentinensis*, *Atomodesma* (*Aphanaia*) *orbirugata* e *Heteropecten paranaensis* indicaram correlação com as assembleias da Formação Bonete, Bacia Sauce Grande, Argentina, sugerindo idade asseliana–sakmariana. Membros típicos das biotas de ambientes marinhos frios, como *Eurydesma–Trigonotreta*, não foram registrados.

Palavras-chave: Bacia do Paraná, Grupo Itararé, Formação Taciba, Bioestratigrafia, Bivalvia.

ABSTRACT

At the Teixeira Soares County, Paraná State, the uppermost portion of the Taciba Formation (~60 m thick), Itararé Group, is dominated by massive to laminated, matrix-supported conglomerates, representing re-sedimented polymitic diamictites. This is succceded by fine to medium-grained sandstone with tabular cross stratification and shell pavements, interpreted as nearshore deposits. Above, laminated and intensely bioturbated siltstones with articulated shells, probably deposited in inner shelf settings occur. To the top, amalgamated, fine to very fine sandstone/siltstone with low-angle cross-stratification or hummocky cross-stratification and intercalated mudstones, including *in situ* shells, are interpreted as stacked storm deposits, in distal shoreface environments. Finally, massive to laminated siltstone/mudstone or gray shales are inferred as outer shelf deposits (Passinho shale), which are capped by fluvio-deltaic sediments of the Rio Bonito Formation. This finning upwards succession characteristically lacks any dropstones or ice-rafted debris, and is associated to the Late Paleozoic post-glacial transgression. Six distinct, bivalve-rich assemblages were identified, reflecting changes in paleoenvironmental parameters. Ninteen species were described, including four new. *Myonia argentinensis*, *Atomodesma* (*Aphanaia*) *orbirugata* and *Heteropecten paranaensis* indicate correlation with assemblages of the Bonete Formation, Sauce Grande Basin, Argentina, indicating a possible Late Asselian–Sakmarian age. Members of the icehouse-style *Eurydesma–Trigonotreta* biota are lacking.

Keywords: Paraná Basin, Itararé Group, Taciba Formation, Biostratigraphy, Bivalvia.

APRESENTAÇÃO

Este documento contém os dados relativos à tese de doutoramento apresentada pela candidata Jacqueline Peixoto Neves (IGCE/UNESP) e seu orientador Prof. Dr. Marcello Guimarães Simões, intitulada ***"Bivalves da Formação Taciba, Cisuraliano, Grupo Itararé, Bacia do Paraná, e seu significado bioestratigráfico e paleoambiental no contexto da glaciação neopaleozoica no Gondwana Central".*** A organização do documento seguiu as *"Normas para organização de teses de Doutorado na forma de artigos"*, estabelecida pelo Programa de Pós-graduação em Geologia Regional, do Instituto de Geociências e Ciências Exatas (IGCE/UNESP, *campus* Rio Claro).

A primeira parte deste documento apresenta a introdução ao tema abordado, isto é, o projeto de pesquisa que motivou a tese, contendo os objetivos e o estado da arte do tema proposto, bem como a descrição dos materiais e métodos empregados e o contexto geológico da presente pesquisa de doutoramento. A segunda parte, o corpo principal da tese, contém dois artigos submetidos a periódicos internacionais de impacto na área de inserção da tese, tratando de distintos aspectos da composição taxonômica, biocorrelação e significado paleoclimático e paleogeográfico das assembleias de bivalves encontradas na porção superior do Grupo Itararé, no Estado do Paraná e Santa Catarina. Os artigos científicos seguem como dois capítulos da tese, conforme recomendado pelas normas acima mencionadas. O primeiro artigo é o de maior volume e abrangência, abordando a revisão e descrição taxonômica das assembleias de bivalves que ocorrem na porção superior da Formação Taciba , na região de Teixeira Soares, PR. É apresentada a descrição e revisão das assembleias fossilíferas e dos litótipos da parte superior da Formação Taciba, na região de estudo, bem como é discutida sua biocorrelação com outras assembleias marinhas, do Paleozoico Superior da América do Sul, em especial da Formação Bonete, Bacia Sauce Grande, Argentina. Esse artigo foi submetido ao periódico "*Journal of South American Earth Sciences*" (JCR, 2013, 1.744), Elsevier. O segundo artigo científico, trata da revisão sistemática de alguns pectinídeos da América do Sul, com foco especial para espécies dos gêneros *Aviculopecten* M'Coy, 1851, e *Heteropecten* Kegel & Costa, 1951, ocorrentes na Formação Taciba e na Formação Cerro Prieto, Montanhas Amotape, Peru. Além das questões taxonômicas, são discutidas as implicações bioestratigráficas e paleogeográficas dos dados obtidos. Tal artigo científico foi submetido ao periódico "Alcheringa" (JCR, 2010, 1.578). Ambos os artigos são acompanhados de cartas de submissão dos respectivos editores. Em seguida, nas considerações finais, são apresentadas as principais conclusões relativas aos aspectos bioestratigráficos, paleoecológicos e paleoambientais, além de comentários sobre os desafios e problemas para estudo futuro. Na sequencia são listadas as referências bibliográficas e, por fim, no item Anexo é apresentado outro artigo científico, relacionado ao tema central da tese, versando sobre a correlação bioestratigráfica das assembleias marinhas da Formação Taciba, provenientes da pedreira Butiá, Mafra, SC, com a fauna da região de Teixera Soares, PR. Este artigo já se encontra publicado no "*Boletim do Instituto de Geociências da USP, Série Científica*".

1. INTRODUÇÃO

Em contraste com a abundante informação tafonômica, taxonômica e paleoecológica disponível para os bivalves fósseis do Grupo Passa Dois (Cisuraliano–Lopingiano, HOLZ *et al.*, 2010), na Bacia do Paraná, o conhecimento científico sobre as faunas de invertebrados da parte superior do Grupo Itararé (Pensilvaniano–Cisuraliano, HOLZ *et al.*, 2010) é ainda escasso, estando completamente desatualizado, frente aos enormes avanços ocorridos nos últimos 20 anos com relação às assembleias coevas da América do Sul, especialmente da Argentina (GONZÁLEZ, 2002a, b, 2006; PAGANI, 2000, 2004a ,b, 2005, 2006a, b; STERREN, 2000, 2003, 2004, 2005; GONZÁLEZ & DÍAZ SARAVIA, 2010; PAGANI & SABATTINI, 2002; CISTERNA & STERREN, 2010, 2011; PAGANI & TABOADA, 2010; STERREN & CISTERNA, 2010; TABOADA, 2010; TABOADA & PAGANI, 2010; PAGANI & FERRARI, 2011) e com relação à sistemática de Bivalvia (BIELER *et al.*, 2010; CARTER *et al.*, 2011). O avanço também procede em relação à estratigrafia, bioestratigrafia e geocronologia das unidades litoestratigráficas do Grupo Itararé, na borda leste da Bacia do Paraná (vide síntese em HOLZ *et al.*, 2010; MORI *et al.*, 2012). De fato, a partir do exame da literatura prévia (veja sínteses em SIMÕES, 1992; SIMÕES *et al.*, 1998a) verifica-se ser ainda imprecisa, por exemplo, a situação taxonômica e posicionamente estratigráfico das assembleias (*sensu* KIDWELL *et al.*, 1986) marinhas de bivalves da porção superior da Formação Taciba, Permiano Inferior, que ocorrem em sucessão estratigráfica nos chamados "arenito Rio d'Areia", "siltito Baitaca" e "folhelho Passinho", na região de Teixeira Soares, PR (SIMÕES *et al.*, 1998a; SIMÕES, 2000). Essas assembleias faunísticas são as mais diversificadas do Grupo Itararé e estão relacionadas à transgressão pós-glacial que precedeu à deposição da Formação Rio Bonito

(Artinskiano). Embora listas faunísticas referentes a essas assembleias circulem na literatura, desde Rocha-Campos (1969, 1970), os fósseis correspondentes permanecem ainda não formalmente descritos e ilustrados. Correlações preliminares (ROCHA-CAMPOS, 1969, 1970; ROCHA-CAMPOS & RÖSLER, 1978), com base nessas faunas, entretanto, têm implicações não apenas quanto à cronologia do Grupo Itararé (vide dados recentes em HOLZ *et al.*, 2010), referentes à idade dessa sucessão sedimentar e das rochas glaciais e pós-glaciais associadas, bem como no que tange ao entendimento da evolução paleogeográfica da Bacia do Paraná, em particular à correlação entre os eventos eustáticos e transgressivos associados aos ciclos glaciais do Paleozóico Superior (vide LIMARINO, *in press*). Por exemplo, pode-se mencionar a afinidade apontada por Rocha-Campos (1969, 1970), Rocha-Campos & Rösler (1978) e Pagani (2000), entre elementos das assembleias da parte superior do Grupo Itararé [*Myonia* ou (? *Vacunella* sp.)] e espécies da fauna de *Eurydesma*, encontrada na Formação Bonete, Sierras Australes, Provincia de Buenos Aires, Argentina (HARRINGTON, 1955; ROCHA-CAMPOS & CARVALHO, 1975; PAGANI, 2000; SIMÕES *et al.*, 2012, em anexo). *Eurydesma*, entretanto, não foi ainda registrada na Bacia do Paraná (vide SIMÕES *et al.*, 1998a, 2012).

1.1. DELIMITANDO O PROBLEMA

Rocha-Campos (1969) revisou as faunas de invertebrados marinhos do “arenito Rio d’Areia”, “siltito Baitaca” e “folhelho Passinho” (ALMEIDA, 1945; BEURLEN, 1955), da parte superior do Grupo Itararé, na região de Teixeira Soares. Os resultados dessas investigações (ROCHA-CAMPOS, 1969) demonstraram que as assembleias eram relativamente mais diversificadas, em comparação com as de outras intercalações marinhas do Itararé (ROCHA-CAMPOS, 1967; ROCHA-CAMPOS & RÖSLER, 1978), incluindo bivalves, gastrópodes e braquiópodes, que se associam a insetos e euripterídeos (PETRI & SOUZA, 1993).

Segundo a lista taxonômica de Rocha-Campos (1970), vários dos elementos presentes nas assembleias de Teixeira Soares mostraram afinidades com espécies do Paleozoico Superior de outras áreas gondvânicas, particularmente às da Formação Bonete, Permiano, (HARRINGTON, 1955; ROCHA-CAMPOS & CARVALHO, 1975; PAGANI, 2000; SIMÕES *et al.*, 2012); do leste da Austrália (DICKINS, 1963; RUNNEGAR, 1967) e da Formação Cerro Prieto (Pensilvaniano médio), nas Montanhas Amotapes do Peru (ROCHA-CAMPOS, 1969, 1970). Embora Rocha-

Campos (1969) tivesse notado a importância desta fauna, no conjunto de assembleias da sucessão Itararé, da Bacia do Paraná, e no quadro das assembleias marinhas do Paleozoico Superior do Gondwana (ROCHA-CAMPOS & RÖSLER, 1978), a publicação dos resultados, maiormente relacionados à sistemática e descrição da fauna permaneceu em segundo plano, devido às incertezas quanto ao posicionamento estratigráfico das ocorrências fossilíferas de Teixeira Soares, PR, na coluna local do Supergrupo Tubarão (ROCHA-CAMPOS informação verbal, 1990). Entretanto, alguns autores, tais como Almeida (1945), Maack (1946) e Beurlen (1955), notaram que o "arenito Rio d'Areia", "siltito Baitaca" e "folhelho Passinho" correspondiam, localmente, à porção superior da coluna sedimentar do Grupo Itararé parananense, fato amplamente confirmado em Mineropar (2007).

No contexto das questões estratigráficas acima, Simões *et al.* (1998a) sugeriram que as diferenças na composição faunística das três litofacies fossilíferas de Teixeira Soares provavelmente refletiam condições paleoecológicas distintas, mais do que diferenças temporais, possibilidade já aventada em Rocha-Campos (1969, p. 14). Essas observações têm profundas implicações na bioestratigrafia, bem como no entendimento das mudanças ambientais que ocorreram, concomitantemente, ao evento de deglaciação ao final da glaciação do Paleozoico Superior, na Bacia do Paraná.

Assim sendo, o exame da literatura prévia revela haver algumas controvérsias quanto: as relações estratigráficas mútuas entre as três litofacies fossilíferas da porção superior do Grupo Itararé, aflorantes na área de Teixeira Soares; os sedimentos glaciais da área (CANUTO, 1985) e o posicionamento das assembleias fósseis no contexto da sucessão Itararé. Almeida (1945) correlacionou todas as ocorrências fossilíferas da área de Teixeira Soares ao último episódio interglacial do Paleozoico Superior. Entretanto, outros estudos (MAACK, 1946, p. 41; MINEROPAR, 2007) discordaram, observando que não há indícios de sedimentação glacial, acima dos diamictitos que constituem, localmente, a base da Formação Taciba, em Teixiera Soares, PR.

Os problemas estratigráficos discutidos acima, e a correlação da fauna do Grupo Itararé, sugerida anteriormente, por Rocha-Campos (1969, 1970) e Rocha-Campos & Rösler (1978), têm implicações do ponto de vista geocronológico e bioestratigráfico, referentes à idade desta seqüência sedimentar, dos sedimentos de origem glacial que a contêm, e no que tange ao entendimento da paleogeografia da Bacia do Paraná (Fig. 1), durante o Paleozoico Superior (vide LIMARINO *et al.*, *in press*). A possível correlação entre as assembleias de Teixeira Soares e as da Formação Bonete, Bacia de Sauce

Grande (Fig. 1), da Argentina (vide PAGANI, 2000; SIMÕES *et al.*, 2012), sugere uma idade asseliana superior–artinskiana para a transgressão pós-glacial (folhelho Passinho), na Bacia do Paraná, o que estaria de acordo com as idades sugeridas para essa porção da sucessão sedimentar permiana da Bacia do Paraná (HOLZ *et al.*, 2010; MORI *et al.*, 2012; SIMAS *et al.*, 2012). Por outro lado, segundo as listas taxonômicas que circularam na literatura (ROCHA-CAMPOS, 1970; ROCHA-CAMPOS & RÖSLER, 1978), na assembleia de Teixeira Soares, estariam presentes espécies comuns à região andina, peruano-boliviana, do Grupo Tarma, Carbonífero. Da mesma forma que Frakes & Crowell (1968), Rocha-Campos (1970) admitiu uma possível conexão entre essas regiões, através da porção sul do escudo Pré-cambriano. Este ponto de vista foi, entretanto, contestado por Loczy (1970) e Helwig (1972), já que o arco Pré-cambriano que se estendia de Cuiabá, Brasil, a Assunção, Paraguai, teria separado a Bacia do Paraná da Pré-cordilheira andina, no Paleozoico. Nesse contexto, González (1989) com base em dados de subsuperfície, comenta que "*el Cratógeno Central habia estado unido al escudo mediante uma prolongación del Arco Pampeana*", sendo possível, portanto, a conexão daquelas áreas. Obviamente, esse é um problema complexo, envolvendo não apenas aspectos paleontológicos, mas também de geologia regional e estrutural, do continente sul-americano. Contudo, parte desta controvérsia poderia ser solucionada através da revisão taxonômica das assembleias de bivalves de Teixeira Soares e do material da Formação Cerro Prieto (NEWELL *et al.*, 1953), Montanhas Amotapes, Peru.

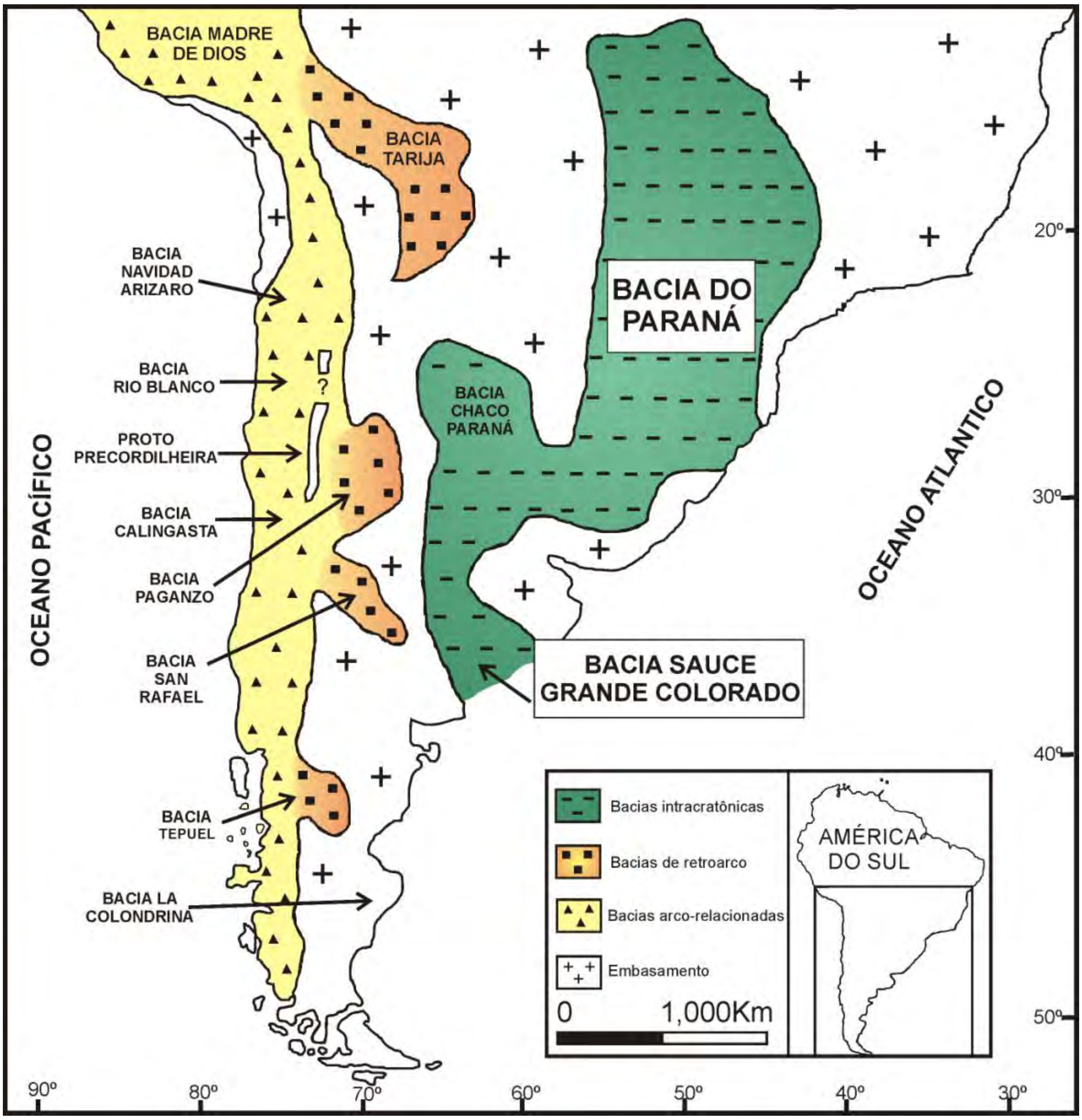

Figura 1– Mapa das principais bacias gondwâncias, da América do Sul, no Paleozóico Superior. Em verde, destacam-se as bacias intracratônicas do Paraná, Brasil, e de Sauce Grande Colorado, na Argentina, das quais provém a maior parte dos fósseis estudados. Modificado de Limarino & Spalletti (2006), (Figuras semelhantes são apresentadas nos artigos do capítulo 1 e anexo).

Em 1992, M.G. Simões chamou a atenção para o fato de o conhecimento taxonômico da fauna ser ainda incipiente e limitado ao estudo de coleções obtidas há muitos anos, pertencentes ao Departamento Nacional da Produção Mineral e o então Departamento de Paleontologia e Estratigrafia (atual GSA), do IGc-USP. Em 1993, esse pesquisador liderou, no âmbito do Projeto FAPESP (93/2747-0), uma prospecção paleontológica na região de Teixeira Soares, PR, onde foram novamente relocalizadas as ocorrências fossilíferas descritas em Almeida (1945) e Maack (1946). De grande importância foi à descoberta, no “siltito Baitaca”, de horizontes fossilíferos relacionados a eventos de tempestades (*obrution deposits*), onde os bivalves estão preservados em posição de vida (*in situ*) (ANELLI *et al.*, 1998; SIMÕES *et al.*, 1998a), abrindo a oportunidade para análises tafonômicas de detalhe, especialmente no âmbito da estratigrafia de eventos (vide HOLZ & SIMÕES, 2005). Por diversas razões, entretanto, M.G. Simões e seus colaboradores (Prof. Rocha-Campos, Prof. Anelli, IGc/USP) não puderam dar prosseguimento ao estudo desse material, o qual permaneceu depositado na coleção de Paleontologia do Departamento de Zoologia do IBB/UNESP e no Instituto de Geociências/USP.

Conforme anteriormente mencionado, em decorrência dos enormes avanços ocorridos nos últimos 10 anos, com relação à sistemática e evolução dos bivalves permianos da América do Sul, a estratigrafia da Bacia do Paraná e de outras regiões gondvânicas, o estudo das faunas da parte superior da Formação Taciba, tanto do Paraná, como as de Santa Catarina, foram retomados.

Tendo em vista os problemas até aqui discutidos, a presente tese de doutoramento tem por objetivo geral responder a seguinte pergunta: O que representam, em termos bioestratigráficos, paleogeográficos e paleoclimáticos, as assembleias da porção superior do Grupo Itararé, da região de Teixeira Soares, PR, em especial no contexto da grande glaciação do Paleozoico Superior (Late Paleozoic Ice Age, LPIA)? Neste contexto, esta tese está fundamentada na hipótese de que as litofácies fossilíferas marinhas, informalmente chamadas de “arenito Rio d’Areia”, “siltito Baitaca” e “folhelho Passinho”, da porção superior da Formação Taciba de Teixeira Soares, PR, materializam distintas condições paleoambientais, especialmente batimétricas, de tipo de fundo e oxigenação, mais do que diferenças geocronológicas. Fundamentada neste pressuposto, a pesquisa desenvolvida procurou subsídios para esclarecer os problemas que ainda persistiam relacionados à sistemática, paleoecologia e bioestratigrafia daquelas assembleias fósseis, tendo em conta seu potencial para biocorrelação, paleogeografia e paleoclimatologia. Para cumprir essa meta, os seguintes objetivos específicos foram traçados:

a- revisar a posição estratigráfica das ocorrências fossilíferas da porção superior do Grupo Itararé, na região de Teixeira Soares, PR, e suas relações mútuas com outras litofacies na área de estudo;

b- descrever e revisar a sistemática dos bivalves da assembleia da porção superior da Formação Taciba de Teixeira Soares, PR;

c- descrever a sistemática dos bivalves da assembleia da porção superior da Formação Taciba de Mafra, SC, (antiga pedreira Butiá);

d- estabelecer o significado bioestratigráfico e discutir as afinidades das assembleias de bivalves da parte superior da Formação Taciba, no âmbito das faunas de invertebrados do Paleozoico Superior da América do Sul, bem como suas implicações paleogeográficas e paleoclimáticas;

e- examinar a fauna de bivalves da Formação Cerro Prieto, Carbonífero, Montanhas Amotapes, Peru, pertencente ao American Museum of Natural History; revisar a espécie *Aviculopecten multicalptus* Thomas, e aventar suas afinidades e idade, no contexto dos domínios paleobiogeográficos do Gondwana e,

f- examinar a fauna de bivalves da Formação Bonete, Sierras Australes, Argentina, pertencente à Universidad de Buenos Aires, afim de verificar a possível afinidade taxonômica de elementos desta, com aqueles das assembleias marinhas da Formação Taciba de Teixeira Soares, PR.

1.2. MATERIAIS E MÉTODOS

1.2.1. Geologia da Área de Estudo

Os macroinvertebrados fósseis marinhos aqui investigados ocorrem na sucessão sedimentar do Grupo Itararé (Baskiriano–Sakmariano), incluída na Supersequencia Gondwana 1 (MILANI *et al.*, 2007), da Bacia do Paraná. Esta sucessão, cujas rochas afloram nas bordas sudeste e noroeste da bacia está, em grande parte, vinculada à glaciação do Paleozoico Superior do Gondwana (vide ROCHA-CAMPOS, 1967; EYLES *et al.*, 1993; SANTOS, 1987; SANTOS *et al.*, 1996; LIMARINO *et al.*, *in press*), tendo sua correlação com outros depósitos glaciogênicos gondvânicos apontada, inicialmente, por Derby (1878). A sucessão Itararé compreende espesso pacote sedimentar (~1.500 m), abrangendo litótipos e associações de fácies predominantemente clásticas, tais como conglomerados, arenitos, diamictitos, ritmitos, argilitos, folhelhos e camadas de carvão subordinadas (ROCHA-CAMPOS, 1967; SANTOS, 1987; MILANI *et al.* 2007; HOLZ *et al.*, 2010). Conforme desmonstrado por Holz *et al.* (2010), essa sucessão materializa duas sequencias deposicionais de terceira ordem, a primeira (LPTS-1), equivalente à Formação Lagoa Azul (FRANÇA & POTTER, 1988) e, a segunda (LPTS-2), abrangendo as formações Campo Mourão e Taciba (FRANÇA & POTTER, 1988) (Fig. 2). O limite entre as sequencias LPTS-1 e LPTS-2 coicide com a transição entre duas biozonas de palinomorfos (*i.e.*, Zona de Intervalo de *Ahrensisporites cristatus* e Zona de Intervalo de *Crucisaccites monoletus*), registrando pronunciada queda no nível de base da bacia (HOLZ *et al.*, 2010), para a margem leste da bacia.

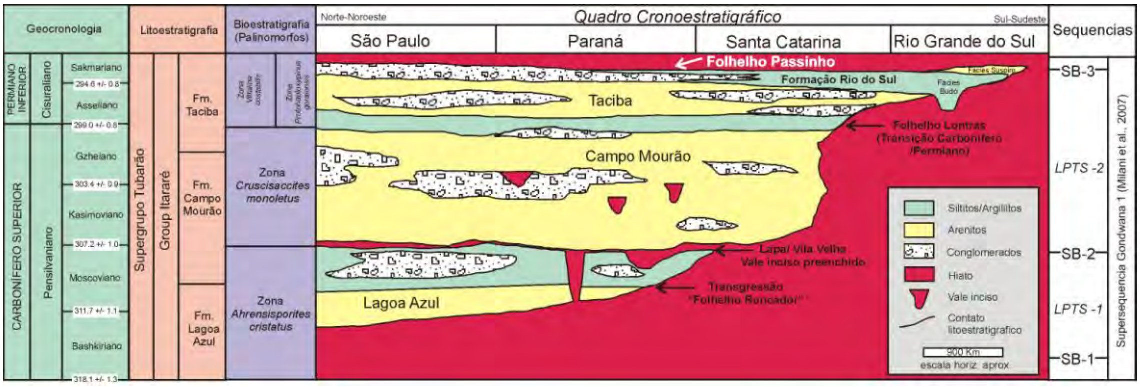

Figura 2– Quadro cronoestratigráfico do Grupo Itararé, Bacia do Paraná, Brasil. Na parte superior da sucessão estratigráfica o folhelho Passinho (seta) corrresponde à superfície de inundação marinha, referente à porção superior das formações Taciba e Rio do Sul (modificado de HOLZ *et al.*, 2010). (Figuras semelhantes são apresentadas nos artigos dos capítulos 1 e 2).

A despeito da notória dificuldade de subdivisão da sucessão Itararé em quase toda a faixa aflorante da Bacia do Paraná, e a integração e homogeneização da nomenclatura concebida para superfície e subsuperfície (Fig. 3) na área de estudo, abrangida pela Folha Ponta Grossa (1:100.000, Mineropar, 2007), Estado do Paraná, o pacote sedimentar pode ser subdivido e correlacionado às unidades de França & Potter (1988), abrangendo as formações Lagoa Azul, Campo Mourão e Taciba (MINEROPAR, 2007) (Fig. 3). Neste amplo contexto, as assembleias fósseis estudadas provêm da porção superior do Grupo Itararé, do município de Teixeira Soares, situado no quilômetro 325,5 da Rede de Viação Paraná-Santa Catarina (25°22’30’’S/50°27’48’’W), junto ao espigão que divide as águas do rio Imbituva das de seu afluente o rio das Almas (Fig. 4). Nesta área, afloram apenas os sedimentos referíveis à Formação Taciba (vide também MINEROPAR, 2007). De especial interesse são os litótipos desta unidade situados acima dos diamictitos, pois apresentam características muito distintas, com os níveis fossilíferos contendo assembleias de bivalves e braquiópodes, cuja diversidade não encontra paralelo em outras ocorrências da sucessão Itararé, na Bacia do Paraná (vide SIMÕES *et al.*, 1998a).

Os litótipos estudados estão representados, em sucessão estratigráfica por arenitos, siltitos e folhelhos, estes últimos, em contato com a Formação Rio Bonito (ALMEIDA, 1945; MAACK, 1946; SIMOES *et al.*, 1998a; MINEROPAR, 2007). Este conjunto peculiar de estratos foi anteriormente referido como Formação Teixeira

Soares, por Almeida (1945) e Lange (1954) ou mesmo Formação Passinho, por Loczy (1964). Entretanto, adotando o esquema de França & Potter (1988) (Fig. 3A), a unidade Teixeira Soares, com os membros "arenito Rio d'Areia", "siltito Baitaca" e "folhelho Passinho" (*sensu* LANGE, 1954), estaria contida na porção superior da Formação Taciba (vide MINEROPAR, 2007) (Fig. 3C).

Dentre as exposições de rochas da região de Teixeira Soares, PR, as observadas ao longo do perfil dos afloramentos rio d'Areia–córrego Baitaca, em parte apresentado na figura 5, se constituem nas mais representativas do topo do Grupo Itararé na área de estudo, destacando-se três, as quais são descritas mais adiante. Essas localidades são as mesmas estudadas por Oliveira (1930), Lange (1944), Almeida (1945), Maack (1946), Beurlen (1955), Simões *et al.* (1998a), Anelli *et al.* (1998) e Mineropar (2007). Porém, uma importante dificuldade para se trabalhar nesta região refere-se ao fato das rochas estarem profundamente intemperizadas e os afloramentos muito encobertos (Fig. 6). De fato, as questões relativas ao intemperismo e a falta de bons afloramentos na região de Teixeira Soares aparecem na literatura desde Lange (1944, p. 137), incluindo-se também Almeida (1945) e Beurlen (1955). Como anteriormente mencionado, no início da década de 1990, Simões, M.G. (IBB/UNESP) logrou êxito em relocalizar tais afloramentos, dos quais três foram incluídos como localidades de estudo (Fig. 6): a- afloramento no rio d'Areia (25°27'48''S/50°23'25''W), situado a 14 km a SE de Teixeira Soares, na localidade de mesmo nome, no leito e ao longo das margens do rio, especialmente "na represa" do antigo Moinho (Fig. 6 G–K); b- afloramento junto à "gruta de Teixeira Soares" (25°23'15''S/50°26'16''W), no vale do rio das Almas (Fig. 6 D–F), onde aflora espesso pacote de arenitos, localmente situados acima dos diamictitos (Fig. 6 D) e c- afloramento no córrego Baitaca (Fig. 6A–C), situado a 2,2 km a SE de Teixeira Soares (25°23'06''S/50°26'53''W), na estrada para a localidade de Rio d'Areia.

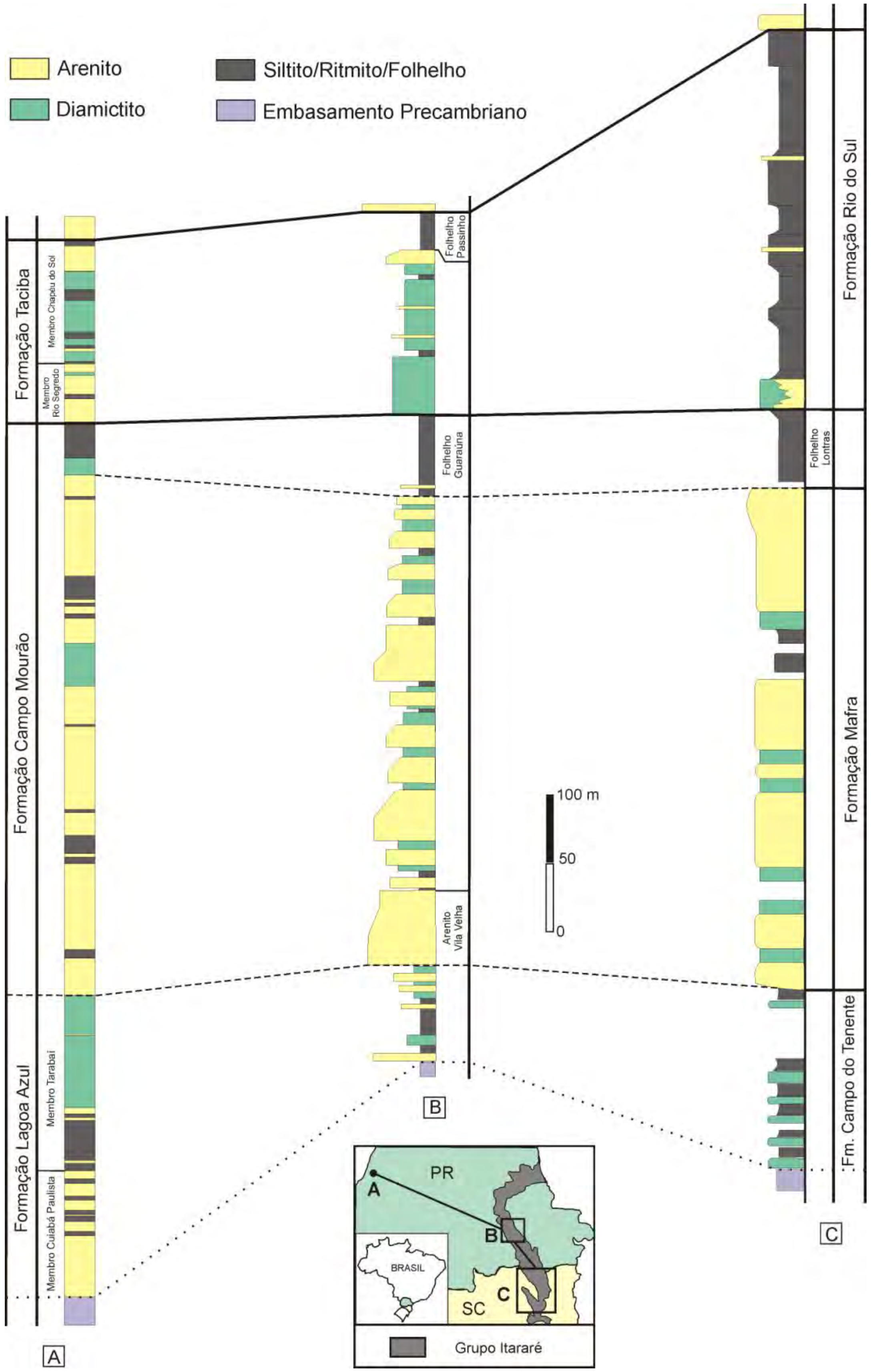

Figura 3- Correlação entre as diferentes unidades litoestratigráficas do Grupo Itararé. Em A, dados de subsuperfície (Poço 2-AN-1-PR) de França & Potter (1988); em B, coluna estratigráfica composta do perfil Ponta Grossa-Teixeira Soares (MINEROPAR, 2007) e, em C, dados de superfície de Schneider *et al.*, (1974). Modificado de Mineropar (2007).

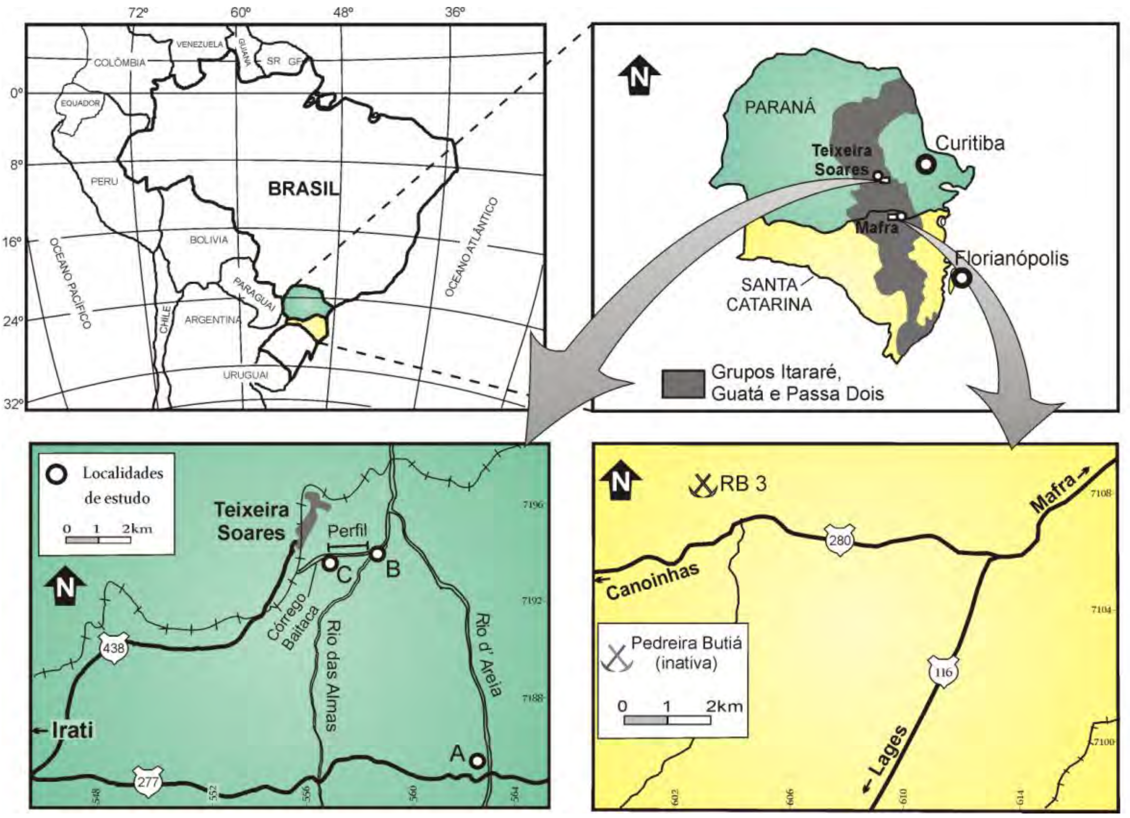

Figura 4– Mapas de localização dos afloramentos fossilíferos estudados na porção superior da Formação Taciba, Grupo Itararé. Em verde, Estado do Paraná, a região de estudo é Teixeira Soares, envolvendo três localidades: A: Rio d’Areia; B: Rio das Almas (gruta de Teixeira Soares) e C: Córrego Baitaca. No estado de Santa Catarina, em amarelo, a localidade de estudo corresponde à cava abandonada da antiga pedreira Butiá, localidade deBela Vista do Sul, a oeste do município de Mafra. (Figuras semelhantes são apresentadas nos artigos do capítulo 1 e anexo).

Nas figuras 06 a 10 estão sintetizados os dados dos mencionados afloramentos e a situação estratigráfica da sucessão local da Formação Taciba a SE de Teixeira Soares, PR. A sucessão apresenta granodecrescência ascendente, caracterizada por conglomerados na base, sucedidos por arenitos e siltitos intercalados e argilitos (folhelhos) no topo, não ultrapassando 60 metros de espessura (MINEROPAR, 2007) (Tab. 1, no capítulo 1; Fig. 12A). Estes dados estão, grosso modo, de acordo com as observações originais de Almeida (1945) e Maack (1946). Com base nas características sedimentológicas e estratigráficas dos litótipos, seu conteúdo paleontológico, paleoecológico e modo de ocorrência dos fósseis (tafonomia), cinco fácies sedimentares foram reconhecidas (Tabs. 1 e 2, no capítulo 1; Fig. 11). A sucessão tem ínicio com os conglomerados ou diamictitos cinza, com clastos polimíticos, seixos (alguns facetados e estriados) e blocos, variando de 1 cm até 1 m, maciço, superposto por ritmito, que é melhor observado no afloramento localizado na pedreira no vale do Rio d’Areia, 2 km a sul da PR-438 (MINEROPAR, 2007). No vale do Rio das Almas (gruta de Teixeira

Soares), o diamictito é maciço, cinza-esverdeado (Fig. 7B, C) na base, e laminado para o topo, com cerca de 4 a 8 m de espessura, às vezes incluindo corpos conglomeráticos ou arenosos. (MINEROPAR, 2007, p.106). Esses caracterizam a Fácies A (Fig. 11A–C), provavelmente, gerada pela ressedimentação de depósitos glaciais (MINEROPAR, 2007) (vide Tab. 1, no capítulo 1). Sucedem, em contato brusco, arenitos finos a médios, muito duros (devido ao cimento silicoso), com estratificação cruzada planar (Fig. 8B). Esses arenitos estão melhor expostos no leito do rio d'Areia, 200 metros acima da ponte, na altura do km 148, da rodovia para Palmeira, PR (vide também MAACK, 1946). Neta localidade, os arenitos formam bancos compactos e lajes (Fig. 6H), aflorante na cota altimétrica de 820 metros. Notavelmente, blocos e seixos deste arenito fossilífero (Fig. 6J) podem ser encontrados a jusante, junto à represa do antigo moinho (Fig. 6G), onde compõem os sedimentos de uma barra arenosa atual, que se desenvolve no leito do rio (Fig. 6J). Os blocos e seixos coletados são constituídos de arenito fino a médio, de coloração acinzentada, alguns amarelados pela decomposição. Esse litótipo foi denominado de "arenito Rio d'Areia", por Lange (1944), Maack (1946) e Beurlen (1955), aflorando também a SE de Teixeira Soares, junto ao vale do Rio das Almas (MINEROPAR, 2007), na estrada vicinal Rio d'Areia–Baitaca–Teixeira Soares (Fig. 4). No afloramento junto à "gruta de Teixeira Soares", os arenitos apresentam estratificação cruzada planar (Fig. 7C) e geometria sigmoidal (vide também MINEROPAR, 2007). No topo dos *sets* são verificadas ondulações simétricas a assimétricas (Fig. 11D) e níveis com laminação flaser ocorrendo intercalados (MINEROPAR. 2007). Em planta, junto às calhas das marcas onduladas ocorrem icnofósseis (*Planolites* sp.) (Fig. 8A). A direção preferencial de fluxo indicada pelas estratificações cruzadas é sudoeste (MINEROPAR. 2007). Os arenitos acima referidos são representativos Facies B (Fig. 11D–F), gerados por deposição subaquosa, provavelmente, na forma de barras de desembocadura ou de maré (MINEROPAR, 2007, p. 107), sendo superpostos, em contato brusco, por intervalo pelítico (siltitos e folhelhos) (Figs. 08–10).

A assembleia de invertebrados do arenito é composta, principalmente, por conchas de bivalves marinhos (n=187 espécimes), tipicamente, formando pavimentos descontínuos de conchas, sendo os pectinídeos o grupo dominante (n=151) (vide Tab. 4, capítulo 1), em geral com as valvas orientadas com convexidade voltada para baixo, em relação ao plano de acamamento. Conchas dispersas caoticamente orientadas na matriz sedimentar também são observadas. As conchas não mostram sinais de fratura, abrasão ou incrustação, mas predominam as valvas esquerdas sobre as direitas. As conchas, em geral, possuem tamanhos semelhantes (~2 a 2,5 cm). Os fósseis ocorrem nos dois metros superiores do arenito (Fig. 8), às vezes, em tal abundância que Maack (1946, p. 136, figs. 3B, D) o denominou de "arenito de *Aviculopecten*", dado o predomínio dos pectinídeos sobre os outros bivalves. Os arenitos que representam a Fácies B foram depositados em condições marinhas (*nearshore*), de água agitadas e fundos estáveis, oxigenados, tendo como fósseis característicos *Heteropecten paranaensis* (Neves *et al.*, submetido, vide capítulo 2) (80,7%, n=151) e *Pleurophorella* sp. (9,1%, n=17). A composição faunística das assembleias de bivalves ocorrentes na Facies B, bem como as guildas ecológicas representadas aparecem na tabela 4, no capítulo 1.

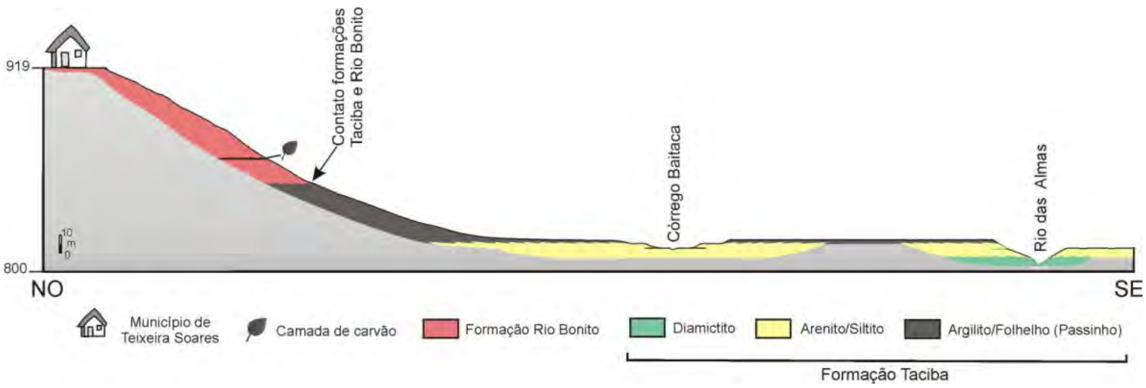

Figura 5– Perfil geológico Teixeira Soares–Rio das Almas (veja também na Fig. 4), mostrando a sucessão de rochas na área de estudo, envolvendo os afloramentos junto ao córrego Baitaca e a "gruta" de Teixeira Soares, às margens do rio das Almas. A terceira localidade, Rio d'Areia, localiza-se a cerca de 8 km a sudoeste do Rio das Almas. Informações referentes à Formação Rio Bonito, segundo Maack (1946) e Mineropar (2007).

Acima dos arenitos da Facies B, ocorrem siltitos intensamente bioturbados, onde, às vezes, é possível ainda reconhecer a laminação plano-paralela original, os quais ocorrem tanto no afloramento de Rio d'Areia, às margens do rio homônimo (Fig. 8C), bem como na base do afloramento do córrego Baitaca (Fig. 9B). Quando intemperizados, esses siltitos são amarelados, avermelhados ou esbranquiçados. Os siltitos são fossilíferos, contendo conchas de bivalves preservadas com as valvas articuladas abertas (*splayed* ou *butterflied*, fig. 11 I). Este litótipo caracteriza a Facies C (Fig. 11G–I), depositada acima do nível de base de ondas de tempestade, em fundo marinho, oxigenado. A presença de conchas articuladas abertas indica deposição rápida, mas não abrupta, para certos intervalos do siltito (vide Tab. 3, no capítulo 1).

Figura 6– Localidades de estudo na região de Teixeira Soares, PR, apresentado exposições com intenso grau de intemperismo e denso recobrimento por vegetação. 1–2: Afloramento do córrego Baitaca. 1: arenito (Facies B) exposto no leito do córrego. 2: afloramento da facies D (seta), com exposição de arenitos finos a muito finos/siltito, acima do nível do córrego Baitaca. 3–4: Afloramento da “gruta” de Teixeira Soares, junto ao rio das Almas. 3: Exposição de diamictitos (facies A), muito intemperizados (seta). 4: exposição completamente encoberta da Facies B, mostrando um dos níveis de arenitos, com estratificação cruzada planar. 5–7: Afloramento da localidade Rio d’Areia. 5: antigo moinho junto à margem do rio d’Areia, ponto de referência para os afloramentos de Teixeira Soares, nas décadas de 40 e 50 (vide MAACK, 1946), fotografia de M. G. Simões (1993). Atualmente, apenas a fundação do moinho ainda pode ser vista. 6: leito atual do rio, formando barras arenosas. 7: blocos arenosos fossilíferos (setas) acumulados nas barras arenosas.

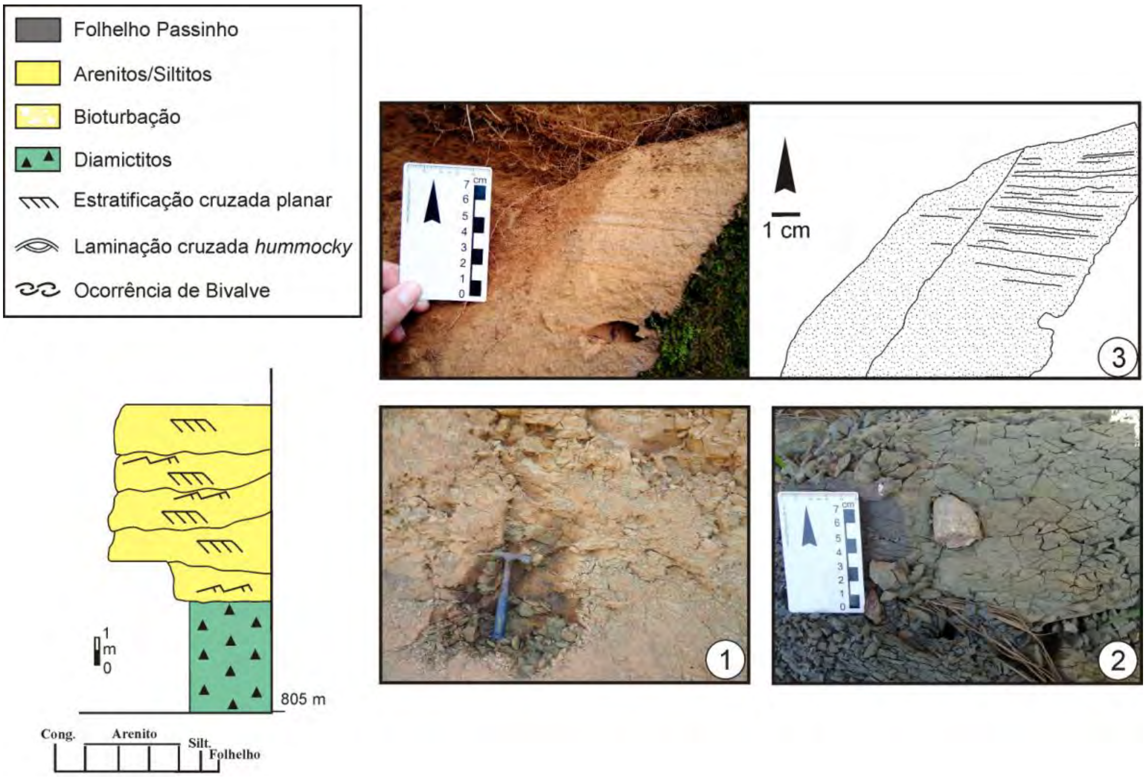

Figura 07– Perfil colunar da gruta de Teixeira Soares ilustrando os litótipos expostos. 1: Diamictito de matriz argilosa (Facies A). 2: Detalhe de 1, mostrando seixo granítico, em matriz argilosa, cinza-esverdeada. 3: Arenito fino, com estratificação cruzada planar, de baixo ângulo (Facies B), veja detalhe (à direita).

Entre os siltitos da Facies C e os argilitos e folhelhos do topo da sucessão estratigráfica da Formação Taciba, na área de estudo, ocorre um pacote de arenitos finos a muito finos, siltitos e argilitos intercalados, cuja origem é bastante complexa. Esse conjunto heterogêneo de rochas (arenito, siltito, argilito) equivale ao que se convencionou chamar de “Siltito Baitaca” ou “Arenito de Baitaca”. Trata-se de pacote de arenito fino a muito fino, com estratificações cruzadas de muito baixo ângulo, onde, às vezes, é possível reconhecer a presença de níveis contendo laminação cruzada *hummocky* (Fig. 11J), gradando para laminação paralela a ondulada. No topo, podem ocorrer arenitos muito finos a siltitos intensamente bioturbados (vide Tab. 1, no capítulo 1), com estruturas de escape, contendo também conchas de bivalves preservadas *in situ*, com o maior eixo da concha inclinado cerca de 40 a 50°, em relação ao acamamento (Fig. 10). Às vezes, a bioturbação é tão intensa que destrói quase que completamente as estruturas primárias presentes no arenito. A porção bioturbada, no topo do corpo síltico-arenoso, é sucedida em contato brusco e irregular, por nova sucessão de arenitos com estratificação cruzada de baixo ângulo, bioturbado no topo. Em outras palavras, os arenitos registram vários episódios de erosão e deposição (Fig. 10). Todo o conjunto, com um pouco mais de 2 metros de espessura, no afloramento do córrego Baitaca (Figs. 09 e 10), caracteriza a Facies D (Fig. 11J–L), gerada sob a influência de diversos eventos de tempestade, em ambiente marinho plataformal, de fundo incoeso, relativamente oxigenado, junto ou acima do nível de base de ondas de tempestades. Esses fundos foram colonizados por diversificada infauna rasa a profunda, suspensívora (Tab. 3 e 4, no capítulo 1; Figs. 13 e 15). Em parte, representam depósitos de sufocamento (*obrution deposits*, *sensu* Seilacher *et al.*,1985) ou tempestitos amalgamados, onde as camadas geradas pelo evento episódico de deposição eram pouco espessas e o intervalo de tempo entre os eventos deposicionais longos o suficiente para a fauna bentônica colonizar e bioturbar o fundo, destruindo porções significativas das estruturas sedimentares primárias, inorgânicas, geradas pelas tempestades (vide Tab. 3, no capítulo 1; Fig. 10).

Os litotipos da Facies D são sucedidos por siltitos e argilitos bem laminados ou maciços (folhelho Passinho), às vezes com níveis muito bioturbados. Os argilitos são acizentados-azulados ou esbranquiçados, quando profundamente intemperizados (vide Maack, 1946). O folhelho é intensamente fraturado, sem indícios de clastos caídos (vide também Mineropar, 2007). Os fósseis, maiormente representados por conchas de bivalves, ocorrem apenas em determinados horizontes (Fig. 12A). As conchas estão dispersas na matriz sedimentar, usualmente com as valvas ainda articuladas abertas (*splayed* ou *butterflied*). Localmente, o contato entre o folhelho (porção superior da Formação Taciba) e a Formação Rio Bonito estaria situado em torno da cota altimétrica de 850 metros (Fig. 5), facilmente identificado no campo, pela quebra de relevo (MINEROPAR, 2007). Os litotipos acima caracterizam a Facies E (Fig. 11M–O), depositada em condições de plataforma aberta (*offshore*), em fundo deficiente em oxigenação e rico em matéria orgânica. Horizontes bioturbados ou contendo raras conchas de bivalves não transportadas são indicativos pulsos de melhoria das condições de oxigenação, com rápida colonização da fauna bentônica oportunista, detritívora, em condições disaeróbias extremas (vide Tab. 3, no capítulo 1; Fig. 13).

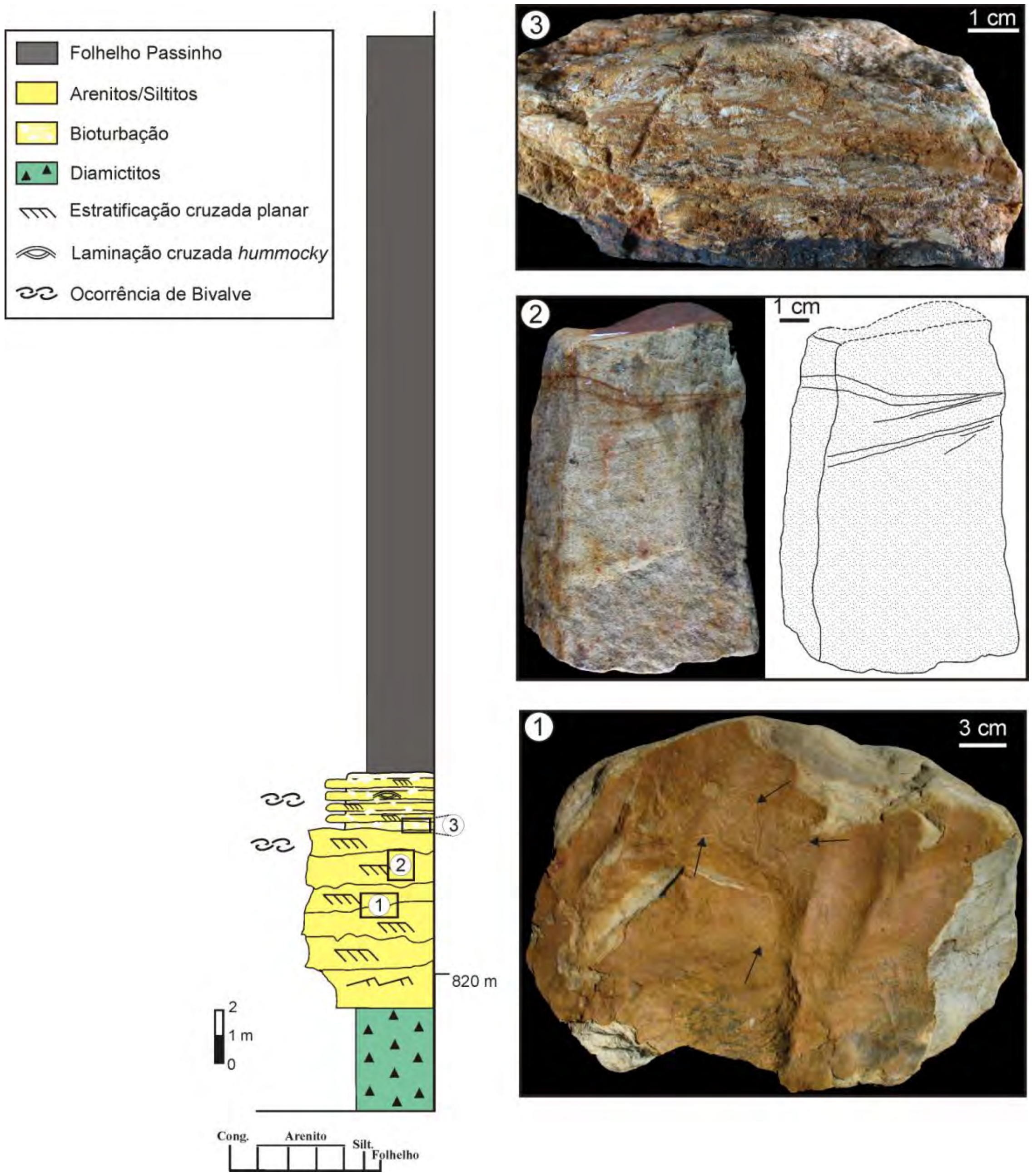

Figura 08– Perfil colunar da localidade Rio d’Areia, ilustrando os litótipos expostos. 1: Vista, em planta, de amostra do arenito da Facies B, exibindo conspícuas cristas de marcas onduladas, entres as quais estão presentes diversos icnofósseis, *Planolites* sp. (setas). 2: Amostra de arenito fino a médio, maciço (porção inferior), com estratificações cruzadas (porção média-superior) e topo com marca ondulada (Facies B). 3: Siltito branco-amarelado, intensamente bioturbado, apresentando alto grau intemperismo (Facies C). Os diamictitos basais e o folhelho encontram-se, atualmente, encobertos pela vegetação.

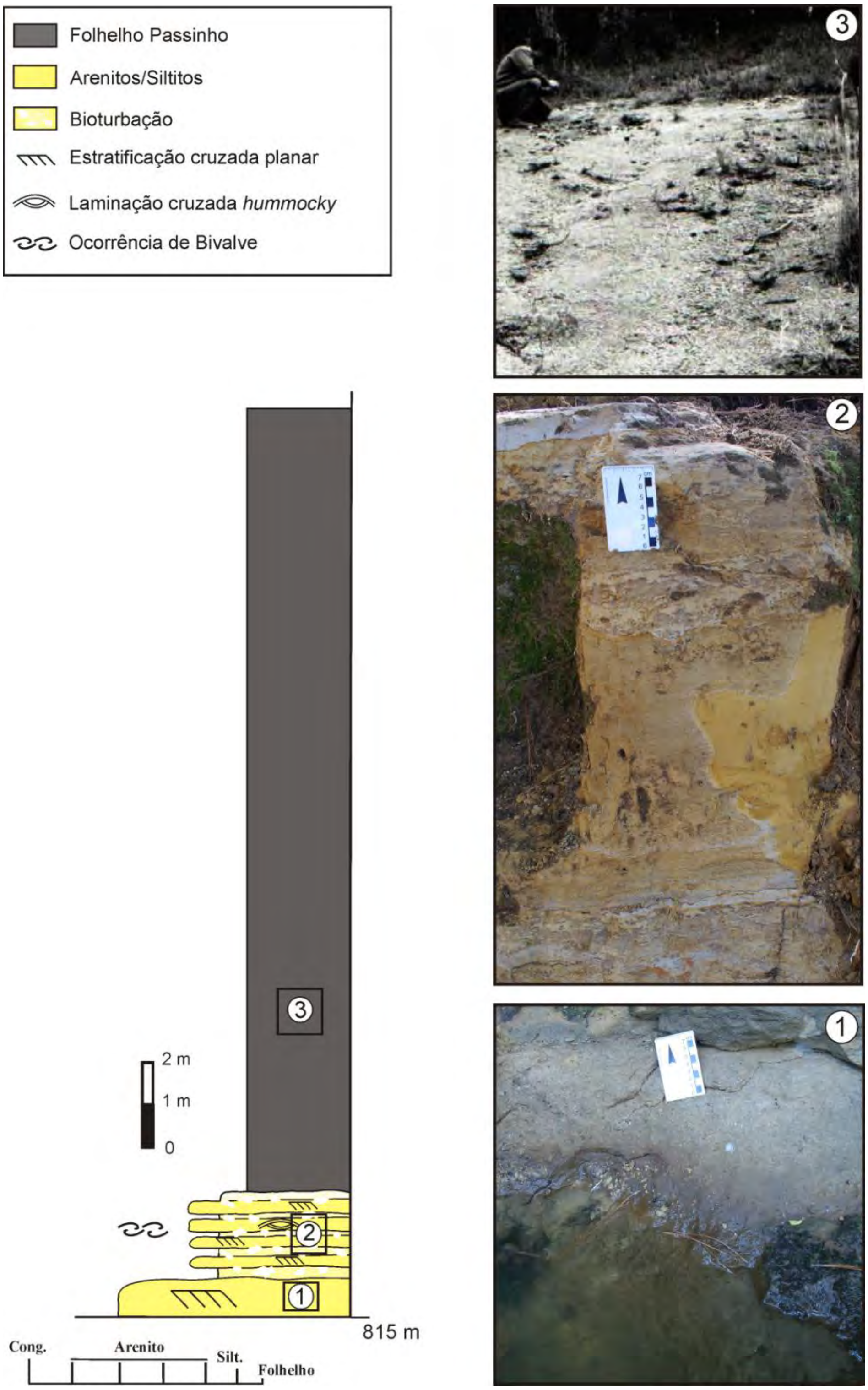

Figura 09– Perfil colunar do afloramento do córrego Baitaca, ilustrando aspectos dos litótipos expostos. 1: Arenito fino a médio, maciço, de coloração cinza (Facies B), exposto no leito do córrego Baitaca. 2: Tempestitos amalgamados da Facies D, apresentando siltitos intensamente bioturbados (branco-amarelados) intercalados com arenitos exibindo laminação cruzada *hummocky*. 3: Imagem obtida em 1993, por M. G. Simões, mostrando exposição do folhelho Passinho (Faceis E), na porção superior do afloramento, hoje completamente encoberto pela vegetação.

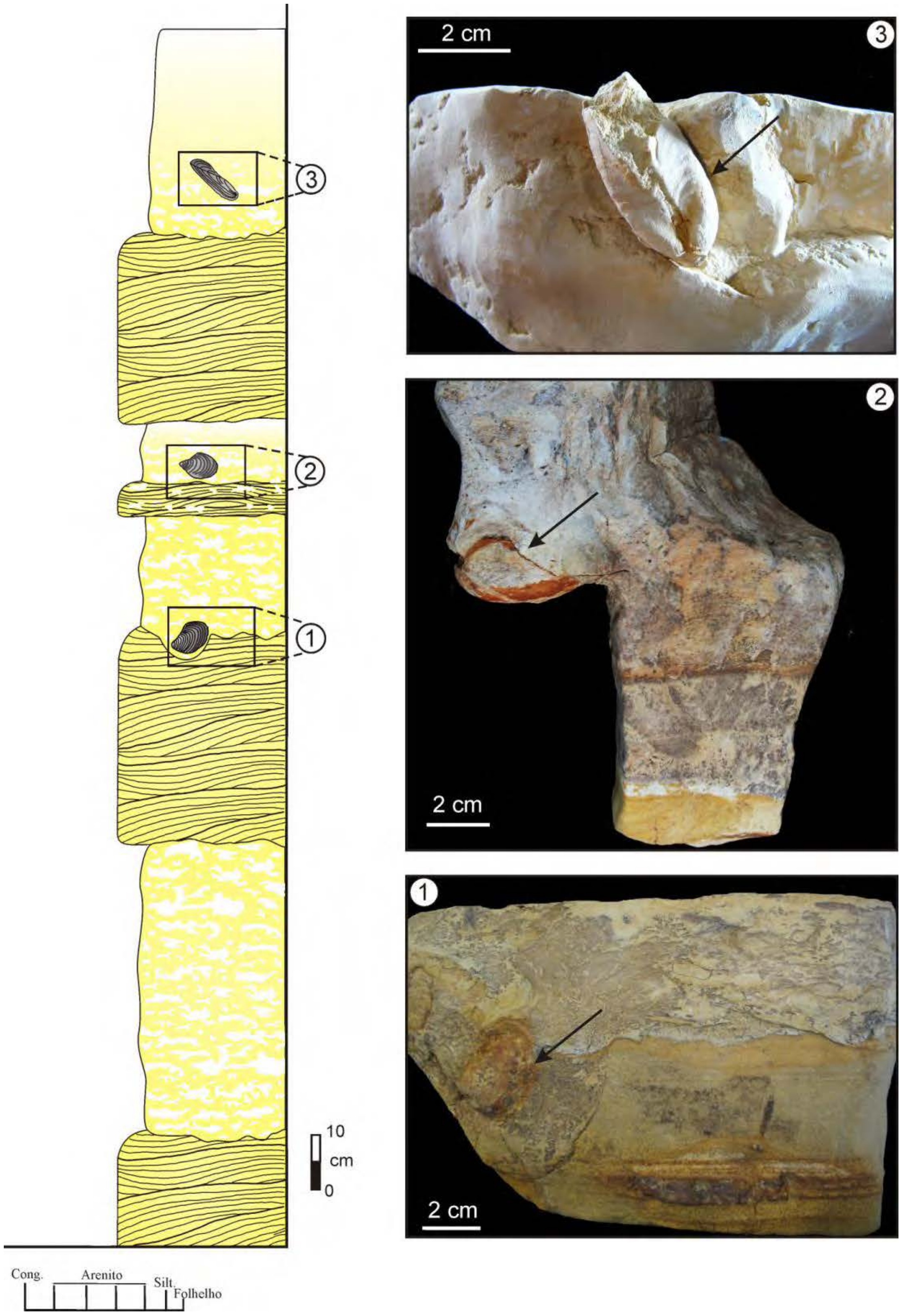

Figura 10– Perfil colunar de detalhe exibindo litótipos da Facies D, no afloramento do córrego Baitaca, incluindo siltito bioturbado sucedido, em contato brusco e irregular, por arenitos finos com estratificação cruzada de baixo ângulo ou *hummocky*, bioturbados no topo. A sucessão basal é afossilífera e as três subsequentes representam tempestitos, com bivalves preservados *in situ* (setas), 1–3. 1: *Exochorhynchus itararensis* sp.n., 2: *Atomodesma* (*Aphanaia*) *orbirugata* e 3: *Myonia argentinensis*.

Figura 11– Litótipos representativos do conjunto de fácies descritas para a porção superior da Formação Taciba, na região de Teixeira Soares, PR. A–C: Diamictitos da Facies A. A: Exposição de diamictitos intensamente intemperizados na localidade gruta de Teixeira Soares, junto ao rio das Almas. B: Detalhe de A, mostrando a matriz argilosa pastilhada. C: Seixo granítico, em matriz argilosa cinza-esverdeada, observado em amostra rolada. D–F: Litótipo referido, na literatura, como ”arenito Rio d'Areia” (Faceis B). D: Fotografia modificada de Mineropar (2007, p. 108), mostrando o arenito com ondulações simétricas a assimétricas com laminação *flaser*. E: Estratificações cruzadas, em arenito médio a grosso. F: Pavimento de conchas de *Heteropecten paranaensis*, em arenito cinza, maciço. G–I: Litótipo referido, na literatura, como “siltito Baitaca” (Facies C). G: siltito intensamente biotubado e profundamente

intemperizado. H: Siltito mostrando alguns níveis com laminações plano-paralelas, ainda não completamente destruídas pela bioturbação. I: *Praeundulomya* cf. *subelongata* preservada com as valvas articuladas abertas (*butterfly*). J–L: Arenitos/siltitos bioturbados (Facies D). J: arenito fino, intensamente bioturbado, com laminação cruzada *hummocky*. K: siltito bioturbado, amarelado, gradando para siltito/argilito branco maciço no topo da amostra. L: *Cosmomya* (*Paleocosmomya*) *baitaquensis* sp.n. preservada *in situ*, representando um dos horizontes de depósitos de tempestito. M–O: Argilitos maciços a laminados, cinza, Folhelho Passinho (Facies E). M: exposição do folhelho na localidade junto ao córrego Baitaca, no ano de 1993, (fotografia de Prof. M. G. Simões), exposição hoje completamente encoberta pela vegetação. N: Amostra de mão do argilito de coloração cinza-escuro. O: *Palaeoneilo brasiliensis* sp.n., espécie preservada com valvas articuladas abertas (*butterfly*), no folhelho Passinho. (Esta figura também é apresentada no artigo do capítulo 1).

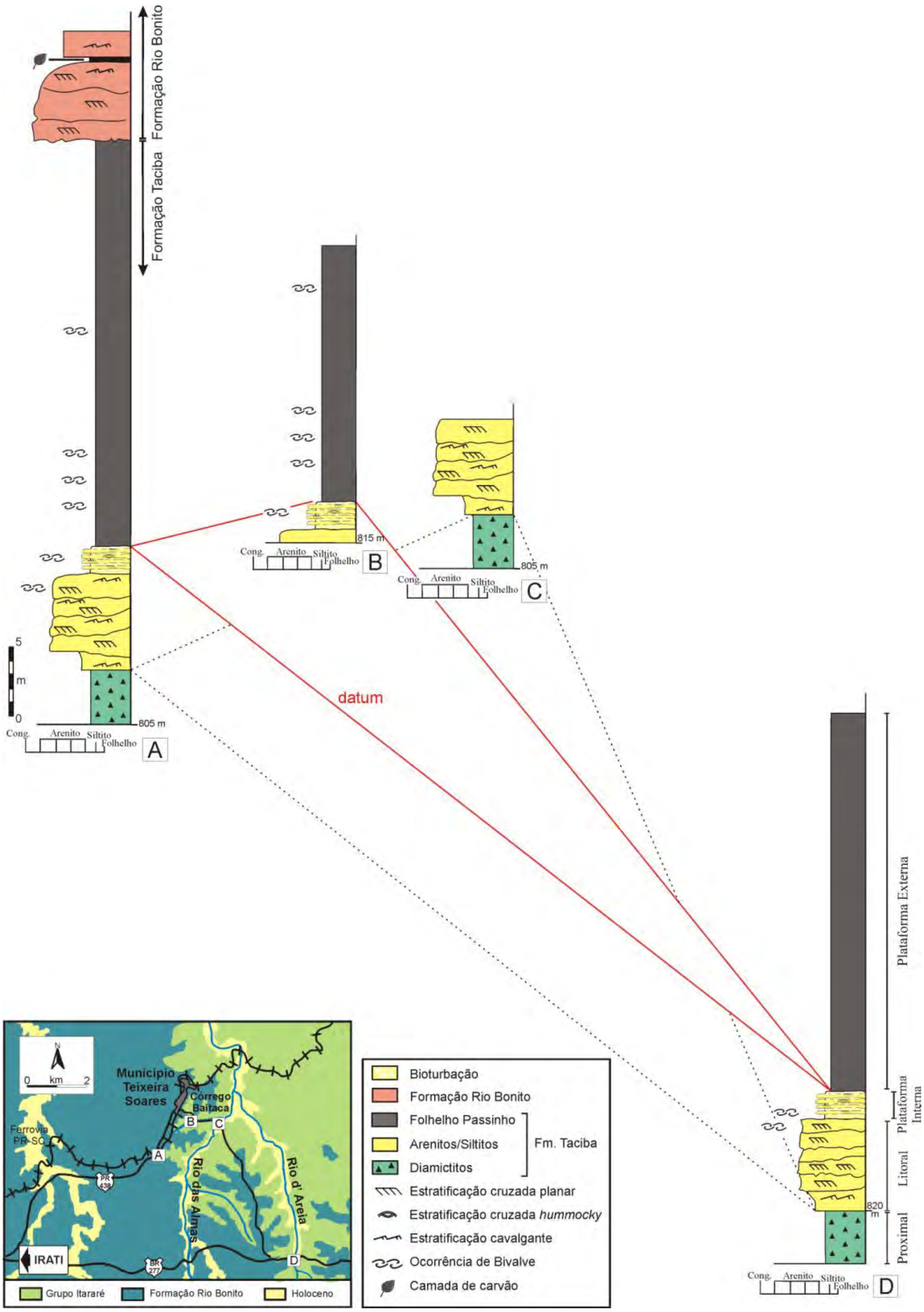

Figura 12– Correlação estratigráfica entre os perfis colunares das localidades de estudo. A: Perfil composto próximo ao município de Teixeira Soares (ferrovia). B: Seção do afloramento do córrego Baitaca. C: Seção do afloramento da gruta de Teixeira Soares, junto ao Rio das Almas. D: Seção da localidade Rio d'Areia. A correlação se fundamenta principalmente pelo datum (Folhelho Passinho) que registra a superfície de inundação marinha, na parte superior da Formação Taciba, na região de Teixeira Soares, PR. (Figura semelhante é apresentada no artigo do capítulo 1).

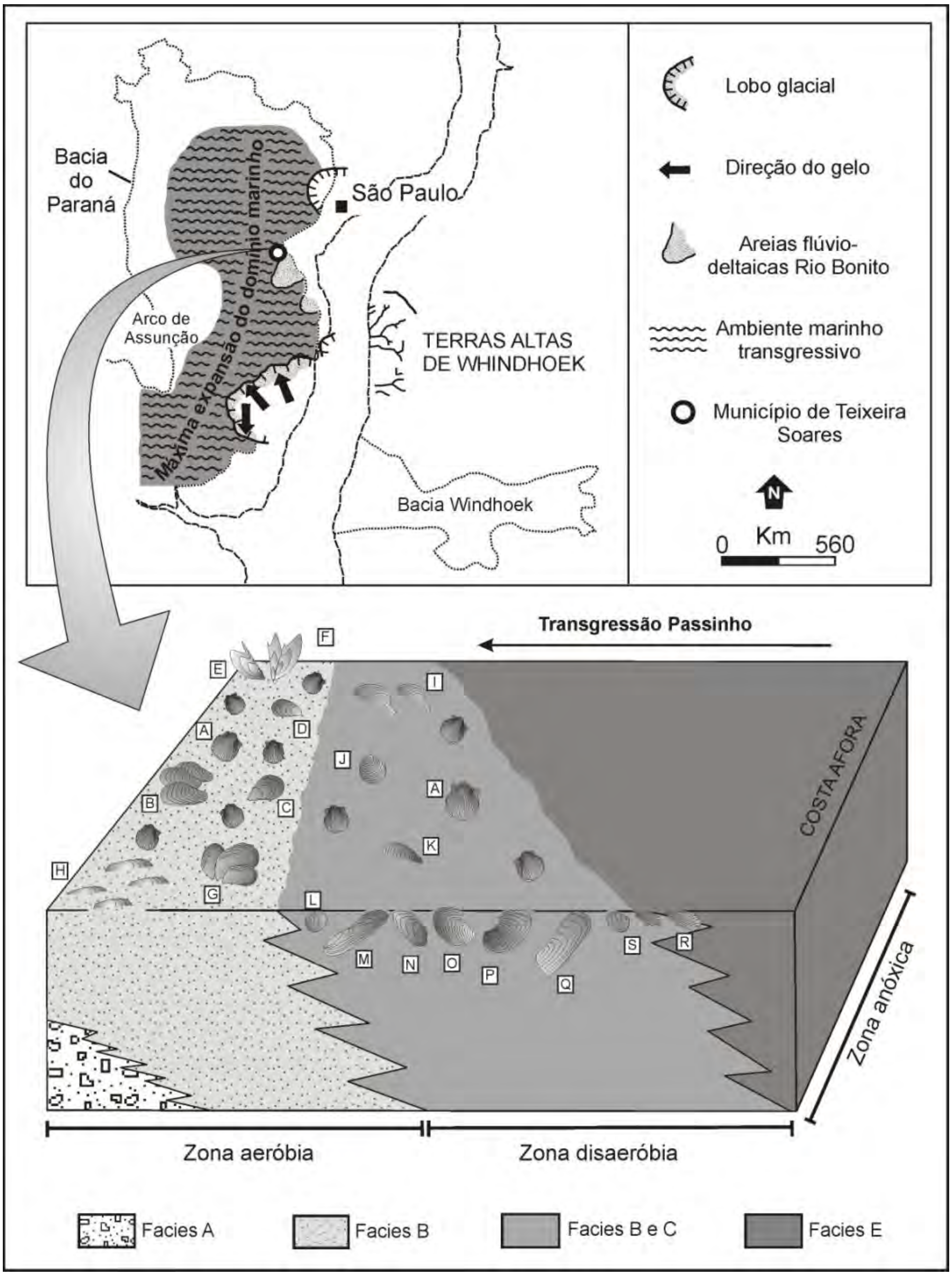

Figura 13– Reconstrução paleogeográfica e paleoecológica da parte superior da Formação Taciba, incluindo as assembleias estudadas. No quadro superior, mapa paleogeográfico, mostrando a máxima expansão do domínio marinho, no Permiano Inferior, durante episódio de deglaciação do Grupo Itararé (SANTOS *et al*., 1996, p. 174). Na região de Teixeira Soares, PR, este episódio é materializado pelo afogamento da fácies costeiras e o folhelho Passinho no topo da sucessão. Blocodiagrama (quadro inferior) apresentando a reconstrução paleoambiental das assembleias de bivalves marinhos da porção superior da Formação Taciba, na região de estudo. Todas as espécies descritas neste trabalho estão ilustradas na figura acima. A: *Heteropecten paranaensis* sp.n., B: *Volsellina areiensis* sp.n., C: *Myalina* (*Myalinella*) sp., D: *Promytilus* sp., E: *Leptodesma* (*Leptodesma*) sp., F: *Leptodesma* (*Leiopteria*) sp., G: *Selenimyalina* sp., H: *Pleurophorella* sp., I: *Atomodesma* (*Aphanaia*) *orbirugata*, J: *Streblopteria* sp., K: *Atomodesma* (*Intodesma*) sp., L: *Schizodus* sp., M: *Myonia argentinensis*, N: *Sanguinolites* sp., O: *Exochorhynchus itararensis* sp.n., P: *Cosmomya* (*Paleocosmomya*) *baitaquensis* sp.n., Q: *Praeundulomya* cf. *subelongata*, R: *Phestia* sp., S: *Palaeoneilo brasiliensis* sp.n. (Figura semelhante é apresentada no abstract gráfico do artigo do capítulo 1).

Já os afloramentos estudados na região de Mafra, SC, incluem, principalmente, as exposições da parte superior da antiga pedreira Butiá (ROCHA-CAMPOS, 1966), 26°09’22’’S/49°53’02’’W, a 20 km da cidade de Mafra, pela BR-280, no sentido Canoinhas, entrando-se à direita em acesso não pavimentado, 1.300 m após o trevo com a BR-116, sentido Lajes (Fig. 4), na localidade de Bela Vista do Sul, SC. Os perfis geológicos da figura 14, incluindo dados de poços rasos (RB-3 e PP-10, veja WEINSCHÜLZ & CASTRO, 2006; SIMÕES *et al.*, 2012) mostram que os fósseis ocorrem acima do diamictito, correspondente ao topo da pedreira abandonada. Trata-se de um delgado horizonte de siltito, bioturbado, situado entre arenitos e folhelhos. Os fósseis presentes são representados por conchas de braquiópodes rhynchonelliformes, principalmente productídeos (ROCHA-CAMPOS, 1966) e conchas de bivalves atribuíveis às espécies *Heteropecten paranaensis* (=*Aviculopecten mulstiscalptus*) e *Myonia argentinensis* (SIMÕES *et al.*, 2012). Estas são espécies de ocorrência comum no intervalo arenoso e pelítico (siltito) da porção superior da Formação Taciba de Teixeira Soares, PR, equivalente à Facies D. De fato, ocorrem em situação estratigráfica similar, entre diamictitos, na base, e o Folhelho Passinho, no topo (Figs. 12 e 14) e apresentam o mesmo modo de preservação, com conchas de bivalves marinhos escavadores, sendo a espécie *M. argentinensis* preservada *in situ*, em horizonte intensamente bioturbado. Em ambas as regiões estudadas, o conjunto de fácies (Facies A a E) da porção superior da Formação Taciba, incluindo conglomerado, arenitos médios a finos, com estratificação cruzada planar, siltitos com laminação paralela, intensamente bioturbados, arenitos finos a muito finos/siltitos com estratificação cruzada *hummocky* e argilitos laminados acinzentados, com fósseis marinhos em comum, configuram um ciclo de granodecrescência ascendente, evidenciando o progressivo afogamento das fácies costeiras e de plataforma (SIMÕES *et al.*, 1998a, p. 446, fig. 3). Assim, o conjunto de estratos da Formação Taciba, de Teixeira Soares, seria correlato, em parte, à sequência Taciba (TC-II) de Weinschütz & Castro (2006) (Fig. 14). Do mesmo modo que em Teixeira Soares, PR, também em Mafra, SC, o folhelho marinho (Passinho) aflorante na seção do perfil rio Butiá, complementar à sequencia sedimentar do poço RB-3 (vide WEINSCHÜTZ & CASTRO, 2006), provavelmente representa uma superfície de inundação marinha, relacionada à deglaciação (SANTOS, *et al.*, 1996; WEINSCHÜTZ & CASTRO, 2006). Em outras palavras, o Folhelho Passinho representa a Superfície de Inundação Máxima (SANTOS, *et al.*, 1996; WEINSCHÜTZ & CASTRO, 2006; MINEROPAR, 2007) e, por esse motivo, apresenta grande continuidade lateral (Figs. 2 e 13), podendo ser rastreado em toda extensão do contato entre a porção superior da Formação Taciba e a porção basal da Formação Rio Bonito, no Estado do Paraná (vide MINEROPAR, 2007). Desse modo, a deposição do pacote relativo ao Folhelho Passinho estaria relacionada à máxima expansão das condições marinhas (Fig. 13), na Bacia do Paraná, em parte, como resposta à rápida desintegração dos lobos glaciais relacionados ao manto de gelo Windhoek (Windhoek Ice Sheet, WIS, Bacia do Kalahari, Namíbia) e da capa de gelo do Rio Grande do Sul (SANTOS, 1987; SANTOS *et al.*, 1996), durante o Permiano inferior. No quadro paleoambiental acima, as diferenças de litofacies, em especial, a energia do meio, o tipo e grau de oxigenação de fundo e seu teor de matéria orgânica seriam responsáveis pela variação no conteúdo fossilífero das assembleias de bivalves estudadas (ROCHA-CAMPOS, 1969, p. 14; SIMÕES *et al.*, 1998a, p. 446) (vide Tab. 3, no capítulo 1; Figs. 13 e 15), refletidas nas distintas guildas ecológicas observadas e no modo de preservação notado (vide Tab. 4, no capítulo 1).

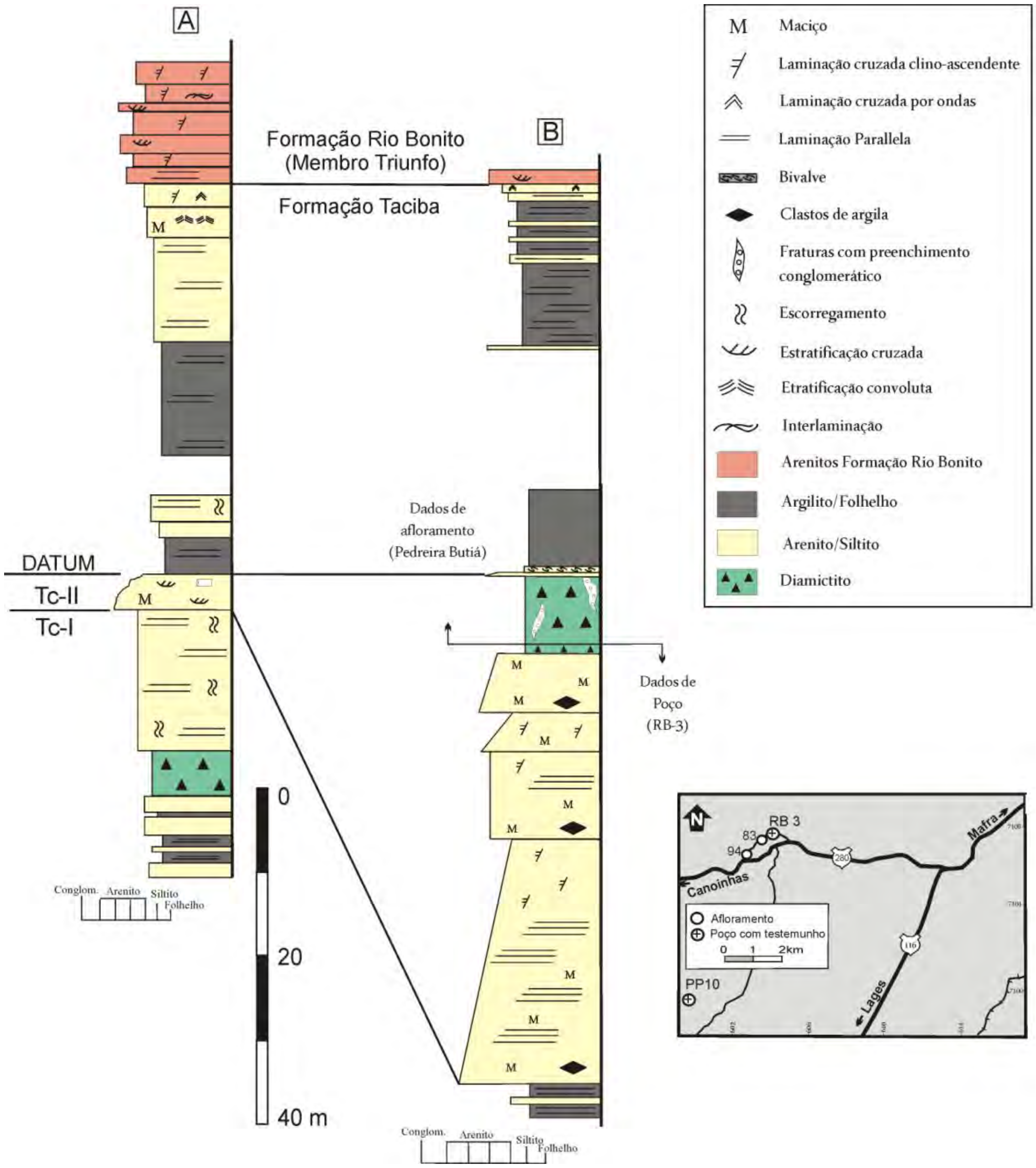

Figura 14– Correlação entre os perfis de poços, complementados com afloramentos vizinhos, A= PP-10, Projeto Pioneiro, e B= RB-3, Poço Rio Butiá mais dados complementares dos pontos 83/94, e *datum* marcando a superfície de inundação máxima da sequencia TC-II (Taciba II), modificado de Weinschütz & Castro (2006). (Esta figura é também apresentada no artigo do capítulo 1).

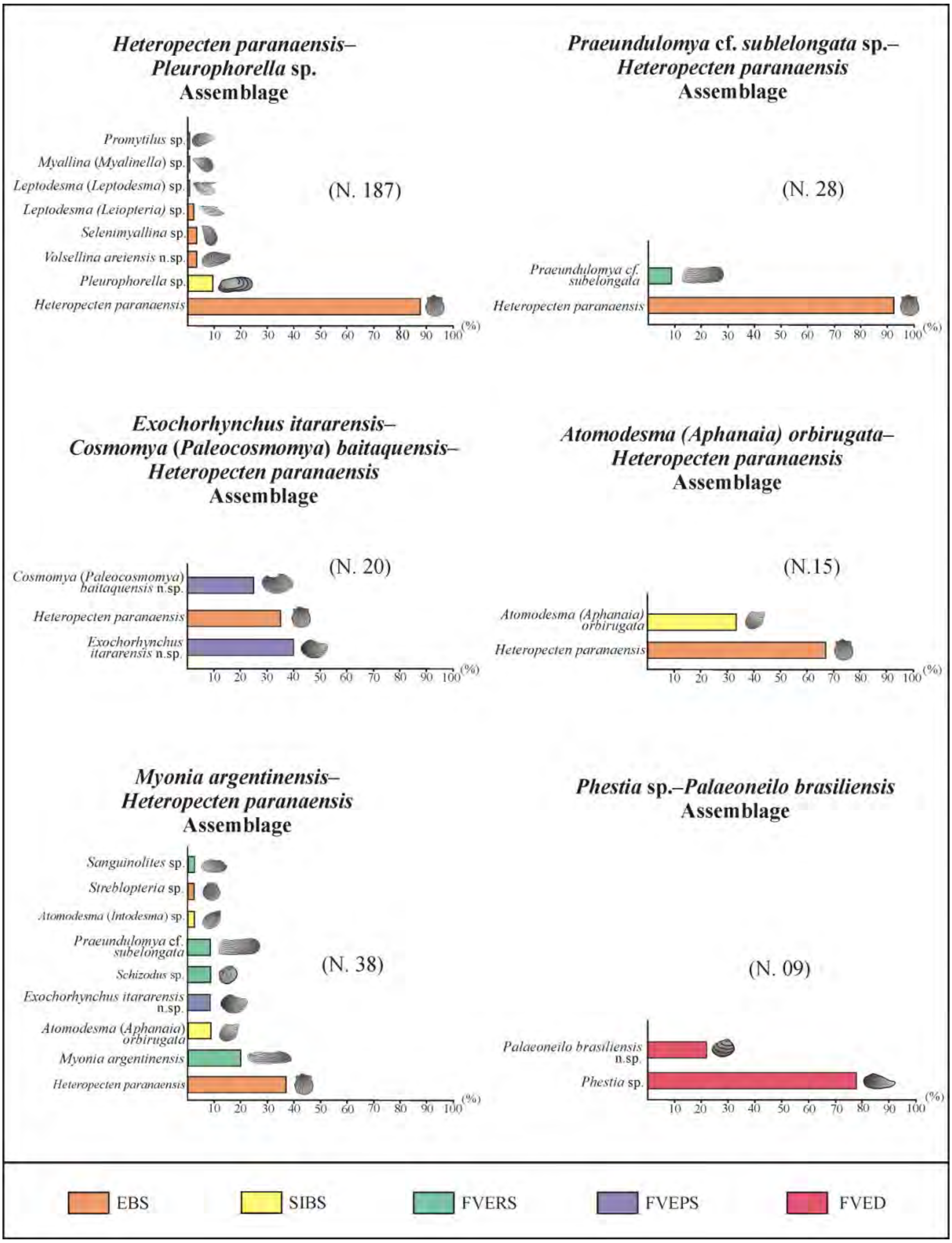

Figura 15– Abundância e diversidade das assembleias de bivalves marinhos da porção superior da Formação Taciba, na região de Teixeira Soares, PR. EBS= Epifauna, bissada, suspensívora; SIBS= Semi-infauna, bissada, suspensívora; FVERS= Facultativamente vágil, escavador raso, suspensívoro; FVEPS= Facultativamente vágil, escavador profundo, suspensívoro; FVED= Facultativamente vágil, escavador, detritívoro. (Esta figura é também apresentada no artigo do capítulo 1).

1.2.2. Exame de coleções científicas, análise taxonômica e correlação

Durante os três anos de desenvolvimento da pesquisa, foram examinadas cinco coleções científicas, nacionais e internacionais, de moluscos bivalves fósseis da Formação Taciba, Estado do Paraná, e de unidades coevas da Bacia do Paraná, bem como de outras bacias neopaleozoicas sul-americanas. Foram as seguintes as coleções examinadas: 1- Departamento de Zoologia do IBB/UNESP, Botucatu/SP; 2- Departamento de Geologia Sedimentar e Ambiental/IGc-USP, São Paulo/SP; nestas coleções foi consultado o material de Teixeira Soares (principal objetivo desta pesquisa); 3- coleção do CENPALEO/ Universidade do Contestado, Mafra, SC, material correspondente à fauna de bivalve da Formação Taciba, na pedreira Butiá; 4- American Museum of Natural History (New York)/Departament of Paleontology, incluindo o material do Carbonífero das Montanhas Amotape, Grupo Tarma, Peru e 5- Universidad de Buenos Aires (UBA)/Departamento de Ciencias Geológicas, abrangendo a fauna da Formação Bonete (Permiano), Bacia de Sauce Grande, Sierras Australes, Argentina. No total, foram estudadas, aproximadamente, três centenas de espécimes, pertencentes a aproximadamente quarenta espécies distintas.

A análise taxonômica das faunas estudadas iniciou-se desde o primeiro ano da pesquisa, abordando a revisão sistemática no nível supragenérico e genérico. No primeiro caso, foram utilizados artigos considerados referência na área (Sistemática de Bivalves do Paleozoico Superior), tais como Waterhouse (2008; 2010), Bieler *et al.* (2010) e Carter *et al.* (2011), este último trata-se da versão precursora do novo *Treatise* em Paleontologia de Invertebrados (Bivalvia). No nível genérico, a análise taxonômica esteve principalmente baseada nos trabalhos de Kegel & Costa (1951); Harrington (1955); Dickins (1957, 1963); Morris *et al.* (1991); González (1997, 2006); Fang & Morris (1999); Pagani (2000); Waterhouse (2008, 2010). Já as interpretações paleoecológicas foram realizadas segundo os estudos de anatomia funcional de Stanley (1970, 1972), Runnegar (1974), Kauffman & Runnegar (1975) e Aberhan *et al.* (2004).

Nas assembleias de Teixeira Soares (vide artigo apresentado no capítulo 1), 297 espécimes de bivalves foram estudados, dos quais 61 foram ilustrados e constituíram a análise taxonômica (vide Plates e Tab. A2, no capítulo 1), pertencentes a 19 espécies, quatro delas novas, e a 13 famílias (vide Tab. 2, capítulo 1). Na região de Mafra, a fauna é composta por duas espécies, até o momento encontradas (SIMÕES *et al.*, 2012, vide Anexo), que também ocorrem em Teixeira Soares: *Heteropecten paranaensis* e *Myonia argentinesis*. Em seu conjunto, a fauna de bivalves da parte superior da Formação

Taciba das regiões de Teixeira Soares, PR, e Mafra, SC, encontradas nas litofáceis e assembleias acima descritas é, maiormente, composta por gêneros cosmopolitas ou de ampla distribuição no Gondwana (vide também SIMÕES *et al.*, 1998a). Em especial, a paleobiota apresenta relação com as faunas da sucessão carbonífera superior e permiana inferior das bacias argentinas. Por exemplo, dos 19 gêneros assinalados nas assembleias estudadas, nove ocorrem nas formações Monjón de Hierro e Las Salinas, e oito na Formação Río Genoa, pertencentes à Bacia Tepuel-Genoa, Patagonia Central (Tab. A1, capítulo 1). Entretanto, a fauna da porção superior da Formação Taciba compartilha espécies apenas com a fauna da Formação Bonete (Tab. 5), da Bacia Sauce Grande, na porção leste da Argentina, veja discussão no item 3.1.2.

A tabela 6 apresenta a lista taxonômica das assembleias de Teixeira Soares segundo dois principais trabalhos prévios (BEURLEN, 1954; ROCHA-CAMPOS, 1969) frente àquela proposta neste trabalho, onde as espécies são, formalmente, descritas pela primeira vez (vide capítulo 1).

2. RESULTADOS

Esta seção está dividida em duas partes. A primeira delas apresenta o artigo de descrição taxonômica da fauna de bivalves da porção superior da Formação Taciba, em Teixeira Soares, PR, que corresponde ao principal resultado desta tese de doutoramento. A segunda parte aborda o artigo de revisão taxonômica no nível genérico e específico de pectinideos da América do Sul, do Peru (fauna das Montanhas Amotape) e do Brasil (Fauna de Teixeira Soares), e suas implicações bioestratigráficas e paleogeográficas.

2.1. CAPÍTULO 1

2.1.1. Comprovante de submissão de artigo ao Journal of South American Earth Science

de: Journal of South American Earth Sciences<kellogg@geol.sc.edu>

para: nevesjp.unesp@gmail.com

data: 19 de julho de 2013 17:51

assunto: A manuscript number has been assigned: SAMES-D-13-00075

Ms. Ref. No.: SAMES-D-13-00075
Title: Early Permian post-glacial bivalve faunas of the Itararé Group, Paraná Basin, Brazil: paleoecology and biocorrelations with South American intraplate basins
Journal of South American Earth Sciences

Dear Ms. Jacqueline Peixoto Neves,

Your submission "Early Permian post-glacial bivalve faunas of the Itararé Group, Paraná Basin, Brazil: paleoecology and biocorrelations with South American intraplate basins" has been assigned manuscript number SAMES-D-13-00075.

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Kind regards,

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Editor-in-Chief
Journal of South American Earth Sciences

****

2.1.2. Artigo submetido ao *Journal of South American Earth Science*

Early Permian post-glacial bivalve faunas of the Itararé Group, Paraná Basin, Brazil: paleoecology and biocorrelations with South American intraplate basins

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ABSTRACT

The uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Brazil, records a succession of depositional environments tied to the demise of Late Paleozoic glaciation. At the study area, Teixeira Soares county, state of Paraná, the unit is dominated by massive to laminated, matrix-supported conglomerates with inclusions of sandstones and other coarse-grained lithotypes, representing re-sedimented polymitic diamictites. This are succceded by fine to medium-grained sandstones with tabular cross-stratification and pectinid-rich shell pavements, interpreted as nearshore deposits. Above this, laminated and intensely bioturbated siltstones with closed articulated bivalve shells, probably deposited in inner shelf settings, are recorded. Amalgamated, fine to very fine sandstone/siltstone with low-angle trough cross-stratification or hummocky cross-stratification and intercalated mudstones, including infaunal *in situ* shells, are interpreted as stacked storm deposits, generated in distal shoreface environments. These are succedded by fossil-poor, massive to laminated siltstone/mudstone or gray shales (=Passinho shale) that are inferred as outer shelf deposits, generated in organic-rich, oxygen-deficient muddy bottoms. In this sedimentary succession dropstones or ice-rafted debris are missing and the Passinho shale marks the maximum flooding surface of the Itararé succession. These are capped by the fluvio-deltaic deposits of the Artinskian Rio Bonito Formation. Six facies-controlled, bivalve-dominated assemblages are recognized, representing faunal associations that thrived in aerobic to extreme dysaerobic bottoms along a nearshore–offshore trend. Within these assemblages, ninetheen bivalves species (four new) were recorded and detailed described. The presence of *Myonia argentinensis*, *Atomodesma* (*Aphanaia*) *orbirugata* and *Heteropecten paranaensis* suggests correlation with bivalve assemblages of the Bonete Formation, Pillahinco Group, Sauce Grande-Colorado Basin, Argentina, indicating a possible Late Asselian–Early Sakmarian age for this diverse post-glacial bivalve fauna. This age is also supported by the presence of *Praeundulomya* cf. *subelonagata* that ressembles *P. subelongata* Dickins from the Fossil Cliff Formation, Australia. Despite the age, typical members of the icehouse-style *Eurydesma–Trigonotreta* biota were not found in the studied bivalve fauna yet.

Keywords: Deglaciation, Taciba Formation, Bivalvia, Itararé Group, Early Permian, Paraná Basin.

1. Introduction

Sedimentary basins of the southeastern Gondwana contain a nearly complete Late Paleozoic stratigraphic record that document the glacial, terminal glacial, cold postglacial and semiarid to arid (Limarino et al., in press) climatic conditions that took place in this supercontinent during the Carboniferous–Permian interval (Rocha-Campos and Archangelsky, 1985; González, 1989; Simões et al., 1998; Limarino and Spaletti, 2006; Césari et al., 2007; Holz et al., 2010; Pagani and Taboada, 2010; Shi and Waterhouse, 2010). Contrary to the Argentinean western retroarc and arc-related basins, where thick Late Carboniferous up to Permian sequences yield abundant fossiliferous occurrences (González and Díaz Saravia, 2007, 2010; Pagani and Taboada, 2010), coeval marine macroinvertebrate assemblages in the Brazilian portion of the huge (up to 1,600,000 km^2, Holz et al., 2010), intraplate Paraná Basin (Fig. 1) are rare and poorly diversified (Rocha-Campos and Rösler, 1978; Simões et al., 1998).

In the last decade, various studies (Pagani, 2000, 2004a,b, 2005, 2006a,b; Sterren 2000, 2003, 2004, 2005; González, 2002a,b; 2006; Pagani and Sabattini, 2002, Cisterna and Sterren, 2010; Pagani and Taboada, 2010, Sterren and Cisterna, 2010; Taboada, 2010; Taboada and Pagani, 2010; Pagani and Ferrari, 2011) on marine invertebrate faunas of the Gondwana succession of Argentina were published. These faunas are mainly dominated by bivalve mollusks and brachiopods (González and Díaz Saravia, 2007; Pagani and Taboada, 2010; Sterren and Cisterna, 2010; Taboada, 2010; Taboada and Pagani, 2010). Thus, there are recent advances in our understandings of the paleobiogeography and biostratigraphy with obvious implications regarding the provincial affinities and age of the fossils assemblages (see a recent review in Pagani and Taboada, 2010). Indeed, those faunas are an essential tool to better constrain the age of major geologic and biotic events of southeastern portion of Gondwana supercontinent (see, for example, Simões et al., 1998; González and Díaz Saravia, 2007; Sterren and Cisterna, 2010), during the Late Paleozoic.

Despite the comments above, the use of the Late Paleozoic marine invertebrate faunas of South America to regional scale correlations, especially among the records of the intraplate basins (*i.e.*, Paraná, Chaco-Paraná, Sauce Grande-Colorado basins) (Fig. 1) is limited, since many of the Brazilian faunas remain poorly or even undescribed and illustrated. Among those faunas, the marine ones in the uppermost portion of the Itararé Group (Westphalian to Early Permian, Mori et al., 2012) (Fig. 2) are of particular interest to regional correlations. These assemblages are associated to a short transgressive-regressive episode at the end of the Late Paleozoic Ice Age (LPIA) in the Paraná Basin (Simões et al., 1998), recording the first appearance of typical Gondwanian marine bivalves in that basin (Rocha-Campos and Rösler, 1978; Simões et al., 1998). Although known since the pioneer work of Oliveira (1930) and Lange (1944), bivalves of those assemblages were poorly studied and a high number of undescribed species exist in the available collections. Actually, since Rocha-Campos (1969) most of data offered appears only in taxonomic check-lists (i.e., Rocha-Campos and Rösler, 1978; Simões et al., 1998). Therefore, the main aim of this contribution is threefold: first, to formally describe the bivalve species found in thin marine beds of the uppermost portion of the Taciba Formation (=Rio do Sul Formation), state of Paraná, Brazil; second, to add new biostratigraphic and age information, and finally, to interpret the bivalve-dominated assemblages in terms of their paleoenvironmental and facies distribution along the studied post-glacial succession of the Itararé Group.

2. Material and Methods

For this study, four main sets of bivalve shells were analyzed, which were reposited in the following fossil collections: a- DGP (Departamento de Geologia Sedimentar e Ambiental, IGc/USP, São Paulo, SP), b- DZP (Departamento de Zoologia, IBB/UNESP, Botucatu, SP), c- DGM (= Seção de Paleontologia da Divisão de Geologia e Mineralogia, Departamento Nacional da Produção Mineral, Rio de Janeiro, RJ), and d- URS (= Escola de Geologia da Universidade Federal do Rio Grande do Sul, Porto Alegre, RS). In the laboratory, the fossil material was prepared according to standard paleontological procedures (see Feldmann, 1989), using precision tools. Latex casts and plasticine molds were prepared for all shells. The fossils were also coated with magnesium oxide sublimate to enhance anatomical details (e.g., ornamentation, muscle scars etc.) for photography (see also Anelli et al., 2006, 2009; Pagani and Ferrari, 2011). The taxonomic analysis follows Waterhouse (2008; 2010), Bieler et al. (2010) and Carter et al. (2011) for the suprageneric categories, and Kegel and Costa, (1951); Harrington (1955); Dickins (1957; 1963); Morris et al. (1991); González (1997, 2006); Fang and Morris (1999), and Pagani (2000), for the genus and species level classification. Paleoecology interpretations of the autoecology of the studied bivalves are mostly based on Stanley (1970, 1972), Runnegar (1974), Kauffman and Runnegar (1975) and Aberhan et al. (2004).

In the field, three main sections were measured and, in addition to detailed lithologic description of major units, all potential event-stratigraphic units/surfaces were noted (see section 3), sampled, and described in as much detail as possible. However, deep weathering and the dense vegetation cover, along the studied outcrop belt, hampered this. All studied outcrops are located in the Teixeira Soares county, state of Paraná (see section 3). Fossil concentrations were sampled along the identified lithofacies (Table 1) and for each bivalve assemblage the following data were compiled (see Tables 2, 3): a- list of the species and their ecological characteristics; b- counts of abundance and dominance; c- vertical and lateral distribution of the identified taxonomic groups; and d- main taphonomic features with special attention to shell bed thickness, lateral continuity, geometry, contacts, shell packing, and taphonomic signatures of the shelly remains. Taphonomic descriptive terms are the same as in Kidwell et al. (1986), and Kidwell and Holland (1991). A combination of taphonomic and paleoecologic attributes were used for the identification of bivalve-dominated assemblages, and their skeletal concentrations were grouped according to the genetic classification scheme of Kidwell et al. (1986) and Kidwell (1993). Finally, the terms aerobic (bottom oxygen content= ml O_2/l H_2O >2), dysaerobic (moderate= ml O_2/l H_2O= 2–1; severe= ml O_2/l H_2O= 1–0.5; extreme= ml O_2/l H_2O= 0.5–0) and anoxic (ml O_2/l H_2O= 0) are used in the sense of Rhodes and Morse (1971), Tyson and Pearson (1991), and Wignall (1994).

3. General Geological Setting

In the intraplate Paraná Basin, the sedimentary deposits recording the Late Paleozoic Ice Age (LPIA, see Shi and Waterhouse, 2010) are mostly referred to the Itararé Group. The unit is up to 1500 m thick and contains several glacio-continental and glacio-marine as well as interglacial deposits (Vesely and Assine, 2004, 2006; Rocha-Campos et al., 2008; Holz et al., 2008, 2010; Limarino et al., in press). These associations are mainly represented by clastic rocks encompassing diamictites, sandstones, rhythmites, mudstones, shales, conglomerates and minor coal seams (Holz et al., 2010). Facies association are indicative of deposition by rain out processes, followed by downslope resedimentation, sediment gravity flows, turbidity currents, and minor lodgment tills (see Holz et al., 2010). Both subsurface as well as surface data indicate that in states of Rio Grande do Sul, Santa Catarina, and Paraná, the uppermost portion of the Itararé Group was mainly marine (Holz et al., 2010) (Fig. 2).

Based on subsurface data, França and Potter (1988) have divided the Itararé sucession into the Lagoa Azul, Campo Mourão and Taciba Formations. The Taciba Formation records the third major fining upward cycle of Itararé Group, including three members: Rio Segredo sandstone, Chapéu do Sol diamictite, and Rio do Sul (rhythmite, siltstone, and shale) (Castro, 1999; Weinschütz and Castro, 2004). On the other hand, surface data from the southern portion of the state of Paraná as well as in the neighboring of the state of Santa Catarina, indicate that the Itararé Group can be divided into three lithostratigraphic units, named Campo do Tenente, Mafra and Rio do Sul Formations (Schneider et al., 1974).

As recently suggested by Mineropar (2007), the subsurface, lithostratigraphical nomenclature of França and Potter (1988) can be applied to the surface deposits of the Itararé Group in the study area, Teixeira Soares county, state of Paraná. Locally, only the upper portion of the Taciba Formation is cropping-out, including diamictites, sandstones, siltstones and mudstones (Passinho shale) (Fig. 2). Three main outcrops were examined, as follow (Figs. 3, 4): a- Outcrop 1 (25°27’48’’S/50°23’25’’W), 14 km SE of Teixeira Soares town, at the Rio d’Areia community, along the margins of the homonymous river; b- Outcrop 2 (25°23’06’’S/50°26’53’’W), 2.2 km SE of Teixeira Soares town, along the margins of the Baitaca stream, and c- Outcrop 3 (25°23’15’’S/50°26’16’’W), Almas river valley, 4 km SE of Teixeira Soares town (Gruta neighborhood), at the unpaved road to Rio d’Areia community (Figs. 3, 4).

Five lithofacies (Facies A to E), mainly representing coastal (Facies A and B) and wave-dominated shelfal (C to E) settings, have been recognized (Table 1, Fig. 4). The lithofacies encompass proximal (Fig. 4, 5), nearshore (upper shoreface) (Fig. 5), inner shelf (transitional, lower shoreface) (Fig. 5) and outer shelf (offshore) (Fig. 5) deposits. The basal portion of the studied sequence is represented by a thick (10m) interval including pectinid-rich sandstone bodies, generated under shallow marine conditions influenced by waves and tides (Fig. 5) (see also Mineropar, 2007). In the middle interval, the sequence is dominated by fine-grained siliciclastic rocks, mainly very fine sandstones and siltstones, deposited by waves, as suggested by the abundance of structures indicative of oscillatory flows (*e.g.*, hummocky cross-stratifications, Fig. 5, 6). These are tempestite deposits that smoothered the bivalve fauna *in situ* (see also Rocha-Campos, 1966; Anelli et al., 1998; Simões et al., 1998). This is ~2m thick, amalgamated sequence of tempestites and are immediately followed by a thick (>30m) interval of massive or finely laminated mudstones or shales recording a transgressive event. Locally, this event is represented by the laterally persistent deposits of the fossil-poor Passinho shale (Facies E), which were generated under extremely dysaerobic to anoxic conditions. Despite the controversy in the literature (see Rocha-Campos, 1969, for a summary) evidences of glacial-generated deposits are absent in the study area (see also Maack, 1946; Mineropar, 2007, p. 108, for a similar conclusion), especially above the basal diamictite deposits (Fig. 4). After the transgressive event, fluvio-deltaic progradation took place, materizalized by the sand-dominated, coal-bearing deposits of the lower portion of the Artinskian, Rio Bonito Formation (Figs. 2, 4). Hence, the studied marine succession is associated to the post-glacial stage 3 (Cisuralian–Guadalupian) of Limarino et al. (in press). Therefore, as stated by those authors, and demonstrated by the data herein, the post-glacial time in the Paraná Basin, probably started in the uppermost part of the Taciba Formation (upper Itararé Group), where resedimented diamictites were replaced by shallow marine, nearshore to offshore deposits, latter capped by a fluvial succession (Artinskian, Rio Bonito Formation) (Mineropar, 2007) (Figs., 4, 5, 6).

4. Results and Discussion

4.1. Faunal Composition, Affinities and Age

In total, 297 bivalve specimens were studied, belonging to nineteen species (four new), encompassing thirteen families (Table 2). These are formally described in the section 5 below, and the taxonomic composition of the studied faunas is summarized in Table 2.

Shells of bivalve molluscs were recorded in all studied lithofacies (except Facies A). Three major groups of bivalves (Protobranchia, Pteriomorphia and Heteroconchia) are represented in the molluscan fauna (Table 2). Among them, epifaunal and semi-infaunal, suspension-feeding Pteriomorphia and infaunal, suspension-feeding Heteroconchia (mainly Sanguinolitidae Miller, 1877 and Pholadomyidae King, 1844) are particularly abundant and widespread in the unit (see section 5). Pectinida, especially Heteropectinidae Beurlen, 1954 (*Heteropecten paranaensis*) is the most abundant (n. 210) and widespread group, occurring in almost all lithofacies and assemblages (Table 3). Indeed, some fossil concentrations of Facies B are almost formed by shells of this pectinid species (section 4, and Fig. 5). Among the burrowing bivalves, the Sanguinolitidae and Pholadomyidae (formerly included into anomalodesmatans) are the most diverse groups (Table 2). The identified bivalve species were grouped into six fossil assemblages, as described in the section 4.2. (Tables 3, 4, Fig. 7).

These assemblages are surprisingly diverse compared to other coeval Late Paleozoic bivalve faunas (see Waterhouse and Shi, 2010), and record the oldest known typical Gondwanian marine species in the sedimentary succession of the Paraná Basin (Simões et al., 1998). Most of the identified bivalves are referred to cosmopolitan or widespread marine bivalves of Gondwana seas. Indeed, many of the identified genera are well represented in Late Paleozoic successions of the eastern intraplate (Sauce Grande-Colorado Basin), western retroarc (Paganzo Basin) and arc-related Argentinean basins (Río Blanco Basin) (Table A1). However, unlike Argentina, where the Late Paleozoic faunas are relatively diverse, better known, and more related with those of Australia (Cisterna and Sterren, 2010; Pagani and Taboada, 2010; Sterren and Cisterna, 2010; Taboada, 2010; Taboada and Pagani, 2010; Pagani and Ferrari, 2011), the usage of the Late Paleozoic bivalves from the Paraná Basin as a tool for biostratigraphic correlation with other South American basins is limited. Definitely, the meager marine bivalve faunas recorded in the Itararé Group, its restrict vertical and lateral distribution, and the high degree of provincialism (Runnegar, 1972; Rocha-Campos, 1973, Rocha-Campos and Rosler, 1978; Simões et al., 1998) are on of the main issues that mar the biocorrelations among the Paraná Basin and other South American Late Paleozoic faunas. As discussed forward, despite this unfavorable scenario, the improvement of the taxonomic knowledge of the marine bivalve assemblages of the Itararé succession support the notion that the biocorrelation and age of the analyzed faunas can only be roughly estimated on the basis of comparisons with other Late Paleozoic faunas of Gondwana, especially those from Argentina.

In this context, the intrabasin biocorrelation of the studied fauna is center on the thin marine intercalations (Butiá beds, see Rocha-Campos and Rösler, 1978) recorded in the upper portion of the Taciba Formation, Mafra county, state of Santa Catarina, which are also associated to post-glacial deposits (see Weinschütz and Castro, 2006; Simões et al., 2012) (Figs. 3, 6). In fact, fossil-rich, deeply bioturbated siltstones of the Taciba Formation cropping-out in abandoned walls of Butiá quarry, in Mafra (see Rocha-Campos, 1966; Weinschütz and Castro, 2006; Simões et al., 2012) (Fig. 3), yielded epifaunal and infaunal suspension feeding bivalves belonging to the same species found in Teixeira Soares. This bivalve assemblage is localy recorded above the last diamictites of the uppermost portion of the Taciba Formation, nearly ~45 m below the contact with the fluvio-deltaic, coal-bearing deposits of the Rio Bonito Formation (Weinschütz and Castro, 2006). In this context, the Butiá fauna, in the north of Santa Catarina state (Figs. 3, 6), is found in a roughly similar stratigraphic context and level of the Teixeira Soares fauna, as already indicated by Rocha-Campos and Rösler (1978). The Mafra fauna share in common with that of Teixeira Soares the following species *Heteropecten paranaensis* (=*Aviculopecten multiscalptus*) (see Simões et al., 2012 and Neves et al., submited) and *Myonia* argentinensis (Harrington) (see also Simões et al., 2012, p. 77). These indicate interbasin biocorrelation with the Bonetian, *Eurydesma* fauna, of the Sauce Grande-Colorado Basin, eastern Argentina (Harrington, 1955; Rocha-Campos and Carvalho, 1975; Pagani, 1998, 2000; González and Díaz Saravia, 2007), also by sharing the species *Atomodesma* (*Aphanaia*) *orbirugata* (Harrington). In other words, the bivalve faunas of the Taciba and Bonete formations share at least three species in common (Table A1). However, typical members of the icehouse-style *Eurydesma–Trigonotreta* biota were not found in the Taciba Formation yet (see a discussion in section 4.5). In addition, *Praeundulomya* cf. *subelonagata* ressembles *P. subelongata* Dickins from the Fossil Cliff Formation, western Australia. Finaly, but not least, the common occurrence of *H. multiscalptus* (=*Aviculopecten multiscalptus*), originally described to the Late Paleozoic deposits of the Cerro Prieto Formation, Amotape Mountains, Peru, in the upper portion of the Itararé Group, as cited in several taxonomic lists (e.g., Lange, 1954; Beurlen, 1954; Rocha-Campos, 1967, 1970; Rocha-Campos and Rösler, 1978; Simões et al., 1998; Simões et al., 2012), was not confirmed during the recent review of the Permian pectinids of Brazil and Peru (Neves et al., submited).

The biocorrelations discussed above highly indicate an Cisuralian age for the studied fauna. Indeed, Rocha-Campos and Rösler (1978) were the first authors to refer the faunas of the Passinho shale and coeval marine beds, in the upper portion of the Taciba Formation (Teixeira Soares and Butiá), to the Early Permian. In Argentina, the Piedra Azul and Bonete formations which are associated to the post-glacial interval of the Sauce Grande–Colorado Basin are referred to the Early Permian (Dickins, 1985; González and Díaz Saravia, 2007), probably Asselian–Sakmarian (Limarino et al., in press) or Asselian–Artinskian (Pagani, 2000) age. The fact that the Taciba Formation bivalve fauna is post-glacial (Weinschütz and Castro, 2006; Simões et al., 2012, p. 77), sharing some species with the Bonetian fauna, may indicate a similar or slightly older age (Limarino et al., in press) for the Brazilian fauna. Indeed, radiometric datings available for the above Early Permian deposits of the Paraná Basin (Matos et al., 2001;

Guerra-Sommer et al. 2006, 2008a,b,c; Rocha-Campos et al., 2006, 2007; Mori et al., 2012; Simas et al., 2012) indicate that the age of the studied bivalve fauna would not be younger than the Early Sakimarian.

4.2. General Taphonomy, Paleoecology and the Paleoenvironmental Distribution of the Bivalve-Dominated Assemblages

Shells of the nineteen identified bivalve species recorded in sedimentary facies of the uppermost part of the Taciba Formation are usually complete, and preserved as external or internal (predominantely) molds. In general, no signs of abrasion, bioerosion or encrusting are visible in the whole shells or fragments. In almost all identified assemblages, bivalve specimens with articulated (closed or splayed) shells, even those of epifauna were recorded, and some were preserved *in situ*. As shown in the tables 3 and 4, the vertical occurrence of some species is very restrict, suggesting a facies-controlled distribution. In contrast, some pectinid species (*H. paranaensis*) are recorded in all platformal deposits (except offshore muds) (Tables 3, 4). This inidicate that the palaeoenvironmental conditions may have been favourable for their abundant development in the Paraná epeiric sea during a short time interval in the Early Permian. Indeed, the climatic amelioration couplet with sea level fluctuations and the stablishment of sand-dominated shallow water environments may favour copious population development of this species.

As described in the section 3, among the studied lithotypes diamictites were replaced by shallow marine (nearshore) to offshore deposits containing organic-rich mudstones. Hence, these are forming a finnining-upward sequence representing various subenvironments, following postglacial eustatic flooding. This is tied to the increasing disintegration of Windhoek Ice Sheet (WIS, sense Santos et al., 1996), in southern Africa, and the Rio Grande do Sul ice cap, at the end of LPIA (Santos et al., 1996; see also the graphical abstract). As can be noted, each lithofacies seems to record assemblages with distinct bivalve abundances and species dominance. Hence, distinct ecologic guilds are also represented in the different studied deposits. In particular, the vertical distribution of the three main bivalve groups (Protobranchia, Pteriomorphia, Heteroconchia) seems to be tied to the environmental factors cited above. From the base to the top, the *H. paranaensis–Pleurophorella* sp. assemblage is characterized by a high proportion of epifaunal pteriomorphans and semi-infaunal bivalves (Tables 3, 4, Fig. 7), mainly occurring as disarticulated and slightly transported valves, in medium to fine-grained sandstones of Facies B. Hence, they are common in shallow water deposits, characterized by stable substrate mainly affected by waves and tides (Tables 3, 4). The three assemblages where heteroconchians are diverse were found in inner shelf to nearshore deposits, representing fine-grained siliclastic bottoms afected by storms (Table 3, 4). Slow, deep to shallow burrowing bivalves in these deposits (Facies D) may represent opportunistic species colonizing soft substrates frequentely affected by high-energy events. Finally, the impoverished *Phestia* sp.–*Palaeoneilobrasiliensis*. assemblage is found in massive to fine laminated mudstones or shales representing the maximum marine flooding (Passinho shale) at the topmost portion of the Taciba Formation (Figs. 2, 4, 5, 7). This assemblage is dominated by shallow burrowing, detritivorous feeding bivalves, suggesting offshore waters (below storm wave base) with oxygen-defficient, organic-rich muddy substrates (Tables 3, 4, Figs. 4, 7). In this context, the climatic amelioration may favored the bivalve-dominated communities to colonize diverse marine bottoms, under aerobic (Facies B to D) to extremely dysaerobic (Facies E) conditions. Hence, the lateral and vertical distribution of main identified bivalve assemblages seems to be primarily controled by a- substrate type, consistency and oxygenation, b- sedimentation rate, c- relative sea level changes, and d- possibly salinity fluctuations. In other words, those differences in species abundance, dominance, and ecological guilds are probably tied to the distinct sedimentary processes responsible by the genesis of studied lithofacies (see also Simões et al., 1998, p. 446).

4.3. Shell-bed genesis

As depicted above, the studied nearshore to offshore facies, and associated fossil assemblages were generated under a broad, short-lived transgressive event (Passinho flooding, see Santos et al., 1996). Hence, a spectrum of bioclastic deposits are recorded along a hypothetical nearshore-to-basin (outer shelf) transect (Facies B to E), where shelly concentrations were generated above fair-weather wave base (Facies B), between fair-weather and storm wave bases (Facies C–D), and smothered bottoms just at or below storm wave base (Facies E). Hence, some shell concentrations were produced under times of predominantly background or episodic (event) conditions.

Among the examined fossil occurrences two main types of shell concentrations (background and event concentrations) can be recognized. In this context, two of them are worth metioning here (see section 4.3.1.), considering the abundance of fossils and the taphonomic, paleoecologic and stratigraphic information locked on each bioclastic concentration, as follow.

4.3.1. Background Shell Concentrations

In this study, background concentrations are associated to sandstones of Facies B, which were mostly generated under shallow water conditions. These were prograding sandy bars, with ripples and flaser laminations, indicating a combined influence of waves and tides during deposition (Mineropar, 2007). In plan-view, *Planolites*-like traces are also recorded associated to the ripples, suggesting oxygenated sandy bottoms. Hence, currents and waves were among the main agents responsible by the lateral transport and sort of shells. The pectinid *H. paranaensis*, which the valves are the main source of bioclasts in those fossil concentrations (Maack, 1946, informally called these as pectinid-sandstones), was an epifaunal form. Their valves are distinctly biconvex with the right one nearly flat. This species thrived just at the sediment/water interface, with the flat right valve at the bottom. Hence, contrary to the burrowing bivalves of the other studied concentrations, after their fate the shells were prone to be at the sediment/water interface, and hence sorted and/or transported. These shells behaviour as sedimentary biomineralized particles, forming thin shell pavements (sense Kidwell et al., 1986). In these bioclastic concentrations disarticulated valves prevail, since of 75 specimens directly counted, from the same bedding plane of a given sandstone slab, 55 are left valves (L= convex) and 20 are right shells (R= ~flat). Hence, these valves have distinct frequencies and its L/R valve ratio is ~70:30. In other words, the left valves are much abundant, than the right ones.

Several detailed studies in comparative taphonomy showed that the proportion of left to right valves in bivalve-rich accumulations (Martin-Kaye 1951, Lever 1958, Lever et al. 1961, Kornicker et al. 1963, Lever and Thijssen 1968; Brett and Baird, 1986) can be used to infer shell transport, residence time in the sediment/water interface, and environmental energy (Simões et al., 2005; Chattopadhyay et al., 2013). Valve bias in bivalve-dominated concentrations is usually introduced by differences in the hydrodynamic properties of shells (see Chattopadhyay et al., 2013, for a recent synthesis). According to them, current velocity for the entrainment of a convex-up shell is generally determined by its size, and a lower velocity is necessary to mobilized smaller shells (compared to a larger one). The right and left valves of a single individual are glanced in distinct directions, according to its asymmetry (Chattopadhyay et al., 2013). As discussed in Simões et al. (2005), in modern shallow marine waters this phenomenon (50/50 valve deviation) seem to be a result of differential transport of one valve due to shell asymmetry. Hence, the distinct frequencies of both left and right valves in studied samples are suggestive of some degree of shell transportation (see also Chen et al., 2010). As shown by Hallman et al. (1996) and Simões et al. (2005), the biased ratio between convex or flat valves is a result of the differential transport of the convex shell. Laboratory experiments (Simões et al., 2005) showed that convex valves have lower average settling velocities, than the flat ones. Hence, during the action of currents and flows the convex valves are more easly transported in the water column and/or in contact with the sediment/water interface, whereas the flat valves settle early and are lag behind (Hallman et al. 1996, and Simões et al., 2005). Another evidence of shell transportation in the studied pectinid pavements is that the convex valves are almost all in a convex-up posture. Thus, the vast majority of valves are in a hydrodynamically stable attitude (Simões et al., 2005). This means that those shells were buried without influence of oscillatory, turbulent flows (see Kidwell et al., 1986; Fürsich and Oschmann, 1989; 1993, Simões et al., 2005). For example, if a storm generated turbulent flow had prevailed most of shells would be in a concave-up posture, including nested or stacked valves (Kidwell et al., 1986; Speyer and Brett, 1986; Fürsich and Oschmann, 1989, 1993; Simões and Kowalewski, 1998). As indicated by various authors (i.e., McFarland et al., 1999; Fürsich and Pandey, 2003), fossil concentrations dominated by convex-up shells were typically generated by waves or currents, above fair-weather wave base. However, signs of abrasion and fragmentation are almost absent in the studied shells. These data implies that those bioclasts underwent a short residence time at the sediment/water interface and have not been either transported for a very long time. Indeed, as noted by Kondo (1997), epifaunal bivalves are easily disarticulated even without disturbance. Hence, the shell pavements are a result of a short post-mortem transportation of the shells in the Facies B deposits, corresponding to parautochthonous to allochthonous (sense Kidwell et al., 1986) assemblages, generated during increasing of sedimentation rate, as suggested by the rare closed articulated epifaunal shells, during fair-weather times. Therefore, these are within-habitat time-averaged, primarily sedimentological concentrations without significantly secondary biogenic imprinting.

4.3.2. Event Concentrations

In the studied bioclastic accumulations event concentrations are especially common in deposits of Facies D, encompassing amalgamated storm deposits. Some are typical obrution beds (sense Seilacher et al.,1985), as those at the top of the sandstones sampled in the outcrop 2 (Tables 1, 3, Fig. 8). As such, they were accumulated through high energy events, with assemblages of intact, benthic organisms, typically preserved *in situ*. Detailed microstratigraphic observations shows that these deposits consist of, at least, two basic units (a buried horizon and an overlaying burial layer). In our case study, fine to very fine-grained, well sorted sandstones with hummocky cross-stratification and sharp and erosive basal contact are covered by a thin layer of high bioturbated siltstones, containg shells of infaunal, suspension-feeding bivalves. This layer (buried horizon) is sharply covered by very fine sandstones or siltstones with hummocky cross-stratification or highly biturbated siltstones or massive white (burial layer), as at the top of the section (Fig. 8). In this mudstones small, mostly left valves or rarely close articulated specimens of pectinid bivalves are also recored.

As shown in the geological section of outcrop 2 (Fig. 8), shells of slow, shallow to deep burrowers [*Myonia argentinensis, Cosmomya* (*Paleocosmomya*) *baitaquencis* and *Exochorhynchus itararensis*] (Anelli et al., 1998) were preserved in life position (*in situ*). The shells are preserved with closed articulated valves with the long axis oriented 40°–50° to the bedding. Antero-posterior, post-mortem compactation of the shells is also visible. They were smothered by fine-grained sediments (sandstones or mudstones), associated to distinct storm processes (migration of large sandy ripples, and the rapid deposition of suspended muds (muddy clouds, see Miller et al., 1988, for similar Devonian storm deposits). They represent superimposed storm events, which were responsible for the rapid burial of the infaunal suspension-feeding bivalves. Small, thin, chaotically oriented shells of *H. paranaensis*, some articulated in mudstones, may indicate the rapid settle of valves that were suspended in the water column.

In addition, profuse, penetrative biotrubation (Fig. 5, 8) is also recorded in those beds, sometimes destroying the primary sedimentary structures, obliterating the layer with *in situ* bivalves. These bioturbations were produced by benthic invertebrates probably during post-storm, fair-weather times. Hence, these were stacked storm beds, representing, in part, *Census* assemblages (sense Kidwell, 1993), with zero or limited time-averaging (hours to days), which were primarily generated by sedimentological processes (buried horizon), also including biologically disrupted, post-event layers (mainly the burial layer) (Fig. 8).

4.4. The Taciba Fauna in the Context of Early Permian Bivalve Diversification Event: Southern Portion of South American Gondwana

The faunas of the upper portion of the Taciba Formation are diverse, including cosmopolitan bivalves and also the first Gondwanian marine species in the Late Paleozoic succession of the Paraná Basin. According to the diversification patterns and faunistic turnovers of marine invertebrates in the Late Paleozoic successions of Argentina (González, 1997; Sterren and Sánchez, 2007; Sterren and Cisterna, 2010), the Early Permian successions (Asselian–Sakmarian) record a large diversification in Pteriomorphia bivalves, mainly in the Pterineidae and Mytilidae as well as in Heteroconchia (Trigoniida, Hiatellida) (Sterren and Cisterna, 2010). As discussed in preceding sections (4.1.), bivalves belonging to these groups are also abundant and diverse in the Taciba fauna. This diversification event of pterioid bivalves is probably linked to the global development of Pteriomorphia, in the Late Paleozoic (see also Babin et al., 1992; Morris et al., 1991; Sterren and Cisterna, 2010). As discussed by Sterren and Cisterna (2010), coeval transgressive events may have created various subenvironments, allowing benthic invertebrates, particularly bivalve mollusks. The assemblages of the upper portion of the Taciba Formation seem to be a record of this generalized Early Permian bivalve bioevent, in accordance with an Asselian to Sakmarian age of the fauna, within the post-gacial stage 3 (Cisuralian–Guadalupian) of Limarino et al. (in press). Hence, the diversification event encompassing the studied fauna is clearly related to a climatic amelioration that took place after Early Permian in this portion of the Gondwana.

4.5. The Puzzling Absence of Eurydesma *fauna in the Late Paleozoic Succession of the Paraná Basin.*

Holz et al. (2010, p. 397) correlated the uppermost part of the Itararé Group to the *Eurysdema* fauna of other parts of the South America Gondwana (Fig. 2). However, despite our efforts during the field samplings and the detailed examination of studied bivalve collections, typical cold-water genera (*Eurydesma*, *Deltopecten*) recorded in Australia and Argentina, were not found, in the Paraná Basin yet (see also Simões et al., 1998, p. 446). This puzzling absence of members of the icehouse style *Eurydesma–Trigonotreta* biota, given the estimate Late Asselian to Early Sakmarian age of the Taciba Formation, may be due to the prevalence of unvaforable environmental conditions or sampling bias, rather than a large-scale difference in age among those Brazilian and Argentinean–Australian faunas. As shown by Runnegar (1979), the *Eurydesma* fauna (in its restrict sense) thrived and preferred hard, clean bottoms and is mainly associated to rocky substrates or rocky shorelines. Deposits of the uppermost part of the Taciba Formation are a record of fine-grained, mainly stable, but soft substrates, largely devoid of bioclasts or coarse grains. Then, the rapid flooding of coastal areas, associated to the Passinho transgression may have reduced the amount of "rocky" substrata available for bivalve colonization (see also Runnegar, 1979, p. 281). Hence, habitat destruction associated to ice cap melting may be an important triggering factor of *Eurydesma* colonization in the studied marine deposits. However, data in Runnegar (1979) show that coeval Permian proximal to distal, sandy shoreface environmentswere colonized by *Schizodus*, *Myonia*, *Phestia*, *Heteropecten*, and *Streblopteria*. All these genera were recorded in the studied marine bivalve assemblages. Finally, this author also suggested that competition with Pachydomidae bivalves, especially *Myonia*, can locally cause the extinction of *Eurydesma* populations. Pachydomidae (including *Myonia*) and allied bivalves flourished into Paraná Basin, during the deposition of the upper part of Taciba Formation (Fig. 7). Hence, bivalve members that thrived in contemporaneous settings with *Eurydesma* are present in the studied fauna and the search for this remarkable bivalve in deposits of the Late Paleozoic of Paraná Basin is still praiseworthy.

5. Systematic Paleontology

Subclass Protobranchia Pelseneer, 1889
Order Nuculanida Carter, Campbell and Campbell, 2000
Superfamily Malletioidea H. Adams and A. Adams, 1858
Family Malletiidae H. Adams and A. Adams, 1858
Genus *Palaeoneilo* Hall and Whitfield, 1869

Type species. Nuculites constricta Conrad (1842, p. 249, pl. I, fig. 8), by subsequent designation of Hall (1885).

Palaeoneilo brasiliensis new species
Pl. 1, figs. 1–3

1969 *Antraconeilo itararensis* n. sp. nom. nud. – Rocha-Campos: 95–96.

Holotype: GP 1E/ 4385A

Paratype: GP 1E/ 4385B

Type locality and age: Teixeira Soares county, state of Paraná, Brazil. Late Asselian-Early Permian.

Derivation of the name: The name of the species refers to the country where shells were found, Brazil.

Diagnosis. Short and relatively high shell, with the anterior margin rounded and the posterior extremity slightly acute; taxodont hinge with 10 to 11 teeth in the posterior hinge area.

Description. Internal mold oval in shape, equivalve, inequilateral, inflated; moderately elongated, posteriorly elongate. Umbones depressed, positioned two fifth of length from the anterior extremity. Anterior margins rounded, continuous with convex ventral margin, posterior extremity slightly acute, dorsal margin slightly convex. Surface of internal mold with irregular spaced, weak, concentric lines and rugae. Taxodont hinge with 10 to 11 teeth in the posterior hinge area. Anterior hinge teeth and muscles scars not visible.

Discussion. Palaeoneilo brasiliensis n.sp. from the Taciba Formation differs from *Palaeoneilo* aff. *concentrica*, described by Gonzalez (1972), from the Las Salinas Formation (Chubut, Argentina), in being less posterioly extended, while the Argentinean specimens exhibit elliptic shape. *Palaeneilo* sp. from the Itararé Group differs from *P. amosi* González, 1977 by its shorter and higher shell. The Brazilian species also can be distinguished from *P. gonzalezi* and *Palaeoneilo* sp., from the Tepuel-Genoa Basin (Pagani, 2004a), by its surface ornament sculpeted by finer growth lines, and by the absence of a sinuosity in the ventral margin. Addionally, the species of the Taciba Formation does not show umbonal carina and is much less posterioly elongated, than all of the above mentioned Argentinean species. Finally, the Brazilian species differs from *P. subquadratum* González, 1992, from the Rio Blanco Basin (western Argentina), by its more expanded anterior extremity.

Material. Two internal molds of butterflied valves, GP 1E/ 4385A and GP 1E/ 4385B (see Table A2).

Occurrence. Uppermost portion of the Taciba Formation, Passinho shale, Itararé Group, Paraná Basin,Teixeira Soares region, state of Paraná, Brazil.

Ecology. Facultatively mobile, infaunal, deposit feeder.

Superfamily Nuculanoidea H. Adams and A. Adams, 1858 (J. Gray, 1854)
Family Nuculanidae H. Adams and A. Adams, 1858 (J. Gray, 1854)
Genus *Phestia* Chernyshev, 1951

Type species. Leda inflatiformis Chernyshev (1939, from Carboniferous of Russia).

Remarks. As discussed by Pagani (2004b) and González (2006), *Phestia* and *Polidevcia* were grouped by Chernyshev (1951) into a subfamily of Paleozoic nuculanoids. Both Paleozoic genera are considered valid by Kumpera et al. (1960) and Waterhouse (1964), based on the nature of the escutcheon. Nakazawa and Newell (1968) and González (1969, 2006) judged *Polidevcia*, as a subgenus of *Phestia*. In this study we follow these authors.

Phestia sp.
Pl. 1, figs. 4–9

1969 *Nuculana woodworthi* (Oliveira) 1930 – Rocha-Campos: 97.

Description. External mold of small shell, very inequilateral, tapering posteriorly with an acute rostrum. Umbones orthogyrous, small, depressed, positioned at anterior third of shell length. The greatest height of the shell occurs at umbones. Anterior margin rounded; ventral margin convex; posterior-dorsal margin straight. Surface ornamentation of thin comarginal striae parallel to the ventral margin. Hinge features and muscles scars unknown.

Discussion. The studied specimens of the Taciba Formation are very similar in general shell shape to *P. sabattinae* Pagani, 2004b, described for the Monjón de Hierro Formation (Pagani, 2004b) and also recorded in the Río Genoa Formation (Pagani and Ferrari, 2010), Argentina. Both species have orthogyrous umbones and straight posterior-dorsal margin, features which also distinguishe the Brazilian species from the

Argentinean species: *P. tepuelensis* González, 1969, *P. regularis* Pagani, 2004b, *P.* sp. Pagani, 2004b, *P.* sp. *aff. P. bellistriata* (see Sterren, 2004) and *P.* sp. (Sterren, 2005). In these species the dorsal margin varies from slightly to strongly concave and the umbones are opisthogyrous. In Australia, *P. lyonsensis* (Dickins) from Lyons Group, Carnavon Basin (Dickisn, 1963), ressembles the Taciba species, but its poor preservation does not allow closer comparisons.

Material. Six fragmented shells, DGM-4336 A–F (see Table A2).

Occurrence. Uppermost portion of the Taciba Formation, Passinho shale, Teixeira Soares region, Itararé Group, Paraná Basin, Brazil.

Ecology. Facultatively mobile, infaunal, deposit feeder.

Infraclass Pteriomorphia Beurlen, 1944
Order Mytilida Férussac, 1822
Superfamily Mytiloidea Rafinesque, 1815
Family Mytilidae Rafinesque, 1815
Subfamily Mytilinae Rafinesque, 1815
Genus *Promytilus* Newell, 1942

Type species. Promytilus annosus Newell (1942, p. 37–39, figs. 9–10).

Promytilus sp.
Pl. 2, figs. 1, 2

1969 *Myalina* (*Myalinella*) sp. – Rocha-Campos: 82, pl. VI, fig. 13.

Description. Internal molds elongate, mytiliform, oval in outline, prosocline. Hinge line slightly convex, less than half size the total length of shell. Anterior lobe very small when present. Beaks slender, terminal, not lobed. Very weak and rounded umbonal ridge runs from beaks to the postero-ventral margin. Anterior margin straight and ventral margin convex, posterior margin almost straight, subparallel to ventral margin. Surface of right valve ornamented with faint commarginal growth lamella. Growth lines not observed. Hinge features and muscle scars unknown.

Comments. Promytilus is a cosmopolitan genus that has been described in several Late Paleozoic deposits of the South America (Harrington, 1955; González, 1975, 2002a; Pagani, 2000, 2005). Unfortunately, the species of the uppermost portion of the Taciba Formation, does not allow close comparisons with other coeval species, due to its poor preservation.

Material. One internal mold of conjugated valves, DGM 1 (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary low-level epifaunal suspension feeder.

Genus *Volsellina* Newell, 1942

Type species. *Pleurophorus subellipticus* Meek , by original designation of Newell (1942, p. 42).

Remarks: The material was designated under the genus *Volsellina*, according to Newell (1942) view: bivalve with elongate shell, subterminal beaks with small anterior lobe; ventral and dorsal margins almost straight.

Volsellina areiensis new species
Pl. 2, figs. 9–16

1969 *Volsellina australis* n. sp. nom. nud. – Rocha-Campos: 76–79, pl. VI, figs. 5–11.

Holotype: DGM-4369, internal mold of conjugated valves.

Paratypes: GP/1E-4370, DGM-4371A, DGM-4371B, DGM-4384.

Type locality and age: Outcrop 1 (Rio d'Areia locality), Teixeira Soares region, state of Paraná, Brazil. Late Asselian–Early Permian.

Derivation of the name: The name of the species refers to the locality where shell were found, Areia river.

Diagnosis. Internal mold of shell strongly elongate posteriorly, with posterior margin espatuliform; dorsal and ventral margins in variable angle nearly 30^o, sometimes subparalell; ventral margin twice as long than dorsal margin.

Description. Internal mold very elongated posteriorly, with straight dorsal and ventral margins forming an angle of around 30^o; ventral margin nearly twice as long than the dorsal; anterior region strongly reduced, bearing a small rounded lobe; posterior extremity espatuliform and rounded. Umbones reduced with orthogyrate beaks, close to anterior end of shell. A very faint and wide umbonal carina extends from umbones to postero-ventral angle. Surface of internal molds ornamented with well marked comarginal lamella. Hinge features and muscles scars not observed.

Discussion. *V. areiensis* n.sp. close resembles *V. subelliptica* (Meek), described by Newell (1942), on the basis of specimens from the Pennsylvanian of Texas and Nebraska. However, the North American material is posterioly eloganted, while the studied shell is transversely (dorso-ventral) elongated.

Material. Two internal molds of conjugated valves, DGM-4369, DGM-4371B, two internal molds of left valves GP/1E-4370, DGM-4371A and one internal mold of right valve DGM-4384 (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary epifaunal suspension feeder.

Order Myalinida H. Paul, 1939
Superfamily Ambonychioidea S. A. Miller, 1877
Family Myalinidae Frech, 1891
Genus Myalina De Koninck, 1842
Subgenus *Myalina* (*Myalinella*) Newell, 1942

Type-species. Myalina meeki Dunbar, by original designation of Newell (1942, p 60).

Myalina (*Myalinella*) sp.
Pl. 2, figs. 3, 4

Description. Internal mold of shell strongly prosocline, subtriangular. Hinge line slightly convex, almost the total length of shell. Beaks slender, terminal, not lobed. Antero-dorsal margin straight, ventral margin convex, posterior margin slightly rounded. Surface of right valve, as seen in the external mold, ornamented with faint commarginal growth lamella. Hinge features and muscle scars unknown.

Discussion. The single specimen of *Myalina* (*Myallinella*) sp. from Taciba Formation, an internal mold of conjugated valves, does not show internal diagnostic features. However, it seems to have some similarities in shape with *Myalinella amosi* González, 1980, from Late Paleozoic of Chile. Yet, the Brazilian species has a shorter anterior margin and a greater ventral margin, being a less elongated shell than the Chilean one. The studied material also resembles, in the general shell shape, *Myalina* (*Myalinella*) *exasperata* Beede, from Kansas (Newell, 1942). However, in the Brazilian shells the anterodorsal margins are straighter than in the North American species.

Material. One internal mold of conjugated valves, GP/1E-709 (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary epifaunal suspension feeder.

Genus *Selenimyalina* Newell, 1942

Type species. Myalina meliniformis Meek and Worthen, by original designation of Newell (1942, p. 623).

Selenimyalina sp.
Pl. 2, figs. 5–8

1969 *Selenimyalina* sp. – Rocha-Campos: 81, pl. VI, fig. 12.

Description: Internal mold of shell moderately to strongly prosocline, almost equivalve, with left valve slightly inflated than the right one. Anterior region of shell strongly reduced, ventral margin straight; postero-dorsal margin slightly rounded, forming an obtuse angle. Umbonal region reduced and flattened. Beak small and not extended, forming a slightly acute angle with the anterior extremity. Angle between intersection of postero-dorsal margin of shell around (β angle) of 128^{o}. Faint comarginal lamella are present on the surface of internal mold. Hinge characters and muscle scars unknown.

Discussion. Selenimyalina sp. records the first occurrence of this genus in Late Paleozoic South American strata. In North America, *Selenimyalina meliniformis* Meek and Worthen, 1866, described by Newell (1942), resembles the Brazilian species, in the general shape. However, both are distinguished by the postero-dorsal margins, forming an obtuse angle in the Taciba shell, while in the North America one the margins are rounded and continuous.

Material. One internal mold of conjugated valves, GP/1E-698; one internal mold of left valve, DGM-4372; one external mold of left valve, DZP-18884C (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary low-level epifaunal suspension feeder.

Superfamily Inoceramoidea C. Geibel, 1852
Family Atomodesmatidae Waterhouse, 1976
Subfamily Atomodesmatinae Waterhouse, 1976
Genus *Atomodesma* Beyrich, 1864

Type species. Atomodesma exarata Beyrich (1894, p. 71, plate 3 figs. 4a*,* b), by subsequent designation of Wanner (1922, p.63).

Remarks. As stated by Gonzalez (2002a), species of the genus *Atomodesma* have a mytiloid-like shell, showing variable shape and terminal anterior umbones. Externally, the shells are ornamented by very conspicuous rugae. Taxonomical uncertainties prevailed for several years, especially due to transitional character observed in the ligament area (Newell and Boyd, 1987), causing misunderstood in species designated under the genus *Atomodesma*, *Aphania* de Koninck, *Intodesma* Popov and *Kolymia* Likharev. Dickins (1963) was the first author to consider *Atomodesma* as a compact group, with three subgeneric categories: *A.* (*Atomodesma*), *A.* (*Aphanaia*) e *A.* (*Kolymia*). Later, Kauffman and Runnegar (1975) considered *Kolymia* as a distinct genus. They also designated a new subgenus to *A.* (*Intodesma*), which is recognized by a developed umbonal area and shell surface ornamented by very strong, assimetric and irregularly spaced commarginal rugae. These authors commented that the subgenus *A.* (*Aphanaia*) is identified by the absence of radial sulci and folds on the anterior flank. Here, the above proposals of Kauffman and Runnegar (1975) are followed.

Subgenus *Atomodesma* (*Aphanaia*) Konick, 1877

Type species. Inoceramus micthelli M'Coy (1847, p. 299, pl. 14, fig. 1), by subsequent designation of Newell (1942, p. 76).

Atomodesma (*Aphanaia*) *orbirugata* (Harrington), 1955
Pl. 3, figs. 1–3

1969, *Atomodesma* (*Atomodesma*) sp. – Rocha-Campos: 84–87, pl. VII, figs. 1–3.

Description. Conjugated internal mold subequivalve, some specimens showing right valve slightly inflated than left; strongly oblique; posteriorly extend, moderately inflated, inflation greatest just behind beaks on posterior dorsal portion of shell; right valve slightly inflated than left one. Umbones inflated and prominent; beaks of right valve situated slightly anterior to left valve, terminal, weakly prosogyrate, situated slightly above dorsal margin. Anterior auricle absent, posterior auricle defined only on right valve, separated from the main shell by a faint sulcus. Dorsal margin nearly straight, posterior extremity broadly rounded; ventral margin straight. Anterior and posterior umbonal carina faintly marked in internal mold. Ornamentation as seen in the internal mold of faint, slightly rounded, irregularly spaced comarginal rugae. Comissure line smooth. Ligament, hinge features and muscles scars not observed.

Discussion. A. (*Aphanaia*) *orbirugata* resembles *A. exaratum* Beyrich described by Dickins (1956) from Permian beds of the Carnavon Basin. Both shells are prosocline with terminal beaks and the anterior auricle is absent. Yet, in these shells the external surface is ornamented by concentric folds. The umbonal septum is small and weak. However, as discussed by Pagani (2000), in *A. exaratum* a fold separates the posterior auricle from the body of shell, the umbonal area is higher and incurved under the cardinal margin. We agree with Pagani (2000) that *A.* (*Aphanaia*) *orbirugata* also differs from *A.* (*Atomodesma*) *bisulcata* Dickins (1961) from the eastearn portion of Australia and northeast of Siberia, by the presence of anterior canals until the margin of shell.

Material. DZP-18832A, internal mold of conjugated valves (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Semi-infaunal, bissate, suspension feeder.

Atomodesma (*Intodesma*) sp.

Pl. 3, figs. 4–6

Description. Internal mold subequivalve; oblique, posteriorly extend, inflated, left valve slightly large than the right. Umbones inflated and prominent, with terminal beaks, very slightly prosogire, positioned above cardinal margin. Anterior auricle absent, posterior auricle observed only on the left valve. Anterior margin slightly convex; anterior cardinal margin straight, ventral and posterior margin rounded. Shell flattened all around ventral and posterior extremity. Anteriorly, a faint anterior umbonal septum is observed in the left valve and a posterior sulcus separates the auricle from the main part of the shell. Shell ornamentation of well marked irregularly spaced asymmetric comarginal rugaes.

Discussion. Atomodesma (*Intodesma*) sp. differs from *A.* (*Aphanaia*) *orbirugata* by the presence of a poorly developed posterior auricle, prominent umbones and well marked asymmetric irregularry spaced commarginal rugaes. *A.* (*Intodesma*) sp. from the Taciba Formation resembles, in the general shape, ?*Atomodesma* sp. described by Gonzalez (1986), based on specimens from the Late Paleozoic of Patagonia. Unfortunately, the Argentinean material is poorly preserved for a more detailed comparison. Pagani (2004b) described *Atomodesma* (*Intodesma*)? sp. from the Early Permian beds of the Tepuel-Genoa Basin, that share the same ornamentation (well marked commarginal rugae) with the Itararé species.The studied specimen ressembles *A.* (*Atomodesma*) *mytiloides* Beyrich, 1864, and *Atomodesma* cf. *timorensis* described by Dickins (1963, p. 67–69), showing prominent umbones, posterior auricle poorly developed and shell ornamented by well marked commarginal rugaes.

Material. One internal mold of conjugated valve, DZP-18831 (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Semi-infaunal, bissate, suspension feeder.

Order Ostreida Férussac, 1822

Family Pterineidae Meek, 1864

Genus *Leptodesma* Hall, 1883

Subgenus Leptodesma Hall, 1883

Type species. Leiopteria dekayi Hall (1883, p. 8), by subsequent designation of Miller (1889, p. 484).

Remarks. The genera *Leptodesma* and *Leiopteria* are difficulty to be recognized, and are, sometimes, misinterpreted with *Merismopteria* Etheridge and *Pteria* Scopolli. In all those shells the internal features are poorly known, rendering proper identification. As discussed by Anelli et al. (2006, p. 1130), based on the shape of the anterior auricle, Newell and La Rocque (1969) separate *Leptodesma* in two subgenera. In *L.* (*Leptodesma*) the auricle is acuminate, whereas it is rounded in *L.* (*Leiopteria*). Rode (2004) discussed that the shape of *L.* (*Leptodesma*) is oblique and the shell is smaller, having a less pronounced byssal sinus. Some authors, as Williams and Breger (1916), and Bradshaw (1999), noted a presence of an anterior clavicle or septum in *L* (*Leiopetria*). They also verified that the shells of *L.* (*Leptodesma*) are smaller in size and with a less pronounced byssal sinus.

Leptodesma (*Leptodesma*) sp.
Pl. 3, fig. 7

Description. Internal mold of left valve, small, prosocline, very elongate, inflated. Umbones close to anterior extremity, slightly projected above hinge line; beaks prosogyrate. Anterior auricle small, subtriangular with anterior extremity acuminate. Posterior auricle large, well-defined, flattened, with almost the length of the shell. Antero-dorsal margins straight, ventral margin concave, posterior margin not well preserved. A weak sulcus radiates from umbonal area to ventral margin. Septum weak running from the umbonal area. Angle between dorsal margin and posterior umbonal slope around 25°. Hinge line extending the full length of valve. Muscle scars and hinge features not observed.

Discussion. The specimen GP/1E-4362, from the Taciba Formation, was included in the *Leptodesma* (*Leptodesma*) due to the pronounced obliquity of the shell; the presence of an acuminate anterior auricle and weak byssal sinus. In general shape, this specimen resembles *Leptodesma*? sp., described by González (1992), from the western Argentina.

Material. One internal mold of left valve, DGM-GP/1E-4362 (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Leptodesma (*Leiopteria*) sp.
Pl. 3, figs. 8–10

1969, *Leiopteria paranaensis* n. sp. nom. nud. – Rocha-Campos: 89–92, pl. VII, figs. 4–8.

Description. Internal mold small, strongly inequilateral, oblique; umbonal region of left valve inflated, posteriorly compressed. Umbones slightly above dorsal margin, beak prosogyrate. Posterior umbonal slope slightly concave, diverging around 20° from posterodorsal margin. Anterodorsal margin straight; Anterior extremity rounded, producing lobate auricle; ventral margin with tenuous concavity at intersection with poorly defined sulcus that radiates from umbonal area. Posterodorsal marginexpanded in short posterior wing. Surface of internal molds with large growth corrugation varying in size. Muscle scars and hinge features not observed.

Discussion. L. (*Leiopteria*) sp. ressembles to *L.* (*Leiopteria*) *dutoiti* (Harrington, 1955), from Sierras Australes, Argentina (Pagani, 2000). The Itararé species differs from *L.* (*Leiopteria*) *bonaerensis* Harrington, from the Bonete Formation (Pagani, 2000), by its less inflated umbones and the finer and external ornamentation yielding numerous growth lines. The Taciba specimens also resembles *Leiopteria*? *carrandibbiensis* Dickins (1957), described from western Australia. However, the Brazilian species have more extended posterior auricles, more elongate and inflated posterior extremities.

Material. Three internal molds of left valves, DGM-4377, DGM-4378, GP/1E-4371 (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary epifaunal suspension feeder.

Order Pectinida Gray, 1854
Superfamily Chaenocardioidea S. A. Miller, 1889
Family Streblochondriidae Newell, 1938

Subfamily Streblopteriinae Waterhouse, 2008
Genus *Streblopteria*, M'Coy, 1851

Type species. Meleagrina laevigata M'Coy (1844, p. 80, pl. 12, fig. 5), by subsequent designation of Meek and Worthen (1866, p. 333) and Miller (1889, p. 514).

Streblopteria sp.
Pl. 4, fig. 13

1969, *Streblopteria* sp. – Rocha-Campos: 54–55, pl. I, figs. 3.

Description. Internal mold of left valve small, oval in shape, higher than long, slightly inflated, acline. Umbones not observed. Both auricles are fragmented. Anterior auricle separated from the shell by narrow byssal sinus. Cardinal margin seems to be straight. External surface of hell ornamentated by faint and fine growth lines. Hinge features not observed.

Discussion. The genus *Streblopteria* was recorded in some South America and Australia faunas. *S. montgomeryi* González, 2006, from Early Permian of the Patagonia beds (Argentina), may be distinguished from the Brazilian species in being much longer than higher. *S. lagunensis* Pagani, 2006a and *S. minuta* Pagani, 2006a, described for the Early Permian beds from the Tepuel-Genoa Basin (see also Pagani and Ferrari, 2010), differ from the Brazilian species, respectively, by a well marked triangular umbonal area and thicker concentric rugae. Dickins (1963, p. 88) described *Streblopetria* sp. from western Australia, which is remarkable similar to *Streblopteria* sp. from the Itararé Group. Both are oval in shape, slightly inflated and ornamented by fine growth lines. However, the poor preservation of the auricles and hinge area of the Brazilian specimen does not allow more detailed comparisons.

Material. One internal mold of leftvalve, GP 1E 4373 (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary epifaunal suspension feeder.

Superfamily Heteropectinoidea Beurlen, 1954
Family Heteropectinidae Beurlen, 1954

Subfamily Heteropectininae Beurlen, 1954

Genus *Heteropecten* Kegel and da Costa, 1951

Type species. Aviculopecten catherinae Reed (1930, p. 10–16), by original designation.

Heteropecten paranaensis Neves et al. (submited)

Pl. 4, figs. 1–12

Remarks. Neves et al. (submited) noted that, contrary to traditional view (Beurlen, 1954, 1955; Rocha-Campos, 1969, 1970; Rocha-Campos and Rösler, 1978), the pectinids of the Itararé Group can not be assigned to *Aviculopecten* M'Coy, 1851. The shell shape, convexity, and ornamentation are the same of *Heteropecten* Kegel and Costa, 1951. Hence, the specimens of Teixeira Soares region were all attributed to *Heteropecten paranaensis*, as in Neves et al. (submitted).

Material. Two external molds of left valves DGM-4379 and DZP-18883; Four internal molds of left valves, DGM-4348A, DGM-4358; GP/1E-4362 B; DZP-18814; two internal molds of conjugated valves, DGM-4348C and DGM 4361; one internal mold of right valve, DZP-18810A2; two external molds of right valves, DGM-4360 and DGM-4367 (see Table A2).

Occurrence. Outcrops 1 and 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Stationary epifaunal suspension feeder.

Infraclass Heterochonchia Hertwig, 1895

Order Trigoniida Dall, 1889

Superfamily Trigonioidea Lamarck, 1819

Family Schizodidae Newell and Boyd, 1975

Subfamily Schizodinae Newell and Boyd, 1975

Genus *Schizodus* de Verneuil and Murschison, 1844

Type species. Axinus obscurus Sowerby (1821, p.12).

Schizodus sp.

Pl. 4, figs. 14–16

1969, *Schizodus* sp.– Rocha-Campos: 94, pl. VII, figs. 12.

Description. Internal mold small, with length slightly greater than height, subcircular in shape, slightly inequilateral, equivalve, slightly elongated; moderately inflated. Umbones slightly inflated, above hinge line; beaks orthogyrous. Postumbonal ridge rounded. Anterodorsal margin continuous with rounded, expanded anterior extremity expanded. ventral margin convex; with large and rounded posterior extremity; posterodorsal margin straight. Lunule and escutcheon absent. External features unknown. Hinge very short. Muscle scars and hinge features unkown.

Comments. Schizodus sp. from the Paraná Basin is poorly preserved for a more accurate comparison with other South American species of this genus, as in Mendes (1966), Chronic (1953), González (1977, 2006), Sterren (2005), Anelli et al. (2009), Pagani (2006a) and Pagani and Taboada (2010). Hence, the studied spcimens are not referred to any known species of this genus.

Material. Two internal molds of butterflied valves DGM-4347 and DGM-4346; one internal mold of conjugated valves, GP/1E-692 (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Shallow infaunal, suspension feeder.

Superfamily Grammysioidea S. A Miller, 1877

Family Sanguinolitidae S. A. Miller, 1877

Genus *Sanguinolites* M'Coy, 1844

Type specie. Sanguinolaria? *angustata* Phillips (1836, p. 208, pl. 5, fig. 2), by subsequent designation of Hind (1900, p.367).

Sanguinolites sp.

Pl. 5, fig. 4

Description. Internal mold elipitic, inflated. Umbones barely above hinge line, prosogyrous; umbonal carina rounded, weakly marked, running from the umbones to inferior angle of respiratory margin. Dorsal and ventral margins straight, parallel to subparallel, anterodorsal margin short, weakly convex; anterior margin rounded, continuous with weakly convex ventral margin; posterior margin truncated, defining respiratory margin; posterodorsal margin straight. Surface of internal mold ornamented with faint irregularly spaced comarginal rugae.Lunule small and deep. Escutcheon, muscle scars and hinge features not observed.

Discussion. According to González (1977, p. 129), *Sanguinolites* may include distinct forms or bivalves belonging to different genera, since the internal features are unknown. Indeed, the generic diagnosis has been only based on external characters, may leading to a gather of unrelated taxa with similar external shape. In this context, the Itararé species ressembles, in the general shape, *S. freytesi* González, 1977, and *S. turnei* González, 1977, from the Carboniferous beds of the Tepuel-Genoa Basin (Patagonia, Argentina).

Material. One internal mold of right valve, DGM-4340 (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Shallow infaunal, suspension feeder.

Genus *Praeundulomya* Dickins, 1957

Type-species. Praeundulomya concentrica Dickins, 1957, by original designation.

Praendulomya cf. *subelongata* Dickins, 1963
Pl. 5, figs. 1–3

1969, *Sanguinolites brasiliensis* n. sp. nom. nud. – Rocha-Campos: 70–72, pl. IV, figs. 1–3.

Description. Internal mold strongly inequilateral, equivalve, very elongate. Senile specimens strongly inflated; young specimens inflated to moderately inflated. Umbones subterminal; beaks slightly prosogyrous. Very shallow sinus broadens from umbo to ventral margin; moderately developed postumbonal ridge, extends to posteroventral extremity at low angle, nearly 25° with dorsal margin. Anterodorsal margin very short; anterior margin rounded; ventral margin weakly sinuous below sinus parallel to the dorsal margin. Posterior extremity rounded but defined with a respiratory margin with weak posterior grooves. Posterior gape not observed. Lunule well defined, oval in shape, small and deep; escutcheon elongated and narrow. Surface ornament of sharp, regularly spaced comarginal rugae. Hinge edentulous. Muscle scars not observed.

Discussion. The genus *Praeundulomya* was described by Dickins (1957), type species *P. concentrica*, from Carnavon Basin, western Australia. In 1963, the same author described the species *P. subelongata*, from the Fossil Cliff Formation, Irwin River area. This species is remarkable similar to the Brazilian specimens described in this study. Despite of that, the Itararé species was kept as *P.* cf. *subelonagata*, because the Australian type material was not checked. Dickins (1957) also described *P. elongata* from the Carnavon Basin, based on specimens that may be distinguished from the Brazilian ones by its more expanded posterior margin. *P.* cf. *subelonagata* also differs from the Argentinean species *P. moreli* González, 2006, by the absence of pustules at the commarginal rugae. *Praeundulomya* cf. *subelongata* from the Itararé Group also resembles, in the shell outline, *Vacunela camachoi* Rocha-Campos and Carvalho, 1975, from the Bonete Formation, Sierras Australes, Argentina.

Material. Two internal mold s of butterflied shells, DGM-4342 and DZP-2910A; one internal mold of right valve, DGM-4337 (see Table A2).

Occurrence: Outcrops 1 and 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Facultatively mobile, shallow infaunal, suspension feeder

Infrasubcohort Cardiida Férussac, 1822
Superfamily Kalenteroidea Marwick, 1953
Family Kalenteridea Marwick, 1953
Genus *Pleurophorella* Girty, 1904

Type species. Pleurophorella papillosa Girty (1904), by original designation.

Remarks. The material from the Taciba Formation is assigned to the genus *Pleurophorella* specially by the absence of cardinal teeth, presence of a well anterior adductor scar bounded at the rear by a buttress, and the presence of some very weak radial ribs in some internal molds.

Pleurophorella sp.

Pl. 5, figs. 5–10

Description. Internal mold of elipitic, inequilateral, inflated, transversely elongate, higher at posterior end. Umbones close to anterior extremity; beaks prosogyrous. Dorsal and ventral margins subparallel; anterodorsal margin greatly reduced; anterior extremity reduced and rounded; ventral margin varying from slightly convex and straight, with large but shallow sulcus close to midlength; posterior extremity rounded; posterodorsal margin almost straight. Lunule small; escutcheon elongated and narrow. Left valve with an elongate lateral tooth running dorsally from mid-length to posterior extremity; a corresponding socket is present in right valve. Anterior adductor muscle scar small, ovoid, located on anterior extremity. A shallow buttress is present behind anterior adductor.

*Comments.*The Itararé species is preserved only as internal molds, which difficult the examination of external features for more accurate comparions with other Late Paleozoic species of this genus.

Material. Five internal molds of left valves, DGM-4376; GP/1E-4372A; DGM-4374A; GP/1E-677; GP/1E-670, and one internal mold of right valve, DGM-4374 C (see Table A2).

Occurrence. Outcrop 1, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Facultatively mobile, shallow infaunal, suspension feeder.

Order Pholadomyida Newell, 1965

Superfamily Pholadomyoidea King, 1844

Family Pholadomyidae King, 1844

Genus *Cosmomya* Holdhaus, 1913

Subgenus *Cosmomya* (*Palaeocosmomya*) Holdhaus, 1913

Type species. Paleocosmomya teicherti Fletcher (1946, p. 402, pl. 34, fig. 4–6; pl. 35, fig. 7,8).

Remarks. Several gondwanic elements of the Late Paleozoic and Mesozoic strata show the surface ornamentation of shell with V-shaped ribs pattern, such as *Cosmomya* Holdhaus, *Palaeocosmomya* Fletcher, *Undulomya* Fletcher, *Pentagrammysia* Chernychev, and *Grammysiopsis* Chernychev, (Morris et al. 1999). The genus *Cosmomya* was originally described by Holdhaus (1913) for a Jurassic specimen with concentric ribs crossed by a groove running from the umbones toward the ventral margin, where the ribs are double inflected (see Gonzalez, 1969). Fletcher (1946) proposed the genus *Palaeocosmomya* to designate forms from the Permian beds of Australia that were related to *Cosmomya*. The genus *Siphogrammysia* Chernychev, 1950, from the Permian of the Malasya, also has a V-shaped ornamentation, but with very prominent vertical ribs (Morris et al., 1991). Additionally, Newell (1955) discussed that *Palaeocosmomya* differs from *Undulomya* in having a more pronounced siphonal gape and a Z-shaped flexure of the ornamentation behind the pedal area. Dickins and Shah (1965) considered *Palaeocosmomya* a subgenus of *Cosmomya*, in which the subgenera *C.* (*Cosmomya*) and *C.* (*Palaeocosmomya*) may be distinguished by details of ribbing ornamentation. In the first one, the posterior arm has a inverted V ribbing relatively shorter than in the second one. Although they show great similarity in the general shape, *C.* (*Palaeocosmomya*) shows the surface ornamentation with V-shaped rib pattern, differing by this feature from the genera *Vacunella* Waterhouse, 1965 and *Myofossa* Waterhouse, 1969. *Cosmomya* (*Palaeocosmomya*) differs from the genus *Undulomya* by its more pronounced siphonal gape (see Newell, 1955). The present study follows the view of Dickins and Shah (1965), with the genus *Cosmomya* grouping species in two subgenera.

Cosmomya (*Palaeocosmomya*) *baitaquensis* n.sp.
Pl. 6, figs. 9–15

1969, *Vacunela* cf. *Vacunella etheridgei* nom. nud.– Rocha– Campos: 58–60, pl. IV, figs. 4, fig. text 8d.

Holotype. DZP-18828

Type locality and age: Outcrop 2 (Baitaca stream) Teixeira Soares region, state of Paraná, Brazil. Late Asselian– Early Permian.

Derivation of the name: The name of the species refers to the locality where shell were found, Baitaca stream locality.

Diagnosis. Shell trapezoidal in shape, strongly inflated, very elongated posteriorly. Umbones orthogyrous to slightly prosogyrous Posterior extremit with strongly dorsal infletion. Two pronunced grooves run from the umbones toward the ventral margin. Posterior extremity with large siphonal gape. Surface ornamentat of V-shaped ribs pattern.

Description. Shell equi- or subequivalve, strongly inequilateral, trapezoidal in shape, very elongate posteriorly. Umbones moderately developed related to the hinge line, beaks orthogyrous to slightly prosogyrous. Dorsal margin concave; anterior margin convex continuous with moderately convex ventral margin; posterior margin rounded, with large siphonal gape, strongly inflexed dorsally. A distinct sulcus bordered by two pronounced ridges run from the umbones toward the ventral margin, Lunule and escutcheon well defined. Ornamentation of pronounced comarginal costae that flex over the umbonal ridges, where it assumes the V-shaped pattern. Hinge edentulous. Muscle scars anknown.

Discussion. The Brazilian specimens have a much more elongate shell than *C. (Palaeocosmomya) chubutensis*, described by González (1969), which is semicircular. Due to the poor preservation of the *C.* (*Palaeocosmomya*) sp. from Patagonia deposits, Argentina (Pagani, 2006b), is not possible to establishe close comparisons with the studied specimens, even though they share the same pattern of ornamentation. *C.* (*Palaeocosmomya*) *baitaquensis* n.sp. is remarkable similar to *C.* (*Palaeocosmomya*) *teicherti* (Fletcher), 1946, described by Dickins and Shah (1965), from Late Paleozoic deposits of the Carnavon Basin, western Australia. Itararé shells are much posteriorly elongated, with larger syphonal gaps and strongly dorsally projected posterior extremities.

Material. DZP-18828, DGM-4344 and DZP-691, internal molds of conjugated valves (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Facultatively mobile, deep infaunal, suspension feeder

Genus *Exochorhynchus* Meek and Hayden, 1865

Type species. ?*Allorisma altirostrata* Meek and Hayden (1858), by original designation.

Remarks. Morris et al. (1991) resurrect the genus *Exochorhynchus* to designate shells that are much shorter than *Undulomya maxima* Portlock. They also show no trace of internal dorsal posterior ribs, characteristically recorded in *Undulomya* and *Praendulomya* (Morris et al., 1991). These authors also examinated the type material of *Allorisma barringtoni* Thomas, 1928, from the Amotape Mountains, Peru, assigning them to *Exochorhynchus barringtoni*. Furthermore, Wilson (1959) placed *Allorisma* King, 1844, in synonymy with *Edmondia* de Koninck, 1842. According to this author, shells designated to *Allorisma*, but having a pallial sinus must be referred to *Wilkingia* Wilson, 1959.

Exochorhynchus itararensis n.sp.
Pl. 6, figs. 1–8

1969, *Allorisma barringtoni* – Rocha-Campos: 55–57, pl. III, figs. 2–8, fig. text 8a,b.

Holotype. DZP-18817C.

Paratypes. DZP-18822, DZP-18829A, DZP-18830, GP/1E-4438.

Type locality and age: Outcrop 2 (Baitaca stream), Teixeira Soares region, state of Paraná, Brazil. Late Asselian– Early Permian.

Derivation of the name: The name of the species refers to the Group in which the species was recorded, Itararé Group.

Diagnosis. Strongly inequilateral sanguinolitid shell, ornamented by regulary spaced commarginal rugae. Ventral margin rounded; posterior extremity very expanded, exceeding the dorsal margin.

Description. Internal mold oval in shape, equivalve, strongly inequilateral, strongly inflated, moderately elongate. Umbones above the hinge line, beaks terminal, slightly prosogyrous . Lunule and escutcheon absent. Posterior extremity large, varying from rounded to slightly truncated, exceeding the dorsal margin line; posterodorsal margin straight; ventral margin convex with slightly developed posterior gape. Surface ornament of regularly spaced comarginal rugae. Hinge features and muscle scars not observed.

Discussion. The Brazilian species resembles *E. barringtoni* (Thomas), 1928 from the Amotape Mountains, Peru (Chronic, 1953), but it may be distinguished by its well developed convex ventral margin. In the Peruvian species the ventral margins are straight to slightly convex. Besides, the extremity of the posterior margin of *E. itararensis* n.sp. is placed above the dorsal margin, while in the Peruvian it does not occur. The Itararé species is very distinct from *E. insolitum* (Thomas), 1928, also from Amotape Mountains, which shows a strongly posteriorly elongate shell. In Argentina, *Exochorhynchus* sp. described by Pagani (2006b) is not well preserved for close comparisons, although it bears a similar ornamentation.

Material. DZP-18817C; DZP-18830 and GP/1E-4438, internal molds of conjugated valves; DZP-18822 and DZP-18829A, internal molds of left valve (see Table A2).

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Facultatively mobile, deep infaunal, suspension feeder

Order Hiatellida Carter, 2011

Superfamily Edmondioidea W. King, 1850

Family Pachydomidae Fischer, 1887

Genus *Myonia* Dana, 1847

Type-species. *Myonia elongata* Dana (1847, p. 158), by subsequent designation of Fletcher (1932, p. 398).

Myonia argentinensis (Harrington), 1955

Pl. 7, figs. 1–6.

1969, *Myonia* ? sp. Rocha-Campos:63, pl. IV, fig. 5,6.

1970, *Myonia* (or *Vacunella*)? *argentinensis* (Harrington); Rocha-Campos: 607, fig. 3.

1975, *Myonia* (or *Vacunella*)? *argentinensis* (Harrington); Rocha-Campos and Carvalho: 186, 189, pl. 1, figs. 13–14.

2012, *Myonia argentinensis* (Harrington); Simões et al.: 76–77, figs. 4G–M.

Remarks. Rocha-Campos and Carvalho (1975) pointed out that *M. argentinensis* is similar to *Myonia* or *Vacunella*? sp. described by Runnegar (1967) from Queensland, Australia. Runnegar (1967) and González (1989) agreed about that great similarity between those Argentinean and Australian species. Later, Pagani (2000) attributed *Myonia* (or *Vacunella*)? *argentinensis* to *Stutchburia argentinensis*. However, very recently, Simões et al. (2012) assigned the specimens referred to *Stucthburia*? *argentinensis* by Pagani (2000) to *Myonia argentinensis* (Harrington), from the Bonete Formation, Sierras Australes, Argentina. *M. argentinensis* are also recorded in the Taciba Formation, at Mafra locality (Simões et al. 2012).

Material. Three internal molds of conjugated valves, DGM-4341, DZP-18826, GP/1E-700.

Occurrence. Outcrop 2, uppermost portion of the Taciba Formation, Itararé Group, Paraná Basin, Teixeira Soares region, state of Paraná, Brazil.

Ecology. Shallow infaunal, suspension feeder.

6. Concluding Remarks

On the basis of the taphonomic, taxonomic, and paleoecologic data gathered, the following main conclusions are highlighted:

- in the the uppermost portion of the Taciba Formation, Itararé Group, above the last diamictites, the unit encompass a thin (>50 m) package of marine deposits starting with sandstones and closing with thin package of shales, which record nearshore to outer shelf (offshore) settings. In this sedimentary succession dropstones or ice-rafted debris are characteristically lacking (see also Mineropar, 2007). Hence, this finning-upward marine succession is tied to the demise of Late Paleozoic glaciation, accompaining the desintegration of the WIS and ice caps around the Paraná Basin (see Santos et al., 1996). In this paleogeographic scenario, the Passinho shales, representing organic-rich, oxygen-defficient environments, mark the maximum flooding surface of the upper portion of the Taciba Formation, and is capped by the fluvio-deltaic deposits of the Artinskian Rio Bonito Formation;

- nineteen bivalve species (four new), distributed in six bivalve-dominated assemblages, were recorded, representing shallow-water to offshore associations that thrived in aerobic to extremely dysaerobic bottoms. The fauna also records the first typical marine bivalves of Gondwana affinities within the sedimentary succession of the Paraná Basin, and is very diversified in comparison to other coeval Late Paleozoic bivalve faunas of South America and Australia. Bivalve diversity may be linked to climatic amelioration and the appearance of several benthic, shefal siliciclasic-dominated subenvironments, which acompained the post-glacial transgression;
- the presence of *Myonia argentinensis*, *Atomodesma* (*Aphanaia*) *orbirugata* and *Heteropecten paranaensis*, among others [e.g., *Leptodesma* (*Leiopetria*) sp.], suggests correlation with bivalve assemblages of the Bonete Formation, Pillahinco Group, Sauce Grande-Colorado Basin, Buenos Aires Province, Argentina, indicating a Late Asselian–Early Sakmarian age for this diverse post-glacial bivalve fauna. This is also supported by the presence of *Praeundulomya* cf. *subelonagata* that ressembles the Sakimarian *P. subelongata* from the Fossil Cliff Formation, Australia, and recent radiometric ages, mainly single-crystal zircon U–Pb SHRIMP ages, available in the literature for the above Rio Bonito Formation.
- despite the biocorrelations above, *Eurydesma* was not found in the Paraná Basin yet. However, rather than the age, habitat destruction and/or ecologic competition as well as taphonomic and sampling bias, may be responsible for the absence of typical members icehouse-style *Eurydesma–Trigonotreta* biota in its *stricto sensu* into Paraná Basin.

Acknowledgements

Fieldwork was financially supported by the state of São Paulo Research Foundation (FAPESP) and National Council for Research and Development (CNPq), through the projects: FAPESP-1993/02747-0, 2009/17555-0, and CNPq-500694/92-3, 302903/2012-7. We thank Mrs Marcelha Paes Landim and Ivone Cardoso Gonzales (IGc/USP Collection Manager) for their help in the laboratory and bivalve collection management. Our thanks are also extended to the Department of Zoology, IBB/UNESP and Sedimentary and Environmental Geology, IGc/USP, which provided laboratory and logistic facilities.

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Figures, Plates and Tables captions

Fig. 1. Sketch map of main Late Paleozoic intraplate, retroarc and arc-related basins of South America, modified from Limarino and Spalletti (2006).

Fig. 2. Generalized chronostratigraphic chart of Late Paleozoic deposits of the Paraná Basin, showing the position of the studied marine deposits (Taciba Formation and coeval units) in the uppermost portion of the Itararé Group (modified from Holz et al., 2010).

Fig. 3. Location map of the three studied outcrops of the Taciba Formation, Teixeira Soares locality, State of Paraná, Brazil. Location of coeval, thin marine intercalations of the uppermost portion of the Taciba Formation, Mafra region (Butiá quarry), State of Santa Catarina, are also indicated.

Fig. 4. Simplified geological map and columnar sections of the uppermost portion of the Taciba Formation at the Teixeira Soares locality, State of Paraná, modified from Mineropar (2007). The distribution of lithofacies, fossil assemblages and sedimentary environments within the studied stratigraphic sections are also highlighted. (1) Composite geological section of the Taciba Formation, SE of Teixeira Soares locality, (2) Outcrop 2; (3) Outcrop 3, and (4) outcrop 1.

Fig. 5. Photographs of the lithofacies and hand samples recorded in the uppermost portion of the Taciba Formation, Teixeira Soares locality, State of Paraná. Facies A (1–3), proximal deposits characterized (1) (2) massive to stratified diamictites, showing (3)

rounded, granitic clasts. Facies B (1–3), (1) nearshore (upper shoreface) deposits including medium to fine-grained sandstones with ripple marks and flaser lamination, modified from Mineropar (2007), (2) planar cross-stratification and (3) shell pavements. Facies C (1–3), possible inner shelf deposits, showing (1) (2) deeply weathered siltstones with almost destroyed parallel-lamination, and profuse bioturbation and (3) well preserved, splayed-out shell of infaunal suspension-feeding bivalve. Facies D (1–3), transitional (inner shelf-nearshore) deposits mainly represented by (1) stacked fine-grained sandstones and siltstone with low angle cross-stratifications. Note the hummocky cross-lamination with profuse penetrative bioturbation (*Skolitos*-like traces, arrow). The sandstone with low angle cross-stratification is succeeded by (2) (3) deeply bioturbated siltstones, and massive mudstones at the top (2), sometimes with *in situ* bivalves (3). Facies E (1–3), outer shelf (offshore) deposits (Passinho shale) characterized by (1) laminated to (2) massive mudstones or shales, also including (3) rare splayed-out shells of detritus-feeding bivalves.

Fig. 6. Columnar sections of the uppermost portion of the Taciba Formation at Mafra region, State of Santa Catarina. (1) Columnar section of PP-10 borehole. (2) Columnar section of RB-3 borehole, modified from Weinschültz and Castro (2006). Note the thin, fossil-rich marine intercalation immediately above the diamicties in (2).

Fig. 7. Composition, abundance, dominance and guild structure of studied bivalve assemblages. Note the widespread distribution of *Heteropecten paranaensis* and the restrict presence of *Phestia* sp. and *Palaeoneilo brasiliensis* n.sp.

Fig. 8. Detailed columnar section of the base of Outcrop 2, Baitaca stream, SE Teixeira Soares locality, showing the interval where infaunal bivalves are preserved *in situ*, in association to low angle cross-stratifications (amalgamated tempestites). Note the abundant penetrative bioturbation in some intervals. (1) *Exochorhynchus itararensis* n.sp., (2) *Atomodesma* (*Aphanaia*) *orbirugata* and (3) *Myonia argentinensis*.

Plate 1. (1–3) *Palaeoneilo brasiliensis* n.sp. (1, 2) GP/1E-4385, (1) internal mold of butterflied valves, (2) latex cast of the same specimen. (3) SEM. NUM., internal mold of butterflied valves. (4–9) *Phestia* sp. (4) DGM-4336A, (5) DGM-4336D, (6) DGM-4336C, (7) DGM-4336G, (8) DGM-4336H, (9) DGM-4336F. Scale bar= 1cm.

Plate 2. (1–2) *Promytilus* sp., DGM-1, internal mold of conjugated valves. (1) right valve view, (2) left valve view. (3–4) *Myalina* (*Myalinella*) sp., GP/1E-709, internal mold of conjugated valves. (3) right valve view, (4) left valve view. (5–8) *Selenimyalina* sp. (5), (8) GP/1E-698, internal mold of conjugated valves; (5) right valve view, (8) left valve view. (6) DZP-18884C; latex cast of external mold, (7) DGM-4372, internal mold of left valve. (9–16) *Volsellina areiensis* n.sp. (9), (12), (14–16) Holotype DGM-4369, internal mold of conjugated valve; (9) left valve view, (12) right valve view, (14) antero-dorsal view, (15) antero-ventral view; (16) postero-dorsal view. (10), (11) internal molds of left valve. (10) GP/1E-4370, (11) DGM-4371A. (13) DGM-4384, internal mold of right valve. Scale bar= 1cm.

Plate 3. (1–3) *Atomodesma* (*Aphanaia*) *orbirugata*, DZP-18832A. (1) Left valve view, (2) right valve view, (3) antero-ventral view. (4–6) *Atomodesma* (*Intodesma*) sp., DZP-18881A. (4) Left valve view, (5) right valve view, (6) antero-ventral view. (7) *Leptodesma* (*Leptodesma*) sp., GP/1E-4362, left valve view. (8–10) *Leptodesma* (*Leiopteria*) sp., left valve views, (8) DGM-4377, (9) DGM-4378, (10) GP/1E-4371. Scale bar= 1cm.

Plate 4. (1–12) *Heteropecten paranaensis*. (1–6) left valves, (1–2) latex cast of external molds, (1) DGM-4379, (2) DZP-18883B, (3–6) internal molds, (3) DGM-4358, (4) DGM-4348A, (5) DZP-18814, (6) GP/1E-4362B, (7–8), (12) internal molds of conjugated valves, (7) DGM-4348C, (8), (12) DGM-4361, (9–11) right valves, (9–10) external molds, (9) DGM-4360, (10) DGM-4367, (11) latex cast of internal mold, DZP-18810 A2. (13) *Streblopteria* sp., internal mold of left valve. (14–16) *Schizodus* sp. (14) internal mold of conjugated valves, GP/1E-692, (15–16) internal molds of butterflied valves, (15) DGM-4347, (16) DGM-4346. Scale bar= 1cm.

Plate 5. (1–3) *Praeundulomya* cf. *subelongata*. (1–2) Internal molds of butterflied valves, (1) DGM-4342, (2) DZP-2910A, (3), internal mold of right valve, DGM- 4337. (4) *Sanguinolites* sp., internal mold of right valve, DGM-4340. (5–10) *Pleurophorella* sp. (5–7), (9–10) internal molds of left valves, (5) DGM-4376, (6) GP/1E-4372, (7) DGM-4374B, (9) GP/1E-670, (10) GP/1E-677, (8), internal mold of right valve, DGM-4374C. Scale bar= 1cm.

Plate 6. (1–8) *Exochorhynchus itararensis* n.sp., internal molds of conjugated valves. (1–3), (7) Left valve views, (1) Holotype, DZP-18817C, (2) DZP-18829, (3) DZP-18830, (7) DZP-18822, (4–5) right valve views, (4) GP/1E-4438, (5) DZP-18830, (6) postero-dorsal view, GP/1E-4438, (8) antero-ventral view, DZP-18830. (9–15) *Cosmomya* (*Paleocosmomya*) *baitaqunesis* n.sp., internal molds of conjugates valves. (10), (13) Holotype, in situ preservation, DZP-18828, (10) left valve view, (13) postero-dorsal view, (9), (11), (14), DGM-4344, (9) anterior view, (11) left valve view, (14) postero-dorsal view, (12), (15) DZP-691, (12) left valve view, (15) antero-dorsal view. Scale bar= 1cm.

Plate 7. (1–6) *Myonia argentinensis*, internal mold of conjugated valves. (1), (3), (4) DGM-4341, (1) left valve view, (3) right valve view, (4) postero-dorsal view, (2), (5) DZP-18826, (2) left valve view, (5) postero-dorsal view, (6) GP/1E-700, postero-dorsal view. Scale bar= 1cm.

Table 1. Summary of the main features of the recorded lithofacies of the uppermost portion, Taciba Formation, Teixeira Soares region, State of Paraná, Brazil.

Table 2. Bivalve groups present in the uppermost portion of the Taciba Formation, Teixeira Soares region.

Table 3. Synthesis of the main taphonomic, paleontologic, and paleoecologic features recorded in the studied bivalve assemblages, Taciba Formation, Teixeira Soares region, State of Paraná, and their paleoenvironmental interpretations.

Table 4. Faunal composition and paleoecology of the studied bivalve assemblages from the uppermost portion of the Taciba Formation, Itararé Group, Teixeira Soares region, State of Paraná, Brazil. Explanation*: FMIDF= Facultatively mobile, infaunal, deposit feeder; FMSISF= Facultatively mobile, shallow infaunal, suspension feeder; FMDISF= Facultatively mobile, deep infaunal, suspension feeder; EBSF= Epifaunal, byssate, suspension feeder; SESF= Stationary, epifaunal, suspension feeder; SMBSF= Semi-infaunal, byssate, suspension feeder.

Table A1. Bivalves recorded in the upper portion of the Taciba Formation, Teixeira Soares region, Paraná Basin e their occurrences in coeval Late Carboniferous-Early Permian units of the Paleozoic Argentinean basins.

Table A2. Dimensions of the studied bivalve species of the uppermost portion of the Taciba Formation.

Graphical Abstract

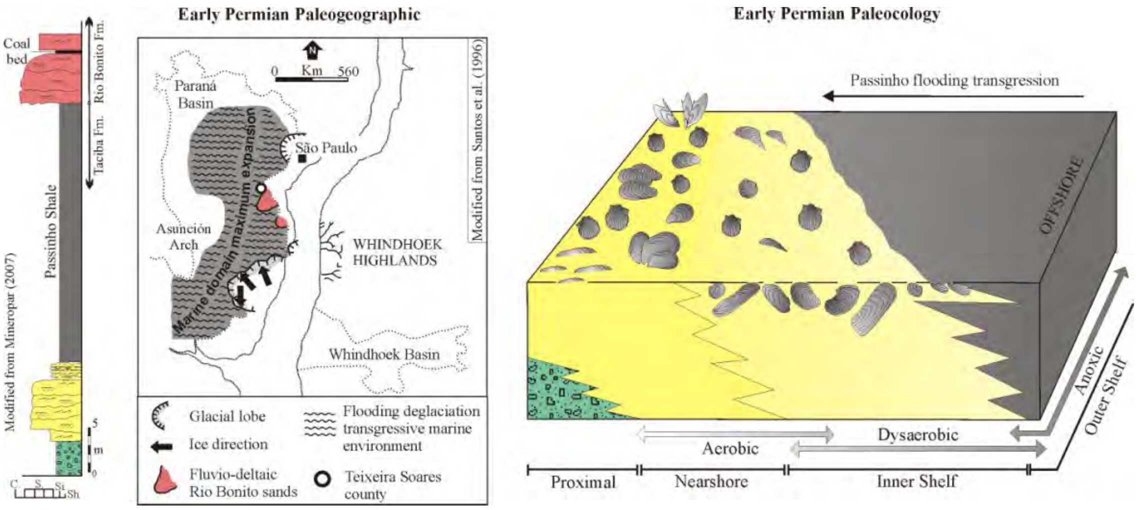


Figure 1

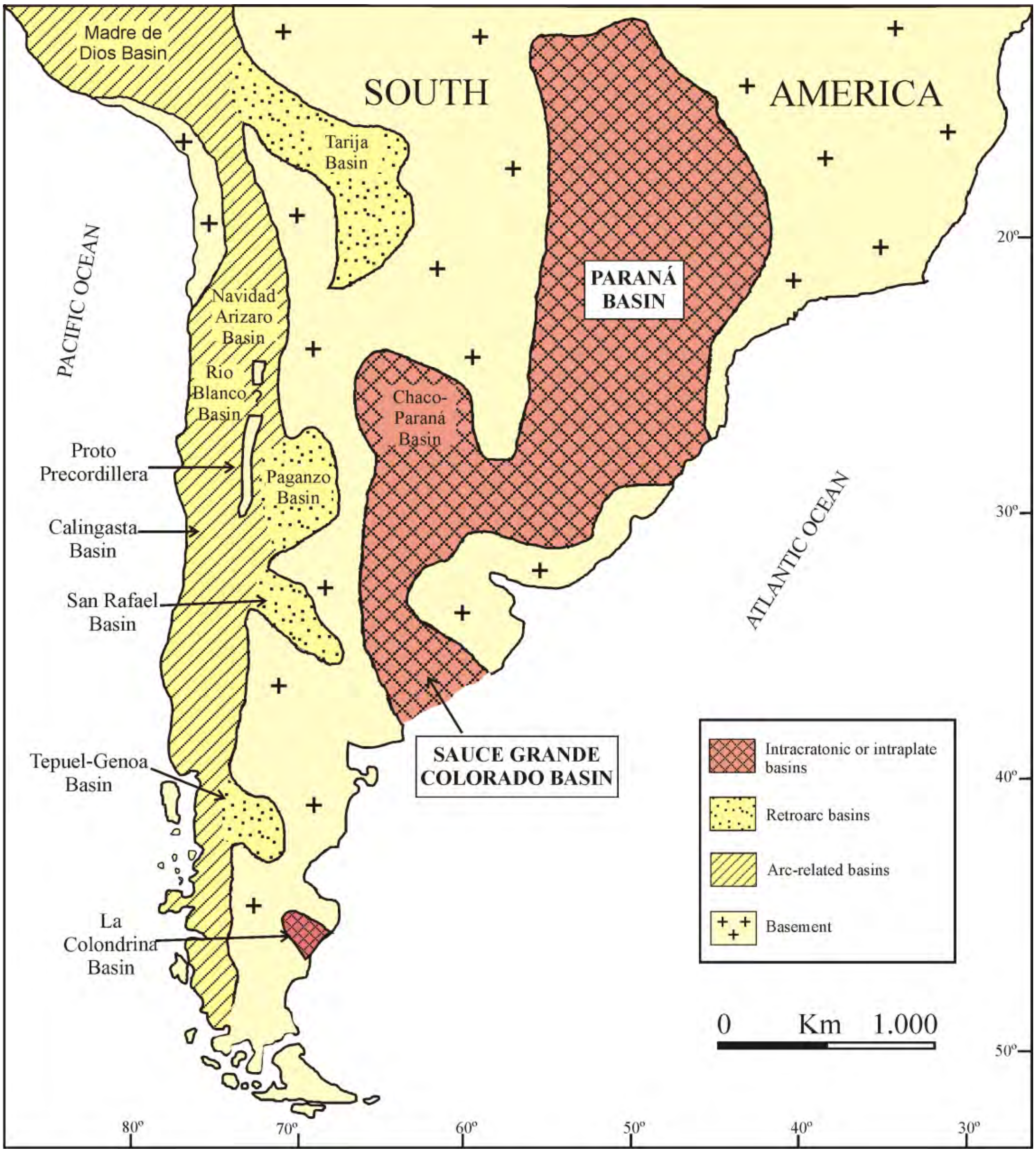

Madre de Dios Basin
SOUTH
AMERICA
Tarija Basin
PACIFIC OCEAN
Navidad Arizaro Basin
Rio Blanco Basin
Proto Precordillera
Paganzo Basin
Calingasta Basin
San Rafael Basin
Chaco-Paraná Basin
PARANÁ BASIN
ATLANTIC OCEAN
Tepuel-Genoa Basin
La Colondrina Basin
SAUCE GRANDE COLORADO BASIN
Intracratonic or intraplate basins
Retroarc basins
Arc-related basins
Basement
0 Km 1.000
20º
30º
40º
50º
80º
70º
60º
50º
40º
30º

Figure 2

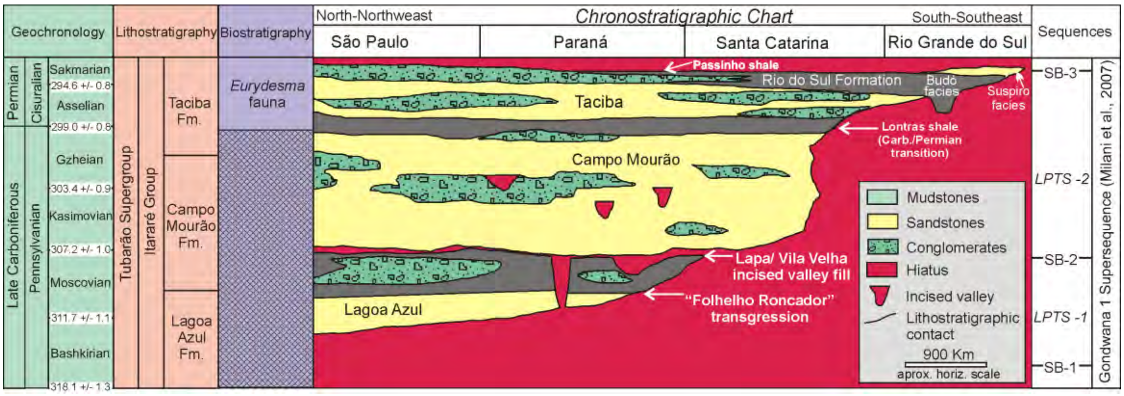

Geochronology
Lithostratigraphy
Biostratigraphy
North-Northweast
Chronostratigraphic Chart
South-Southeast
Sequences
São Paulo
Paraná
Santa Catarina
Rio Grande do Sul
Permian
Cisuralian
Sakmarian
294.6 +/- 0.8
Asselian
299.0 +/- 0.8
Late Carboniferous
Pennsylvanian
Gzheian
303.4 +/- 0.9
Kasimovian
307.2 +/- 1.0
Moscovian
311.7 +/- 1.1
Bashkirian
318.1 +/- 1.3
Tubarão Supergroup
Itararé Group
Taciba Fm.
Campo Mourão Fm.
Lagoa Azul Fm.
Eurydesma fauna
Passinho shale
Rio do Sul Formation
Budò facies
Suspiro facies
Taciba
Lontras shale (Carb./Permian transition)
Campo Mourão
Lapa/ Vila Velha incised valley fill
"Folhelho Roncador" transgression
Lagoa Azul
Mudstones
Sandstones
Conglomerates
Hiatus
Incised valley
Lithostratigraphic contact
900 Km
aprox. horiz. scale
SB-3
LPTS -2
SB-2
LPTS -1
SB-1
Gondwana 1 Supersequence (Milani et al., 2007)

Figure 3

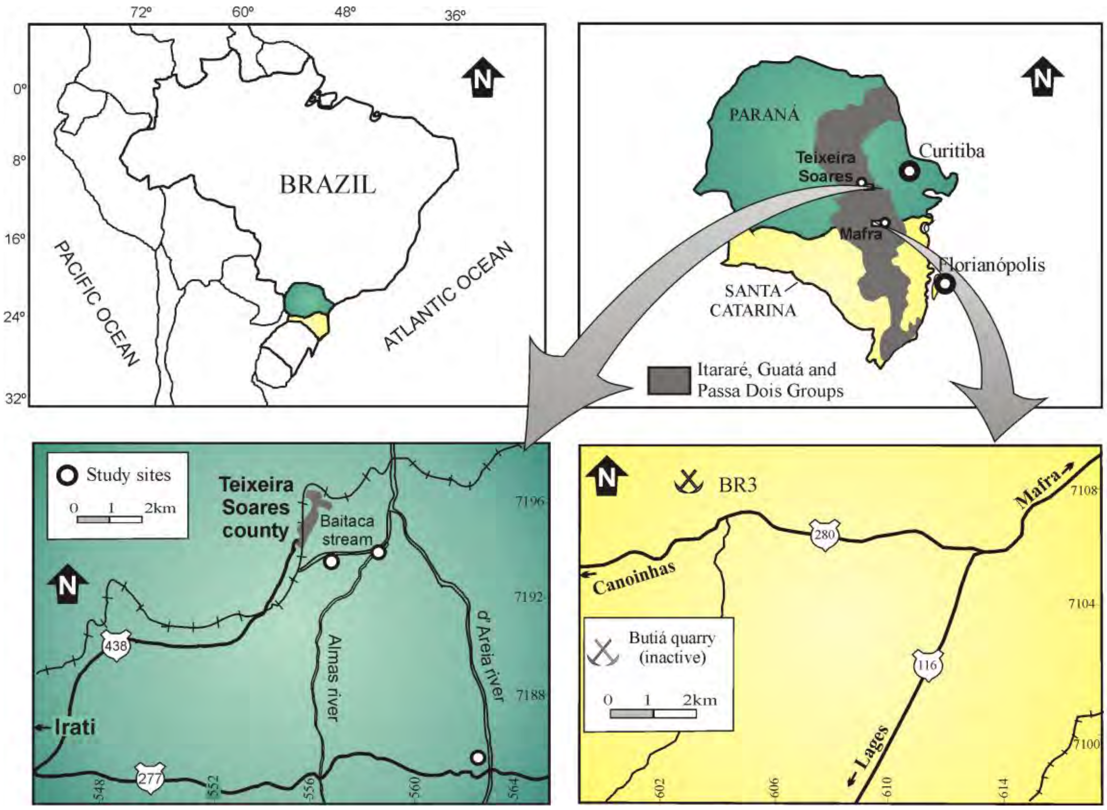

72°
60°
48°
36°
0°
8°
16°
24°
32°
N
BRAZIL
PACIFIC OCEAN
ATLANTIC OCEAN
N
PARANÁ
Teixeira
Soares
Curitiba
Mafra
Florianópolis
SANTA
CATARINA
Itararé, Guatá and
Passa Dois Groups
Study sites
0 1 2km
Teixeira
Soares
county
Baitaca
stream
N
438
Irati
Almas river
d' Areia river
277
7196
7192
7188
548
552
556
560
564
N
BR3
Mafra
7108
280
Canoinhas
7104
Butiá quarry
(inactive)
0 1 2km
116
Lages
7100
602
606
610
614

Figure 4

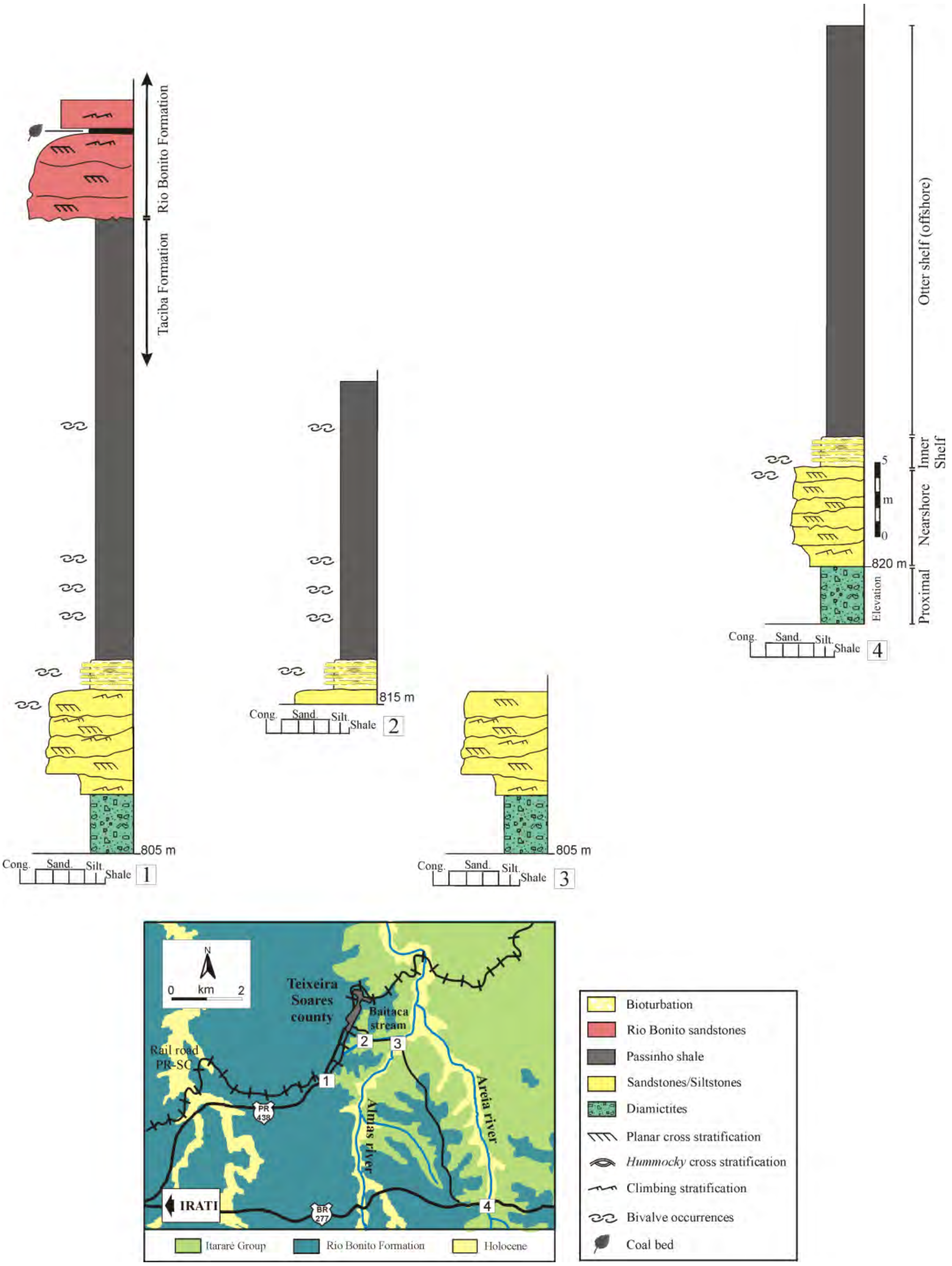
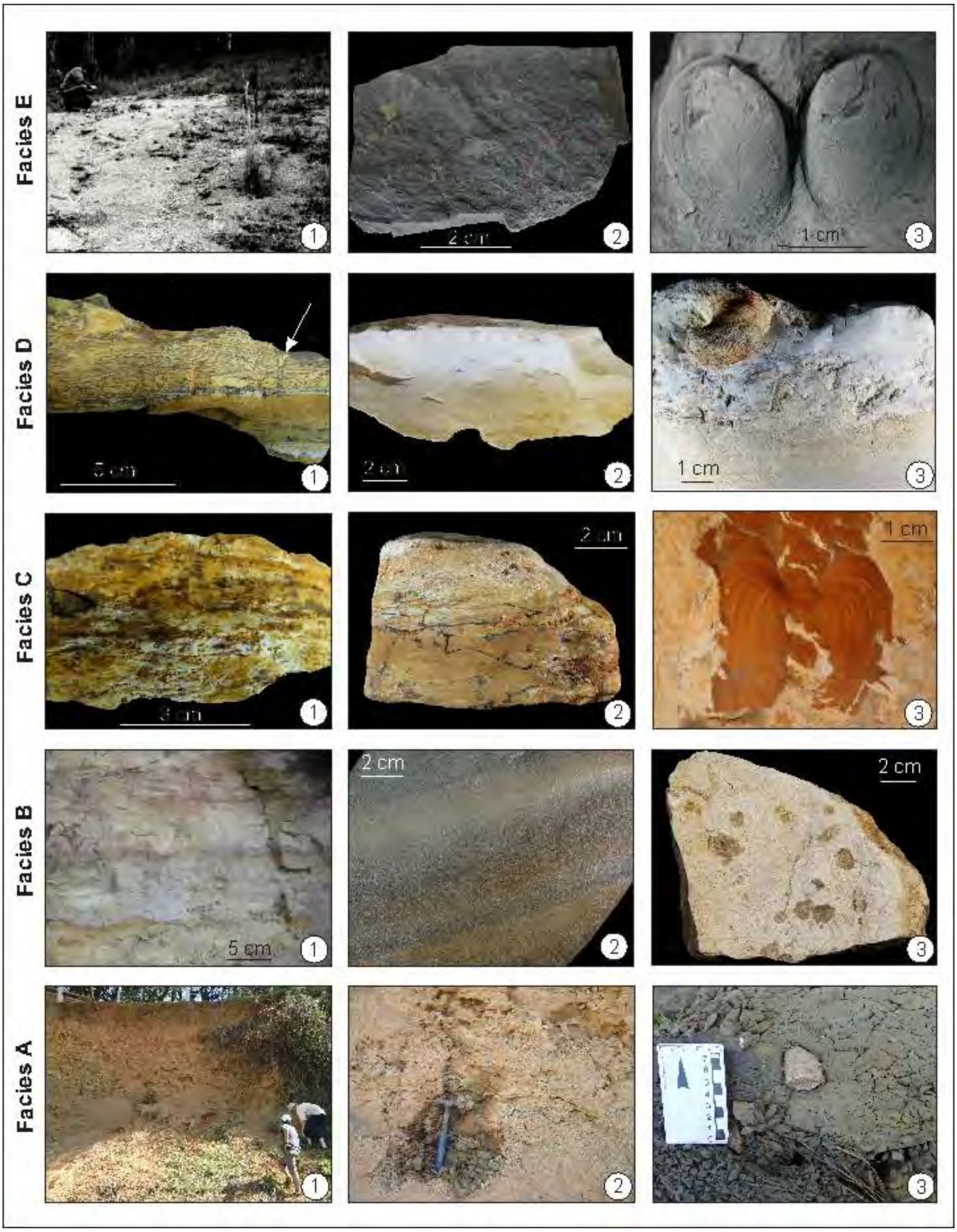

Rio Bonito Formation
Taciba Formation
805 m
Cong.
Sand.
Silt.
Shale
1
815 m
2
805 m
3
Otter shelf (offshore)
Inner Shelf
Nearshore
Proximal
5
m
0
820 m
Elevation
4
N
0 km 2
Teixeira Soares county
Baitaca stream
Rail road PR-SC
PR 438
BR 277
IRATI
Almas river
Areia river
Itararé Group
Rio Bonito Formation
Holocene
Bioturbation
Rio Bonito sandstones
Passinho shale
Sandstones/Siltstones
Diamictites
Planar cross stratification
Hummocky cross stratification
Climbing stratification
Bivalve occurrences
Coal bed

Figure 5


Facies E
1
2 cm
2
1 cm
3
Facies D
5 cm
1
2 cm
2
1 cm
3
Facies C
3 cm
1
2 cm
2
1 cm
3
Facies B
5 cm
1
2 cm
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2 cm
3
Facies A
1
2
3

Figure 6

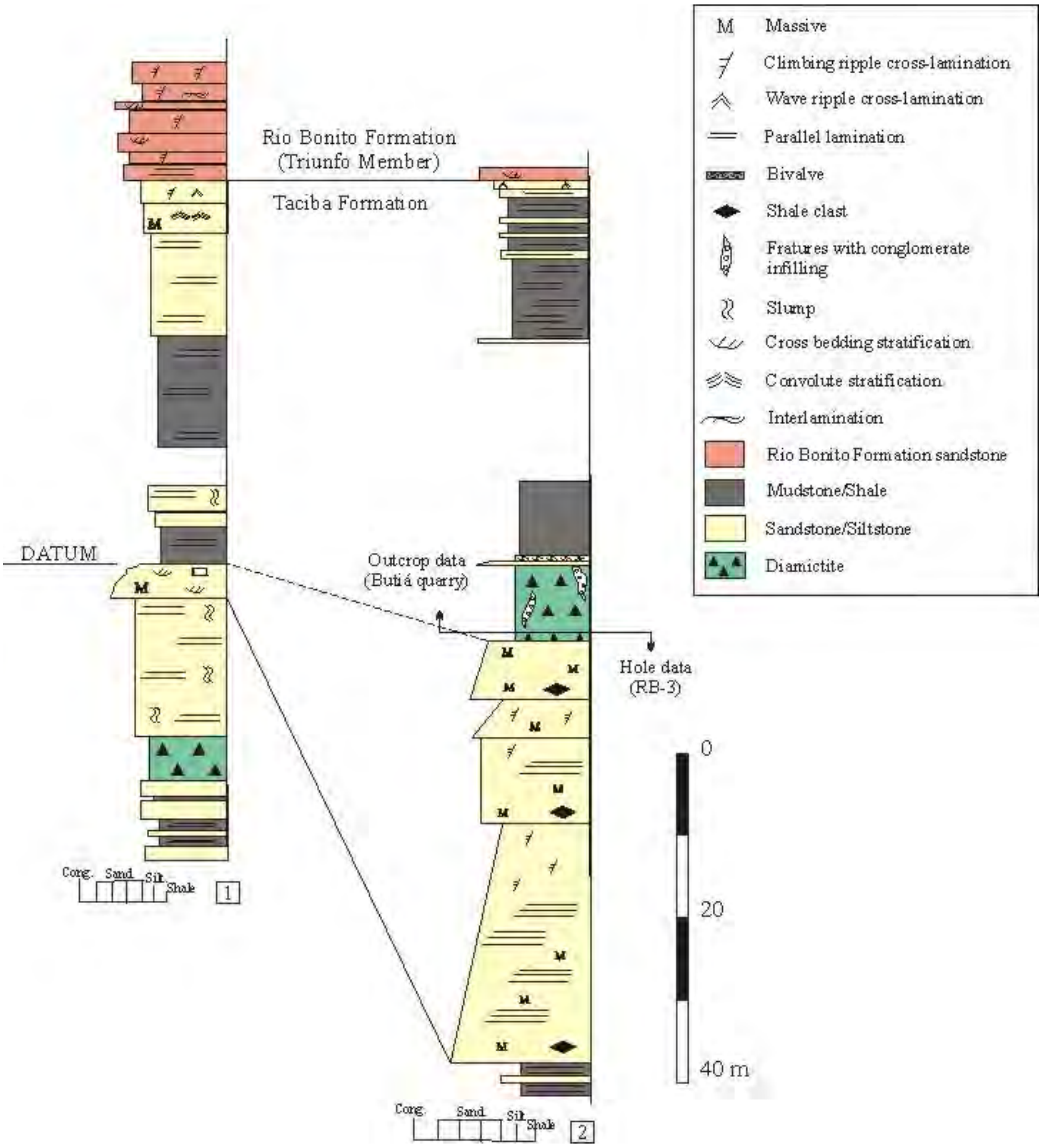
Rio Bonito Formation
(Triunfo Member)
Taciba Formation
DATUM
Outcrop data
(Butiá quarry)
Hole data
(RB-3)
M
Cong. Sand Silt Shale
1
Cong. Sand Silt Shale
2
0
20
40 m
M Massive
Climbing ripple cross-lamination
Wave ripple cross-lamination
Parallel lamination
Bivalve
Shale clast
Fratures with conglomerate infilling
Slump
Cross bedding stratification
Convolute stratification
Interlamination
Rio Bonito Formation sandstone
Mudstone/Shale
Sandstone/Siltstone
Diamictite

Figure 7

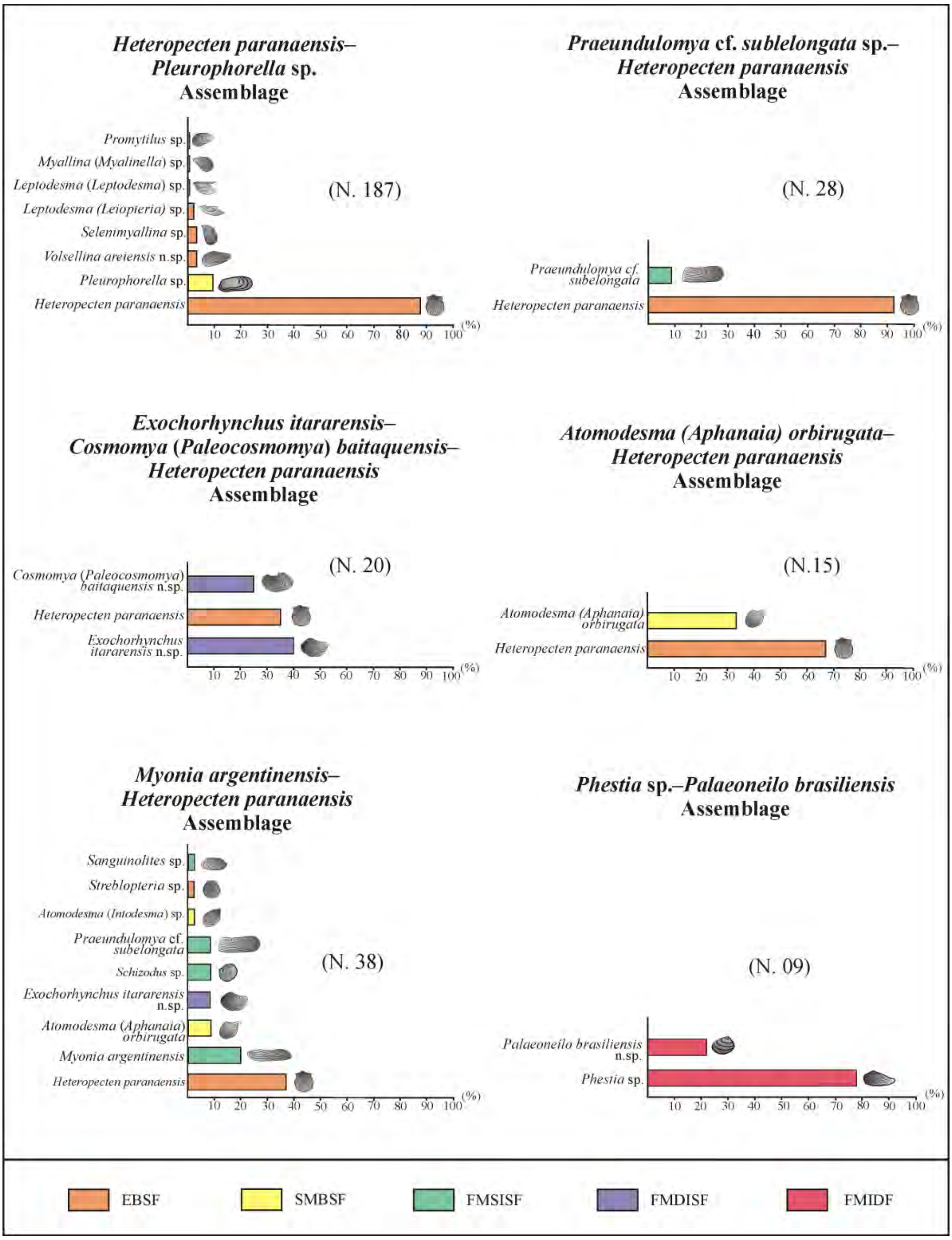
Heteropecten paranaensis–Pleurophorella sp. Assemblage
Promytilus sp.
Myallina (Myalinella) sp.
Leptodesma (Leptodesma) sp.
Leptodesma (Leioptieria) sp.
Selenimyallina sp.
Volsellina areiensis n.sp.
Pleurophorella sp.
Heteropecten paranaensis
(N. 187)
10 20 30 40 50 60 70 80 90 100 (%)
Praeundulomya cf. sublelongata sp.–Heteropecten paranaensis Assemblage
Praeundulomya cf. subelongata
Heteropecten paranaensis
(N. 28)
10 20 30 40 50 60 70 80 90 100 (%)
Exochorhynchus itararensis–Cosmomya (Paleocosmomya) baitaquensis–Heteropecten paranaensis Assemblage
Cosmomya (Paleocosmomya) baitaquensis n.sp.
Heteropecten paranaensis
Exochorhynchus itararensis n.sp.
(N. 20)
10 20 30 40 50 60 70 80 90 100 (%)
Atomodesma (Aphanaia) orbirugata–Heteropecten paranaensis Assemblage
Atomodesma (Aphanaia) orbirugata
Heteropecten paranaensis
(N.15)
10 20 30 40 50 60 70 80 90 100 (%)
Myonia argentinensis–Heteropecten paranaensis Assemblage
Sanguinolites sp.
Streblopteria sp.
Atomodesma (Intodesma) sp.
Praeundulomya cf. subelongata
Schizodus sp.
Exochorhynchus itararensis n.sp.
Atomodesma (Aphanaia) orbirugata
Myonia argentinensis
Heteropecten paranaensis
(N. 38)
10 20 30 40 50 60 70 80 90 100 (%)
Phestia sp.–Palaeoneilo brasiliensis Assemblage
Palaeoneilo brasiliensis n.sp.
Phestia sp.
(N. 09)
10 20 30 40 50 60 70 80 90 100 (%)
EBSF
SMBSF
FMSISF
FMDISF
FMIDF

Figure 8

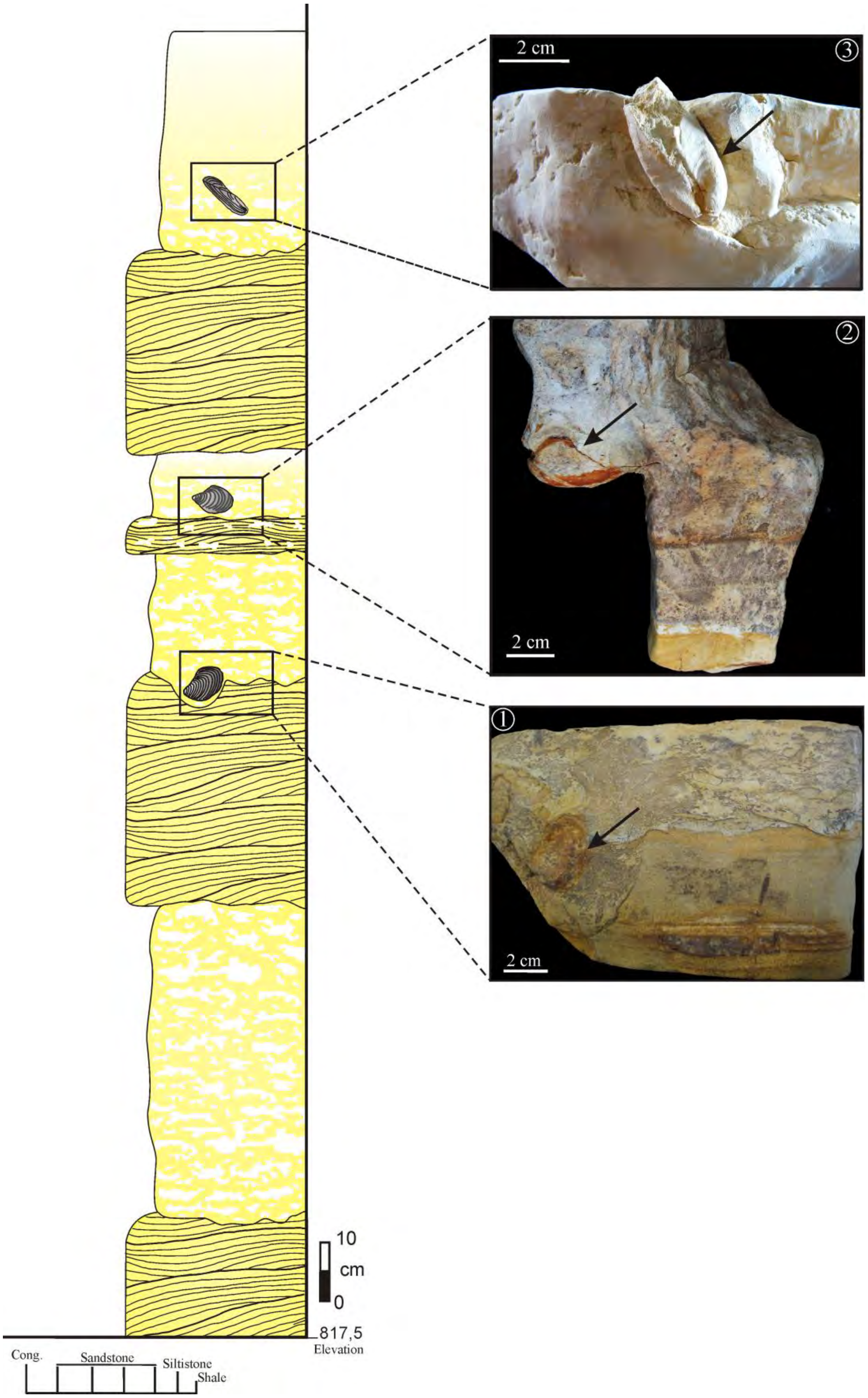
2 cm
③
②
2 cm
①
2 cm
10
cm
0
817,5
Elevation
Cong.
Sandstone
Siltstone
Shale

Plate 1

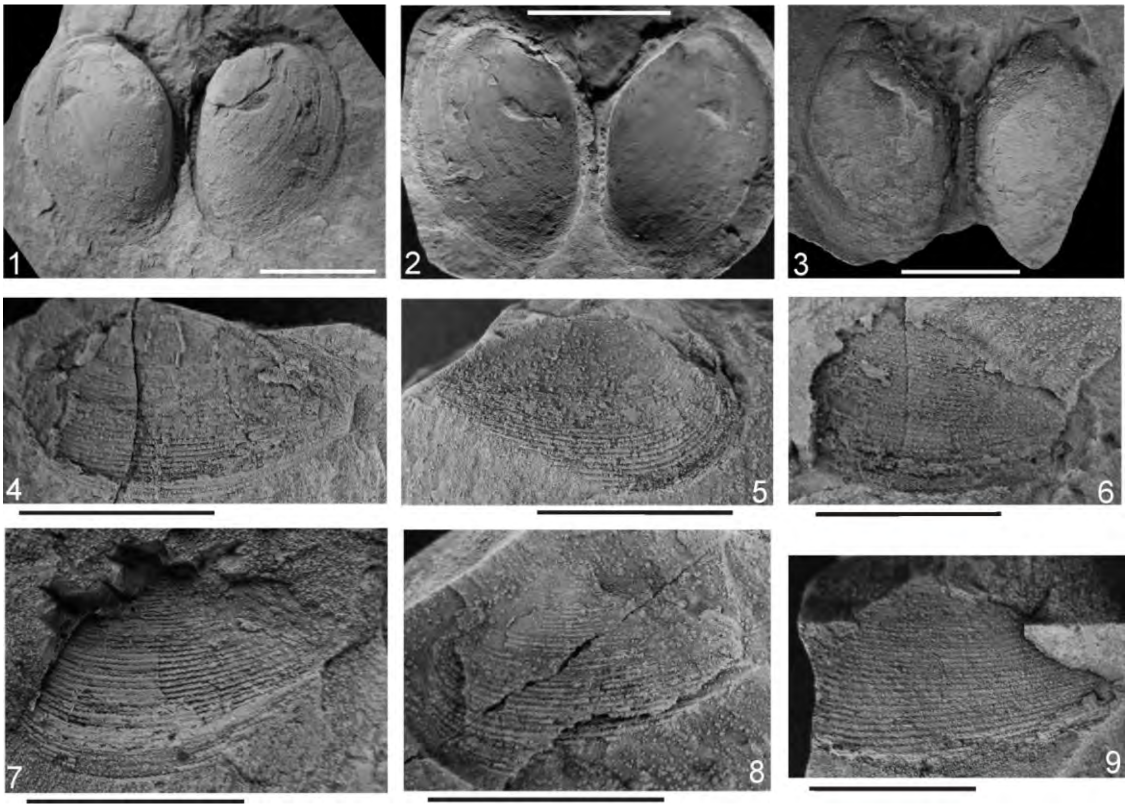

Plate 2

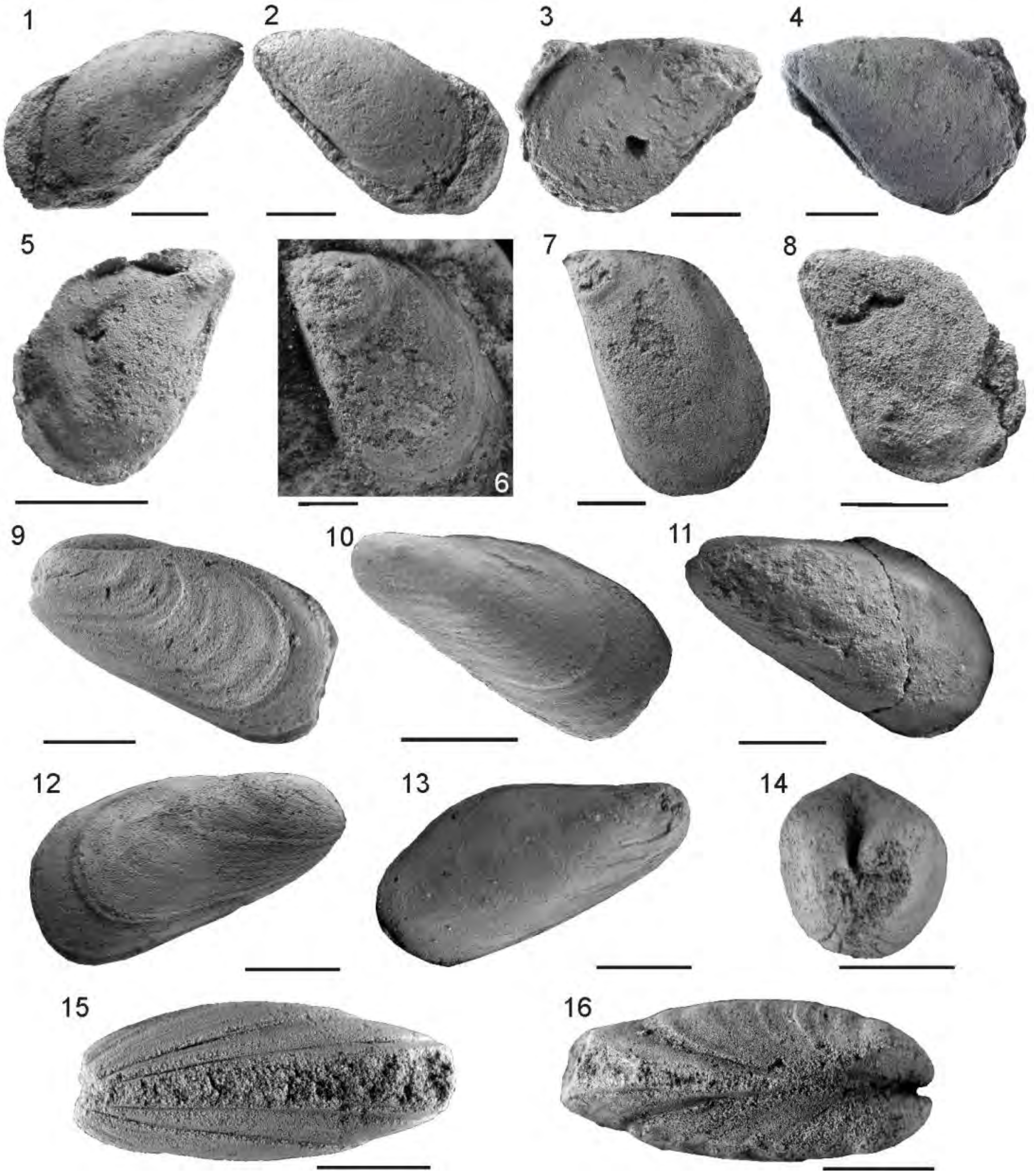

Plate 3

1

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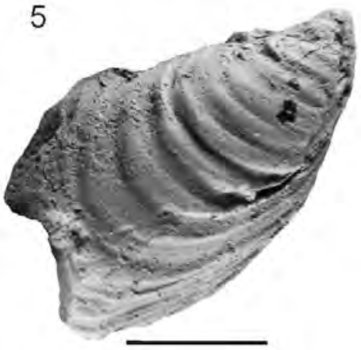

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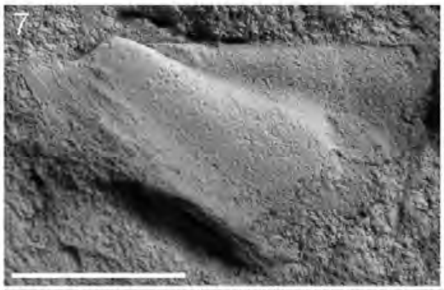

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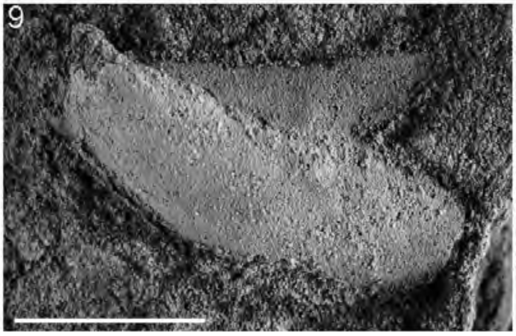

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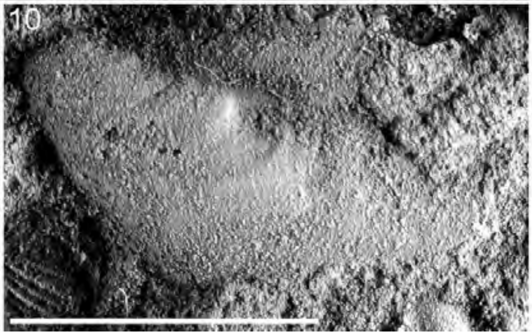
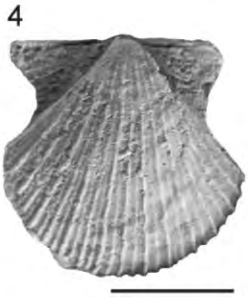


Plate 4


1


2


3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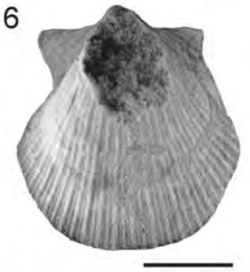
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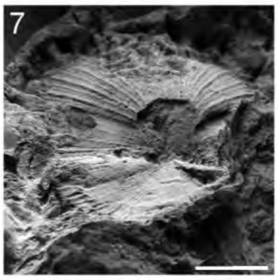
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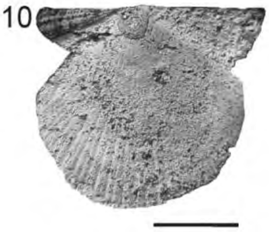
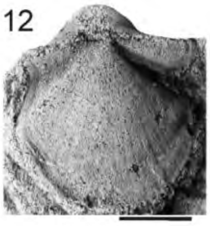

10


11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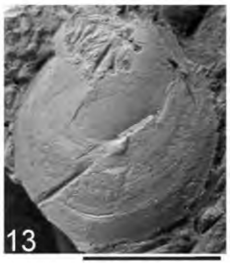
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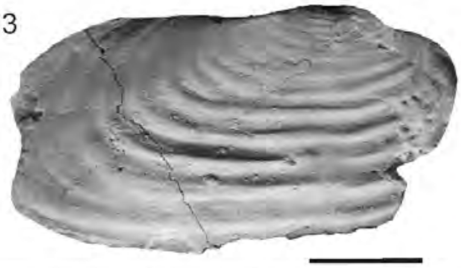
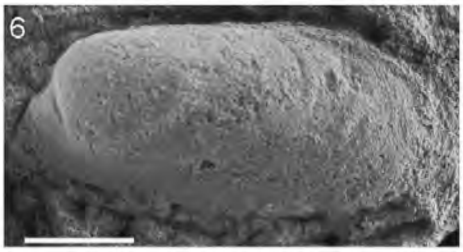
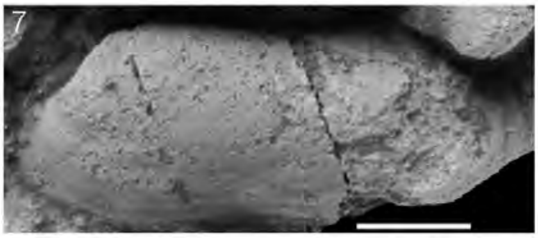
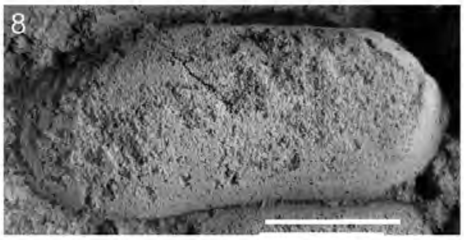
Plate 5









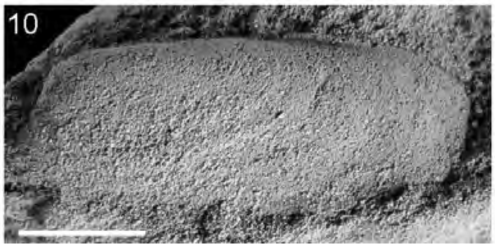


Plate 6

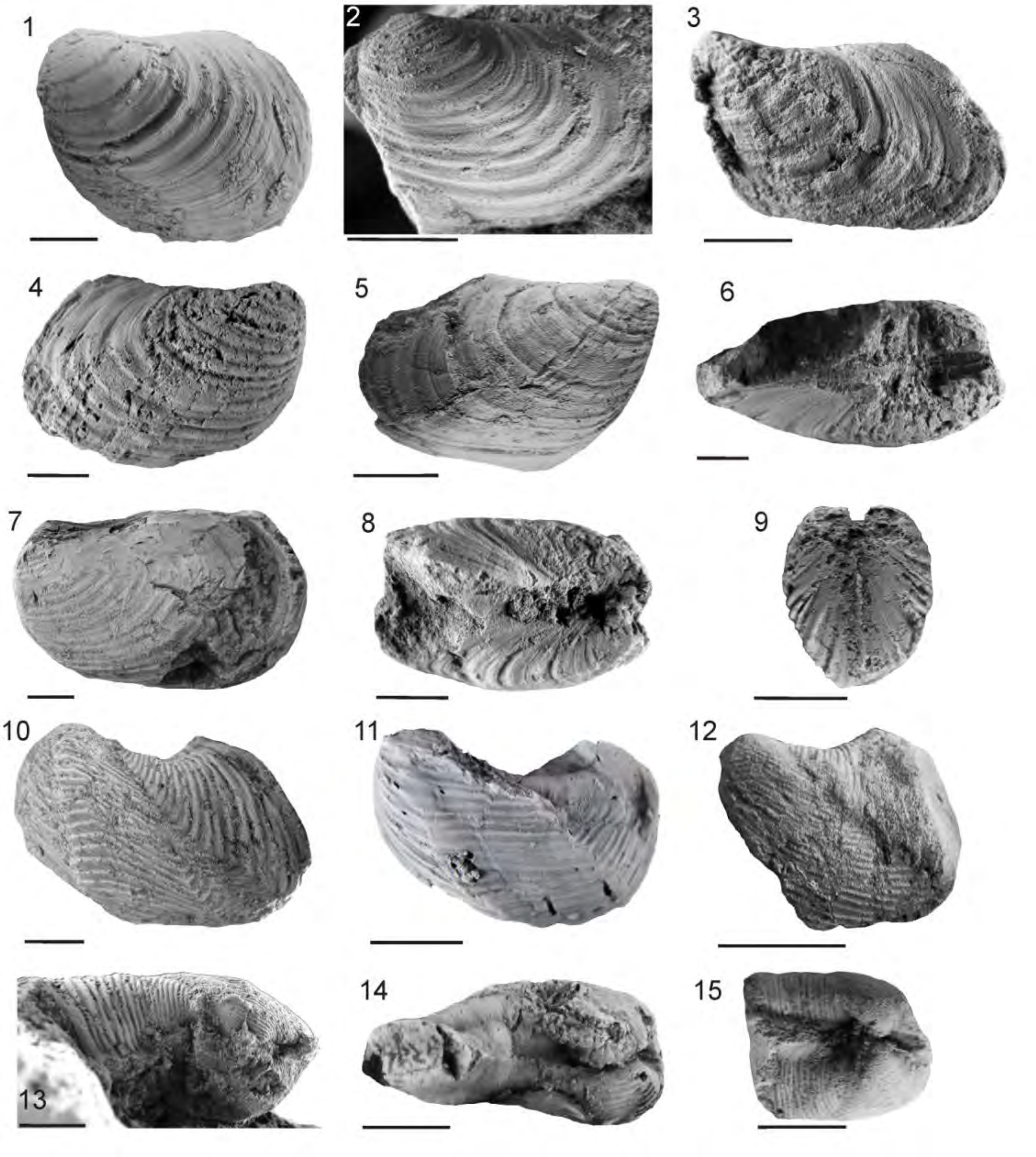


Plate 7

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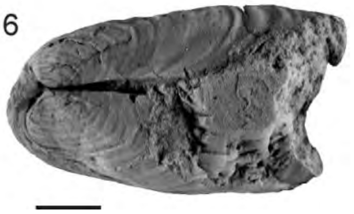

Facies	Local Designation	Lithology & Sedimentary Structures	Interpretation	
			Sedimentary Processes	Sedimentary Environment
Facies E Parallel-laminated and mudstone facies	"Passinho Shale"	Thick (>30m), laterally persistent, dark grey (fresh) to white-yellowish (weathered), thinly parallel-laminated mudstones lacking dropstones. Locally massive. At places, the mudstone contains small, butterflied or isolated bivalve shells, concordant to bedding.	Deposition of background sediments from suspension under low-energy conditions, below storm wave base.	Outer shelf (offshore).
Facies D: Interbedded, fine to very fine sandstone with low-angle trough cross-stratification and hummocky cross-stratified sandstone and siltstone	_________	Thick succession (2.15m) including fine to very fine, well sorted sandstones showing low-angle trough cross-stratifications. The base is sharp and the top intensely bioturbated, including bivalve shells preserved in situ and scape structures. In some cases, hummocky cross-stratification is visible. At least, three stacked sandstone beds are recorded, and in the uppermost one a massive, white to yellowish colored siltistone/mudstone abruptly covers the bioturbated layer of the top of the sandstone. The siltstone is parallel-laminated, but these structures can be deeply obliterated by the profuse bioturbation.	High-energy oscillatory flows due to repeated storms, alternating with background suspension fall-out during fair-weather periods. The presence of in situ shells of burrowing bivalves, the intense bioturbation and escape traces indicate very rapid (abruptly), episodic deposition. The presence of bioturbation destroying the sedimentary structures, such as hummocky cross-stratification indicates the post-storm colonization of the bottoms by opportunistic benthic invertebrates, during fair-weather times. Multiple erosional and depositional events are inferred by the amalgamated occurrence of these sandstones. The *in situ* bivalves indicate distal storm deposition.	Inner shelf (lower shoreface) to nearshore (upper shoreface).
Facies C: Parallel-laminated, intensely bioturbated siltstone facies	"Baitaca siltstone"	Thin interval (50cm), deeply bioturbated fossiliferous siltstones including scattered shells of burrowing bivalves. Shells are splayed-out (butterflied). When not destroyed by the bioturbation the siltstone is parallel laminated. Contacts are not visible in the field exposures.	Low-energy, suspension fall-out deposition during fair-weather periods punctuated by erosional events, as indicated by the splayed valves of burrowing bivalves. Deposition above storm wave base.	Inner shelf.
Facies B: Fine to medium-grained, yellowish sandstone with tabular cross stratification	"Rio d'areia sandstone" or "Pectinid sandstone"	Thick package (7m) of sigmoidal clinoforms (see Mineropar, 2007, p. 107) of well-sorted, medium to fine-grained sandstones, with planar cross stratifications. Sometimes, very rare quartz granules disperse in the matrix is noted. Flaser lamination occurs at the top of the sets, and subordinated symmetric and asymmetric ripples are also noted. SW is the main flow direction (Mineropar, 2007). In plan-view, *Planolites*-like traces are associated to the ripples. Bivalve-dominated shell pavements occur at the upper (2 m) portion of the sandstone.	Combined wave and tidal influenced, prograding sandy bars (mouth- or tidal-bars).	Nearshore (upper shoreface).
Facies A: Matrix supported, massive conglomerate facies	_________	Thick body (10m), polymitic, matrix-supported, massive conglomerate with rounded, striated and faceted clasts (granules/boulders) of granites. This massive lithotype may grade upward to crudely stratified mudstones. Locally, sandstones and "deformed" conglomerate bodies in the way of inclusions within the diamictite are also recorded (see Mineropar, 2007, p. 106).	In part, gravity-driven, resedimented deposits. The intake of water may lead the gradation of chaotic matrix to crude stratifications in mudstones to the top.	Proximal settings.

Subclass/ Infraclass	**Infrasubcohort/ Order**	**Superfamily**	**Family**	**Genus**	**Species**	**N.**
Protobranchia	Nuculanida	Malletidoidea	Malledidae	*Palaeoneilo*	*Palaeoneilo brasiliensis* n.sp.	2
		Nuculanoidea	Nuculanidae	*Phestia*	*Phestia* sp.	7
Pteriomorphia	Mytilida	Mytiloidea	Mytilidae	*Promytilus*	*Promytilus* sp.	1
				Volsellina	*Volsellina areiensis* n.sp.	6
	Myalinida	Ambonychioidea	Myalinidae	*Myallina*	*Myalina* (*Myalinella*) sp.	1
				Selenimyalina	*Selenimyalina* sp.	6
		Inoceramoidea	Atomodesmatidae	*Atomodesma*	*A.* (*Aphanaia*) *orbirugata*	8
					Atomodesma (*Intodesma*) sp. .	1
	Ostreida		Pterineidae	*Leptodesma*	*Leptodesma* (*Leiopteria*) sp.	3
					Leptodesma (*Leptodesma*) sp.	1
	Pectinida	Chaenocardioidea	Streblocondriidae	*Streblopteria*	*Streblopteria* sp.	1
		Heteropectinoidea	Heteropectinidae	*Heteropecten*	*H. paranaensis* n. sp.	210
Heteroconchia	Trigoniida	Trigonioidea	Schizodidae	*Schizodus*	*Schizodus* sp.	3
	Cardiidia	Grammysioidea	Sanguinolitidae	*Sanguinolites*	*Sanguinolites* sp.	1
				Praeundulomya	*P.* cf. *subelongata*	5
	Cardiida	Kalenterroidea	Kalenteridae	*Pleurophorella*	*Pleurophorella* sp.	17
	Pholadomyida	Pholadomyoidea	Pholadomidae	*Cosmomya*	*C.* (*Paleocosmomya*) *baitaquensis* n.sp.	5
				Exochorhynchus	*E. itararensis* n.sp.	11
	Hiatellida	Edmondioidea	Pachydomidae	*Myonia*	*Myonia argentinensis*	7

Assemblage	Facies	Description	Interpretation
Phestia sp.-*Palaeoneilo brasiliensis*	Facies E	Low abundant, poorly diversified assemblage, dominated by small, shallow burrowing, detritivorous bivalves. Shells of epifaunal ou pseudoplanktonic bivalves are completely absent. Shells are commonly articulated and butterflied.	Parautochthonous assemblage of opportunistic bivalves. The fossiliferous horizons are intercalated in a thick succession of laminated to massive mudstones or dark colored (gray) shales. The presence of bivalves in certain intervals indicates pulses of oxygenation in a broad anoxic to extremely dysaerobic context of organic-rich, muddy bottoms in offshore settings.
Myonia argentinensis-Heteropecten paranaensis	Facies D	Diversified assemblage including shallow to deep burrowing bivalves, usually preserved *in situ*, associated to disarticulated valves of epifaunal and semi-infaunal bivalves, which are chaotically oriented in the matrix. The fossiliferous layer is deeply bioturbated, grading to massive white siltstones or mudstones to the top.	Recurrence of the storm events in inner shelf settings, as described below, by considering the stacked, amalgamated, nature of the succession with similar faunal content in respect to the ecological guilds, taxonomic composition, and preservation.
Atomodesma (A.) orbirugata-Heteropecten paranaensis	Facies D	Poorly diversified assemblage of epifaunal and semi-infaunal, suspension-feeding bivalves. Shells of epifaunal bivalves are disperse and chaotically oriented in the matrix. Semi-infaunal bivalves were preserved in situ. The original life orientation was however disrupted by the dense, intrastratal activity, indicated by the profuse bioturbation of the fossiliferous layers.	Recurrence of the storm events in inner shelf settings, as described below, by considering the stacked, amalgamated, nature of the succession with similar faunal content in respect to the ecological guilds, taxonomic composition, and preservation.
Exochorhynchus itararensis-Cosmomya (P.) baitaquensis-Heteropecten paranaenses	Facies D	Poorly diversified bivalve assemblage, dominated by suspension-feeding, deep burrowing species, various preserved *in situ*. The horizon including these infaunal forms in position of life is highly bioturbated. Small disarticulated, pectiniform shells, are also noted.	Autochthonous to parautochthonous tempestite bed, including bivalves in situ, which were smothered by mud blankets of fine-grained (silts and muds) sediments and/or sands, during or immediately after storms. Post-storm colonization of the substrate by infaunal elements, during fair-weather conditions is suggested by the intense bioturbation of the horizon with in situ bivalves and the destruction of the associated sedimentary structures (hummocky cross-stratifications). The presence of suspension-feeding bivalves and the profuse bioturbation are indicative of aerobic to dysaerobic, sandy/muddy bottoms in inner shelf settings.
Praeundolomya cf. subelongata-Heteropecten paranaenses	Facies C	Poorly diversified assemblage, including shells of suspension-feeding, shallow to intermediate burrowing bivalves. Shells are disperse in the matrix, parallel (convex-up) to bedding, normally with articulated, splayed valves. Intense bioturbation is recorded in association with the fossiliferous bedding plane, destroying the original parallel lamination.	Parautochthonous to allochthonous assemblage of burrowing bivalves, also including epifaunal suspension-feeding ones. Infaunal bivalves were probably disrupted of sediments by the intense bioturbation or substrate erosion. The presence of butterflied valves indicate rapid (but not abruptly) sedimentation of fine-grained sediments. This assemblage may represent aerobic to dysaerobic bottoms in inner shelf settings.
Heteropecten-Pleurophorella	Facies B	Diverse assemblage, dominated by abundant shells of epifaunal and semi-infaunal suspension-feeding bivalves. Shells occur as bioclastic pavements of predominantly convex-up, disperse shells showing 50/50 valve deviation. Imbricated shells are also common. Abrasion, encrustation and fragmentation are absent. Rare shells are still articulated.	Parautochthonous to allochthonous assemblage, including laterally transported shells. Both shell residence time in the sediment/water interface and transport were short due to the absence of encrustation, bioerosion and fragmentation. Shells deposited in nearshore, aerobic, sand-dominated bottoms.

Fossil Assemblage	Composition and Diversity	PALEOECOLOGY		
		Abundance	Dominance	Main Guilds*
Phestia sp.–*Palaeoneilo brasiliensis*	*Phestia* sp. (n. 7), *P. brasiliensis* (n. 2)	09	*Phestia* sp. (78%), *P. brasiliensis* (22%)	FMIDF (100%)
Myonia argentinensis–Heteropecten paranaensis	*H. paranaensis* (n. 16), *M. argentinensis* (n. 7), *Atomodesma.* (*Aphanaia*) *orbirugata* (n. 3), *Exochorhyncus itararensis* (n. 3), *Schizodus* sp. (n. 3), *Praeundulomya* sp. (n. 3), *Sanguinolites* sp. (n. 1), *Streblopteria* sp. (n. 1), *Atomodesma* (*Intodesma*) sp.	38	*H. paranaensis* (37%), *M. argentinensis* (20%)	EBSF (45%) FMSISF (37%) SMBSF (10%) FMDISF (08%)
Atomodesma. (Aphanaia) orbirugata–Heteropecten paranaensis	*H. paranaensis* (n. 10), *A.* (*Aphanaia*) *orbirugata* (n. 5)	15	*H. paranaensis* (67%), *A.* (*Aphanaia*) *orbirugata* (33%)	EBSF (67%) SMBSF (33%)
Exochorhyncus itararensis–Cosmomya Paleocosmomya) baitaquensis–Heteropecten paranaensis	*E .itararensis* (n. 8), *H. paranaensis* (n. 7), *C.* (*Paleocosmomya*) *baitaquensis* (n. 5)	20	*E.itararensis* (40 %), *H. paranaensis* (35%), *C.* (*Paleocosmomya*) *baitaquensis* (25%)	FMDISF (65%) EBSF (35%)
Praeundolomya cf. *subelonagata–Heteropecten paranaensis*	*H. paranaensis* (n. 26), *Praeundulomya* cf. *subelongata* (n. 2)	28	*H. paranaensis* (93%), *Praeundulomya* sp. (7%)	EBSF (93%) FMSISF (7%)
Heteropecten paranaensis–Pleurophorella sp.	*H. paranaensis* (n. 151), *Pleurophorella* sp. (n. 17), *Volsellina areiensis* (n. 6), *Selenimyalina* sp. (n. 6), *L.* (*Leiopteria*) sp. (n. 4), *L.* (*Leptodesma*) sp. (n. 1), *M.* (*Myalinella*) sp. (n. 1), *Promytilus* sp. (n. 1)	187	*H. paranaensis* (80.7%), *Pleurophorella* sp. (9.1%), *V. areiensis* (3.3%), *Selenimyalina* sp. (3.3%), *L.* (*Leiopteria*) sp. (2.1%), *L.* (*Leptodesma*) sp. (0.5%), *M.* (*Myalinella*) sp. (0.5%), *Promytilus* sp. (0.5%).	EBSF (94%) SMBSF (06%)

TAXA	Paraná Basin	Sauce Grande Basin*	Tepuel-Genoa Basin (Central Patagonia)**				Paganzo Basin***	Uspallata-Iglesia Basin****
								Rio Blanco Sub-basin
	Taciba Fm.	Bonete Fm.	Río Genoa Fm.	Monjón de Hierro Fm.	Pampa de Tepuel Fm.	Las Salinas Fm.	Tupe Fm.	Rio del Peñón Fm.
Palaeoneilo	X	--------	X	X	X	X	--------	--------
P. brasiliensis	X	--------	--------	--------	--------	--------	--------	--------
P. gonzalezi	--------	--------	X	X	X	X	--------	--------
P. amosi	--------	--------	--------	X	X	--------	--------	--------
P. sp.	--------	--------	--------	X	--------	X	--------	--------
Phestia	X	--------	X	X	X	X	X	--------
P. sp.	X	--------	X	--------	X	X	X	--------
P.? sp.	--------	--------	--------	X	--------	--------	--------	--------
P. regularis	--------	--------	X	X	--------	X	--------	--------
P. tepuelensis	--------	--------	X	--------	X	X	--------	--------
P. sabattinae	--------	--------	X	X	--------	--------	--------	--------
P. sp. aff. P. bellistriata	--------	--------	--------	--------	--------	--------	X	--------
Promytilus	X	X	--------	--------	--------	X	--------	X
P. sp.	X	--------	--------	--------	--------	--------	--------	X
P.? sp.	--------	--------	--------	--------	--------	X	--------	--------
P. acinaciformis	--------	X	--------	--------	--------	--------	--------	--------
Volsellina	X	--------	--------	--------	--------	--------	--------	--------
V. areiensis n.sp.	X	--------	--------	--------	--------	--------	--------	--------
***Myalina* (*Myalinella*)**	X	--------	--------	--------	--------	--------	--------	--------
M. (*M.*) sp.	X	--------	--------	--------	--------	--------	--------	--------
Selenimyalina	X	--------	--------	--------	--------	--------	--------	--------
S. sp.	X	--------	--------	--------	--------	--------	--------	--------
Atomodesma	X	X	--------	--------	--------	X	--------	--------
Atomodesma (Aphanaia)	X	X	--------	--------	--------	--------	--------	--------
A. (*A.*) *orbirugata*	X	X	--------	--------	--------	--------	--------	--------
A. (*Aphanaia*) sp.	--------	--------	--------	--------	--------	X	--------	--------
***Atomodesma* (*Kolymia*)**	--------	--------	--------	--------	--------	X	--------	--------
A. (*Kolymia*) sp.	--------	--------	--------	--------	--------	X	--------	--------
A. (*Intodesma*)	X	--------	--------	--------	--------	--------	--------	--------
A. (*Intodesma*) sp.	X	--------	--------	--------	--------	X	--------	--------
***Leptodesma* (*Leiopteria*)**	X	X	--------	--------	X	--------	--------	X
L. (*L.*) sp.	X	--------	--------	--------	--------	--------	--------	--------
L. (*L.*) *dutoiti*	--------	X	--------	--------	--------	--------	--------	--------
L. (*L.*) *bonaerensis*	--------	X	--------	--------	--------	--------	--------	--------
L. (*L.*) *variabilis*	--------	--------	--------	--------	X	--------	--------	--------
L. (*L.*) *veladerensis*	--------	--------	--------	--------	--------	--------	--------	X
***Leptodesma* (*Leptodesma*)**	X	--------	--------	--------	--------	--------	--------	X
L. (*L.*) sp.	X	--------	--------	--------	--------	--------	--------	X
L. (*L.*) cf. *potens*	--------	--------	--------	--------	--------	--------	--------	--------
Streblopteria	X	--------	X	X	X	--------	--------	X
S. sp.	X	--------	--------	--------	--------	--------	--------	X
S. lagunensis	--------	--------	X	X	X	--------	--------	--------
S. montgomeryi	--------	--------	--------	X	--------	--------	--------	--------
S. minuta	--------	--------	--------	X	--------	--------	--------	--------

Continuation

TAXA	Paraná Basin	Sauce Grande Basin*	Tepuel-Genoa Basin (Central Patagonia)**				Paganzo Basin***	Uspallata-Iglesia Basin****
	Taciba Fm.	Bonete Fm.	Río Genoa Fm.	Monjón de Hierro Fm.	Pampa de Tepuel Fm.	Las Salinas Fm.	Tupe Fm.	Rio Blanco Sub-basin Rio del Peñón Fm.
Heteropecten	X	X	--------	X	--------	--------	--------	X
H. parananensis n.sp.	X	X	--------	--------	--------	--------	--------	--------
H. sp.	--------	X	--------	--------	--------	--------	--------	--------
H. anteloi	--------	--------	--------	X	--------	--------	--------	X
H. cortignasi	--------	--------	--------	X	--------	--------	--------	--------
H. argentinensis	--------	--------	--------	X	--------	--------	--------	--------
Schizodus	X	X	X	X	X	X	X	X
S. sp.	X	--------	--------	--------	--------	--------	--------	--------
S. cycloliratus	--------	X	--------	--------	--------	--------	--------	--------
S. sp.	--------	--------	X	X	--------	--------	X	X
S.? sp.	--------	--------	X	--------	--------	--------	--------	--------
S. paucus	--------	--------	--------	--------	X	X	--------	--------
S. arrondoi	--------	--------	--------	--------	--------	--------	--------	X
Sanguinolites	X	--------	--------	--------	X	X	--------	--------
S. sp.	X	--------	--------	--------	X	X	--------	--------
S. freytesi	--------	--------	--------	--------	X		--------	--------
S. turnei	--------	--------	--------	--------	--------	X	--------	--------
***Cosmomya* (*Palaeocosmomya*)**	X	--------	X	X	X	X	--------	--------
C. (*P.*) *baitaquensis* n.sp.	X	--------	--------	--------	--------		--------	--------
C. (*P.*) *chubutensis*	--------	--------	X	--------	X	X	--------	--------
C. (*P.*) sp.	--------	--------	--------	X	--------	--------	--------	--------
Exochorhynchus	X	X	--------	--------	--------	X	--------	--------
E. itararensis n.sp.	X	--------	--------	--------	--------	--------	--------	--------
E. inflectoventris	--------	X	--------	--------	--------	--------	--------	--------
E. sp.	--------	--------	--------	--------	--------	X	--------	--------
Praeundulomya	X	--------	X	X	--------	--------	--------	--------
P. cf. *subelongata*	X	--------	--------	--------	--------	--------	--------	--------
P. moreli	--------	--------	X	X	--------	--------	--------	--------
Pleurophorella	X	--------	X	X	--------	--------	X	X
P. sp.	X	--------	--------	--------	--------	--------	--------	--------
P.? sp.	--------	--------	--------	--------	--------	--------	X	X
P. elongate	--------	--------	X	X	--------	--------	--------	--------
Myonia	X	X	X	X	--------	--------	--------	--------
M. argentinensis	X	X	--------	--------	--------	--------	--------	--------
M.? sp.	--------	X	X	X	--------	--------	--------	--------

Species	Specimen	Measurements (mm)		
		Length	Height	Width
Palaeoneilo brasiliensis n.sp.	GP/1E-4385	19	13	~2
	SEM NUM.	19	12	-
Phestia sp.	DGM-4336A	~17	~10	-
	DGM-4336B	~14	~9	-
	DGM-4336C	~13	~10	-
	DGM-4336D	~15	~10	-
	DGM-4336E	~14	~9	-
	DGM-4336F	~13	~10	-
Promytilus sp.	DGM-1	35	28	36
Volselina areiensis n.sp.	DGM-4369	34	20	15
	DGM-4371A	36	20	7
	GP/1E-4370	28	15	8
	DGM-4371B	24	12	13
	DGP-4384	29	19	7
Myalina (*Myalinella*) sp.	GP/1E-709	36	26	11
Selenimyalina sp.	DZP-18884C	39	23	-
	DGM-4372	46	25	-
	GP/1E-698	21	13	5
Atomodesma (*Aphanaia*) *orbirugata*	DZP-18832A	~15	16	9
Atomodesma (*Intodesma*) sp.	DZP-18831A	~19	~15	11
Leptodesma (*Leptodesma*) sp.	GP/1E-4362	~23	~12	-
Leptodesma (Leiopteria) sp.	DGM-4377	42	22	-
	DGM 4378	21	13	-
	GP/1E-4371	15	10	-
Streblopetria sp.	GP/1E-4373	13	~16	-
Heteropecten paranaensis	DZP-18883B	~17	20	-
	DGM-4358	28	31	8
	DGM-4361 (LV)	21	24	-
	DGM-4361 (RV)	17	18	-
	DGM-4379	17	18	-
	GP/1E-4362B	23	24	6
	DZP-18810A2	21	24	-
	DGM-4360	23	24	-
	DGM-4367	21	22	-
	DZP-18814	26	29	-
	DGM-4348A	18	20	-
	DGM-4348C (LV)	~27	~19	-
	DGM-4348C (RV)	~18	~11	-
Schizodus sp.	DGM-4346 (LV)	~11	~4	-
	DGM-4346 (RV)	~8	~7	-
	DGM-4347	22	22	5
	GP/1E-692 (LV)	~15	~7	8
	GP/1E-692 (RV)	16	~7	9
Sanguinolites sp.	DGM-4340	34	18	-
Praeundulomya cf. *subelongata*	DGM-4337	~48	22	-
	DGM-4342 (LV)	~42	~15	-
	DGM-4342 (RV)	~71	27	-
	DZP-2910A (LV)	~41	25	-
	DZP-2910A (RV)	~40	~19	-
Pleurophorella sp.	DGM-4374B	~30	17	-
	DGM-374C	~36	16	-
	GP/1E-4372	28	14	4
	GP/1E-670	41	19	-
	GP/13 677	40	14	-
	DGM-4376	38	18	-
Exochorhynchus itararensis n.sp.	DZP-18817C (LV)	40	30	14
	DZP-18817C (RV)	~39	30	-
	DZP-18822	58	39	
	DZP-18829 (LV)	~26	18	-
	DZP-18830 (LV)	34	~26	20
	DZP-18830 (RV)	~33	~18	-
	GP/1E-4438 (LV)	45	34	24
	GP/1E-4438 (RV)	-	~23	-
Cosmomya (*Paleocosmomya*) *baitaquensis* n.sp.	DZP-18828 (LV)	49	23	21
	DZP-18828 (RV)	-	-	~13
	DGM-4344 (LV)	33	16	10
	DGM-4344 (RV)	34	-	10
	DZP-691 (LV)	~31	20	~11
	DZP-691 (RV)	~27	-	~10
Myonia argentinensis	DGM-4341 (LV)	59	13	10
	DGM-4341 (RV)	~56	13	11
	DZP-18826 (LV)	~35	11	10
	DZP-18826 (RV)	~34	11	9
	GP 1E/700 (LV)	~48	-	-
	GP 1E/700 (RV)	57	~12	-

2.2. CAPÍTULO 2

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2.2.2. Artigo

Late Palaeozoic South American pectinids revised: biostratigraphical and palaeogeographical implications

Journal:	*Alcheringa*
Manuscript ID:	Draft
Manuscript Type:	Standard Research Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Neves, Jacqueline; Instituto de Geociências e Ciências Exatas, Anelli, Luiz; Instituto de Geociências, Pagani, Maria; Museo Paleontologico Egidio Feruglio - CONICET, Simões, Marcello; Instituto de Biociências, Universidade Estadual Paulista,
Keywords:	Late Palaeozoic, Pectinids, South America, biostratigraphy, palaeogeography

Late Palaeozoic South American pectinids revised: biostratigraphical and palaeogeographical implications

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NEVES, J.P., ANELLI, L.E., PAGANI, M.A. & SIMÕES, M.G. 2013. Late Palaeozoic South American pectinids revised: biostratigraphical and palaeogeographical implications. *Alcheringa*.

South American Late Palaeozoic bivalve faunas are distributed in the Central Gondwanic, cold Perigondwanic, and warm Extragondwanic realms. Assemblages of the first two realms are currently recorded east of the southern Andes region and are partially contemporary to those of the Extragondwanic Realm, which show affinities to typical Carboniferous, tethyan-like warm water faunas of the American Midcontinent, north and northeastern Brazil. Contrary, the Central Gondwanic faunas in South America are more endemic and related to those of Australia, New Zealand, South Africa, and Namibia. Based on the common occurrence of *Heteropecten multiscalptus* (Thomas) (=*Aviculopecten multiscalptus*) and *Allorisma barringthoni* Thomas, in the upper portion of the Itararé Group, Paraná Basin (Central Gondwanic Realm), Brazil and the Cerro Prieto Formation, Amotape Mountains (Extragondwanic Realm), Peru, some studies have suggested that these faunas were contemporary and closely related. Because these species were recorded in distinct geological units of widely separated localities, this hypothesis has important palaeogeographical and geochronological implications. Hence, the Peruvian and Brazilian type materials of *Aviculopecten* M'Coy, the most common bivalve species in those faunas, are revised and show that the original taxonomic interpretations are inconsistent. The long-established record of *H. multiscalptus* (= *Aviculopecten multiscalptus*) in the Itararé Group is not confirmed. The new Brazilian species (*Heteropecten paranaensis* n.sp.) lived in siliciclastic-dominated, cold, epeiric waters, and is morphologically close to some Australian and Argentinean species. Contrary, the Peruvian *H. multiscalptus* thrived in the warm-water seas of the Extragondwanic Realm, during the Late Palaeozoic. The new information provided here emphasize the notion that Late Palaeozoic pectinids from the Paraná Basin are much closer to their coeval Central Gondwanic counterparts than to species of the Extragondwanic belt of the South American continent.

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Key Words: Pectinids, Late Palaeozoic, South America, biostratigraphy, palaeogeography

IN the decades following Runnergar’s (1972) study, Late Palaeozoic marine faunas from South America were understood as belonging to two main realms: the Gondwanan fauna, found in the southern portion of the continent, and the Boreal (Tethyan) warm water fauna recorded in the northern portion of South America (Rocha-Campos & Archangelsky 1985).

According to recent palaeontological data (González & Saravia 2010), this simple palaeobiogeographical model appears to be much more complex (see Pagani & Taboada 2010, Taboada & Shi 2011, Taboada 2010). As noted by González (1989), the Late Palaeozoic invertebrate marine faunas were distributed in South America across three main domains: the Central Gondwanic, Perigondwanic, and Extragondwanic realms (Fig. 1). The Central Gondwanic and Perigondwanic cold realms belong to the Gondwana Province and are both currently found east of the southern Andes region (González 1989). Their cold water faunas are partially contemporary to those of the Extragondwanic Realm, which show affinities to typical tethyan-like warm water faunas, especially Carboniferous ones from the American Midcontinent (Chronic 1953, Newell *et al.* 1953, Rocha-Campos & Archangelsky 1985, González 1989) and from the Amazon and Parnaíba basins, Brazil (Mendes 1966, Anelli *et al.* 2002, 2006, 2009, 2012). These coeval cold and warm faunas share some fossil taxa in common (González 1989, Pagani 2000, 2004a,b, 2005, 2006a,b, Sterren 2000, 2003, 2004, 2005, González 2002a,b, 2006, Pagani & Sabattini 2002, Cisterna & Sterren 2010, Pagani & Taboada 2010, Sterren & Cisterna 2010, Taboada 2010, Taboada & Pagani 2010, Pagani & Ferrari 2011). Although, this may reveal some degree of palaeobiogeographic affinity (Rocha-Campos & Archangelsky 1985, González 1986, 1989), recent findings indicate distinct coeval marine invertebrate faunas along the western Argentinean basins, during the Pennsylvanian–earliest Permian (Taboada & Shi 2011, Taboada 2010, Pagani & Taboada 2010). Yet, some faunas of the Perigondwanic Realm, as those of the Late Palaeozoic from Tepuel-Genoa Basin, closely resemble contemporary faunas of Australia (Taboada & Shi 2011, Taboada

2010, Pagani & Taboada 2010).

Include the Figure 1 here

A particular palaeogeographic scenario is shown by the marine bivalve faunas of the Central Gondwanic Realm, which are more endemic and show affinities to Late Palaeozoic faunas of Australia, New Zealand, South Africa and Namíbia. However, some authors (Rocha-Campos 1967, 1969, Rocha-Campos & Rösler 1978), based on the common occurrence of the species *Heteropecten multiscalptus* (=*Aviculopecten multiscalptus* Thomas) and *Allorisma barringtoni* Thomas, in assemblages of the Taciba Formation (=Rio do Sul Formation), Itararé Group, Paraná Basin, Brazil (Central Gondwanic Realm) and the Cerro Prieto Formation, Amotape Mountains, Peru (Extragondwanic Realm), have suggested that the Brazilian and Peruvian faunas were contemporary and closely related (*e.g.*, see also Beurlen 1954, 1957 for a similar reasoning). Because those marine assemblages were recorded in distinct geological units of widely separated localities, this hypothesis may have important palaeogeographical and geochronological implications regarding the age, biocorrelation, and environmental settings of Late Palaeozoic strata of South America.

Pectinids were a diverse and abundant group of marine bivalves in Gondwana during the Late Palaeozoic. They are specially known by the extensive and widespread fossil record of members of the Superfamilies Aviculopectinoidea Meek and Hayden, 1865, represented by the genera *Aviculopecten* M'Coy, 1851 and *Deltopecten* Dickins, 1957, and of the Heteropectinoidea Beurlen, 1954 (see Waterhouse 2010, Bieler *et al.* 2010, Carter *et al.* 2011), exemplified by *Heteropecten* Kegel and Costa, 1951 and *Etheripecten* Waterhouse, 1963. The cosmopolitan genus *Aviculopecten* was largely distributed in South America during Carboniferous and Permian times. In Brazil, *Aviculopecten* is present in the carbonates of the Itaituba Formation, Amazon Basin (Mendes 1966), Piauí Formation, Parnaíba Basin (Anelli *et* *al.* 2006), and Itararé Group, Paraná Basin (Rocha-Campos 1969, Rocha-Campos & Rösler 1978). The genus was also recognized in Argentina, in the Tepuel-Genoa Basin (Patagonia) by Pagani (2006a) and in the Precordillera region, in the Río Blanco, Calingasta-Uspallata, and western Paganzo basins (Sterren & Cisterna 2010, Cisterna & Sterren 2011). *Aviculopecten* was also reported to the Late Palaeozoic strata of the northern South America (see a summary in Rocha-Campos 1985), including occurrences in the Rio Palmar Formation, Sierra de Perijá, Venezuela and Colombia; Mucuchachi Formation, Merida Andes, and Palmarito Formation, Carache area, both in Venezuela, and in the La Jagua section Huila, Cordilera Oriental, Colombia. In these occurrences, *Aviculopecten* is usually associated to Late Palaeozoic warm water, marine invertebrates (Rocha-Campos 1985).

Several authors (Rocha-Campos 1970a, Fang & Morris 1999, Anelli *et al.* 2006, Waterhouse 2008) have called attention to the fact that the species assigned to *Aviculopecten* could actually be referred to *Heteropecten* or *Etheripecten*. Waterhouse (2008) also noted that this genus is closely related to *Hayasakapecten* Nakazawa & Newell, 1968. The assumptions above have important consequences if one considers the numerous geochronological and stratigraphic intra and inter-basinal correlations of South American Late Palaeozoic strata that were made using these genera (Rocha-Campos 1970b, Rocha-Campos & Rösler 1978, Pagani 2000; Simões *et al*. 2012). For example, in Peru, *Aviculopecten multiscalptus* Thomas, 1928 (Chronic 1953) was described from Late Carboniferous strata of the Tarma Group and correlated by Rocha-Campos (1969) with the Late Palaeozoic pectinids from the upper portion of the Itararé Group, Paraná Basin, Brazil (see also Rocha-Campos 1970b, Rocha-Campos & Rösler 1978). However, despite the advances in anatomical knowledge and consequent refinement of systematic affinities among those genera (Newell & Boyd 1995, Fang & Morris 1999, Waterhouse 2008, Bieler *et al,* 2010, Carter *et al,* 2011), preservational bias and the puzzling nature of shell ornament make the accurate taxonomic designation of specimens coming from distinct places and ages a difficult task (see Waterhouse 2008).

Herein the original Peruvian material studied by Thomas (1928) and Chronic (1953), and the Brazilian specimens originally investigated by Rocha-Campos (1969, 1970b), all previously assigned under *Aviculopecten* are revised. Based on these and hundreds (n=217 specimens) of additional pectinid specimens recovered from the same Permian beds studied by Rocha-Campos (1969), is shown that, in light of current knowledge of Late Palaeozoic pectinids (Fang & Morris 1999, Waterhouse 2008), the original taxonomic interpretations made by those authors are flawed. Hence, the taxonomy of the Brazilian and Peruvian specimens are revised. A new pectinid species is described for the Early Permian Itararé Group, state of Paraná, Brazil. Additionally, the geological implications of the systematic review made are discussed.

Background

As commented by Amler (1996), Late Palaeozoic pectinaceans (including aviculopectinids and coeval pectiniform bivalves) are an extensive group of benthic, marine mollusks with a profusion of species of distinct taxonomical value, probably, including various *nomina nuda* and *nomina dubia*. Based in palaeobiological data, Amler (1996, p. 2) suspected that nearly 50% of all proposed Devonian and Carboniferous aviculopectinaceans and pectinaceans species are, probably, synonymous. There are several possible reasons for this taxonomically unclear scenario including: **a**– the strikingly different morphology and sculpture of the right and left valves of a single species (see Waterhouse 2008, and discussions below), **b**– species erected on the basis of specimens showing distinct preservational states of the same species (see discussion in Rocha-Campos 1970a); **c**– the poorly knowledge of the species variability based on distinct stratigraphical and palaeogeographical distributions (see Amler 1996), and **d**– the erection of new species on the basis of poorly preserved specimens (see discussions in

Newell & Boyd 1995, Amler 1996, Fang & Morris 1999, Pagani 2000, Waterhouse 2008). Despite of that, benchmark studies concerning the morphology, stratigraphical and geographical distribution of these pectiniform bivalves (Newell & Boyd 1995, Fang & Morris 1999, Waterhouse 2008) leads to a more precise picture of their taxonomy, especially in reference to aviculopectinids and heteropectinids. Aviculopectinoidea is one of the main Palaeozoic groups of extinct pectinid bivalves, whose palaeobiogeographic distribution was concentrated in high latitudes during the Permian (see Waterhouse 2008). Members of this group typically inhabited plataformal settings (above storm wave base).

Until now aviculopectinids were thought to be the main pectiniform bivalves found in the Permian strata of the Itararé Group. By revising the descriptions made by Waterhouse (1969, 2008), and Fang & Morris (1999), *Aviculopecten* can be typified as an alivincular, unevenly biconvex pectinid and ornamented with narrow simple plicae. According to Waterhouse (2008, p. 73), the left valve shows various ribs with almost flat broad crests and narrow interspaces. The same author (p. 74) summarizes the morphology of *Aviculopecten* and much of the controversy related to this genera as well, and concluded that it is a pectiniform bivalve with unequally biconvex, sturdy ornamented shells with a resilifer. The pattern of ornamentation is pretty the same in both valves (Waterhouse 2008, p. 74). Unfortunately, the internal morphology and shells structure of *Aviculopecten* is still poorly known. On the other hand, heteropectinid bivalves are characterized by shells having more inflated left valves and amphidetic alivincular hinge (Kegel & Costa 1951; Rocha-Campos 1970a, Waterhouse 2008). Particularly in *Heteropecten*, the valves are moderately large with the right shell weakly convex to flat. The left valve is ornamented by narrow plicae with flat to rounded crests and the interspaces are narrow to moderately width, including one or two orders of costae (Waterhouse 2008). Contrary, the right valve is ornamented by broad, branching costae (Kegel & Costa 1951, Rocha-Campos 1970a, Waterhouse 2008). Internally, the palial line is dorsally open (see Rocha-Campos 1970a, Waterhouse 2008).

Geological setting

The South American pectinids here studied come from Late Palaeozoic strata from Peru and Brazil. Additional material for comparisons comes from Late Asselian–Sakmarian deposits of the Bonete Formation, Sauce Grande-Colorado Basin, and possibly Early Artinskian marine deposits from the Tepuel-Genoa Basin, Patagonia, Argentina (see Pagani 2000, 2005).

In the Central Andean area of Peru, the Amotape Group is made up of a 4700 m thick sequence of clastic rocks, encompassing the Cerro Negro, Chaleco de Paño, Cerro Prieto, and Palaus formations (Rocha-Campos 1985). The type section of the Cerro Prieto Formation (section 19 of Chronic 1953, fig. 2) at the Quebrada Landry, about 28 km east of Negritos, shows shales that crop out in a prominent hill at the southwest end of the Amotape Mountains, in the northwestern portion of Peru (Rocha-Campos 1985; Rocha-Campos & Archangelsky1985). These shales yielded an abundant fauna of bivalve mollusks (mainly) and brachiopods, originally studied by Chronic (1953) and Newell *et al.* (1953). The fauna of the Cerro Prieto Formation is regarded as Pennsylvanian, showing affinity to North American Midcontinent warm water faunas (Rocha-Campos & Archangelsky 1985). Among the bivalves, pectinids are especially abundant in some bed plans of various localities (Chronic 1953, p. 149) and mainly represented by distinct species of "*Aviculopecten*" (Chronic 1953). *Heteropecten multiscalptus* (Thomas) roughly resembles some Permian Brazilian pectinids (Chronic 1953), and was also reported in the Paraná Basin by Rocha-Campos (1969).

The Paraná Basin, a huge intraplate basin, is located in the southern and southeastern portions of Brazil, encompasses six major supersequences., which span from the Caradoc–Llandovery to Aptian–Maastrichtian times (Milani 1997, Milani *et al.* 2007, Holz *et al.* 2010). The 2500 m thick Gondwana I Supersequence is a sedimentologically heterogeneous and complex succession, recording various key palaeoclimatic events, including the Late Palaeozoic glaciation (Itararé Group) and the arid continental environments of the Triassic period (Milani 1997, Milani *et al.* 2007). The lowermost section of the Gondwana I Supersequence is composed of a succession of glaciogenic rocks (Itararé Group and Aquidauana Formation) including diamictites, turbiditic sandstones, conglomerates and subordinate varvites and tillites (Milani 1997, Rocha-Campos *et al.* 2008).

In the southern portion of the Paraná Basin, the Itararé succession (Westphalian to early Permian, Mori *et al.* 2012) is divided into three main units, namely Campo do Tenente, Mafra, and Rio do Sul formations (Schneider *et al.* 1974), and their respective coeval subsurface formations: Lagoa Azul, Campo Mourão, and Taciba (França & Potter 1988, Milani *et al.* 1994, 1998). As recently suggested by Mineropar (2007), the subsurface lithostratigraphical nomenclature of França and Potter (1988) can be applied to the surface deposits of the Itararé Group in our study area, Teixeira Soares county (25°22'30''S/50°27'48''W), state of Paraná, Brazil (Fig. 2). Locally, two geological sections were studied , Rio d'Areia (25°27'48''S/50°23'25''W) and Baitaca (25°23'06''S/50°26'53''W) where the marine succession is referred to the upper portion of the Taciba Formation (Fig. 3). The base of the geological succession starts with thick (10 m, see Mineropar 2007), polymitic, matrix-supported, massive conglomerates with rounded, striated and faceted clasts of granites. The diamictites also show inclusions of pre-lithified rocks, as sandstones and deformed conglomerates. These are interpreted, in part, as gravity-driven, resedimented deposits in proximal settings (Mineropar, 2007). Directly above, in sharp contact, thick (07 m), well-sorted, medium to fine-grained sandstones, with planar cross stratification contain abundant heteropectinid shells. Symmetric and asymmetric ripples, flaser lamination and trace fossils (*Planolites* sp.) are noted at the top of the sets. Thin, pectinid-dominated shell pavements occur at the upper (2 m) portion of the sandstones (Fig. 4). These fossil-rich concentrations were generated in nearshore (above fair-weather wave base), aerobic settings. These are succeeded by thin (50 cm), deeply bioturbated fossiliferous siltstones with scattered burrowing bivalves (*Praeundulomya* sp.) and heteropectinids. Above, a thick (2.15 m) succession of fine to very fine grained, well sorted sandstones showing low-angle trough cross-stratifications occurs (Fig. 5). The base of the sandstone is sharp and the top intensely bioturbated where escape structures are commonly present. In some cases, hummocky laminae are visible in the sandstone. Here, *in situ* shells of burrowing bivalves (Anelli *et al.* 1998, Simões *et al.* 1998) are associated to chaotically oriented heteropectinid shells. At least, four stacked sandstone bodies are recorded, and in the uppermost one a massive, white to yellowish colored siltstone/mudstone abruptly covers the bioturbated layer of the sandstone where the burrowing bivalves were smothered *in situ*. These are amalgamated tempestites, which were generated just at or above storm wave base in inner shelf environments. Finally, thick (35 m), dark grey (fresh) to white-yellowish (weathered), thinly laminated or locally massive mudstones or shales, lacking dropstones, are succeeded by fluvio-deltaic, coal-bearing deposits of the Artinskian Rio Bonito Formation (Fig. 3) (see also Mineropar 2007). At places, the mudstones of the uppermost portion of the Taciba Formation contain small, butterflied (splayed) valves or isolated shells of detritus feeding bivalves (*Phestia* sp., *Palaeoneilo* sp.), all concordant to bedding. These mudstones and shales were deposited in oxygen-deficient, outer shelf environments (below storm wave base) with organic-rich bottoms. Heteropectinid shells were not found in these offshore deposits yet.

Include the Figure 2 here

As recently described by Simões *et al.* (2012), the bivalve fauna of the upper portion of the Taciba Formation, from the Teixeira Soares region, seems coeval to that of thin marine intercalations of the uppermost portion of the same unit, cropping out at the Mafra region, state of Santa Catarina, Brazil, and to the Bonete Formation (Pagani 2000), Sierras Australes, Buenos Aires Province, Argentina, all suggesting an Early Permian, possibly Asselian–Sakmarian age.

Include the Figure 3 here

Material and methods

Studied Collection. The studied Peruvian pectinids are housed in the American Museum of Natural History (AMNH), NY, USA, and consist of five specimens, all internal molds, including a small (centimeter-long) slab with three shells. The material is coded as AMHN 34114, 34115 (slab), and 34116, and comes from AMNH locality 309, southwest end of the Amotape Mountains, nearly 20 km east of Talara, Peru. The Brazilian material includes numerous specimens (257), which are deposited in 1) the palaeontological collection of the Geosciences Institute, University of São Paulo (n= 40), São Paulo, coded as DGM and GP, and 2) the collection of the Department of Zoology (n= 217), São Paulo State University, at Botucatu campus, São Paulo, coded as DZP. The DGM and GP material was acquired from the same beds (Fig. 2) originally studied by Lange (1944, 1954), Almeida (1945), Beurlen (1954, 1957), and Rocha-Campos (1969, 1970b). The additional material from the DZP collection helped to shed light on the issue of the taxonomic assignment of Brazilian fossils to the Peruvian species *Heteropecten multiscalptus* (Thomas), 1928. The Argentinean specimen (Fig. 7L), coded as CPBA, is housed in the colletion of the Departament of Geology at the University of Buenos Aires, Argentina.

Laboratory and Taxonomical Decisions. As commented above, most shells are represented by internal and external molds. Except for a few specimens of the DZP collection, all others were previously cleaned and prepared. Hence, laboratory actions involved only the preparation of plasticine casts using soft modeling clay (FIMO brand) for the detailed study of the morphological characteristics of pectinid shells. The casts and some original specimens of the DGM and DZP collections were also coated with sublimated magnesium oxide to enhance anatomical details (i.e., ornamentation, muscle scars, etc.) on behalf of better photography (Anelli *et al.* 2006, 2009, Pagani & Ferrari 2011, Simões *et al.* 2012). Morphological terms are used as in Amler (1996) and Waterhouse (2008). Finally, the suprageneric taxonomy is based on Carter *et al.* (2011), which is the upcoming revision of Bivalvia volumes of the *Treatise on Invertebrate Paleontology*. Pectinid systematics followed Kegel & Costa (1951), Newell & Boyd (1995), Fang & Morris (1999), and Waterhouse (2008, 2010).

Include the Figure 4 and 5 here

Systematic palaeontology

Order PECTINIDA Gray, 1854

Superfamily HETEROPECTINOIDEA Beurlen, 1954

Family HETEROPECTINIDAE Beurlen, 1954

Subfamily HETEROPECTININAE Beurlen, 1954

Heteropecten Kegel & da Costa, 1951

Type species. *Aviculopecten catherinae* Reed (1930, p. 10–16) for original designation.

Remarks. Rocha-Campos (1970a) emphasized that a great number of species designated under the genus *Aviculopecten* in Late Palaeozoic deposits of different continents should actually be considered as *Heteropecten*. The main confusion regarding the type species of *Aviculopecten* (*A. planoradiatus* M'Coy, 1851) stems from the fact that M'Coy (1851) used only the left valve to describe and erect this new genus. According to Newell (1938), no right valve was known, even though Hind (1903) had suggested that some incomplete molds of right valves of *Pecten tabulatus* M'Coy, 1844 were conspecific to *A. planoradiatus*. Later, *Aviculopecten* and *Heteropecten* were considered synonyms by Newell (1969, p. N336). However, according to Fang & Morris (1999), the hypothesis of Newell was not valid because some North American Pennsylvanian pectinids actually belong to the genus *Heteropecten*, which shows striking differences from the British type species of *Aviculopecten* (Fang & Morris 1999, p. 38). Based on new findings and reexamination of the type species, including the right valve, Fang & Morris (1999) revised the genus *Aviculopecten*. They argued that the main distinctive feature of the genus is the presence of simple radial plicae in *Aviculopecten*, differently from *Heteropecten* (Fig. 6), which has grading costae. Additionally, the genus *Etheripecten* has been also misinterpreted with *Heteropecten*, what according to Fang & Morris (1999) occurred because both are characterized by intercalated costae. The latter two genera were considered synonyms by Newell & Boyd (1995), but according to Waterhouse (2008, p. 137), *Heteropecten* differs from *Etheripecten* in that it shows broad primary ribs, whereas *Etheripecten* shows solid costae of several orders. Additionally, interspaces between primary ribs are narrower in *Heteropecten*, occupying much of the width of the valve, and may bear one or two orders of finer ribs. Finally, as observed by Waterhouse (2008), both valves of *Heteropecten* are undulose, whereas left valves of *Etheripecten* are not.

Emended Diagnosis. Pectiniform shell as in Waterhouse (2008, p. 144), but including one to three orders costae.

Include the Figure 6 here

Heteropecten paranaensis new species (Fig. 7A–T, Tab. 1)

1944 *Aviculopecten* sp., nom. nud.,; Lange, p. 279.

1952 *Aviculopecten* sp., nom. nud.,; Kegel, p. 84, fig. 4.

1951 *Aviculopecten* sp., nom. nud.,; Kegel & Costa, p. 171.

1954 *Aviculopecten* sp., nom. nud.,; Lange, p. 54.

1954 *Aviculopecten multicalptus* Thomas, nom. nud.,; Lange, p. 54.

1954 *Prosopecten alternatus* Beurlen, nom. nud., Lange, 1954, p. 55.

1954 *Prosopecten elegans* Beurlen, nom. nud.; Lange, p. 55.

1954 *Prosopecten densicostatus* Beurlen, nom. nud.; Lange, p. 55.

1954 *Prosopecten radiatus* Beurlen, nom. nud.; Lange, p. 55.

1967 *Aviculopecten*? sp.; Rocha-Campos, p. 67, pl. XXIX, fig. 15.

1969 *Aviculopcten multiscalptus* Thomas; Rocha-Campos, p. 41, pl. 1, figs. 1–3, 5–9, 11.

1978 *Aviculopcten* cf. *A. multiscalptus*; Rocha-Campos & Rösler, p. 5.

2000 *Heteropecten* sp., *in part*; Pagani, p.308–309, fig. 3A

2012 *Aviculopecten multiscalptus*; Simões *et al.*, p. 74, pl. 4, figs A–F.

Diagnosis. Left valve with umbones above hinge line; ribs increasing by intercalation, with second order ribs thinner than the first; ribs increasing by branching or bifurcation. Right valve with deep byssal furrow under the anterior auricle and an acute and well developed posterior auricle.

Etymology. The species name refers to the basin where shells were recorded.

Material. The holotype is the specimen DGM-4379, a well preserved external mold of left valve. Measurements of the holotype and paratypes are shown in Table 1. The width of some specimens could not be measured.

Occurrence. Rio d'Areia and Baitaca localities, at Teixeira Soares county, state of Paraná, Brazil.

Description. Shell infracrescent, strongly inequivalve, including a very convex left valve and an slightly flat right valve. Both the left and right valves are slightly inequilateral. Umbonal angle about 90°. Umbo inflated with slightly prosogyrate beaks. Left valve inflated; anterior auricle well developed, triangular, with rounded anterior margin, separated from the body of shell by a curved fold, ornamented with five to nine costae. Posterior auricle acuminate, with concave posterior margin, separated from the body of shell by slightly curved fold, ornamented with four radial costae; growth lines barely visible in both auricles. Hyote spines absent in both auricles. Surface ornament of plicae increasing by fasciculation; primary radial costae extending from umbonal region until ventral margin; secondary costae originated by intercalation on the midheight of shell, extending until ventral margin. Around 21 to 23 primary costae are present, always intercalated with secondary costae; primary costae thicker than secondary. Dorsal area straight. Right valve flat or slightly convex. Anterior auricle well developed with rounded anterior end, ornamented with slightly marked nonfasciculate costae showing poorly developed hyote spines. A deep byssal furrow under anterior auricle separates the auricle from the main body of valve. Posterior auricle well developed, acute, with concave posterior margin. Surface of valve ornamented with faint radial costae, better defined close to ventral margin. Muscle scars and hinge features not observed.

Remarks. Kegel & Costa (1951) noted that pectinids from marine intercalations of the Taciba Formation, in the Teixeira Soares region, are not fasciculated as in *Heteropecten*, emphasizing that this genus is not present in that fauna. However, fasciculated ribs are not a diagnostic feature for *Heteropecten*, and may or may not be present. The right valve of *H. paranaensis* n.sp. is similar to those of *H. multiscalptus* (Thomas) from Peru (Chronic 1953). Both share the same pattern of ornamentation with costae increasing by branching and ears of both valves with eight to 10 fine ribs. The differences between those species occur only on the left valve. Chronic (1953) mentioned that the left valve of *Aviculopecten occidentalis* (Shumard), reported by Derby (1874) and Katzer (1903) from the Itaituba Formation, Amazon Basin, Brazil, is closely comparable to the one from Peru assigned to *H. multiscalptus*, which shows remarkable differentiation between primary, secondary, and tertiary ribs on the left valve. Although right valves of Itararé specimens are extremely similar to *H. multiscalptus*, their left valves show rib differentiation in just two order levels. The same occurs with *Hillaepecten queenslandica* Waterhouse, 2010 from Tiverton Formation, Australia, a Heteropectinidae whose right valve also resembles that of *H. paranaensis* n.sp. However, there is an important distinction in the left valve of *Hillaepecten queenslandica*, which bears concentric spiny laminae in the primary and secondary costae, even though those spines are absent in some specimens described by Waterhouse (2010) (e.g., specimen UQF 81622) and in *H. paranaensis* n.sp.

In the Bonete Formation, Sauce Grande Basin (Central Gondwanic Realm), Sierras Australes, Argentina, *Heteropecten* was firstly recorded and described by Pagani (2000) on the basis of eight fragmentary specimens. One specimen in particular (CPBA 5889, see fig. 4A in Pagani, 2000) is a very distinct left valve, when compared with other coeval individuals of *Heteropecten* sp. from the same unit (Pagani, 2000, p. 308–309). This specimen was found in the Cerro Bonete locality, differently from the other ones (illustrated), which come from Piedra Azul locality. This specimen is also referred to *H. paranaensis* n. sp. because its closely morphological general shape, the beaks are located above the hinge line, there are only two order ribs, where the second one increases by intercalation. Yet, the primary ribs in the

Argentinean specimen are thicker than the secondary ones, and the third order ribs are absent. These conditions are the same observed for the material of *H. paranaensis* n. sp. from the Taciba Formation of the Paraná Basin. Another three Argentinean species are different in shape to the Brazilian shells and in some details of surface ornamentation, such as the presence of fasciculation. *H. paranaensis* n.sp. is distinguished from *Heteropecten anteloi*, described by González (1997) from Late Carboniferous of Western Argentina, by the presence of left valve ribs that increase by intercalation, whereas in *H. anteloi* that process may occur by division on some specimens (e.g., sample IPI 1904, González, 1997, p. 202). *Heteropecten paranaensis* n.sp. and *Heteropecten argentinaensis* Pagani, 2005 from Early Permian of Patagonia, Argentina differ in the right valve ornamentation: ribs increase by bifurcation in the former and intercalation in the latter. Finally, *H. paranaensis* n.sp. is distinguished from *Heteropecten cortignasi* González, 2006, also from Central Patagonia, by the presence of ribs that increase only by intercalation on the left valve and bifurcation on the right one, whereas in *H. cortignasi* costae intercalate and bifurcate on both valves.

Heteropecten multiscalptus (Thomas, 1928) new combination (Fig. 8A–H)

1928 *Aviculopecten multiscalptus* Thomas, p. 148, pl. 5, figs. 1, 3–8a.

1928 *Aviculopecten sullanaensis* Thomas, p. 151, pl. 5, fig. 9, 1928.

1953 *Aviculopecten multiscalptus* Thomas; Chronic, p. 154, pl. 31, figs. 3–5.

Remarks. While in *Aviculopecten* shells are unevenly biconvex, with the same pattern ornament on both valves, in *Heteropecten* the shells are strongly inequivalve, with grading costae. The left valve is convex, ornamented by narrow plicae and the right valve is nearly flat and ornamented by branching. Hence, the specimens previously described as *Aviculopecten* *multiscalptus* Thomas (Chronic 1953), were herein relocated to the genus *Heteropecten*.

Material. Samples: AMNH FI 34114, complete right valve, length 18 mm, height 17 mm, and width could not be measured; AMNH FI 34115, slab with three fragmented left valves; AMNH FI 34116, a fragmented shell with conjugated valves. AMNH: American Museum of Natural History; FI: fossil invertebrate. DZP-18922; 18924, 18925; 18926; 18928, plasticine casts of the above mentioned specimens.

Occurrence. Amotape Mountains, Peru, Tarma Group, Cerro Prieto Formation. Locality 309, section 19 of American Museum of Natural History (Newell *et al.* 1953, p. 06).

Description. Shell varying in size, inequivalved, nearly circular in shape. Hinge line straight; anterior, ventral, and posterior margins rounded. Left valve moderately convex, with small incurved umbone projecting above hinge line; anterior auricle convex, umbonal slope marked by a deep depression; posterior auricle concave, slightly longer than anterior, faintly detached from the main body of the shell, with an acute anterodorsal extremity. Surface ornament of numerous radiating ribs, nine to 10 primary ribs, secondary ribs the same size as the primaries; tertiary ribs increasing in the interspaces with one or more much finer ribs on either side; auricles with nine to 10 fine radial ribs; concentric lirae sharp and closely spaced, quite distinct except over primaries and secondaries. Right valve nearly flat; anterior auricle with deep byssal sinus; posterior auricle concave and not well defined. Surface ornament of 13 to 14 ribs increasing by bifurcation; both auricles with fine radial ribs, and thin, closely arranged concentric lirae. Hinge features unknown.

Remarks. The pectinid from the Amotape Mountains is designated under the genus

Heteropecten because of: 1) its strong inequivalve shells; 2) the presence of grading costae in both valves; and 3) the absence of simple radial plicae. The type material of *H. catharinae* Kegel and Costa (1951) from Rio Bonito Formation, Paraná Basin, is distinctive from *H. multiscalptus* in the presence of primary and secondary ribs, with the secondary being thinner, and by the presence of fasciculating ribs, as seen in many specimens. *Heteropecten multiscalptus* does not have fasciculation pattern, but three order costae are present, with intercalation of first and second orders costae of same width, and very thin third order costae occupying interspaces (Chronic 1953). Finally, *H. paranaensis* n.sp. from Taciba Formation, Paraná Basin, Brazil, differently from *H. multiscalptus* shows third order ribs.

Include the Figure 7 and 8 here

Discussion

Rocha-Campos (1970a, p. 22) mentioned that species described from various continents under the genus *Aviculopecten* could, indeed, belong to the genus *Heteropecten*. This was the case for North America, especially the material studied by N. D. Newell (Fang & Morris 1999, p. 148), and South America, in the Amotape Mountains fauna studied by Thomas (1928) and Chronic (1953), and in Brazil by Kegel & Costa (1951) and Mendes (1966). The designation of some South American pectinids under the genus *Aviculopecten* certainly followed previous studies of Carboniferous specimens from North America. The species described from the Amotape Mountains, Peru does not show the diagnostic features that are present in *Aviculopecten*, as discussed in the systematic section. Based on these data, the Peruvian material is relocated from the genus *Aviculopecten* to the genus *Heteropecten*. Additionally, the specimens from the Taciba Formation, Brazil previously informally designated under the species *A. multiscalptus* (Rocha-Campos 1969) is here described as a new species under *Heteropecten paranaensis* n.sp. , also including rare specimens found in the Early Permian, Bonete Formation, Sierras Australes, Argentina. In sum, despite the general close resemblance, *H. paranaensis* and *H. multiscalptus* are morphologically distinct regarding the pattern of ornamentation of the left valve.

The genus *Heteropecten* was first described by Kegel & Costa (1951) from Rio Bonito Formation. This occurrence was later interpreted by Rocha-Campos & Rösler (1978) as Artinskian in age (Rocha-Campos & Simões 1992). Indeed, the age of the Rio Bonito Formation is now well constrained to 281.4±3.4 Ma, indicating an Artinskian (Cisuralian, Early Permian) age based on absolute dating of U–Pb in zircons from volcaniclastic rocks (Mori *et al.* 2012). Dickins (1963) and Dickins & Thomas (1959) identified species of *Heteropecten* in Western Australia with a similar pattern of ornamentation to that seen in the type species (*H. catharinae*, Rocha-Campos 1970a, p. 22). Since then, the genus has been identified in several Permian strata around the world. Additionally, in the upper portion of the Taciba Formation, where *Heteropecten* shells are extremely abundant in platformal siliclastic lithofacies, coeval bivalve species (*e.g.*, *Myonia argentinensis*) indicate a Cisuralian (Asselian–Sakmarian) age (see also Simões *et al.* 2012). Hence, the presence of the genus *Heteropecten* in the Cerro Prieto Formation may suggest that the marine fauna of central Peru is younger than previously thought. The fauna was originally assigned to the Carboniferous (Newell *et al*, 1953), but Morris *et al.* (1991), based on the type material of *Allorisma barringtoni* Thomas, 1928, interpreted the Amotape Mountains fauna as being of Late Artinskian age (Morris *et al.* 1991, p. 80). Indeed, the Pennsylvanian age of the Peruvian fauna is mainly supported by the two fragmentary specimens of the goniatite *Pseudoparalegoceras peruvianum* Berry, 1928 from a single locality in central–northern Peru (Rocha-Campos 1985). According to some studies (Chronic 1953, Murray *et al.* 1960), this species closely resembles Middle Pennsylvanian goniatites from North America. Moreover, as discussed in Rocha-Campos (1985), this age is also supported by rare fusulinids and palynomorphs of Pennsylvanian affinity that were listed, but not described/figured, by Seminario & Guizado (1976, in Rocha-Campos 1985). Unfortunately, the invertebrate fauna of the Cerro Prieto Formation is still inadequately described and in need of a full revision considering our current knowledge of Late Palaeozoic marine bivalve faunas, an issue highlighted nearly 45 years ago by Rocha-Campos (1969, p. 27). Hence, the age of the Cerro Prieto marine fauna and its correlation with other faunas of the Gondwana Supercontinent (Dickins 1957, 1963) remain open issues in the scientific literature on the geology of South America.

Mode of life of *Heteropecten paranaensis* n.sp.

According to, and by comparison with other pectinids, *H. paranaensis* with its slightly asymmetrical shells was an epibyssate, attached (uncemented) bivalve lying with the flat, right valve directly to the substrate (see also Stanley 1972, Amler 1996, Waterhouse 2008, p. 189). As described below, *H. paranaensis* preferred sand-sized substrates, made up of siliciclastc and/or bioclastic grains, under shallow water (above storm wave base), aerobic conditions. Indeed, *H. paranaensis* is the most abundant and widespread bivalve species in the studied lithofacies of the upper portion of the Taciba Formation (Figs. 4, 5). Shells are found disperse or concentrated in sandstones and siltstones, but are really common in medium to fine-grained sandstones deposited in nearshore to inner shelf conditions. Despite the predominance of left valves over the right ones in various fossil concentrations, which may indicate some degree of lateral transport, sings of extensive residence time at the sediment/water interface and transportation (e.g., abrasion, fragmentation etc.) are typically lacking. In the sandstone bodies representing coastal deposits (Fig. 4), where heteropectinid shells are extremely abundant, some valves still closed articulated, suggesting an autochthonous to parautochthonous (sense Kidwell *et al.* 1986) occurrence. In these sandstones, the presence of symmetric and asymmetric ripples and flaser lamination at the top of the sets of the planar cross-stratifications indicate deposition in nearshore settings influenced by waves and tides (see also Mineropar 2007). This species is also common in fine-grained sandstones and siltstones showing trough cross-stratification and hummocky cross-stratification, representing amalgamated storm beds (tempestites) (Fig. 5). These beds are deeply bioturbated suggesting aerobic bottoms, deposited just at or above the storm wave base. Shells of *H. paranaensis* are not found in mudstones and shales (Passinho shale) (Figs. 4, 5), deposited below storm wave base in outer shelf (offshore) settings with dysaerobic to anaerobic bottom conditions. In sum, *H. paranaensis* probably was an opportunistic epifaunal, byssate species that thrived in cold, aerobic, siliclastic-dominated bottoms, in platformal, transgressive settings generated during the demise of the Permian glacial event in the Paraná Basin and Sauce Grande-Colorado Basin.

Final remarks

As shown above, the main diagnostic characters of the genus *Aviculopecten* are absent in the Brazilian and Peruvian species. Hence, based on the current review, the long-established presence of *Heteropecten multiscalptus* in the Itararé Group, Paraná Basin, Brazil (Beurlen 1954, 1957, Rocha-Campos 1967, 1969, 1970b, Frakes & Crowell 1968, Rocha-Campos & Rösler 1978, Simões *et al.* 1998) is not confirmed. González (1989) pointed out that palaeoecologic and palaeogeographic issues hinder the direct connection between the Brazilian species (*H. paranaensis* n.sp.) and the Peruvian one (*H. multiscalptus*). Indeed, the Brazilian species thrived under cold water conditions, as indicated by its association with glacial deposits and the low diversity of the associated invertebrate fauna (Simões *et al.* 1998). Conversely, the Cerro Prieto assemblage is a typical, well diversified warm water fauna with close affinities to American Midcontinent assemblages and Carboniferous faunas of northern

Brazil (Mendes 1966, Anelli *et al.* 2002, 2006, 2009, 2012). As commented by González (1989), the shared occurrence of species in the Paraná Basin (Central Gondwanic Realm) and central Andean area (Peru and Bolivia) (Extragondwanic Realm), as previously conceived, is difficult to envisage as the southern connection between the Paraná Basin and the Peruvian-Bolivian Andean area across the Pre-Cambrian shield (Helwig 1972), due to "the interposition of the Asunción Arch and the austral closure of the Bolivian Basin" (González 1989, p. 15). The assignment of the Brazilian species to *Heteropecten paranaensis* n.sp., which resembles *Hillaepecten queenslandica* from Tiverton Formation (Waterhouse 2010), Australia and their possible occurrence in deposits of the Bonete Formation, Sauce Grande-Colorado Basin (Central Gondwanic Realm), Argentina (Pagani 2000), reinforces the notion that Late Palaeozoic pectinids from Paraná Basin are much closer to the Argentinean and Australian faunas of Gondwana than to the fauna of the Extragondwanic belt of the South American continent.

Acknowledgements

The authors are indebted to Mrs Bushra Hussaini (senior scientific assistant) and Dr. Neil Landman (curator-in-charge, Invertebrate Palaeontology collection) of American Museum of Natural History, New York, for allowing us to study the original material of the Late Palaeozoic from Peru, in 2011. Thanks are due to Department of Zoology, IBB-UNESP, Brazil and Department of Environmental and Sedimentary Geology, IGc-USP, Brazil, for the permission to study the bivalve collections. Funds were provided by the Brazilian agencies FAPESP and CNPq. We thank Brian Pratt (College of Arts & Science, University of Saskatchewan, Canada) for general comments on early version of this contribution. We also appreciate the valuable comments of reviewers (XXXX) and the time, careful revision, corrections and critical comments of the Editor (XXXXX), which substantially improved the

paper.

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Figures and table captions

Fig.1. Left: Paleogeographic reconstructions of the Gondwana in the Late Paleozoic, showing the main realms according to González (1989). Right: Schematic paleogeographic representation of Western Gondwana. A, B: Studied basins in this work. A, Paraná Basin, Brazil, in the Central Gondwanic realm. B, Amotape Mountains, Tarma Group, Amotape Mountains, Peru, in the Extragondwanic realm. 1–9: Other basins from Western Gondwana. 1, Argentine–Bolivian Basin; 2, Uspallata–Iglesia Basin; 3, San Rafael Basin; 4, Andacollo Basin; 5, Languiñeo–Genoa Basin; 6, Chaco Paraná Basin; 7, Sauce Grande Basin; 8, Namibia Basin, 9, Karoo Basin.

Fig. 2. Location maps showing the fossil sites from where the studied specimens come from. Right: Teixeira Soares county, State of Paraná, Brazil. Left, Amotape Mountains, Peru; *Section 19 from Newell *et al.* (1953, p. 06).

Fig. 3. Chronostratigraphic chart of the Late Paleozoic in the Paraná Basin (Itararé and Guatá Groups), modified of Holz *et al.* (2010). Passinho shale transgression is shown in the uppermost portion of the Taciba Formation (Rio do Sul Formation), where the studied

bivalves were recorded. Passinho shale is succeeded by the Rio Bonito Formation, unit in which the genus *Heteropecten* was described by the first time by Kegel & Costa (1951).

Fig. 4. **A**, Columnar section of the uppermost portion of the Taciba Formation, in Teixeira Soares region, State of Paraná, Brazil, at the Rio d'Areia locality. **B**, Shell pavements showing disarticulated valves of *H. paranaensis* n.sp., at the upper (2 m) portion of the fine to medium-grained sandstone. **C**, Detail of a well preserved right valve of *H. paranaensis* n.sp.

Fig. 5. Columnar section of the uppermost portion of the Taciba Formation, in Teixeira Soares region, State of Paraná, Brazil, at the Baitaca locality. *H. paranaensis* occurs on three horizons of fine-grained sandstone/siltstone, intensely bioturbated, as indicated in the columnar section.

Fig. 6. Drawings of some Late Paleozoic pectinids. **A**, *Aviculopecten planoradiatus* M'Coy (1851), type species, fragmented left valve from Lower Carboniferous, Narrowdale Hill, Derbyshire, stored at British Museum of Natural History, BH(NH) L45141 (modified from Fang & Morris, 1999, pl. 1, fig. 3). **B**, *Heteropecten paranaensis* n.sp., internal mold of left valve from Itararé Group, Taciba (=Rio do Sul) Formation, stored at Geosciences Institute, University of São Paulo, Brazil, DGM-4379. Note the drawings of cutting series showing the external surface ornamentation of the shells: in the specimen 1, there are no grading costae, shell is ornamented by simple radial plicae and in the specimen 2, there are grading costae in two order ribs, in which the second order is thinner than the first one. Scale bar= 1 cm.

Fig. 7. Heteropecten paranaensis n.sp. from Taciba Formation, Itararé Group, Brazil, and Bonete Formation, Pillahuinco Group, Argentina. **A–I**; **K–L**: Left valves view. **A**: DGM-

4379; **B**: DZP-18883; **C**: DGM-4358; **D**: DGM-4359A; **E**: DGM-4368; **F**: DZP-18810A2; **G**: GP/1E-4362B; **H**: GP 1E/4372B; **I**: DZP-18814; **J**: DGM-4348C, internal mold of butterflied valves; **K**: DZP-18815; **L**: CPBA 5889. **M–P**; **R–T**: Right valves views. **M**: DGM-4360; **N**: DGM-4367; **O**: DZP-18810A1; **P**, **Q**: internal mold of conjugated valves, DGM-4361; **R**: DZP-18810A3; **S**: GP/1E-705A; **T**: GP/1E-705B. Scale bar= 1 cm.

Fig. 8. Heteropecten multiscalptus (Thomas) from Amotape Mountains fauna, Cierro Prieto Formation, Peru. **A**: Right valve sample, FI 34114; **B**: Pavement of left valves, sample FI 34115; **C**: plasticine cast, sample DZP-18922, of the specimen illustrated in A, showing ribs increasing by branching; **D–H**: Plasticine casts of left valves, showing ribs increasing by intercalation in three orders hierarchy. **D**: DZP-18925; **E**: Detail of **D**; **F**: DZP-18928; **G**: DZP-18926; **H**: DZP-18824. Scale bar= 1 cm, except in **E**, scale bar= 0.5 cm.

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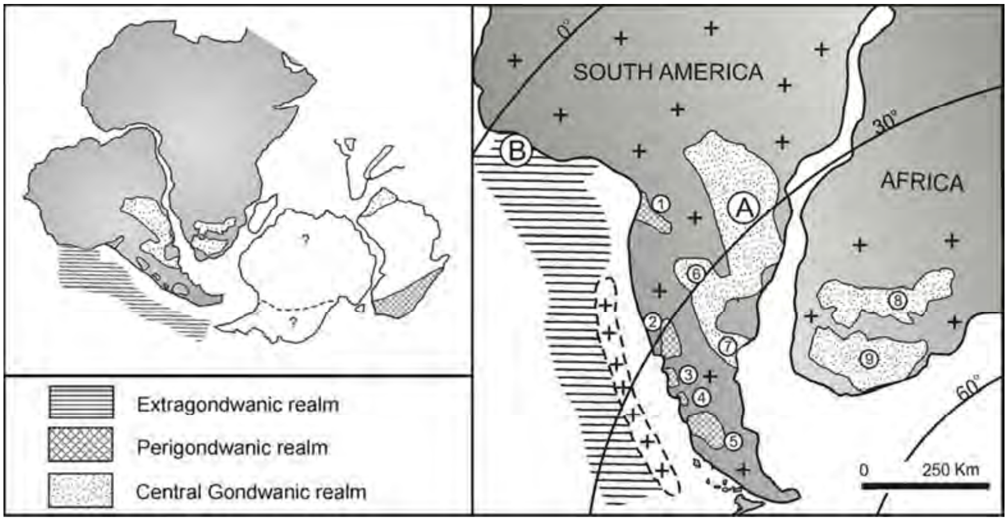

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81x41mm (300 x 300 DPI)

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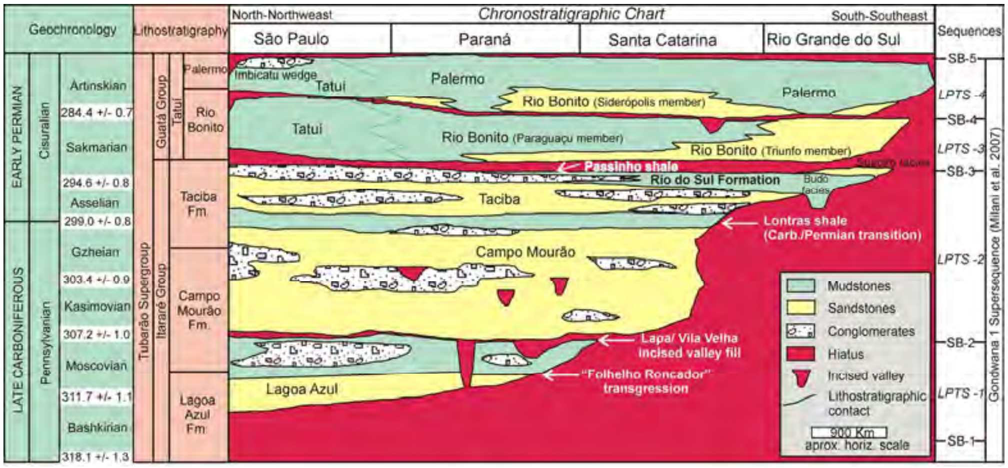
166x49mm (300 x 300 DPI)



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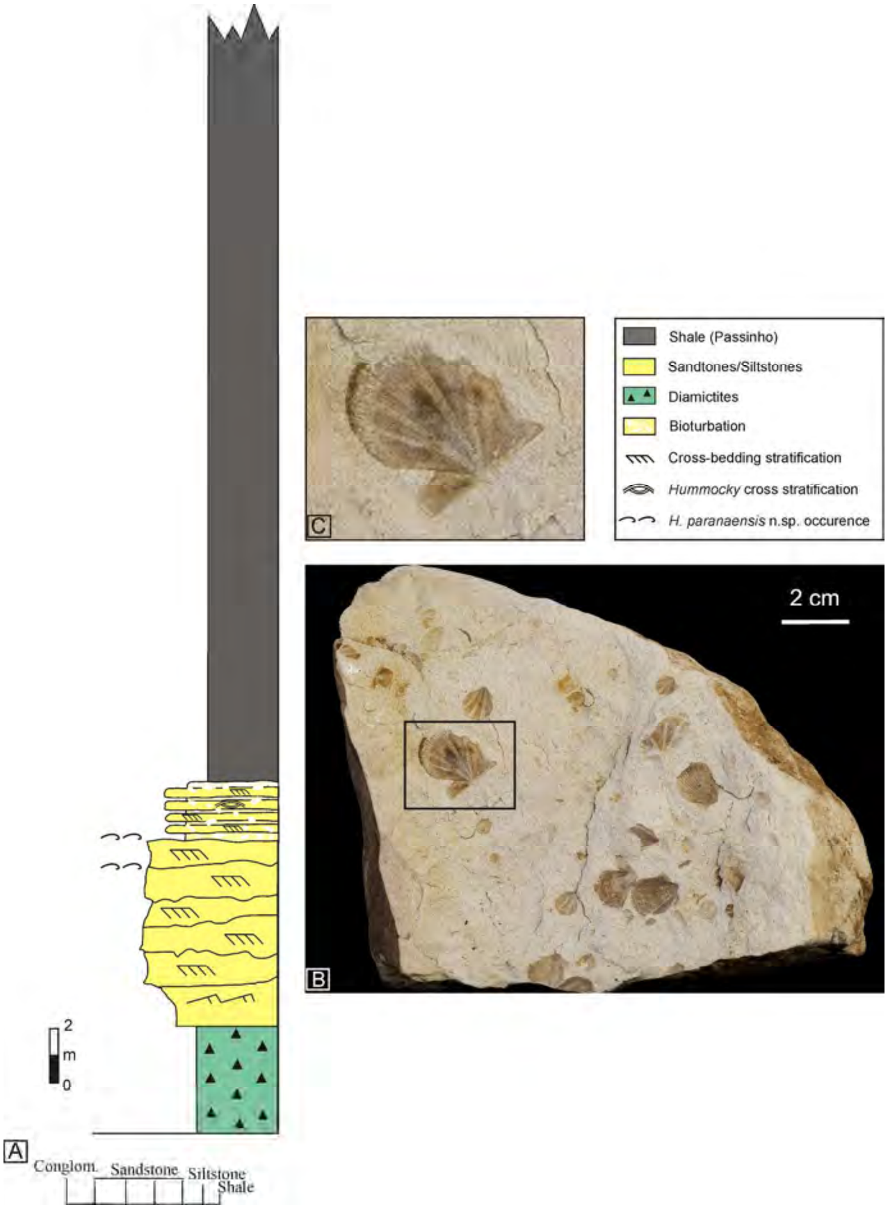
75x34mm (600 x 600 DPI)



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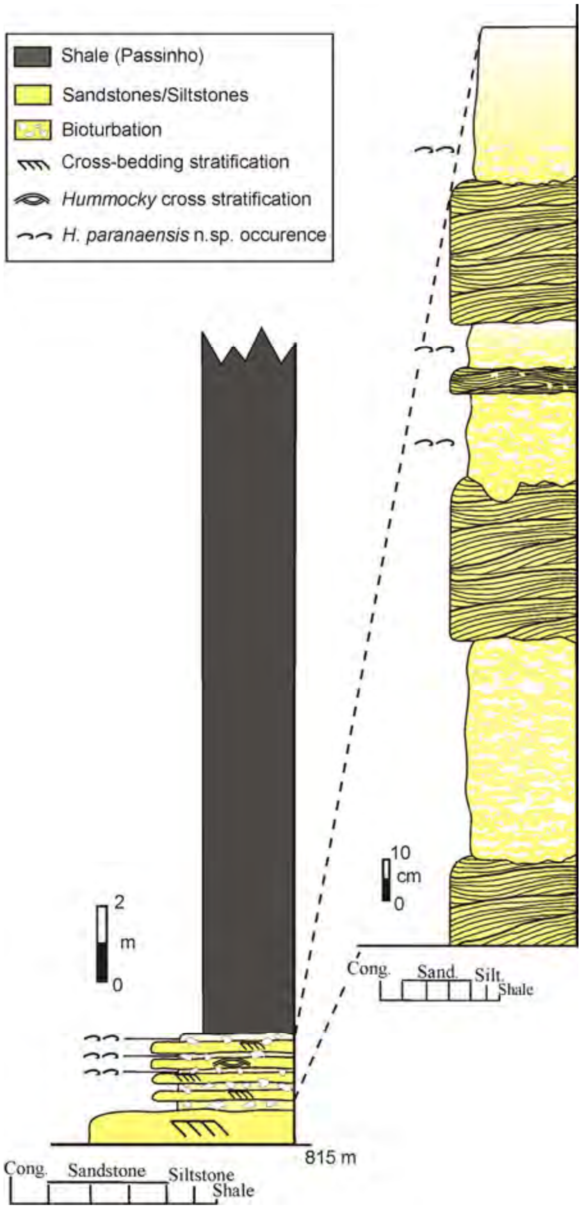
219x299mm (300 x 300 DPI)



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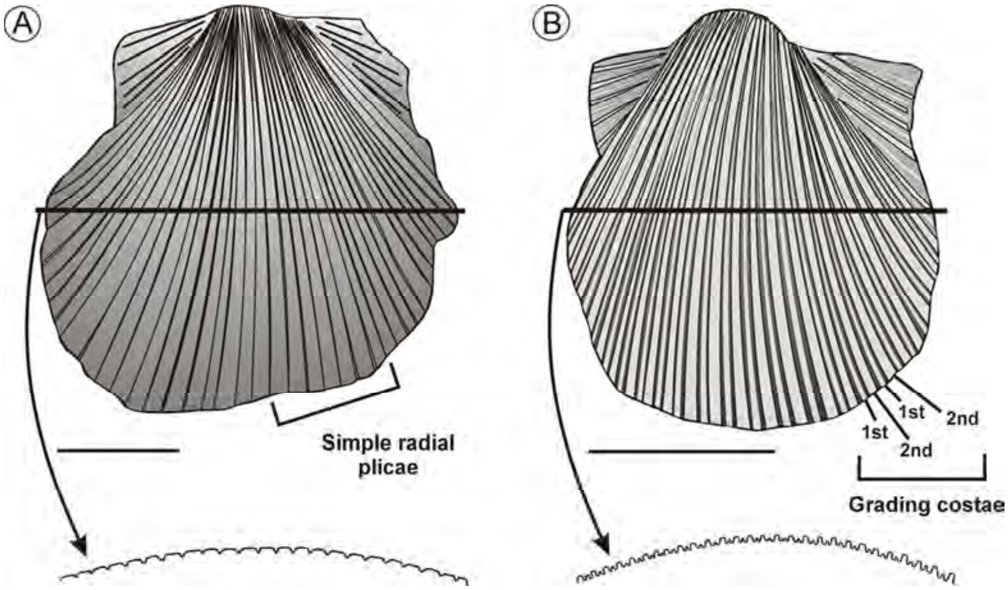
157x328mm (300 x 300 DPI)



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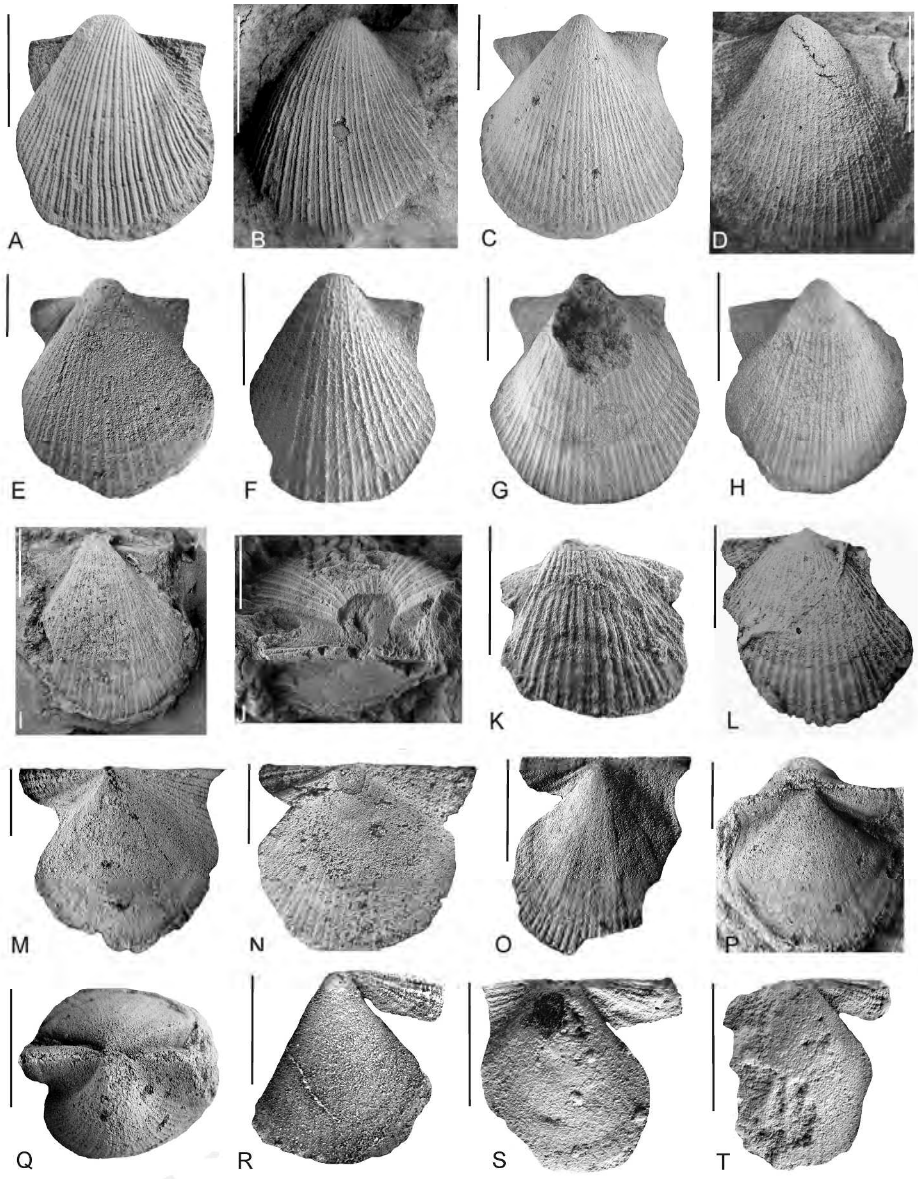
96x55mm (300 x 300 DPI)



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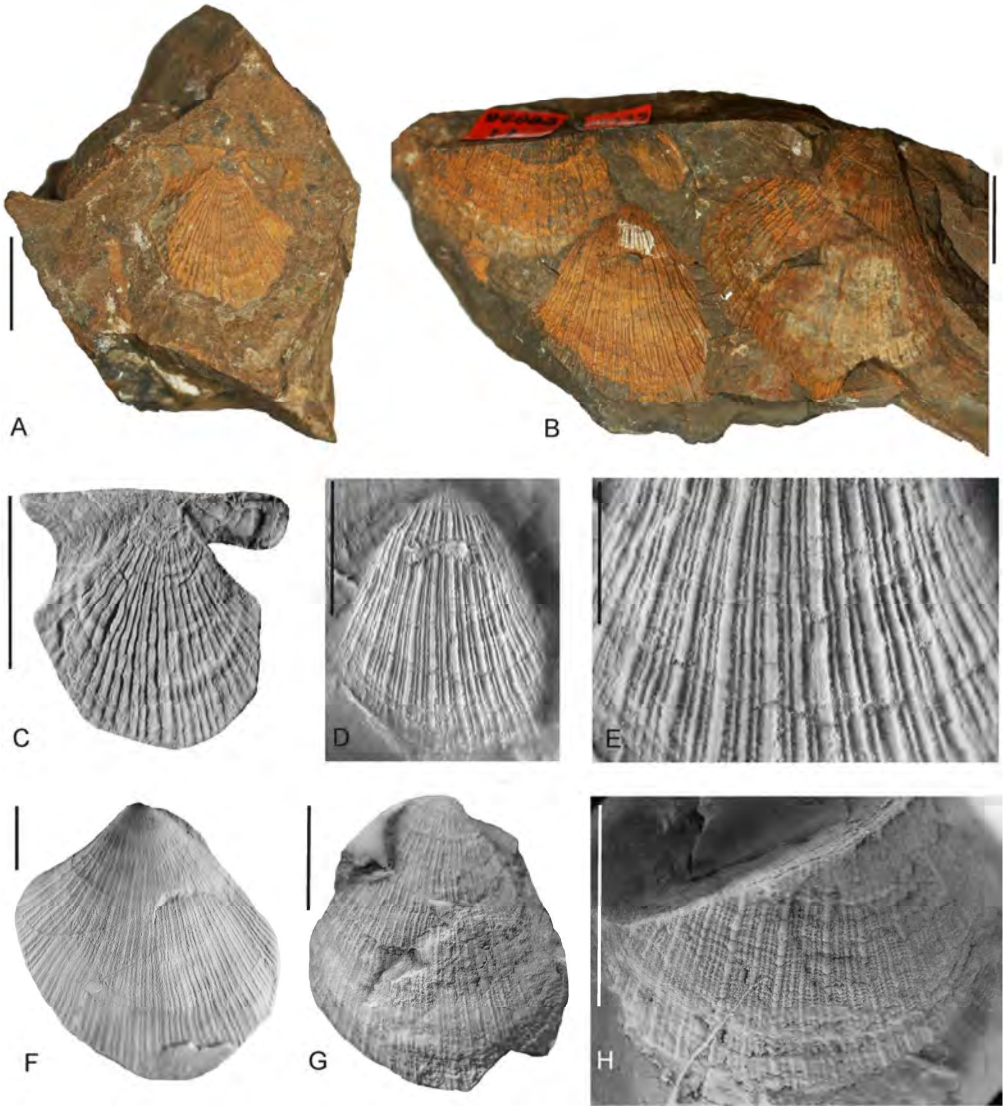
224x286mm (300 x 300 DPI)



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187x207mm (300 x 300 DPI)

Specimen	Length (mm)	Height (mm)	Width (mm)	Locality	Preservation
DZP-18810A1	21	24	-	Rio d'Areia	Internal mold of right valve
DZP-18810A2	ca 16	17	-	Rio d'Areia	External mold of left valve
DZP-18810A3	14	18	-	Rio d'Areia	External mold of right valve
DZP-18814	26	29	-	Baitaca	Internal mold of right valve
DZP-18815	ca 17	16	-	Baitaca	Internal mold of left valve
DZP-18883	17	20	-	Rio d'Areia	External mold of left valve
DGM-4348C (LV)	ca 18	ca 11	-	Baitaca	Internal mold of
DGM-4348C (RV)	ca 11	ca 4	-	Baitaca	butterflied valves
DGM-4358	28	31	8	Rio d'Areia	Internal mold of left valve
DGM-4359	23	28	-	Rio d'Areia	Internal mold of left valve
DGM-4360	23	24	-	Rio d'Areia	External mold of right valve
DGM-4361 (LV)	21	24	-	Rio d'Areia	Internal mold of
DGM-4361 (RV)	17	18	-	Rio d'Areia	conjugated valves
DGM-4367	21	22	-	Rio d'Areia	External mold of right valve
DGM 4368	31	35	-	Rio d'Areia	Internal mold of left valve
DGM-4379	17	18	-	Rio d'Areia	External mold of left valve
GP/1E-705A	15	16	-	Rio d'Areia	External mold of right valve
GP/1E-705B	ca 14	ca 16	-	Rio d'Areia	External mold of right valve
GP/1E-4362B	23	24	6	Rio d'Areia	Internal mold of left valve
GP 1E/4372B	19	21	-	Rio d'Areia	Internal mold of left valve

3. CONSIDERAÇÕES FINAIS

3.1. CONCLUSÕES

3.1.1. Contexto Paleoecológico e Paleoambiental

Na parte superior da Formação Taciba, na região de Teixeira Soares, PR, acima de espesso pacote (>150 m) de diamictitos, ocorre um intervalo com características distintas, logo abaixo do contato com a Formação Rio Bonito. Esse pacote é composto por uma unidade arenosa (informalmente designada arenito Rio d'a Areia) e uma pelítica (incluindo, dentre outros litótipos, o folhelho Passinho). Conforme anteriormente notado (ROCHA-CAMPOS, 1969; ROCHA-CAMPOS & RÖSLER, 1978; SIMÕES, 1992; SIMÕES *et al.*,1998a) e confirmado pelos dados aqui obtidos, essas litofacies contêm assembleias de bivalves de composição taxonômica e caráter paleoecológico distintos, refletindo condições paleoambientais diferentes, associadas à transgressão pós-glacial, materializada pelo folhelho Passinho (LAVINA & LOPES, 1986; SANTOS *et al.*, 1996; SIMÕES *et al.*, 1998a; CANUTO *et al.*, 2001; MINEROPAR, 2007).

As faunas de invertebrados marinhos do topo da Formação Taciba de Teixeira Soares são correlatas à de Mafra, SC, ambas representando, provavelmente, comunidades pioneiras, com os horizontes fossilíferos, exibindo alta dominância de um táxon particular (*Heteropecten paranaensis*, no arenito e siltito, e *Phestia* sp., no folhelho). Os taxa aqui identificados ocuparam novos ambientes plataformais siliciclásticos gerados pela melhoria climática e deglaciação, após o último pulso glacial do Paleozoico Superior, durante o Asseliano–Sakmariano (Permiano Inferior), da Bacia do Paraná. A presença de *Myonia*, *Praeundulomya* e pectinídeos indica condições de águas frias, temperadas (vide DICKINS, 1993).

Conforme ilustrado na figura 11, as litofacies da parte superior da Formação Taciba, em Teixeira Soares, PR, contêm distintas assembleias de bivalves (vide Tabs. 3 e 4, no capítulo 1), com características tafonômicas e paleoecológicas peculiares. Tais diferenças refletem especialmente as mudanças ocorridas nas variáveis ambientais, tais como o nível do mar, a taxa de aporte sedimentar, o tipo e consistência do substrato, a oxigenação do fundo e, possivelmente, a salinidade e a temperatura das águas. Assim sendo, os horizontes fossilíferos das litofacies identificadas e suas assembleias de bivalves podem ser modeladas, segundo os esquemas de biofáceis depletadas em oxigênio (*biofacies sensu* LUDVIGSEN *et al.*, 1986 e LAZO, 2007), em ambientes marinhos plataformais, de bacias sedimentares intracratônicas. Este modelo está fundamentado no fato de que, nos ambientes marinhos, as associações faunísticas refletem as variações e mudanças nos parâmetros físico-químicos do meio, bem como as interações bióticas entre os organismos. As *biofacies* aqui identificadas estão fundamentadas na divisão tripartite, inicialmente, proposta por Rhoads & Morse (1971) e refinada por Tyson & Pearson (1991) e Wignall (1994). Neste contexto, três tipos principais de biofacies foram reconhecidas, ou seja, (a) biofacies aeróbia (ml O_2/l H_2O >2), (b) biofacies disaeróbia (moderada-ml O_2/l H_2O = 2–1; severa-ml O_2/l H_2O = 1–0.5; extrema ml O_2/l H_2O = 0.5–0) e (c) biofacies anóxica (ml O_2/l H_2O = 0). A biofacies aeróbia, inserida no contexto das litofacies B, é caracterizada por condições de fundos arenosos, de águas rasas agitadas, representada por diversificada assembleia de bivalves de epifauna e semi-infauna, ocorrendo na forma de pavimentos bioclásticos (Figs. 11J e 13). Nas Facies C e D, situam-se as *biofacies* de teor de oxigenação mais variável, entre aeróbias a disaeróbias, representadas por diferentes assembleias fósseis (vide Tab. 3, no capítulo 1; Fig. 13), que se sucedem estratigraficamente. Assim, as assembleias com bivalves escavadores, suspensívoros, preservados em posição de vida, em arenitos gerados por tempestades, devem representar condições aeróbias a disaeróbias moderadas. Uma vez que, no topo, os arenitos e siltitos estão intensamente bioturbados, é possível inferir que após a preservação *in situ* dos bivalves, por evento episódico de sedimentação (tempestade), houve retorno às condições de bom tempo, com boa oxigenação do fundo, com o limite redox situado bem abaixo da interface água/sedimento. Estes são, entretanto, sucedidos por siltitos, argilitos maciços ou laminados (folhelho Passinho), ricos em matéria orgânica, indicativos de anoxia, onde, em certos horizontes, ocorrem raras conchas de bivalves detritívoros, preservadas com as valvas articuladas abertas (*butterfly*). Esta se caracteriza como sendo uma biofacies extremamente disaeróbia a anóxica, caracterizada pelos estratos da Facies E, equivalentes aos folhelhos cinza escuros, laminados, ricos em matéria organica, desprovidos de fósseis de invertebrados bentônicos e depositados em contexto de máxima inundação marinha (Figs. 11M–O e 13). Neste contexto, estes horizontes devem representar condições disaeróbias severas a extremas, em contexto de ampla anoxia, ligada à transgressão Passinho. Tais intervalos fossilíferos devem representar pulsos de oxigenação de fundo, permitindo a instalação e o rápido desenvolvimento de bivalves detritívoros, oportunistas. De particular interesse é a preservação de conchas com as valvas articuladas abertas que, neste contexto, é indicativa de anoxia ou mudança do limite redox para a coluna d’água (vide OSCHMANN, 1994).

Espécies da Formação Taciba (Grupo Itararé, Bacia do Paraná), em Teixeira Soares, Estado do Paraná, Brasil	**Espécies da Formação Bonete (Grupo Pillahuincó, Bacia de Sauce Grande), em Sierras Australes, Provincia de Buenos Aires, Argentina**
Palaeoneilobrasiliensis sp.n.	---
Phestia sp.	---
Promytilus sp.	*Promytilus acinaciformis*
Volsellina areiensis sp.n.	---
Myalina (*Myalinella*) sp.	---
Selenimyalina sp.	---
Atomodesma (*Aphanaia*) *orbirugata*	*Atomodesma* (*Aphanaia*) *orbirugata*
Atomodesma (*Intodesma*) sp.	---
---	*Eurydesma cordartum*
---	*Eurydesma horbatense*
---	*Eurydesma mytiloides*
---	*Eurydesma altum*
Leptodesma (*Leiopteria*) sp.	*Leptodesma* (*Leiopteria*) *dutoiti*
---	*Leptodesma* (*Leiopteria*) *bonaerensis*
Leptodesma (*Leptodesma*) sp.	---
---	*Deltopecten harringtoni*
Streblopteria sp.	---
Heteropecten paranaensis sp.n.	*Heteropecten paranaensis*
	Heteropecten sp.
Schizodus sp.	*Schizodus cycloliratus*
---	*Astartella*? *pusilla*
Sanguinolites sp.	---
Cosmomya (Palaeocosmomya) baitaquensis sp.n.	---
Exochorhynchus itararensis sp.n.	*Allorisma inflectoventris*
Praeundulomya cf. *subelongata*	---
Pleurophorella sp.	---
---	*Vacunella camachoi*
Myonia argentinensis	*Myonia argentinesis* (= *Stutchburia argentinensis*)
---	*Myonia* sp.

Tabela 5- Na coluna da esquerda estão listadas as espécies descritas neste trabalho, para a porção mais superior da Formação Taciba, em Teixeira Soares, PR. Na coluna da direita, as espécies descritas por Harrington (1955); Rocha-Campos & Carvalho (1975), Pagani (2000) e este trabalho, para a Formação Bonete, Argentina.

3.1.2. Contexto Taxonômico e Bioestratigráfico

Em seu conjunto, as assembleias de bivalves da parte superior da Formação Taciba de Teixeira Soares, PR, se destacam como dentre as mais diversificadas de todo o Gondwana, o que é sugestivo de melhoria das condições climáticas, corroborando a deposição pós-glacial. A fauna é correlata à da porção superior da Formação Taciba de Mafra, SC, (SIMÕES *et al.*, 2012, vide Anexo). Em ambas, a presença das espécies *Myonia argentinensis*, *Atomodesma* (*Aphanaia*) *orbirugata* e *Heteropecten paranaensis* indicam correlação com a fauna de bivalves da Formação Bonete, Argentina, sugerindo idade Asseliana–Sakmariana. Esta fauna contêm representantes da biota de *Eurydesma* & *Trigonotreta*, tais como *E. cordatum* e *E. hobartense* (veja HARRINGTON, 1955), espécies que também ocorrem na Austrália. Este gênero, porém, não foi verificado nas coleções estudadas (vide também SIMÕES *et al.*, 1998a) e sua ausência na Bacia do Paraná pode ser devido (a) às condições paleoecológicas desfavoráveis de tipo de fundo (mais moles e inconsolidados) e temperatura das águas (relativamente mais amenas na Bacia do Paraná) e (b) a esforços de coleta e tamanho amostral (viés analítico), o que parece improvável tendo em vista o tamanho das coleções examinadas e ao fato das assembleias terem sido amostras por muitos anos. Talvez os depósitos marinhos que possivelmente poderiam conter elementos da biota de *Eurydesma* & *Trigonotreta* fossem aqueles relativos às ingressões marinhas da porção superior da Formação Campo Mourão (folhelhos Lontras e Guaraúna e litofacies coevas) ou da porção inferior da Formação Taciba (Membro Rio Segredo), os quais podem ser considerados intraglaciais.

A fauna estudada também apresenta similaridades ao nível genérico, com as da Bacia Tepuel-Genoa (vide Tab. A1, no capítulo 1), formações Monjón de Hierro e Las Salinas, da Patagonia Central, dado inédito em termos de bioestratigrafia das faunas de macroinvertebrados marinhos da América do Sul. Vale ressaltar que *Sanguinolites* sp. da Formação Taciba se assemelha morfologicamente às espécies *Sanguinolites freytesi* González, 1977, e *Sanguinolites turnei* González, 1977, presentes nesta bacia argentina (vide seção 5, capítulo 1). Tais assembleias argentinas possuem idade cisuraliana reforçando a noção de que as faunas da porção superior do Grupo Itararé não são mais antigas que o Permiano Inferior.

Ainda, *Praeundulomya* cf. *subelongata* da Formação Taciba é morfologicamente semelhante à *Praeundulomya subelongata*, descrita por Dickins (1963), para Formação Fossil Cliff, Australia, cuja idade é sakmariana. Portanto, é muito provável que a fauna da porção superior da Formação Taciba, aqui estudada, pertença ao Asseliano–Sakmariano (vide também SIMÕES *et al.*, 2012, anexo deste documento).

Conforme visto anteriormente (vide Tabs. 3 e 4, capítulo 1), na maior parte das assembleias estudadas ocorrem bivalves pectinídeos, anteriormente atribuídos a *Aviculopecten multiscalptus* (BEURLEN, 1954, 1957; ROCHA-CAMPOS, 1967, 1969, 1970; FRAKES & CROWELL, 1968; ROCHA-CAMPOS & RÖSLER, 1978), cuja presença na Bacia do Paraná, não foi confirmada por este estudo. A espécie da Bacia do Paraná, aqui denominada *Heteropecten paranaensis*, também presente na Formação Bonete, Argentina (vide capítulo 2), prosperou sob condições de água geladas, como indicado por sua associação com depósitos de deglaciação e a baixa diversidade da fauna de invertebrados marinhos associados (SIMÕES *et al.*, 1998a). Por outro lado, *Heteropecten multiscalptus* da assembleia de Cerro Prieto, Peru, ocorre associada a uma típica e diversificada fauna marinha de águas quentes, tendo afinidades com assembleias do continente americano e com as faunas carboníferas do norte do Brasil (MENDES, 1966; ANELLI *et al.* 2002, 2006, 2009, 2012). Vale mencionar que *Heteropecten paranaensis* apresenta semelhanças morfológicas com a espécie *Hillaepecten queenslandica*, da Formação Tiverton (WATERHOUSE, 2010), na Austrália. Estes dados reforçam a idéia de que os pectinídeos do Paleozoico Superior da Bacia do Paraná apresentam afinidades estreitas com as faunas gondwânicas da Argentina e Austrália, mais do que com as faunas da faixa extragondwânica, do continente sul-americano (vide artigos apresentados nos capítulos 1 e 2).

Beurlen (1954, in Lange, 1954)	Rocha-Campos (1969)	Este Estudo
	Anthraconeilo itararensis sp.n.	*Palaeoneilo brasiliensis* sp.n.
Nuculana woodworthi	*Nuculana woodworthi*	*Phestia* sp.
Nuculana cf. *browni*		
		Promytilus sp.
	Volsellina australis sp.n.	*Volsellina areiensis* sp.n.
Myalina obliqua	*Myalina* (*Myalinella*) sp.	*Myalina* (*Myalinella*) sp.
	Selenimyalina? sp.	*Selenimyalina* sp.
	Atomodesma (*Atomodesma*) sp.	*Atomodesma* (*Aphanaia*) *orbirugata*
		Atomodesma (*Intodesma*) sp.
Leiopteria obliqua *Leiopteria* sp.	*Leiopteria paranaensis* sp.n.	*Leptodesma* (*Leiopteria*) sp.
		Leptodesma (*Leptodesma*) sp.
	Streblopteria sp.	*Streblopteria* sp.
Aviculopecten sp.	*Aviculopecten multiscalptus*	*Heteropecten paranaensis* sp.n.
Aviculopecten multiscalptus		
Prosopecten densicostatus		
Prosopecten elegans		
Prosopecten radiatus		
Prosopecten rhomboidalis		
Limipecten araneosus	*Limipecten* sp.	
Schizodus cf. *affinis*	*Schizodus* sp.	*Schizodus* sp.
Schizodus sp.		
Sanguinolites (?) *arenosus*		
Sanguinolites baitacensis		*Sanguinolites* sp.
Sanguinolites langei		
Sanguinolites pauciplicatus		
Sanguinolites (?) *amotapensis*		
	Vacunella etheridgei	*Cosmomya* (*Paleocosmomya*) *baitaquensis* sp.n.
Allorisma barringtoni	*"Allorisma" barringtoni*	*Exochorhynchus itararensis* sp.n.
Allorisma maaki		
Allorisma parinaensis		
Edmondia sp.	*Sanguinolites brasilinensis* sp.n.	*Praeundulomya* cf. *subelongata*
	Praeundulomya? sp.	
Solenomorpha paranaensis	*Permophorus*? sp.	*Pleurophorella* sp.
	Myonia sp. A	*Myonia argentinensis*
	Myonia sp. B	
Chaenomya densiplicata		

Tabela 6- Composição taxonômica das assembleias da porção mais superior da Formação Taciba, na região de Teixeira Soares, PR, segundo Lange (1954), Rocha-Campos (1969) e a prosposta deste estudo (coluna da direita).

3.2. PROBLEMAS AINDA PENDENTES E DESAFIOS PARA O FUTURO

Há mais de 20 anos, Simões (1992) apresentou uma revisão da literatura disponível para os bivalves da sucessão Itararé-Guatá, do Paleozoico Superior, da Bacia do Paraná, Brasil, tendo contabilizado cerca de 40 artigos científicos. Desde então, pouco foi adicionado a esse tema (vide SIMÕES *et al.*, 2012, para referências recentes), sendo reduzidíssimos os avanços quanto à identidade taxonômica dos elementos constituintes das assembleias fósseis, especialmente da sucessão Itararé, bem como de sua tafonomia, bioestratigrafia e afinidades paleobiogeográficas. Esta situação contrasta, entretanto, com os enormes avanços estratigráficos (HOLZ *et al.*, 2010; MORI *et al*, 2012), bioestratigráficos (PETRI & SOUZA, 1993; SOUZA, 1998; 2000; 2003; 2006; SOUZA & PETRI, 1998; SOUZA & VESELY, 1999; SOUZA & MARQUES-TOIGO, 2001, 2003, 2005; SOUZA & CALLEGARI, 2004; SOUZA *et al.*, 2000, 2003, 2007) e geocronológicos (MATOS *et al.*, 2001; GUERRA-SOMMER *et al.*, 2006, 2008a, b, c; ROCHA-CAMPOS *et al.*, 2006, 2007; MORI *et al.*, 2012, SIMAS *et al.*, 2012), para a Supersequencia Gondwana 1 (MILANI, 1997; MILANI *et al.*, 2007), da Bacia do Paraná. Também cabe ressaltar o admirável progresso ocorrido no conhecimento das assembleias de bivalves do Carbonífero e Permiano, da América do Sul, em especial da Argentina (GONZÁLEZ, 1989; PAGANI, 2000, 2004a, 2004b, 2005, 2006a, 2006b; STERREN 2000, 2003, 2004, 2005; GONZÁLEZ, 2002a, 2002b, 2006; PAGANI & SABATTINI, 2002; CISTERNA & STERREN, 2010; PAGANI & TABOADA, 2010; STERREN & CISTERNA, 2010; TABOADA, 2010; TABOADA & PAGANI, 2010; PAGANI & FERRARI, 2011).

Os dados apresentados e discutidos acima, no âmbito da presente tese de doutoramento mostram o potencial das assembleias de bivalves para o entendimento de questões geológicas (biocorrelação, paleogeografia) e paleoentológicas (taxonomia), de enorme relevância. Neste sentido, as assembleias marinhas da sucessão Itararé (vide Petri & Souza, 1993, p. 14), tais como, Budó, RS, Mafra, SC, Capivari e Itaporanga, SP, carecem de urgente revisão já que contêm bivalves e outros invertebrados marinhos (*e.g.*, braquiópodes, gastrópodes). No caso das faunas da região de Mafra (Formações Mafra e Taciba) há uma grande quantidade de amostras não estudadas na coleção científica do Cenpaleo, Universidade do Contestado.

A despeito dos avanços aqui obtidos, maiormente quanto a taxonomia e bioestratigrafia das faunas da porção superior da sucessão Itararé, pouco é ainda sabido quanto à gênese das assembleias de bivalves, no que tange aos processos bioestratinômicos e diagenéticos (vide SIMÕES, 1998). Algumas concentrações fósseis, como as dos arenitos muito finos a siltitos da Facies D, têm enorme potencial para integração com a estratigrafia de eventos e de sequências, dada a presença de tempestitos amalgamados (vide SIMÕES *et al.*, 1998b). Infelizmente, entretanto, não houve tempo no contexto do presente projeto de doutoramento para se aprofundar em tais questões tão relevantes à paleontologia e geologia da Bacia do Paraná. Assim, com a finalização do presente doutoramento, esses problemas científicos serão priorizados em projeto de pós-doutoramento, a ser submetido, brevemente, à FAPESP e ao CNPq.

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ANEXO

Artigo publicado no Boletim do Instituto de Geociências da USP, Série Científica: "*Permian bivalves of the Taciba Formation, Itararé Group, Paraná Basin, and their biostratigraphic significance*".

Geologia
Série Científica USP

DOI: 10.5327/Z1519-874X2012000100006

Revista do Instituto de Geociências - USP

Geol. USP, Sér. cient., São Paulo, v. 12, n. 1, p. 71-82, Abril 2012

Permian bivalves of the Taciba Formation, Itararé Group, Paraná Basin, and their biostratigraphic significance

Bivalves permianos da Formação Taciba, Grupo Itararé, Bacia do Paraná e seu significado bioestratigráfico

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Received 18 october 2011; accepted 08 march 2012

Abstract

A small and poorly diversified bivalve fauna from Taciba Formation, Itararé Group, Paraná Basin (State of Santa Catarina, Mafra Municipality), is described in this paper for the first time, based on new findings. The fauna is recorded in a 30 cm thick interval of fine sandstone locally at the top of Taciba Formation, in the Butiá quarry. The studied fossil-bearing sandstone bed is a marine intercalation recording a brief eustatic rise in sea-level, probably following glacier retreat and climate amelioration at the end of a broad glacial scenario. The fauna is mainly dominated by productid brachiopods, which are not described here, and rare mollusk shells (bivalves and gastropods). Two bivalve species were identified: *Myonia argentinensis* (Harrington, 1955), and *Aviculopecten multiscalptus* (Thomas, 1928). The presence of *Myonia argentinensis* is noteworthy since this species is also present in the Baitaca assemblage found in marine siltstones (Baitaca assemblage) of the Rio do Sul Formation, cropping out at the Teixeira Soares region, Paraná State. This species is also recorded in the bivalve fauna from the Bonete Formation, Pillahinco Group, Sauce Grande Basin, Buenos Aires Province, in Argentina. Hence, the marine bivalves of the Taciba Formation are associated with the transgressive event that characterizes the *Eurydesma* fauna, indicating a Late Asselian-Sakmarian age for the bivalve fauna. Presence of the *Myonia argentinensis* megadesmid species reinforces the Gondwanic nature of the studied fauna.

Keywords: Bivalvia; Megadesmidae; Permian; Paraná Basin; Taciba Formation; *Eurydesma* fauna.

Resumo

Uma pequena e pouco diversificada assembleia de bivalves permianos da Formação Taciba, Grupo Itararé, Bacia do Paraná (Estado de Santa Catarina, Município de Mafra) é descrita pela primeira vez, com base em novos achados. A fauna foi registrada em um intervalo de 30 cm de espessura de arenito bioturbado, localizado no topo da Formação Taciba, na pedreira Butiá. A camada de arenito fossilífero representa uma intercalação marinha, que registra variação estática do nível do mar, provavelmente como reflexo do evento de deglaciação. A fauna é principalmente dominada por braquiópodes productídeos (não descritos neste artigo) e raras conchas de moluscos (bivalves e gastrópodes). Duas espécies de bivalves foram identificadas: *Myonia argentinensis* (Harrington, 1955) e *Aviculopecten multiscalptus* (Thomas, 1928). A presença de *Myonia argentinensis* é notável, pois esta espécie está também presente na assembleia de Baitaca, encontrada em siltitos marinhos, no topo da Formação Rio do Sul, na região de Teixeira Soares, Estado do Paraná. É registrada também na fauna de bivalves da Formação Bonete, Grupo Pillahinco, Bacia Sauce Grande, Província de Buenos Aires, Argentina. Desse modo, os bivalves marinhos da Formação Taciba estão associados ao evento transgressivo que caracteriza a fauna de *Eurydesma*, indicando uma idade Asseliana Tardia-Sakmariana para a fauna. A presença do megadesmídeo *Myonia argentinensis* reforça a natureza Gondwânica da fauna estudada.

Palavras-chave: Bivalvia; Megadesmidae; Permiano; Bacia do Paraná; Formação Taciba; Fauna de *Eurydesma*.

INTRODUCTION

Contrary to Argentina, where thick lower carboniferous up to Permian sequences yield abundant and diversified marine fossiliferous records (González and Saravia, 2007; Pagani and Taboada, 2010), coeval occurrences in the Brazilian portion of the huge, up to 1,600,000 km^2 (Holz et al., 2010), foreland Paraná Basin are rare and poorly diversified (Rocha-Campos and Rösler, 1978; Simões, Rocha-Campos, Anelli, 1998).

In the last decade, several papers (Pagani, 2000, 2004a, 2004b, 2005, 2006, 2006b; Sterren, 2000, 2003, 2004, 2005; González, 2002a, 2002b, 2006; Pagani and Sabattini, 2002; Cisterna and Sterren, 2010; Pagani and Taboada, 2010; Sterren and Cisterna, 2010; Taboada, 2010; Taboada and Pagani, 2010; Pagani and Ferrari, 2011) about the marine invertebrate faunas of the Gondwana succession of Argentina were published (González and Saravia, 2007; Pagani and Taboada, 2010; Sterren and Cisterna, 2010; Taboada, 2010; Taboada and Pagani, 2010). Hence, there were recent advances in our understandings of the paleobiogeography and biostratigraphy of brachiopod- and bivalve-dominated faunas, with obvious implications to the provincial affinities and age of these assemblages (Pagani and Taboada, 2010). Indeed, such faunas have been long recognized as essentials tools to constrain the age of major geologic and biotic events of the Southeastern portion of Gondwana supercontinent, during the Late Paleozoic (Simões, Rocha-Campos, Anelli, 1998; González and Saravia, 2007; Sterren and Cisterna, 2010; Anelli et al., *in press*).

In spite of that, the use of the Late Paleozoic marine invertebrate faunas of South America to regional scale correlations is limited, since many of the Brazilian faunas remain virtuously undescribed and/or poorly described or illustrated. Among those, the Butiá assemblage, known since Rocha-Campos (1966), in the upper most portion of the Itararé Group is of particular interest to regional correlations. This assemblage is associated with a short transgressive-regressive episode at the end of the Late Paleozoic glaciation in the Paraná Basin (Simões, Anelli, Rocha-Campos, 1998), and record the first appearance of typical Gondwanian marine bivalves in the basin (Rocha-Campos and Rösler, 1978; Simões, Anelli, Rocha-Campos, 1998). Therefore, the aim of this contribution was to describe, by the first time, the bivalve species of the Butiá assemblage found in the Taciba Formation in the top of Itararé succession at the State of Santa Catarina, Southern Brazil. By accomplishing this, we add herein new palaeobiogeographic and biostratigraphic information to Late Paleozoic bivalve faunas of Western Gondwana.

BACKGROUND

Bivalves and other marine invertebrates are poorly diversified and sparsely distributed in the glacial (Itararé Group) and post-glacial successions (Guatá Group) of Paraná Basin (Simões, Anelli, Rocha-Campos, 1998, p. 445). However, some of these are key faunas for interbasinal correlations since data on checklists available (Rocha-Campos, 1970; Rocha-Campos and Rösler, 1978) indicate that such assemblages at the top most portion of the Rio do Sul or Taciba Formations (upper third of Itararé Group) may show affinities with the Lower Permian bivalves, from the Bonete Formation, Sierras Australes, Buenos Aires Province, in Argentina (Harrington, 1955; Pagani, 2000).

Rocha-Campos (1966) had listed (but not described or illustrated) the presence of marine invertebrates (e.g., brachiopods and mollusks) associated with glaciogenic rocks (e.g., diamictites) at the top of Itararé succession, in the Butiá Quarry. As well noted by Rocha-Campos (1966), this fauna can be distinguished from all other coeval ones (Capivari, Rio da Areia, Baitaca, Budó assemblages) by the uncommon numeric dominance of brachiopods, mainly productids, over mollusks (e.g., bivalves and gastropods).

Renewed interest in this fauna, in the broad context of a join scientific project, including São Paulo State University – UNESP, São Paulo University – USP and the Paleontological Center – CENPALEO of the University of Constestado, have lead to the discovery of new bivalve specimens in the same horizon sampled by Rocha-Campos in 1966, which allowed us to do a better stratigraphic correlation with the “Butiá horizon” and other coeval marine intercalations of Paraná Basin, Brazil, and Sauce Grande Basin, Argentina (Figure 1).

GEOLOGICAL SETTING

In the Paraná Basin, the Gondwanian glacial-postglacial sedimentary succession of the Itararé Group consists of thinly-laminated rhythmite and mudstone, dark gray to black shale, massive siltic-argilaceous matrix diamictite, heterolithic siltstone and sandstone, and fine- to medium-grained sandstone with trough cross-stratification, parallel to sub-parallel stratification, climbing ripple cross-lamination, and wave ripples (Rocha-Campos, 1967; Schneider et al., 1974). Intraclasts and mud drapes are common in the sandy deposits (Balistieri, 2003).

In Southern Paraná, as well as in the neighboring Santa Catarina State, the Itararé succession is divided into three units, namely Campo do Tenente Formation at the bottom, Mafra and Rio do Sul (Schneider et al., 1974) or Taciba Formations (França and Potter, 1988) above. The Taciba Formation records the third major fining upward cycle of Itararé Group, encompassing three members: Rio Segredo sandstone, Chapéu do Sol diamictite, and Rio do Sul (rhythmite, siltstone, and shale).

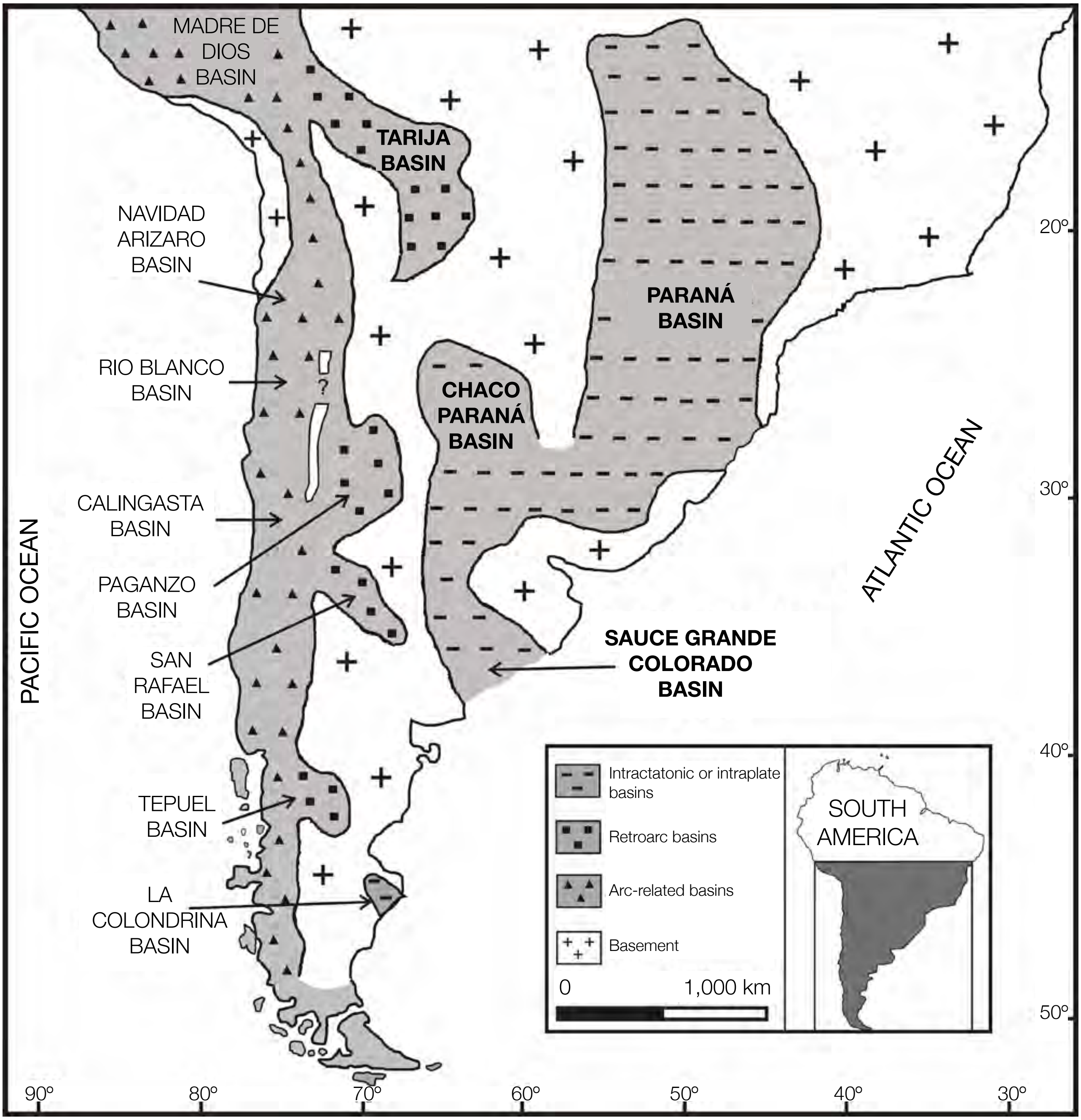

Figure 1. Sketch map showing the main Late Paleozoic basins of southern South America (modified from Limarino and Spalletti, 2006).

Weinschütz and Castro (2006) identified two depositional sequences in Taciba Formation. A 65 m-thick interval of diamictite with intercalations of massive argillaceous sandstone (*slurry*), siltstone and thin rhythmite, which characterizes the lower Taciba-I sequence (TC-I). Slumping, contorted beds, sandstone dykes, and a large, *in situ*, turbidite block with dropstone are also recorded in those rocks. In its upper part, the diamictite is stratified and includes abundant dropstones. In core, it passes laterally to a coarsening-upwards succession of varvic shale, siltstone and slumped thin rhythmites (Weinschütz and Castro, 2006). All the lithofacies can be assigned to transgressive and high-stand system tracts. In outcrops, the deglaciation interval is made-up of a 10 m-thick stratified diamictite, overlain by thin stratified conglomerate and sandstone; bioturbated, fossiliferous sandstone and shale, representing the transgressive systems tract (Weinschütz and Castro, 2006). The sandstone includes numerous fossils, such as: brachiopods and mollusks (bivalves and gastropods).

MATERIAL AND METHODS

The material described herein is from the Butiá Quarry (Figures 2 and 3), Mafra Municipality, Santa Catarina State, in Southern Brazil. We also analyzed fossil specimens from the Teixeira Soares region, Paraná State (Figure 3). All the studied material is reposited in three main scientific collections and coded as: DGM (*Departamento de Geologia e Mineralogia*, *IGc*/USP, São Paulo, SP); DZP (*Departamento de Zoologia*, IBB/UNESP, Botucatu, SP), and CP (*Centro Paleontológico*/CENPALEO, *Universidade do Contestado*, Mafra, SC).

In the laboratory, the material was prepared according to standard paleontological procedures (Feldmann, Chapman, Hannibal, 1989), using precision tools. Most of the shells are represented by internal and external moulds. The material was coated with magnesium oxide sublimate to enhance anatomical details (i.e., ornamentation, muscle scars etc.) for photography (Anelli, Rocha-Campos, Simões, 2006; Anelli et al., 2009; Pagani and Ferrari, 2011). Finally, the suprageneric systematics is based on Morris, Dickins and Astafieva-Urbaitis (1991), and, at the family level, on Runnegar and Newell (1971), Runnegar (1974) and Simões et al. (1997).

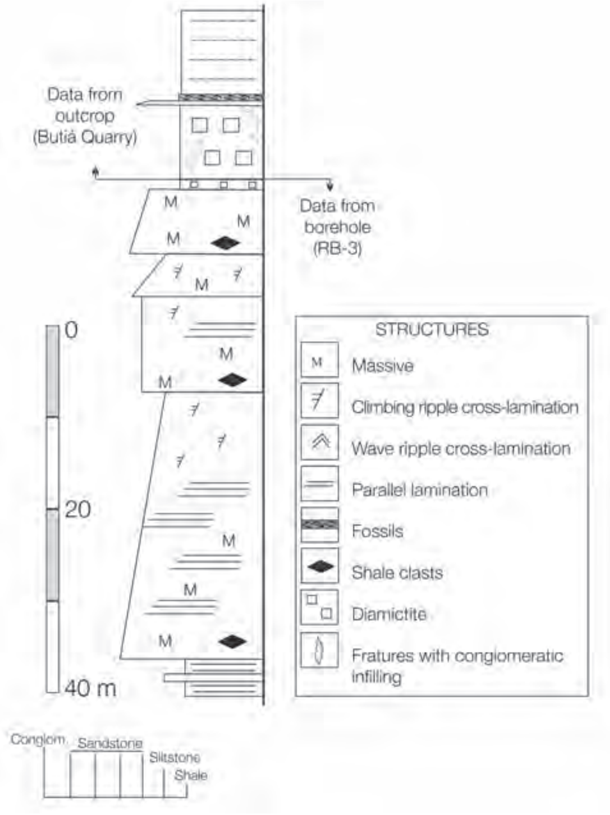

Figure 2. Composite columnar section of the upper portion of the Taciba Formation, Mafra region, State of Paraná.

RESULTS

Systematic

Superfamily Pectinacea Rafinesque, 1815
Family Aviculopectinidae Meek; Hayden, 1865
Genus *Aviculopecten* M'Coy, 1851

Type species

Aviculopecten planoradiatus M'Coy, 1851, p. 171, by latter designation of Hind, 1903, p. 66.

Aviculopecten multiscalptus Thomas, 1928,
(Figures 4A to F.)

Aviculopecten sp. Lange, 1944, p. 279.
Aviculopecten sp. Kegel, 1952, p. 84, Figure 4.
Aviculopecten sp. Kegel; Costa, 1951, p. 171.
Aviculopecten sp. Lange, 1954, p. 54.
Aviculopecten multicalptus Thomas; Beurlen, 1954; *In* Lange, 1954, p. 54.
Prosopecten alternatus Beurlen, 1954; *nom. nud.*, *in* Lange, 1954, p. 55.
Prosopecten elegans Beurlen, 1954; *nom. nud.*, *in* Lange, 1954, p. 55.
Prosopecten densicostatus Beurlen, 1954; *nom. nud.*, *in* Lange, 1954, p. 55.
Prosopecten radiatus Beurlen, 1954; *nom. nud.*, *in* Lange, 1954, p. 55.
Aviculopecten? sp. Rocha-Campos, 1967, p. 29, Figure 15.
Aviculopcten multiscalptus Thomas, 1928; Rocha-Campos, 1969, p. 41.
Aviculopcten cf. *A. multiscalptus* Rocha-Campos; Rösler, 1978, p. 5.

Material

Two fragmented internal molds of the left valve were used.

Description

Left valve slightly convex, with inflated umbones, and faintly orthogyrate beaks. Posterior auricle acuminate,

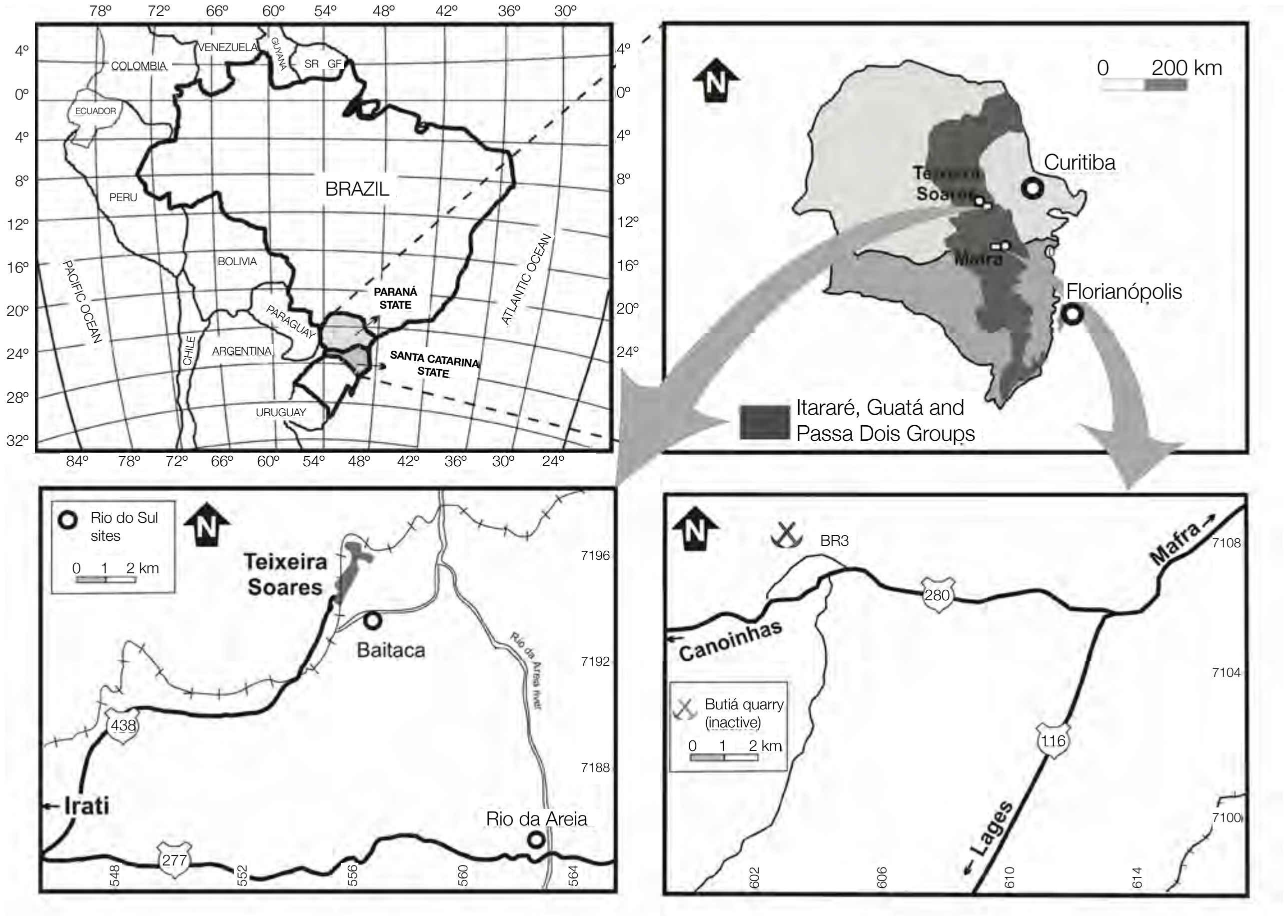

Figure 3. Location map of the studied marine fossil-rich intercalations in the upper portion of the Itararé Group.

with slightly concave ventral margin, separated from the shell body by weak curved fold. Surface ornament of the left valve consisting of primary radial costae beginning at umbonal region and extending until ventral margin; secondary costae begin high elevated on umbonal region by intercalation, extending until ventral margin. Around 20 to 23 primary costae are identifiable, always intercalated with secondary costae; dorsal area straight; and right valve is still unknown in Taciba Formation.

Comments

The material from Taciba Formation (Table 1) is highly similar to the one present in the Rio da Areia sandstone and Baitaca siltstone at the top of the Rio do Sul Formation, Teixeira Soares, Paraná State. It shows radial ornamentation (Figure 4G to M) with the same number of primary radial costae, with secondary costae added by intercalation. Usually, the primary ribs are thicker than the secondary ones. Additionally, specimens of both formations show the left valves slightly convex with posterior auricle acuminated and beaks typically above hinge line.

Table 1. Dimensions (mm) of the *Aviculopecten multiscalptus* shells.

Specimens	Length	Height	Weight
DGM 4358	28	30	8
DGM 4372	25	28	–
DGM 4360	23	24	–
DZP 18860	~ 31	~ 33	–
DZP 18820	29	35	–
DZP 18861	~ 21	~ 22	–

Family Megadesmidae Vokes, 1967
Subfamily Megadesminae Simões et al., 1997
Genus *Myonia* Dana, 1847

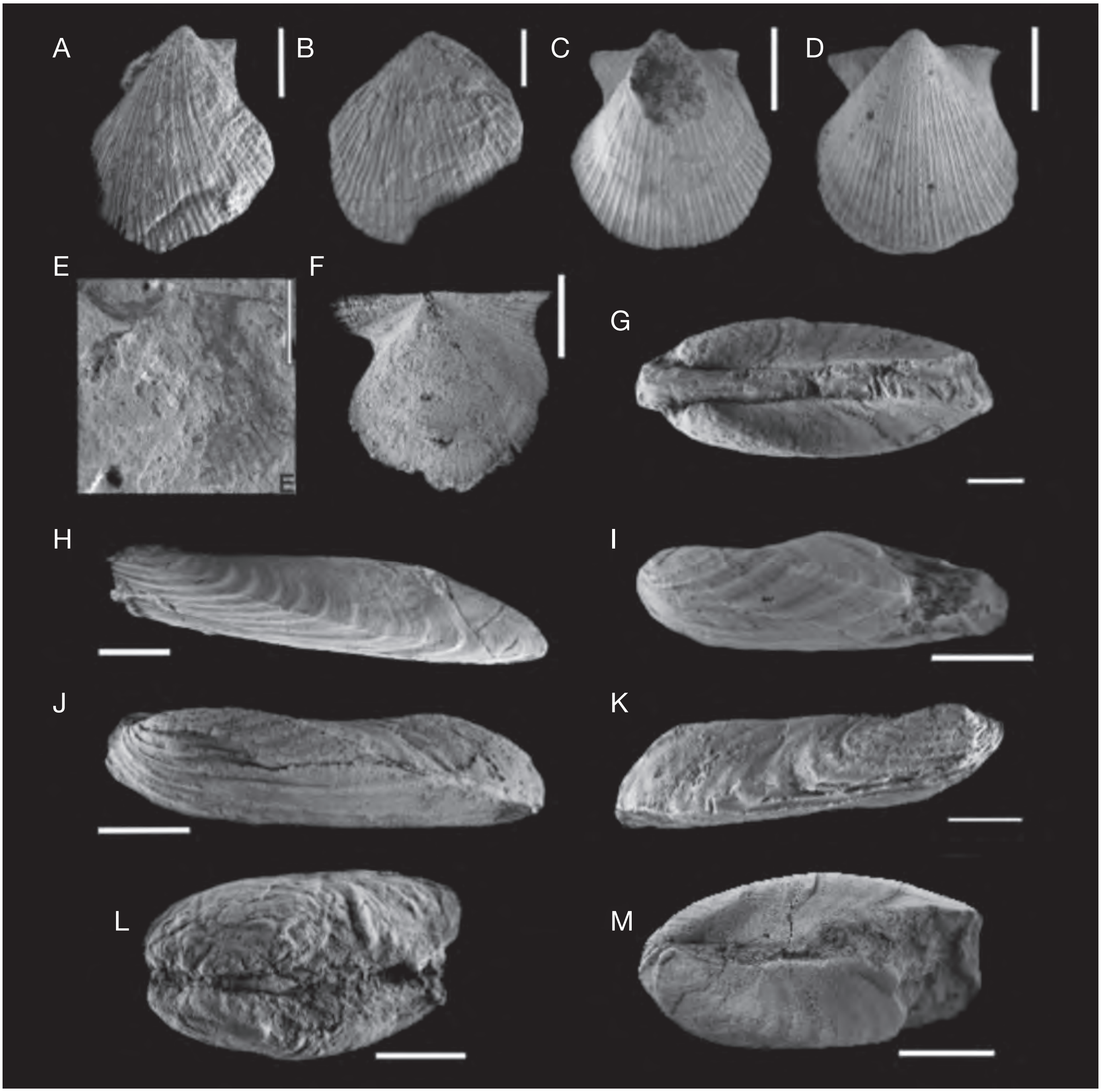

Figure 4. (A-F) *Aviculopecten multiscalptus* (Thomas, 1928); (A-D) internal mold of left valve; (A) DZP 18820; (B) DZP 18860; (C) DGM 4372; (D) DGM 4358; (E-F) internal mold of right valve; (E) DZP 18861; (F) DGM 4360; (G-M) *Myonia argentinensis* (Harrington); (G, L, M) internal mold of conjugated valves, dorsal view; (G) DGM 4341; (L) DZP 18859; (M) DZP 18826; (H-J) left valve; (H) CPI; 475; (I) DZP 18826; (J) DGM 4341; (K) right valve; DGM 4341. Specimens (A, B, E, H, L) Taciba Formation, Butiá Quarry, Mafra State of Santa Catarina. Specimens (C, D, F, G, I, J K, M) Rio do Sul Formation, Teixeira Soares, State of Paraná. Scale = 1 cm.

Type species

Myonia elongata Dana, 1847, p. 158, by posterior designation of Fletcher, 1932, p. 398.

Myonia argentinensis Harrington, 1955
(Figures 4G to M)

Stutchburia? *argentinensis* Harrington, 1955, p. 117, pl. 24, figures 1 to 3.
Praeundulomya argentinensis (Harrington); Dickins, 1963, p. 23.
Myonia (or *Vacunella*)? *argentinensis* (Harrington); Rocha-Campos, 1970).

Myonia (or *Vacunella*)? *argentinensis* (Harrington); Rocha-Campos; Carvalho, 1975, p. 186, 189, plate 1, figures 13 to 14.
Stutchburia? *argentinensis* Harrington; Amos, 1979, p. 137.
Psedolomya? *argentinensis* (Harrington); Harrington, 1980, p. 974.
Stutchburia? *argentinensis* Harrington; Andreis et al., 1987, p. 221.
Stutchburia argentinensis Harrington; Andreis; Japas, 1996, p. 63.
Stutchburia argentinensis Harrington; Pagani, 2000, p. 312.

Material

Two articulated internal moulds, one from the Taciba Formation, Mafra, Santa Catarina State, and one from Rio do Sul Formation, Baitaca siltstone, Teixeira Soares region, Paraná State.

Description

Shell equivalve, strongly inequilateral, and elongated posteriorly. Posterior and ventral margins parallel to sub-parallel. The anterior dorsal margin is very short, straight; anterior extremity rounded; ventral margin straight to slightly convex; posterior extremity truncated, entirely occupied by respiratory margin. An obscure sulcus extends from beaks to ventral margin. Margins do not gap. The posterior dorsal margin is straight. Umbonal area slightly inflated, with beaks slightly elevated above hinge line. Umbonal carina well marked, running from beaks to postero-ventral angle. Lunule and escutcheon absent. Surface ornament of well-marked regular spaced comarginal rugae; slightly marked growth lines are visible near the posterior end of the shell. Narrow ligament furrow is present immediately posterior to beaks, until medial portion of the postero-dorsal margin. Hinge edentulous. The muscle scars are not observed.

Comments

Pagani (2000) designated under *Stutchburia*? *argentinensis* Harrington, 1955, specimens from the Lower Permian Bonete Formation. Similar material from Permian Rio do Sul Formation, Baitaca assemblage (Simões, Rocha-Campos, Anelli, 1998), studied by Rocha-Campos (1969, 1970), was designated under a different genus, *Myonia argentinensis* Harrington, 1955. *Stutchburia* is characterized by the presence of a well-marked radial costae and well-defined lunule and escutcheon. Furthermore, internally, *Stutchburia* also presents a well-marked buttress behind the anterior adductor scar. All these features are absent both in the Argentinean material from the Bonete Formation and the Brazilian specimens (Table 2) from the Rio do Sul Formation. The same is true for the material here studied from Taciba Formation. Therefore, by the lack of key characters of *Stutchburia* and the presence of well-defined carina, an obscure umbonal lateral sulcus and non-gaping margins, we recognize the Brazilian and Argentinean specimens under the genus *Myonia*.

Table 2. Dimensions (mm) of the *Myonia argentinensis* shells.

Specimens	Length	Height	Weight
DGM 4341	55	13	–
CP. I-475	~67	15	17
DZP 18826	~35	11	15
DZP 18859	32	~13	–

DISCUSSION

Contrary to Argentina, where the Late Paleozoic faunas are relatively diverse, better known, and more easily correlated with the Australian faunas, the use of the Late Paleozoic bivalves from the Paraná Basin (Figure 1) for correlations is limited. Therefore, the meager and poorly diversified marine invertebrate faunas recorded in the Itararé Group, their restrict vertical and lateral distribution, and high-degree of provincialism, due to basin isolation and strong climatic gradients recorded in the South American continent during the Late Paleozoic (Runnegar, 1972; Rocha-Campos, 1970; Pagani and Ferrarri, 2011), are among the main issues that mar the biocorrelations.

Elongate, probably dorsoventrally compressed bivalve specimens of the marine thin intercalations of the Itararé succession from the Santa Catarina State, Butiá assemblage, and Paraná State, Baitaca assemblage (Simões, Anelli, Rocha-Campos, 1998) are remarkable similar to specimens formerly assigned to *Stutchburia*? *argentinensis*, by Harrington (1955) and Pagani (2000) from the Bonete Formation. As commented, we here assign them to *Myonia argentinensis*. These specimens are also similar to that recorded by Rocha-Campos (1970) in the top of the Itararé Group (Rocha-Campos and Carvalho, 1975). In both the Argentinean and Brazilian specimens of *Myonia argentinensis*, a well-defined carina and an obliquely truncated posterior margin are visible.

As shown here, both *Myonia argentinensis* and *Aviculopecten multiscalptus* are present in the Baitaca siltstone of the Rio do Sul (or Taciba) Formation at the Teixeira Soares region, Paraná State. Hence, the Butiá and Baitaca assemblages are correlated to the "*Eurydesma* fauna" of the Bonete Formation (Asselian-Sakmarian) and with the fauna of the Amotape Formation (Middle Pennsylvanian) of Peru (Newell, Chronic, Roberts, 1953), as indicated by the common occurrence of *Aviculopecten multiscalptus* (Rocha-Campos, 1970; Rocha-Campos and Rösler, 1978).

Our findings in Itararé succession of a bivalve species, which is typical of Bonetian fauna, open new avenues to better constrain the age of the marine intercalations recorded at the top of Itararé succession. In the Eastern Argentina, the Piedra Azul and Bonete Formations contain members of the typical *Eurydesma* fauna, and they are associated with the post-glacial transgression of the end of Gondwana Ice Age (Dickins, 1985; González and Saravia, 2007, Anelli et al., *in press*). As noted by González and Saravia (2007), the *Glossopteris* flora as well as the *Eurydesma* fauna in the Sauce Grande Basin (Harrington, 1955; Rocha-Campos and Carvalho, 1975; Archangelsky, 1996; Pagani, 1998, 2000) and Karoo-Kalahari Basin (Dickins, 1961; Mclachlan and Anderson, 1973) is suggestive of an Asselian age to this climatic deglatiation event (Dickins, 1985). Hence, Pagani (1998, 2000) have referred the *Eurydesma* fauna of the Saunce Grande Basin to the Late Asselian-Sakmarian, while González and Saravia (2007) to the Sakmarian.

Although *Eurydesma* has not been found yet in the marine assemblages of the Itararé succession of the Paraná Basin (Simões, Anelli, Rocha-Campos, 1998), the common occurrence of *Myonia argentinensis* in the Brazilian and Argentinean faunas indicate a Late Asselian-Sakmarian age for the assemblages. Therefore, new SHRIMP U-Pb zircon ages (Rocha-Campos et al., 2011, p. 9, Figure 6) from tuffs recorded at the top of the Itararé Group (Rio do Sul Formation) indicate that this portion of the Late Paleozoic succession of the Paraná Basin was deposited during the Asselian. Hence, the age of the section containing the studied fauna is sound with the age and biocorrelations with the Bonetian fauna of Argentina, as already suggested by other authors (Rocha-Campos and Rösler, 1978; González, 1997; Simões, Anelli, Rocha-Campos, 1998; Pagani, 1998, 2000). Finally, based on their mutual faunal content, both the Butiá and Baitaca assemblages are, indeed, an evident record of members of *Eurydesma*-fauna within the Late Paleozoic succession of Paraná Basin.

CONCLUSIONS

Until now, despite its close paleogeographic location within the Gondwana supercontinent, a free connection between Paraná Basin and Sauce Grande Basin (Figure 1), favoring the full interchange of members of the Paranian and Bonetian faunas, was very difficult to envisage. Despite the general suprageneric composition similarities of these faunas, as pointed out by previous authors (Rocha-Campos and Rösler, 1978; González, 1997; Simões, Anelli, Rocha-Campos, 1998; Pagani, 1998, 2000), the complete lack of bivalve species in common was always an evidence for some degree of faunal distinction among these basins (González and Saravia, 2007). Our new findings are, however, noteworthy, since they indicate that both faunas may yield species in common. Although *Eurydesma* is missing, *Myonia argentinensis* is the first conspicuous member of the Bonete Formation recorded in the Paraná Basin. We should highlight that Itararé faunas are virtually undescribed and still poorly sampled. This mars our comparisons with other Late Paleozoic faunas of Argentina.

In addition, the huge size of both basins (Paraná/Sauce Grande) and the pronounced climatic gradient, which was typical of the late Paleozoic times in the Gondwana supercontinent, may account for the development of several regional faunas, with variable degrees of endemism. One of the main differences between the Butiá assemblage and those of the upper portion of the unit in Teixeira Soares (Rio da Areia sandstone, Baitaca siltstone and Passinho shale), Paraná State, is that the first is largely dominated by productid brachiopods indicating distinct paleoenvironmental conditions. The marine invertebrates of the three main lithofacies of Itararé succession at Teixeira Soares region thrived in nearshore to inner and outer shelf environments (Simões, Rocha-Campos, Anelli, 1998). The studied fossiliferous sandstone found in the Butiá Quarry was probably deposited, under nearshore conditions.

Despite the paleoenvironmental similarities, this pattern is very interesting since the Paleozoic brachiopods and bivalves occupied different habitats and played different roles in the environment. As stated by Gould and Calloway (1980), there is no evidence that both groups actually competed with each other. Several Permian bivalves were shallow to deep burrowers, a new condition that characterizes the Late Paleozoic marine faunas (Bush and Bambach, 2011). The Baitaca assemblage is largely dominated by shallow to deep burrowers, mainly Anomalodesmatan bivalves (Simões, Rocha-Campos, Anelli, 1998). This is noticeable because the deep bioturbation (deep tiering) may have prevented the full colonization of the substrate by the brachiopods. The suspension-feeding organism may not coupe with intense bioturbation (deep tiering), which makes feeding more difficult or even impossible (Graham Budd at http://www.palaeontology.geo.uu.se/Download/Palaeobiology/Lecture_10.pdf). Bioturbation seems less intense (shallow tiering) in the fossiliferous siltstone of the Butiá Quarry, making the substrate more favorable to the brachiopod fauna. Hence, this may represent a good case study on trophic amensalim to be tested in the future.

ACKNOWLEDGEMENTS

Fieldwork was financially supported by the State of São Paulo Research Foundation (FAPESP) and the National Council for Research and Development (CNPq), through the projects: FAPESP-1993/02747-0 and 2009/17555-0, and CNPq-500694/92-3. We are deeply indebted with Vilson Greinert (CENPALEO), for his careful and detailed laboratory preparation of some bivalve specimens used in this article. We are grateful to Juliana de Moraes Leme (IGc/USP) and Renato Pirani Ghilardi (FC/UNESP-Bauru) for their comments and constructive suggestions in this paper. We also thank Suzana Aparecida Matos da Silva (IGCE/UNESP) for her help during the field trips. Our thanks are extended to the Paleontological Center of the University of Contestado, which provided laboratory and logistic facilities, during our stay in Mafra, Santa Catarina State.

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