UNIVERSITY OF BRASÍLIA – UnB
INSTITUTE OF GEOSCIENCES – IG
GRADUATE RESEARCH PROGRAM IN GEOLOGY

TAXONOMY, PALEOECOLOGY AND CHRONOBIOSTRATIGRAPHY ACROSS THE EDIACARAN-CAMBRIAN BOUNDARY: TAMENGO AND GUAICURUS FORMATIONS

Doctoral thesis N° 157

Doctoral thesis by Rodrigo Rodrigues Adôrno

Supervisor: Prof. Dermeval Aparecido Do Carmo

Brasília, May 2019

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Thesis submitted to the coordination of the graduate research program in geology, University of Brasília, in partial fulfillment of the requirements for the degree of doctor on geology.

Area of concentration: Biostratigraphy and Paleoecology

Supervisor and Chair of Committee:
Prof. Dermeval Aparecido do Carmo (IG/UnB – BR)

Committee Members:
Prof. Shuhai Xiao - Virginia Polytechnic Institute and State University – USA

Prof. Juliana de Moraes Leme Basso - IAG-USP – BR

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DEDICATION

I dedicate this thesis to my wife, Gabriela Adôrno, and my parents, Rui Adôrno and Cirene Adôrno, for the love and support during my PhD journey. I also dedicate this thesis to Prof. Detlef. H. G. Walde, for being an outstanding professor and an inspiration to my study.

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“Every new beginning comes from some other beginning's end”

“Todo novo começo, nasce do fim de outro começo”

Lucius Annaeus Seneca

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RESUMO EXPANDIDO

Taxonomia, paleocologia e cronobioestratigrafia através do limite Ediacariano-Cambriano: formações Tamengo e Guaicurus

Rodrigo Rodrigues Adôrno
Laboratório de Micropaleontologia – Instituto de Geociências – Universidade de Brasília – Campus Darcy Ribeiro Asa Norte CEP: 70.910-900

RESUMO–Neste trabaho são apresentados resultados do estudo taxonômico e de distribuição estratigráfica de vinte e seis espécies de fósseis que integram a assemblagem fossilífera estudada a partir das formações Tamengo e Guaicurus em cinco seções na região de Corumbá e Ladário, a saber: Pedreiras Corcal e Laginha, Porto Sobramil, Porto Figueiras e Ecoparque Cacimba. Adicionalmente são apresentadas inferências paleoecológicas e paleoambientais com base na ocorrência desta assemblagem fóssil e na atualização da descrição litoestratigráfica destas seções. *Cloudina carinata* Cortijo et al., 2010, até então com ocorrências documentadas na Espanha e Sibéria, foi identificada a partir dos siltitos da Formação Tamengo na seção do Porto Figueiras, este registro representa a primeira ocorrência desta espécie em continente americano. A paelobiota estudada é composta por quatro espécies de organismos bentônicos sésseis: três metazoários biomineralizadores *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata*, *Corumbella werneri* Hahn et al., 1982, pelo vendotaenideo *Vendotaenia antiqua* Gnilovskaya, 1971, e pelo registro fragmentos de poríferos. O presente trabalho também aborda taxonomia e distribuição estratigráfica de quatro icnoespécies: *Gordia marina* Emmons, 1844, *Pilichnus* cf. *P. dichotomus* Uchman, 1999, *Didymaulichnus lyelli* (Rouault, 1850) e *Multina minima* Uchman, 2001 que integram a icnofauna bentônica vágil atualizada para a porção superior do Grupo Corumbá. Também é apresentado taxonomia sistemática para as duas espécies de macroalgas na Formação Guaicurus: *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979). A diversidade de espécies es da Formação Tamengo foi complementada pela ocorrência de dezesseis espécies de microfósseis que possivelmente representavam o plâncton marinho, composta por espécimes permineralizados de *Chuaria circularis* Walcott, 1899 e pela ocorrência de outras quinze espécies de microfósseis de parede orgânica: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. e Gen 1. sp. 1 (*chitinozoan like flask-shaped*). Foram identificadas significativa mudança nas condições paleoambientais de deposição entre as formações Tamengo e Guaicurus. Esta mudança parece estar relacionada com a eliminação de quase 95% da assemblagem fossilífera entre as formações Tamengo e Guaicurus durante a passagem Ediacariano-Cambriano. Dentre todas as vinte e duas espécies restritas à Formação Tamengo, houve apenas uma sobrevivente, a icnoespécie *Multina mínima*. Este desaparecimento local pode estar relacionado com a extinção global experimentada no limite Ediacariano-Cambriano, sendo aqui interpretado como um evento de extinção em massa. Adicionalmente foram feitas preparações palinológicas e análises de amostras do Ediacariano mais superior provenientes de seções de três países, com recuperação de nove espécies de microfósseis orgânicos na Formação Nomtsas, Namíbia, quatro espécies na Formação Tagatiya Guazu, Paraguai e seis espécies na Formação Dengying, China. Estes resultados ampliaram o escasso registro de espécies de microfósseis orgânicos para as seções do Ediacariano mais superior. Com base nos resultados taxonômicos e na distribuição estratigráfica das espécies, foi proposto ensaio bioestratigráfico consituido por sete biozonas: Superzona de Assemblagem *Cloudina;* inseridas nesta superzona há três biozonas distribuídas em seções do Brasil e do Paraguai, denominadas Zona diferencial inferior *Cloudina lucianoi*/*Corumbella werneri*; Zona de Amplitude *Corumbella werneri*; Zona diferencial superior *Corumbellla werneri*/*Cloudina lucianoi*; Subzona de Assemblagem *Bavlinella faveolata-Leiosphaeridia minutissima*. Esta subzona está inserida na base da Zona de Amplitude *Corumbella werneri*. A subzona *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone está inserida no topo da Zona diferencial superior *Corumbellla werneri*/*Cloudina lucianoi*. Por último a Zona de Assemblagem *Didymaulichnus lyelli/Eoholynia corumbensis* foi proposta. Esta biozona pertence ao Eo-Cambriano e está restrita, até o momento, à localidade da pedreira Laginha.

Palavras-Chave: Ediacariano-Cambriano, Grupo Corumbá, bioestratigrafia, *Cloudina*, *Corumbella*, micropaleontologia.

INTRODUÇÃO

O objetivo do presente trabalho é apresentar estudo detalhado da taxonomia, análise da distribuição estratigráfica das espécies e apresentar proposta de ensaio cronobioestratigráfico baseados na análise da assemblagem fossilífera das formações Tamengo e Guaicurus. Adicionalmente apresentam-se inferências paleoecológicas e paleoambientais com base na ocorrência das espécies e na atualização litoestratigráfica das seções estudadas na região de Corumbá e Ladário, Estado de Mato Grosso do Sul, Brasil. Considerando a escassez de dados micropaleontológicos para maioria das seções do Ediacariano mais superior, foram escolhidas seções para preparação e análise de amostras a partir de três localidades: Formação Nomtsas, Namíbia, Formação Tagatiya Guazu, Paraguai e Formação Dengying, China. Este estudo adicional visa complementar o escasso registro de espécies de microfósseis orgânicos descritas para o Ediacariano mais superior de seções consideradas importantes para correlação e comparação com as seções do Brasil. Finalmente constitui-se objetivo do presente trabalho apresentar integração e comparação dos resultados obtidos a partir da análise da assemblagem fossilífera das formações Tamengo e Guaicurus com aqueles publicados para outras seções do Ediacariano mais superior no Paraguai, Uruguai, Argentina, Namíbia, China, Rússia, Canadá, Estados Unidos e Omã, através da proposição de ensaio bioestratigráfico que siga as recomendações do código de nomenclatura estratigráfica internacional.

O horizonte cronoestratigráfico de interesse neste trabalho abrange o limite entre Neoproterozoico e o início do Fanerozoico. O Neoproterozoico é marcado por significativas mudanças paleoambientais, incluindo importantes eventos de oxidação atmosférica, seguida pela oxidação da porção mais profunda dos mares, além de também registrar eventos glaciais com capas de gelo que puderam alcançar baixas latitudes (Hoffman, 2009). As publicações científicas indicam pelo menos três eventos glaciais mais expressivos durante o Neoproterozoico: o primeiro é denominado glaciação Sturtiana (~720 Ma); o segundo, glaciação Marinoana (~635 Ma); e o terceiro, glaciação Gaskiers (~580 Ma) (Hoffman, 2009). O Ediacariano também registrou eventos de significativa mudança e extinções de biotas, especialmente nos intervalos cronoestratigráficos próximos à explosão do Cambriano. O Ediacariano é marcado pelo surgimento de um diversificado conjunto de grupos de metazoários, e o intervalo mais dramático de inovação morfológica que este grupo experimentou em sua história (Erwin, 2013; Darroch et al., 2018).

Além das mudanças paleoclimáticas, os níveis de O_2 dos mares e da atmosfera também oscilaram dramaticamente durante o Ediacariano. Há evidências de que as concentrações de O_2 variaram de cerca de 3 - 10% para mais de 100% do nível atual (Fike et al., 2006; Canfield & Teske, 1996). É discutido que a simultaneidade entre aparecimento de formas complexas de vida, ao mesmo tempo em que há evidências geoquímicas de que os níveis de oxigênio disponíveis subiram durante o Ediacariano (635 - 541Ma) poderia representar relação de causa e efeito. Esta simultaneidade tem levado diversos autores a proporem que a maior disponibilidade de oxigênio teria sido uma das principais causas do aparecimento dos animais complexos (Evans et al., 2018). A disponibilidade maior de oxigênio teria possibilitado o aparecimento e diversificação de grupos dotados de células eucarióticas e multicelulares e também a difusão de oxigênio através de tecidos complexos. A síntese de alguns dos tecidos envolve gasto metabólico de oxigênio substancial, como é caso da síntese de colágeno (Fike et al., 2006; Canfield & Teske, 1996). A natureza da relação entre inovações biológicas e as mudanças simultâneas paleoambientais e paleoclimáticas estão ainda sob debate, se causal ou meramente de simultaneidade.

O Período Ediacariano também registra uma das mais importantes inovações biológicas: o surgimento do esqueleto biomineralizado. As espécies inicialmente descritas como portadaroras desta inovação e as que foram mais bem estudadas são as espécies de *Cloudina* Germs, 1972. Além das espécies deste genero, há inumeras especies biomineralizadoras distribuídas nos gêneros *Sinotubulites* Chen, et al., 1981, *Conotubus* Zhang and Lin, 1986 in (Lin et al., 1986), *Namacalathus*, *Corumbella* Hahn et al., 1982 and *Gaojiashania* Yang et al., 1986 in (Lin et al., 1986).

Dentre todos os gêneros que abrigam espécies de animais biomineralizadores do Ediacariano mais superior, *Cloudina* é o possui maior distribuição geográfica, com ocorrências em diversas seções do Andar Ediacariano mais superior na Namíbia (Grant, 1990), Omã (Conway Morris et al., 1990), Sul da China (Hua et al., 2005; Cai et al., 2013; Cortijo et al., 2015a), Espanha (Cortijo et al., 2010; Cortijo et al., 2015b), Sibéria (Kontorovich et al., 2008, 2009; Zhuravlev et al., 2012; Grazhdankin et al., 2015), Canadá (Hofmann & Mountjoy, 2001), México (Sour-Tovar et al., 2007), Brasil, Argentina e Uruguai (Gaucher et al., 2003; 2005b; Warren et al., 2014; Adôrno et al., 2017), Paraguai (Warren et al., 2011; 2012; 2017; 2019) e California (Grant, 1990; Zhuravlev et al., 2012). Especies do animal biomineralizador *Sinotubulites* Chen et al., 1981 também tem distribuição geográfica ampla e têm sido descritos em seções do Ediacariano mais superior do Sul da China (Cai et al., 2015), México (McMenamin, 1985), na California e Nevada nos Estados Unidos (Signor et al., 1987), e na Espanha (Cortijo et al., 2015b). A espécie problemática *Namacalathus hermanastes* Grotzinger et al., 2000 foi originalmente descrita a partir do Grupo Nama, Namíbia (Grotzinger et al., 2000; Zhuravlev et al., 2015). Adicionalmente, esta especie também ocorre no Ediacariano mais superior no oeste do Canadá, (Hofmann & Mountjoy, 2001), Omã (Amthor et al., 2003), Sibéria (Kontorovich et al., 2008, 2009; Grazhdankin et al., 2015) e Paraguai (Warren et al., 2017).

Na América do Sul as seções da Formação Tamengo do Grupo Corumbá representam as melhores oportunidades de estudo relacionadas às mudanças climáticas e inovações biológicas experimentadas durante o Ediacariano terminal (Boggiani et al., 2010). O Grupo Corumbá é constituído da base para o topo pelas formações Cadieus, Cerradinho, Bocaina, Tamengo e Guaiucurus. Trabalhos têm sido produzidos sobre a paleontologia do Grupo Corumbá (Beurlen & Sommer, 1957; Fairchild, 1978; Hahn et al., 1982; Walde et al., 1982; Zaine & Fairchild, 1985; Zaine 1991; Hidalgo, 2002; Gaucher et al., 2003; Becker-Kerber et al., 2013; Tobias, 2014; Pacheco, 2012; Leme et al., 2008; Pacheco et al., 2011; Walde et al., 2015; Adôrno et al., 2017; Parry et al., 2017) e também sobre a estratigrafia e evolução tectono-estrutural (Barbosa, 1949; Almeida, 1964, 1965, 1984; Alvarenga & Trompette 1992; Boggiani & Alvarenga 2004; Gaucher et al. 2003; Babinski et al. 2008; Boggiani et al. 2010; Meira, 2011; Spangenberg et al., 2014; D’el-Rey et al. 2016; Sial et al., 2016) e sobre o contexto sedimentológico (Boggiani et al., 1993; Boggiani, 1998; Oliveira, 2010; Campanha et al., 2011; Fontanela, 2012; Fazio et al., 2019).

METODOLOGIA

Diversos trabalhos de campo foram realizados nas cercanias dos municípios de Corumbá e Ladário, Mato Grosso do Sul, além de um trabalho de campo na Namíbia e África do Sul e outro no Sul da China. Durante os trabalhos de campo, foram levantados seções e perfis litoestratigráficos com posicionamento das amostras de rochas coletadas de maneira sistemática, com espaçamento regular entre as coletas. As localidades estudadas do Grupo Corumbá incluem os afloramentos de cinco principais localidades: Ecoparque da

Cacimba, pedreira Corcal, a pedreira Laginha, Porto Sobramil e Porto Figueiras (atualmente denominada Marina do Gerson). Adicionalmente, foram preparadas amostras coletadas em seções das formações Dengying, China, Tagatiya Guazu, Paraguai e Nomtsas, Namíbia visando complementar o escasso registro de espécies de microfósseis orgânicos para estas seções.

Três modalidades de preparação de amostras foram empregadas durante a execução da pesquisa visando à recuperação de fósseis: 1. Invertebrados, 2. Microfósseis biomineralizadores e permineralizados, e 3. Microfósseis orgânicos (macerações palinológicas). Quanto ao estudo de ocorrência de invertebrados como *Cloudina lucianoi* e *Corumbella werneri* bem como dos icnofósseis e algas macroscópicas, o estudo consistiu inicialmente na descrição e análise direta a partir da amostra de rocha com uso de microscópico estereoscópico, da confecção de seções polidas e lâminas delgadas para estudo com auxílio de microscópico estereoscópico, microscópio petrográfico, e em casos específicos de microscopia eletrônica de varredura (MEV).

Para a preparação química e concentração dos componentes orgânicos particulados (macerações palinolígicas) utilizou-se a metodologia própria desenvolvida no Laboratório de Micropaleontologia. A preparação consiste em atacar as amostras por 2 h com ácido clorídrico 37%. Em seguida as amostras devem ser neutralizadas para então serem atacadas com ácido fluorídrico 47% por 12h. Novamente as amostras devem ser neutralizadas por meio de diversas lavagens com água destilada até que o pH esteja próximo de 7. Uma nova digestão com ácido clorídrico pode ser feita visando consumo de fluorita, encerrando a preparação com neutralização com água destilada. Para a montagem da lâmina palinológica permanente utiliza-se o sobrenadante, e Entelan como meio de montagem padrão e fixação da lamínula.

Uma extensa consulta bibliográfica foi realizada para se determinar quais seções seriam selecionadas para estudos de comparação com os resultados obtidos a partir das seções das formações Tamengo e Guaicurus. A consulta bibliográfica permitiu incluir, além das cinco seções estudadas do Grupo Corumbá, onze seções adicionais distribuídas no Paraguai (três seções), Uruguai, Argentina, Namíbia, China, Rússia, Canadá, Estados Unidos e Omã com uma seção cada, compondo um total de 15 seções. Todo material ilustrado encontra-se depositado nas coleções de macrofósseis sob o sufixo (MAF-), Micropaleontológicos (MP-) ou na coleção de pesquisa (CP-) do Museu de Geociências, no Laboratório de Micropaleontologia da Universidade de Brasília UnB.

RESULTADOS E DISCUSSÃO

Os principais resultados obtidos com o desenvolvimento da pesquisa foi a realização de estudo taxonômico e de distribuição estratigráfica de vinte e seis espécies de fósseis que integram a assemblagem fossilífera das formações Tamengo e Guaicurus em cinco seções na região de Corumbá e Ladário, Estado de Mato Grosso do Sul, Brasil. Adicionalmente são apresentadas inferências paleoecológicas e paleoambientais com base na ocorrência das espécies e na atualização litoestratigráfica das seções da Formação Tamengo. A biota da Formação Tamengo é composta por metazoários biomineralizadores bentônicos sésseis e por registro de atividade de metazoários bentônicos vágeis representados pelos icnofósseis. Adicionalmente, a biota da desta formação é complementada por microfósseis que compunham possivelmente o plâncton marinho desta formação. Além destes resultados, novas amostras de seções adicionais das formações Dengying, China, Tagatiya Guazu, Paraguai e Nomtsas, Namíbia foram coletadas e preparadas. O resultado da preparação e análise destas amostras complementaram o escasso registro de espécies de microfósseis orgânicos para estas seções. Finalmente foi apresentado integração e comparação dos resultados obtidos a partir da análise da biota da Formação Tamengo com aqueles publicados para outras seções selecionadas do Ediacariano mais superior no Paraguai, Uruguai, Argentina, Namíbia, China, Rússia, Canadá, Estados Unidos e Omã.

A taxonomia de *Cloudina* Germs, 1972 foi atualizada e teve sua diagnose emendada (Adôrnoet al., 2017). O material-tipo de *Cloudina lucianoi* (Beurlen e Sommer, 1957) foi redescrito e posteriormente comparado com outras espécies de *Cloudina*, em especial com o material-tipo de *Cloudina hartmanae* Germs, 1972. O estudo comparativo entre estas duas espécies foi baseado em critérios morfológicos e morfométricos objetivos, que permitiram propor que *Cloudina hartmanae* deveria ser considerada sinônimo júnior de *Cloudina lucnianoi*. Esta última espécie passou então a ocupar a posição de espécie-tipo do Gênero *Cloudina* e a ter sua distribuição geográfica ampliada para todos os continentes, revelando uma grande importância para estudos de correlação bioestratigráfica global.

A ocorrência *Cloudina carinata* Cortijo et al., 2010 foi registrada a partir de siltitos da Formação Tamengo na localidade denominada Porto Figueiras, Município de Corumbá. Esta ocorrência é o primeiro registro desta espécie no continente americano, ampliando sua distribuição geográfica, cuja ocorrência já havia sido documentada, até o presente, em seções na Espanha e na Sibéria. Além de *Cloudina carinata* foram descritas ocorrências inéditas de estruturas aciculares interpretadas como espículas de poríferos, uma câmara interpretada como possível gêmula de porífero, que juntamente com *Corumbella werneri* e *Cloudina lucianoi*, integram a assemblagem de metazoários biomineralizadores bentônicos epibiontes sésseis da Formação Tamengo.

As ocorrências de *Cloudina lucianoi* da Formação Tamengo consideradas autóctone são associadas a carbonatos interpretados como representantes de paleoambientes com baixa sedimentação siliciclástica e em condições de água raza na zona fótica. *Cloudina lucianoi* tem sido considerada como responsáveis pelas primeiras construções recifais produzidas por metazoários em diversas seções do Edicariano mais superior globalmente distribuídas (Grotzinger & Al-Rawahi, 2014; 2015; Wood, 2011; Penny et al., 2014). Por outro lado, os metazoários *Corumbella werneri* e *Cloudina carinata* ocorrem com maior frequência associados a camadas de rochas siliciclásticas, interpretadas como tendo sido depositadas em paleoambientes relativamente mais profundos, ou ainda em condições episódicas de maior aporte de sedimentos. Finas lâminas de siltito com coloração vermelha abrigam grande número de espécimes de *Corumbella werneri* e mais raramente de *Cloudina carinata*, onde também se observa ocorrências abundantes de icnofósseis *Gordia marina* e *Pilichnus cf. P. dichotomus*. A coloração vermelha destas finas camadas de siltito em meio a camadas com coloração cinza escuro, se devem a presença de óxido de ferro, podendo representar episódios de oxigenação do paleoambiente, que tornavam possíveis a colonização episódica por metazoários bentônicos sésseis e vágeis.

O presente trabalho apresenta sistemática paleontológica para as icnoespécies *Didymaulichnus lyelli* e *Multina minima* previamente registradas no topo da Formação Tamengo e base da Formação Guaricurus na seção da pedreira Laginha (Parry et al., 2017), assim como para duas novas ocorrências de *Gordia marina* Emmons, 1844 e *Pilichnus* cf. *P. dichotomus* Uchman, 1999 na Formação Tamengo, pedreira Corcal. *Multina mínima*, *Gordia marina* e *Pilichnus* cf. *P. dichotomus* integram a assemblagem icnológica atualizada para a Formação Tamengo, das quais aquela denominada *Multina minima* ocorre também na Formação Guaicurus enquanto que *Didymaulichnus lyelli* possui, até o momento, ocorrência restrita à Formação Guaicurus.

Pilichnus cf. P. dichotomus é constituído por escavações complexas e bifurcadas, representando organismos epibiontes com estratégias elabodadas de escavação. *Didymaulichnus lyelli*, é representada por escavações produzidas por organismos endobiontes vágeis. *Gordia marina* representa traços possivelmente produzidos por organismos bentônicos epibiontes vágeis. *Gordia marina* constiui-se de traços superficiais simples curvados ou em forma de laços que possivelmente estão associados a organismos epibiontes vágeis exploradores do substrato na interface água-sedimento. *Multina mínima* é representada por microtúneis que representam complexos padrões de escavações possivelmente associados a pequenos organismos vermiformes endobiontes vágeis capazes de penetrar porções constituídas por material macio e inconsolidadas do substrato.

O conteúdo micropaleontológico da Formação Tamengo é constituído por microfósseis permineralizados e orgânicos. Os microfósseis permineralizados incluem registros inéditos de vesículas identificadas como *Chuaria circularis* e uma câmara com afinidade taxonômica incerta, tentativamente atribuída a gêmula de porífero, incrustada na superfície reticular de um espécime provavelmente representante de porífero na localidade do porto Sobramil.

Quinze espécies de microfósseis orgânicos, provavelmente oriundos de organismos plantônicos, foram identificadas a partir das amostras da Formação Tamengo: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp. and Gen1. sp. 1 (chitinozoan like flask-shaped); Cinco espécies de palinomorfos foram identificadas a partir de amostras da Formação Dengying, China: *Bavlinella faveolata, Leiosphaeridia minutissima, Leiosphaeridia crassa, Leiosphaeridia obsuleta* (Naumova, 1949) e *Ostiama microcystis*; Nove espécies da Formação Nomtsas, Namíbia: *Bavlinella faveolata, Ostiama microcystis, Leiosphaeridia crassa, Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima, Leiosphaeridia minutissima, Soldadophycus major, Coniunctiophycus conglobatum* e *Myxococcoides siderophila*. Quatro espécies da Formação Tagatiya Guazu, Paraguai: *Ostiama microcystis, Leiosphaeridia obsuleta* (Naumova, 1949) *e Leiosphaeridia minutissima* e uma espécie indeterminada Gen. 1 sp. 1. Percebeu-se a ausência de vesículas orgânicas maiores e ornamentadas em todas as seções estudadas do Brasil (Formação Tamengo), Paraguai (Formação Tagatiya Guazu), Namíbia (Formação Nomtsas) e China (Formação Dengying), como tipicamente é descrito para sequências do Ediacariano mais superior em diversas seções globalmente distribuídas (Knoll, 1996; Vidal & Moczydlowska-Vidal, 1997; Gaucher, 2000).

É possível notar uma mudança dramática entre a assemblagem fossilífera das formações Tamengo e Guaicurus. Essa mudança é seguida por mudanças no paleoambiente deposicional. A Formação Tamengo foi depositada em contexto paleoambiental favorável à precipitação de carbonatos, que seria interrompida episodicamente por entrada de sedimentos siliciclásticos imaturos muito finos de uma área-fonte proximal. A Formação Guaicurus, por outro lado, é o resultado de um fornecimento siliciclástico ininterrupto, imaturo e muito fino, proveniente de uma área-fonte proximal. Aparentemente, entre todas as vinte e duas espécies restritas à Formação Tamengo, houve apenas uma sobrevivente, a icnospécie *Multina minima* que ocorre nessas duas formações. Possivelmente, o hábito bentônico endobionte poderia ser a estratégia para resistir às mudanças paleoambientais registradas na porção superior do Grupo Corumbá, responsável pelo evento de extinção em massa observado no limite entre a Formação Tamengo e Guaicurus, Grupo Corumbá, Ediacariano-Cambriano.

A integração das informações relativas à taxonomia e distribuição estratigráfica das espécies que integram a biota da Formação Tamengo foi apresentada na forma de um ensaio bioestratigráfico composto por sete biozonas, da base para o topo respectivamente denominadas: Superzona de Assemblagem *Cloudina* com abrangência em todas as 15 seções avaliadas. Inseridas nesta superzona, foram propostas três biozonas, distribuídas nas seções do Brasil e do Paraguai: Zona diferencial inferior *Cloudina lucianoi*/*Corumbella werneri*; Zona de Amplitude *Corumbella werneri*; Zona diferencial superior *Corumbellla werneri*/*Cloudina lucianoi*. Foi proposta uma Subzona de Assemblagem *Bavlinella faveolata-Leiosphaeridia minutissima*, inserida na base da Zona de Amplitude *Corumbella werneri*. Esta subzona tem abrangência geográfica em seções do Brasil, Argentina, Uruguai, Namibia e China. A subzona *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone está inserida no topo da Zona diferencial superior *Corumbellla* *werneri*/*Cloudina lucianoi*. Por último foi apresentado uma biozona na base da FormaçãoGuaicurus, denominada Zona de Assemblagem *Didymaulichnus lyelli/Eoholynia corumbensis*. Esta biozona pertence ao Eo-Cambriano e está restrita, até o momento, à localidade da pedreira Laginha.

CONCLUSÕES

Vinte e seis espécies foram descritas a partir das formações Tamengo e Guaicurus, porção superior do Grupo Corumbá, limte Ediacaraniano-Cambriano do Brasil. Esta assemblagem fossilífera foi agrupada em cinco categorias: metazoários biomineralizadores, vendotaenídeos, icnofósseis, microfósseis permineralizados e microfósseis de paredes orgânicas.

A fossil assemblage de Formação Tamengo consiste de vinte e três espécies. Deste total, três espécies representam organismos biomineralizadores bênticos sésseis de hábito epibionte: *Cloudina lucianoi* (Beurlen e Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982 e uma espécie indeterminada de porífero. Uma espécie vendotaenídio epibionte séssil *Vendotaenia antiqua* Gnilovskaya, 1971 também foi aqui estudada. Duas icnospices representam atividade de organismos de hábito bentônico endobionte vágil: *Multina minima* Uchman, 2001 e *Pilichnus cf. P. dichotomus* Uchman, 1999. *Gordia marina* Emmons e *Pilichnus cf. P. dichotomus* representam animais sésseis epibiontes exploradores da interface água-sedimento. Adicionalmente, foram recuperadas dezesseis espécies provavelmente derivadas de organismos plactônicos. Quinze microfósseis de parede orgânica: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp. and Gen1. sp. 1 (chitinozoan like flask-shaped), e uma espécie de microfóssil permineralizado *Chuaria circularis* Walcott, 1899.

Quatro espécies representam a assemblagem bentônica para a Formação Guaicurus: *Eoholynia corumbensis* Gaucher et al., 2003, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979), *Multina minima* e *Didymaulichnus lyelli* (Rouault, 1850). Deste total, três espécies têm ocorrências restritas a essa formação: *Eoholynia corumbensis*, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) e *Didymaulichnus lyelli*. Apenas *Multina minima* possui ocorrências compartilhadas com a Formação Tamengo.

Como é possível notar, a Formação Tamengo é detentora da maior diversidade de espécies do Grupo Corumbá, Ediacariano mais superior. Um evento de desaparecimento local é conspícuo durante a passagem da Formação Tamengo para a Formaçaõ Guaicurus. Com base na datação disponível e nas mudanças dramáticas no paleoambiente e na biota, foi apresentada uma hipótese de que este desapareciemento local poderia estar relacionada à extinção em massa a nível global do limite Ediacariano-Cambriano, pouco antes da explosão do Cambriano, conforme observado em outras seções consideradas cronocorrelatas.

Aparentemente, dentre todas as vinte e duas espécies restritas à Formação Tamengo, houve apenas uma sobrevivente, a icnospécie *Multina minima* que ocorre nas duas formações estudadas. Possivelmente, o hábito bentônico endobionte poderia ser a estratégia para resistir às mudanças paleoambientais registradas e ao evento de extinção em massa experimentado na porção superior do Grupo Corumbá.

Cinco seções da Formação Tamengo tiveram descrição litoestratigráficas atualizadas: seção do Ecoparque da Cacimba, Porto Figueiras, Porto Sobramil, pedreiras Corcal e Laginha. Além do levantamento dos perfis litoestratigráficos, as ocorrências das espécies foram posicionadas em cada perfil, permitindo a proposição de ensaios bioestratigráficos.

Também foram recuperadas e identificadas cinco espécies de microfósseis orgânicos a partir de amostras da Formação Dengying, China: *Bavlinella faveolata, Leiosphaeridia minutissima*, *Leiosphaeridia crassa, Leiosphaeridia obsuleta* (Naumova, 1949) e *Ostiama microcystis*; Nove espécies a partir de amostras do Grupo Nama, Namíbia: *Bavlinella faveolata*, *Ostiama microcystis*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima, Leiosphaeridia minutissima, Soldadophycus major, Coniunctiophycus conglobatum* e *Myxococcoides siderophila.* Quatro espécies na Formação Tagatiya Guazu, Paraguai: *Ostiama microcystis*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Leiosphaeridia minutissima* e Gen. 1 sp. 1. O resultado micropaleontológico para estas seções complementou o escasso registro de espécies de microfósseis orgânicos no Ediacariano mais superior.

Sete biozonas foram propostas, sendo representadas da base para o topo: Superzona de Assemblagem *Cloudina* distribuída em todas as seções avaliadas no Brasil, Paraguai, Uruguai, Argentina, Estados Unidos, Canadá, Namíbia, Omã, Russia e China. Inseridas nesta superzona, há três biozonas, distribuídas em seções do Brasil e do Paraguai, da base para o topo: 1*)* Zona diferencial inferior *Cloudina lucianoi*/*Corumbella werneri*; 2) Zona de Amplitude *Corumbella werneri*; 3) Zona diferencial superior *Corumbellla werneri*/*Cloudina lucianoi*. Com base no registro micropaleontológico foi possível propor a Subzona de Assemblagem *Bavlinella faveolata-Leiosphaeridia minutíssima*, inserida na base da Zona de Amplitude *Corumbella werneri*, que possui distribuição geográfica no Brasil, Argentina, Uruguai, Namíbia e China. A subzona *Vendotaenia antiqua*-*Cloudina lucianoi* Concurrent-Range Subzone está inserida no topo da Zona diferencial superior *Corumbellla werneri*/*Cloudina lucianoi*. Por último foi apresentado uma biozona na base da FormaçãoGuaicurus, denominada Zona de Assemblagem *Didymaulichnus lyelli/Eoholynia corumbensis*. Esta biozona pertence ao Eo-Cambriano e está restrita, até o momento, à localidade da pedreira Laginha.

Futuros estudos envolvendo taxonomia e distribuição estratigráfica da biota de seções que representam o Ediacariano mais superior serão de grande importância para avanços bioestratigráficos do intervalo Ediacariano mais superior. Atenção especial precisa ser dada às ocorrências de *Cloudina* sp. reportadas na Formação Sete Lagoas, Grupo Bambuí, principalmente visando o posicionamento estratigráfico e taxonômico precisos para aquelas ocorrências. Adicionalmente, estudos sobre biologia especialmente nas áreas de filogenia e morfologia comparada com metazoários, além de estudos aprofundados sobre a microbiota deste importante intervalo, devem ser encorajados.

REFERÊNCIAS BIBLIOGRÁFICAS

Todas referências bibiográficas são apresentadas no capítulo REFERENCES desta tese.

EXPANDED ABSTRACT

Taxonomy, paleoecology and chronobiostratigraphy across the Ediacaran-Cambrian boundary: Tamengo and Guaicurus formations

Rodrigo Rodrigues Adôrno
Laboratory of Micropaleontology - Institute of Geosciences - University of Brasília -
Campus Darcy Ribeiro Asa Norte, Postal Code: 70.910-900

ABSTRACT–This work presents results of the taxonomic study and the stratigraphic distribution of twenty-six species of Tamengo and Guaicurus formations in five sections in the Corumbá and Ladário regions: Corcal and Laginha quarries, Porto Sobramil, Porto Figueiras and Ecoparque Cacimba. In addition, paleoecological and paleoenvironmental inferences are presented based on the occurrence of this fossil assemblage and the updating of the lithostratigraphic description of the sections of upper Corumbá Group. *Cloudina carinata* Cortijo et al., 2010, had documented occurrences in Spain and Siberia, and now it is presented unprecedented occurrence in America continent, from siltstones of the Tamengo Formation at Porto Figueiras section, Brazil. The studied paelobiota is composed of three biomineralizing metazoan: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata*, *Corumbella werneri* Hahn et al., 1982, poriferous spicules, putative sponge gemmule and sessile epibionts prokaryotic-colony *Vendotaenia antiqua* Gnilovskaya, 1971. The present work also deals with taxonomy and stratigraphic distribution of the four ichnospecies: *Gordia marina* Emmons, 1844, *Pilichnus cf. P. dichotomus* Uchman, 1999, *Didymaulichnus lyelli* (Rouault, 1850) and *Multina minima* Uchman, 2001 that integrate the updated benthic vagile ichnofauna for upper portion of Corumbá Group. Three vendotaenid species were identified: *Vendotaenia antiqua* in Tamengo Formation, and two species in Guaicurus Formation: *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979). The species diversity of the Tamengo Formation fossil assemblage was complemented by the occurrence of sixteen microfissil species that possibly represented marine planktic, characterized by the permineralized microfossil *Chuaria circularis* Walcott, 1899 and other fifteen species of small sphaeromorphs organic-walled microfossils: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen. 1 sp. 1. A dramatic changed was identified in paleoenvironmental conditions for deposition of Tamengo and Guaicurus formations. It can be clearly seen that there is a possibility of these changes contributing to the elimination of almost 95% of the paleobiota, including the extinction of the epibenthic metazoan and the disappearance of planktic organic-walled microfossil. Among all twenty-two species restricted to Tamengo Formation, there was only one survivior, the ichnospecies *Multina minima* that occurs in both of these formations. This local disappearance could be attributed to the global Ediacaran-Cambrian mass extinction. In addition, samples were prepared and analyzed from sections of three countries where organic-walled microfossils were recovered: nine species from the Nomtsas Formation, Namibia; four species from the Tagatiya Guazu Formation, Paraguay; and six species from the Dengying Formation, China. These results increased the scarce record of organic-walled microfossils species from these additional uppermost Ediacaran selected sections. Based on the taxonomic results and the stratigraphic distribution of the species identified from the Tamengo Formation in the Corcal quarry, a biostratigraphic essay consisting of seven biozones was proposed. Based on the complementation of the micropaleontological data for the three additional studied sections, and based on the paleontological record present in the bibliography for other selected sections, the Tamengo

Formation biozones could be extended covering fifteen uppermost Ediacaran sections from nine countries: Brazil (four sections), Paraguay (three sections), Uruguay, Argentina, Namibia, China, Russia, Canada, United States and Oman, one section each. The seven biozones proposed were named, from bottom to top: *Cloudina* Assemblage Superzone that is distributed in all 15 analyzed sections. Inserted in this superzone, there are three biozones: *Cloudina lucianoi/Corumbella werneri* Interval Zone; *Corumbella werneri* Range Zone; *Corumbellla werneri/Cloudina lucianoi* Interval Zone, these three biozones have geographic distribution until the present which is restricted to Brazil and Paraguay. Two subzones are proposed: *Bavlinella faveolata-Leiosphaeridia minutissima* Assemblage Subzone inserted in the base of *Corumbella werneri* Range Zone and *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone at the upper portion of the *Corumbella werneri/Cloudina lucianoi* Interval Zone. The first subzone spans across Brazil, Argentina, Uruguay, Namibia and China, the second across Brazil, Namibia, China and Siberia. Finally, *Eoholynia corumbensis* Range Zone was proposed in the base of Guaicurus Formation at Laginha quarry, lowermost Cambrian, which is restricted to Laginha quarry locality so far.

Key words: Ediacaran-Cambrian, Corumbá Group, biostratigraphy, micropaleontology.

INTRODUCTION

The objective of this work is to present a detailed taxonomic study, to perform analysis of stratigraphic distribution of the species and to propose a chronobiostatigraphic framework for the biota of the Tamengo and Guaicurus formations, Ediacaran-Cambrian boundary, Brazil. In addition, paleoecological and paleoenvironmental inferences are presented based on the occurrence of the species and the lithostratigraphic update of the sections in Corumbá and Ladário regions, Mato Grosso do Sul State, Brazil. Considering the scarcity of micropaleontological data for uppermost Ediacaran sections, samples from three additional sections were prepared and analyzed from the Nomtsas Formation, Namibia, Tagatiya Guazu Formation, Paraguay and Dengying Formation, China. This additional study aims to complement the record of organic-walled microfossils species described for these three additional sections. Finally, it is the objective of this work to present an integration and comparison of the results obtained from the analysis of the Tamengo Formation fossil assemblage with those published for other uppermost Ediacaran sections from Paraguay, Uruguay, Argentina, Namibia, China, Russia, Canada, United States and Oman, by proposing a biostratigraphic essay following the recommendations of the International Stratigraphic Code.

The chronostratigraphic horizon of interest in this work covers the uppermost Ediacaran and lowermost Cambrian. The Neoproterozoic is marked by significant paleoenvironmental changes, including important atmospheric oxidation events, followed by the oxidation of the deeper portion of the seas, and also to record glacial events with ice caps that could reach low latitudes (Hoffman, 2009). Scientific publications indicate at least three most significant glacial events during the Neoproterozoic: the first is called Sturtian glaciation (~ 720 Ma); the second Marinoan glaciation (~ 635 Ma); and the third glacial event would have occurred in the Ediacarian and became known as the Gaskiers glaciation (~ 580 Ma) (Hoffman, 2009).

In addition to the paleoclimatic changes, the O_2 levels of the seas and the atmosphere also oscillated dramatically during the Ediacaran Period. There is evidence that O_2 concentrations varied from about 3 - 10% to more than 100% of the current level (Fike et al., 2006; Canfield & Teske, 1996). It is argued that the simultaneity between appearances of complex life forms, while there is geochemical evidence that the available oxygen levels rose during the Ediacaran (635 - 541Ma) could represent cause and effect relationship. This simultaneity has led several authors to propose that increased oxygen availability would have been one of the main causes of the onset of complex animals (Evans et al., 2018). The increased availability of oxygen would have enabled the emergence and diversification of groups with eukaryotic cells and multicellular and also the diffusion of oxygen through complex tissues. The synthesis of some of the tissues involves substantial metabolic expenditure of oxygen, such as the case of collagen synthesis (Fike et al., 2006; Canfield & Teske, 1996). The nature of the relationship between biological innovations and the simultaneous paleoenvironmental and paleoclimatic changes are still under debate, whether causal or merely simultaneity.

The Ediacaran Period also records one of the most important biological innovations: the emergence of the biomineralized skeleton. In addition to the species of *Cloudina* Genus, there are other numerous biomineralizing species of distributed into the genus *Sinotubulites* Chen, et al., 1981, *Conotubus* Zhang and Lin, 1986 in (Lin et al., 1986), *Namacalathus*, *Corumbella* Hahn et al., 1982 and *Gaojiashania* Yang et al., 1986 in (Lin et al., 1986). The Ediacaran also records biotic turnover and extinction closely followed by the Cambrian Explosion, marked by the appearance of a diverse array of metazoan groups, and the most dramatic interval of metazoan morphologic innovation in the history of life (Erwin, 2013; Darroch et al., 2018).

Among the biomineralizing species, *Cloudina* species are the most widely geographically distributed, with occurrences in several sections of the uppermost Ediacaran stage in Namibia (Grant, 1990), Oman (Conway Morris et al., 1990) , South China (Hua et al., 2005, Cai et al., 2013, Cortijo et al., 2015a), Spain (Cortijo et al., 2010, Cortijo et al., 2015b), Siberia (Kontorovich et al., 2008; Sour-Tovar et al., 2007), Brazil, Argentina, and Uruguay (Gaucher et al., 2006), Canada (Hofmann & Mountjoy, 2001) (Warren et al., 2014), Paraguay (Warren et al., 2011, 2012, 2017, 2019) and the USA (Grant, 1990; Zhuravlev et al., 2012). *Sinotubulites* species also have broad geographical distribution and have been described in sections of the uppermost Ediacaran of Southern China (Cai et al., 2015), Mexico (McMenamin, 1985), California and Nevada in the United States (Signor et al. 1987), and in Spain (Cortijo et al., 2015b). The problematic species *Namacalathus hermanastes*, was originally described from the Nama Group, Namibia (Grotzinger et al., 2000; Zhuravlev et al., 2015), with occurrences also recorded in Paraguay (Warren et al., 2019). In addition, this species also occurs in the uppermost Ediacaran in western Canada (Hofmann & Mountjoy, 2001), Oman (Amthor et al., 2003), Siberia (Kontorovich et al., 2008, 2009; Grazhdankin et al., 2015) and Paraguay (Warren et al., 2017).

The upper Corumbá Group sections represent the best opportunities to study the terminal Ediacaran climate changes and biological innovations in South America (Boggiani et al., 2010). The Corumbá Group is constituted from the base to the top by Cadieus, Cerradinho, Bocaina, Tamengo and Guaiucurus formations. Several works have been produced on the palaeontology of the Corumbá Group (Beurlen & Sommer, 1957; Fairchild, 1978; Hahn et al., 1982; Walde et al., 1982; Zaine & Fairchild, 1985; Zaine 1991; Hidalgo, 2002; Gaucher et al., 2003; Becker-Kerber et al., 2013; Tobias, 2014; Pacheco, 2012; Leme et al., 2008; Pacheco et al., 2011; Walde et al., 2015; Adôrno et al., 2017; Parry et al., 2017), also on the stratigraphy and tectono-structural evolution (Barbosa 1949; Almeida 1964, 1965, 1984; Alvarenga & Trompette, 1992; Boggiani & Alvarenga, 2004; Gaucher et al., 2003; Babinski et al., 2008; Boggiani et al., 2010; Meira, 2011; Spangenberg et al., 2014; D'el-Rey et al., 2016; Sial et al., 2016); and finally on the sedimentological context (Boggiani et al., 1993; Boggiani, 1998; Oliveira, 2010; Campanha et al., 2011; Fontanela, 2012; Fazio et al., 2019).

METHODOLOGY

Several fieldworks were carried out in the vicinity of the municipalities of Corumbá and Ladário, Mato Grosso do Sul, in addition to a field work in Namibia and South Africa and another in the South of China sections. During the field works in Corumbá region, lithostratigraphic logs were uptdated and samples were collected in a systematic way with positioning of each collected sample. The studied locations of the Tamengo Formation, Corumbá Group include the outcrops of five main localities: Ecoparque da Cacimba, Corcal and Laginha quarries, Porto Sobramil and Porto Figueiras. In addition, samples collected from sections of the Dengying, China, Tagatiya Guazu, Paraguay (collected and shared by Professor Lucas V. Warren) and Namtsas, Namibia formations were prepared to complement the scarce organic microfossils species register for these sections.

Three modalities of samples preparation were used aiming at the recovery of fossils: 1. Invertebrates, 2. permineralized microfossils and, 3. Organic-walled microfossils (palynologic maceration). As for the study of the occurrence of invertebrates such as *Corumbella werneri* and *Cloudina lucianoi* as well as the ichnofossils and macroscopic algae, the study initially consists of the description and direct analysis from rock using stereoscopic microscopy; polished sections were prepared as well as thin slides for study on the stereoscopic microscopy, petrographic microscope and in specific cases of scanning electron microscopy (SEM).

For the chemical preparation and concentration of the particulate organic components (organic-walled microfossils), the own methodology developed in the Laboratory of Micropaleontology was used. The preparation consists of attacking the samples for 2h with 37% hydrochloric acid. The samples were neutralized and treated with 47% hydrofluoric acid for 12h. Again the samples were neutralized by several washes with distilled water until the pH was close to 7. A further hydrochloric acid digestion can be done for fluorite consumption. For the assembly of the permanent palynological slides, the supernatant organic-matter content was used, and Entelan was used as the standard mounting medium covered with cover slip glass.

An extensive literature survey was conducted to determine which sections would be selected for comparison studies with the results obtained from the sections studied in the Tamengo Formation. The bibliographic consultation allowed to include, in addition to the five studied sections, eleven additional sections distributed in Paraguay (three sections), Uruguay, Argentina, Namibia, China, Russia, Canada, the United States and Oman with one section each. All illustrated material are housed in the collections of macroscopic fossils under the suffix (MAF-), Micropaleontological collection (MP-) or in the research collection (CP-) of the Museum of Geosciences, at the Laboratory of Micropaleontology of the University of Brasilia-UnB.

RESULTS AND DISCUSSION

Twenty-six described species integrate the fossil assemblage of the Tamengo and Guaicurus formations, and were clustered six categories: biomineralizing metazoan, biomineralizing microfossils, vendotaenids, ichnofossils, organic-permineralized microfossils and organic-walled microfossils.

Tamengo Formation fossil assemblage consists of twenty-three species. From the total of twenty-three species, three represent benthic biomineralizing epibiont of sessile habit: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982 and an indeterminate species of poriferous. Three ichnospecies represent activity of vagile organisms of benthic habit: *Multina minima* Uchman, 2001, *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999. *Multina minima* represents endobiot organisms while *Gordia marina* and *Pilichnus cf. P. dichotomus* represent epibiont vagile explorers of water-sediment interface. Additionally, sixteen species probably derived from plankticic organisms were recovered. Fifteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp. and Gen1. sp. 1 and one species of permineralized microfossils *Chuaria circularis* Walcott, 1899. The sessile epibionts prokaryotic-colony *Vendotaenia* *antiqua* was previously reported in Cerradinho and Bocaina formations, and herein the occurrences are expanded to Tamengo Formation.

Four species represent the benthic fossil assemblage for Guaicurus Formation: *Eoholynia corumbensis* Gaucher et al., 2003, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979), *Multina minima* and *Didymaulichnus lyelli* (Rouault, 1850). From the total, three species have occurrences restricted to this formation: *Eoholynia corumbensis*, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) and *Didymaulichnus lyelli*, only *Multina minima* has shared occurrences with Tamengo Formation. It is worthy of note that, Tamengo Formation yielded the greatest biodiversity.

It is possible to note a dramatic change in the fossil assemblage from Tamengo to Guaicurus formations. This change in the fossil assemblage are followed by changes in the depositional paleoenvironment. The Tamengo Formation was deposited in a favorable paleoenvironment for deposition of carbonates, which was episodically interrupted by immature siliciclastic supply from very fine-grained rocks of a nearby source area. The Guaicurus Formation, on the other hand, is a result of an uninterrupted immature siliciclastic supply from a nearby source area, composed of very fine-grained rocks (Fazio et al., 2019). Apparently, 95% of the twenty-three species of Tamengo Formation disappeared, only the ichnospecies *Multina minima* have occurences in both of these formations. Possibly, the benthic endobiont habit could be the strategy to resist the paleonvironmental changes recorded in the upper Corumbá Group.

This disappearance recorded during the passage of Tamengo to Guaicurus formation could be related to the Ediacaran-Cambrian global mass extinction event, just before the Cambrian Explosion as observed globally (Darroch et al., 2018). This inference is reinforced by the dating of ash beds at the upper portion of Tamengo Formation at Corcal quarry section presented in Parry et al. (2017) as 541.85 ± 0.75 Ma. Considering this age for the top of Tamengo Formation, an early Cambrian age would be expected for Guaicurus Formation. Furthermore, it is worth mentioning that all occurrences of organic-walled from Tamengo have small size (majority between 5 - 70µ diameter), and that no organic-walled microfossil was found in the Guaicurus Formation. The small size organic-walled microfossil in Tamengo Formation, tending toward complete absence in the Guaicurus Formation could also reinforce the hypothesis of a local disappearance during the passage of Tamengo to Guaicurus, and could also be related to the Ediacaran-Cambrian extinction as already mentioned.

In addition to these results, new samples of additional sections of the Dengying, China, Tagatiya Guazu, Paraguay and Nomtsas, Namibia formations were collected and prepared. The results of the preparation and analysis of these samples complemented the scarce register of organic-walled microfossil species for these uppermost Ediacaran sections. The absence of larger and ornate organic vesicles was observed in all studied sections of Brazil (Tamengo Formation), Paraguay (Tagatiya Guazu Formation), Namibia (Formation Nomtsas) and China (Dengying Formation), as is typically described for sequences of the most uppermost Ediacaran sections globally distributed (Knoll, 1996; Vidal & Moczydlowska-Vidal, 1997; Gaucher, 2000).

The taxonomy of *Cloudina* Germs, 1972 was updated and had its diagnosis emended (Adôrnoet al., 2017). The type-material of *Cloudina lucianoi* was redescribed and later compared to other *Cloudina* species, especially *Cloudina hartmanae* Germs, 1972. The comparative study between these two species was based on objective morphological and morphometric criteria, which allowed to propose that *Cloudina hartmanae* Germs, 1972 should be considered a junior synonym of *Cloudina lucnianoi* (Beurlen & Sommer, 1957). The latter species then occupied the position of type-species of the *Cloudina* Genus and has its geographical distribution extended to all continents, revealing a great importance for studies of global biostratigraphic correlation.

The occurrence *Cloudina carinata* Cortijo et al., 2010 was recorded from siltstones of the Tamengo Formation in the locality called Porto Figueiras, Municipality of Corumbá.

It is the first record of this species in the American continent, expanding its geographic distribution, whose occurrence has been documented in sections from Spain and Siberia.

The occurrences of *Cloudina lucianoi* considered autochthonous in the Tamengo Formation are associated with carbonate rock interpreted as representing paleoenvironments with low siliciclastic input and in shallow water conditions in the photic zone. Moreover, *Cloudina lucianoi* has been considered as being responsible for the first reef constructions produced by metazoans in several uppermost Edicarian sections (Grotzinger & Al-Rawahi, 2014, Wood, et al., 2011; Penny et al., 2014). On the other hand, the metazoan *Corumbella werneri* and *Cloudina carinata* are most frequently associated with layers of siliciclastic rocks of the Tamengo Formation, interpreted as having been deposited in relatively deeper paleoenvironments and/or in a condition of higher siliciclastc supply. Fine reddish-colored siltstones layers present large numbers of *Corumbella werneri,* ichnofossils *Gordia marina* and *Pilichnus cf. P. dichotomus* specimens and more rarely *Cloudina carinata*. The redish coloration of these thin layers of siltstone interbeded between layers with dark gray color are due to the presence of iron oxide, which may represent episodes of oxygenation of the paleoenvironment, which made possible the episodic colonization by sessile and vagile benthic metazoans.

The current work presents the taxonomy for the ichnoespecies *Didymaulichnus lyelli* and *Multina minima* Uchman, 2001 previously documented in the top of the Tamengo Formation and at the base of the Guaricurus Formation in the Laginha quarry section (Parry et al., 2017). Two other new occurrences identified as *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999 are herein presented. *Didymaulichnus lyelli* occurs only in Guaicurus Formation. *Multina minima*, *Gordia marina* and *Pilichnus cf. P. dichotomus* integrate the updated ichnology assembly for the Tamengo Formation, of which *Multina minima* also occurs in the Guaicurus Formation.

Pilichnus cf. P. dichotomus consists of complex and bifurcated excavations, representing epibiont organisms with elaborate excavation strategies. *Didymaulichnus lyelli*, is represented by excavations produced by vagile endobiont organisms. *Gordia marina* represents tracks possibly produced by vagile epibiont worms. This species consists of simple curved or loop-like surficial tracks that are possibly associated with substrate exploratory, vagile epibiont organisms at the water-sediment interface. *Multina minima* is represented by complex patterns microtunnels that represent excavations possibly associated with small, endobiont worm that are able to penetrate portions made up of soft and unconsolidated sediment.

The integration of the information regarding taxonomy and stratigraphic distribution of the species was presented as a biostratigraphic essay composed of seven biozones, from the base to the top, respectively named: *Cloudina* Assemblage Superzone that is distributed in all 15 analyzed sections. Inserted in this superzone, there are three biozones, distributed in sections of Brazil and Paraguay: *Cloudina lucianoi/Corumbella werneri* Interval Zone; *Corumbella werneri* Range Zone; and *Corumbellla werneri/Cloudina lucianoi* Interval Zone (Adôrno et al., 2016b; Adôrno et al., 2017). It was possible to propose two subzones: *Bavlinella faveolata - Leiosphaeridia minutissima* Assemblage Subzone inserted in the base of *Corumbella werneri* Range Zone and *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone at the upper portion of the *Corumbella werneri/Cloudina lucianoi* Interval Zone. The first subzone spans across Brazil, Argentina, Uruguay, Namibia and China, the second across Brazil, Namibia, China and Siberia. Finally, *Eoholynia corumbensis* Range Zone was proposed in the base of Guaicurus Formation at Laginha quarry, lowermost Cambrian. The geographic distribution of this biozone is restricted to Laginha quarry locality so far.

CONCLUSIONS

Twenty-six species were described from Tamengo and Guaicurus formations. This fossil assemblage were clustered six categories: biomineralizing metazoan, biomineralizing microfossils, vendotaenids, ichnofossils, organic-permineralized microfossils and organic-walled microfossils.

Tamengo Formation fossil assemblage consists of twenty-three species. From the total of twenty-two species, three represent benthic biomineralizing epibiont of sessile habit: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982 and an indeterminate species of poriferous. *Vendotaenia antiqua* represents the sessile epibionts prokaryotic-colony. Three ichnospecies represent activity of vagile organisms of benthic habit: *Multina minima* Uchman, 2001, *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999. *Multina minima* represents endobiot organisms while *Gordia marina* and *Pilichnus cf. P. dichotomus* represent epibiont vagile explorers of water-sediment interface. Additionally, sixteen species probably derived from plankticic organisms were recovered. Fifteen organic-walled microfossils: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp. and Gen1. sp. 1 and one species of permineralized microfossils *Chuaria circularis* Walcott, 1899.

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It is worthy of note that, Tamengo Formation yielded the greatest diversity of species for terminal Ediacaran Corumbá Group. One event of local disappearance was proposed, and based on the dating available and in the dramatic changes in the paleoenvironment and biota, a hypothesis of this local disappearance which can be related to the global Ediacaran-Cambrian extinction, just before the Cambrian explosion was presented.

Five sections of the upper Corumbá Group had updated lithostratigraphic description: Ecoparque da Cacimba, Porto Sobramil, Corcal and Laginha quarries and Porto Figueiras. In addition to the updates of the lithostratigraphic logs, the occurrences of the species were positioned in each log, allowing the proposition of biostratigraphic essay.

Additionally, five species of organic-walled microfossils were recovered and identified from samples of the Dengying Formation, China: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Ostiama microcystis*; Nine species from samples from Nama Group, Namibia: *Bavlinella faveolata*, *Ostiama microcystis*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima*, *Leiosphaeridia minutissima*, *Soldadophycus major*, *Coniunctiophycus conglobatum* and *Myxococcoides siderophila*. Four species in the Tagatiya Guazu Formation, Paraguay: *Ostiama microcystis*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Leiosphaeridia minutissima* and Gen.1 sp. 1. The micropaleontological result for these sections complemented the scarce record of species of organic-walled microfossils from the uppermost Ediacaran.

Seven biozones were proposed, from bottom to top: *Cloudina* Assemblage Superzone that is distributed in all 15 analyzed sections in Brazil, Paraguay, Uruguay, Argentina, United States, Canada, Namibia, Oman, Russia and China. Inserted in this superzone, there are three biozones, distributed in sections of Brazil and Paraguay: *Cloudina lucianoi/Corumbella werneri* Interval Zone; *Corumbella werneri* Range Zone; *Corumbellla werneri/Cloudina lucianoi* Interval Zone (Adôrno et al., 2016b; Adôrno et al., 2017). It was possible to propose two subzones: *Bavlinella faveolata* - *Leiosphaeridia* *minutissima* Assemblage Subzone inserted in the base of *Corumbella werneri* Range Zone and *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone at the upper portion of the *Corumbella werneri/Cloudina lucianoi* Interval Zone. The first subzone spass across Brazil, Argentina, Uruguay, Namibia and China, the second across Brazil, Namibia, China and Siberia. Finally, *Eoholynia corumbensis* Range Zone was proposed in the base of Guaicurus Formation at Laginha quarry, lowermost Cambrian. The geographic distribution of this biozone is restricted to Laginha quarry locality so far.

Future studies involving taxonomy and stratigraphic distribution of the uppermost Ediacaran fossil assemblage would be of great importance for advances in the biostratigraphy. Special attention must be given to the occurrences of *Cloudina* sp. reported in the Sete Lagoas Formation, Bambuí Group, mainly aiming at stratigraphic positioning and precise taxonomic positioning for those occurrences. In addition, studies on biology especially in the areas of phylogeny and morphology compared with metazoa, in addition to in-depth studies on the microbiota of this important interval, should be encouraged.

BIBLIOGRAPHIC REFERENCES

All citations in this expanded abstract are included in the chapter REFERENCES.

TAXONOMY, PALEOECOLOGY AND CHRONOBIOSTRATIGRAPHY ACROSS THE EDIACARAN- CAMBRIAN BOUNDARY: TAMENGO AND GUAICURUS FORMATIONS

Doctoral thesis by
Rodrigo Rodrigues Adôrno

CHAPTER – 1: INTRODUCTION

The objective of this work is to present a detailed study of the taxonomy, analysis of the stratigraphic distribution of the species and to propose a chronobiostatigraphic essay for the analyzed fossil assemblage of the Tamengo and Guaicurus formations. In addition, paleoecological and paleoenvironmental inferences are presented based on the occurrence of the species and the lithostratigraphic update of the sections of the Tamengo Formation in the region of Corumbá, Mato Grosso do Sul State, Brazil. Considering the scarcity of micropaleontological data for most uppermost Ediacaran sections, samples from three localities were prepared and analyzed from Nomtsas Formation, Namibia; Tagatiya Guazu Formation, Paraguay and Dengying Formation, China. This additional study aims to complement the record of species described in the bibiography, through the systematic description of new occurrences of organic-walled microfossils for these three additional sections. Finally, it is the objective of this work to present an integration and comparison of the results obtained from the analysis of the Tamengo Formation fossil assemblage with those published for other uppermost Ediacaran sections from Paraguay, Uruguay, Argentina, Namibia, China, Russia, Canada, United States and Oman, by proposing a biostratigraphic essay following the recommendations of the International Stratigraphic Code.

The Neoproterozoic is marked by significant paleoenvironmental changes, including important atmospheric oxidation events, followed by the oxidation of the deeper portion of the seas, and also to record glacial events with ice caps that could reach low latitudes (Hoffman, 2009). Scientific publications indicate at least three most significant glacial events during the Neoproterozoic: the first is called Sturtian glaciation (~ 720 Ma);

the second Marinoan glaciation (~ 635 Ma); and the third glacial event would have occurred in the Ediacarian and became known as the Gaskiers glaciation (~ 580 Ma) (Hoffman, 2009).

In addition to the paleoclimatic changes, the O_2 levels of the seas and the atmosphere also oscillated dramatically during the Ediacaran Period. There is evidence that O_2 concentrations varied from about 3 - 10% to more than 100% of the current level (Fike et al., 2006; Canfield & Teske, 1996). It is argued that the simultaneity between appearances of complex life forms, while there is geochemical evidence that the available oxygen levels rose during the Ediacaran (635 - 541Ma) could represent cause and effect relationship. This simultaneity has led several authors to propose that increased oxygen availability would have been one of the main causes of the onset of complex animals (Evans et al., 2018). The increased availability of oxygen would have enabled the emergence and diversification of groups with eukaryotic and multicellular cells and also the diffusion of oxygen through complex tissues. The synthesis of some of the tissues involves substantial metabolic expenditure of oxygen, such as the case of collagen synthesis (Fike et al., 2006; Canfield & Teske, 1996). The nature of the relationship between biological innovations and the simultaneous paleoenvironmental and paleoclimatic changes are still under debate, whether causal or merely simultaneity.

Ediacaran Period records one of the most innovative biological adaptations, the advent of the biomineralized skeleton. The first Ediacaran fossils described as having biomineralized skeletons and certainly the best studied are the *Cloudina* species. Among the biomineralizings of uppermost Ediacaran stage (TES), *Cloudina* is the most widespread, occurring in uppermost Ediacaran successions in Namibia (Grant, 1990), Oman (Conway Morris et al., 1990), South China (Hua et al., 2005; Cai et al., 2013; Cortijo et al., 2015a), Spain (Cortijo et al., 2010; Cortijo et al., 2015b), Siberia (Kontorovich et al., 2008; Zhuravlev et al., 2012; Grazhdankin et al., 2015), Canada (Hofmann and Mountjoy, 2001), Mexico (Sour-Tovar et al., 2007), Brazil and Uruguay (Gaucher et al., 2003; Warren et al., 2014; Adôrno et al., 2017), Paraguay (Warren et al., 2011) and eastern California Grant (1990) and Zhuravlev et al. (2012) (Table 1. 1Table **1. 1.** Occurrences of *Cloudina* species and their localities. (Font: <www.gbif.org>).

Table 1. 1. Occurrences of *Cloudina* species and their localities. (Font: <www.gbif.org>).

Species	**Country**	**Locality**	**Latit grau dec**	**Long grau dec**
Cloudina **sp.**	Mongolia	ridge above Khunker Gorge	46.72892	95.99601
Cloudina lucianoi **(Beurlen & Sommer, 1957)**	Paraguay	2 outcrops, 10 km apart, E of the Paraguay River, Rio Apa Block Warren et al., 2011	-22.7667	-57.48333
Cloudina **sp.**	Mexico	FCIP 01/625, near Rancho Fatima.	30.11667	-111.9833
Cloudina carinata **Cortijo et al., 2010**	SPAIN	lower reaches of the Estena River on the Membrillar property, NE Badajoz	39.36167	-4.837778
Cloudina carinata **Cortijo et al., 2010**	Brazil	Porto Figueiras Section Corumbá Municipality, Mato Grosso do Sul State, Brazil	-18.998937°	-57.62873°
Cloudina lucianoi **(Beurlen & Sommer, 1957)**	Russia	borehole Vostok 3 at the Northern Vezdekhodnyi Horst between western Lisitsa trough and RosOmãkha trough	59.4	85.66666
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Cloudina lucianoi **(Beurlen & Sommer, 1957)**	Canada	Jasper National Park of Canadá	53.03333	-118.7333
Cloudina lucianoi **(Beurlen & Sommer, 1957)**	China	SPECIFIC LOCATION: Shuimoshan, Xingshan County, Hubei, China. LAT/LONG: estimated based on Xingshan, China.	31.30833	110.8039
Cloudina lucianoi **(Beurlen & Sommer, 1957)**	China	SPECIFIC LOCATION: Lijiagou/Kuanchuanpu, Ningqiang County, Shaanxi, China. LAT/LONG: estimated based on Ningqiang, China.	32.94222	106.2264
Cloudina lucianoi **(Beurlen & Sommer, 1957)**	China	Hanzhong, Shaanxi	32.98333	106.2667
Cloudina **sp.**	USA	Nopah Range. SE 1/4, SE 1/4, SW 1/4, sec. 11, T20N, R8E, Tecopa Pass 7.5' quadrangle. Talus slope exposed on North-trending Ridge about 2.4km(1.5mi)NNE of Noonday Mine, Inyo County, California.	35.842	-116.089
Cloudina **sp.**	USA	Montgomery Mountains. SW 1/4, NW 1/4, SW 1/4, sec. 11, T185, R52E, Mt. Schader 7.5"" quadrangle. Talus slope on E side of an unnamed wash. 3.4km(2.1mi)SW of ghost town of Johnie, Nye County, Nevada.	36.4	-116.1035
Cloudina **sp.**	USA	Spring Mountains SW 1/4, sec. 34, T18S, R54E, Horse Springs 7.5"" quadrangle. Talus slope immediately NE of Santa Clara Spring, just W of the approximate border between Nye and Clark Counties, Nevada.	36.34	-115.902
Cloudina **sp.**	Namibia	Latitude and longitude coordinates are general for the country of Namíbia.	-22	17
Cloudina lucianoi **(Beurlen & Sommer, 1957)**	Oman	The formation outcrops throughout the Salt Basin Birba Area. Specimens from the Birba North-1 borehole at a subsurface depth of about 4500 m.	18	55.31667

***Cloudina* *lucianoi* (Beurlen & Sommer, 1957)**	China	Exposure in a stream section about 300m to the west of the hamlet of Xuanjiangping and about 2.8km south of the village of Kuanchuanpu	36.85	109.31
***Cloudina* sp.**	Antarctica	Specimens collected near the top of Taylor Nunatak on the east side of the Skackleton Glacier, central Transantarctic Mountains.	-84.7333	-176.1667
***Cloudina* *lucianoi* (Beurlen & Sommer, 1957)**	China	Lijiagou/Kuanchuanpu [Dengying Fm]	32.9422	106.226
***Cloudina* *lucianoi* (Beurlen & Sommer, 1957)**	China	Shuimoshan [Dengying Fm]	31.3083	110.804
***Cloudina* sp.**	Brazil	Corumba-Ladario, Brazil	-19	-57.62
***Cloudina* sp.**	Oman	Thrombolites, Mukhaizna-11 well	18.75	54.5
***Cloudina* sp.**	Namibia	Thrombolite Reef, Schwarzrand Subgroup	-28.58	18
***Cloudina* *lucianoi* (Beurlen & Sommer, 1957)**	Canada	Ediacaran, Lijiagou, Bed 8, Kuanchuanpu, Shaanxi	32.98	106.27
***Cloudina* *lucianoi* (Beurlen & Sommer, 1957)**	China	*Cloudina* of the Gaojiashan Fm., Shaanxi Province - Conway Morris et. al 1990	36.85	109.31
***Cloudina* *lucianoi* (Beurlen & Sommer, 1957)**	Oman	*Cloudina* of the Ara Formation, Omãn - Conway Morris et. al 1990	18	55.32
***Cloudina* sp.**	Namibia	Zaris Formation, Kubis Subgroup, Nama Group, Namíbia - Germs 1995	-25	17
***Cloudina* sp.**	Namibia	Nomtsas Formation, Schwarzrand Subgroup, Nama Group, Namíbia - Germs 1995	-22	17
***Cloudina* sp.**	Namibia	Urusis Formation, Schwarzrnad Subgroup, Nama Group, Namíbia - Germs 1995	-22	17
***Cloudina* sp.**	Antarctica	Taylor Formation, Antártica - Yochelson et. al. 1977	-84.73	-176.17
***Cloudina* sp.**	USA	LACMNH loc. 17132, Wood Canyon Fm., Inyo County, CA - Hagadorn and Waggoner 2000	38.08	-120.3
***Cloudina* sp.**	USA	LACMNH loc. 17130, Wood Canyon Fm., Nye County, NV - Hagadorn and Waggoner 2000	36.57	-116.15
***Cloudina* sp.**	USA	LACMNH loc. 17131, Wood Canyon Fm., Nye County, NV - Hagadorn and Waggoner 2000	37	-115.68
***Cloudina* sp.**	Namibia	Late Precambrian Dabis Formation, Germs 1995	-22	17
***Cloudina* sp.**	Brazil	Quarry in the Januaria City, Late Precambrian Sete Lagoas Formation, Warren, et al 2014	-15.4	-44.4
***Cloudina* *riemkeae*? Germs (1972)**	Argentina	Loma Negra Formation, Sierras Bayas Group, Argentina (Gaucher et al., 2005)	-37.851	-58.261
***Cloudina* sp.**	Uruguay	Yerbal Formation, Arroyo del Soldado Group, Uruguay (Gaucher et al., 2003)	-34	-55

Sinotubulites, also has a wide geographic distribution and has been recovered from uppermost Ediacaran strata in South China (Cai et al., 2015), Mexico (McMenamin, 1985), eastern California and Nevada (Signor et al., 1987), and Spain (Cortijo et al., 2015b), *Conotubus* Zhang and Lin, 1986 in (Lin et al., 1986) and *Gaojiashania* Yang et al., 1986 in (Lin et al., 1986) in South China. The colonial *Namacalathus* was first described from Namibia (Grotzinger et al., 2000; Zhuravlev et al., 2015) also occurring in uppermost Ediacaran strata in western Canada (Hofmann and Mountjoy, 2001), Oman (Amthor et al., 2003), Siberia (Kontorovich et al., 2008; Grazhdankin et al., 2015) and Paraguay (Warren et al., 2017) (Figure 1. 1).

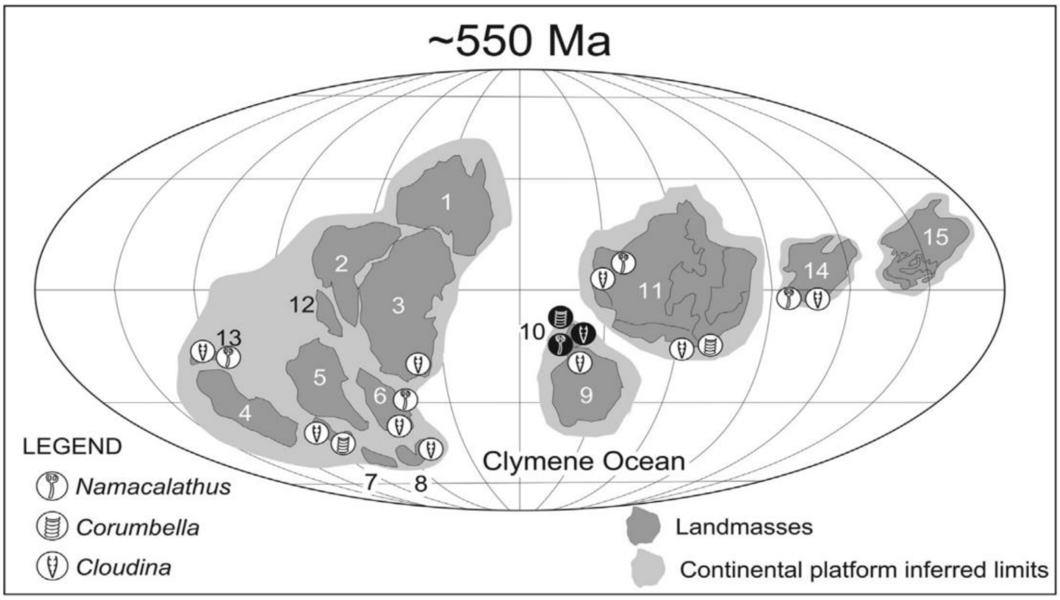


Figure 1. 1. Paleogeographic reconstruction and occurrence of *Cloudina*, *Corumbella* and *Namacalathus*. 1 – Australia, 2 – India, 3 – Antarctica, 4 – West Africa, 5 – Congo-São Francisco, 6 – Kalahari, 7 – Paraná, 8 – Rio de la Plata, 9 – Amazonia, 10 – Rio Apa, 11 – Laurentia, 12 – Madagascar, 13 – Arabia-Nubia, 14 – Siberia, 15 – Baltica (Warren et al. 2017).

Cloudina species have been considered as potential guide fossils for the Ediacaran/Cambrian boundary (Grant, 1990). The *Cloudina* genus was regarded as the oldest representative of the first aparison of the biomineralized skeleton (Brasier, 1979; Conway Morris, 1987, 1989; Conway Morris et al., 1990). Although new findings of tubular fossils such as *Ramitubus increscens* Liu et al., 2008, *Ramitubus decrescens* Liu et al., 2008, *Sinocyclocyclicus guizhouensis* Xue et al., 1992, *Quadratitubus orbigoniatus* Xue et al., 1992, and *Crassitubus costatus* Liu et al., 2008 were recovered from the Doushantuo Formation (635.2 ± 0.6 Ma and 551.1 ± 0.7 Ma) (Condon et al. 2005). These older biomineralizings skeletons are attributed to calcifying metazoan, allowing to admit that the emergence of the biomineralized skeleton is older than all *Cloudina* species described so far (Figure 1. 2).

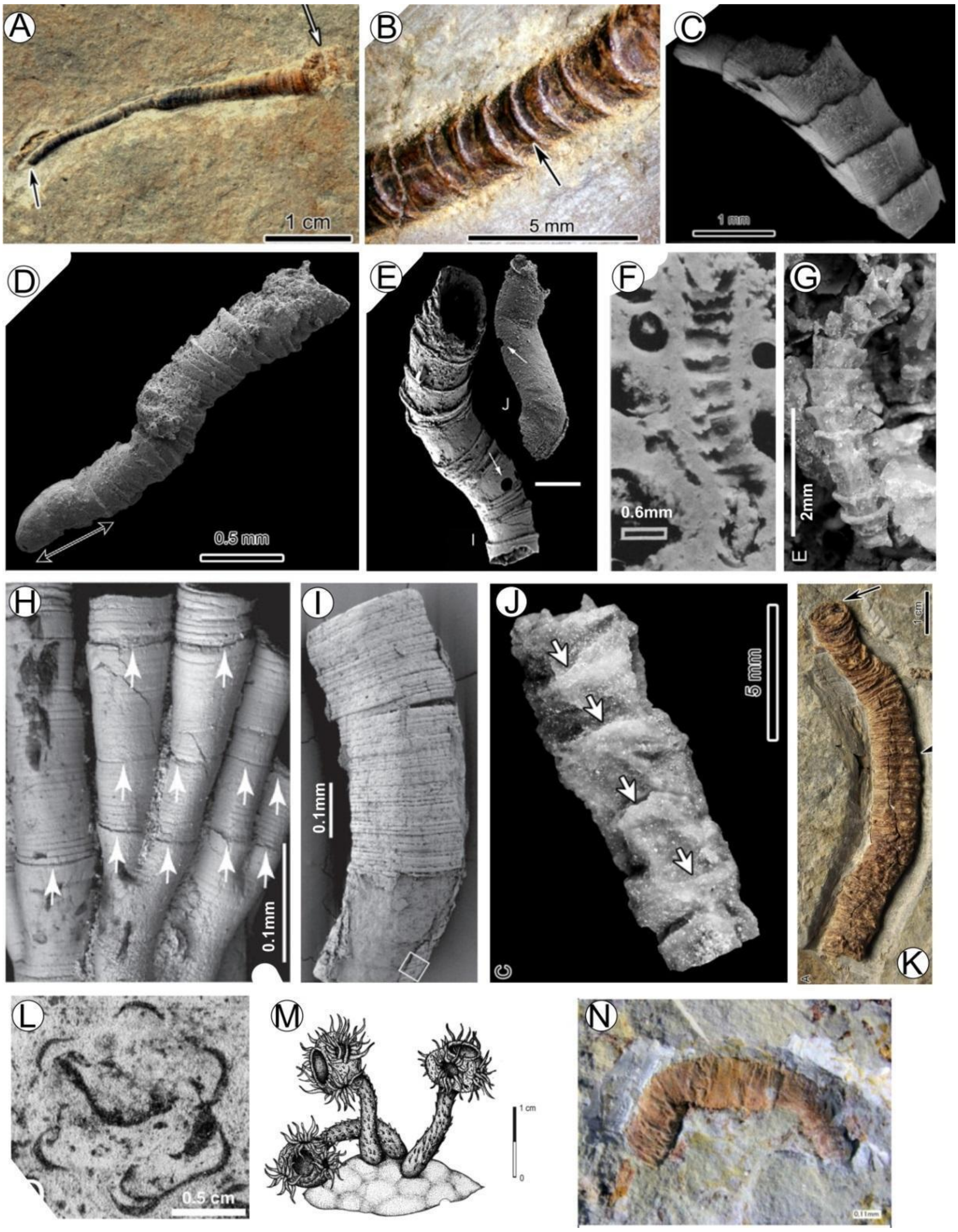


Figure 1. 2. Main species of tubular fossils of the upper and uppermost Ediacaran. A) (Cai et al., 2011, Fig. 3A) *Conotubus hemiannulatus* Zhang and Lin 1986; B) (Cai et al., 2011, Fig. 3C) Close-up view of a three-dimensionally pyritized specimen of *Conotubus hemiannulatus*; C) (Cai et al., 2017, Fig. 7A) *Cloudina xuanjiangpingensis* Cai et al., 2017; D) (Cai et al., 2017 Fig. 6A). *Cloudina ningqiangensis* Cai et al., 2017; E) Hua et al., 2003, Fig. 3A) *Cloudina lucianoi* (Beurlen & Sommer, 1957); F) (Grant, 1990, Fig. 5A) *Cloudina riemkeae* Germs, 1972; G) (Cortijo et al., 2010 Fig. 4E). *Cloudina carinata* Cortijo et al., 2010; H) (Liu et al., 2008 Plate 1 -6) *Ramitubus increscens* Liu et al., 2008; I) (Liu et al., 2008, Fig. 6C). *Quadratitubus orbigoniatus* Xue et al., 1992; J) (Cai et al., 2015 Fig 3C). *Sinotubulites baimatuoensis*. Chen, Chen and Qian, 1981; K) (Cai et al., 2013, Fig. 4A) *Gaojiashania cyclus* Yang et al., 1986 in (Lin et al., 1986); L) (Grotzinger et al., 2000, Fig. 8D) *Namacalathus hermanastes* Grotzinger et al., 2000. M) Digital reconstruction of *Namacalathus hermanastes* (Warren et al., 2017); N) (Walde et al., 2018, Fig. 12) *Corumbella werneri* Hahn et al., 1982.

The Tamengo Formation sections represent the best opportunities to study the terminal Ediacaran climate changes and biological innovations in South America (Boggiani et al., 2010) (Figure 1. 3). Corumbá Group crops out in the southern Paraguay Fold Belt in Brazil, representing one of the most complete Ediacaran sedimentary archives of palaeogeographic, climatic, biogeochemical and biotic evolution in southwestern Gondwana (Boggiani et al., 2010).

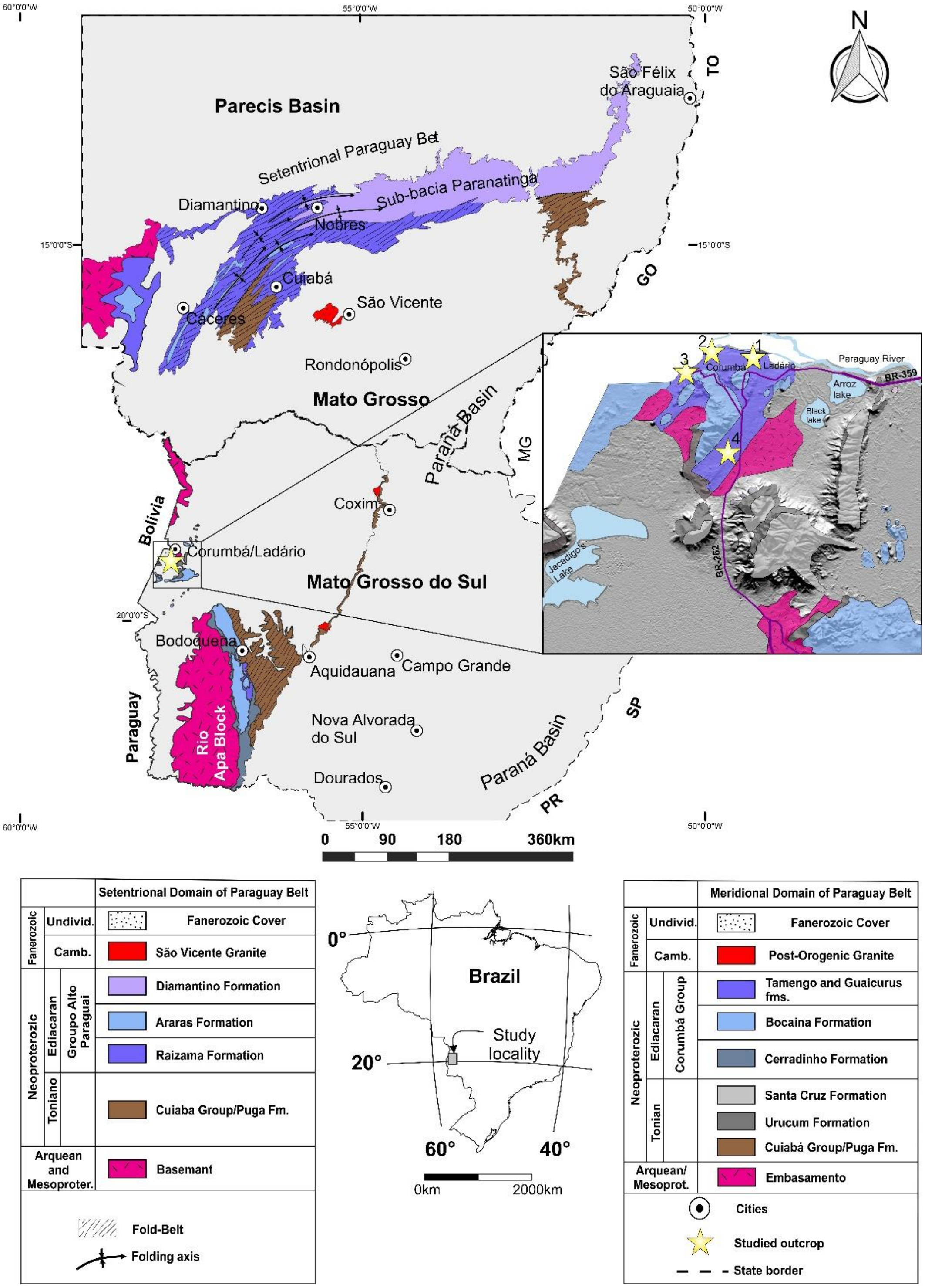


Figure 1. 3. Regional simplified geological map of the North and south Paraguay fold belt: 1) Section in the Sobramil port; 2) Section in the ecopark of Cacimba; 3) Corcal quarry; and 4) Laginha quarry section in Corumbá and Ladário, Mato Grosso do Sul State (Modified by Silva & Jost, 2006).

The first fossils of the Tamengo Formation, Corumbá Group, were discovered by Octávio Barbosa and later described by Beurlen & Sommer (1957) as *Aulophycus lucianoi* and the remains of algae were indicated to be Cambrian. Beurlen & Sommer (1957) describe and classify the tubular fossils in the limestones of the Tamengo Formation as *Aulophycus lucianoi* interpreted as algae fragments, possibly indicating Cambrian age. Fairchild (1978) noted the great similarity of *Aulophycus lucianoi* with two species of tubular fossils of the *Cloudina* genus Germs, 1972, which occur in limestones of the Nama Group, uppermost Ediacaran of Namibia. Hahn & Pflug (1985) and Zaine & Fairchild (1985) independently confirm the transfer of *Aulophycus lucianoi* to the *Cloudina* Genus.

In 1980, *Corumbella werneri*, a fossil metazoan, was descovered by Professor Detlef Walde. Two years latter, *Corumbella werneri*, was formally described by Hahn et al. 1982. This species presents centimetric dimensions, pinned shape, preserved three-dimensional and tubular geometry, with the possibility of noticing the presence of periderm probably chitinous, weakly biomineralized, possibly indicating a Cnidaria Scyphozoa.

The first mention of the occurrence of organic-walled microfossils was presented by Sommer in 1971 where the occurrence of *Bambuites* sp. in the limestones of Tamengo Formation was documented (Sommer, 1971b). Fairchild & Sundaram (1981) also documented organic-walled microfossils in Tamengo Formation, with occurrences subsequently confirmed by Zaine & Fairchild (1987). The first systematic paleontological framework was presented in Zaine (1991), which recorded occurrences of acritarchs, filamentous microfossils in the Tamengo Formation. Zaine (1991) also identified the Genus *Vandalosphaeridium* and, subsequently, macroscopic algae *Tyrasotenia* sp. (redescribed by Steiner, 1994 as *Vendotaenia* sp.) and the microfossil *Sphaerocongregus variabilis*, currently synonymous of *Bavlinella faveolata*. Possible ichnofossils, new stromatolites, oncolytes and probably cyanobacteria were described by Fairchild et al. (2000). Marine macroalgae *Eoholynia corumbensis* and *Tawuia* sp. were identified at the base of the Guaicurus Formation (Gaucher, 2000; Gaucher et al., 2003), while the agglutinate foraminifera *Titanoteca coimbrae* occurs in the phosphorites of the Bocaina Formation in the Serra da Bodoquena locality (Gaucher et al., 2003).

Updates on the trace fossils of the Corumbá Group were recently presented by Parry et al. (2017) and the stratigraphic distribution of ichnofossils *Multina minima* Uchman, 2001 and *Didymaulichnus lyelli* Rouault 1850 at the top of the Tamengo Formation and the base of the Guaicurus Formation were also presented. It should be noted that *M. minima* was described from the Hecho Group, Early to Mid Eocene of Spain, and *Didymaulichnus lyelli* was restricted to the Ordovician, been described from the Bell Island and Wabana groups in the locality of Newfoundland, Canada (Fillion, D. & Pickerill, 1990). Another important contribution of this work is the dating of zircon grains from volcanic ash at the base and top of the Tamengo Formation, allowing to date the beginning and the end of its deposition (Parry et al., 2017) (Figure 1. 4).

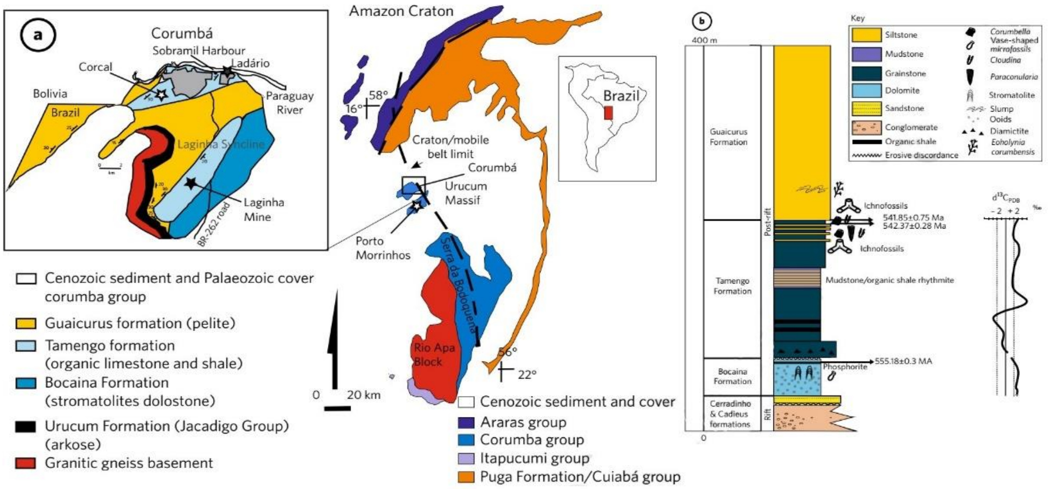


Figure 1. 4. Map of localities and stratigraphic column of the Neoproterozoic Corumbá Group: a) map of localities and b) stratigraphic column. The dates are from the work of Parry et al. (2017). White star indicates localities with samples collected for geochronology. Black stars locality with ichnofossil: Laginha quarry (Guaicurus Formation) 19 ° 07 '09.8' 'S, 057 ° 38' 40.4 " W. Ladário (Tamengo Formation) 19 ° 0 '04.0' 'S, 57 ° 36' 00.7 " W. The carbon isotope curve was obtained from Laginha quarry (Modified from Parry et al., 2017).

1.1. SPECIFIC OBJECTIVES

The main scientific question addressed in the present thesis is to describe occurrences of species in the studied area and to analyze their paleoecologic, stratigrafic distribution in order to understand their significance to paleoenvironmental evolution and potencial for application on biostratigraphy for latest Ediacaran and earliest Cambrian. The specific objetives are:

- ✓ to present a taxonomic study for the analyzed upper Corumbá Group fossil assemblage;
- ✓ to analyze the stratigraphic distribution of the studied species;
- ✓ to develop paleoecological and paleoenvironmental inferences for the uppermost Ediacaran/lowermost Cambrian, Tamengo and Guaicurus formations, Corumbá Group;
- ✓ to propose a chronobiostatigraphic essay for the fossil assemblage of the Tamengo and Guaicurus formations;
- ✓ to present lithostratigraphic description for five studied sections in Porto Sobramil, Laginha and Corcal quarries, Porto Figueiras and Ecoparque Cacimba sections;
- ✓ to integrate and compare the studied fossil assemblage with those published for other uppermost Ediacaran sections in Paraguay, Uruguay, Argentina, Namibia, China, Russia, Canada, United States and Oman;
- ✓ to propose an international biostratigraphic essay for the uppermost Ediacaran/lowermost Cambrian interval.

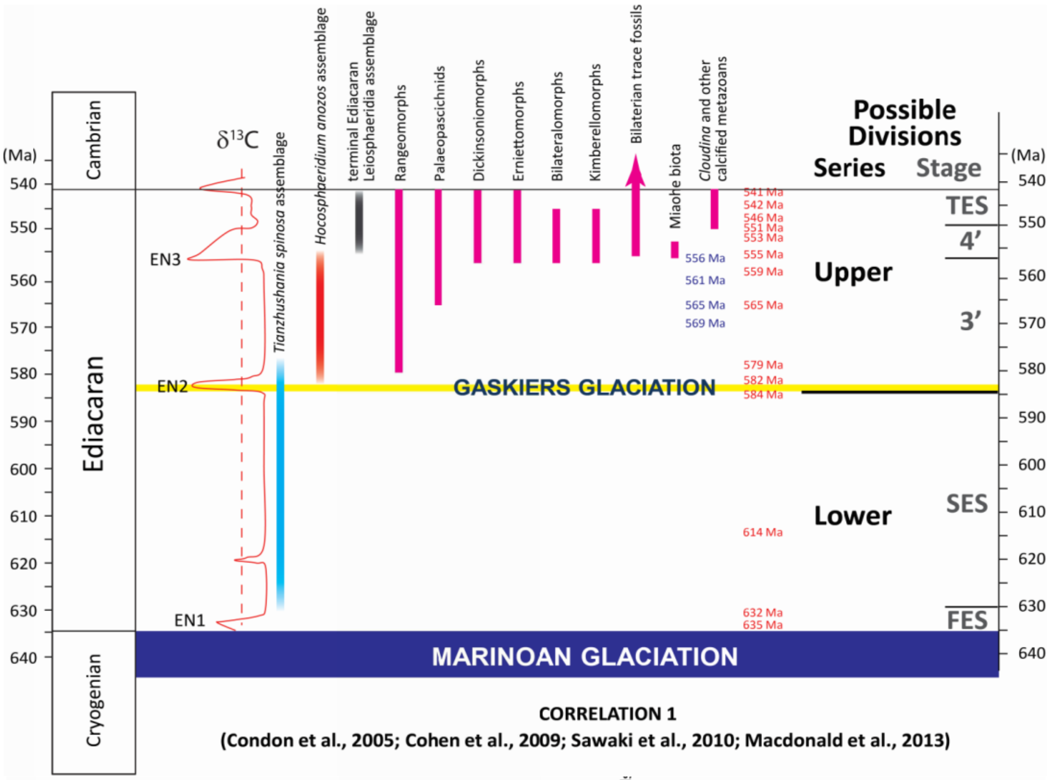
1.1. EDIACARAN PERIOD AND LIFE RECORD

The Ediacaran Period spans between 635 and 541 ± 1 million years (International Stratigraphic Chart v2018/8). The base of the Ediacaran System is defined as the base of the Marinoan cap carbonate Nuccaleena Formation in the Enorama Creek section of the central Flinders Ranges, Adelaide Rift Complex, South Australia (Knoll et al., 2006). The top of Ediacaran (and base of the Cambrian) is intended to coincide with the first appearance of the trace fossil *Treptichnus pedum* in southeast Newfoundland (Landing, 1994; Gehling et al., 2001; Darroch et al., 2018).

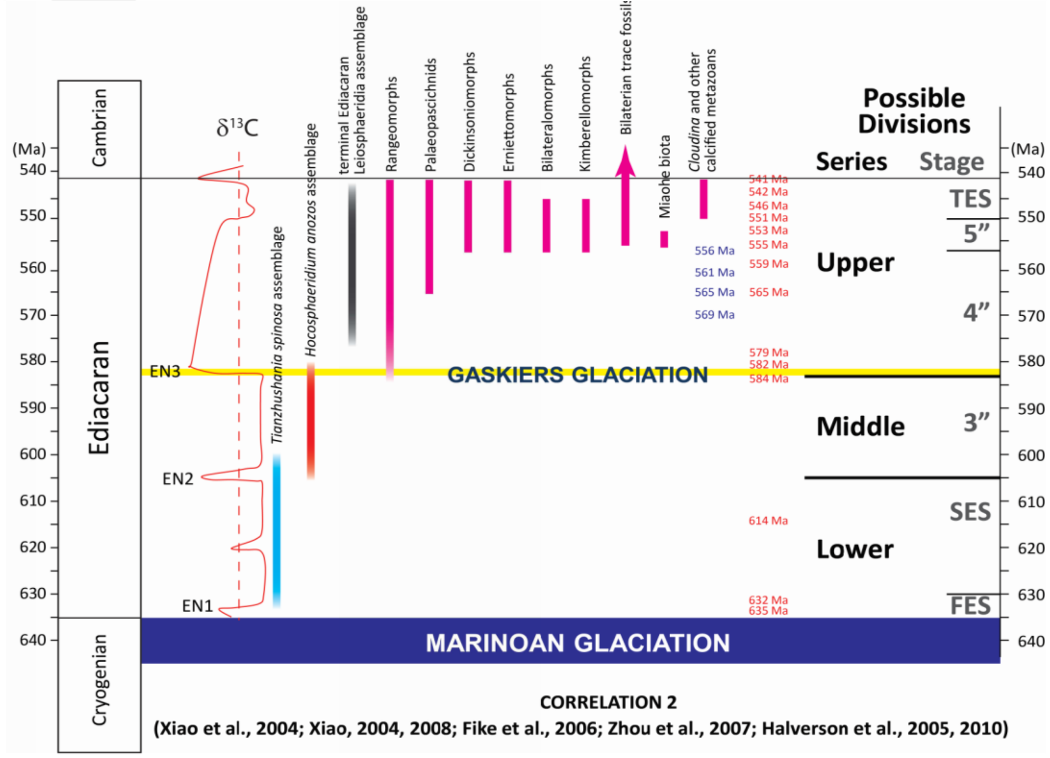
Since the formalization of this period (Knoll et al., 2004), internal subdivision and correlation of Ediacaran strata based on biostratigraphy when fossil is present and additional techniques using climatic and chemostratigrpahic events (e.g., Gaskiers glaciation and Shuram $\delta^{13}C$ excursion) as tools to correlate Ediacaran strata (Xiao et al.,

2016) have been proposed. Several problems regarding taphonomic limitation in Ediacaran restrain the usage of the first appearance datum (FAD) to define and correlate stratigraphic boundaries. Therefore, the uses of FAD for correlation and comparison for Ediacaran strata must be carefully examined and tested (Xiao et al., 2016). Recognizing the fossiliferous challenges for correlation of Ediacaran strata, Narbonne et al. (2012) presented alternative tools to divide the Ediacaran System into two or three series, although the initial survey of the Subcommission on Neoproterozoic Stratigraphy in 2009 recommended a two-series approach (Figure 1. 5) (see Xiao et al., 2016).

Together, the biostratigraphic, chemo-stratigraphic, lithostratigraphic, and geochronological data would enable the proposal of global correlation throughlinkages with climatic, geochemical, and evolutionary events. This integrative approach offers high potential to define the Ediacaran Stages (ES) as extensively discussed in Xiao et al. (2016). Several macrofossils from uppermost Ediacaran strata stand out for their potential as biostratigraphic markers, which include biomineralizing animals *Cloudina*, *Conotubus*, *Sinotubulites*, *Corumbella* and *Namacalathus*.



CORRELATION 1
(Condon et al., 2005; Cohen et al., 2009; Sawaki et al., 2010; Macdonald et al., 2013)



CORRELATION 2
(Xiao et al., 2004; Xiao, 2004, 2008; Fike et al., 2006; Zhou et al., 2007; Halverson et al., 2005, 2010)

Figure 1. 5. Two models for Ediacaran subdivision and correlation. The key difference between these two models relates to how the Shuram excursion is correlated with the Gaskiers glaciation. FES: first Ediacaran stage; SES: second Ediacaran stage; TES: terminal Ediacaran stage (extracted from Xiao et al., 2016).

The Ediacara biota (600–541Ma) marks the first appearance of large, architecturally complex organisms in Earth history (Narbone, 2005). A detailed discussion and analyses of Ediacara biota cluster of the diverse fossils and localities that constitute the

Ediacara biota worldwide are presented in Waggoner (2003) and Narbone (2005). These analyses have shown that most or all occurrences of Ediacara-type fossils can be grouped into three main clusters or assemblages:

1) The **Avalon Assemblage** (Figure 1. 6) is the oldest (ca. 575– 560 Ma; Benus, 1988; Bowring et al., 2003) and occurs only in very deepwater, volcaniclastic settings of the Avalon Zone of Newfoundland (Misra, 1969; Anderson & Conway-Morris, 1982; Clapham et al., 2003; Narbone, 2005) and England (Ford 1958, Boynton & Ford 1995). None of the taxa were skeletonized or capable of mobility (Narbone 2005).

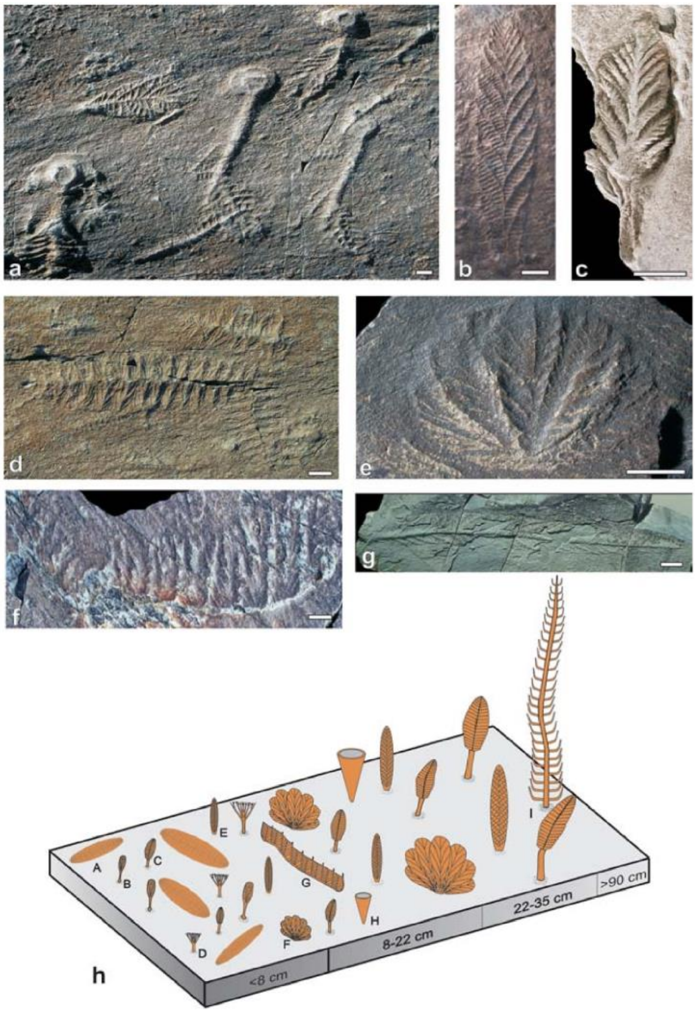


Figure 1. 6. Avalon Assemblage on upper bedding surfaces from Newfoundland (a, c–h) and Charnwood, England (b). Scale bar represents 2 cm (a, b; d–g) or 0.25 cm (c). (a) Current-aligned fronds of *Charniodiscus*, spindle-shaped rangeomorphs (lower and center), and a frond-shaped rangeomorph (upper left), Mistaken Point Formation. (b) Holotype of the probable rangeomorph frond *Charnia masoni*, New Walk Museum, Leicester (extracted from Narbone, 2005).

2) The **White Sea Assemblage** (Figure 1. 7) is known from the Vendian sections in the White Sea in Russia (Fedonkin, 1981, 1992; Sokolov & Iwanowski, 1990) and the

Ediacara Member in Australia (Glaessner & Wade, 1966, Jenkins, 1992). The oldest occurrences are older than 560 Ma and the youngest may be close to the base of Cambrian (Martin et al., 2000, Grazhdankin, 2004). Abundant worm burrows can be attributed to the presence of mobile bilaterians in the fauna, but none of the taxa were skeletonized. Lower diversity assemblages from mainly offshore and slope deposits in Finnmark (northern Norway), northwestern Canada, the Urals, and Khatyspyt in Siberia are plotted as a subassemblage in Waggoner's analysis (Narbone, 2005);

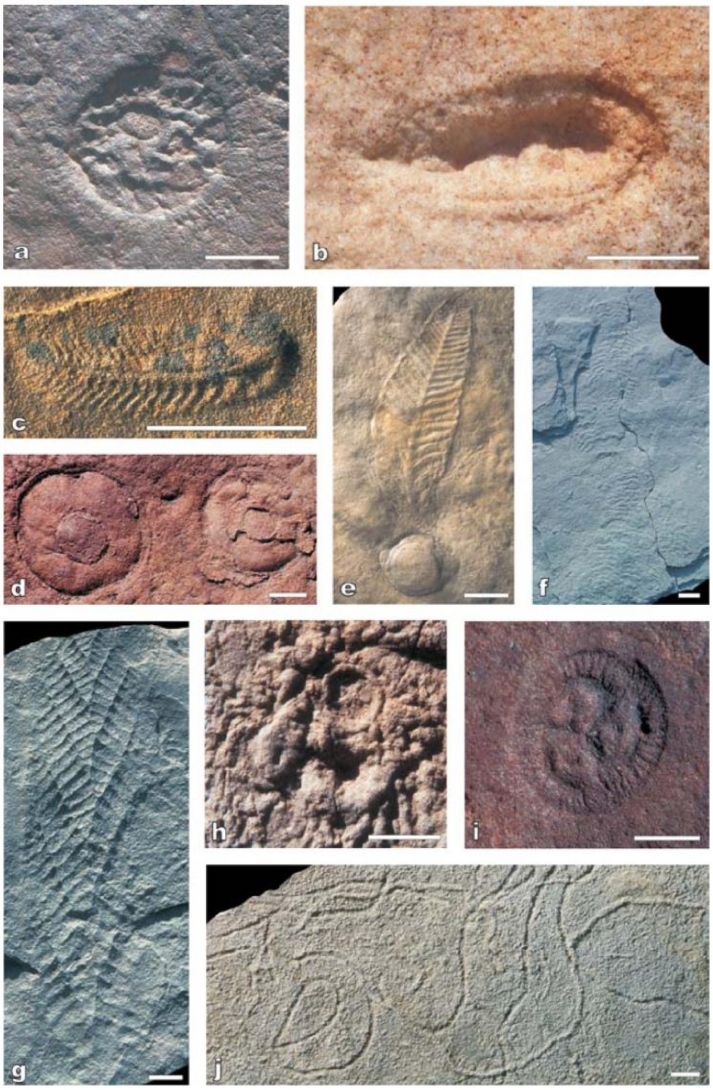


Figure 1. 7. White Sea assemblage preserved on bed soles from Australia (a–e, h–i), northern Russia (f – g), and northwestern Canada (j). Scale bar represents 1 cm (a–c), 2 cm (d, f–j), or 5 cm (e) (extracted from Narbone 2005).

3) The **Nama Assemblage** (Figure 1. 8) is best known from the Kuibis and Schwarzrand subgroups of the Nama Group in Namibia (Gürich, 1933; Germs, 1972; Narbonne et al., 1997; Grotzinger et al., 2000; Grazhdankin & Seilacher, 2002). This type of assemblage is

of shallow-water origin and has been dated as older than 549–542 Ma (Grotzinger et al., 1995), although similar assemblages occur in both older and deeper-water strata elsewhere. The assemblage consists mainly of multifoliate fronds, bilaterian burrows, and early calcifying metazoans (Narbone, 2005).

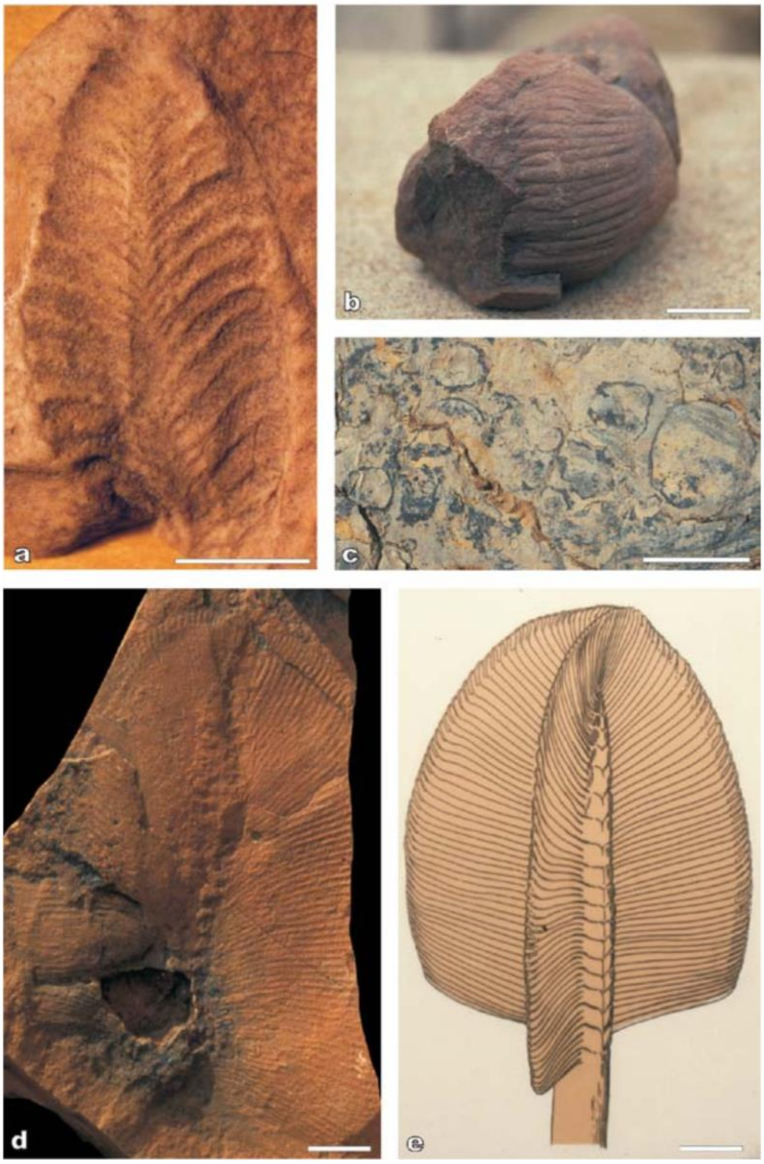


Figure 1. 8. Nama Assemblage fossils from Nambia. Scale bar represents 2 cm. (a) Mold of the holotype of *Rangea*, a rangeomorph frond. (b) *Ernietta* preserved as a natural cast. (c) *Namacalathus*, a weakly calcifying Ediacaran metazoan. (d, e) *Swartpuntia* holotype and reconstruction (extracted from Narbone, 2005).

Regarding biological changes in Ediacaran Period, until 2007, the oldest accepted multicellular fossils were represented by the macrofauna of the Drook Formation Newfoundland, which appeared about 60Ma after the Marinoan glaciation (635Ma) (Hoffman, 2009). However, metazoan embryos were described in the Doushantuo

Formation in South China, c.a 3Ma after the Nantuo glaciation, equivalent to Marinoan glaciation in Southern China (Chen et al., 2009; Hu et al., 2012). This occurrence in Doushantou Formation increased the age of the first well which accepted multicellular metazoa from 580Ma to about 630Ma. Moreover, diagnostic sponge biomarkers, 24-*isopropyl-cholestane*, occur in strata considered to be coeval in the Masirah Bay Formation, representative of post-glacial Marinoan siliciclastic sedimentation in Oman, also constituting evidence of presence of multicellular animals in strata related to post-Marinoan glaciation (Hoffman, 2009; Allen & Leather, 2006) (Figure 1. 9).

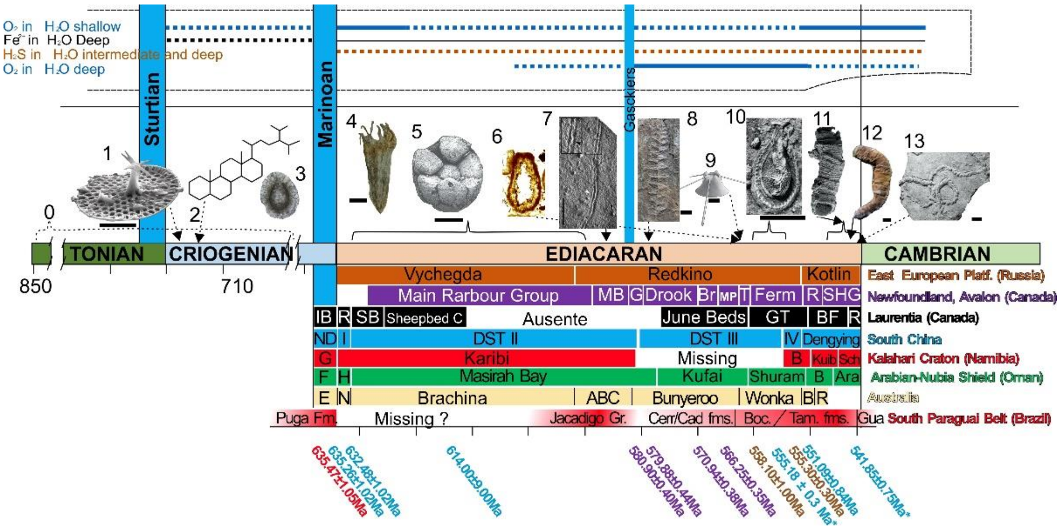


Figure 1. 9. Summary of major changes in ocean chemistry and biotic events through the Neoproterozoic. Major milestones of evolutionary events: 0, Origin of metazoa from molecular clock 850–650 Ma (Dos Reis et al., 2015), 1, 812–717 Ma, Phosphate biomineralization in microfossils, 15 Mile Group, Yukon, Canada (Figure 1a SEM of *Characodictyon*, scale bar (SB)= 2 µm; Cohen et al., 2011); 2, 713 Ma, maximum age of the demospongiae biomarkers (24-isopropylcholestane), Huqf Supergroup, Omã; 3, vase-shaped microfossils (VSM) *Cycliocyrillium simplex*, Urucum Formation, Brazil, ~740Ma (Morais et al., 2017; 2019); 4, 635–590 Ma, possible Cnidarian stem-group *Lantianella laevis*, preserved in black shale of the Lantian Member II SB = 3 mm (Yuan et al., 2011); 5, Phosphatized embryos Doushantuo members II and III Weng'na section, SB = 200 µm (Xiao et al., 1998); 6, VSM from Bocaina Formation (Moraes, 2013, 2017); 7, Older evidence trace fossil caused by the mobility of Bilateria, Tacuarí Formation, Uruguay, SB=2.5 mm (>585 ± 3.3 Ma) (Pecoits et al., 2012); 8, Mistaken Point biota, *Fractofusus misrai*, Drook Formation (>578.8 ± 1 Ma), =20 mm (Liu et al., 2015); 9, sponge spicules and "Multi-elements" metazoan, *Coronacollina acula*, Ediacara member, Austrália SB =~5 mm (equivalent to the White Sea assemblage, (~560–550 Ma) (Clites et al., 2012); 10, ~558–555 Ma, Motile bilateralian *Kimberella quadrata*, SB=10 mm (Fedonkin et al., 2007; Martin et al., 2000); 11, ~550 Ma, Biomineralizing metazoan reef bielders, *Cloudina* (Penny et al., 2014), SB=200 µm (Bengtson & Zhao, 1992); 12, metazoan *Corumbella werneri* assembled with *Cloudina lucianoi* from Tamengo Formation, Brazil (* indicates ash bad dated from base and top of the Tamengo Formation (Parry et al., 2017). 13, *Treptichnus pedum* which marks the Ediacaran/Cambrian boundary in the Global Boundary Stratotype Section and Point GSSP in Fortunehead, Newfoundland (Wilson et al., 2012), figure modified from Bowyer et al. (2016).

1.2. UPPERMOST EDIACARAN STRATA IN SOUTH AMERICA

South America has an important geological record of Neoproterozoic sedimentary rocks. The main sections of upper and uppermost Ediacaran in South America are present in four countries: Brazil (Corumbá Group, Bambuí Group, Pajucá Formation and Camarinha Formation), Uruguay (Arroyo del Soldado Group), Paraguay (Itapucumi Group); Argentina (Grupo Sierras Bayas) (Figure 1. 10).

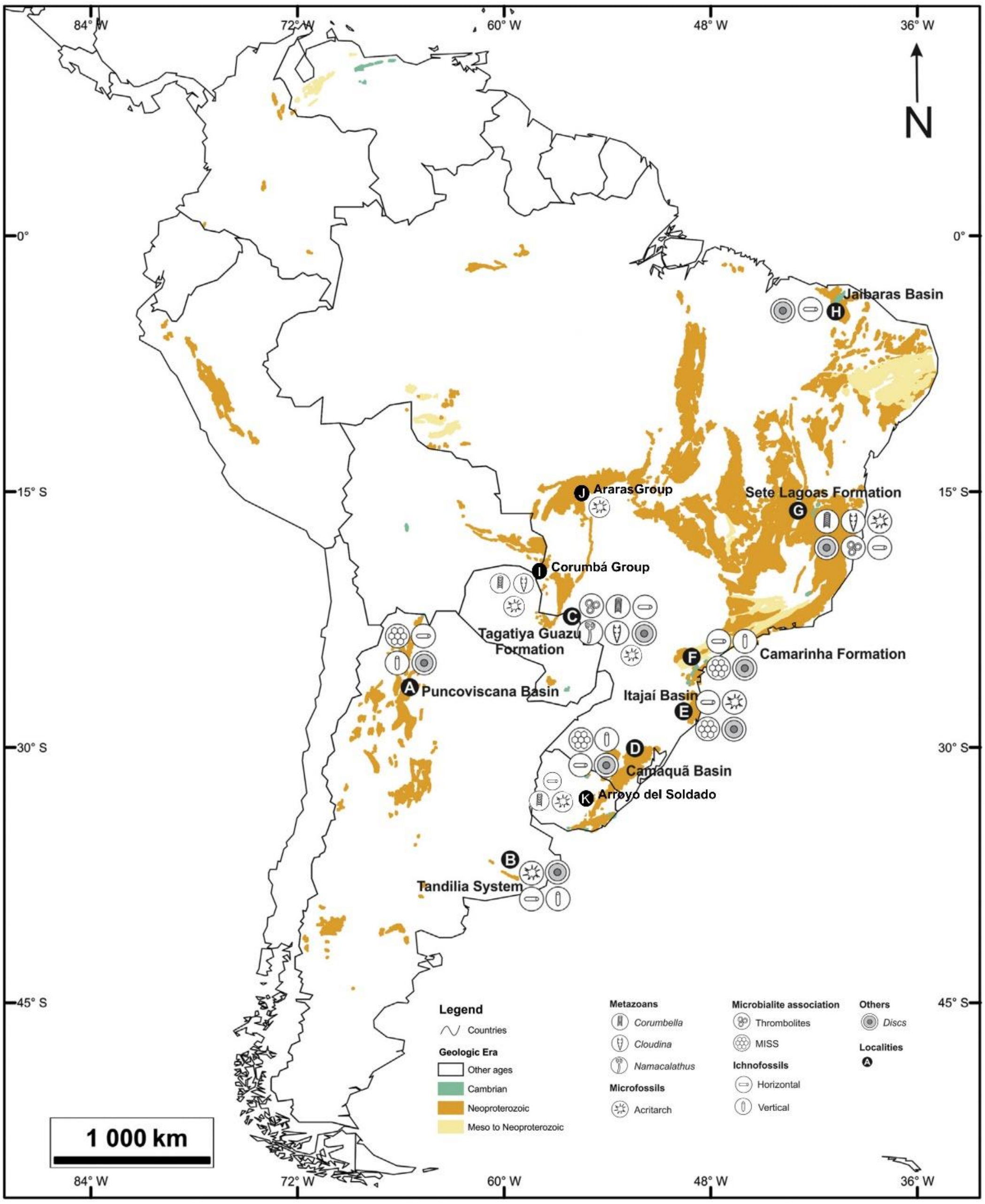


Figure 1. 10. Map of Proterozoic to Cambrian geologic units of South America highlighting the occurrence of discoidal structures, metazoans, microfossils and other main paleontological components. A – Puncoviscana Basin (AR); B – Tandilla System, La Providencia Group (AR); C – Itapucumi Group (PY); D – Camaquã Basin, Santa Barbara and Bom Jardim groups (BR); E–Itajaí Basin (BR); F – Camarinha Basin (BR), G – Bambuí Group (BR); H – Jaibaras Basin (BR); I – Corumbá Group (BR); J – Araras Group (BR); K – Arroyo del Soldado Group (UY) (modified from Inglez et al., 2019).

1.2.1. CORUMBÁ GROUP, BRAZIL

In South America, the lithostratigraphic interval that best represents the paleoclimatic, biochemical and biological evolution of the Ediacaran period is the Corumbá Group in the State of Mato Grosso do Sul, Midwestern Brazil (Boggiani et al., 2010; Adôrno, et al., 2017). The Corumbá Group rests on the glacial-marine sedimentary rocks of the Puga Formation, consisting of five formations: Cadiueus, Cerradinho, Bocaina, Tamengo and Guaicurus. The Cadiueus Formation is represented by conglomerates and arches deposited in proximal environments. The Cerradinho Formation is composed of a siliciclasic succession that gradually passes to the carbonates of the Bocaina Formation. The Bocaina Formation consists of a thick package of stromatolytic dolomites with lateral variations of facies, including occurrences of phosphorites with more than 34% of P_2O_5 (Boggiani et al., 1993; Boggiani, 1998). The Tamengo Formation lies above the Bocaina Formation, represented by black limestones, rich in organic matter where it occurs *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Corumbella werneri* Hahn et al., 1982 and *Paraconularia* sp. (Van Iten et al., 2014, 2016). Capping all carbonate and siliciclastic sequence of the Tamengo Formation lies the siltstones and shales of the Guaicurus Formation, marking the end of the deposition of the Corumbá Group (Gaucher et al., 2003; Boggiani et al., 2010) (Figure 1. 11).

In terms of paleoenvironmental conditions, the Tamengo Formation was deposited in a favorable environment for deposition of carbonates, which was episodically interrupted by immature siliciclastic supply from very finegrained rocks of a nearby source area. The Guaicurus Formation, on the other hand, is a result of an uninterrupted immature siliciclastic supply from a nearby source area, composed of very fine-grained rocks. Chemical variations, however, are observed especially in Na_2O content, higher in siltstones from the Guaicurus Formation, implying changes in the source area or in the chemistry of the water. The sediments of the Guaicurus Formation were deposited under a low energy setting in a high water level, below fair-weather wave (Fazio et al., 2019).

Several works have been produced on the palaeontology of the Corumbá Group (Beurlen & Sommer, 1957; Fairchild, 1978; Hahn et al., 1982; Walde et al., 1982; Zaine & Fairchild, 1985; Zaine 1991; Hidalgo, 2002; Gaucher et al., 2003; Becker-Kerber et al., 2013; Tobias, 2014; Pacheco, 2012; Leme et al., 2008; Pacheco et al., 2011; Walde et al., 2015; Adôrno et al., 2017; Van Iten et al., 2014, 2016; Parry et al., 2017), also on the stratigraphy and tectono-structural evolution (Barbosa, 1949; Almeida, 1964, 1965, 1984; Alvarenga & Trompette, 1992; Boggiani & Alvarenga, 2004; Gaucher et al., 2003; Babinski et al., 2008; Boggiani et al., 2010; Meira, 2011; Spangenberg et al., 2014; D'el-Rey et al., 2016; Sial et al., 2016); and finally on the sedimentological context (Boggiani et al., 1993; Boggiani, 1998; Oliveira, 2010; Campanha et al.,, 2011; Fontanela, 2012; Fazio et al., 2019).

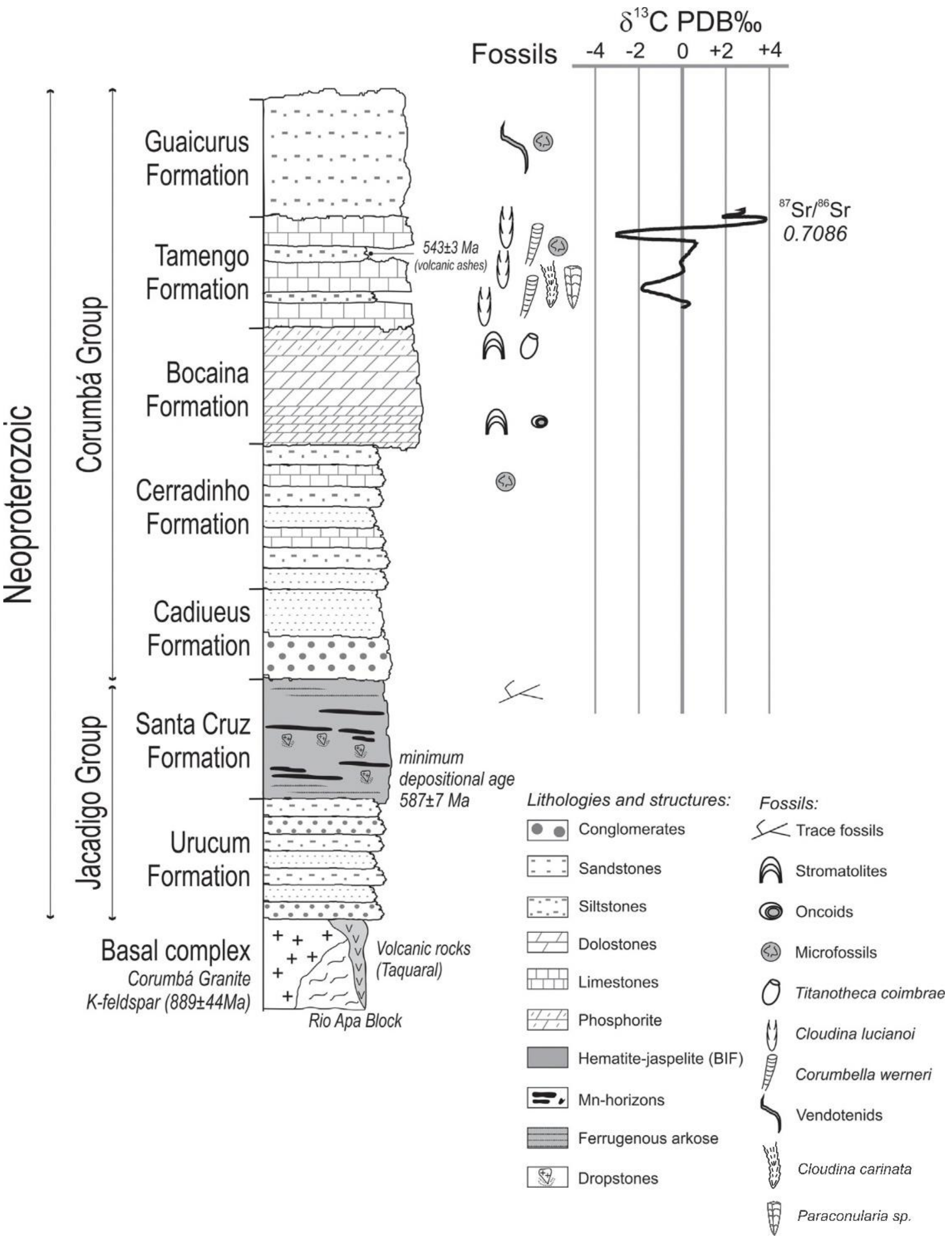


Figure 1. 11. Stratigraphic scheme of Jacadigo and Corumbá groups with fossil record and the 13C isotopic curve. Note the strong negative incursion (After Walde et al., 2015).

1.2.2. ARROYO DEL SOLDADO GROUP, URUGUAY

The Arroyo del Soldado Group was defined by Gaucher et al. (1996) being constituted by 5,000 meters of thickness of platform marine sediments occurring in the field Nico Pérez, Uruguay. The Arroyo del Soldado Group consists of four formations from the base to the top: Yerbal Formation, Polanco Formation, Barriga Negra Formation and Cerro Espuelitas Formation. Yerbal Formation, composed of conglomerates and arkoses at the base, passing to green siltstones and laminated siltstones at the top, representing a siliciclastic sequence of ascending *deepening-upward* (Gaucher et al., 1998; Gaucher & Sprechmann, 1999; Gaucher, 2000; Gaucher et al., 2003). The Yerbal Formation is succeeded by the Polanco Formation, composed of calcitic and dolomitic rhythmites of blue to black coloration, with frequent tempestites and rare oolitic calcarenites, marking the beginning of sedimentation in a carbonaceous ramp.

The west region of the basin corresponds to the shallower portions, in these localities, the carbonates of the Polanco Formation are capped by conglomerates and arkoses of the Barriga Negra Formation. The Black Belly Formation gradually passes to shales and siltstones of the basal portion of the Cerro Espuelitas Formation (Gaucher et al., 2003). To the east is located the deeper portion of the basin, in this locality, the Polanco Formation gives rise directly to the sediments of the Cerro Espuelitas Formation (Gaucher & Sprechmann, 1999; Gaucher et al., 2000).

Gaucher et al. (2003) presents a first attempt to correlate the Corumbá and Arroyo del Soldado groups, presenting the stratigraphic distribution of organic-walled microfossils, biomineralized fossils and ichnofossils that were described in these two groups. There is still a significant difference between the density of paleontological information of the sections from Brazil and Uruguay, the section of the Corumbá Group has fewer and less precise data with regard to stratigraphic distributions of the fossil occurrences (Figure 1. 12).

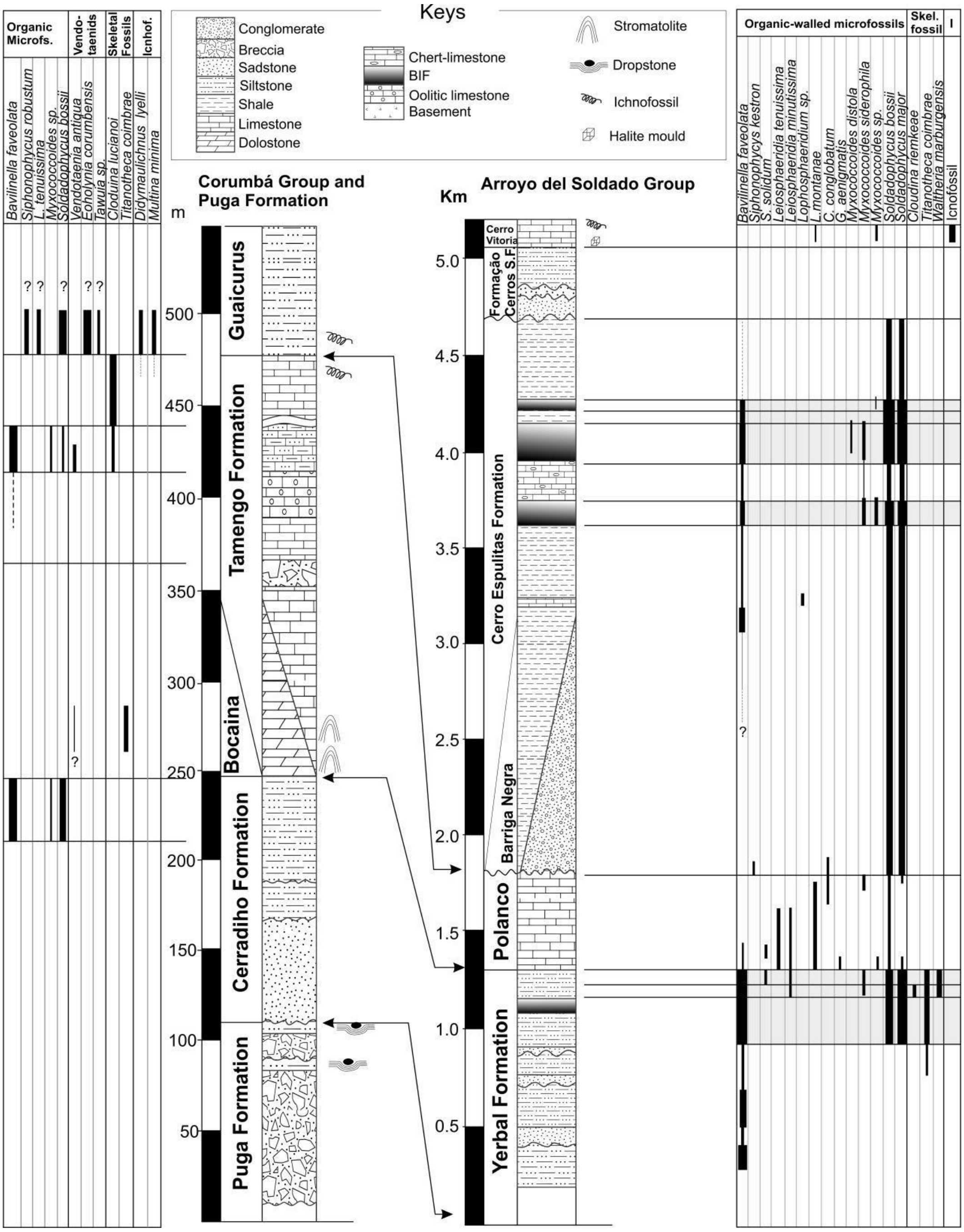


Figure 1. 12. Composite stratigraphic columns for the Corumbá and Arroyo del Soldado groups, showing a correlation between the lithostratigraphic units and the stratigraphic distribution of the taxa of palynomorphs, calcifying metazoan and ichnofossil (modified from Boggiani, 1998; Gaucher, 2000; Gaucher et al., 2003, with the paleontological updates of Parry et al., 2017).

1.2.3. SIERRAS BAYAS GROUP AND CERRO NEGRO FORMATION, ARGENTINA

In the Chillar-Olavarría area, the Sierras Bayas Group and the Cerro Negro Formation represent a sequence of sedimentary rocks composed of lithostratigraphic units limited by erosive discordances at the base and at the top (Poiré, 1987, 1993; Iñiguez et al., 1989; Cingolani & Dalla Salda, 2000; Zalba & Andreis, 2003; Gaucher et al., 2005b).

The Sierras Bayas Group consists of three formations, from the base to the top: Villa Mónica Formation, Cerro Largo Formation, and finally, the Loma Negra Formation. Villa Mónica Formation is constituted of sandstone at the base and stromatolitic limestones at the top. The Villa Mónica Formation has thin-walled sphaeromorph acritarchs microfossils described by Gaucher et al. (2005b); Cerro Largo Formation constitutes diamictites and pelites in the base passing to the sandstone in the intermediate portion and by pelite at the top. The microfossiliferous record of Cerro Largo Formation consists of sphaeromorphic acritarchs described by Pothe de Baldis et al. (1983) and updated by Gaucher et al. (2005b); finally, the Loma Negra Formation closes the depositional cycle of the Sierras Bayas Group, being constituted by organic matter rich limestone and levels of concentration of sedimentary phosphate where possible *Cloudina lucianoi* also occurs, previous classified as *Cloudina riemkeae* by Gaucher et al. (2005b). The Sierras Bayas Group is capped by pelite, marls and layers with heterolytic stratification. The Cerro Negro Formation has acritarch microfossils described by Cingolani et al. (1991). The stratigraphic distribution of the fossils present in the Sierras Bayas Group is presented by Gaucher et al. (2005b) (Figure 1. 13).

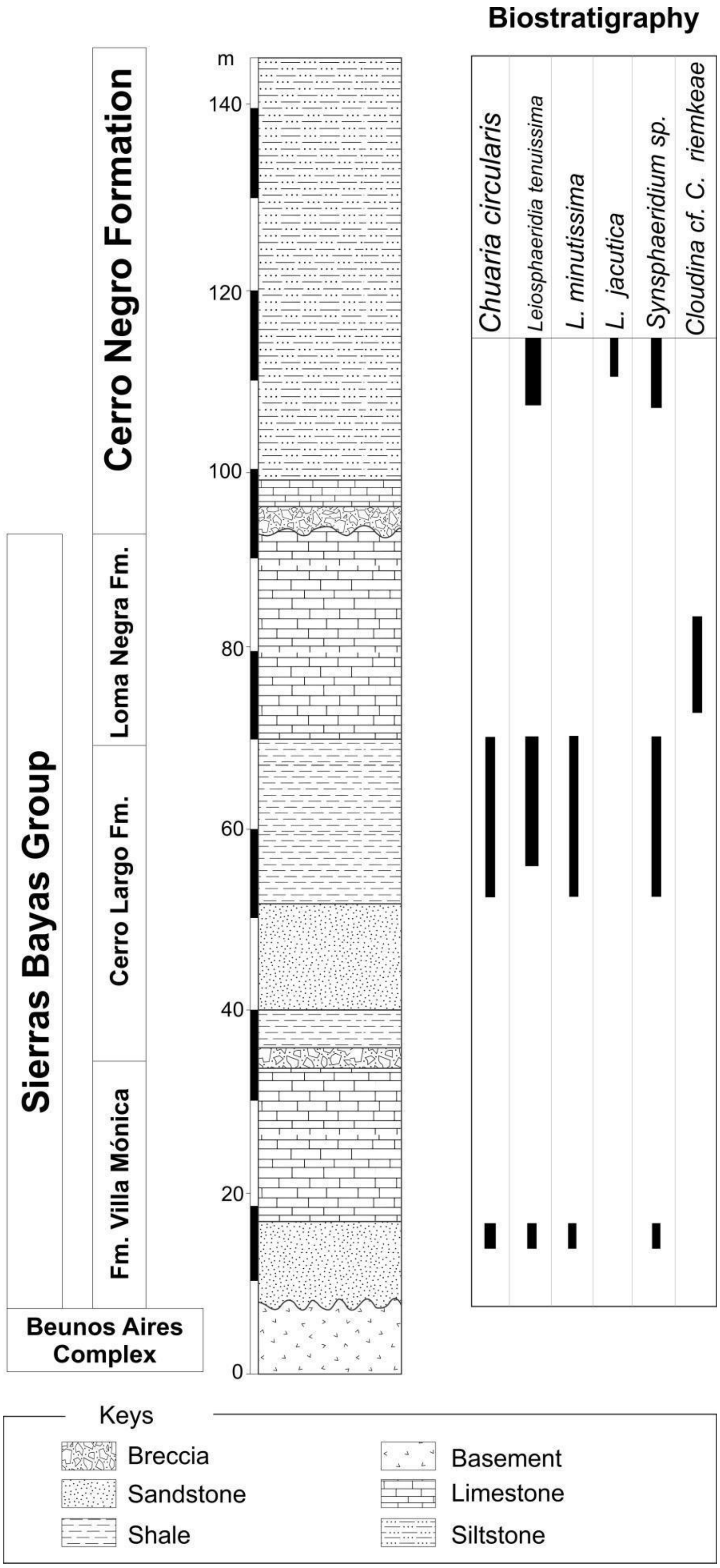


Figure 1. 13. Stratigraphic column for the Sierras Bayas Group and Cerro Negro Formation, Uruguay, presenting the stratigraphic distribution of the fossils and microfossils (Modified from Gaucher et al., 2005b).

1.2.4. ITAPUCUMI GOUP, PARAGUAY

The Itapucumi Group, northern Paraguay, has recently received considerable attention due to the occurrence of its remarkable uppermost Ediacaran skeletal fossil assemblage in carbonates of the Tagatiya Guazu Formation (Warren et al., 2011; 2012; 2013; 2019). The Itapucumi Group crops out in the Rio Apa Block, parallel to the course of the Paraguay River. This group consists of three formations from the base to the top: Vallemi Formation, consisting of sandstones and siltstones that gradually pass to limestones and dolomites of the Camba Jhopo Formation, culminating in pelites and dolomites of the Cerro Curuzu Formation. The Tagatiya Guazu Formation is considered the cratonic lateral equivalent of the Camba Jhopo Formation, which is in the Vallemi fold belt (Warren, et al., 2011; 2012; 2019) (Figure 1. 14).

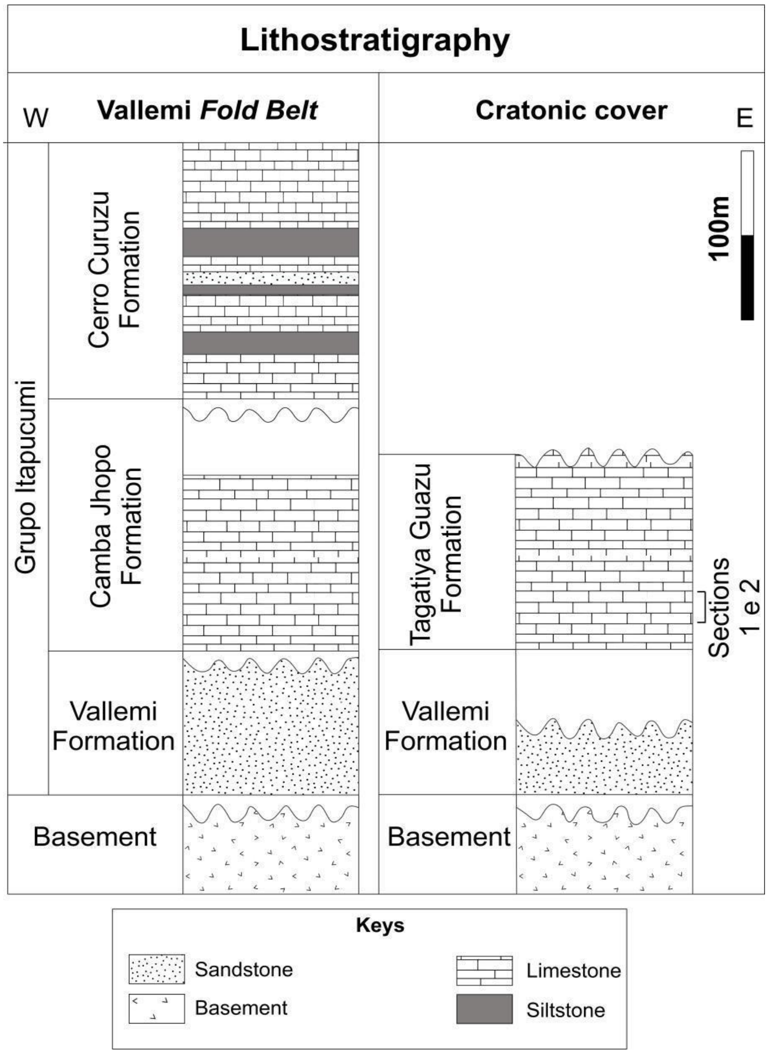


Figure 1. 14. Lithostratigraphic sections of the Itapucumi Group, Ediacarano, Northeast of Paraguay (modified from Warrem et al., 2011).

The Itapucumi Group has special relevance because it contains fossil assemblages shared with those of the Corumbá Group, making studies of biostratigraphic correlation between the sections of Brazil and Paraguay possible. The stratigraphic distribution of *Cloudina lucianoi* and *Corumbella werneri* in the Itapucumi Group presented by Warren et al. (2011; 2019) was used to extend the biozones proposed from the Tamengo Formation to the sections of Paraguay (Adôrno et al., 2017). For more detail, see the chapter on biostratigraphy.

1.2.5. SETE LAGOAS FORMATION, BAMBUÍ GROUP

The Bambuí Group is a north-south trending basin that covers hundreds of thousands of square kilometers in the states of Minas Gerais, Bahia, Goiás and Tocantins in east-central Brazil. The lithostratigraphic column most diffused in the literature was proposed by Dardenne (1978), in which the Bambuí Group is divided from the bottom up into the five formations, overlying rocks of the Macaúbas Group and Jequitaí Formation and the Carrancas conglomerate, units supposedly deposited during Sturtian glaciation. The Bambuí Group is 700–1000 m thick (Misi et al., 2007) and comprises: 1) Sete Lagoas Formation, composed of dolomites, limestone and pellets with well preserved stromatolites; 2) Serra de Santa Helena Formation, formed by shales, siltstones and secondarily sandstones; 3) Lagoa do Jacaré Formation by siltstones, marl and black limestones; 4) Serra da Saudade Formation, which includes green shales, pelites, siltstones and limestone lenses; 5) Três Marias Formation, which occupies the top of succession comprising siltstones and arcuate deposited in environments alluvial to shallow marine (Figure 1. 15). These five units make up two cycles of carbonic sedimentation (Vieira, 2007; Warren et al., 2014; Paula-Santos et al., 2017).

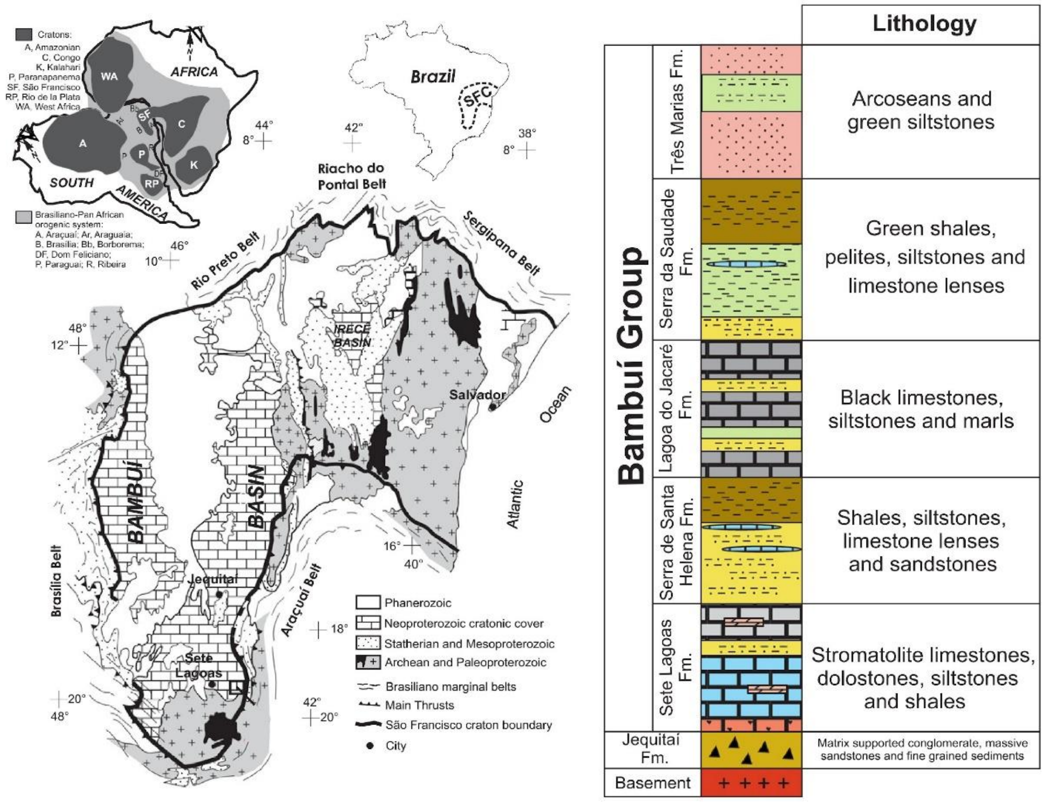


Figure 1. 15. Geological map of São Francisco craton with the paleogeographic reconstruction of West Gondwana (modified from Alkmim et al., 2006) and stratigraphic column of the Bambuí Group (extracted from Paula-Santos et al., 2015).

The age of the Bambuí Group is under debate since the investigation on Bambuí Group has started. Several attempts of direct dating of the rocks of the Bambuí Group by the Pb-Pb and U-Pb methods were not successful. A $^{207}Pb/^{206}Pb$ isochronous 686 ± 69 Ma was obtained by Babinski et al. (1999) in the Sete Lagoas Formation. The presence of *Conophyton* sp., silicified microbial mats, rare fossilized algal phytolites and microphytolites, and other long-ranging microfossils, such as coccoid and filamentous cyanobacteria (Fairchild et al., 1996), do not contribute to accurate age determination (Nobre-Lopes & Coimbra, 2000; Warren et al., 2014). Almost all radiometric ages on Bambuí Group and their considered lateral equivalents, fall in the range of 700 to 450 Ma (see Trompete, 1994). The apparent absence of key index fossils has led to several attempts to determine the age of Bambuí Group and related units based on geochronologic and isotopic methods (Misi et al., 2007; Babinski et al., 2007). It is currently been suggested that the Bambuí Group is entirely Neoproterozoic in age, ranging from the late Tonian to the early Ediacaran.

The description of *Cloudina* sp. and *Corumbella* sp. in the Sete Lagoas Formation in Januaria region indicates an even younger age for the base of Bambuí Group, possible latest Ediacaran (Warren et al., 2014, Paula-Santos et al., 2015, 2017; Perrella-Júnior et al., 2017; Uhlein et al., 2017; Caixito et al., 2018). In addition, new dates of detrital zircon suggest a maximum age of deposition of the Sete Lagoas Formation around 557 Ma (Paula-Santos et al., 2015). However, all *Cloudina* specimens illustrations published so far, are not clear, and the taxonomy is always open, making it difficult for additional interpretations based on this important finding.

Denezine (2018) performed a detailed study at Januaria region focused on the organic-walled microfossil assemblage. The Sete Lagoas Formation in the Santa Luzia quarry at Januaria was fitted into the *Leiosphaeridia jacutica* - *Leiosphaeridia crassa* Assemblage Zone. *Leiosphaeridia jacutica* - *Leiosphaeridia crassa* Assemblage Zone is characterized by the appearance of *Leiosphaeridia jacutica* together with three other species *Leiosphaeridia crassa, Leiosphaeridia minutissima* and *Leiosphaeridia tenuissima*. The top of this biostratigraphic unit has been attributed to Mid-Ediacaran, ~ 580 Ma, and marked with the impact of Acraman (Denezine, 2018). The base of this zone has been tentatively positioned in 587 Ma (Gray, 2005). Considering the issue regarding the age of Bambuí Group, this group was not included in the comparation for evading the purpose of the present research.

1.3. UPPERMOST EDIACARAN STRATA IN ÁFRICA

Sections of the African continent have their paleontological content intensively studied, since Germs (1972) described *Cloudina hartmanae* (currently considered synonym of *Cloudina lucianoi*) and *Cloudina riemkeae* from the limestones of the Nama Group. Three lithostratigraphic units are the most important for the study of fossils of the uppermost Ediacaran of Africa: The Cango Caves Group and the Port Nolloth in South Africa and Nama Group in Namibia (Gaucher et al., 2005a).

The Port Nolloth Group is represented by three depositional megasequences (M1-M3) (Frimmel et al., 2002). The Stinkfontein Subgroup represents the sequence M1, with deposition in alluvial fans in continental rift. The Kaigas Formation occurs along faults that limit the Gariep basin, being represented by discontinuous glacial diamictite lenses interspersed with arches and graviac where olistostromes develop. Based on the negative curves of $\delta^{13}C$ and low ratios of $^{87}Sr/^{86}Sr$, besides the similarity with other sequences of the Neoproterozoic, this glacial event is correlated with the global Sturtian glaciation (Frimmel et al., 2002).

The Pickelhaube Formation is represented by succession of postglacial carbonates interspersed with pellets, loams and sandstones representing the second megasequence M2. The Dabie River Formation represents areas that escaped from erosion and allowed the precipitation of carbonates in the form of stromatolytic bioconstructions and also in the form of oolitic calcarenite. The Numees Formation is located stratigraphically at the top of the M2 megasequence, where sea level fall is observed due to the advance of the glacial event, represented by the deposition of massive packages of diamytites.

The Numees Formation is capped by a thick sequence of carbonate Bloeddrif Member, Holgat Formation that represents the third megasequence M3. Elongated columnar stromatolites of about 2 to 5 cm in diameter occur in Bloeddrif Member. The upper part of the Holgat Formation consists of sandstone, arcoseum and siltstone. Above the three megasequences lies the Nama Group, representing the deposition in a shallow water foraland system whose deposition of the basal portion started around 550Ma, followed by the deposition of molybdenum siliciclastic sediments from the upper portion deposited in 540Ma. In the central and southern part of Namibia, the Nama Group rests discordantly on the crystalline basement, its basal portion is represented by a succession of siliciclastic and carbonate rocks with occurrences of skeletal fossils of *Cloudina lucianoi* and other fossils with calcareous skeletons, as well as ichnofossils and palynomorphs in the Kuibis Formation (Germs, 1995, Gaucher et al., 2005a). The upper portion of the Nama Group is represented by the Schwarzrand Subgroup which contains the ichnofossil Phycodes pedum and *Cloudina* as well as palynomorphs (Germs, 1983; Germs & Gresse, 1991; Gaucher et al., 2005a) (Figure 1. 16).

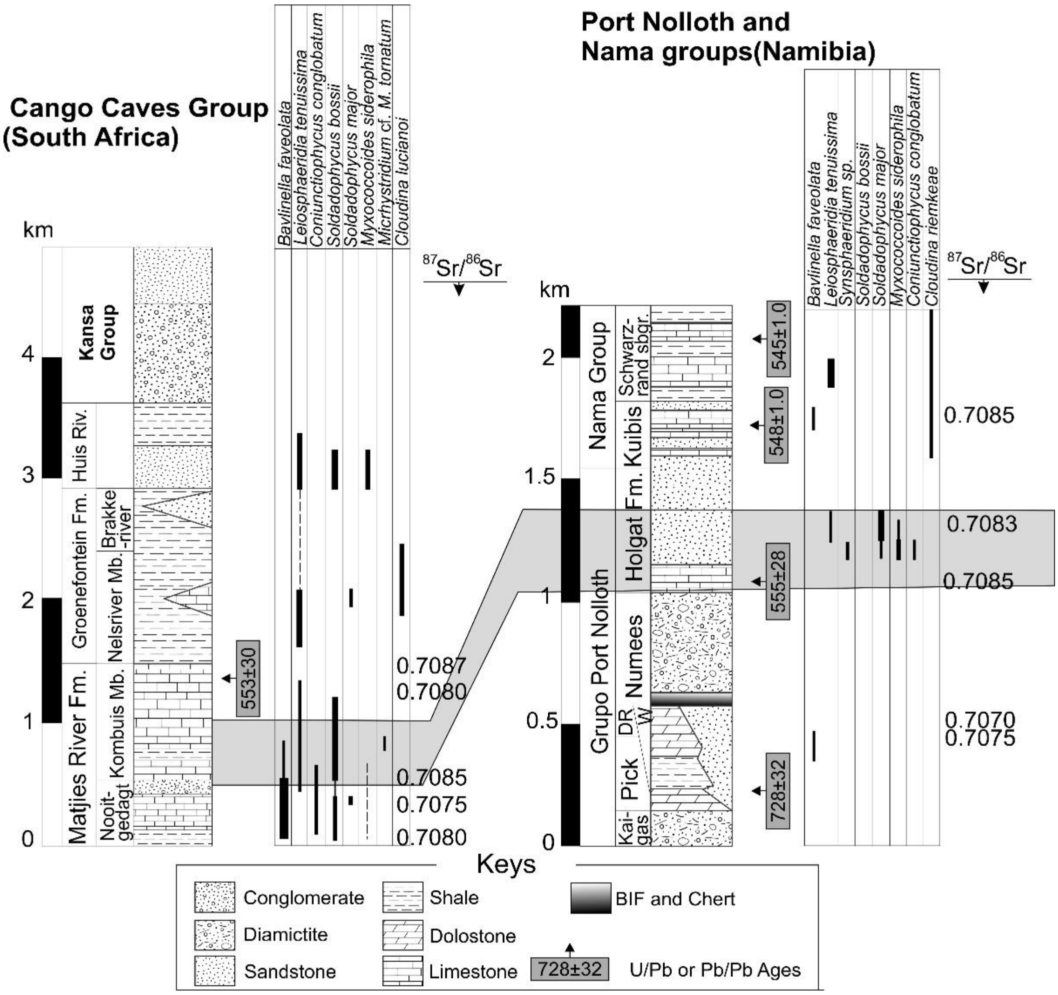


Figure 1. 16. Composite stratigraphic columns for the Cango Caves (South Africa), Port Nollth and Nama (Namibia) groups, showing correlation between the lithostratigraphic units and the stratigraphic distribution of the palynomorphs, mineralized fossil skeletons and ichnofossils (modified from Gaucher et al., 2005a).

1.4. UPPERMOST EDIACARAN STRATA IN CHINA

The Doushantuo Formation (635-551 Ma) in southern China is one of the most heavily studied Ediacaran lithostratigraphic units in the World, with recordings of exceptionally well preserved fossils (Yuan et al., 2002; Chen, 2005, Jiang et al., 2011). There are several localities where it is possible to access Ediacaran sections along the Yangtze platform, the most well-known locality is the area called Gorges area in southern

China which represents one of the most important locations for studying successions of Ediacaran.

The investigation of the Ediacaran sections of China began with the works of Lee (1924) who developed research at the Yangtze Gorges area, later chosen as the standard locality for the Sinian System. In 2002, the Sinian System was redefined to include only the Doushantuo and Dengying formations (*China Commission on Stratigraphy*, 2002). The lower limit of the Sinian System is positioned at the base of the carbonate layer, in contact with the top of the diamictite of the Nantuo Formation (local representative of the Marinoan glaciation), the top of this system was defined by the appearance of the first association of small shelly fossil of the Cambrian, namely, *Anabarites trisulcatus-Protohertzina anabarica* that appears in the Yanjiahe formation that also contains other groups of small shelly fossil such as the microfossils *Asteridium-Comasphaeridium-Heliosphaeridium* (Chen, 1984; Steiner et al., 2007; Dong et al., 2009; Jiang et al., 2012). Radiometric dates U/Pb in ash beds interspersed at the base of the Dengying Formation allow to position geochronologically, the deposition of this formation between 551 Ma and 541 Ma (Condon et al., 2005; Chen et al, 2014).

The Dengying Formation lies above the Doushantuo Formation, being constituted at the base by the Hamajing, Shibantan, and Baimatuo members and their equivalent in other areas in China. The Hamajing Member consists of dolomites deposited in a tidal environment, with features of karsification; Shibantan member consists of black limestone and dark ash and bituminous, deposited in a marine environment; and the Baimatuo Member is made up of clear and massive dolomite deposited in a tidal environment. Ichnofossils have been recorded in the Shibantan Member (Zhao et al., 1988; Weber et al., 2007), as well as macroscopic fossils similar to those of Ediacaran *Paracharnia* sp. (Sun, 1986) and *Yangtziramulus* sp. (Xiao et al., 2005; Shen et al., 2009) and the macroscopic algae *Vendotaenia antiqua* (Zhao et al., 1988; Shen et al., 2009) (Figure 1. 17).

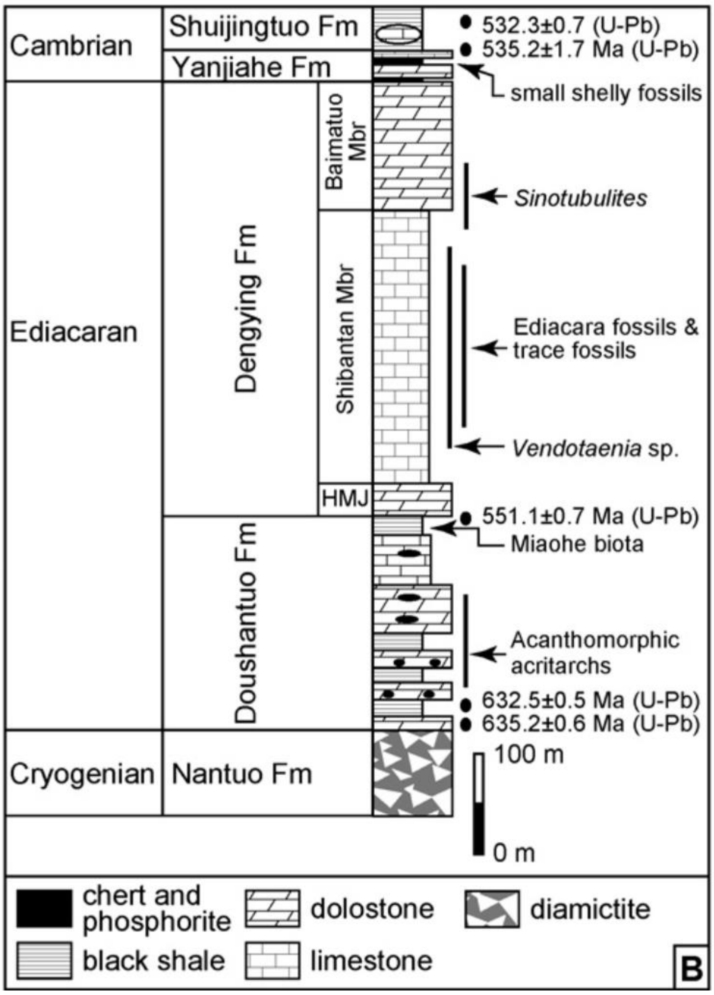


Figure 1. 17. Stratigraphic column for the Doushantuo and Dengying formations, showing the main associations of fossils and radiometric dating available (from Chen et al., 2013).

Sinotubulites species have been recorded in the lower portion of the Baimatuo Member of the Dengying Formation, Southern China (Zhao et al., 1988). In the Shaanxi region of southern China, strata equivalent to that of the Shibantan and Baimatuo members of the Dengying Formation also contains tubular fossils such as *Shaanxilithes*, *Conotubus*, *Gaojiashania*, *Sinotubulites*, and *Cloudina* (Grant, 1990; Hua et al., 2003, 2005; Chen et al, 2008;. Cortijo et al, 2009; Cai et al, 2010, 2011, 2012; Meyer et al, 2012).

1.5. UPPERMOST EDIACARAN STRATA IN THE USA

In the southwestern Great Basin, the Ediacaran-Cambrian boundary occurs within a 1 km-thick, northwestward-thickening siliciclastic-dominated succession of miogeoclinal sediments (Prave et al., 1991) that records the development of a passive margin along southwestern Laurentia (Stewart, 1982). In this region, the Stirling Quartzite is divided into five informal members (A through E) and the Wood Canyon Formation is divided into lower, middle, and upper members (Stewart, 1970, Hagadorn & Waggoner, 2000; Smith et al., 2017). The upper Stirling is a medium to coarse quartz arenite that interfingers with, and is conformably overlain by, the lower member of the Wood Canyon Formation (Wertz, 1982). The lower and middle members of the Wood Canyon Formation record a shallow marine-continental braidplain transition (Diehl, 1979; Fedo & Cooper, 1990; Fedo & Prave, 1991), with the lower member recording a highstand systems tract consisting of three carbonate-capped parasequences (Prave et al., 1991; Horodyski et al., 1994; Runnegar et al., 1995).

Smith et al. (2017) argued that Ediacaran fossils from the southwestern Great Basin may help constrain regional uppermost Ediacaran-Cambrian biostratigraphy and provide biogeographic links between facies in this region and elsewhere. For these authors, the presence of trace fossils suggest the Uppermost Ediacaran-Cambrian boundary which occurs within or below the upper third of the lower member of the Wood Canyon Formation. Ediacaran soft-bodied and tubular fossils, including the frondlike fossil *Swartpuntia* and tubular, mineralized or agglutinated fossils similar to *Archaeichnium*, *Cloudina*, *Corumbella*, and *Onuphionella* occur in the lowermost Wood Canyon Formation (Figure 1. 18). These fossils occur directly below Lower Cambrian trace fossils, including *Treptichnus pedum*, and confirm the persistence of the Ediacaran biota close to the base of the Cambrian. These faunas may also help strengthen previously proposed correlation schemes between the two main facies belts of the southwestern Great Basin (the Death Valley and White-Inyo facies), because a nearly identical Uppermost Ediacaran-lowest Cambrian succession of faunas occurs in both regions.

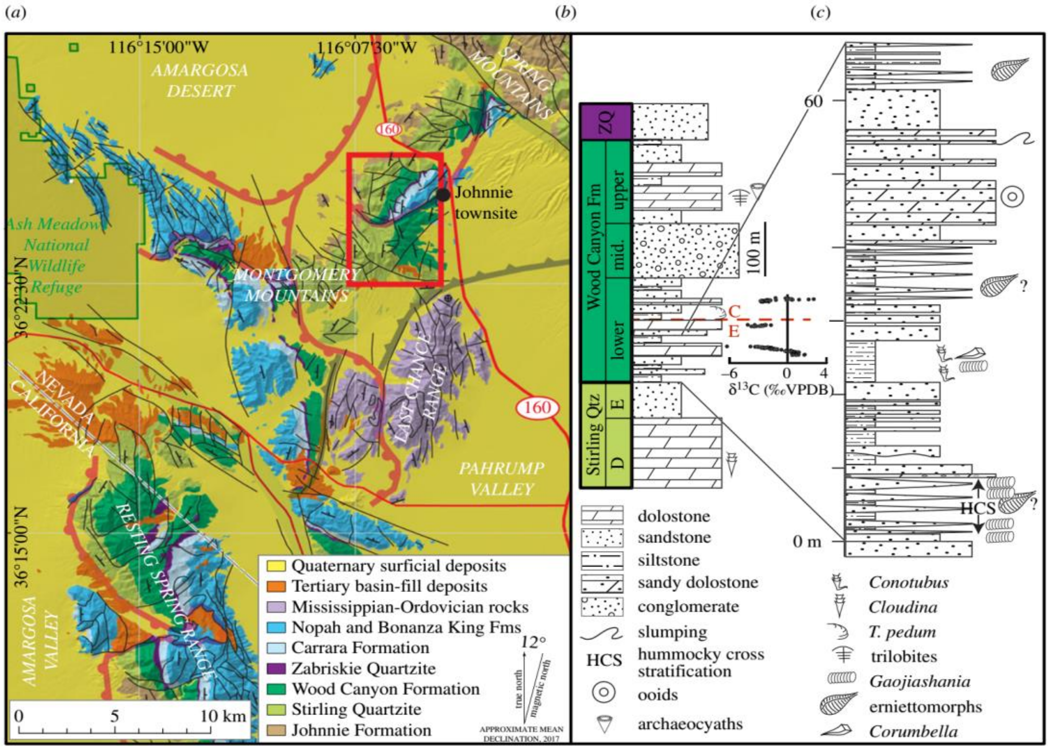


Figure 1. 18. (a) Geologic map of the Montgomery Mountains, Nevada. The fossils and measured sections included in this report are from within the red box near the Johnnie townsite. (b) Generalized regional stratigraphy and biostratigraphy, and carbon isotope chemostratigraphy. Dashed red line marks the Ediacaran–Cambrian boundary. (c) Composite detailed measured section of fossiliferous latest Ediacaran strata of the lower member of the Wood Canyon Fmormation. Fossil horizons are marked on the right-hand side of stratigraphic column (extracted from Smith et al., 2017).

1.6. UPPERMOST EDIACARAN STRATA IN CANADA

The uppermost Ediacaran strata in Canada is represented by biostromes and bioherms which are present in platform margin carbonates in the uppermost part of the Byng Formation, Miette Group, British Columbia. The Byng carbonate platform is exposed in several thrust sheets in the Mount Robson Provincial Park region (Mountjoy, 1980, Hofmann & Mountjoy, 2001). This platform is overlain abruptly by quartz-rich sandstones of the McNaughton Formation (Gog Group), traditionally assigned to the Cambrian (Mountjoy, 1962; Fritz & Mountjoy, 1975; Hofmann & Mountjoy, 2001) (Figure 1. 19).

The most common fossil types are the tubular *Cloudina lucianoi* and *Namacalathus hermanastes*. The biostromal platform carbonate overlies a thick sequence of siliciclastics that carries miscellaneous bedding parallel traces and burrows, particularly *Planolites* and *Helminthoidichnites*, and Ediacaran taxa such as Aspidella and, rarely, Bradgatia (Hofmann & Mountjoy, 1998). The Ediacaran biota is also present in correlative siliciclastics to the southeast (Hofmann et al., 1985, 1991; Hofmann & Mountjoy, 2001).

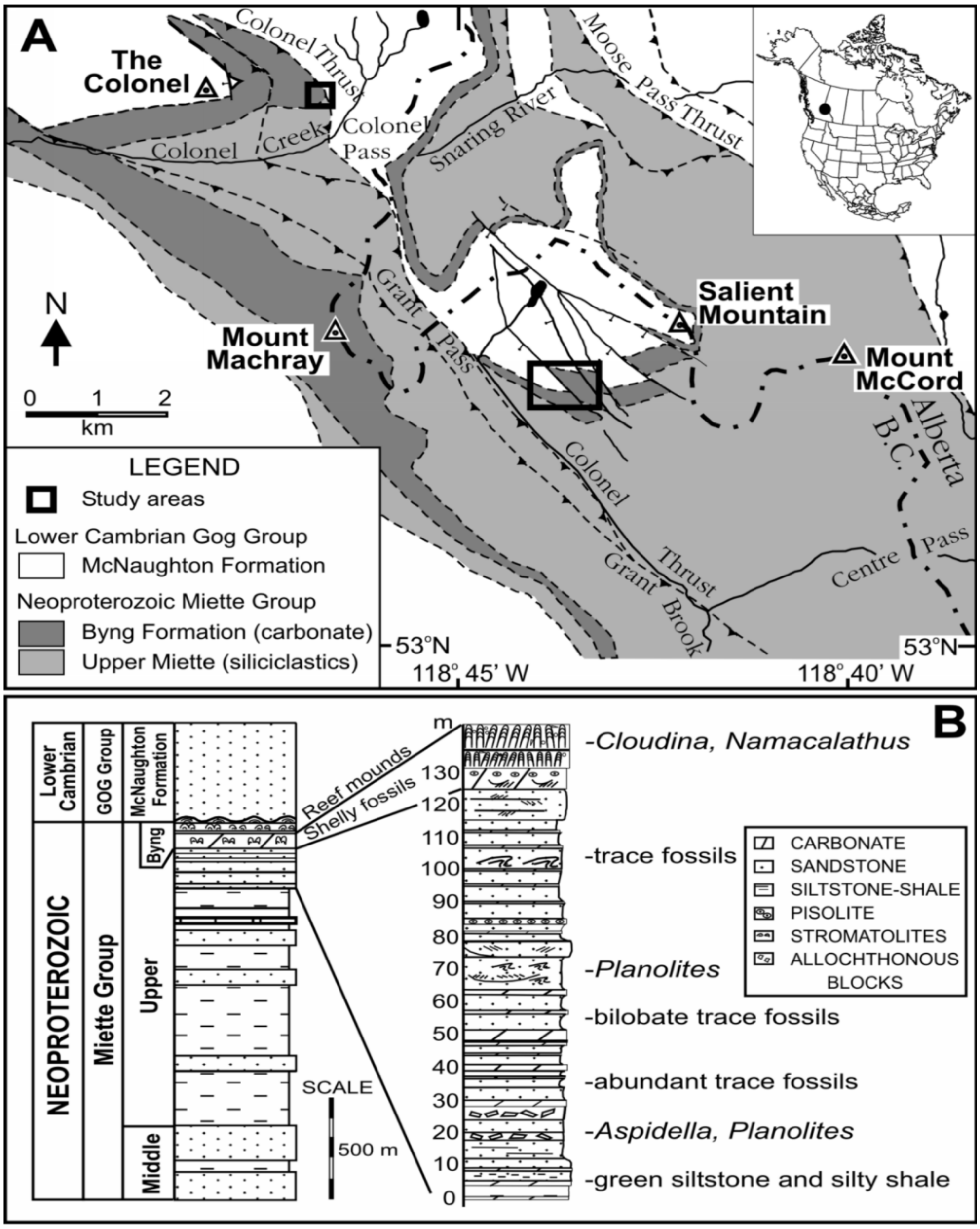


Figure 1. 19. Location of *Namacalathus hermanastes* Grotzinger et al., 2000 –*Cloudina lucianoi* (Beurlen & Sommer, 1957) assemblage in Miette Group, Salient Mountain area, British Columbia. A: Index map and general geologic map, updated from Mountjoy (1980). B: Generalized stratigraphic section (extracted from Hofmann & Mountjoy, 2001).

1.7. UPPERMOST EDIACARAN STRATA IN OMAN

Several sedimentary basins within the interior of Oman were developed on crystalline basement (ca. 800 Ma) and filled with unmetamorphosed strata of the Neoproterozoic to Cambrian Huqf Supergroup (Mattes & Conway-Morris, 1990; Burns &

Matter, 1993; Brasier et al., 1999, Amthor et al., 2003). The Huqf Supergroup comprises synrift volcanic, siliciclastic, and glacio-marine rocks (Ghadir Manquil Formation), siliciclastic and carbonate rocks (Masirah Bay and Shuram Formations), carbonates (Khufai and Buah Formations), and a thick carbonate-evaporite unit (Ara Group) (Amthor et al., 2003).

The record of early animal evolution from Oman includes biomarker evidence for eukaryotic sponges (Demospongiae) from the Abu Mahara Group onwards as well as abundant bacteria and chlorophyte microalgae primary producers (Bergmann, 2013). The Ara Group includes both *Cloudina lucianoi* and *Namacalathus hermanaste*, early calcifying organisms (Amthor et al., 2003) (Figure 1. 20). However, unlike most other late Precambrian records, the Huqf Supergroup does not contain abundant macroscopic Ediacaran fauna. Instead, the Nafun and Ara Groups are dominated by microbially-influenced carbonates including a variety of stromatolite morphologies, crinkly laminite and thrombolite facies (Bergmann, 2013).

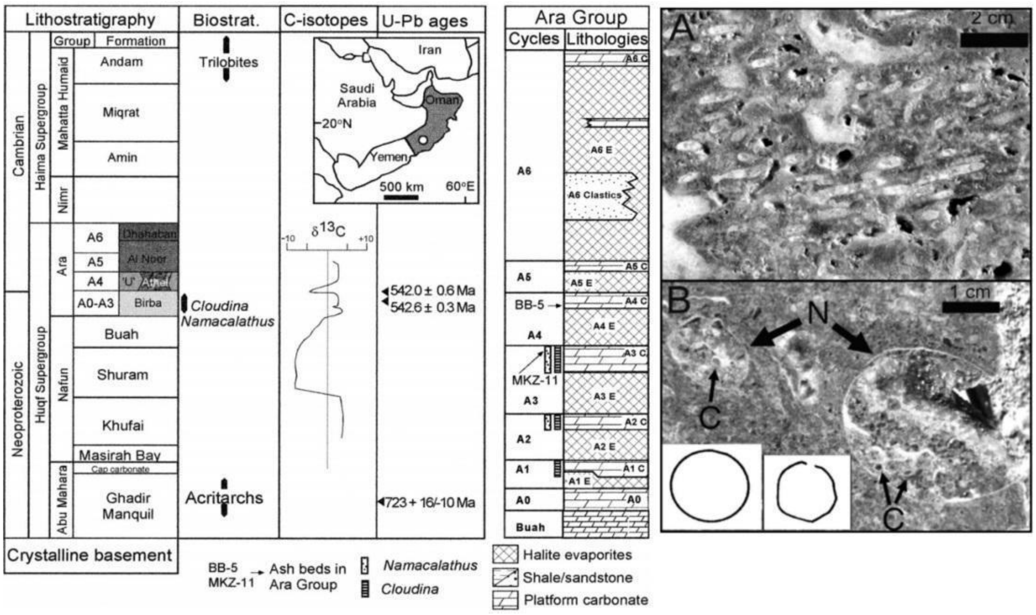


Figure 1. 20. Stratigraphy of Huqf Supergroup. Inset map shows location of subsurface basin in Sultanate of Oman (unfilled circle). Carbon isotope data (‰) for Ara Group derive from this paper; for Nafun Group, see Burns and Matter (1993). Right-hand column shows internal Ara Group stratigraphic subdivisions. Each cycle consists of a lower evaporite (halite and/ or anhydrite) unit and upper carbonate unit. *Cloudina lucianoi* (Beurlen & Sommer 1957) in well-developed thrombolite buildup; B) *Namacalathus hermanaste* Grotzinger et al., 2000 (‘‘N’’) in well developed thrombolite buildup (extracted from Amthor et al., 2003).

1.8. UPPERMOST EDIACARAN STRATA IN SIBERIA

It was selected from the Eastern Tomsk region in Siberia, Russia for comparison, based on information from the Borehole BH Vostok-3. The comparation between Corumbá sections and Eastern Tomsk section was possible because of the availability of the fossil distribution presented by Kontorovich et al. (2009) from the studied borehole.

The uppermost Ediacaran strata in Eastern Tomsk region are represented by deposits intercepted in the Borehole called Vostok-3. It is subdivided into three formations: the Poiga, Kotodzha, and Raiga formations (Kontorovich et al., 2009). The Poiga Formation is composed of gray, irregularly recrystallized dolomites in places with well preserved signs of the noncolumnar, dolarenitic, dolosiltitic, and pelitomorphic textures, which characterize the belt of stromatolithic biostromes under conditions of a relatively stable shelf. Overlying deposits of the Kotodzha Formation are represented by gray dolomites (dolarenites recrystallized to different extents, slightly recrystallized pelitomorphic dolomites, noncolumnar stromatolites, and microbiolites), which are interpreted as facies of a carbonate ramp. The Raiga Formation terminating the section of Ediacaran deposits is made of four progressive cyclites from 40 to 130 m thick, each being composed of alternating clastic limestones, micaceous sandstones, siltstones, and mudstones in the lower part, as well as by fine-clastic limestones in the upper part (see Kontorovich et al., 2009).

The latest Ediacaran age of the selected Siberia area was established by the occurrence of microbiolites *Korilophyton* in the lower part of the Poiga Formation, which are regarded as typical for deposits of late Ediacaran age. Deposits of the Kotodzha and Raiga formations comprise a typical latest Ediacaran assemblage with tubular (as nested funnels-within-funnels) calcitic skeletal fossils *Cloudina lucianoi*, goblet-shaped weakly mineralized skeletal fossils *Namacalathus hermanastes*, straight and bent tubular agglutinated skeletal fossils *Platysolenites* and *Spirosolenites*, and carbonaceous fossils *Vendotaenia* and sponge spicules (Kontorovich et al., 2009) (Figure 1. 21).

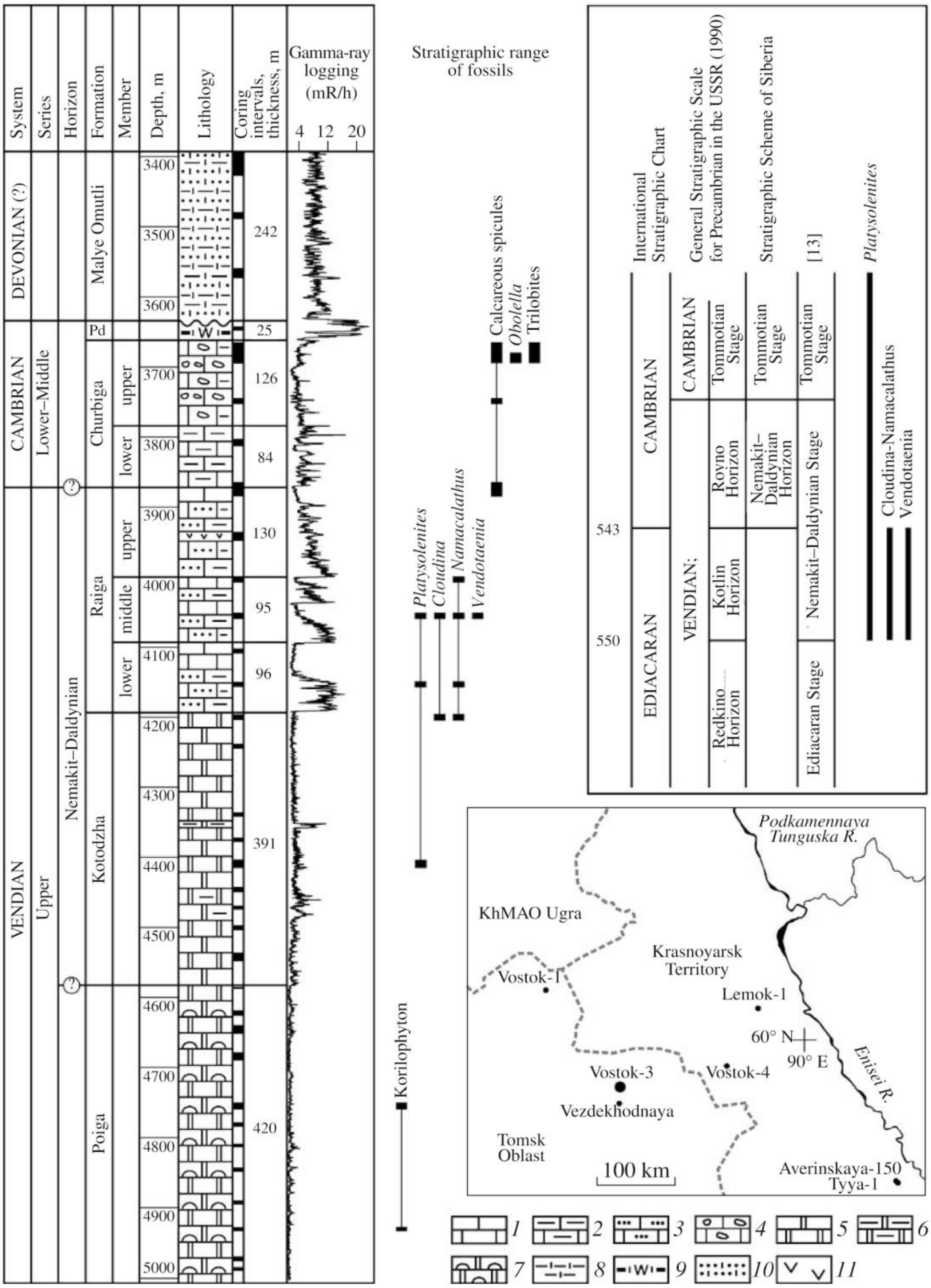


Figure 1. 21. The geological–geophysical section of uppermost Ediacaran and Cambrian deposits in BH Vostok-3, with stratigraphic distribution of fossils. The layout of boreholes penetrated pre-Mesozoic deposits in the southeastern part of the West Siberian geosyncline. Correlation of stratigraphic schemes of Ediacaran–Cambrian boundary deposits (age, Ma). (1) Limestones; (2) clayey limestones; (3) sandy limestones; (4) synsedimentary limestone breccia; (5) dolomites; (6) clayey dolomites; (7) noncolumnar stromatolithic dolomites; (8) mudstones, calcareous silt–mudstones; (9) carbonaceous carbonates, shales and silicites; (10) calcareous sandstones; (11) dolerites. (Pd) Paidugina Formation (extracted from Kontorovich et al., 2009).

CHAPTER – 2: LOCATION AND ACCESS ROADS TO THE STUDY SECTIONS IN BRAZIL

The studied outcrops of Corumbá Group are located in the municipalities of Corumbá, and Ladário Mato Grosso do Sul State, near the border with Bolivia in Midwestern Brazil. The access to Corumbá from Brasília is by the federal road BR-060 passing through municipalities of Goiânia, capital of Goiás State, and then through municipalities of Rio Verde, Jataí and Campo Grande, the capital of the Mato Grosso do Sul State. From Campo Grande, it goes west on federal road BR-262, passing through the municipalities of Aquidauana, Miranda and then Corumbá making a total of about 1500 km from Brasilia.

The access to the outcrops of the Porto Sobramil, Porto Figueiras, Ecoparque da Cacimba and Corcal quarry are within the urban zone of Corumbá. The section of the Laginha quarry is remote and can be accessed following the south by the state road MS-228 about 10 kilometers from Corumbá (

Figure 2. ***1***).

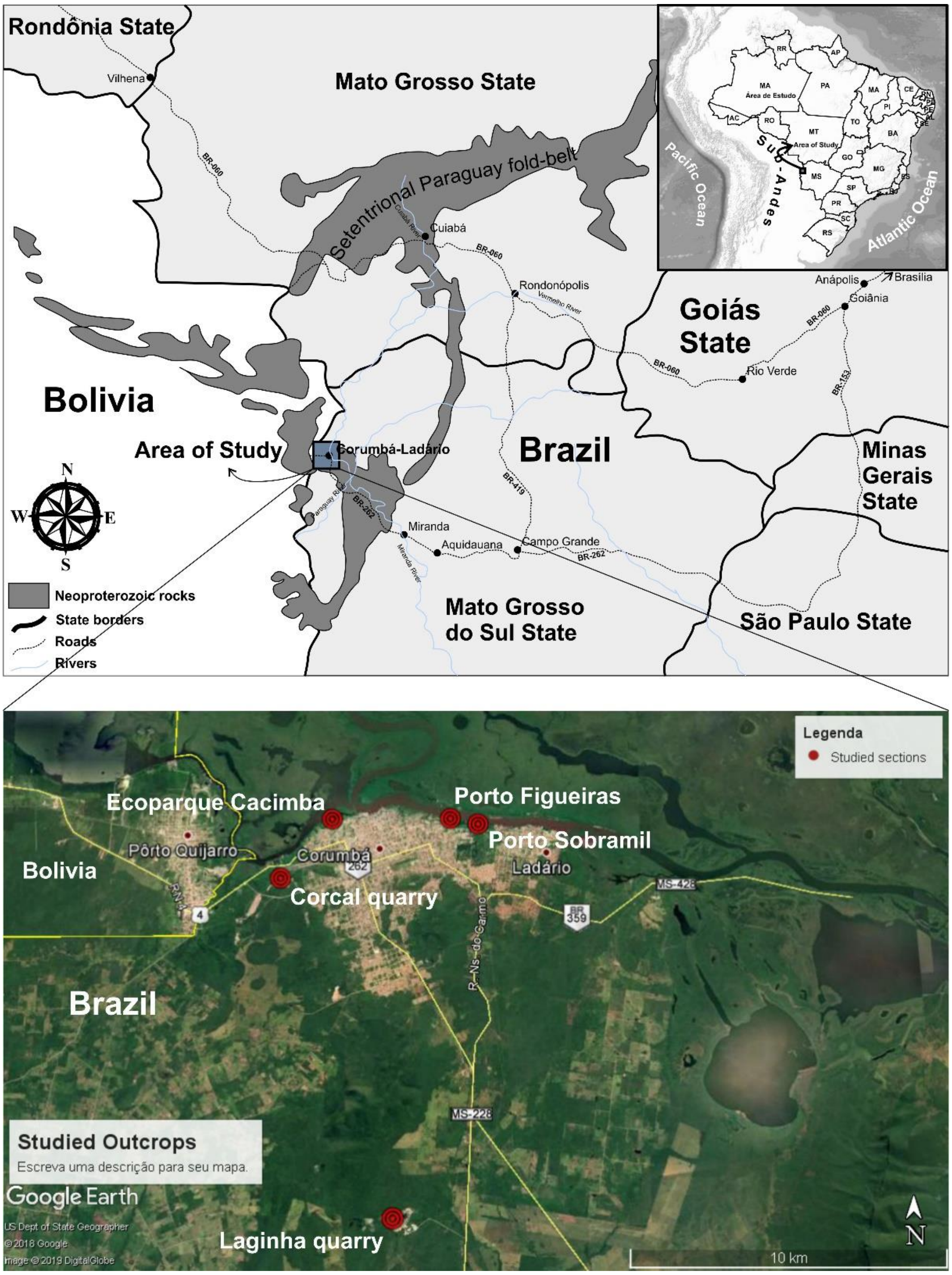


Figure 2. 1. Location of the studied outcrops (sections) in Corumbá region and the main access roads.

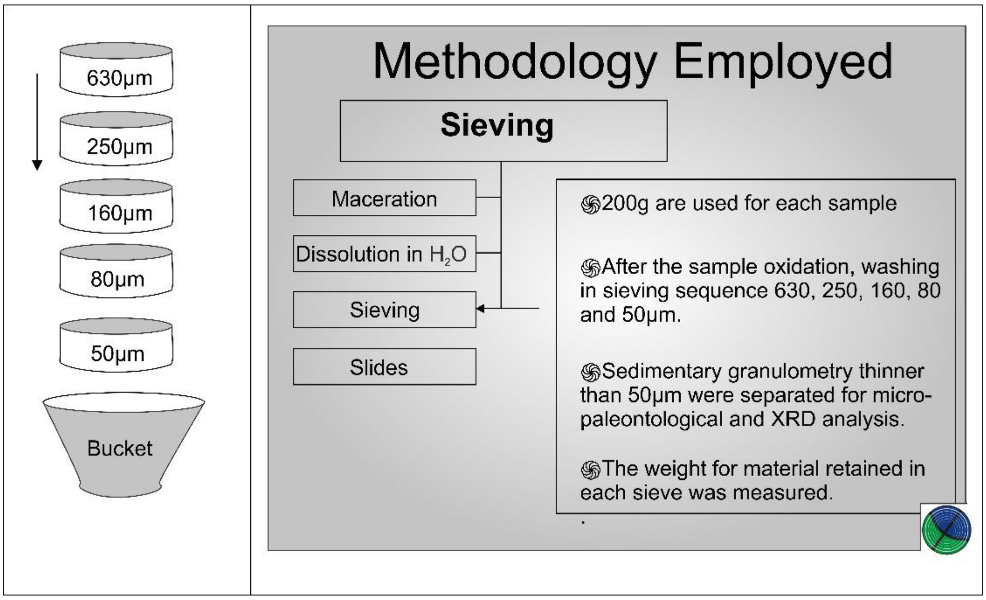
CHAPTER – 3: METHODOLOGY

Several fieldworks were carried out in the Corumbá region, Mato Grosso do Sul State. During the fieldwork lithostratigraphic logs were made with positioning of the collected rock samples, always as possible observing the systematic methodology, with regular spacing between each collected sample whenever possible. The studied locations of the Tamengo Formation, Corumbá Group include the outcrops of five main localities: Ecoparque da Cacimba, Corcal quarry, Laginha quarry, Sobramil quarry and Porto Figueiras section.

A total of 544 rock samples were collected from the Corumbá Group, with a focus on the Tamengo and Guaicurus formations material. From the total, 389 samples are from the Tamengo Formation and 155 from the Guaicurus Formation. All samples, specimens and slides were housed in the collection of the UnB micropaleontology laboratory on MP-prefix, with each organic maceration extract, screening residue, and palynological slides also carrying the MP- number of the respective sample of origin and CP- that represents the internal number of the research collection of the Museum of Geosciences at UnB. The record of all macrophossiliferous occurrences was indicated in the lithostratigraphic logs and include *Cloudina lucianoi*, *Corumbella werneri* in the Tamengo Formation and ichnofossils and carbonaceous impressions of macroalgae in the Tamengo and Guaicurus formations. The micropaleontological records mainly include palinomorphs acritarchs that will also have their positioning later recorded in each log made in the fieldworks.

Three modalities of sample preparation were employed aiming at the fossiliferous recovery: 1. Invertebrates, 2. Mineralized microfossils and, 3. Organic-walled microfossils maceration (palynomorphs). As for the study of the occurrence of invertebrates such as *Corumbella werneri* and *Cloudina lucianoi*, as well as ichnofossils and macroscopic algae, the study initially consists of the description and direct analysis from rock using stereoscopic microscopy; for the preparation of polished sections and study of thin sections, stereoscopic microscopy and petrographic microscope were used, and in specific cases, scanning electron microscopy (SEM) was used.

The micropaleontological preparation was used with the objective of recovering mineralized microfossils besides fragments of invertebrates, sponge spicules, and remains of cyanobacteria or even protists diagenetically mineralized, through battery of sieves. The methodology employed follows the one proposed by Do Carmo et al. (2011) which aims at the recovery of mineralized skeletons and mineralized particles from the disintegration of the sedimentary rocks samples and washing them in sieves. After mechanical disaggregation, the sample is left in a beaker of 2 L for 48 h with water, then the sample is washed in sieves (630, 250, 160, 80,56 and 10 µm opening sizes) (Figure 3. 1). The granulometric fractions smaller than 10 µm are retained in an appropriate container, together with the other fractions, to be dried in a kiln at 60 °C and also to be examined in a stereoscopic microscope for the screening of microfossils and subsequent imaging in SEM.



200g are used for each sample

After the sample oxidation, washing in sieving sequence 630, 250, 160, 80 and 50µm.

Sedimentary granulometry thinner than 50µm were separated for micro-paleontological and XRD analysis.

The weight for material retained in each sieve was measured.

Figure 3. 1. Micropaleontological preparation flowchart (Do Carmo et al., 2011).

For the chemical preparation and concentration of the particulate organic components (palynomorphs), the methodology developed in the Laboratory of Micropaleontology of UnB was used. The methodology involves attacking the samples for 2 h with 37% hydrochloric acid. The samples were neutralized and then treated with 47% hydrofluoric acid for 12 hours. Again the samples were neutralized by distilled water until the pH reaches 7. A further 10% hydrochloric acid digestion can be applied for fluorite consumption and finishing the preparation with neutralization step in distilled water. Finally, the organic material is allowed to decant in the bottom (one day standby) and then stored in its own pots ready to make the slides. For the assembly of the permanent palynological slides, the supernatant is used, employing Entelan as the standard mounting medium and cover slides, according to standard preparation flowchart adopted in the UnB micropaleontology laboratory (Figure 3. 2)

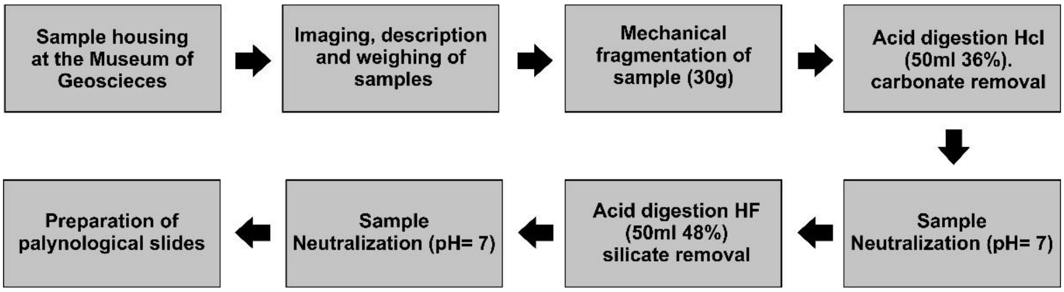


Figure 3. 2. Flowchart of the palynological preparation of the Laboratory of Micropaleontology, University of Brasília (Denezine, 2018).

Tests were conducted in order to recover *Cloudina lucianoi* from the Corumbá and Nama groups in three dimensions. Studies of this nature have been successfully conducted by Chinese research studies, with phosphatized material from the Doushantuo and Dengying formations (Hua et al., 2007). The preparation that returned a positive result uses 4% acetic acid, able to attack preferentially the carbonate matrix, in detriment of the carapace, which, because of its slightly larger magnesium content, is dissolved more slowly than the carbonate matrix (Figure 3. 3). The dissolved fraction of the sample is separated for analysis of the palynological content.

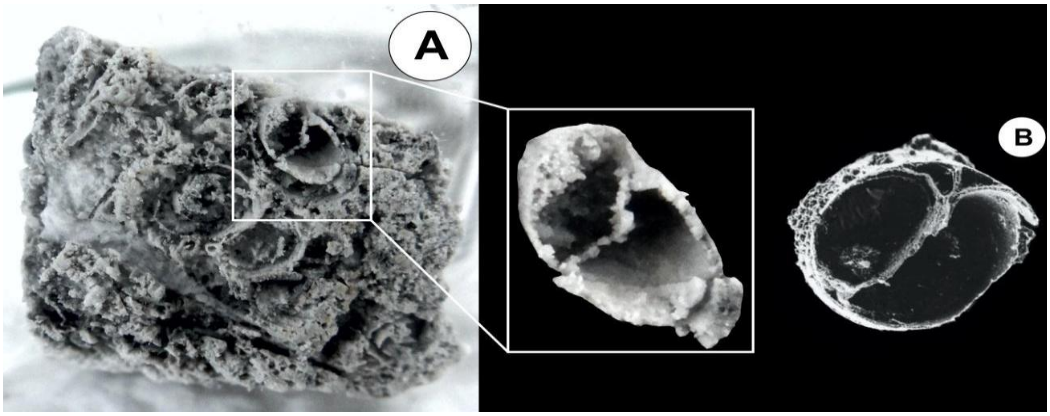


Figure 3. 3. Specimens of *Cloudina lucianoi* (Beurlen & Sommer, 1957) after preparation using 3D extraction. A) Carbonate Skeleton of *Cloudina lucianoi* from the Nama Group, Namibia with new preparation procedure. B) Phosphatized skeleton of *Cloudina lucianoi* from the Dengying Formation, South China (Hua et al., 2005) (Adôrno et al., 2016a).

CHAPTER – 4: RESULTS

It is presented herein results on update of lithostratigraphic description of studied sections, species identification of Tamengo and Guaicurus formation paleobiota, paleoenvironmental inferences and, a biostratigraphic essay. Five sections were studied: Corcal and Laginha quarries, Porto Sobramil, Porto Figueiras and Ecoparque Cacimba. In these five sections, Tamengo Formation crops out, and Guaicurus Formation crops out only at Laginha quarry section.

Twenty-six described species integrate the fossil assemblage of the Tamengo and Guaicurus formations, and were clustered six categories: biomineralizing metazoan, biomineralizing microfossils, vendotaenids, ichnofossils, organic-permineralized microfossils and organic-walled microfossils. In addition, paleoecological and paleoenvironmental inferences are presented based on the occurrence of the species and the lithostratigraphic update of Tamengo Formation sections.

Furthermore, in order to compare microfossil assemblage recovered from Tamengo Formation, sampling was conducted in three additional sections: Dengying Formation, China, Tagatiya Guazu Formation, Paraguay and Nomtsas Formation, Namibia. The result of the preparation and analysis of these samples complemented the scarce register of organic-walled microfossil species for these uppermost Ediacaran sections.

Finally, the results obtained from the analysis of the Tamengo Formation fossil assemblage were compared with those published for other uppermost Ediacaran selected sections in Paraguay, Uruguay, Argentina, Namibia, China, Russia, Canada, the United States and Oman which were presented as a proposal of biostratigraphic essay. This essay represents an advance on the previous one presented in Adôrno et al. (2017).

4.1. DESCRIPTION OF TAMENGO FORMATION SECTIONS

The results presented for Tamengo and Guaicurus formations in the region of Corumbá were obtained from the geological sections in five localities: 1) Porto Sobramil;

2) Corcal quarry; 3) Ecoparque Cacimba; 4) Laginha quarry; 5) Porto Figueiras and Porto Figueiras sections (Table 4. 1). The descriptions for the localities 1-3 have been presented in Adôrno et al. (2017) and herein an uptdated description for the Laginha quarry and Porto Figueiras sections is presented.

Table 4. 1. Localities and coordinates of the studied outcrops in Corumbá-Ladário region, Mato Grosso do Sul State, Brazil.

LOCALITY	GEOLOGY	COORDINATES
1. Corumbá - Corcal quarry	Tamengo Fm.	21K 0428106 / 7897065
2. Corumbá – Ecoparque Cacimba da Saúde	Tamengo Fm.	21K 0429794 / 7899135
3. Ladário - Porto Sobramil*	Tamengo Fm.	21K 0434770 / 7898980
4. Corumbá - Laginha quarry	Tamengo Fm.	21K 0432101 / 7886020
5. Corumbá – Porto Figueiras	Tamengo Fm.	21K 0433880 / 7899144

* This locality also refers to the limestone quarry area of the company Itaú, known by two denominations: Cláudio quarry and Saladeiro quarry. These two quarries were located side by side on the same bank of the Paraguay River. In order to avoid confusion, the name Sobramil is chosen, which refers to the company that owns the property where the two quarries were formerly located. Currently, in this classic locality, there is activities of iron and manganese port.

4.1.1. PORTO SOBRAMIL SECTION

The section of the Tamengo Formation in the Porto Sobramil area is a total of 29 m thick and comprises six layers. The first layer, L1, comprises laminated siltstone, three meters thick, in which occurrences of *Corumbella werneri* are found. The second layer, L2, is 13 m thick and comprises mainly calcarenite and limestone with the occurrence of *Cloudina lucianoi*. The third layer, L3, represents the middle portion of the outcrop and comprises siltstone and claystone with *Corumbella werneri*. The fourth layer, L4, comprises a calcarenite with occurrences of *Cloudina lucianoi*. The fifth layer, L5, comprises siltstone with occurrences of *Corumbella werneri*. The sixth layer, L6, of the Tamengo Formation in the Sobramil port area represents the top of the Tamengo Formation and consists of 5.5 m of limestone with *Cloudina lucianoi* (Figure 4. 1). (Adôrno et al., 2017).

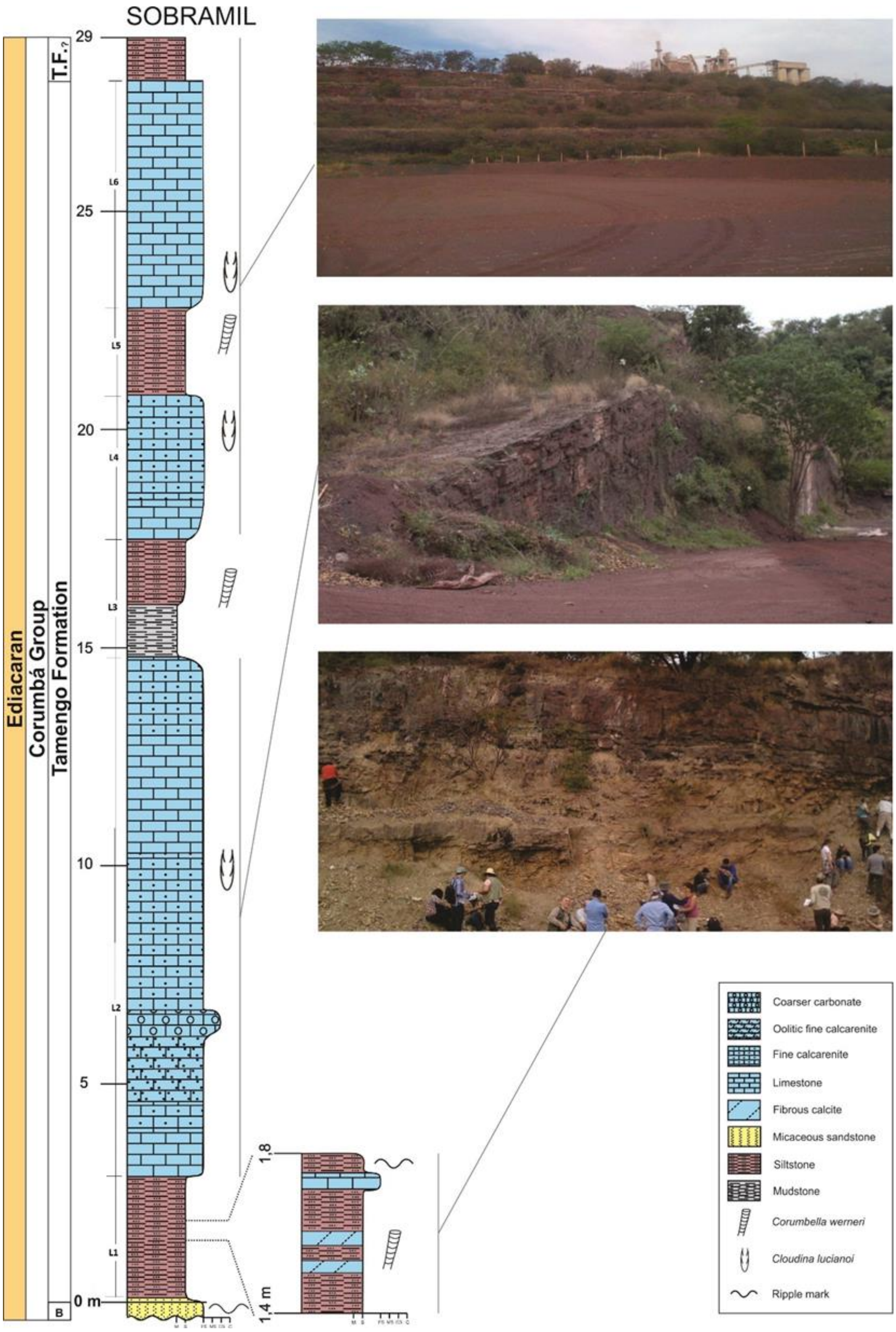


Figure 4. 1. Lithostratigraphic log and biostratigraphic data of the upper Tamengo Formation at Sobramil port, Ladário Municipality, Mato Grosso do Sul State, Brazil (Adôrno et al., 2017).

4.1.2. ECOPARQUE CACIMBA SECTION

The section of the Tamengo Formation in the Ecoparque Cacimba is composed of six layers and is 28 m thick. The first layer, L1, comprises laminated siltstone three meters thick in which occurrences of *Corumbella werneri* are found. The second layer, L2, is 2.5 m thick and comprises mainly calcarenite and limestone with occurrence of *Cloudina lucianoi*. The third layer, L3, is represented by siltstone and calcarenite with occurrence of *Cloudina lucianoi*. In these calcarenites, it is possible to observe ripple marks and overload structures. The fourth layer, L4, comprises a calcarenite layer with occurrence of *Cloudina lucianoi*. The fifth layer, L5, comprises siltstone intercalated with discontinuous carbonate layers. The sixth layer, L6, of the Tamengo Formation in the Cacimba Ecopark represents the top of the Tamengo Formation and consists of 12 m of a huge intercalation of siltstone and limestone with *Cloudina lucianoi* (Figure 4. 2) (Adôrno et al., 2017).

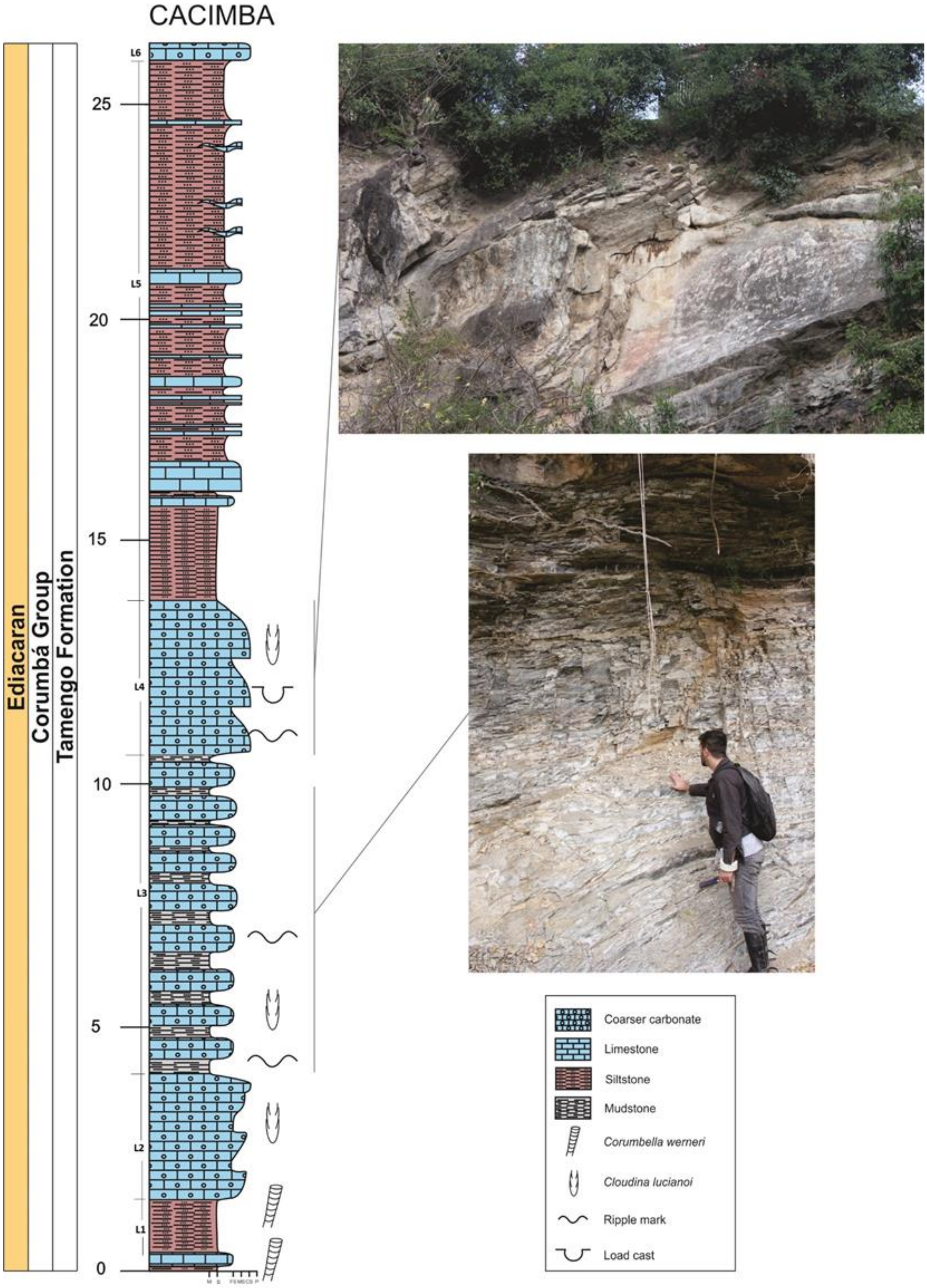


Figure 4. 2. Lithostratigraphic log and biostratigraphy data of the upper Tamengo Formation at Ecoparque Cacimba, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Adôrno et al., 2017).

4.1.3. CORCAL QUARRY SECTION

In the Corcal quarry, the Tamengo Formation is composed of six layers. The first layer, L1, comprises laminated siltstone, 1.5 m thick. The second layer, L2, is seven meters thick and is mainly composed of calcarenite with the occurrence of *Cloudina lucianoi*. The third layer, L3, comprises mainly siliciclastic rock with Corumbella werneri intercalated with carbonate layers with *Cloudina lucianoi*. The fourth layer, L4, represents the middle portion of the outcrop and consists of calcarenite with occurrences of *Cloudina lucianoi*. The fifth layer, L5, comprises siltstone with occurrences of *Corumbella werneri*. The sixth layer, L6, of the Tamengo Formation in Corcal quarry comprises a thick layer with 19 m of calcarenite with *Cloudina lucianoi* (Figure 4. 3).

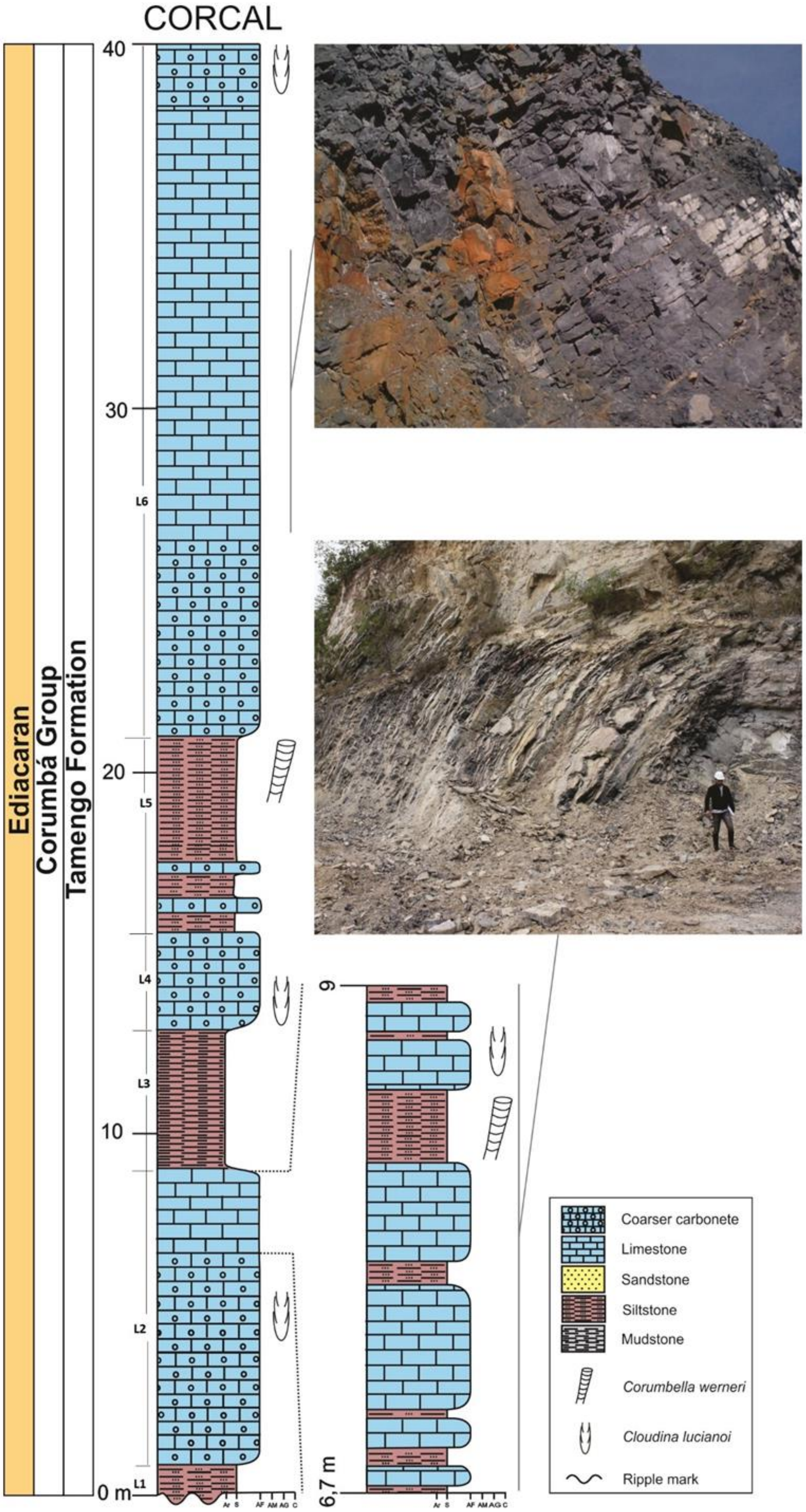


Figure 4. 3. Lithostratigraphic log and biostratigraphic data of the upper Tamengo Formation at Corcal quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Adôrno et al., 2017).

4.1.4. LAGINHA QUARRY SECTION

At the base of the section, there are approximately 16 m of diamictite with clasts of up to 30 cm diameter, composed of granite, quartzite, chert, oolitic limestone and eventually limestone (Figure 4. 4). The matrix of this diamictite is gray in color. Above the diamictite, occurs one layer with about 6 m of breccia, constituted by angular clasts of limestone and fragments of black phosphorite. The matrix is composed of gray carbonate with intense calcite venulation and fluorite of intense violet color. Above the carbonate breccia layer, there are oolitic black grainstone.

Figure 4. 4. Panoramic view of the Laginha quarry section.

Samples were collected at intervals of 10 to 60 cm, in the sequence of dark gray grainstone with intercalations of black pelitic levels, also sampled. The base is formed by layers of massive mudstone, succeeded by layers smaller than 0.5 m thick, with black shale, containing pyrite. Toward the top, the darkest laminated grainstone predominates, usually oolitic, presenting load structures. This is a 50 m packet of medium gray grainstone, very fractured and recrystallized, with calcite veins. This carbonate sequence is covered by a layer of finely-laminated, light gray shale, which when altered gives ocher coloring, this layer represents the basal portion of the Guaicurus Formation (Figure 4. 5).

The sequence ends with the siltstones of the Guaicurus Formation that are persistently laminated, well sorted and homogeneous. Occurrences of *Cloudina lucianoi* at Laginha quarry are rarer than other localities and *Corumbella werneri* was not found thus far at this section. The fossil assemblage recovered is mostly composed of microfissils in the Tamengo Formation and rare remains of fragments of macroalgae as impressions and trace fossils in the Guaicurus laminated siltstones.

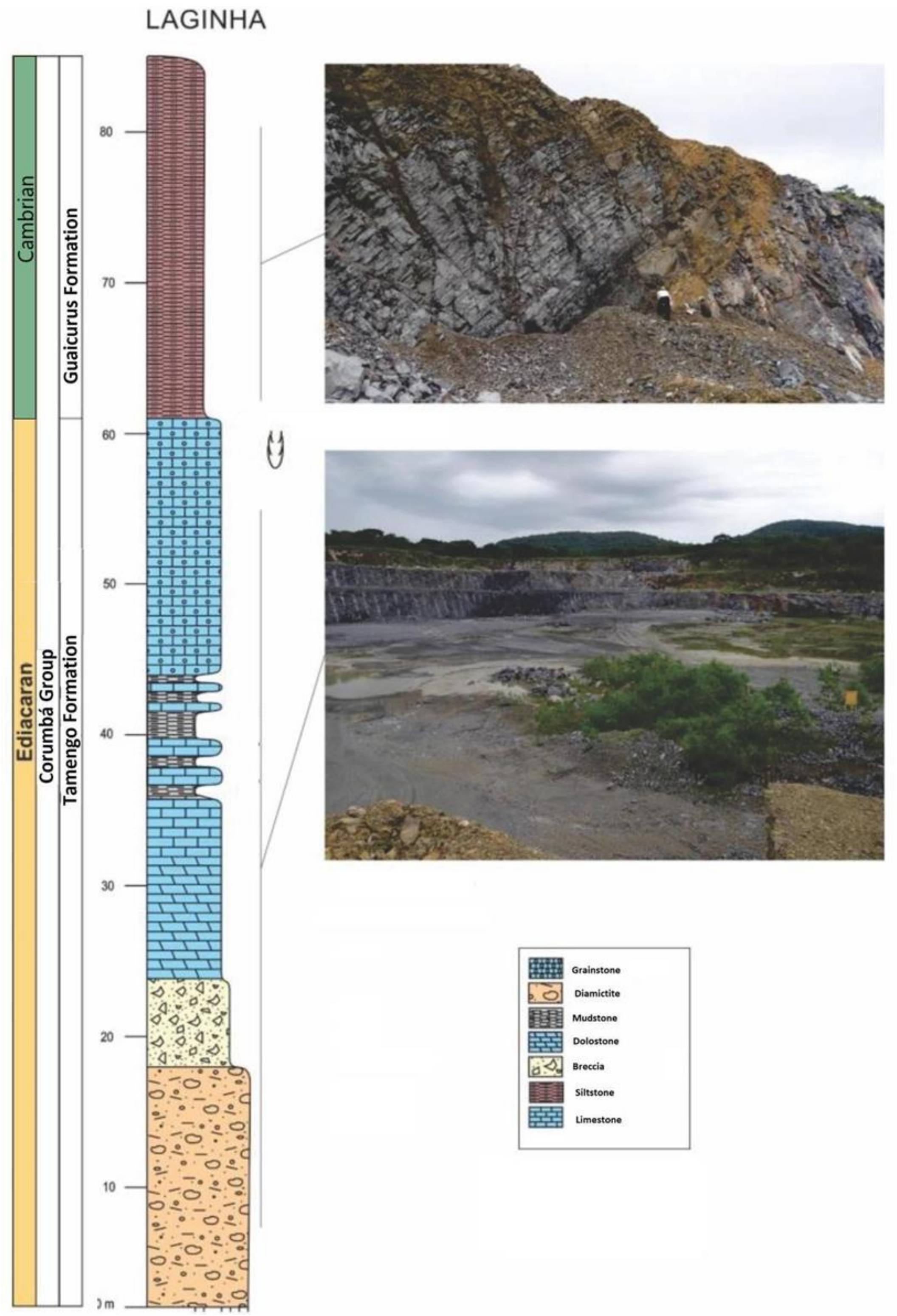


Figure 4. 5. Lithostratigraphic section of the Laginha quarry, in the Municipality of Corumbá, Mato Grosso do Sul State, Brazil. UTM Coordinates zone 21K 0432101mE/7886020mS.

4.1.5. PORTO FIGUEIRAS SECTION

The section of Porto Figueiras is located behind the Gerson’s Marina in Corumbá (Brazil), around 200m from the southern banks of the Paraguay River. It consists of light yellow siltstone and dark gray limestone, with total thickness of 8.25m (Figure 4. 6).

At the base of the section, there are approximately 2.5m of massive siltstone with several lenses of sandstone - with tens of centimeter wide and a few centimeters thick. Around 0.4m from the basal level, there are fossil occurrences of *Corumbella werneri* and *Cloudina carinata*. Above the siltstone, lies 5.75m of recrystallized limestones arranged as thick massive beds showing planar cross-stratification or as amalgamated sets of thin beds with wavy contacts.

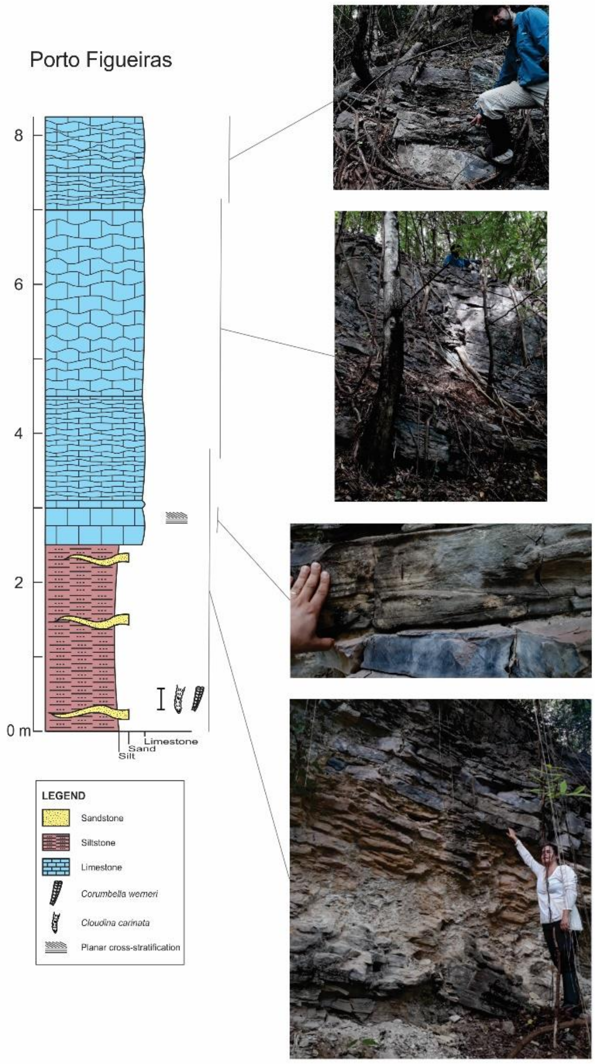


Figure 4. 6. Lithostratigraphic section of the Porto Figueiras (Marina do Gerson) section, in the municipality of Corumbá, Mato Grosso do Sul State, Brazil. UTM Coordinates zone 21K 0433880mE / 7899144mS.

4.1.6. DISCUSSION ON LITHOSTRATIGRAPHIC RECORD

The results presented for Tamengo and Guaicurus formations in the region of Corumbá and Ladário Municipalities were obtained from the geological sections in five localities. These sections were lithologically described, and the fossil occurrences were positioned in the updated logs.

The description of lithology represents an advance to understand the package, yet, it is not itself enough to understand the sequence stratigraphy and for the reconstruction of deeper analysis such as paleobathymetry for example. It is recommended further integrative and complementary research, especially on sequence stratigraphy, necessary for more robust paleoenvironmental reconstructions.

Further investigation regarding the lithologic characterization of Tamengo and Guaicurus formation must be done. Some efforts have already been made in order to individualize the siltstones of the upper portion of Tamengo Formation and the siltistones of the base of Guaicurus Formation. According to Fazio et al. (2019) at Corcal quarry section, the Guaicurus Formation is composed for yellow siltstone with some carbonate, but this limit is not completely clear. Still according to Fazio et al. (op. cit.) there is a huge marine paleoenvironmental shift marked by petrography, X-ray diffraction and mineral composition between Tamengo and Guaicurus formations, which is clearer at Laginha quarry than other sections.

4.2. STUDIED FOSSIL ASSEMBLAGE OF TAMENGO AND GUAICURUS FORMATIONS

Twenty-six species integrate the studied fossil assemblage of Tamengo and Guaicurus formations from five sections in Corumbá and Ladário regions. Three sessile benthic biomineralizing metazoan species were described from Tamengo Formation: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982. Additionally, sponge spicules were recovered, but a question remains regarding its original composition, if it is calcareous or siliceous.

Regardless of the original composition, these sponge spicules present a calcareous composition.

The taxonomy for four ichnoespecies *Didymaulichnus lyelli* and *Multina minima* Uchman, 2001 from Guaicurus Formation, and for the two other new occurrences identified as *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999, is presented from Tamengo Formation. Additionally, the taxonomy for three species of Vendotaenids *Vendotaenia antiqua* Gnilovskaya, 1971 from Tamengo Formation, *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) is presented from Guaicurus Formation.

The micropaleontological content of Tamengo Formation consists of one species of permineralized and fifteen species of organic-walled microfossils. Permineralized microfossils identified as *Chuaria circularis* Walcott, 1899, and a small chamber microfossil (sponge gemmule?) with uncertain taxonomic affinity inserted in the reticular surface of a specimen of a putative poriferous. This possible sponge gemmule is similar to that described in Du et al. (2014) from Doushantuo Formation. The organic-walled microfossils are mainly represented by small and spheroidal species without process and ornamentation (Table 4. 2).

Table 4. 2. Described species from Tamengo and Guaicurus formations.

	Paleoecology	**Species**	**Locality (Brazil)**	**Formation**
Biomineralizing Metazoan	Sessile-Epibenthic	*Cloudina lucianoi* (Beurlen & Sommer, 1957)	Corcal, Cacimba, Sobramil,	Tamengo,
	Sessile-Epibenthic	*Cloudina carinata* Cortijo et al., 2010	Porto Figueiras	Tamengo
	Sessile-Epibenthic	*Corumbella werneri* Hahn et al., 1982	Corcal, Cacimba, Sobramil	Tamengo
Biomineralizing Microfossils	Sessile-Epibenthic	Undeterminated sponge spicules and wall fragments	Sobramil	Tamengo
	Undetermined	Undeterminated microfossil chamber sponge gemmule?	Sobramil	Tamengo
Vendotaenids	Sessile-Epibenthic	*Vendotaenia antiqua* Gnilovskaya, 1971	Corcal	Tamengo, Cerradinho and Bocaina
	Sessile-Epibenthic	*Eoholynia corumbensis* Gaucher et al., 2003	Laginha	Guaicurus

	Sessile-Epibenthic	*Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979)	Laginha	Guaicurus
Ichnofossils	Vagile-Epibenthic	*Gordia marina* Emmons, 1844	Corcal	Tamengo
	Vagile-Epibenthic	*Pilichnus cf. P. dichotomus* Uchman, 1999	Corcal	Tamengo
	Vagile-Endobenthic	*Multina minima* Uchman, 2001	Laginha	Tamengo, Guaicurus
	Vagile-Endobenthic	*Didymaulichnus lyelli* (Rouault, 1850)	Laginha	Guaicurus
Permiineralized microfossils	Possible marine planktic	*Chuaria circularis* Walcott, 1899	Cacimba	Tamengo
Organic-walled microfossils	Possibly marine planktic	*Arctacellularia januarensis* Denezine, 2018 *nomem nudum*	Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia ternata* (Timofeev, 1966)	Cocal	Tamengo
	Possibly marine planktic	*Leiosphaeridia crassa* (Naumova, 1949)	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia jacutica* (Timofeev, 1966)	Corcal, Cacimba	Tamengo
	Possibly marine planktic	*Leiosphaeridia minutissima* (Naumova, 1949)	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia tenuissima* Eisenack, 1958	Corcal, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Bavlinella faveolata* Vidal, 1976	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Bambuites erichsenii* Sommer, 1971	Porto Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia obsuleta* (Naumova, 1949)	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Synsphaeridium* sp.	Corcal	Tamengo
	Possibly marine planktic	*Jacutianema* sp.	Corcal	Tamengo
	Possibly marine planktic	*Lophosphaeridium* sp.	Corcal	Tamengo
	Possibly marine planktic	*Ostiama microcystis* Hermann in Timofeev et al., 1976	Corcal	Tamengo
	Possibly marine planktic	Gen1. Sp. 1 (flask-shaped) Chitinozoan like	Cacimba	Tamengo
	Possibly marine planktic	*Navifusa* sp.	Corcal	Tamengo

Biomineralizing species

Two categories of biomineralizing species were recovered in Tamengo Formation: biomineralizing metazoan and biomineralizing microfossil species. Biomineralizing metazoan comprises three cnidarian species and undetermined remains of sponge. Three cnidarian species are: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010 and *Corumbella werneri* Hahn et al., 1982.

The taxonomy of *Cloudina* Germs, 1972 was updated and had its diagnosis emended in Adôrnoet al. (2017). The type-material of *Cloudina lucianoi* (Beurlen &

Sommer, 1957) was revised and compared with other *Cloudina* species, especially *Cloudina hartmanae* Germs, 1972. The comparative study between these two species was based on objective morphological and morphometric criteria, which allowed to propose that *Cloudina hartmanae* should be considered a junior synonym of *Cloudina lucnianoi*. Based on this concept, *Cloudina lucianoi* occupied the position of type-species of genus and had its geographical distribution extended to all continents, revealing a great importance for paleozoogeographic studies and biostratigraphic correlation. The list of valid *Cloudina* species was updated and composed of five species: 1) *Cloudina riemkeae* Germs, 1972, 2) *Cloudina lucianoi* (Beurlen & Sommer, 1957), 3) *Cloudina carinata* Cortijo et al., 2010, 4) *Cloudina ningqiangensis* Cai et al., 2017, 5) *Cloudina xuanjiangpingensis* Cai et al., 2017 (Table 4. 3).

Table 4. 3. Updated list of valid species of *Cloudina* Germs, 1972 after Adôrno et al. (2017) and Cai et al. (2017).

SPECIES	**COUNTRY**
1. *Cloudina lucianoi* (Beurlen & Sommer, 1957)	Namibia, Brazil, Paraguay, China, USA, Canada, Mexico, Spain, Oman, Siberia
2. *Cloudina riemkeae* Germs, 1972	Namibia, Brazil? Uruguay, Russia
3. *Cloudina carinata* Cortijo *et al.*, 2010	Spain, Siberia, Brazil*
4. *Cloudina ningqiangensis* Cai et al., 2017	China
5. *Cloudina xuanjiangpingensis* Cai et al., 2017	China

*This is the first occurrence of *Cloudina carinata* in South America.

From the eleven described species of *Cloudina*, six species has taxonomic issues. Two were transferred to other genus, three were synonymized and one does not followed the statement of the International Code of Zoological Nomenclature (ICZN). Considering these issues, a discussion for each species with problematic issues is presented below.

Remarks are presented dealing with the taxonomic position of two *Cloudina* species: *Cloudina waldei* Hahn & Pflug, 1985, *Cloudina? borrelloi* Yochelson & Herrera, 19. Considering the original description for *Cloudina waldei* type-material presented in Hahn & Pflug (1985), the skeleton has wrinkled walls instead of funnel-in-funnel or even cone-in-cone skeletal architecture. Based on this description, *Cloudina waldei* would fit better as *Sinotubulites waldei* (Hahn & Pflug, 1985). Unfortunately, the type-materials of this species are at the Institute of Geosciences, University of Marburg (responsibility of Prof. Gerhard Hahn) and in the Institute of Geosciences of the University of Giessen (Prof. Hans D. Pflug, deceased) and therefore was not accessed during this research. Tubes of lower Cambrian from the locality named Sierra de Villicum, Argentina, were identified as *Cloudina? borrelloi* Yochelson & Herrera, 1974. This material was subsequently studied in Hahn & Pflug (1985) and transferred to *Acuticloudina borrelloi* (Yochelson & Herrera, 1974) (Conway Morris et al., 1990; Brasier et al., 2017).

Three species are synonymized: *Cloudina hartmanae* Germs, 1972, *Cloudina lijiagouensis* Zhang et al., 1992 and *Cloudina sinensis* Zhang et al., 1992. For *Cloudina hartmanae*, as earlier discussed in this text, based on Adôrno et al. (2017), it is a junior synonym of *Cloudina lucianoi*. The other two species were revised in Cai et al. (2017). This study includes analysis of the type-material from Dengying Formation, China: *Cloudina lijiagouensis* Zhang et al., 1992 and *Cloudina sinensis* Zhang et al., 1992. The holotype of *Cloudina lijiagouensis* was synonymized with *Cloudina hartmanae*, and as earlier discussed, it is considered a junior synonym of *Cloudina lucianoi* in Adôrno et al. (2017). It was also proposed in Cai et al. (2017) that a part of the *Cloudina sinensis* illustrated material in Zhang et al. (1992) is synonymized with *Cloudina hartmanae* and another part synonymized with *Cloudina ningqiangensis* Cai et al., 2017.

The validity of *Cloudina latilabrum* Meira, 2011 *nomem nudum* is questionable considering Article 8.1, Chapter 3 of the International Code of Zoological Nomenclature (ICZN). The ICZN determines that a valid species must have its proposition in a scientific journal of wide circulation and also printed on paper. What’s more, Article 9, Chapter 3 of the ICZN also defines “*What does not constitute published work*” and it includes, among others, Ph.D. thesis and dissertations explicitly. Furthermore, Becker-Kerber (2015) presented arguments to consider *Cloudina latilabrum* as a synonym of *Cloudina lucianoi*, which present small morphological variations due to its taphonomic processes.

Among the five valid *Cloudina* species, two species occur in uppermost Ediacaran Tamengo Formation sections of Brazil: *Cloudina lucianoi* and *Cloudina carinata* (Table 4. 3). *Cloudina lucianoi* has the greatest geographic distribution in the sections of Tamengo Formation at Corumbá and Ladário regions with occurrences recorded in four studied sections: Corcal quarry, Porto Sobramil and Ecoparque da Cacimba (Figure 4. 7) (Adôrno et al., 2017; 2018). *Cloudina lucianoi* also occurs in coeval strata in Paraguay (Warren et al., 2011), Namibia (Germs, 1972), China (Cai et al., 2017), USA (Hagadorn & Wagoner, 2000), Canada (Hofmann & Mountjoy, 2001); Mexico (Sour-Tovar et al., 2007), Spain (Cortijo et al., 2010); Oman (Conway Morris, 1990) and Russia (Terleev et al., 2011).

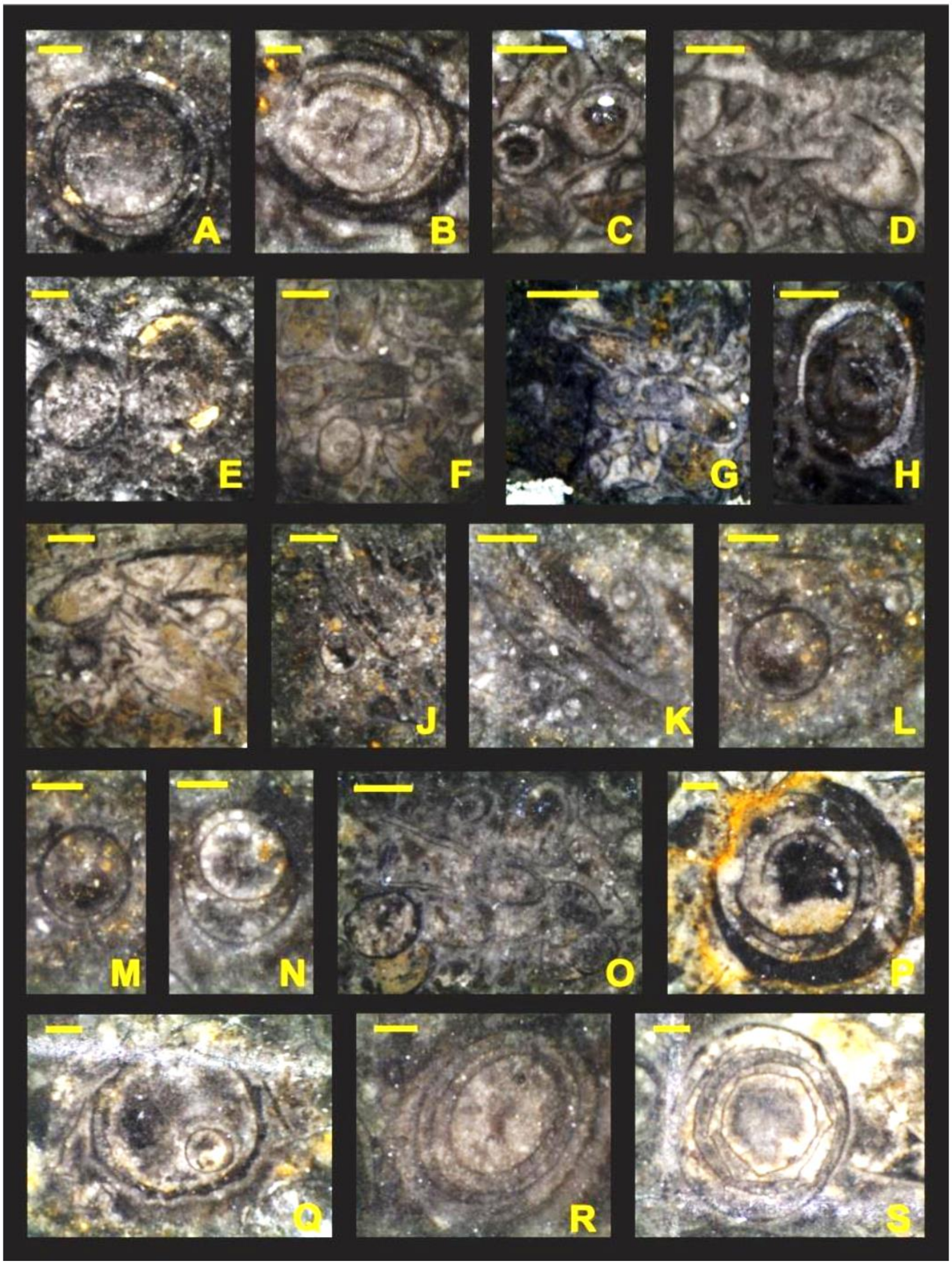


Figure 4. 7. Polished sections with specimens of *Cloudina lucianoi* (Beurlen & Sommer, 1957). Section 1153: A-C and E, specimens in transverse section (Obs: Note the funnel-within-funnel structure); D, specimens in longitudinal section. Section 1154: F, overview of the sample; G, I, longitudinal section emphasizing the thickness of the wall of the skeletal body, including transverse sections; H, Specimen possibly recrystallized. Section 1157: J, K and N, longitudinal sections highlighting the variation in diameter along the wall of the skeletal body; cross sections are also presented; L, M, transverse section (note the funnel-within-funnel structure). Section 1158: O, transverse and longitudinal sections; P–S, transverse sections (note the funnel-in-funnel structure). Scale bars: A, B, E, L, M, N, P–S = 500 µm; D, H, K = 1000 µm; C, F, G, I, O = 2000 µm (Extracted from Adôrno et al., 2017).

The occurrence *Cloudina carinata* Cortijo et al., 2010 is recovered from siltstones of the Tamengo Formation in the locality named Porto Figueiras, Municipality of Corumbá, Mato Grosso do Sul State, Brazil. This occurrence is the first record of this species in the

American continent (Figure 4. 8), expanding the geographic distribution of this species, whose occurrence has been documented in sections in Spain and Siberia (Cortijo et al., 2010; 2015b; Terleev et al., 2011).

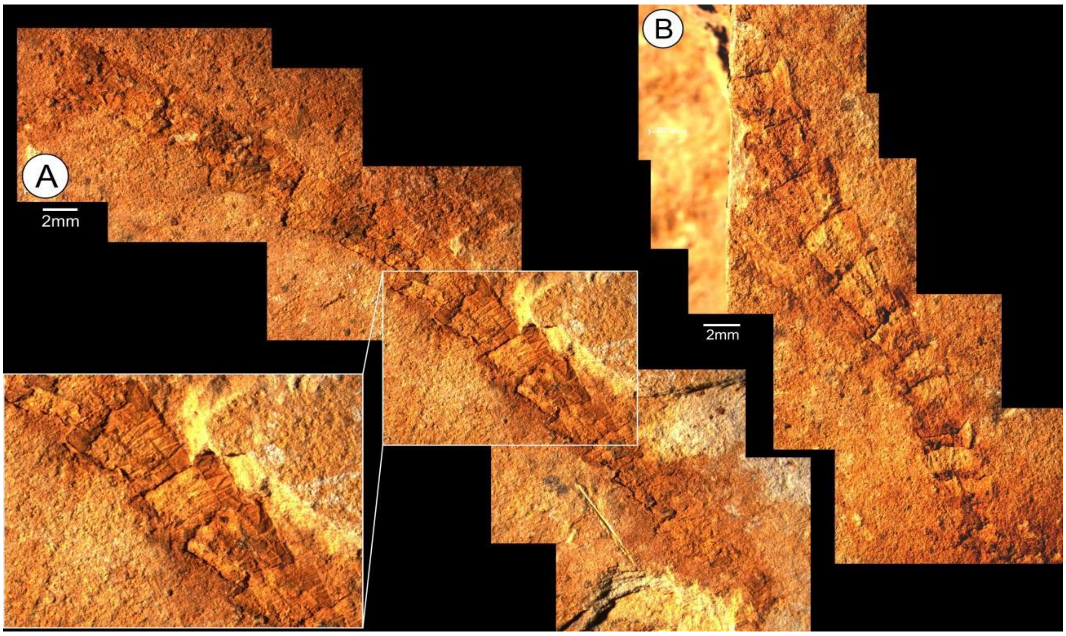


Figure 4. 8. Two specimens of *Cloudina carinata* Cortijo et al., 2010, Tamengo Formation, Porto Figueiras section, Corumbá Municipality, Mato Grosso do Sul State, Brazil. UTM coordinates Zone 21K 433880.06m E/7899144.76 m S, illustrated specimen MAF-522 (original number MP-717).

The biological affinities of the sessile benthic metazoan *Corumbella werneri* Hahn et al., 1982 remain under discussion. Some publications have considered *Corumbella werneri* as conulariids, and more recently, new interpretations of the morphology and the fossil diagenesis have led to alternative proposition, considering this species as closer allied to cloudinids. In fact, there are currently three diagnosis for *Corumbella werneri*, the original presented in Hahn et al. (1982), the other one from Babcock et al. (2005) and the last one published in Pacheco et al. (2015). These three diagnoses include conflicting characteristics, including interpretations of morphological features such as the presence of carina in the internal portion of the septa. Babcock et al. (2005) describe the presence of carina as a diagnostic property of the genus and species, but in the emended diagnosis presented in Paccheco et al. (2014), it is explicitly stated that such structure is not present.

Furthermore, it was proposed that *Corumbella weneri* would have tetragonal geometry and a longitudinal midline (mandatory element for conulariids) (Pacheco et al., 2010, Van Iten et al., 2014, Pacheco et al., 2015). Walde et al. (2018), on the other hand, argue that such longitudinal median lines are crack-lines formed due to diagenetic compaction. The argument that supports this interpretation is multiple and based on the fact that crack-lines occur only in incomplete skeleton. Warren et al. (2011) examined rocks of the Itapucumi Group, Paraguay, where *Corumbella werneri* occurs completely cylindrical and without the median line or crack-line (Warren, 2011; Warren et al. 2012; 2014). New occurrences of specimens with no compaction features, nor crack-lines, and seems to corroborate the assertion that such longitudinal lines are occasionally present in *Corumbella werneri* skeleton could be interpreted as postmortem processes (Figure 4. 9) (Walde et al., 2015; Erdtmann & Walde, 2016; Walde et al., 2018; Adôrno et al., in preparation, appendix 2).

Corumbella werneri is mostly associated with the siltstone layers of Tamengo Formation (Hahn et al., 1982; Walde et al., 2015; Erdtmann & Walde, 2016; Walde et al., 2018, Adôrno et al., 2017; 2018). This genus is thus far monospecific, occurring in the uppermost Ediacaran Tamengo Formation, Brazil and in the coeval Itapucumi Group, Paraguay (Warren et al., 2011). Occurrences of undetermined species assigned as *Corumbella* sp. have been described in other localities such as Sete Lagoas Formation, Bambuí Group, Brazil (Warren et al., 2014) and Wood Canyon Formation in the United States of America (Hagadorn & Wagoner, 2000, Smith et al., 2016; 2017).

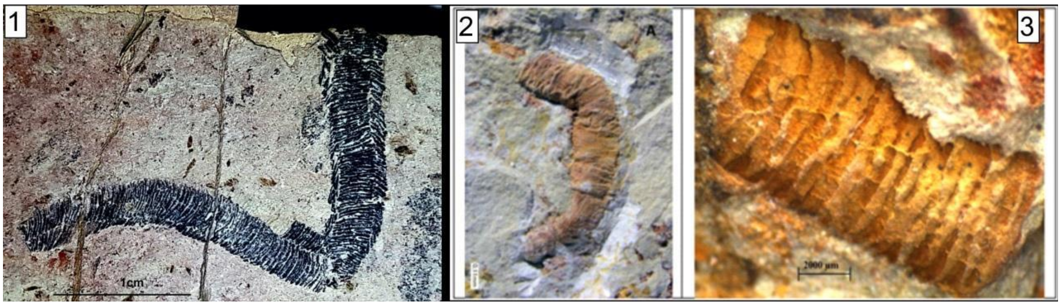


Figure 4. 9. Specimens of *Corumbella werneri* Hahn et al., 1982 from the Tamengo Formation, Corumbá Group, Corumbá Municipality, Mato Grosso do Sul State, Brazil. 1) Adult specimen with exceptional preservation of the original cuticle MAF-523. 2) Possible basal part (juvenile form?), CP-746. 3) Median portion of *Corumbella werneri* tube showing cylindrical geometry and absence of midline, CP-747 (Walde et al., 2018).

The sponge spicules were recovered from Tamengo Formation at Corcal quarry, Porto Sobramil and Laginha quarry sections. The mineralized spicules were recovered isolated and in an imbricated assemblage possibly related to sponge wall (Figure 4. 14: 13.3). These mineralized putative spicules, one sponge gemmule and wall fragments are remains of sessile benthic biomineralizing metazoan possibly related to marine sponge (Adôrno et al., in preparation, appendix 2).

Vendotaenids

Three species of vendotaenids occur in the studied sections: *Vendotaenia antiqua* Gnilovskaya, 1971, *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979). *Vendotaenia antiqua* constitutes the benthic fossil assemblage of Cerradinho, Bocaina (Gaucher et al., 2003) and Tamengo Formation (Figure 4. 10) (Adôrno et al., in preparation, appendix 2). *Eoholynia corumbensis* and *Tawuia dalensis* are benthic fossil assemblage and are restricted to Guaicurus Formation.

The systematic taxonomy for *Vendotaenia antiqua*, *Eoholynia corumbensis* and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) was presented in Gaucher et al. (2003). *Eoholynia corumbensis* was assigned as remains of eucaryotic algae, probably Phaeophyta or Rhodophyta. *Vendotaenia antiqua* is assigned as probably abandoned sheaths of sulfide-oxidizing organotrophic bacteria related to the Beggiatoaceae (Vidal, 1989; Gaucher et al., 2003, Adôrno et al., in preparation, appendix 2). *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) were probably photosynthesizers species assigned to cyanobacteria (Steiner et al., 1996).

On preservational mode, *Vendotaenia antiqua* was recovered in three distinct modalities: as impressions from red siltistone bedding (Figure 4. 11), as organic-walled remains and as permineralized fragments (Figure 4. 14: 9) (Adôrno et al., in preparation, appendix 2).

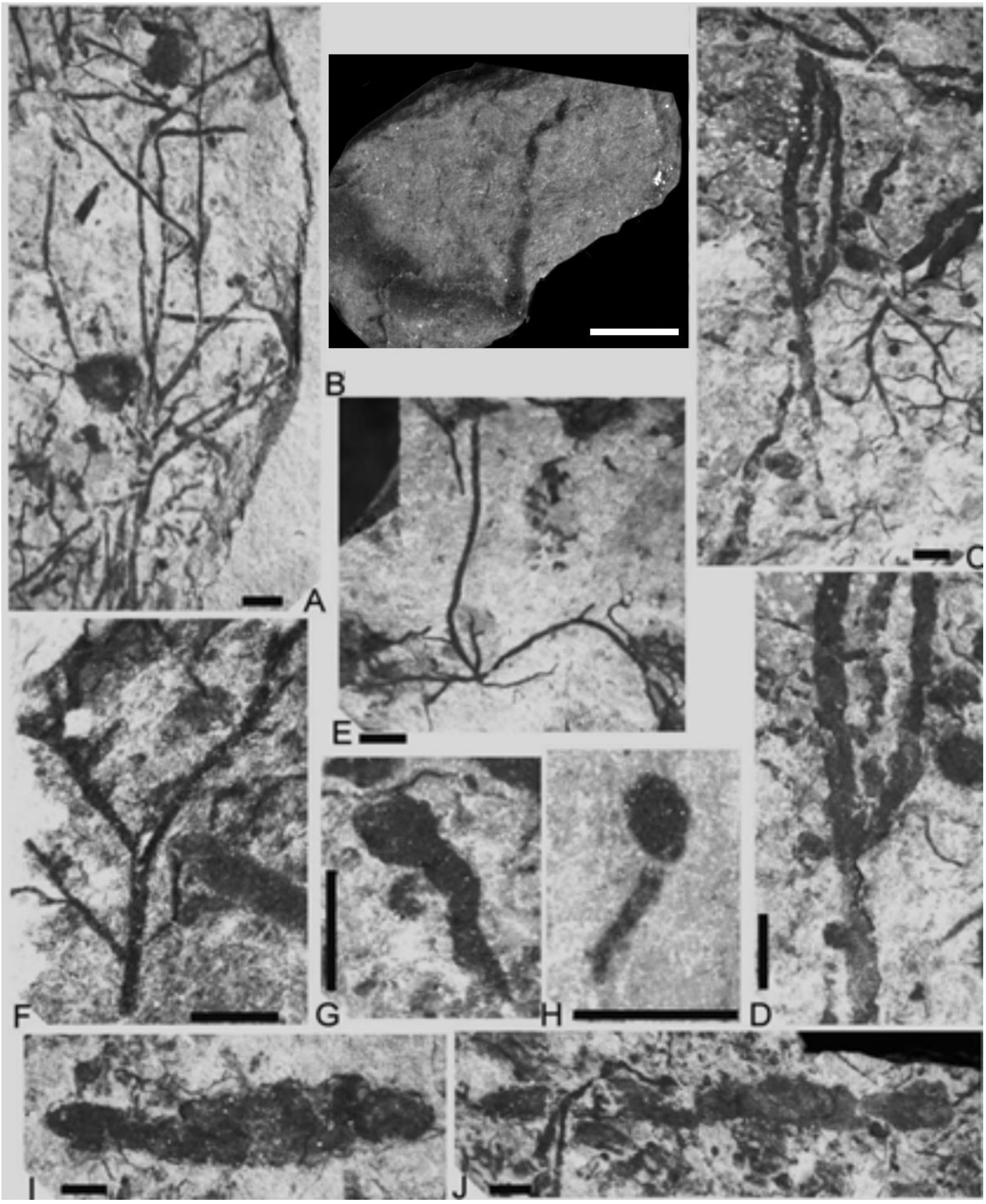


Figure 4. 10. *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) from the bedding surface of the gray siltstones of the lower portion of the Guaicurus Formation in the Laginha quarry, lower Cambrian. A-H) *Eoholynia corumbensis*; A) Full rectilinear thalli (FCDP 3613 specimen) with multiple branches; B) Specimen from Laginha quarry, Guaicurus Formation (original number MP 3225) recorded during this doctorate; C-D) Holotype PDGF 3615, with main branch covered with spherical bodies (sporangia); E) PDGF Paratype 3222 with intense ramifications from the main stem; F) Rectilinear thalli; G) terminal sporangium; H) FDCP specimen 3616, terminal sporangium parenchyma; I-J) *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979); I) slightly curved specimen FCDP 3617; J) rectilinear specimen with numerous overlapping of *Eoholynia* stems. Scale bars have 1 mm (modified from Gaucher et al., 2003, with the inclusion of illustration of studied specimen B).

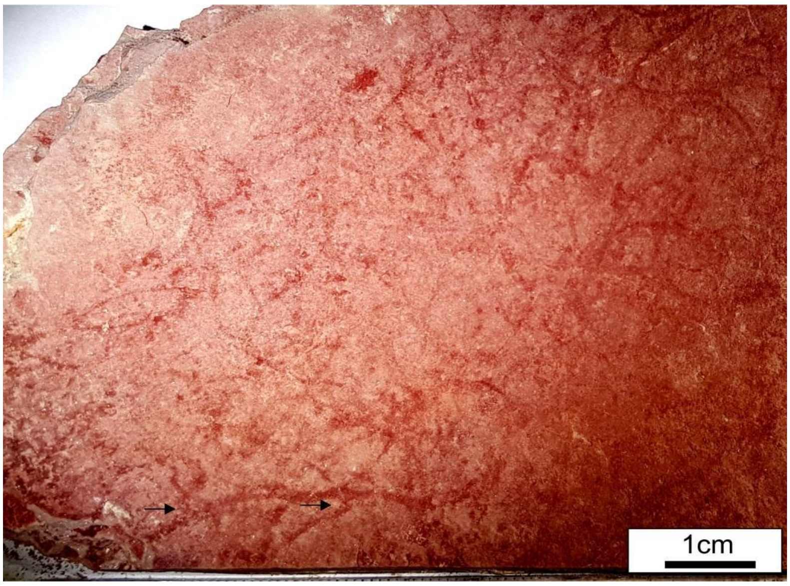


Figure 4. 11. *Vendotaenia antiqua* Gnilovskaya, 1971 from the surface of the red siltstone of the upper portion of the Tamengo Formation, sample MAF-516, locality Corcal quarry.

Ichnofossils

Four ichnospecies have occurrences recorded in this work: *Didymaulichnus lyelli* (Rouault, 1850), *Multina minima* Uchman, 2001, *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999. These four ichnospecies integrate the updated ichnoassemblage for upper Corumbá Group (Parry et al., 2017; Adôrno et al., in preparation, appendix 2).

Didymaulichnus lyelli is represented by small excavations around 5 mm in diameter, probably produced by vagile endobiont organisms. *Multina minima* is represented by complex patterns microtunnels, 2mm diameter, that represent excavations possibly associated with small, endobiont organisms that are able to penetrate portions made up of soft and unconsolidated sediment. *Gordia marina* represents tracks possibly produced by vagile epibiont organisms, consisting of simple curved or loop-like surficial tracks with 0.5 to 2 mm diameter that are possibly associated with substrate exploratory, vagile epibiont organisms at the water-sediment interface. *Pilichnus cf. P. dichotomus* consists of complex and bifurcated excavations, representing epibiont organisms with elaborate excavation strategies (Figure 4. 13).

Didymaulichnus lyelli have occurrences restricted to Guaicurus Formation. *Multina minima* occurs at the top of the Tamengo Formation and at the base of the Guaricurus Formation in the section of the Laginha quarry (Figure 4. 12) (Parry et al., 2017). *Gordia marina* and *Pilichnus cf. P. dichotomus* are described herein in the Tamengo Formation at the Corcal quarry section (Figure 4. 13) (Adôrno et al., in preparation, appendix 2).

Additional occurrences of *Didymaulichnus lyelli* are recorded in Badhaura Formation, Permian of India (Kulkarni & Borkar, 2014) and in Bell Island and Wabana groups, Ordovician of Canada, Newfoundland (Fillion & Pickerill, 1990). *Multina minima* besides the occurrences in the Tamengo and Guaicurus formations, also occurs in the Grupo Hecho Pirineus, Eocene in Northern Spain (Uchman, 2001) and lower Cretaceous of Bulgaria (Uchman & Tchoumatchenco, 2003). *Gordia marina* are also recovered from Spain (Vidal et al., 1994), Canada and China (Crimes, 1987) and the United States of America (Hagadorn & Wagoner, 2000). *Pilichnus cf. P. dichotomus* are also recovered from Cambrian of China (e.g., Zhang et al., 2007) and Canadá (Mángano, 2011) and Ordovician shallow-marine deposits (Mikulás, 2003), and Carboniferous turbidities of Czech Republic (e.g. Mikulás et al., 2004). Considering these publications mentioned above, excepted for *Gordia marina*, occurrences in Tamengo Formation represent the oldest record of *Didymaulichnus lyelli*, *Multina minima* and *Pilichnus cf. P. dichotomus*. *Gordia marina* occurs in uppermost Ediacaran strata in Spain and also occurs in the Phanerozoic strata (Hofmann, 1990; Vidal et al., 1994).

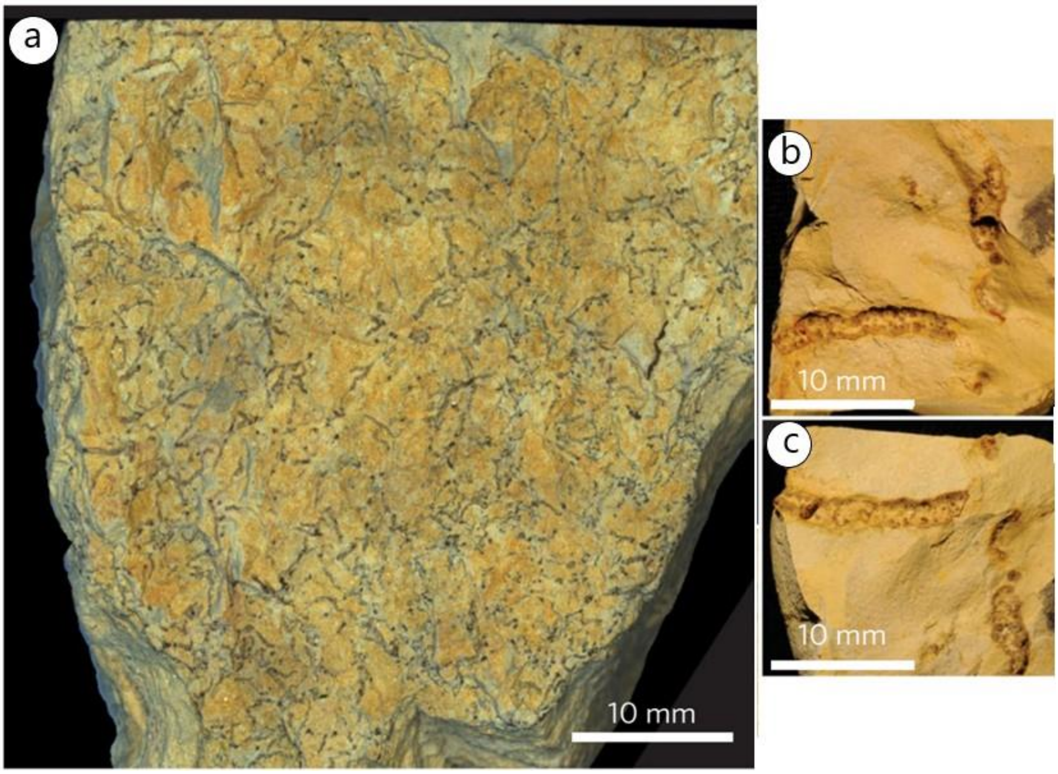


Figure 4. 12. Photographs of hand samples and SEM images of the ichnofossils *Multina minima* (Uchman, 2001) from the Tamengo and Guaicurus Formation and *Didymaulichnus lyelli* (Rouault, 1850) from the Guaicurus Formation, Laginha quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil. a) *Multina minima* specimens; b-c) part and counterpart of bilobed traits of *Didymaulichnus lyelli* seen on the bedding surface (modified from Parry et al., 2017).

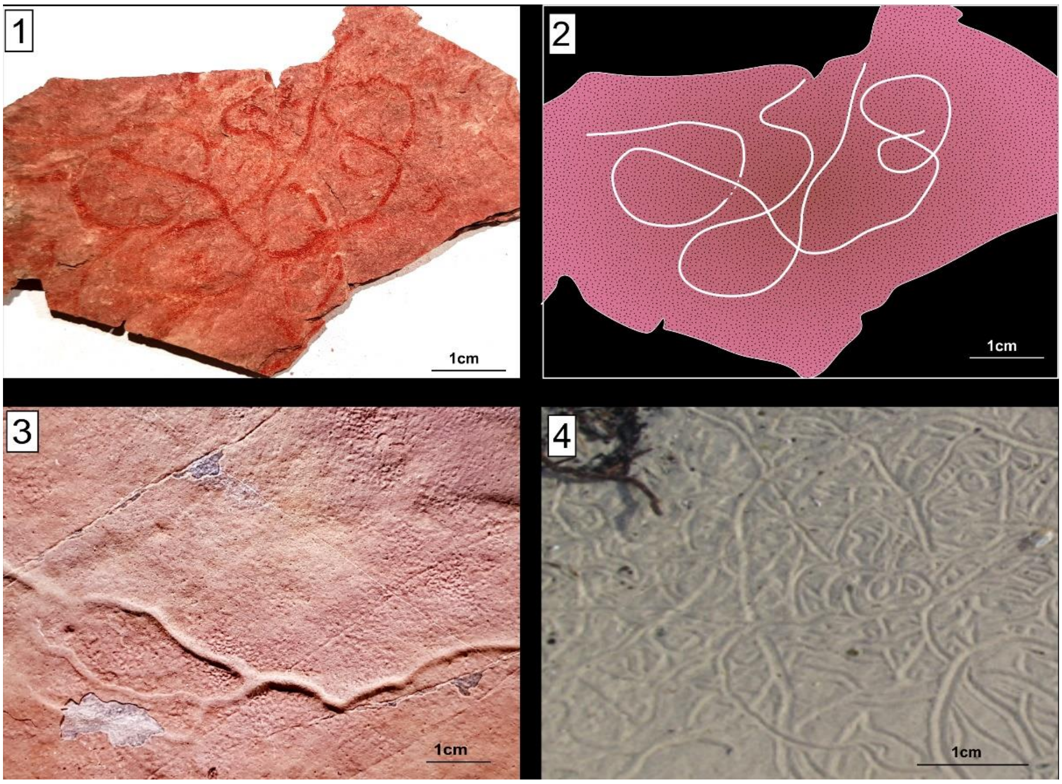


Figure 4. 13. Trace fossils of the Tamengo Formation, Corcal quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil. 1-2) *Gordia marina* Emmons, 1844; 1. Sample MAF-517; 2) schematic representation of the trace fossil 1; 3) *Pilichnus cf. P. dichotomus* Uchman, 1999, Sample MAF-520; 4) Wormtrack in recent beach sand.

Permineralized microfossils

Permineralized vesicles assigned to *Chuaria circularis* Walcott, 1899, were recovered from pelites of Tamengo Formation at Ecopoarque Cacimba, Corumbá Municipality, Mato Grosso do Sul State, Brazil section. This permineralized vesicles were assigned with *Chuaria circularis* considering the size of the specimens (between 500 and 600 µm), their subcircular morphology and the absence of surface ornamentation, it is assigned as *Chuaria circularis* (Ford & Breed, 1973; Gussow, 1973; Vidal et al., 1993). This species was already been reported in pelites of Tamengo Formation, in the locality of Ecoparque Cacimba (Pacheco, 2012). However, this occurrence was related to only one specimen preserved as a carbonaceous impression, reported to be associated with *Corumbella werneri* Hahn et al., 1982. In addition, few other specimens of *Chuaria circularis* were recovered from palynological macerations (Pacheco, 2012). Permineralized *Chuaria circularis* represents unprecedented preservation and recovery (Figure 4. 14: 5-7) (Adôrno et al., in preparation, appendix 2).

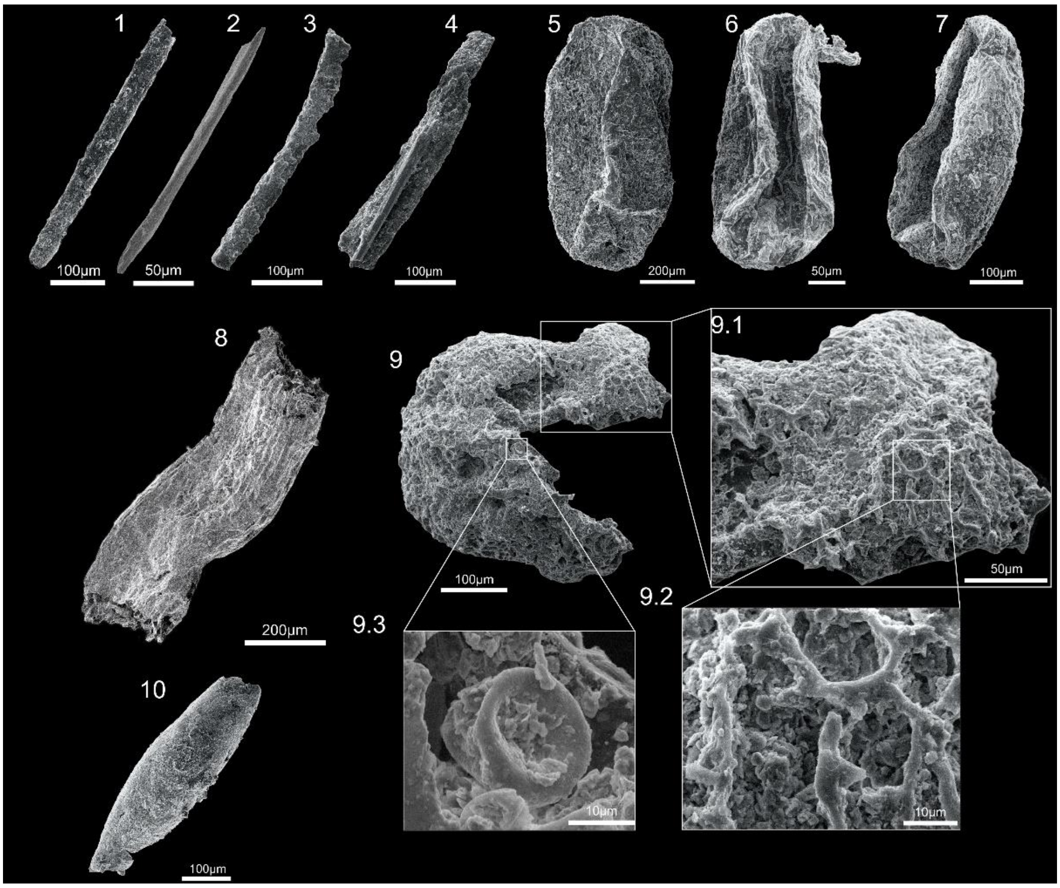


Figure 4. 14. Mineralized and permineralized microfossils from the Tamengo Formation. 1-4 and 13) putative mineralized sponge spicules, 1) MP-1713 Needle-shaped spicule fragment, Porto Sobramil; 2) MP-1649 outcrop of Corcal quarry; 3) MP-1710, Porto Sobramil; 4) MP-1667- Fragment acicular (spicule) fragment encrusted in rock, Laginha quarry; 5-7) Permineralized *Chuaria circularis* Walcott, 1899, 5) MP-1603, Ecoparque Cacimba, 6-7) MP-1607 Ecoparque Cacimba. OBS: Note flattened and folded vesicular appearance on all three specimens; 8) Permineralized fragment of *Vendotaenia antiqua* Gnilovskaya, 1971 MP-1656 Pedreira Corcal, 9) MP-1710 putative mineralized sponge wall fragment, Porto Sobramil, 9.1 Enhanced for cross-linked appearance formed by needles (putative sponge mineralized spicules); 9.2. Even larger zoom showing detail reticulated structure; 9.3. Small microfossil chamber with uncertain taxonomic affinity (sponge gemmule?); 10) Unamed permineralized microfossil vase-shaped microfossil MP-1607 Ecoparque Cacimba.

Organic-walled microfossils

Fifteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen 1. sp. 1 (chitinozoan like flask-shaped).

Additionally, organic fragments of the species *Vendotaenia antiqua* Gnilovskaya, 1971 were recovered in palynological macerations.

From these fifteen species of organic-walled microfossils, five have occurences in both Tamengo and Dengying formations: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Ostiama microcystis*. Six of them also occur in the Nomtsas Formation, Namibia: *Bavlinella faveolata*, *Ostiama microcystis*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima*, *Leiosphaeridia minutíssima*. Four of the fifteen organic-walled microfossils of Tamengo Formation also occur in Tagatiya Guazu Formation, Paraguay: *Ostiama microcystis*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia minutissima* and Gen.1 sp. 1 (Adôrno et al., in preparation, appendix 2).

The organic-walled microfossil assemblage of Tamengo, Nomtsas, Tagatiya Guazu and Dengying formations, constitutes small and simple sphaeromorphs (Adôrno et al., in preparation, appendix 2). This assemblage is described as typical for uppermost Ediacaran sections globally distributed (Figure 4. 15; Figure 4. 16 and Figure 4. 17) (Knoll, 1996; Vidal & Moczydlowska-Vidal, 1997; Gaucher, 2000).

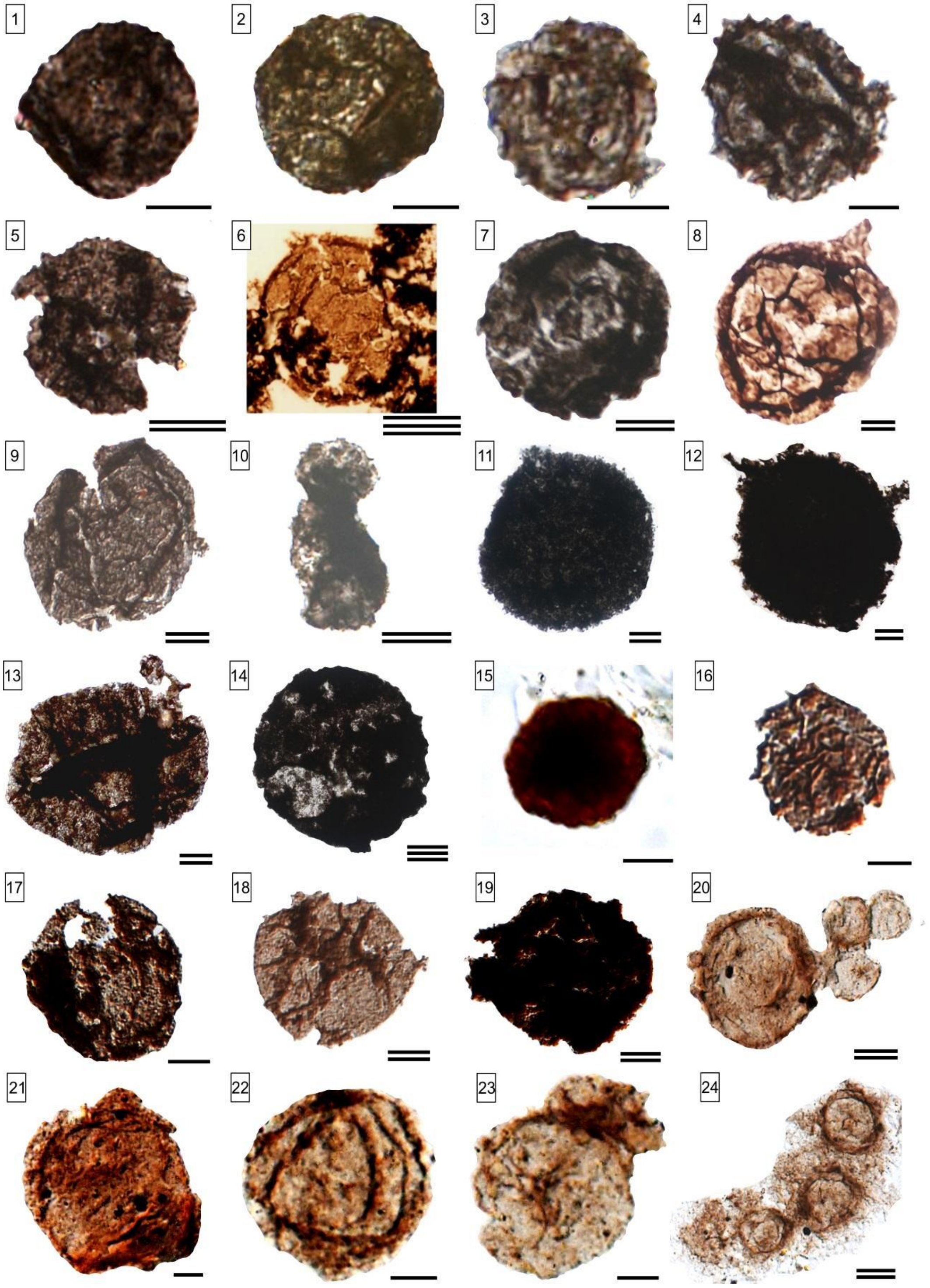


Figure 4. 15. Sphaeromorph organic-walled microfossils from acidic macerations. 1-15) Coming from the Tamengo Formation, Corumbá Group (Brazil); 16-19) From Dengying Formation, China; 20-24) From Tagatiya Guazu Formation, Paraguay. 1-5) *Leiosphaeridia crassa* (Naumova, 1949), specimens and England Finder slide location: 1. CP-941 (original slide number MP-1632) L34[2]; 2. CP-942 (original slide number MP-1626) Q43[3]; 3 MP1626 Y57[2]; 4. CP-943 (original slide number MP-1630) T45; 5. CP-944 (original slide number MP-1633) H54[1]; 6) *Leiosphaeridia tenuissima* Eisenack, 1958: lâmina CP-793; 7) *Lophosphaeridium sp*.: CP-941 (original slide number MP-1632) K53[1]; 9) *Leiosphaeridia obsuleta* (Naumova, 1949): CP-943 (original slide number MP-1630) T45[3]; 10) *Jacutianema* sp.: CP-945 (original slide number MP-1621) G43[3]; 11-12, 19) *Leiosphaeridia obsuleta:* 11. CP-946 (original slide number MP-1714) N55[3], 12. CP-940 (original slide number 1706) V53[4], 19. CP-949 (original slide number MP-2218) S41[4]; 13-14) *Leiosphaeridia jacutica* (Timofeev, 1966): 13. MP1626 T52, 14. CP-947 (original slide number MP-1714) M44; 15) *Bavlinella faveolata* Vidal, 1976: CP-948 (original slide number MP-1636) O46[4]; 8, 16-

18, 20-23) *Leiosphaeridia minutissima* (Naumova, 1949): 8. CP-941 (original slide number MP-1632) L40[2], 16. CP-950 (original slide number MP-2183) E50[3], 18. CP-951 (original slide number MP-2203) B42[1], 20. CP-952 (original slide number MP-4312-II) U40; 21. CP-952 (original slide number MP-4312-II) H27[2], 22) CP-952 (original slide number MP-4312-II) F43. 23. CP-952 (original slide number MP-4312-II) L41[4]; 20, 24) *Ostiama microcystis* * small vesicles: 20. CP-952 (original slide number MP-4312-II) U40, 24. CP-952 (original slide number MP-4312-II) U24. Scale bar: single= 5µm, double= 10 µm and triple=50µm.

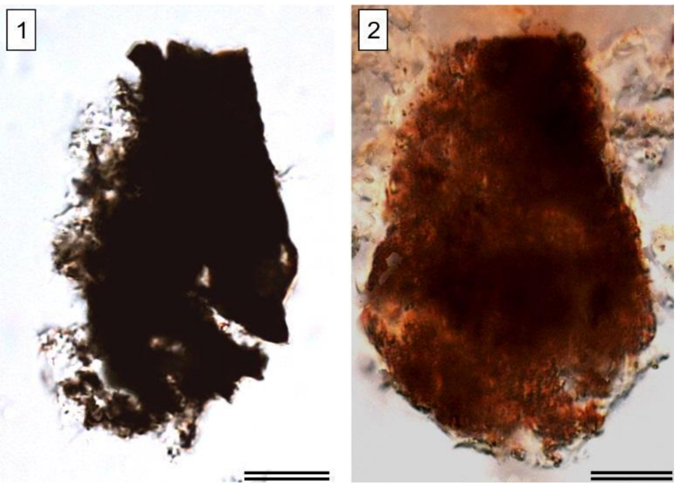


Figure 4. 16. Gen. 1 sp.1. Flask-shaped organic-walled microfossils (Chitinozoa like) recovered from acidic maceration. 1) Specimen and England Finder slide location CP-953 (original slide number MP-1590) C37[1], Tamengo Formation, Corumbá Group (Brazil); 2) CP-952 (original slide number MP-4312)-Q24[2] from Tagatiya Guazu Formation (Paraguay). Scale bar = 10µm.

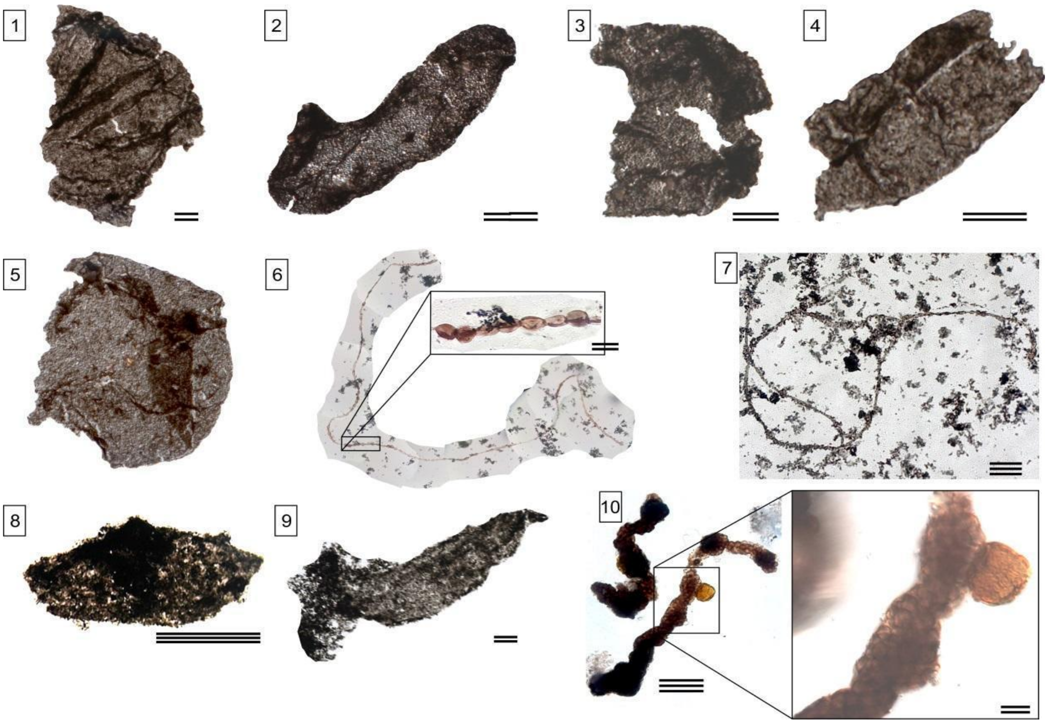


Figure 4. 17. Miscellaneous palynomorphs recovered from acidic macerations. 1-9) Samples from Tamengo Formation, Corumbá Group, Brazil; 10) Specimens from Nama Group, Namibia. 1, 3, 4, 5, 8 and 9) unnamed forms. 2) *Navifusa* sp.; 6) *Arctacellularia januarensis*; 10) *Ostiama microcistis*. Specimens and England Finder slide location 1) CP-943 (original slide number MP-1630) V41[1]; 2) CP-942 (original slide number MP-1626) S56; 3) CP-943 (original slide number MP-1630) D52[2]; 4) CP-943 (original slide number MP-1630) EJ47[3]; 5) CP-943 (original slide number MP-1630) F39[4]; 6) CP-940 (original slide number 1706) X31; 7) CP-940 (original slide number 1706) T33; 8) CP-954 (original slide number MP-3189) S56[2]; 9) CP-947 (original slide number MP-1714) N32[1]; 10) CP-955 (original slide number MP-2289) G44 [4]. Scale bar: double= 10 µm and triple=50µm.

4.2.1. DISCUSSION ON FOSSIL ASSEMBLAGE

The illustrated species presented in this thesis are from the study of the fossil material from samples from upper Corumbá Group, Itapucumi Group, Nama, and Dengying Formation. From the total of 26 studied species, only *Didymaulichnus lyelli* (Rouault, 1850) specimen was not direct studied. This species was included in this thesis due to its availability of positioning in the Guaicurus Formation at Laginha quarry section and its relevance to the understanding of the paleoecology and paleoenvironmental reconstruction during the latest Ediacaran/earliest Cambrian transition.

It is important to mention that the 26 studied species do not represent all the described occurrences for upper Corumbá Group. Only species with information regarding the positioning in the lithostratigraphic log from one of the five studied sections were considered from bibliography, case of the inclusion of *Didymaulichnus lyelli* in the list of studied species. There are many other occurrences form upper Corumbá Group to be studied in order to determine their positioning (first/last appearance datum FAD) in the additional sections and to the complementation of the proposed biostratigraphic framework.

The complete and formal taxonomy is presented for all 26 studied species. The original information such as, type-locality, type-horizon, type-species and other important informations were complemented and presented in the article in preparation (Adôrno et al., in preparation, appendix 2).

For some species, it was presented illustrations from previous publications, it was done because it was not possible to find complete specimens as good as the already published. One of the objectives of this thesis is to be a reference for future identification of the representants of the upper Corumbá Group fossil assemblage. In order to reach this objective, it was considered to present illustrations of complete specimens, rather than to present illustrations of incomplete and fragmented specimens, hard to identify.

4.3. PALEOECOLOGY AND PALEOENVIRONMENTAL INFERENCES

In Brazil, all twenty-six identified species are related to neritic marine paleoenvironment of Corumbá Group. Twenty-one of them are restricted to Tamengo Formation: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982, *Gordia marina* Emmons, 1844, *Pilichnus cf. P. dichotomus* Uchman, 1999, *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen1. sp. 1. Only *Multina minima* Uchman, 2001 has occurrences in Tamengo and Guaicurus formations. *Vendotaenia antiqua* Gnilovskaya, 1971 occur in occurs not only in Tamengo Formation, but also in lower Corumbá Group strata: Cerradinho and Bocaina formations. Three species have occurrences restricted to Guaicurus Formation: *Eoholynia corumbensis* Gaucher et al., 2003, *Didymaulichnus lyelli* (Rouault, 1850) and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979). It is worthy of note that, Tamengo Formation yielded the greatest diversity of species for the upper Corumbá Group.

Sixteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp., *Chuaria circularis* Walcott, 1899 and Gen1. Sp. 1. Among this assemblage, *Arctacellularia januarensis*, *Chuaria circularis* and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) were probably photosynthesizers species assigned to cyanobacteria. The *Leiosphaeridia*, *Lophosphaeridium* and *Synsphaeridium* species are considered protist. The other *Bavlinella*, *Ostiama*, *Jacutianema* species are assigned to acritarch group.

Six species represent the benthic assemblage of Tamengo Formation: three sessile epibionts metazoan *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982; sessile epibionts prokaryotic-colony *Vendotaenia antiqua* Gnilovskaya, 1971; two vagile epibiont: *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999. The vagile endobiont *Multina minima* Uchman, 2001 occurs in both Tamengo and Guaicurus formations.

Among the three benthic metazoans, *Cloudina lucianoi* has been considered as responsible for the first reef constructions produced by metazoans in several uppermost Edicarian sections (Grotzinger & Al-Rawahi, 2014, Wood, et al., 2011; Penny et al., 2014). The occurrences of *Cloudina lucianoi* in the Tamengo Formation are attributed to carbonate rock interpreted as representing paleoenvironments with low siliciclastic input and in shallow water conditions in the photic zone and microbial mats. On the other hand, the benthic metazoans *Corumbella werneri* and *Cloudina carinata* and in addition, the ichnospecies *Multina minima* have occrurences most frequently associated with layers of siliciclastic rocks of Tamengo Formation. Two hypotheses of paleoenvironmental conditions could explain these siliciclastic layers: deposition in a relatively deeper water column than the carbonate where *Cloudina lucianoi* is recovered; the second hypothesis could be a complement to the first and consists of episodes of higher siliciclastic sediment input condition, which would be responsible for the inhibition of the precipitation of carbonate.

Thin fossiliferous layers composed of fine reddish-colored siltstones are intercalated with afossiliferous gray siltstone layers in the Tamengo Formation at Corcal quarry section. These reddish siltstones present large numbers of occurrences of benthic assemblage mainly represented by *Corumbella werneri*, *Gordia marina, Pilichnus cf. P. dichotomus* and *Vendotaenia antiqua*. The reddish coloration of the thin fossiliferous siltstone layers, could be interpreted as the result of the presence of possibly primary oxidized material, which may represent episodes of oxygenation of the paleoenvironment, concomitantly with episodic colonization by sessile and vagile benthic metazoans. The redish color is confined to continuous layers, which supports at least two explanations: 1) primary oxidized sediments in oxidized paleonvironments; or 2) posterior oxidation of sedimentary rocks deposited in reduced paleoenvironments with presence of material such as sufides. The presence of large number of autochthonous and *in situ* specimens of sessile benthic metazoans and vagile metazoans are suggestive of oxidized paleonvironment. The colonization of the paleoenvironment by these assembled metazoans is not expected in anoxic marine regions.

The assemblage of Guaicurus Formation is represented by two sessile epibenthic species: *Eoholynia corumbensis* and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) and two vagile endobenthic: *Multina minima* and *Didymaulichnus lyelli* (Rouault, 1850). No microfossil occurrences were recoverd from the Guaicurus formation.

The dramatic change in the fossil assemblage from Tamengo to Guaicurus formations is followed by changes in the depositional paleoenvironment. At Laginha quarry, the Tamengo and Guaicurus formations present an abrupt contact, defined by the dark gray carbonate rocks underlying 1 m of yellowish beige siltstone. The Tamengo Formation was deposited in a favorable paleoenvironment for deposition of carbonates, which was episodically interrupted by immature siliciclastic supply from very fine-grained rocks of a nearby source area. The Guaicurus Formation on the other hand, is a result of an uninterrupted immature siliciclastic supply from a nearby source area, composed of very fine-grained rocks (Fazio et al., 2019).

When comparing paleoenvironmental conditions for deposition of Tamengo and Guaicurus formations, a possibility of these changes contributing to elimination of 95% of uppermost Ediacaran fossil assemblage recovered from Tamengo Formation is clearly seen. Apparently, the greatest part of the twenty-three species of Tamengo Formation disappeared, only the ichnospecies *Multina minima* could exceed the limit between these two formations. Possibly, the endobenthic habit of this ichnospecies could be the strategy to resist the paleonvironmental changes recorded in these two formations of the upper Corumbá Group.

The extinction in the uppermost Tamengo Formation is materialized by the elimination of three epibenthic biomineralizing metazoans: *Cloudina lucianoi*, *Cloudina carinata* and *Corumbella werneri*. The extinction of these species could be correlatetad to the Ediacaran-Cambrian extinction globally recorded (Amthor et al., 2003; Darroch et al., 2018).

Together with the extinction of the three basal cnidarian species, the disappearance of other nineteen epibenthic and planktic species of the Tamengo-Guaicurus transition was also observed: *Gordia marina* Emmons, 1844, *Pilichnus cf. P. dichotomus* Uchman, 1999 and *Vendotaenia antiqua* Gnilovskaya, 1971 plus fifteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp., *Chuaria circularis* Walcott, 1899 and Gen 1. sp. 1. The disappearance of these nineteen species is herein interpreted as possibly a local response related to the Ediacaran-Cambrian extinction (Figure 4. 18).

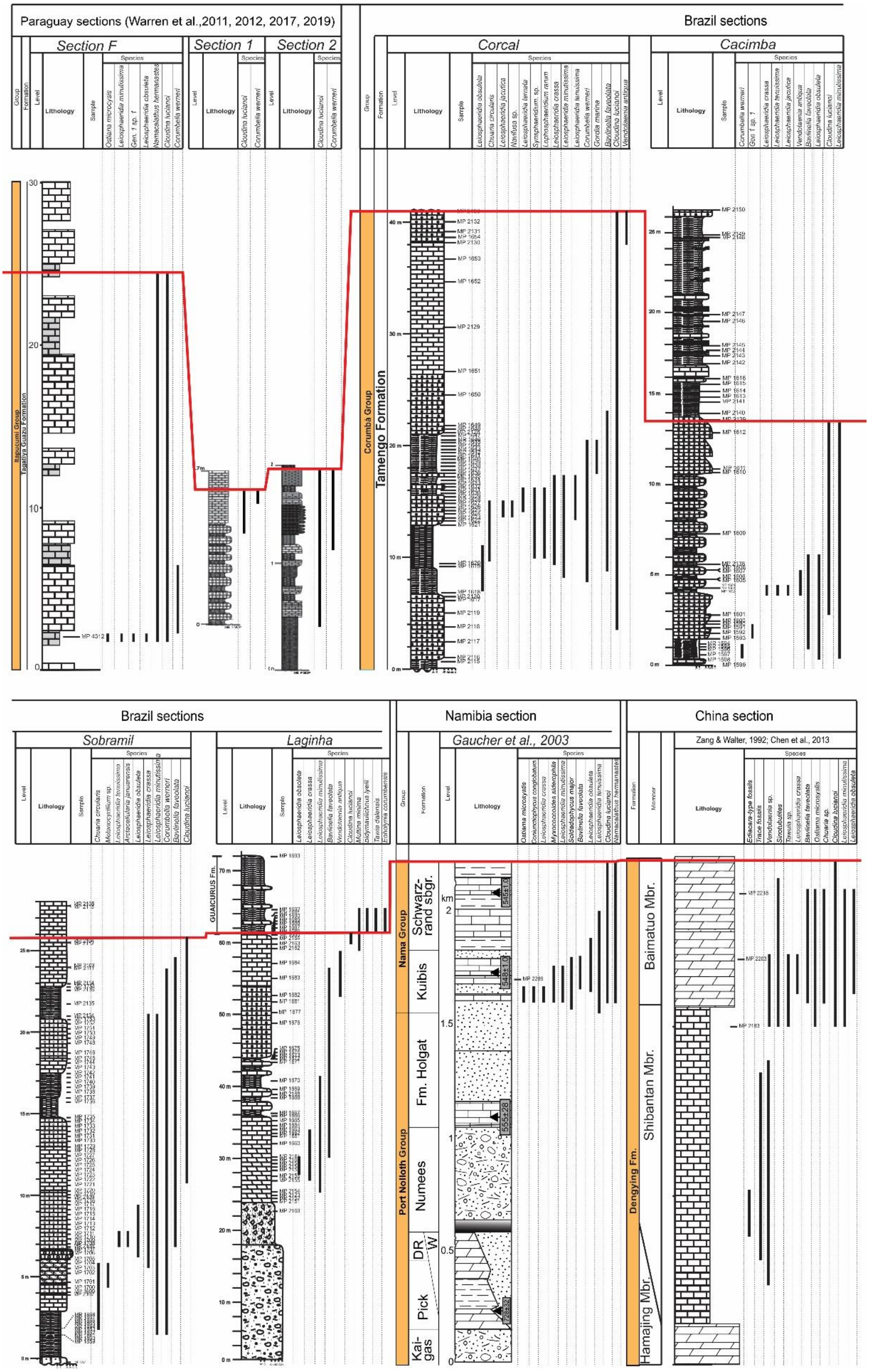


Figure 4. 18. Stratigraphic distribution of the uppermost Ediacaran fossil assemblage of the Tamengo Formation and the additional complementary micropaleontology species for section in Paraguay (after Warren et al., 2011), Namibia (after Gaucher et al., 2005) and China (after Chen et al., 2013). The red line marks the extinction of epibenthic biomineralizing metazoan: *Cloudina lucianoi*, *Cloudina carinata* and *Corumbella werneri*.

The chronostratigraphic positioning of the extinction and disappearance of species at the upper Corumbá Group as related to the global Ediacaran-Cambrian extinction is reinforced by the age of 541.85 ± 0.75 Ma for ash beds at the upper portion Tamengo Formation at Corcal quarry section (Figure 4. 19) (Parry et al., 2017). Moreover, it is worth mentioning that all occurrences of the planktic organic-walled microfossil assemblage from Tamengo Formation have small size (majority between 5 - 70µ diameter). Moreover, no organic-walled microfossil was found in the Guaicurus Formation. The small size of the Tamengo Formation planktic assemblage could indicate some biological pressure "somehow Lilliput effect related", which could have culminated in complete disappearance of this planktic assemblage in the Guaicurus Formation.

Furthermore, it is not expected much younger age than early Cambrian, Furtunian, for deposition of Guaicurus Formation, due the influence of Brasiliano deformation, which is constrained to 550–520 Ma as one of the latest events in the Brasiliano Orogeny (Alvarenga & Trompete, 1992; Trompette, 1994; Pimentel et al., 1996). which limits the minimum age of the Guaicurus Formation at least to the Cambrian, based on the age of São Vicente Granite 528±4Ma (Trivelli, 2016).

As comented by Gaucher et al. (2003), "the uppermost units of the Corumbá Group (Guaicurus Formation) might reveal the Proterozoic/Cambrian transition as well". Besides in this publication, clear boundary between Ediacaran/Cambrian systems were not provided. According to Boggiani et al. (2010), based on occurrences of *Eoholynia corumbensis,* at least the base of this formation could still be latest Ediacaran. It is herein considered an early Cambrian age for deposition of Guaicurus Formation, based on mass extinction recorded in the uppermost Tamengo/lowermost Guaicurus formations, were only *Multina minima* could survive and co-occur with the sudden appearance of *Eoholynia corumbensis* in the Guaicurus Formation. This characteristic corroborate the hypothesis of a younger assemblage for Guaicurus Formation, due the absence of *Eoholynia corumbensis* in the Tamengo Formation.

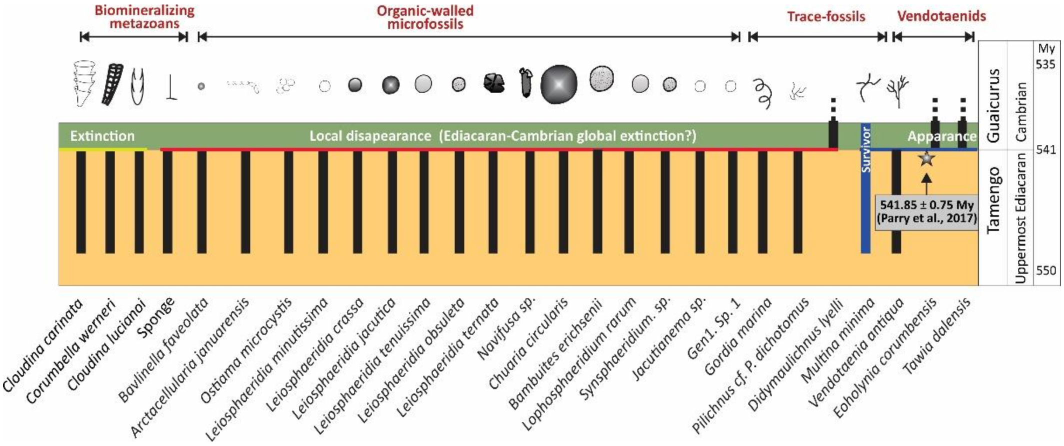


Figure 4. 19. Generalized stratigraphic distribution of the fossil assemblage of Tamengo and Guaicurus formations. Note the greater diversity of species in Tamengo and the red line indicating the local extinction event possibly related to the Ediacaran-Cambrian (E-C) global extinction.

Occurrences of *Cloudina lucianoi*, *Cloudina carinata*, *Cloudina riemkeae*, *Gordia marina*, *Corumbella werneri* and *Namacalathus hermanastes* were plotted in the paleogeographic map showing the reconstruction of Proto-Gondwana in 550 Ma (Warren et al., 2017). Warren et al. (2017) presents a discussion on paleobiogeography in which the occurrences of *Namacalathus hermanastes* in the paleogeographic reconstruction presented in Trindade et al., (2006); Li et al., (2008); Tohver et al., (2012) show that this species has spread through several oceans and interior seas surrounding low latitude paleocontinents. The scenario was complemented with paleogeographic distribution of four additional species: *Cloudina lucianoi*, *Cloudina carinata*, *Cloudina riemkeae*, *Gordia marina*, *Corumbella werneri* (**Figure 4. 20**).

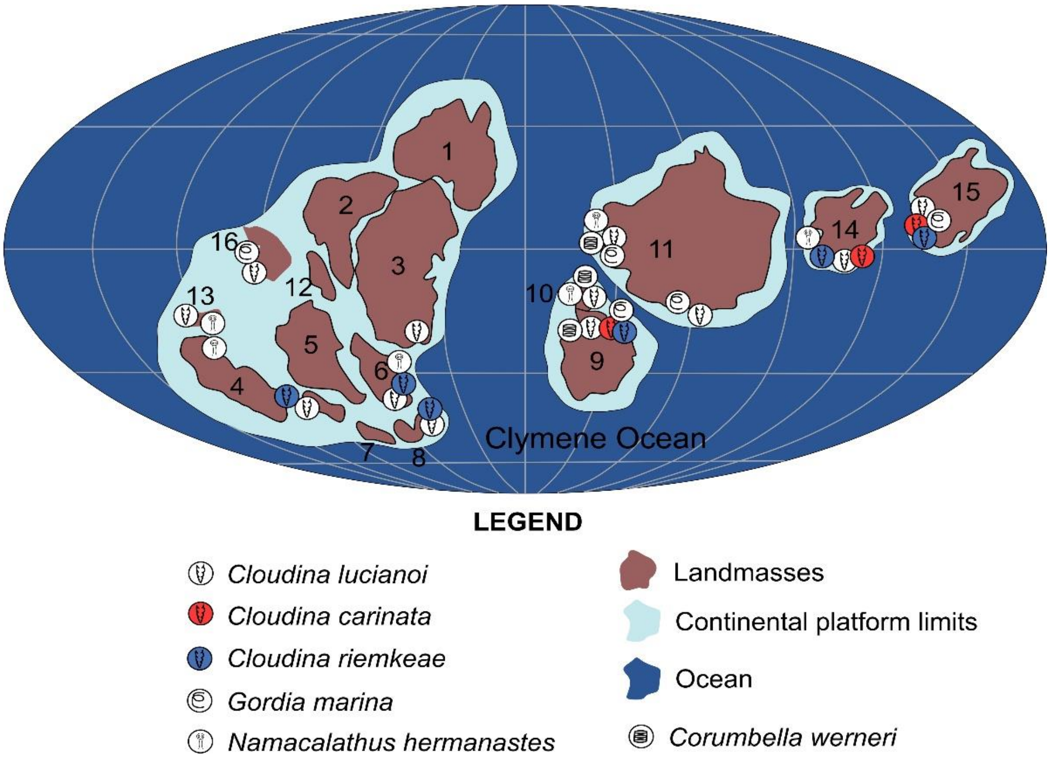


Figure 4. 20. Paleogeographic reconstructions of Gondwana ca. 550 Ma highlighting the *Cloudina lucianoi*, *Cloudina carinata*, *Cloudina riemkeae*, *Gordia marina*, *Corumbella werneri* and *Namacalathus hermanastes*-occurrences. 1 – Australia, 2 – India, 3 – Antarctica, 4 – West Africa, 5 – Congo-São Francisco, 6 – Kalahari, 7 – Paraná, 8 –Rio de la Plata, 9 – Amazonia, 10 – Rio Apa, 11 – Laurentia, 12 – Madagascar, 13 – Arabia-Nubia, 14 – Siberia, 15 – Baltica, 16 – Yangtze Block (South China). The paleogeographic reconstruction is based on Germs (1972), Yochelson and Stump (1977), Hagadorn and Waggoner (2000), Grotzinger et al. (2000), Hofmann and Mountjoy (2001), Amthor et al. (2003), Gaucher et al. (2003), Trindade et al. (2006), Li et al. (2008), Kontorovich et al. (2008), Warren et al. (2011), and Tohver et al. (2012), Merdith et al., (2017) (Modified from Warren et al., 2017).

4.3.1. DISCUSSION ON PALEOECOLOGY AND PALEOENVIRONMENTAL INFERENCES

The update on the paleogeographic map presented in this thesis is related to the use of taxonomy in species level. As it is possible to note at Figure 4. 20, there seems to be a corridor of occurrences of assembled species *Cloudina lucianoi*, *Cloudina carinata*, and *Cloudina riemkeae* in the paleo margins of the paleocontinents South America, West Africa, Baltica and Siberia. In terms of paleolatitude, *Cloudina lucianoi* has the widest distribution among the analized species, occurring since low latitudes to the equator, indicating the highest tolerance to variation in temperature. The occurrences of *Gordia marina* is restricted to high latitudes, indicating to a certain point, colonization of warm water regions.

The strategy of dispersion of *Cloudina* species and *Namacalathus* could be similar to modern benthic cnidarians, where the larvae can be transported to long distances (Warren et al., 2017). It could explain why these species are so widespread through almost all paleocontinents during the terminal Ediacaran.

4.4. BIOSTRATIGRAPHIC ESSAY

The first formal biostratigraphic units for the uppermost Ediacaran in Brazil and Paraguay were proposed by Adôrno et al. (2017). These biostratigraphic frameworks are composed of three biozones, from top: 1) *Cloudina lucianoi/Corumbella werneri* Interval Zone; 2) *Corumbella werneri* Range Zone; 3) *Corumbellla werneri/Cloudina lucianoi* Interval Zone (Adôrno et al., 2016b; Adôrno et al., 2017). These three biozones were originally recognized in Brazil and Paraguay sections.

In addition to those three biozones proposed by Adôrno et al. (2017), it is herein presented four new biostratigraphic unities, from the base to the top, respectively named: *Cloudina* Assemblage Superzone, *Bavlinella faveolata - Leiosphaeridia minutissima* Assemblage Subzone, *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone and *Eoholynia corumbensis* Range Zone.

Cloudina Assemblage Superzone presents the widest geographic and stratigraphic distributions, covering all 15 analyzed uppermost Ediacarian sections: Paraguay (three, Warren et al., 2011, 2013, 2017, 2019), Uruguay (one, Gaucher et al., 2003), Argentina (one Gaucher et al., 2005b), Namibia (one Gaucher et al., 2005a), China (one, Zang & Walter, 1992; Chen et al., 2013), Russia (one, Kontorovich et al., 2008, 2009), Canada (one Hofmann & Mountjoy, 2001), the United States of America (one Hagadorn & Waggoner, 2000), Oman (one, Amthor et al., 2003) and herein Brazil (four).

Cloudina Assemblage Superzone is divided into three biozones: *Cloudina lucianoi/Corumbella werneri* Interval Zone; *Corumbella werneri* Range Zone and *Corumbellla werneri/Cloudina lucianoi* Interval Zone (Adôrno et al., 2016b; Adôrno et al., 2017). These three biozones are geographically distributed in sections of Brazil (three sections) and Paraguay (three) (Adôrno et al., 2017). *Bavlinella faveolata - Leiosphaeridia minutissima* Assemblage Subzone is inserted at the base of *Corumbella werneri* Range Zone, distributed in sections from Brazil, Argentina, Uruguay, Namibia and China. *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone is inserted at the upper portion of the *Corumbella werneri/Cloudina lucianoi* Interval Zone, distributed in sections from Brazil, Namibia, China and Siberia. Finally, above other biostratigraphic unities is inserted *Eoholynia corumbensis* Range Zone recognized at the base of Guaicurus Formation, Laginha quarry, lowermost Cambrian.

Considering the criteria presented in Adôrno et al. (2017), the Corcal quarry was chosen as type-locality for all proposed biozones except for *Eoholynia corumbensis* Range Zone, which has the type-locality placed at Laginha quarry. The proposition of all seven biostratigraphic unities follows the recommendations of the International Stratigraphic Code, exploring three kinds of biozones: Interval Zone, Range Zone and Assemblage Zone (Figure 4. 21).

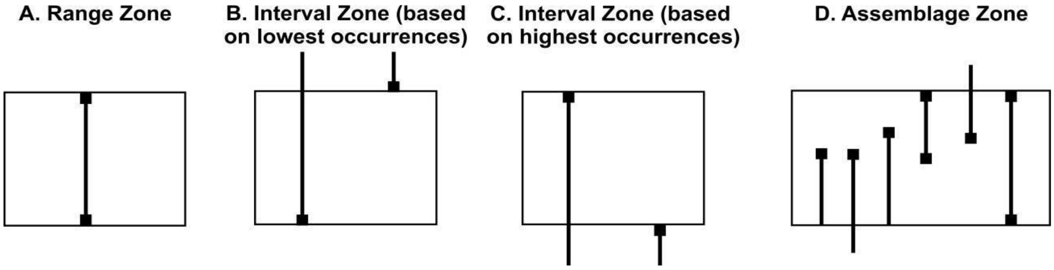


Figure 4. 21. Examples of kinds of biozones used in this biostratigraphic framework (International Stratigraphic Code).

A range biozone is a body of rock representing the known stratigraphic and geographic range of occurrence of any selected element or elements of the chosen fossil taxon, or taxa, present in the rock record. Two kinds of range biozone were explored: taxon-range biozone and concurrent range zone. An interval biozone is a body of rock between two specified biostratigraphic surfaces. The features on which biohorizons were defined here are based on lowest occurrences and highest occurrences. An assemblage biozone is a body of rock characterized by a unique association of three or more taxa, the association of which distinguishes it in biostratigraphic character from adjacent strata. An assemblage biozone may be based on a single taxonomic group, for example, trilobites, or on more than one group, such as acritarchs and metazoans, for example (International Stratigraphic Code).

4.4.1. *Cloudina* Assemblage Superzone - new unit

The *Cloudina* Assemblage Superzone is a biostratigraphy unit characterized by the occurrence of species of genera, such as: *Cloudina, Corumbella, Sinotubulites, Conotubus* and *Namacalathus*. The base of *Cloudina* Assemblage Superzone is characterized by the lowermost occurrence of assembled species, and the top is characterized by the uppermost occurrence of assembled species. This superzone has a lower geochronological resolution, and it was proposed as an essay of a correlation tool to be applied especially when the taxonomic studies which are of biomineralizing species are left in open nomenclature. This superzone occurs in all 15 examined sections (Figure 4. 22).

4.4.2. *Cloudina lucianoi*/*Corumbella werneri* Interval Zone (Adôrno et al., 2017)

The base of the *Cloudina lucianoi*/*Corumbella werneri* Interval Zone is characterized by the first occurrence of *Cloudina lucianoi*, and the top of this zone is characterized by the first occurrence of *Corumbella werneri* (Figure 4. 22). This biozone spans only in South America because *Corumbella werneri* has not yet been found in another continent, so this biozone is useful for international correlation between Brazil and Paraguay until now.

4.4.3. *Corumbella werneri* Range Zone (Adôrno et al., 2017)

The base and top of *Corumbella werneri* Range Zone are marked by the first and last occurrences of *Corumbella werneri*, respectively (Figure 4. 22). This biozone spans only in South America because *Corumbella werneri* has not yet been found in another continent, so this biozone is useful for international correlation between Brazil and Paraguay until now.

4.4.4. *Corumbella werneri/Cloudina lucianoi* Interval Zone (Adôrno et al., 2017)

The base of *Corumbella werneri/Cloudina lucianoi* Interval Zone is characterized by the last occurrence of *Corumbella werneri*, and the top of this zone is marked by the extinction of *Cloudina lucianoi* (Figure 4. 22). This biozone spans only in South America as a result of the same reason given for the other two above. Stratigraphic distribution of *Corumbella werneri* in Laginha quarry has not yet been presented, considering the lack of stratigraphic distribution of this species at this locality, so far, this biozone was not recognized at Laginha quarry. Future studies dealing with occurrences and stratigraphic distribution of *Corumbella werneri* might contribute to better understanding of upper Ediacaran biomineralizing metazoans applied to uppermost Ediacaran biostratigraphy.

4.4.5. *Bavlinella faveolata-Leiosphaeridia minutissima Assemblage Subzone* - new unity

Bavlinella faveolata - Leiosphaeridia minutissima Assemblage Subzone, *Bf-Lm* – ASZ, is characterized by the assemblage of six species: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Cloudina lucianoi*, *Cloudina riemkeae, Corumbella werneri*. The base of *Bf-Lm* -ASZ is marked by the first occurrence of *Leiosphaeridia minutissima* or the first occurrence of *Cloudina lucianoi* when the first is absent. The top of *Bf-Lm* -ASZ is marked by the first occurrence of *Bavlinella faveolata* (Figure 4. 22). This biozone is a subzone inserted at the base of the *Corubmella werneri* Range Zone.

4.4.6. *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone - new unity

Vendotaenia antiqua-Cloudina lucianoi Concurrent-Range Subzone is characterized by the occurrences of two species: *Vendotaenia antiqua* and *Cloudina lucianoi*. The base of this subzone is marked by the first occurrence of *Vendotaenia antiqua* and the top by the last occurrence of *Cloudina lucianoi*. This subzone occurs at six localities, three in Brazil, Namibia, China and Siberia. In Brazil, these localities are: Ecoparque Cacimba, Corcal quarry and Laginha quarry sections (Figure 4. 22). In Corcal quarry and Ecoparque Cacimba sections, this subzone is recognized at the upper portion of the *Corumbella werneri/Cloudina lucianoi* Interval Zone, uppermost Ediacaran.

4.4.7. *Eoholynia corumbensis* Range Zone - new unity

The base and top of *Eoholynia corumbensis* Range Zone are characterized by the first and last occurrences of *Eoholynia corumbensis*. The type-locality of this biozone is Laginha quarry section, lowermost Cambrian (Figure 4. 22). Considering five studied sections in Brazil, this biozone is restricted to Laginha quarry, the sole locality which also outcrops Guaicurus Formation. New occurrences of *Eoholynia corumbensis* would improve the analysis of stratigraphic distribution, as well as, to evaluate its significance of this biozone for the lowermost Cambrian.

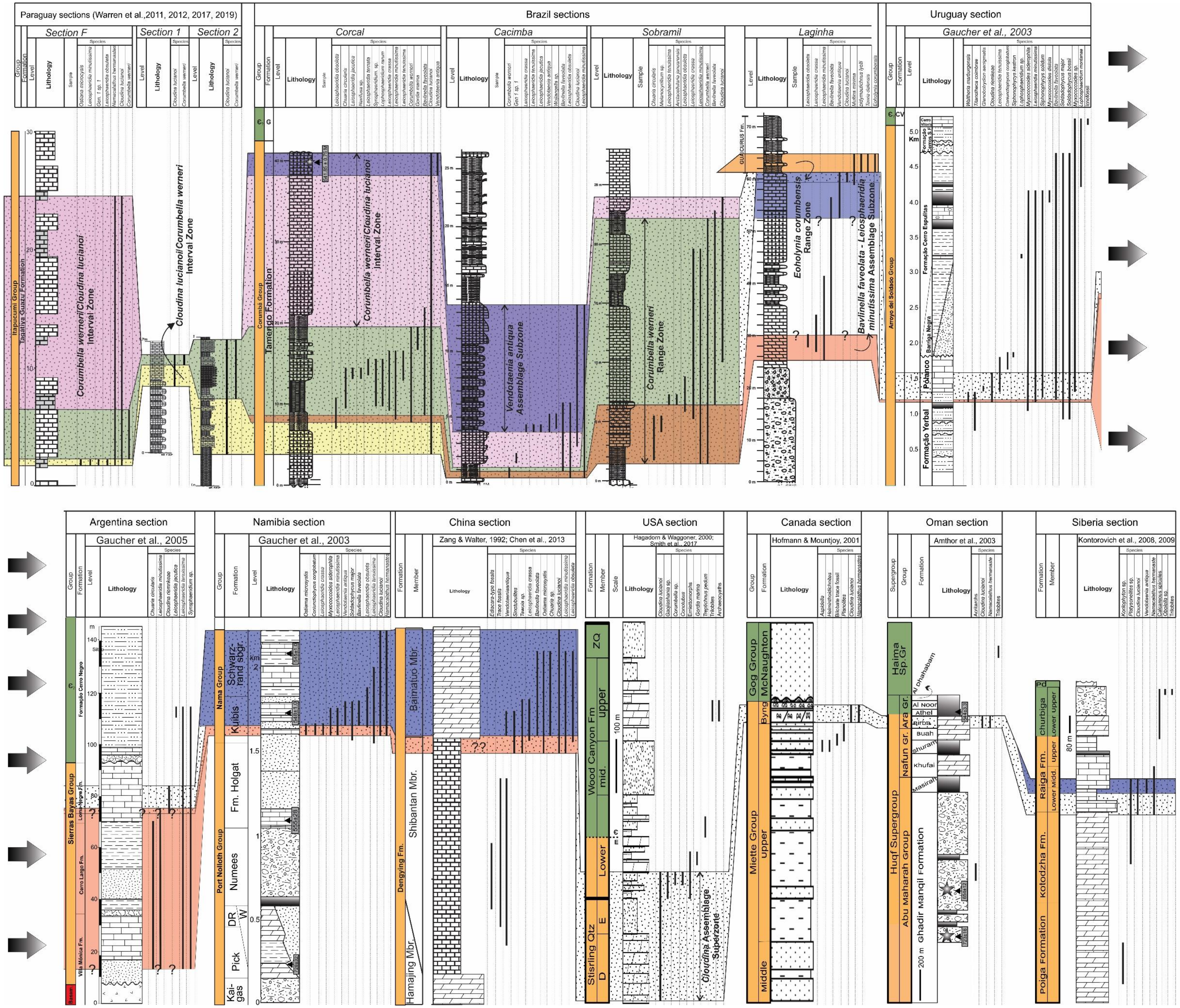
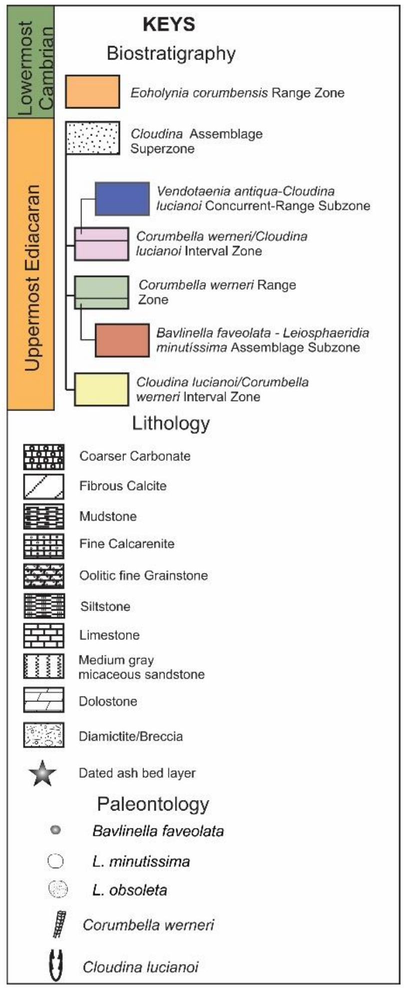


Figure 4. 22. Bioestratigraphy proposal essay based on the stratigraphic distribution of the species in the Tamengo Formations and for the selected sections. (Paleontological informations from the selected sections out of Brazil: Gaucher et al., 2003; Warren et al., 2011, 2012, 2013, 2017 and 2019; Gaucher et al., 2005; Zang & Walter, 1992; Hagadorn & Waggoner, 2000; Smith et al., 2017; Hofmann & Mountjoy, 2001; Amthor et al., 2003; Kontorovich et al., 2009; Dating presented in Corcal quarry is from Parry et al., 2017).



4.2.1. DISCUSSION ON BIOSTRATIGRAPHY RECORD

All seven proposed biozones presented herein are based on the first and last appearance datum. For the five studied sections in Brazil, the information regarding the fossil occurrences was obtained during the field works. For the sections of Namibia, China and Paraguay the information of the occurrences are compilations of the bibliography information added to data from new samples preparations. For the sections of Argentina, Uruguay, USA, Canadá, Oman, and Siberia, the information of the occurrences came from the bibliographic compilation.

The biostratigraphic framework presented herein represents a work in progress and it is expected to be tested in order to evaluate its validity and potential for relative dating the Ediacaran-Cambrian boundary in South America and also to be useful for international correlation. Ash beds have been identified at the lower and upper portion of the Tamengo Formation allowing to define the age of the beginning and end of deposition of Tamengo Formation (Babinski et al., 2008; Parry et al., 2017). The identification of new ash beds from upper Corumbá Group could be helpful for calibrating the geochronology of these biozones. This data allied with further studies on paleontological characterization for Guaicurus Formation would certainly improve the chronobiostratigraphic framework for the Ediacaran/Cambrian boundary in South America.

CHAPTER – 5: CONCLUSIONS

The fossil assemblage recovered from the Tamengo and Guaicurus formations is composed of twenty-six species. Twenty-two have occurrences restricted to Tamengo Formation and three species are restricted to Guaicurus Formation. Only *Multina minima* Uchman, 2001 has occurrences in both Tamengo and Guaicurus formations.

From the total twenty-three species of Tamengo Formation, three were epibenthic biomineralizing sessile: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982 and an indeterminate species of poriferous. Three ichnospecies represent activity of vagile benthic organisms: *Multina* *minima* Uchman, 2001, *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999. *Multina minima* were endobiot organisms while *Gordia marina* and *Pilichnus cf. P. dichotomus* were vagile epibiont on water-sediment interface. In addition, sixteen species probably derived from planktic organisms were recovered. Fifteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann in Timofeev et al., 1976, *Navifusa* sp. and Gen1. sp. 1; and one species of permineralized microfossils *Chuaria circularis* Walcott, 1899. The sessile epibionts prokaryotic-colony *Vendotaenia antiqua* was previously reported in Cerradinho and Bocaina formations, and herein their latest occurrences and extinction are recorded in the mass extinction event recorded in uppermost Tamengo Formation.

Four species represent the benthic fossil assemblage for Guaicurus Formation: *Eoholynia corumbensis* Gaucher et al., 2003, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979), *Multina minima* and *Didymaulichnus lyelli* (Rouault, 1850). From the total, three species have occurrences restricted to this formation: *Eoholynia corumbensis*, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) and *Didymaulichnus lyelli*, only *Multina minima* has shared occurrences with Tamengo Formation. It is worthy of note that, Tamengo Formation yielded the greatest diversity of species for terminal Ediacaran Corumbá Group.

A dramatic change was recorded in the fossil assemblage from Tamengo to Guaicurus formations with disappearance of almost 95% of the species from Tamengo to Guaicurus formations. The mass extinction event recorded in the uppermost Tamengo

Formation is materialized by the elimination of three epibenthic biomineralizing metazoan: *Cloudina lucianoi*, *Cloudina carinata* and *Corumbella werneri*. Other nineteen epibenthic and planktic species disappeared in the uppermost Tamengo Formation. The contact between Tamengo and Guaicurus Formation is concordant and it is marked by the appearance of three new species: *Eoholynia corumbensis*, *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) and *Didymaulichnus lyelli*. Only *Multina minima* survived the mass extinction event that occurred across Ediacaran to Cambrian boundary. This local mass extinction is herein correlated to the uppermost Ediacaran-Cambrian extinction event, which together with the dating of the ash bed in the upper Tamengo Formation, reinforce the hypothesis of lowermost Cambrian age for the Guaucurus Formation. The small size of the Tamengo Formation planktic assemblage could indicate some biological pressure “somehow Lilliput effect related”, which could have culminated in complete disappearance of this planktic assemblage in the Guaicurus Formation. Furthermore, it is not expected much younger age for Guaicurus Formation, due the presence of Brasiliano deformation, which is constrained to 550–520 Ma as one of the latest events in the Brasiliano Orogeny (Pimentel et al., 1996; Trompette, 1994) which limits the minimum age of the Guaicurus Formation at least to the Cambrian, based on the age of São Vicente Granite 528±4Ma (Trivelli, 2016).

In addition, a change in the depositional paleoenvironment from Tamengo to Guaicurus formations was also observed. The Tamengo Formation was deposited in a favorable paleoenvironment for deposition of carbonates, which was episodically interrupted by immature siliciclastic supply. The Guaicurus Formation on the other hand, is a result of an uninterrupted immature siliciclastic supply.

Moreover, five species of organic-walled microfossils were recovered and identified from samples of the Dengying Formation, China: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Ostiama microcystis*; Nine species from samples from Nama Group, Namibia:

Bavlinella faveolata, *Ostiama microcystis*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima*, *Leiosphaeridia minutissima*, *Soldadophycus major*, *Coniunctiophycus conglobatum* and *Myxococcoides siderophila*. Four species in the Tagatiya Guazu Formation, Paraguay: *Ostiama microcystis*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Leiosphaeridia minutissima* and Gen. 1 sp. 1. The micropaleontological result for these sections complemented the scarce record of species of organic-walled microfossils from the uppermost Ediacaran.

Based on the stratigraphic and geographic distribution of the studied fossil assemblage, seven biozones were proposed, from bottom to top: *Cloudina* Assemblage Superzone that is distributed in all 15 analyzed sections in Brazil, Paraguay, Uruguay, Argentina, United States, Canada, Namibia, Oman, Russia and China. Inserted in this superzone, there are three biozones, distributed in sections of Brazil and Paraguay: *Cloudina lucianoi/Corumbella werneri* Interval Zone; *Corumbella werneri* Range Zone; and *Corumbellla werneri/Cloudina lucianoi* Interval Zone. It was possible to propose two subzones: *Bavlinella faveolata - Leiosphaeridia minutissima* Assemblage Subzone inserted in the base of *Corumbella werneri* Range Zone and *Vendotaenia antiqua-Cloudina lucianoi* Concurrent-Range Subzone at the upper portion of the *Corumbella werneri/Cloudina lucianoi* Interval Zone. The first subzone spans across Brazil, Argentina, Uruguay, Namibia and China, and the second across Brazil, Namibia, China and Siberia. Finally, *Eoholynia corumbensis* Range Zone was proposed for the base of Guaicurus Formation at Laginha quarry, lowermost Cambrian. The geographic distribution of this biozone is apparently restricted to Laginha quarry locality, so far.

Future studies involving taxonomy and stratigraphic distribution of the uppermost Ediacaran fossil assemblage would be of great importance for advances in biostratigraphy. Special attention must be given to the occurrences of *Cloudina* sp. reported in the Sete Lagoas Formation, Bambuí Group, mainly aiming at stratigraphic positioning and precise taxonomic positioning for those occurrences. Furthermore, studies on biology especially in the areas of phylogeny and morphology compared with metazoan, in addition to in-depth studies on the microbiota of the uppermost Ediacaran, should be encouraged. Chemical analysis of the skeleton of calcifying metazoans must be done, in order to determine if the original chemistry remains preserved, and if so it could be useful to reconstruct the paleoenvironmental conditions. Future work on the identification of new levels of volcanic ash, and geochemical characterization of the ashes already identified at the Corcal quarry must be done. The Laginha quarry section must be studied in more detail, aiming to discover new biomineralizing metazoans occurrences such as *Cloudina lucianoi*, *Cloudina carinata* and *Corumbella werneri* presenting their stratigraphic distribution. Additional locations with Guaicurus Formation are crucial to be studied in order to evaluate validity of the biostratigraphic framework and dating the Ediacaran-Cambrian boundary in South America.

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APPENDIX

Appendix 1: Scientific production from this research.

Authors	**Year**	**Complete article (Journal and DOI)**	**Title**
Walde et al.	2015	Annales de Paléontologie 101 (2015) 213–224 <http://dx.doi.org/10.1016/j.annpal.2015.07.002>	New aspects of Neoproterozoic-Cambrian transition in the Corumbá region (state of Mato Grosso do Sul, Brazil)
Adôrno et al.	2017	Precambrian Research 301 (2017) 19–35 <http://dx.doi.org/10.1016/j.precamres.2017.08.023>	*Cloudina lucianoi* (Beurlen & Sommer, 1957), Tamengo Formation, Ediacaran, Brazil: Taxonomy, analysis of stratigraphic distribution and biostratigraphy
Adôrno et al.	2018	Precambrian Research 317 (2018) 271–274 <http://dx.doi.org/10.1016/j.precamres.2017.08.023>	Reply to comment on Adôrno et al. (2017) "*Cloudina lucianoi* (Beurlen & Sommer, 1957), Tamengo Formation, Ediacaran, Brazil: Taxonomy, Analysis of Stratigraphic Distribution and Biostratigraphy"
Fazio et al.	2019	Journal of South American Earth Sciences 90 (2019) 487–503 <https://doi.org/10.1016/j.jsames.2018.11.025>	Mineralogical and chemical composition of Ediacaran-Cambrian politic rocks of The Tamengo and Guaicurus formations, (Corumbá Group - MS, Brazil): Stratigraphic positioning and paleoenvironmental interpretations
Authors	**Year**	**Scientific meeting**	**Title**
Adôrno et al.	2015	XIV Simpósio de geologia do Centro-Oeste	Implicações estratigráficas das ocorrências de Espécies do Gênero *Cloudina* no Brasil
Adôrno et al.	2016	35th International Geological Congress Capetown, Session: The dawn of animals, abstr., paper 4131.	Three-dimensional *Cloudina* specimens extraction from limestone of the Nama Group, Namibia.
Adôrno et al.	2016	35th International Geological Congress, Capetown, Session: The dawn of animals, abstr., paper 4144.	Biostratigraphy of Neoproterozoic strata based on invertebrate species from South America.
Adôrno et al.	2018	International Conference on Ediacaran and Cambrian Sciences Xi'an China.	Taxonomic remarks and stratigraphic implication of *Cloudina* species in Neoproterozoic strata
Erdtmann et al.	2018	International Conference on Ediacaran and Cambrian Sciences Xi'an China.	The multiple (?) Ediacaran/Cambrian boundary hiatus: possible causes and consequences.

Appendix 2: Adôrno et al. (in preparation): Taxonomy and stratigraphic distribution of fossil assemblage from Tamengo and Guaicurus formations, Corumbá Group, Ediacaran-Cambrian boundary in the Midwest of Brazil.

Taxonomy and stratigraphic distribution of the fossil assemblage from Tamengo and Guaicurus formations, Corumbá Group, Ediacaran-Cambrian boundary in the Midwest of Brazil

ABSTRACT–It is herein presented analysis on taxonomic and the stratigraphic distribution for twenty-six species of Tamengo and Guaicurus formations. Only one out of this total, *Multina minima* Uchman, 2001, occurs in both Tamengo and Guaicurus formations. The fossil assemblage of the Tamengo Formation is represented by twenty-three species: three biominerailizing metazoans, three ichnospecies, one vendotaenid and sixteen microfossils species. Three species of biomineralizing metazoan of Tamengo Formation are described: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982 and unidentified sponge spicules. Additionally, one sessile epibiont prokaryotic-colony *Vendotaenia antiqua* was recovered from Tamengo Formation (Gnilovskaya, 1971). Three ichnospecies are described from Tamengo Formation: *Gordia marina* Emmons, 1844, *Pilichnus cf. P. dichotomus* Uchman, 1999, and *Multina minima*. Sixteen microfossil species occur in Tamengo Formation, one permineralized species *Chuaria circularis* Walcott, 1899 and other fifteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen 1. sp. 1 (chitinozoan like flask-shaped). Four species occur in Guaicurus Formation: two icnhospecies and two vendotaenids. The endobenthic ichnospecies assemblage of Guaicurus Formation is

represented by: *Didymaulichnus lyelli* (Rouault, 1850) and *Multina minima*. *Didymaulichnus lyelli* is restricted to Guaicurus Formation. The epibenthic assemblage of Guaicurus Formation is represented by two vendotaenid ispecies: *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979). The results here presented for upper Corumbá Group come from five studied sections in Corumbá and Ladário regions, Mato Grosso do Sul State, Brazil: Corcal and Laginha quarries, Porto Sobramil, Porto Figueiras and Ecoparque Cacimba. In addition, samples were prepared and analyzed from sections of three countries, with recovery of nine species of organic-walled microfossils from Nomtsas Formation, Namibia, four species from the Tagatiya Guazu Formation, Paraguay and six species from Dengying Formation, China. These results increased the scarce register of organic-walled microfossils for uppermost Ediacaran sections of Tamengo Formation and for these additional selected sections.

Keywords: Ediacaran/Cambrian boundary; upper Corumbá Group; Taxonomy.

1. INTRODUCTION

It is presented herein a detailed study of the taxonomy and analysis of the stratigraphic distribution of Tamengo and Guaicurus formations fossil assemblage, Corumbá Group, uppermost Ediacaran, lowermost Cambrian of Corumbá and Ladário regions, State of Mato Grosso do Sul, Brazil. Twenty-six species integrate the fossil assemblage of Tamengo and Guaicurus formations from five sections in Corumbá and Ladário regions (Tab. 2). This fossil assemblage yield biomineralizing metazoans, biomineralizing microfossils, vendotaenids, ichnofossils, permineralized microfossils and organic-walled microfossils (Tab. 1).

In order to complete micropaleontological data from coeval sections around the World, three additional sections were selected to perform micropaleontological analysis: Nomtsas Formation, Namibia; Tagatiya Guazu Formation, Paraguay and Dengying Formation, China. These additional sections were selected based on their potential for recovering organic-walled microfossils in order to compare the assemblage recovered from Tamengo Formation. These additional selected areas are recognized as uppermost Ediacaran yet, they are seeking micropaleontological data.

Despite the large number of papers dealing with organic-walled microfossil assemblages, the majority deals with Meso to Early Neoproterozoic sections from several sites all over the World (see Beghin et al., 2015; Couëffé & Vecoli, 2011; Grey, 2005; Knoll et al., 2013; Baludikay et al., 2016; Sergeev et al., 2017; Loron & Moczydlowska, 2017; Vorob'eva et al., 2015; Tang et al., 2013; Singh & Sharma, 2016 and many others). The studies on Ediacaran/Cambrian boudary intervals are mostly focused on the biomineralizing metazoan. Consequently, the organic-walled microfossil assemblage are not so well studied at the Ediacaran/Cambrian limt, some exceptions can be cited (Blanco & Gaucher, 2005; Chiglino et al., 2014; Gaucher et al., 2003; 2005a, 2005b, 2008; Gaucher & Poiré 2009; Moczydłowska, 2007; Palacios et al., 2016; Sergeev & Shopf, 2010; Sommer, 1971; Zaine, 1991; Zaine & Fairchild, 1987; Zang & Walter, 1992). The scarcity of works in this area becomes even clearer, e.g., when the number of the published article dealing with the organic-walled microfossils assemblages from the Doushantuo and Dengying formations are compared. Proterozoic paleontological data are crucial for the study of early eukaryote evolution, biostratigraphy correlation, and paleoenvironmental reconstruction (Butterfield & Chandler, 1992; Knoll, 1994; Knoll et al., 2006, Grey et al., 2005).

The Ediacaran Period (c. 635–540 Ma) is an important geological interval following the Cryogenian snowball Earth glaciations and preceding the Cambrian explosion of animals (Xiao et al. 2016). One of the most representative stratigraphic intervals for studies on Ediacaran/Cambrian paleontology in South America are Tamengo and Guaicurus formations, upper Corumbá Group (Fig. 1).

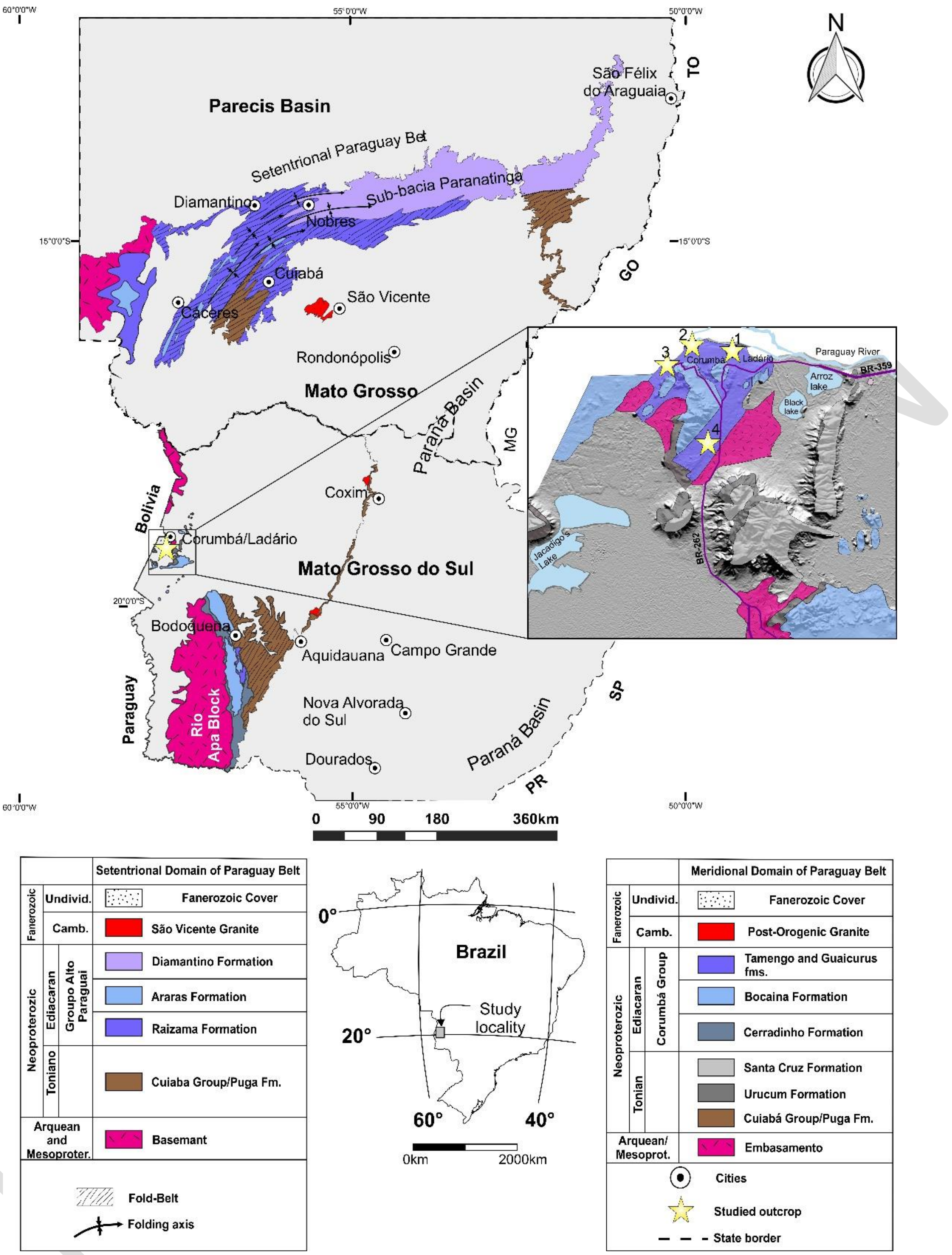


Figure 1. Regional simplified geological map of the North and south Paraguay fold belt: 1) Porto Sobramil and Porto Figueiras sections; 2) Ecopaque da Cacimba section; 3) Corcal quarry section; and 4) Laginha quarry section in Corumbá and Ladário, Mato Grosso do Sul State (Modified by Silva & Jost, 2006).

Location and access roads to the studied sections

The studied sections of Corumbá Group are located in the municipalities of Corumbá, and Ladário Mato Grosso do Sul State, near the border with Bolivia in Midwestern Brazil. The access to Corumbá from Brasília is by the federal road BR-060 passing through municipalities of Goiânia, capital of the State of Goiás, and then through municipalities of Rio Verde, Jataí and Campo Grande the capital of the State of Mato Grosso do Sul. From Campo Grande, it goes west on federal road BR-262, passing through the municipalities of Aquidauana, Miranda and then Corumbá making a total of about 1500 km from Brasilia.

The access to the outcrops of the Porto Sobramil, Ecoparque da Cacimba and Corcal quarry are within the urban zone of Corumbá. The section of the Laginha quarry is remote and can be accessed following the south by the state road MS-228 about 10 kilometers from Corumbá (Fig. 2).

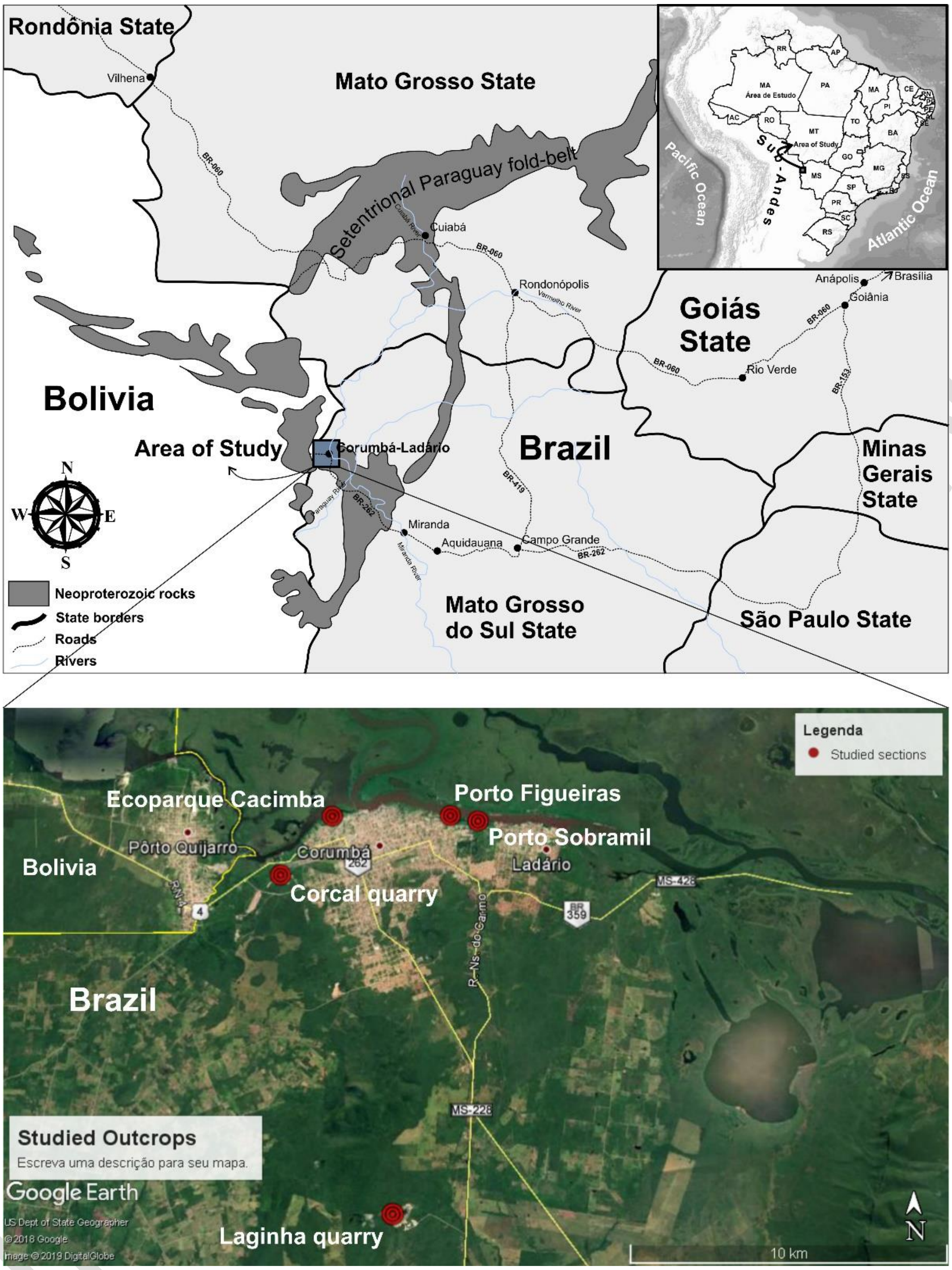


Figure 2. Location of the studied outcrops (sections) in Corumbá region and the main access roads.

2. GEOLOGICAL SETTINGS

The Corumbá Group overlies the Puga Formation at many localities, e.g., at the Morro do Puga (Corrê et al., 1979; Boggiani, 1998; Alvarenga and Saes, 1992; Alvarenga et al., 2000, Gaucher et al., 2003). The Corumbá Group was deposited on a stable continental margin (Almeida, 1984: 274; Zaine, 1991; Boggiani et al., 1993, 1998; Boggiani, 1998; Boggiani et al., 2010), and includes alternating siliciclastic and carbonatic units with a composite thickness of approximately 600 m (Boggiani, 1998). Cerradinho Formation represents a siliciclastic deepening upward sequence (Almeida, 1965, 1984; Boggiani, 1998). Cadiueus Formation is interpreted as synrift alluvial fan deposits generated during opening of the Corumbá basin (Boggiani, 1998).

The Cerradinho Formation conformably passes into carbonates of the Bocaina Formation, or more rarely, directly into the Tamengo Formation (Almeida, 1965, 1984; Boggiani, 1998). The Bocaina Formation is characterized by thick deposits of stromatolitic dolostones, that show a great lateral variation of facies (Boggiani et al., 1993; Boggiani, 1998), including phosphorites with up to 34% P_2O_5 (Boggiani et al., 2010). The overlying Tamengo Formation is mainly composed of dark, organic rich limestones and marls with occasional *Cloudina lucianoi* and *Corumbella werneri* (Almeida, 1965, 1984; Zaine, 1991; Boggiani, 1998; Boggiani et al., 2010; Adôrno et al., 2017). Finally, carbonates of the Tamengo Formation are concordantly overlain by gray siltstones of the Guaicurus Formation (Almeida, 1965; Boggiani, 1998), marking the end of deposition in the Corumbá basin assigned as deposited during the lowermost Cambrian (Fig. 3).

The fossil assemblage recovered from upper units of the Corumbá Group – the Tamengo and Guaicurus formations places it in the Ediacaran/ Cambrian boundary (Zaine & Fairchild, 1987; Gaucher et al., 2003; Boggiani & Alvarenga, 2004; Adôrno et al., 2017; Parry et al., 2017; Fazio et al., 2019). C and Sr isotopic curves show similarities to other uppermost Ediacaran units in Uruguay, Namibia, South China and Oman (Boggiani et al., 2010). Additionally, zircons from volcanic ashes in the superior portion of the Tamengo Formation were dated at 543 ± 3 Ma by U/Pb method (Babinski et al., 2008) which was, later on, supported by Parry et al. (2017), who dated ash beds from the same location at around 542 Ma by U/Pb method.

The basal portion of the Tamengo Formation has a polymictic breccia containing clasts of granite, rhyolite, chert and shale, also dolomite stromatolite fragments and phosphorite from the Bocaina Formation. The middle portion of the Tamengo Formation'is composed of calcitic mudstone, mudstone rhythmites, carbonaceous marl and shales where *Corumbella werneri* occurs. Toward the top, there are oolitic grainstones (Boggiani et al., 2010). The upper portion of the Tamengo Formation consists of rudstones in which *Cloudina lucianoi* occurs. Besides some lithostratigraphic differences among the four classic outcrops, Sobramil Port, Corcal quarry, Cacimba Ecopark and Laginha quarry, in this last outcrop, the uppermost portion is composed of pure black limestone, locally dolomite. In the other three outcrops, the upper Tamengo Formation alternates rhythmically between shale and marl (Boggiani et al., 2010; Boggiani & Alvarenga, 2004; Gaucher et al., 2003) where the new occurrence of *Cloudina carinata* is herein presented from the Porto Figueiras locality near the Sobramil Port.

It is important to point out that the present work shows a wider stratigraphic distribution for *Cloudina lucianoi* than earlier recognized, and the first appearance of this species seems to be older than *Corumbella werneri*. The Tamengo Formation represents, as already discussed, the drift stage related to a transgressive event under a neritic platform under occasional storm waves influence that accumulate *Cloudina lucianoi* in the carbonate layers and *Corumbella werneri* and *Cloudina carinata* in the siliciclastic layers. The Guaicurus Formation consists of thick homogeneous gray siltstone package and, according to Boggiani (1998), Gaucher et al. (2003) and Oliveira (2010), is probably deposited below fair-weather wave base related to an abrupt climate change or a drowning of the basin (Fazio et al., 2019).

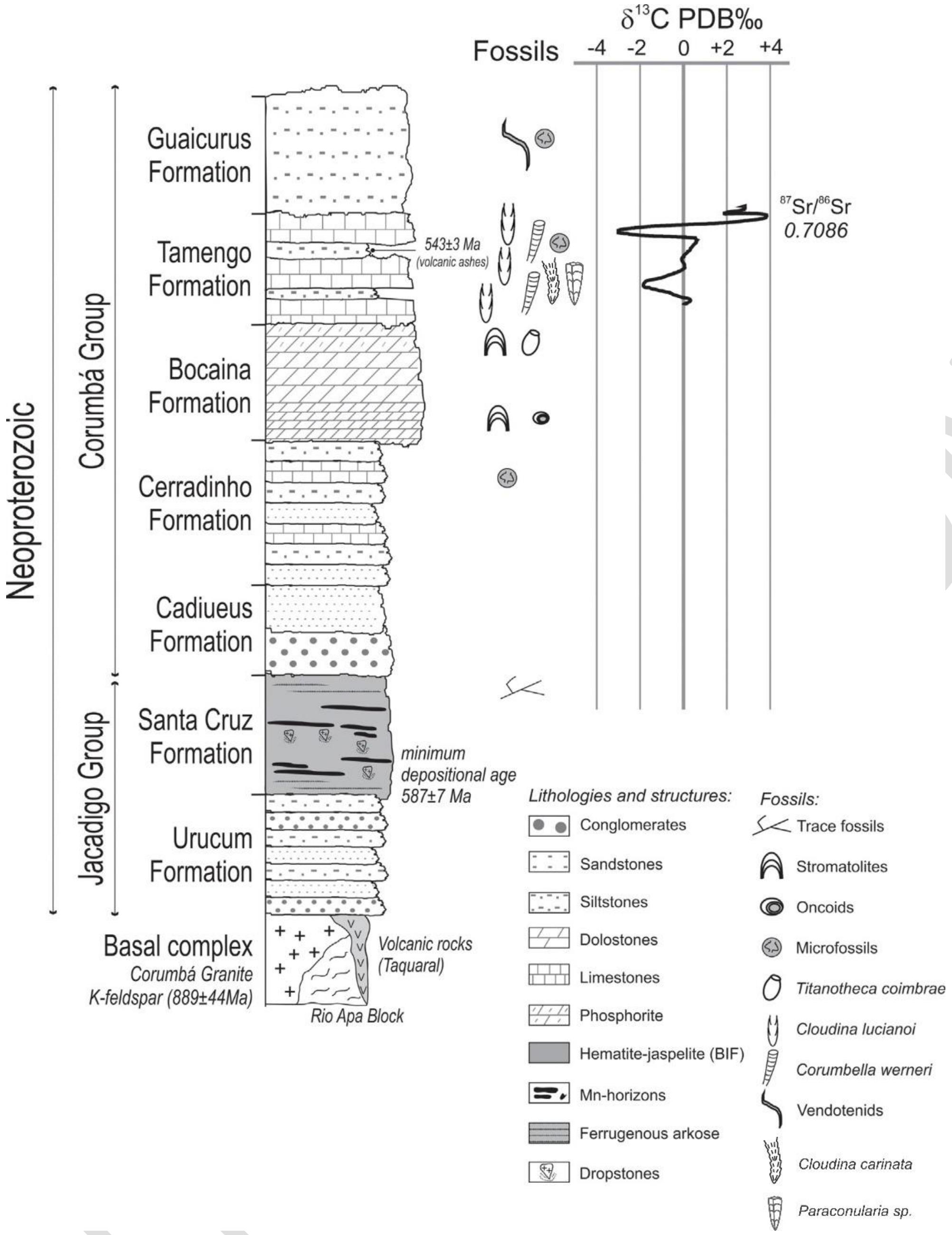


Figure 3. Stratigraphic scheme of Jacadigo and Corumbá groups with fossil record and the δ13C isotopic curve. Note the strong negative incursion. Isotopic data after Boggiani et al. (2010) and ages at the base of Jacadigo Group and embasement after Piacentini et al. (2013), *Ages from Parry et al. (2017), **Age from Babinski et al., (2008) (modified from Walde et al., 2015).

3. MATERIALS AND METHODS

The results presented for Tamengo and Guaicurus formations in Corumbá and Ladário regions were obtained from the geological sections at five localities: 1) Porto Sobramil; 2) Corcal quarry; 3) Ecoparque Cacimba; 4) Laginha quarry and 5) Porto Figueiras (Tab. 1).

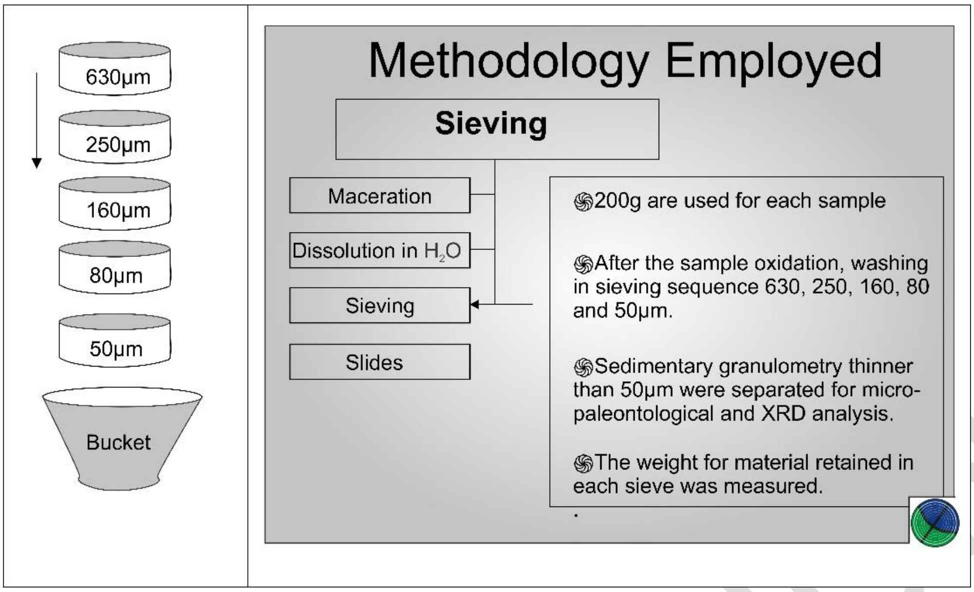
Table 1. Localities of the outcrops studied in Corumbá and Ladário municipalities, Mato Grosso do Sul State, Brazil.

LOCALITY	GEOLOGY	COORDINATES
1. Corumbá - Corcal quarry	Tamengo Fm.	21K 0428106 / 7897065
2. Corumbá – Ecoparque Cacimba da Saúde	Tamengo Fm.	21K 0429794 / 7899135
3. Ladário - Porto Sobramil*	Tamengo Fm.	21K 0434770 / 7898980
4. Corumbá - Laginha quarry	Tamengo Fm.	21K 0432101 / 7886020
5. Corumbá – Porto Figueiras	Tamengo Fm.	21K 0433880 / 7899144

* This locality also refers to the limestone quarry area of the company Itaú, known by two denominations: Cláudio quarry and Saladeiro quarry. These two quarries were located side by side on the same bank of the Paraguay River. In order to avoid confusion, the name Sobramil is chosen, which refers to the company that owns the property where the two quarries were formerly located. Currently, in this classic locality, there is activities of iron and manganese port.

Samples were collected from the studied outcrops systematically spaced. Several fossiliferous samples which are composed of the sample collected were housed in the Laboratory of Micropaleontology, University of Brasília. The macrofossils such as the ichnofossils were studied directly from the sample surface using Carl ZEISS Stereo Discovery.V20.

The micropaleontology studies were conducted in two ways of samples preparation: 1) for permineralized microfossils and 2) for organic-walled microfossils. The micropaleontological preparation was used with the objective of recovering permineralized microfossils besides fragments of invertebrates, sponge spicules, and remains of cyanobacteria or even protists diagenetically permineralized, through battery of sieves. The methodology employed in this research follows that proposed by Do Carmo et al. (2011) aims at the recovery of biomineralized skeletons and permineralized particles from the disintegration of the sedimentary rocks samples and washing them in sieves. After mechanical disaggregation, the sample is left in a beaker of 2 L for 48 h with water, then the sample is washed in sieves (630, 250, 160, 80, 56 and 10 µm opening sizes) (Fig. 4). The granulometric fractions smaller than 10 µm are retained in an appropriate container, together with the other fractions, to be dried in a kiln at 60 °C and also examined in a stereoscopic microscope for the screening of microfossils and subsequent imaging in SEM.



- 200g are used for each sample
- After the sample oxidation, washing in sieving sequence 630, 250, 160, 80 and 50µm.
- Sedimentary granulometry thinner than 50µm were separated for micro-paleontological and XRD analysis.
- The weight for material retained in each sieve was measured.

Figure 4. Micropaleontological preparation flowchart (Do Carmo et al., 2011).

For the chemical preparation and concentration of the particulate organic components (palynomorphs), the methodology developed in the Laboratory of Micropaleontology of UnB was used. The methodology involves attacking the samples for 2 h with 37% hydrochloric acid. The samples were neutralized and then treated with 47% hydrofluoric acid for 12 hours. Again the samples were neutralized by distilled water until the pH reaches 7.

A further 10% hydrochloric acid digestion can be applied for fluorite consumption and finishing the preparation with neutralization step in distilled water. Finally, the organic material is allowed to decant in the bottom (one day standby) and then stored in its own pots ready to make the slides. For the assembly of the permanent palynological slides, the supernatant is used, employing Entelan as the standard mounting medium and cover slides, according to standard preparation flowchart adopted in the UnB micropaleontology laboratory (Fig. 5).

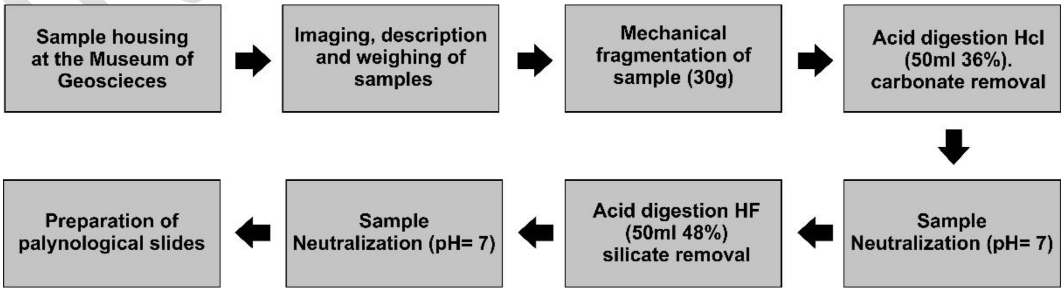


Figure 5. Flowchart of the palynological preparation of the Laboratory of microaleontology, University of Brasília (Denezine, 2018).

4. RESULTS

The lithostratigraphic and taxonomic results are herein presented. Lithostratigraphic description and log update of Porto Sobramil, Corcal quarry and Ecoparque Cacimba sections were presented in Adôrno et al., (2017). Considering this, an update on the lithostratigraphic log for two additional localities: Laginha quarry and Porto Figueiras section is presented here.

Twenty-six species integrate the fossil assemblage of Tamengo and Guaicurus formations from five sections in Corumbá and Ladário regions. This fossil assemblage yield biomineralizing metazoans, biomineralizing microfossils, vendotaenids, ichnofossils, permineralized microfossils and organic-walled microfossils.

Three sessile benthic mineralizing metazoan species were described: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982. Three species of vendotaenids occur in the studied sections: the benthic assemblage represented by *Vendotaenia antiqua* Gnilovskaya, 1971, *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979), *Vendotaenia antiqua* constitutes the benthic fossil assemblage of Cerradinho, Bocaina (Gaucher et al., 2003) and Tamengo Formation. *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) constitute the benthic fossil assemblage and are restricted to Guaicurus Formation.

Three vendotaenid species are described here: *Eoholynia corumbensis* was assigned as remains of eucaryotic algae, probably Phaeophyta or Rhodophyta, *Vendotaenia antiqua* was assigned as probably abandoned sheaths of sulfide-oxidizing organotrophic bacteria related to the Beggiatoaceae (Vidal, 1989; Gaucher et al., 2003) and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) probably photosynthesizers species assigned to cyanobacteria (Steiner et al., 1996).

Four ichnospecies have occurrences recorded: *Didymaulichnus lyelli* (Rouault, 1850), *Multina minima* Uchman, 2001, *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999. These four ichnospecies integrate the updated ichnology assemblage for Tamengo and Guaicurus formations (Parry et al., 2017). *Gordia marina* Emmons, 1844 and *Pilichnus cf.*

P. dichotomus Uchman, 1999 occur in Tamengo Formation, *Multina minima* in both Tamengo and Guaicurus formations and *Didymaulichnus lyelli* have occurrences exclusively in Guaicurus Formation.

Sixteen species of microfossils represent the marine planktic assemblage for Tamengo Formation. One species of permineralized vesicles assigned as *Chuaria circularis* Walcott, 1899, was recovered from pelites of Tamengo Formation at Ecopoarque Cacimba section, Corumbá Municipality, Mato Grosso do Sul State, Brazil. Fifteen species of small sphaeromorphs organic-walled microfossils: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* (Sommer, 1971), *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen 1. sp. 1 (chitinozoan like flask-shaped). In addition, organic fragments of the species *Vendotaenia antiqua* Gnilovskaya, 1971 were recovered in palynological macerations.

4.1. Lithostratigraphic description of the Laginha quarry section

At the base of the Laginh quarry section, there are approximately 16 m of diamictite with clasts of up to 30 cm, composed of granite, quartzite, chert, oolitic limestone and eventually limestone. The matrix of this diamictite is grayish-arrenous of gray color. Above the diamictite, occurs a layer with about 6m of breccia, constituted by angular clasts of limestone and fragments of black phosphorite. The matrix is composed of gray carbonate with intense calcite venulation and fluorite of intense violet color. Above the carbonate layer, there are oolitic black grainstones.

Samples were collected at intervals of 10 to 60 cm, in the sequence of dark gray grainstone with intercalations of black pelitic levels, also sampled. The base is formed by layers of massive mudstone, succeeded by layers smaller than 0.5 m thick, with black shale, containing pyrite. Toward the top, the darkest laminated grainstone predominates, usually oolitic, presenting load structures. This is a 50 m of medium gray grainstone, very fractured and recrystallized, with calcite veins. This carbonate sequence is covered by a layer of finely-laminated, light gray shale, which when altered gives ocher coloring, this layer represents the basal portion of the Guaicurus Formation (Fig. 6).

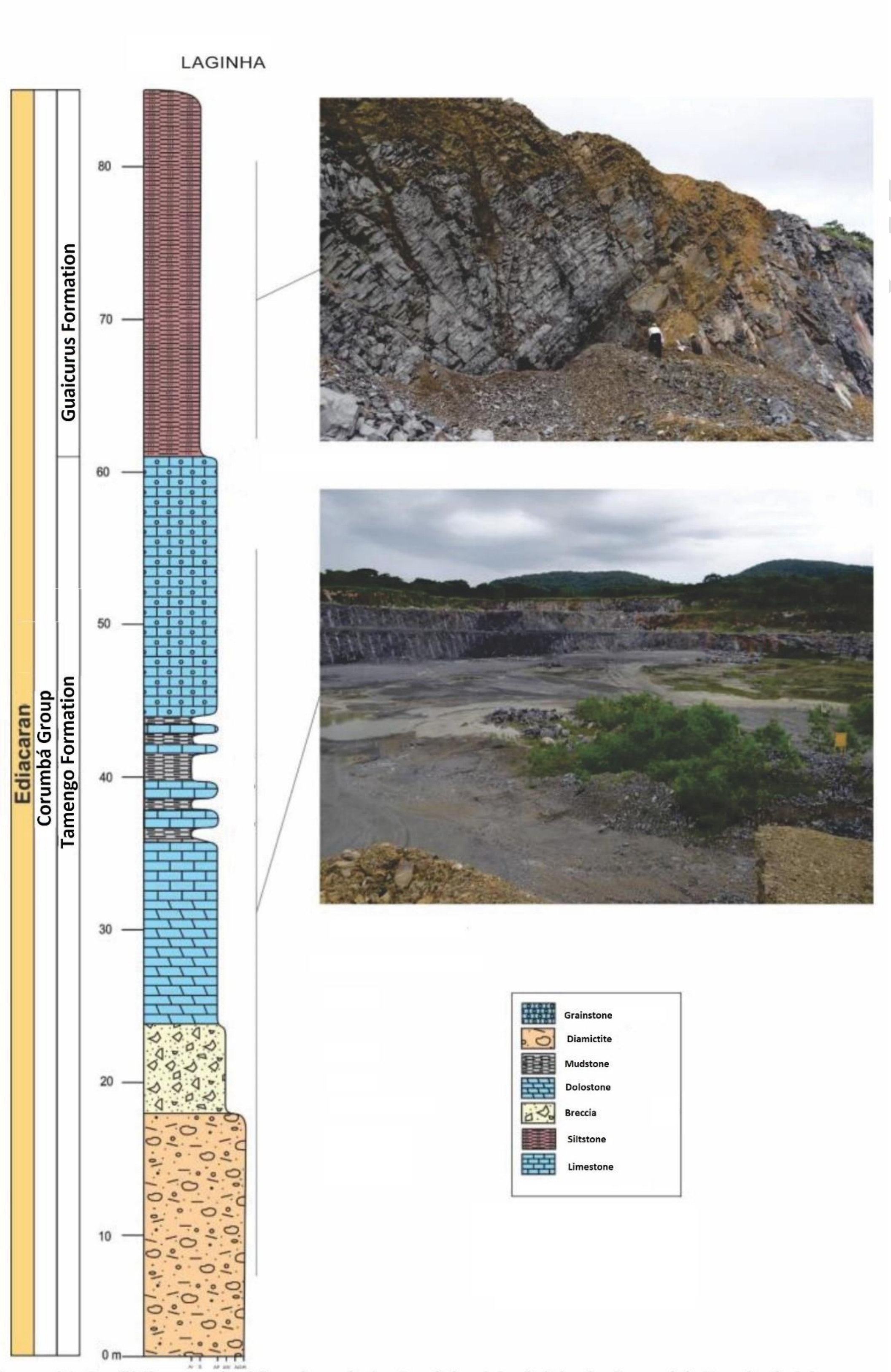


Figure 6. Lithostratigraphic section of the Laginha quarry, in the municipality of Corumbá, Mato Grosso do Sul, Brazil, with apparent thickness.

4.2. Lithostratigraphic description of the Porto Figueiras section

The section of Porto Figueiras is also named “Marina do Gerson” locality in Corumbá Municipality, Mato Grosso do Sul State, Brazil. This section is around 200 m from the southern banks of the Paraguay River and approximately 750m west of Porto Sobramil section.

It consists of light yellow siltstone and dark gray limestone, with total thickness of 8.25m (Fig. 7). At the base of the section, there are approximately 2.5m of massive siltstone with several lenses of sandstone - with tens of centimeter wide and a few centimeters thick. Around 0.4m from the basal level, there are fossil occurrences of *Corumbella werneri* and *Cloudina carinata*. Above the siltstone, lies 5.75m of recrystallized limestones arranged as thick massive beds showing planar cross-stratification or as amalgamated sets of thin beds with wavy contacts.

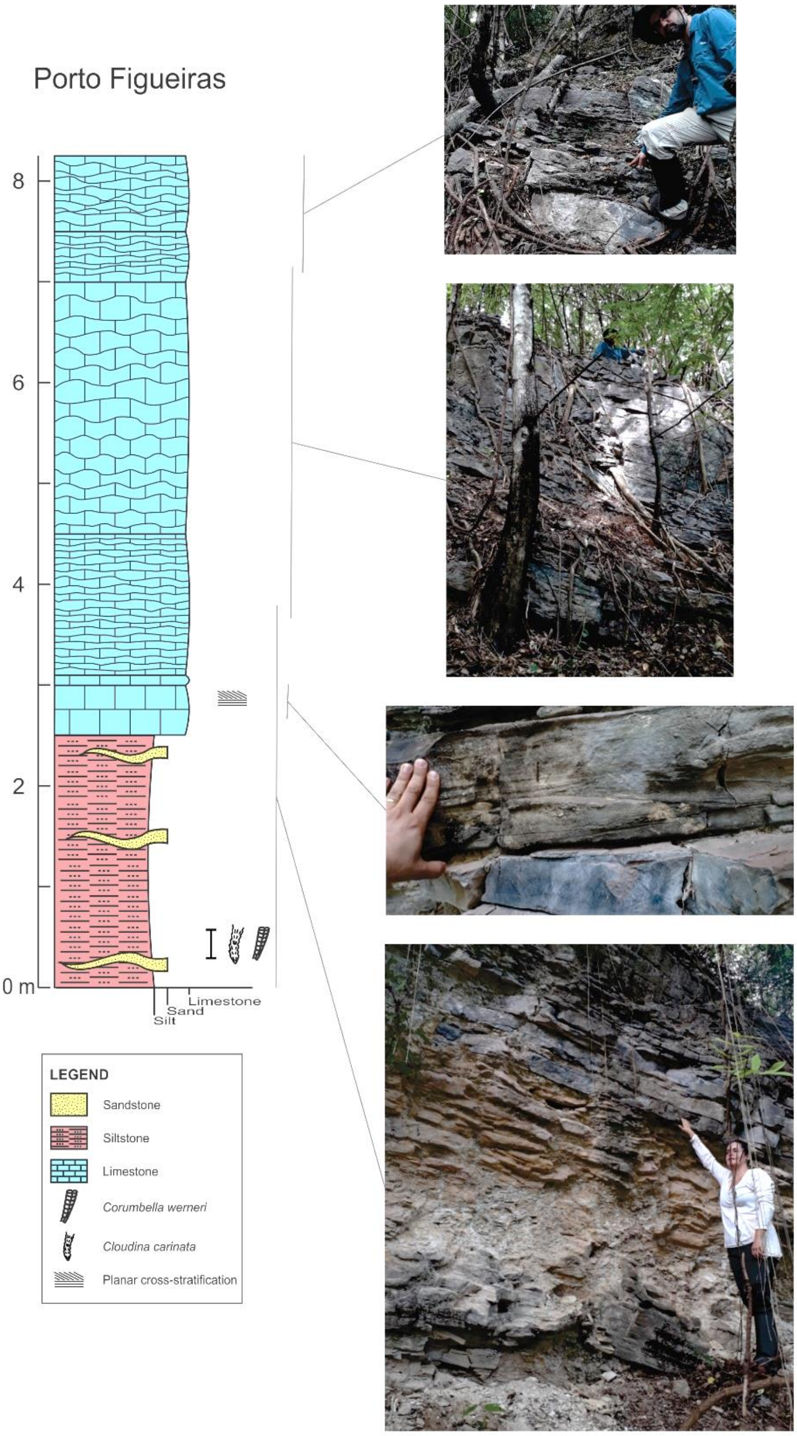


Figure 7. Lithostratigraphic section of the Porto Figueiras (Marina do Gerson) section, in the municipality of Corumbá, Mato Grosso do Sul State, Brazil. UTM Coordinates zone 21K 0433880mE / 7899144mS.

4.3. TAXONOMY OF PALEOBIOTA

The fossil assemblage of Tamengo and Guaicurus formations include twenty-six species distributed in five sections in Corumbá and Ladário regions (Tab. 2). These species were clustered into six categories: biomineralizing metazoan, biomineralizing microfossils, vendotaenids, ichnofossils, permiineralized microfossils and organic-walled microfossils.

Table 2. Described species from the Tamengo and Guaicurus formations, Mato Grosso do Sul State, Brazil.

	Paleoecology	**Species**	**Locality (Brazil)**	**Formation**
Biomineralizing Metazoan	Benthic-epibiont sessile	*Cloudina lucianoi* (Beurlen & Sommer, 1957)	Corcal, Cacimba, Sobramil,	Tamengo,
	Benthic-epibiont sessile	*Cloudina carinata* Cortijo et al., 2010	Porto Figueiras	Tamengo
	Benthic-epibiont sessile	*Corumbella werneri* Hahn et al., 1982	Corcal, Cacimba, Sobramil	Tamengo
Biomineralizing Microfossils	Benthic-epibiont sessile	Undeterminated sponge spicules and wall fragments	Sobramil	Tamengo
	undetermined	Undeterminated microfossil chamber sponge gemmule?	Sobramil	Tamengo
Vendotaenids	Benthic-epibiont sessile	*Vendotaenia antiqua* Gnilovskaya, 1971	Corcal	Tamengo, Cerradinho and Bocaina
	Benthic-epibiont sessile	*Eoholynia corumbensis* Gaucher et al., 2003	Laginha	Guaicurus
	Benthic-epibiont sessile	*Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979)	Laginha	Guaicurus
Ichnofossils	Benthic-endobiont vagile	*Gordia marina* Emmons, 1844	Corcal	Tamengo
	Benthic-epibiont vagile	*Pilichnus cf. P. dichotomus* Uchman, 1999	Corcal	Tamengo
	Benthic-endobiont vagile	*Multina minima* Uchman, 2001	Laginha	Tamengo, Guaicurus
	Benthic-epibiont vagile	*Didymaulichnus lyelli* (Rouault, 1850)	Laginha	Guaicurus
Permineralized microfossils	Possible marine planktic	*Chuaria circularis* Walcott, 1899	Cacimba	Tamengo
Organic-walled microfossils	Possibly marine planktic	*Arctacellularia januarensis* Denezine, 2018 *nomem nudum*	Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia ternata* (Timofeev, 1966)	Cocal	Tamengo
	Possibly marine planktic	*Leiosphaeridia crassa* (Naumova, 1949)	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia jacutica* (Timofeev, 1966)	Corcal, Cacimba	Tamengo
	Possibly marine planktic	*Leiosphaeridia minutissima* (Naumova, 1949)	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia tenuissima* Eisenack, 1958	Corcal, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Leiosphaeridia obsuleta* (Naumova, 1949)	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Bavlinella faveolata* Vidal, 1976	Corcal, Laginha, Cacimba, Sobramil	Tamengo
	Possibly marine planktic	*Bambuites erichsenii* Sommer, 1971	Porto Sobramil	Tamengo
	Possibly marine planktic	*Synsphaeridium* sp.	Corcal	Tamengo

	Possibly marine planktic	*Jacutianema* sp.	Corcal	Tamengo
	Possibly marine planktic	*Lophosphaeridium* sp.	Corcal	Tamengo
	Possibly marine planktic	*Ostiama microcystis* Hermann in Timofeev et al., 1976	Corcal	Tamengo
	Possibly marine planktic	Gen1. Sp. 1 (flask-shaped) chitinozoan like	Cacimba	Tamengo
	Possibly marine planktic	*Navifusa* sp.	Corcal	Tamengo

Biomineralizing metazoan

Three sessile benthic mineralizing metazoan species were described: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982. Additionally, sponge spicules were recovered, but a question remains regarding its original composition, if it is calcareous or siliceous. Regardless of the original composition, these sponge spicules present a calcareous composition.

KINGDOM Animalia Linnaeus, 1735

PHYLUM Incertae sedis

CLASS Incertae sedis

ORDER Incertae sedis

FAMILY Cloudinidae Hahn & Pflug, 1985

GENUS: *Cloudina* Germs, 1972

Type-species: *Aulophycus lucianoi* Beurlen & Sommer, 1957 pl.: I-VI

Emended diagnosis: The tiny calcareous funnel-within-funnel elongated skeletons are sinuous and are composed of stacked funnels that are arranged as nested funnels in longitudinal section. On transverse section, they usually have two or more walls and vary from circular to oval, rarely polygonal. The outer wall bears annular ridges and depressions. The inner wall is smoother and, in some specimens, shows very fine annular ridges. The inner funnel is ordinarily not centrally located in transverse section. The basal end has nearly always been found closed, whereas the distal end has always been found open (Adôrno et al. 2017).

Remarks: Eleven species of *Cloudina* have been described so far: 1. *Cloudina lucianoi* (Beurlen & Sommer, 1957), type-horizon Tamengo Formation, Brazil; 2. *Cloudina hartmanae* Germs, 1972, type-horizon Nama Group, Namibia; 3. *Cloudina riemkeae* Germs, 1972, type-horizon Nama Group, Namibia; 4. *Cloudina waldei* Hahn and Pflug, 1985, type-horizon Tamengo Formation, Brazil; 5. *Cloudina lijiagouensis* Zhang et al., 1992, type-horizon Dengying Formation, Yangtze Platform, China; 6. *Cloudina sinensis* Zhang et al., 1992, type-horizon Dengying Formation, Yangtze Platform, China; and 7. *Cloudina carinata* Cortijo et al., 2010, type-horizon Membrillar Olistostrome, Spain; 8. *Cloudina ningqiangensis* Cai et al., 2017, type-horizon Beiwan Member of the Dengying Formation at the Lijiagou section in Ningqiang, Shaanxi Province, South China; 9. *Cloudina xuanjiangpingensis* Cai et al., 2017 type-horizon Beiwan Member of the Dengying Formation at the Lijiagou section in Ningqiang, Shaanxi Province, South China; 10. *Cloudina latilabrum* Meira, 2011, type-locality Pedreira Sobramil, Tamengo Formation, Brazil; 11. *Cloudina? borrelloi* Yochelson & Herrera, 1974 type-locality Sierra de Villicum, Argentina. From the eleven described species of *Cloudina*, six species have taxonomic issues. Two were transferred to other genus, three were synonymized and one does not followed the statement of the International Code of Zoological Nomenclature (ICZN). Remarks are presented dealing with the taxonomic position of two *Cloudina* species: *Cloudina waldei* Hahn & Pflug, 1985 *Cloudina waldei* (Hahn & Pflug, 1985), *Cloudina? borrelloi* Yochelson & Herrera, 1974). Considering the original description for *Cloudina waldei* type-material presented in Hahn & Pflug (1985), the skeleton has wrinkled walls instead of funnel-in-funnel or even cone-in-cone skeletal architecture. Based on this description, *Cloudina waldei* would fit better as *Sinotubulites waldei* (Hahn & Pflug, 1985). Unfortunately, the type-materials of this species are at the Institute of Geosciences, University of Marburg (responsibility of Prof. Gerhard Hahn) and in the Institute of Geosciences of the University of Giessen (Prof. Hans D. Pflug, deceased) and therefore was not accessed during this research. Tubes of lower Cambrian from the locality named Sierra de Villicum, Argentina, were identified as *Cloudina? borrelloi* (Yochelson & Herrera, 1974). This material was subsequently studied in Hahn & Pflug (1985) and transferred to *Acuticloudina borrelloi* (Yochelson & Herrera, 1974) (Conway Morris et al., 1990; Brasier et al., 2017).

Three species are synonymized: *Cloudina hartmanae* Germs, 1972, *Cloudina lijiagouensis* Zhang et al., 1992 and *Cloudina sinensis* Zhang et al., 1992 *Cloudina hartmanae*

(Germs, 1972), *Cloudina lijiagouensis* (Zhang et al., 1992) and *Cloudina sinensis* (Zhang et al., 1992). For *Cloudina hartmanae*, as earlier discussed in this text, based on Adôrno et al. (2017), it is a junior synonym of *Cloudina lucianoi*. The other two species were revised in Cai et al. (2017). This study includes analysis of the type-material from Dengying Formation, China: *Cloudina lijiagouensis* (Zhang et al., 1992) and *Cloudina sinensis* (Zhang et al., 1992)*Cloudina lijiagouensis* Zhang et al., 1992 and *Cloudina sinensis* Zhang et al., 1992. The holotype of *Cloudina lijiagouensis* was synonymized with *Cloudina hartmanae*, and as earlier discussed, it is considered a junior synonym of *Cloudina lucianoi* in Adôrno et al. (2017). It was also proposed in Cai et al. (2017) that a part of the *Cloudina sinensis* illustrated material in Zhang et al. (1992) is synonymized with *Cloudina hartmanae* and another part synonymized with *Cloudina ningqiangensis* Cai et al., 2017.

The validity of *Cloudina latilabrum* Meira, 2011 *nomem nudum* is questionable considering Article 8.1, Chapter 3 of the International Code of Zoological Nomenclature (ICZN). The ICZN determines that a valid species must have its proposition in a scientific journal of wide circulation and also printed on paper. What's more, Article 9, Chapter 3 of the ICZN also defines "*What does not constitute published work*" and it includes, among others, Ph.D. thesis and dissertations explicitly. Furthermore, Becker-Kerber (2015) presented arguments to consider *Cloudina latilabrum* as a synonym of *Cloudina lucianoi*, which present small morphological variations due to its taphonomic processes.

Among the five valid *Cloudina* species, two species occur in uppermost Ediacaran Tamengo Formation sections of Brazil: *Cloudina lucianoi* and *Cloudina carinata* (Table 4. ***3***). *Cloudina lucianoi* has the greatest geographic distribution in the sections of Tamengo Formation at Corumbá and Ladário regions with occurrences recorded in four studied sections: Corcal and Laginha quarries, Porto Sobramil and Ecoparque da Cacimba (Adôrno et al., 2017; 2018). *Cloudina lucianoi* also occurs in coeval strata in Paraguay (Warren et al., 2011), Namibia (Germs, 1972), China (Cai et al., 2017), USA (Hagadorn & Wagoner, 2000), Canada (Hofmann & Mountjoy, 2001); Mexico (Sour-Tovar et al., 2007), Spain (Cortijo et al., 2010); Oman (Conway Morris, 1990) and Russia (Terleev et al., 2011).

Table 3. Updated list of valid species of *Cloudina* Germs, 1972 after Adôrno et al. (2017) and Cai et al. (2017).

SPECIES	**COUNTRY**
1. *Cloudina lucianoi* (Beurlen & Sommer, 1957)	Brazil, Namibia, Paraguay, China, USA, Canada, Mexico, Spain, Oman, Siberia
2. *Cloudina riemkeae* Germs, 1972	Namibia, Brazil?, Uruguay, Russia
3. *Cloudina carinata* Cortijo *et al.*, 2010	Spain, Siberia, Brazil*
4. *Cloudina ningqiangensis* Cai et al., 2017	China
5. *Cloudina xuanjiangpingensis* Cai et al., 2017	China

*This is the first occurrence of *Cloudina carinata* in South America.

Cloudina lucianoi (Beurlen & Sommer, 1957) emended.
(Fig. 8)

1957 *Aulophycus lucianoi* Beurlen & Sommer, 1957 Pl. I–VI, p. 36–47.
1972 *Cloudina hartmannae* Germs, 1972 Pl. 1: Figs. 1–7, pp. 756–757; Fig. 3: C, p. 758.
1976 *Cloudina hartmannae* Germs, 1972 in Glaessner, Pl. 1: Fig. 2, p. 266; Fig. 3, p. 267; Pl. 2: Figs. 1–6, p. 267.
1987 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Zaine & Fairchild, Est. 1: Figs. 1–7, pp. 806–807.
1990 *Cloudina hartmanae* Germs, 1972 in Grant, Fig. 4: E-F, p. 270; Fig. 6: A-B, p. 272; Fig. 8: D, p. 285.
1990 *Cloudina* sp. (Germs, 1972) Grant, Fig. 10: E, p. 280.
1992 *Cloudina lijiagouensis* Zhang, Li, and Dong in Ding et al., p. 94, pl. VIII, Fig. 6.
1992 *Cloudina sinensis* Zhang, Li and Dong in Ding et al., 1992 (p. 93, pl. VIII, Figs. 1–3, 5, 7-8, 10–12, 14–15, 18 (fig 9 was transferred to *Cloudina ningqiangensis* Cai et al., 2017.
2000 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Gaucher pl.: 21.1, non 2 and 3.
2001 *Cloudina sinensis* Chen and Sun, p. 183–188, pl. I, Fig. 1.
2001 *Cloudina* Chen and Sun, p. 183–188, pl. I, Fig. 4, 5, 7, 9, 10, 11.
2003 *Cloudina hartmannae* Germs, 1972 in Hua et al., Figs. D–H, p. 456.
2003 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Gaucher et al., Fig. 10: A-B, D–K; non Fig.10C, p. 262.
2003 *Cloudina* Hua et al., Fig. 3A, E, F.
2005 *Cloudina hartmannae* Germs, 1972 in Hua et al., Figs. A–P, p. 278.
?2007 *Cloudina hartmannae* Germs, 1972 in Hua et al., Fig. 5: 4 and 6, p. 269.
2007 *Cloudina* Hua et al., Fig. 6.3, 6.4.
2008 *Cloudina* Chen et al., Fig. 2D.
2011 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Warren et al., Fig. 2: D, p. 384; Fig. 3: A–E, p. 285; Fig. 4: A–G, p. 386.
2011 *Cloudina latilabrum nomem nudom* Meira, pp. 77, Pl. 10 A-H: Pl. 10 A (holotype GP/1E – 6218) and Pl. 10 B-C (paratype);
2012 *Cloudina hartmannae* Germs, 1972 in Zhuravlev et al.,pp. 209 Fig. 3.
2015 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Walde et al., Fig. 4: C, p. 219; Fig. 5: A–D, p. 220; Fig. 6: B, p. 222.
2015 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Becker-Kerber, Fig. 11, 12
2015 *Cloudina hartmannae* Germs, 1972 in Becker-Kerber, Fig. 32.

2015 *Cloudina* spp. em Cortijo et al., Fig. 2: A–E, G–H, N, non 2F and 2I, p. 421; Fig. 3: A, C–F, not B, p. 422
2017 *Cloudina hartmannae* Germs, 1972 in Cai et al., 2017 Fig. 4.
2017 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Adôrno et al., figs. 9: A-B; 10: A-E;11: A-B; 12.
2017 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Warren et al., Fig. 3 A, B.
2018 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Walde et al., 2018, Fig. 6.
2019 *Cloudina lucianoi* (Beurlen & Sommer, 1957) in Warren et al., Fig. 8:A.

Type-material: Holotype number D.G.M. 1149 housed at the Museum of Earth Sciences, Rio de Janeiro, Rio de Janeiro State, Brazil. Three additional types (D.G.M. 1156, 1156 and 1159) were designated as syntypes. Topotypes are available.

Type-locality: (Adôrno et al., 2017).

Type-horizon: (Adôrno et al., 2017).

Examined material: (Adôrno et al., 2017).

Illustrated material: (Adôrno et al., 2017).

Description: (Adôrno et al., 2017).

Diagnosis: (Adôrno et al., 2017).

Remarks: It is herein presented an updated synonymic list and remarks for *Cloudina lucianoi*. To access the complete systematic taxonomic description such as type-material, illustrated material, original diagnosis and emended diagnosis of *Cloudina lucianoi*, see Adôrno et al. (2017). A detailed remarks for this species was presented comparing it with *Cloudina riemkeae*, *Cloudina carinata* and *Cloudina hartmanae* in Adôrno et al. (2017). Here, additional remarks for *Cloudina lucianoi* are presented, especially considering the further advances on recent propositions of synonym of the material from China, which should be considered in the least case, synonym of *Cloudina lucianoi*. Cai et al. (2017) studying phophatized extracted 3D specimens of *Cloudina lucianoi* from China, proposed an emended diagnosis to emphasize the occurrence of transverse and/or oblique annulations on the exterior surface of the tubes. This ultrastructural morphology is possible to recognize due to the phosphatization. The illustrated material of two species were synonymized with *Cloudina lucianoi* in Cai et al. (2017): *Cloudina lijiagouensis* (only illustrated specimen: Zhang, Li, and Dong (1992) in Ding et al. (1992) p. 94, pl. VIII, Fig 6), and *Cloudina sinensis* (part of the illustrated material in Zhang, Li and Dong in Ding et al.,

(1992) p. 93, pl. VIII, Figs. 1–3, 5, 7-8, 10–12, 14–15, 18 (including the holotype of *Cloudina sinensis*: Zhang, Li, and Dong (1992) in Ding et al. (1992) p. 94, pl. VIII, Fig 7). The illustrated specimen (Zhang, Li, and Dong (1992) in Ding et al. (1992) p. 94, pl. VIII, Fig 9) was transferred to *Cloudina ningqiangensis* (Cai et al., 2017), so the list of illustrated material transferred to *Cloudina lucianoi* is here updated and complemented in order to clarify these important taxonomic procedures.

Occurrence: (Adôrno et al., 2017).

Geographic and stratigraphic distribution: (Adôrno et al., 2017).

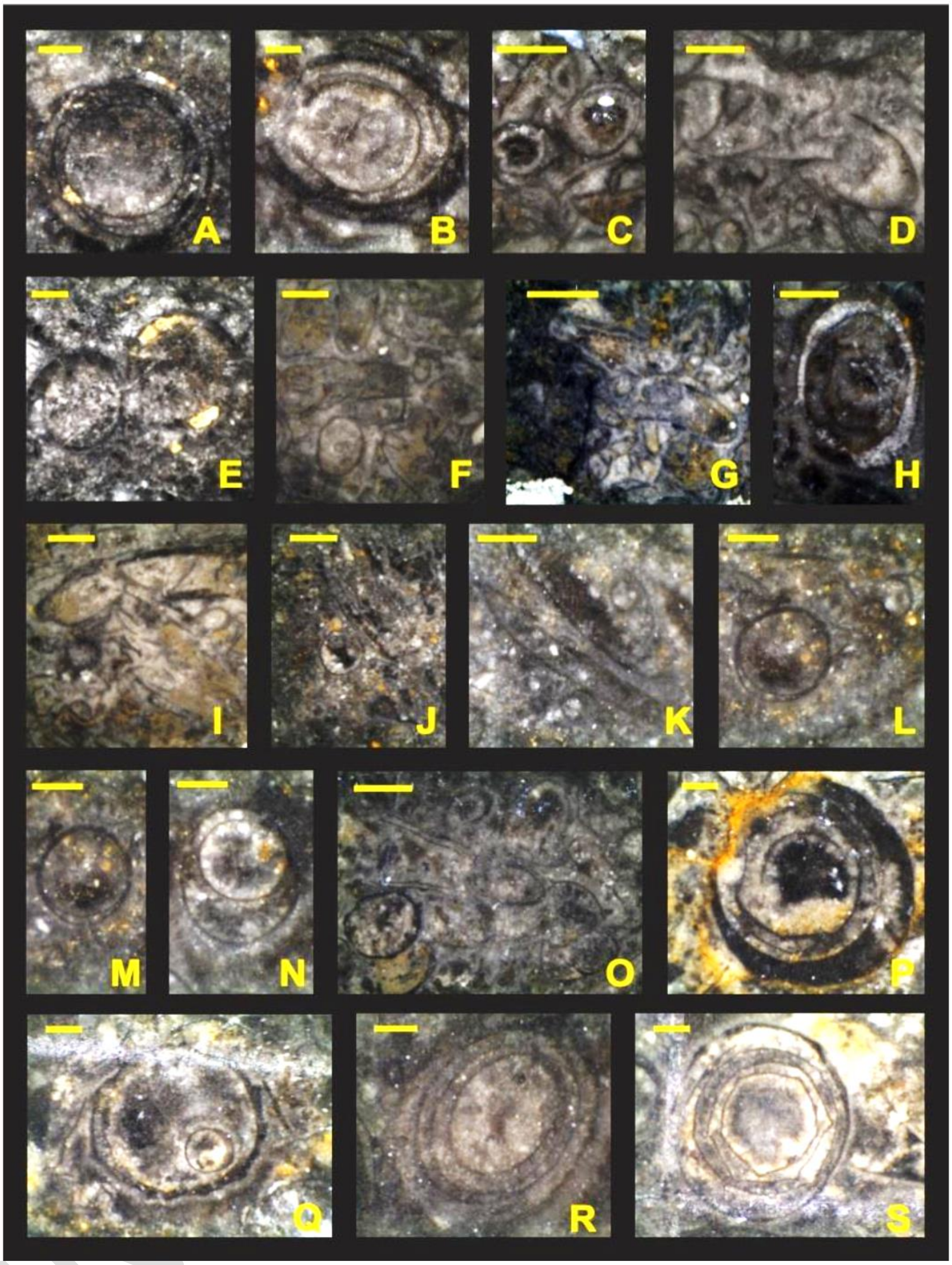


Figure 8. Polished sections with specimens of *Cloudina luciano*i (Beurlen & Sommer, 1957). Section 1153: A-C and E, specimens in transverse section (Obs: Note the funnel-within-funnel structure); D, specimens in longitudinal section. Section 1154: F, overview of the sample; G, I, longitudinal section emphasizing the thickness of the wall of the skeletal body, including transverse sections; H, Specimen possibly recrystallized. Section 1157: J, K and N, longitudinal sections highlighting the variation in diameter along the wall of the skeletal body; cross sections are also presented; L, M, transverse section (note the funnel-within-funnel structure). Section 1158: O, transverse and longitudinal sections; P–S, transverse sections (note the funnel-in-funnel structure). Scale bars: A, B, E, L, M, N, P–S = 500 µm; D, H, K = 1000 µm; C, F, G, I, O = 2000 µm (Extracted from Adôrno et al., 2017).

Cloudina carinata Cortijo et al., 2010
(Figs. 9: A-B)

1990 ?*Cloudina* sp. in Grant, fig. 7c.
1994 *Cloudina* sp. in Vidal et al., fig. 12c.
1994 ?*Cloudina* sp. in Vidal et al., fig. 12d.

2009 *Cloudina carinata* n. sp. in Cortijo et al., pp. 175–176, fig. 1.
2010 *Cloudina carinata* n. sp. in Cortijo et al., pp 4, fig. 4-9.
2011 *Cloudina carinata* Cortijo et al., 2010 in Terleev et al., pp 97, fig. 38F.
2015b *Cloudina carinata* Cortijo et al., 2010 in Cortijo et al., pp. 188, fig. 2.
2015 *Cloudina carinata* Cortijo et al., 2010 in Grazhdankin et al., pp 565, fig. 3C.

Type-material: Holotype specimen illustrated in Cortijo et al. (2010) Fig. 4E, UEXP709Me2:006, is housed in the collections of Área de Paleontología, Universidad de Extremadura, Badajoz.

Type-locality: Lower reaches of the Estena River on the Membrillar property (Fig. 2C), northeastern Badajoz, south-central Spain. 39° 21'42''N, 4° 50' 16'' W (Cortijo et al., 2010).

Type-horizon: Carbonate blocks in the Membrillar olistostrome (Cortijo et al., 2010).

Illustrated material: One hand sample specimen MP-717; MAF-.

Description: (see Cortijo et al., 2010).

Diagnosis: A species of *Cloudina* characterized by prominent external, longitudinal crests. Funnels have a basal, slightly constricted circular opening, and a thickened apertural rim (Cortijo et al., 2010).

Remarks: Considering characteristics of the illustrated material, it is clearly a member of *Cloudina* (Germs, 1972). The funnel-within-funnel structure of the *Cloudina carinata* differs from the pattern presented by *Cloudina lucianoi* which has nested funnels instead of stacked funnel-within-funnel overlapping only the basal portion of each next funnel in *Cloudina carinata*. Another diagnostic feature that allows to differ this occurrence from *Cloudina lucianoi* is the presence of the prominent external longitudinal crests **(**keel). Considering these morphological assignments, and the morphometric matching, it was possible to classify this Tamengo Formation specimen as *Cloudina carinata*.

Occurrence: A new occurrence is reported herein for the first time in American continent in one hand sample specimen MP-717; MAF-, Porto Figueiras section, Tamengo Formation, Corumbá Group, Corumbá, Mato Grosso do Sul State, Brazil. UTM Coordinates zone 21K 0433880mE / 7899144mS.

Geographic and stratigraphic distribution: Spain in association with *Cloudina lucianoi* within Membrillar olistostrome, and in the Navalpino anticline, was also recovered in the Fuentes olistostrome in the Arroyo del Cubilar section, in the Toledo Province, and Villarta de los Montes locality all related to the Ibor Group in central Spain (Cortijo et al., 2010; 2015b). Occurences of *Cloudina carinata* in association with *Cloudina lucianoi* and *Cloudina* riemkeae have been reported in the Siberia Platform, Russia (Terleev et al., 2011; Zhuravlev et al., 2012). Tamengo Formation, Corumbá Group, uppermost Ediacaran, Porto Figueiras section, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

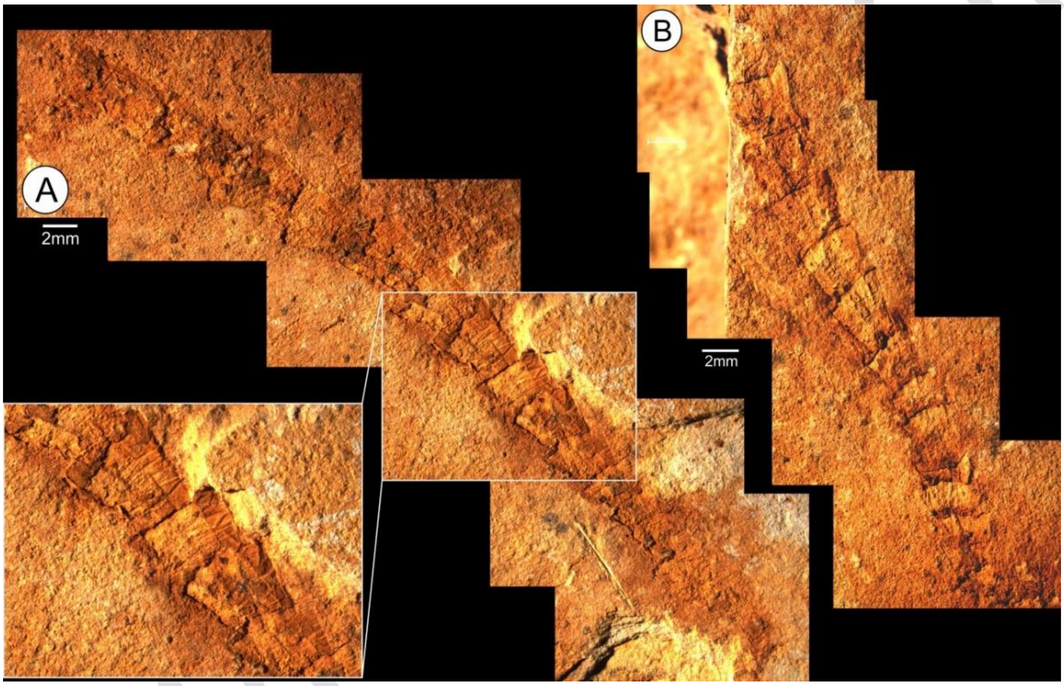


Figure 9. Two specimens of *Cloudina carinata* Cortijo et al., 2010 from the Tamengo Formation, specimen MP-717.

PHYLUM Cnidaria Hatschek, 1888

CLASS Scyphozoa Götte, 1887

FAMILY Corumbellidae Hahn et al., 1982

GENUS *Corumbella* Hahn et al., 1982

Type-species: *Corumbella werneri* Hahn et al., 1982.

Original diagnosis, translated from German: Columnar structures without branches and length of 8 to 10 cm, approximately half of this length is proximal (primary polyp) and the other half distal area (secondary polyp region). Secondary polyps are bilateral, composed of at least three polyps positioned horizontally side by side, probably more than three, in the vertical sequence (from proximal to distal), approximately two hundred secondary polyps. In addition, these polyps have all Subclass characteristics (Hahn et al., 1982).

First emended diagnosis: Annulated tube expanding slightly from a narrow apex to an elongate, narrow, parallel-sided section; cross section squarish with rounded corners; annulations present on each face; midline consists of a longitudinal groove externally that reflects position of longitudinal carina internally (Babcock et al. (2005).

Second emended diagnosis: Polyhedral, elongated tube, with internal septa formed by junction of alternate rings at midlines (Pacheco et al., 2014).

Remarks: See remarks for *Corumbella werneri*.

Corumbella werneri Hahn et al., 1982 emended.

(Fig. 10: 1-3)

1982 *Corumbella werneri* Hahn et al., taff. 1-3, abb. 3-5, 9, 11, Brazil.
1982 *Corumbella werneri* Hahn et al., Walde et al., Brazil.
1987 *Corumbella werneri* Hahn et al., Zaine & Fairchild, figs 8, 9 and 10, Brazil.
2000 *Corumbella n.* sp. Hagadorn & Waggoner, Fig. 5 p. 356.
2005 *Corumbella werneri* Hahn et al., Babcock et al., figs 4, 5 and 6.
2011 *Corumbella werneri* Hahn et al., in Pacheco, figs 3, 4, 5 and 6, Brazil.
2011 *Corumbella werneri* Hahn et al., in: Warren et al., figs F and G, Paraguay.
2011 *Corumbella werneri* Hahn et al., in: Meira, pp. 46, Pl. 3.
2012 *Corumbella werneri* Hahn et al., in: Warren et al., figs B-K, Brazil.
2013 *Corumbella werneri* Hahn et al., in: Warren et al., fig. K, Paraguay.5
2015 *Corumbella werneri* Hahn et al., in: Walde et al., 2005 fgs 4 a-c.
2017 *Corumbella werneri* Hahn et al., in in Warren et al., Fig. 3: C.
2018 *Corumbella werneri* Hahn et al., in Walde et al., 2018, Fig. 9, 11-14.
2019 *Corumbella werneri* Hahn et al., in Warren et al., Fig. 8:B.
2019 *Corumbella werneri* Hahn et al., in Walde et al., figs. 5-7.

Type-material: DGM 5.602-I, housed in the collection of paleobotany, Division of Geology and Mineralogy of the Museum of Earth Sceiences, Rio de Janeiro, Brazil (Hahn et al., 1982).

Type-locality: Claudio quarry (currently called Porto Sobramil), Corumba/Ladário municipalities, Mato Grosso do Sul State, Brazil (Hahn et al., 1982).

Type-horizon: Corumba Group, Vendian, upper Precambrian (Hahn et al., 1982). Although not included in the characterization of the type-horizon, these layers were attributed to the Tamengo Formation (Hahn et al., 1982), uppermost Ediacaran (Boggiani et al., 2010).

Illustrated material: Three specimens were illustrated from the Porto Sobramil section: An adult specimen with exceptional preservation of the original cuticle (MAF-523), possible basal part (juvenile form?) (CP-746) and median portion of *Corumbella werneri* tube showing cylindrical geometry and absence of midline (crack line) (CP-747).

Original diagnosis: Same as the genus *Corumbella* Hahn et al., 1982.

First emended diagnosis: *Corumbella* expanding up to 5 mm in diameter; annulations across each of four faces closely spaced (approximately 40–45/cm), welldefined; annulations meet and are offset slightly at midline of each face (Babcock et al., 2005).

Second emended diagnosis: Elongated polyhedral pyramidal exoskeleton (theca), thick, diameter along tube slightly variable; cross section circular at basal part, otherwise quadratic distalwards; external midline groove formed by junction of polygonal rings at apothem, continuous along the polyhedral tube; internal septa located internally to midline, when present; rings continuous over lateral edges, absence of carinae (Pacheco et al., 2014).

Remarks: A brief history of the research studies on *Corumbella werneri* Hahn et al., 1982, and the translations of the original diagnoses from German (original) to English were presented. There are three diagnoses for *Corumbella werneri*, the original by Hahn et al. (1982), the one from Babcock et al. (2005) and the last one published in Paccheco et al. (2014). These three diagnoses include conflicting characteristics between interpretations of morphological features such as the presence of carina in the internal portion of the septa; Babcock et al. (2005) describe the presence of carina as a diagnostic property of the genus and species, but in the diagnosis presented in Paccheco et al. (2014), it is explicitly stated that such structure is not present. There are two descriptions for *Corumbella werneri*, namely the original by Hahn et al. (1982) and another presented in Pacheco et al. (2014). Raquel Pacheco studied an extensive collection of samples from Corumbá, made up of more than 400 samples at the Institute of Geosciences of the University of São Paulo (Pacheco, 2012). Pacheco proposed that *Corumbella weneri* would have tetragonal geometry and a longitudinal midline, mandatory element for conulariids (Pacheco et al., 2010; Van Iten et al., 2014; Pacheco et al., 2015). Walde et al. (2018), on the other hand, based on taphonomic analysis, argue that such longitudinal median lines could be reinterpreted as crack-lines formed during diagenetic compaction processes. The argument that supports this interpretation is multiple and based on the fact that crack-lines occur only in incomplete tubes. Warren (2011) examined rocks of the Itapucumi Group in Paraguay where *Corumbella werneri* occurs completely cylindrical and without either median line or crack-line (Warren, 2011; Warren et al. 2012; 2014). New occurrences of specimens with neither compaction features nor crack-lines in these specimens corroborate the assertion that such longitudinal lines occasionally occurr in *Corumbella werneri* tubes due to postmortem processes (Walde et al., 2015; Erdtmann & Walde, 2016; Walde et al., 2018). Considering the multiple diagnoses, which somehow contradict, it is notable that this genus and species need a thorough taxonomic revision and a new emended diagnosis considering the new data presented on the effect of diagenesis on postmortem structures in some specimens (Walde et al., accepted). Apart from the *post-mortem* crack-lines, there are no other morphological features in the remains of *Corumbella werneri* indicating that neither the proximal nor the distal portions of the tubes possessed a tetragonal cross-section as postulated by Babcock *et al.* (2005) and Pacheco (2012). Furthermore, corumbellids and conulariids differ significantly in general shape of the tube: corumbellids have long, narrow, minimally expanding tubes, whereas conulariids have rapidly expanding tubes. This character may not, however, have significance for ascertaining the phylogenetic affinities of the two animals (Babcock et al., 2005). Occurrences of *Corumbella werneri* was also recorded in Paraguay (Warren et al., 2011, 2013, 2017, 2019). Other undetermined *Corumbella* sp. occurrences have been recorded in the region of Januária, State of Minas Gerais in the Sete Lagoas Formation, Bambuí Group (Warren et al., 2014) and also reported in Nevada, Woodcanyon Formation, Ediacaran of the United States of America (Hagadorn & Wagoner, 2000, Smith et al., 2017). These new occurrences have indicated potential for paleographical distribution for this species.

Occurrences: Brazil, Tamengo Formation outcrop: Cacimba Ecopark, Corumbá Municipality, Mato Grosso do Sul State, Brazil; Tamengo Formation outcrop: Sobramil port, Ladário Municipality, Mato Grosso do Sul State, Brazil; Tamengo Formation outcrop, Corcal quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil, Tamengo Formation outcrop, Porto Figueiras.

Geographic and stratigraphic distribution: *Corumbella werneri* has occurrences documented in the upper Ediacaran Tamengo Formation in Corumbá and Ladário regions, Mato Grosso do Sul State, Brazil (Hahn et al. 1982; Walde et al. 1982; Zaine & Fairchild 1985; Zaine, 1991; Hidalgo, 2002; Gaucher et al., 2003; Meira, 2011; Becker-Kerber et al., 2013; Tobias, 2014; Van Iten et al., 2014; Pacheco et al., 2015; Walde et al., 2015; Adôrno et al., 2017; Walde et al., 2015; Erdtmann & Walde, 2016; Walde et al., 2018 and others). Occurrences are also documented from Itapucumi Group, Paraguay (Warren et al., 2011).

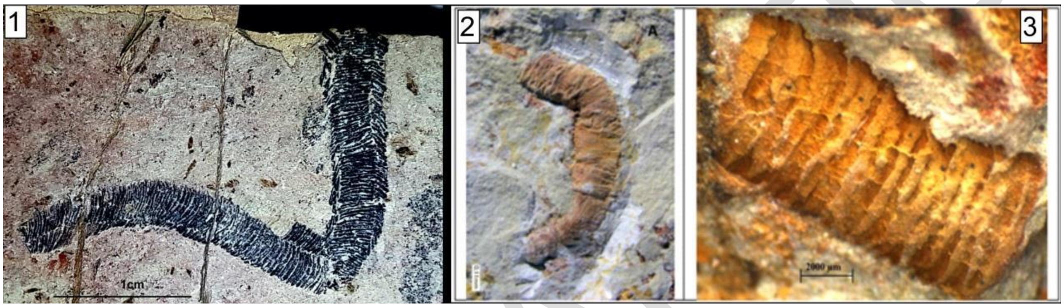


Figure 10. Specimens of *Corumbella werneri* Hahn et al., 1982 from the Tamengo Formation, Corumbá Group. 1) Adult specimen with exceptional preservation of the original cuticle MAF-523. 2) Possible basal part (juvenile form?), CP-746. 3) Median portion of *Corumbella werneri* tube showing cylindrical geometry and absence of midline, CP-747 (Walde et al., 2018).

Vendotaenids

Three vendotaenid species occur in Tamengo and Guaicurus formations: *Vendotaenia antiqua* Gnilovskaya, 1971, *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979). As already mentioned, *Vendotaenia antiqua* occurs in Cerradinho, Bocaina and Tamengo formations. *Eoholynia corumbensis* and *Tawuia dalensis* have occurences restricted to Guaicurus Formation.

Vendotaenia antiqua is assigned as probably abandoned sheaths of sulfide-oxidizing organotrophic bacteria related to the Beggiatoaceae (Vidal, 1989; Gaucher et al., 2003). On preservational mode, *Vendotaenia antiqua* was recovered in three distinct modalities: as impressions from red siltistone bedding, as organic-walled remains and as permineralized fragments. *Eoholynia corumbensis* is assigned as remains of eucaryotic algae, probably

Phaeophyta or Rhodophyta, and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) is probably related to photosynthesizers cyanobacteria (Steiner et al., 1996).

CLASS Vendophyceae Gnilovskaya, 1986

ORDER Eoholyniales Gnilovskaya, 1986

FAMILY Eoholyniaceae Gnilovskaya, 1986

GENUS *Eoholynia* Gnilovskaya, 1975

Type-species: *Eoholynia mosquensis* Gnilovskaya, 1975

Diagnosis: Thallus string-like, intensively branching, centrally attached. Main branch branches monopodially, lateral branches dichotomously. Surface of thallus is finely granular. Sporangia are sessile, located on main and lateral branches or at ends of terminal lateral branches (Gnilovskaya, 1975).

Remarks: Genus well established.

Eoholynia corumbensis Gaucher et al., 2003
(Fig. 11: A-H)

2000 *Eoholynia* sp. Gaucher et al. pl. 17.7.

Type-material: Holotype FC DP3615. Paratypes of an individual with multiple basal branchs is the specimen FC DP 3222. One terminal sporangium, specimen FC DP 3616 was designate as paratype (Gaucher et al., 2003).

Type-locality: Laginha quarry section, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Gaucher et al., 2003).

Type-horizon: Lower portion of Guaicurus Formation (Gaucher et al., 2003).

Illustrated material: FC DP 3615 (Fig. 7C/D in Gaucher et al., 2003). Paratypes of an individual with multiple basal branchs is the specimen FC DP 3222 (Fig. 7E in Gaucher et al., 2003, also figured by Gaucher, 2000: pl. 17.7). As paratype of terminal sporangium, we designate the specimen FC DP 3616 (Fig. 7H in Gaucher et al., 2003).

Description: Not presented in Gaucher et al. (2003).

Diagnosis: A species of *Eoholynia* characterized by a cord- or ribbon-like thallus composed of 3/5 main branches, 0.05/0.6 mm wide (mean0.24 mm, S.D./0.15 mm, N/34). Main branches develop secondary branches of several orders, mostly dichotomously. Spherical bodies are frequently (but not always) attached to the surface of the main branch, and also to the ends of the lateral branches (here interpreted as terminal sporangia). Size of spherical bodies ranging between 0.3 and 1.2 mm (mean/0.54 mm, S.D./0.26 mm, N/11). Height of complete specimens 3/18 mm, mostly around 8 mm (Gaucher et al., 2003).

Remarks: (see Gaucher et al., 2003).

Occurrences: Specimens FC DP 3615 FC DP 3222 FC DP 3616 lower Guaicurus Foramation, lowermost Cambrian, Laginha quarry section (Gaucher et al., 2003).

Geographic and Stratigraphic distribution: Guaicurus Formation, Laginha quarry section, Corumbá Group, lowermost Cambrian, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Gaucher et al., 2003).

CLASS Chuariaphyceae Gnilovskaya & Ishchenko, in Hofmann, 1994

ORDER Chuariales Gnilovskaya, 1986

FAMILY Tawuiaceae Ishchenko, in Hofmann, 1994

GENUS *Tawuia* Gnilovskaya, 1975

Type-species: *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979)

Diagnosis: Rod-and ribbon-like compressions of millimetric width and centimetric length; outlines smooth and even; sides parallel to slight tapering, ends approximately semicircular (Hofmann & Altken, 1979).

Remarks: Genus well established.

Tawuia dalensis Hofmann, 1979 in (Hofmann & Aitken, 1979)

(Fig. 8: I-J)

1979 *Tawuia dalensis* Hofmann in Hofmann & Altken, Fig. 13 A-I.
1982 *Tawuia dalensis* Hofmann in Duan, pp. 62, Fig. 5 K-N.
1987 *Tawuia dalensis* Hofmann in Sun,
1992 *Tawuia dalensis* Hofmann in Hofmann,

1992 *Tawuia dalensis* Hofmann in Zang & Walter, pp. 257, Pl. IV: D-E.
2001 *Tawuia dalensis* Hofmann, in Kumar, Fig. 9a–d; Fig. 14j and k.
2003 *Tawuia dalensis* Hofmann, in Gaucher et al., pp. 258, Fig. 7: I-J.

Type-material: Holotype: GSC 57893: paratypes: SSC 57890-57892; 57894-57897.

Type-locality: 76AC-2; 64°48'N 129°47'W; headwaters of the Sayna River (Hofmann & Altken, 1979).

Type-horizon: Little Dal Group, "basinal sequence" of Aitken (1977. p. 13 1 in Hofmann & Altken, 1979).

Illustrated material: Sample FCDP 3617 (Fig. 7: I-J in Gaucher et al., 2003).

Description: Rod- and ribbon-like films, short to slender, par-allel-sided, somewhat tapering in one direction in short specimens, with approximately semicircular termini; coloul- yellowish- and greenish-brown, to dark grey and black, depending on lithology ; lustre matte to resinous; diameter 1.7-6.0 mm, length 7.0 to more than 77 mm (Fig. 15 in Hofmann & Altken, 1979); margins very smooth and distinct; surface finely granular, probably due to diagenesis. Morphology rather variable (Fig. 16 in Hofmann & Altken, 1979); specimens mostly slightly curved, occasionally reflexed, with a tendency toward a-ectilinearity in short specimens; specimens sometimes overlying one another, but not twisted or folded over themselves. Originally probably soft, blunt, smooth cylindrical bodies with taut outer membrane. No openings observed, but large vague, circular structure located at one end in certain specimens (Fig. 13 F, Cr in Hofmann & Altken, 1979) (possibly representing sporangium, float, or attachment disc). Other specimens (Fig. 13 E, W in Hofmann & Altken, 1979) with darker, axial stripe or zone. Two specimens show a recurved habit (Fig. 13 E, F in Hofmann & Altken, 1979); the larger one is 60 mm long and has arms 4.8-6.0 mm wide. with an axial ~narking 2.5 mm wide; the smaller one is 11.5 mm long and has arms 1.8-2.0mm wide, but lacks an axial marking, having instead a terminal circular structure in its left arm (Hofmann & Altken, 1979).

Diagnosis: *Tawuia* with maximum diameter in the range of 2-6 mm (Hofmann & Altken, 1979).

Remarls: See Hofmann & Altken (1979).

Occurrences: Sample FCDP 3617 Guaicurus Formation, upper Corumbá Group, lowermost Cambrian (Gaucher et al., 2003).

Geographic and stratigraphic distribution: Guaicurus Formation, Corumbá Group lowermost Cambrian, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Gaucher et al., 2003), Little Dal Group, Mackenzie Mountains, northwestern Canada (Hofmann & Altken, 1979); Liulaobei Formation; Mt Bagongshan, Shouxian County, Anhui Province, China (Cheng-Hua, 1982); Mesoproterozoic, Vindhyan Supergroup, Central India (Kumar, 2001).

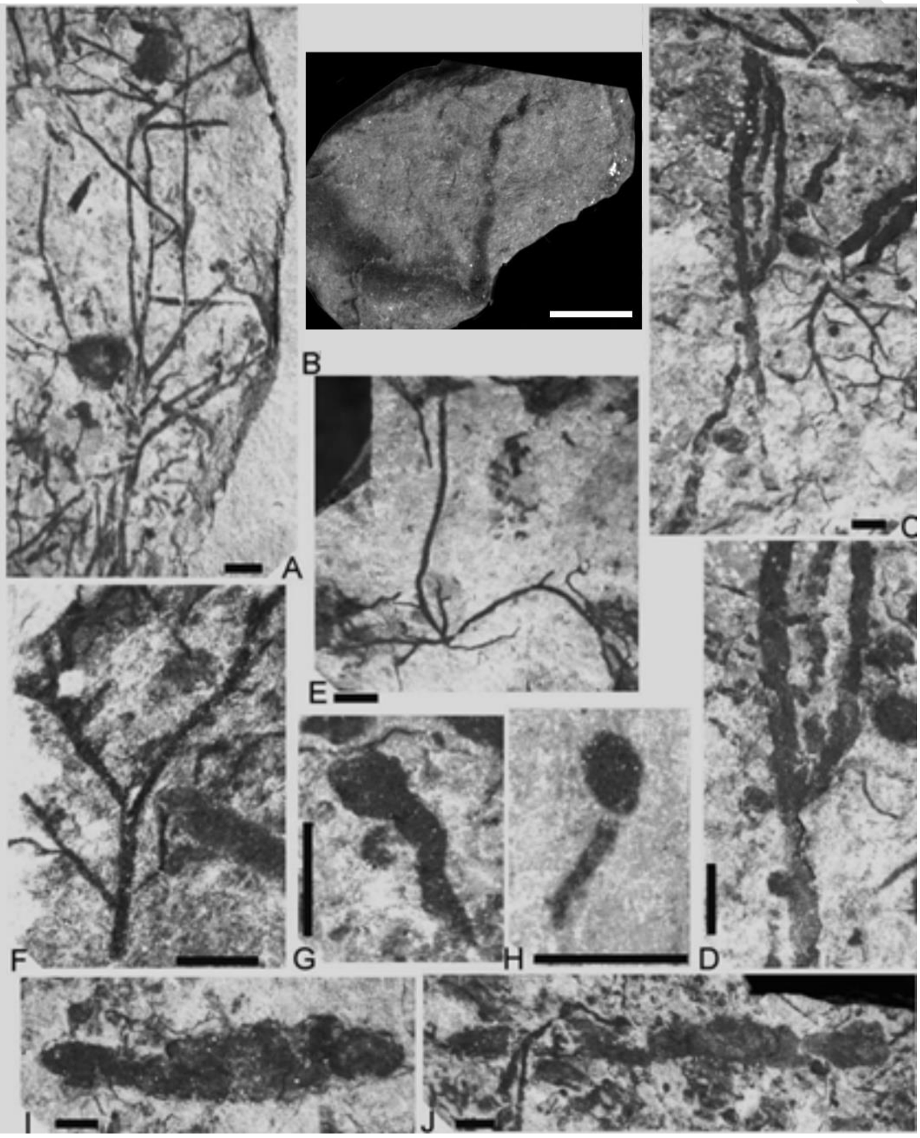


Figure 11. *Eoholynia corumbensis* Gaucher et al., 2003 and *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979) from the bedding surface of the gray siltstones of the lower portion of the Guaicurus Formation in the Laginha quarry, lower Cambrian. A-H) *Eoholynia corumbensis*; A) Full rectilinear thalli (FCDP 3613 specimen) with multiple branches; B) Specimen from Laginha quarry, Guaicurus Formation (original number MP 3225) recorded during this doctorate; C-D) Holotype PDGF 3615, with main branch covered with spherical bodies (sporangia); E) PDGF Paratype 3222 with intense ramifications from the main stem; F) Rectilinear thalli; G) terminal sporangium; H) FDCP specimen 3616, terminal sporangium parenchyma; I-J) *Tawuia dalensis* Hofmann, 1979 in (Hofmann & Aitken, 1979); I) slightly curved specimen FCDP 3617; J) rectilinear specimen with numerous overlapping of *Eoholynia* stems. Scale bars have 1 mm (modified from Gaucher et al., 2003, with the inclusion of illustration of studied specimen B).

ORDER Vendotaeniales Gnilovskaya, 1986

FAMILY Vendotaeniaceae Gnilovskaya, 1986

GENUS Vendotaenia Gnilovskaya, 1971

Type-species: *Vendotaenia antiqua* Gnilovskaya, 1971.

Diagnosis: Ribbons long, straight or gently bending, fairly broad and comparatively coarse. Surface of ribbons reveals filamemous structure (Gnilovskaya, 1971).

Remarks: Genus well established.

Vendotaenia antiqua Gnilovskaya, 1971
(Figs. 8 and 12: 9)

1966 *Laminarites antiguissimus* Eichwald, 1966 in Timofeyev, pp. 16- 17, pl. l, fig. 1; pl. Il, fig. 1a.
1971 *Vendotaenia antiqua* Gnilovskaya, in Gnilovskaya pl. XI: 6-8
1971 *Tyrasotaenia podolica* in Gnilovskaya, S. 106, 107, T. XI, Fig. 1-5
1978 *Vendotaenia antiqua* in Gnilovskaya; Cao & Zhao, S. 17, T. 2, Fig. 1-4
1978 *Vendotaenia didymos* in Cao & Zhao, S. 18, T. 2, Fig. 5,6
1983 *Vendotaenia antiqua* in Gnilovskaya, S. 48, T. XXXIX-XLIII
1983 *Tyrasotaenia podolica* in Gnilovskaya, T. XIV, Fig. 1-5, 7
1983 *Tyrasotaenia tungusica* in Gnilovskaya, S. 48, 49, T. XIV, Fig. 6
1985 *Vendotaenia* sp. in Duan et al., S. 76, T. 17, Fig. 13
1985 *Tyrasotaenia cf. podolica* Gnilovskaya in Duan et al., S. 77, T. 17, Fig. 11-12
1985 *Vendotaenia antiqua*; Gnilovskaya in Sokolov & Iwanowski, S. 140, T. 30, Fig. 1-5, T. 31 , Fig. 1-6, T. 32, Fig. 1-4, T. 33, Fig. 1- 3, T. 36, Fig. 2
1985 *Tyrasotaenia podolica*; Gnilovskaya in Sokolov & Iwanowski, T. 34, Fig. 1, 3, 4
1985 *Tyrasotaenia tungusica*; Gnilovskaya in Sokolov & Iwanowski, T. 34, Fig. 2
1986 *Vendotaenia* sp. in Germs, Knüll & Vidal, S. 55, Fig. 5 a, c
1987 *Vendotaenia*? sp. in Narbonne & Hofmann, S. 671, Text-fig. lOg
1988 *Vendotaenia antiqua* in Gnilovskaya et al., S. 39-44, T. V-Vll, VIII, Fig. 1-2
1988 *Tyrasotaenia podolica* in Gnilovskaya et al., T. IX, Fig. 4, T. XIV, Fig. 1-4
1988 *Vendotaenia antiqua* Gnilovskaya et al.,T. XIV, Fig. 4 -8, XVI, Fig. 2-5
1989 *Vendotaenide* Vidal, Fig. 1, C, E
1991 *Tyrasotaenia* sp. in Zaine: fig. 5.6, pl. 10
1992 *Vendotaenia didymos* Cao & Zhao in Zang & Walter, S. 111-112, T. 6, Fig. A-F
1992 *Vendotaenia* sp. in Zang & Walter, S. 112, T. 7, Fig. A-B, T. 8, Fig. C
1992 *Tyrasotaenia* ? sp. (Type-1) in Zang & Walter, S. 110-111, T. 6, Fig. G-H, T. 7, Fig. E-F
1992 *Tyrasotaenia*? sp. (Type-2) in Zang & Walter, S. 111, T. 8, Fig. D-F
1994 *Vendotaenia antiqua* Gnilovskaya, Steiner: fig. 41k, l; fig. 45a/c; Fig. 47
2003 *Vendotaenia antiqua* Gnilovskaya, in Gaucher et al., fig 5A.

Type-material: Holotype: Specimen IGGD AN SSSR, No. 6931/20 from the Kotlin Horizon in St. Petersburg, figured by Gnilovskaya (1971: pl. XI.8).

Type-locality: Siberia, Russia (Gnilovskaya, 1971).

Type-horizon: Horizonte Kotil, Rússia (Gnilovskaya, 1971).

Diagnosis: The same as from the genus.

Ilustrated material: Hand sample MAF-516 from upper portion of the Tamengo Formation, sample, locality Corcal quarry (Fig. 12); permineralized fragments from sample MP-1656 Corcal quarry section (Fig. 15: 8).

Description (translated from Russian): The vast majority of thalli are in form of extremely slender filmlike ribbons arranged parallel to bedding plane. Ribbons comparatively broad (l.5-2.0 mm) and long (up to 50mm in the fragments). Specimens from Leningrad Province slightly broader than those from Podolia. Ribbons straight or slightly bent in gentle curves; no definite branching found in available material. Most ribbons are found not as separate specin1ens but in mass clusters. They are super imposed one on the other and form intricate plexuses in bedding planes which might create impression of branching of ribbons. Both in the rock and in ribbons separated from the rock by hydrofluoric acidis a distinct undissected contour which is accentuated by the deeper color along stra ight margins of ribbons. The extremely fine, longitudinally extended filaments which give the ribbons a "textile" structure also distinguished on surface of ribbons by darker color. Filaments approxi mately 0.025 mm wide. No transverse septa found in filaments. Sometimes ribbons do not lie directly on clay substrate, but are apparently submerged in a sapropelite mass preserved as a thin s tructureless film of indeterminate outline. In the rock these films a nd ribbons are cinnamon –brown a nd dark cinnamon- brown. In transmitted light these film s separated from rock with hydrofluoric acid are yellow and ribbons are golden-cinnamon-brown (Gnilovskaya, 1971).

Remarks: Similar to the material recovered by Gaucher et al. (2003), stems and fragments were recovered in the acid macerations of Tamengo Formation samples. Therefore, the occurrence of *Vendotaenia antiqua* in the Tamengo Formation is confirmed, and therefore its distribution becomes the top of the Corumbá Group, between the Cerradinho, Tamengo formations.

Occurrence: Hand sample MAF-516 and permineralized fragments from sample MP-1656. *Vendotaenia antiqua* was identified in Ecoparque Cacimba (sample MP- 1608) and the Laginha quarry (sample MP-1683), both in Corumbá, MS.

Geographic and stratigraphic distribution: East-European Platform, Ediacaran of Russia (Gnilovskaya, 1971), Uruguay and Brazil at the top of Cerradinho and Bocaina formations (Gaucher et al., 2003), and also at Corcal quarry, Tamengo Formation. Shibantan Member, Dengying Formation, Yichang, China (Steiner, 1994). Nama Group, Namibia (Germs et al., 1986). Wemecke Mountains, Yukon, Canada (Narbonne & Hoffmann, 1987).

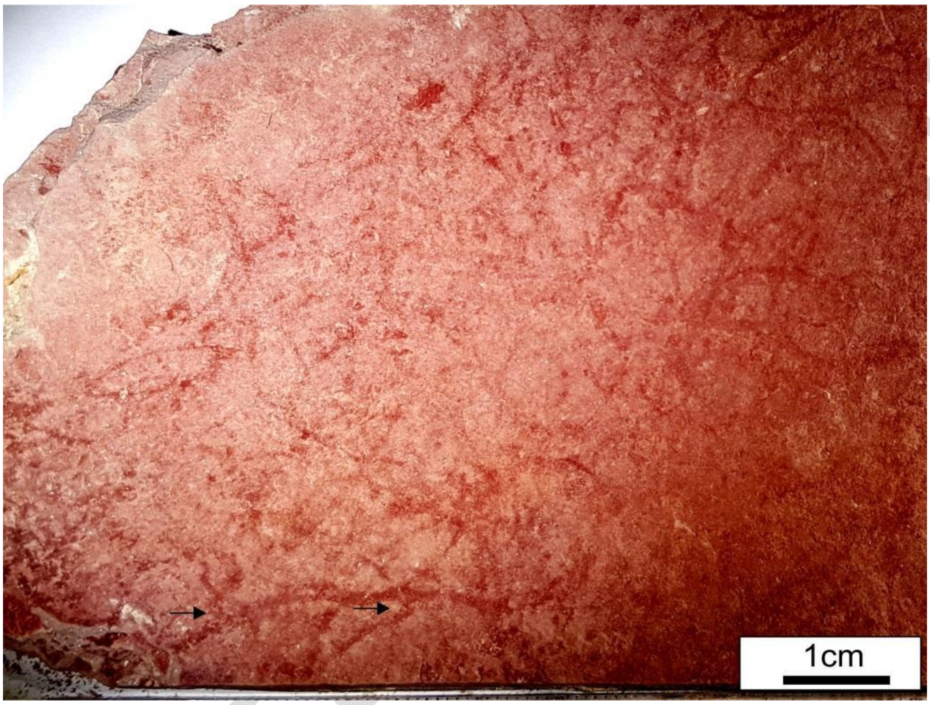


Figure 12. *Vendotaenia antiqua* Gnilovskaya, 1971 from the surface of the red siltstone of the upper portion of the Tamengo Formation, sample MAF-516, locality Corcal quarry.

Ichnofossils

Four ichnoespecies represent the vagile benthic assemblage of Tamengo and Guaicurus formations: *Didymaulichnus lyelli* and *Multina minima* Uchman, 2001, *Gordia marina* and *Pilichnus cf. P. dichotomus*. *Multina minima*, *Gordia marina* and *Pilichnus cf. P. dichotomus* occur in the Tamengo Formation. *Multina minima*, and *Didymaulichnus lyelli* occur in Guaicurus Formation.

ICHNOGENUS *Didymaulichnus* Young, 1972

Type-species: *Fraena lyelli* Rouault, 1850, by subsequent designation of Young, 1972.

Diagnosis: Gently curving, moderately deep, smooth, furrow-like trails, which are bisected longitudinally by a narrow median ridge. Trails oriented parallel to bedding planes, and may overlap and truncate one another (Young, 1972).

Remarks: According to Häntzschel (1962), the name *Fraena* Rouault, 1850 is unsuitable because it was originally used to include a heterogeneous group of trails, some of which were bilobate, and now classed as *Cruziana* and *Rouaultia,* and others nonbilobate, smooth trails, and horizontal tunnel-fillings. Häntzschel (1962) followed the suggestion of deTromelin and Lebesconte (1876) of restricting *Fraena* to designate the nonbilobate forms. This type of doubly furrowed trail has been commonly referred to previously as *Rouaultia* deTromelin. This name was invalidated by Häntzschel (1965, p. 80), however, because it was applied to a gastropod genus prior to its application to a trail by DeTromelin, 1878. Ksiazkiewicz (1970) used the term Taphrhelminthopsis Sacco (pro parte) for all "freely winding and meandering" bilobate trails. However, in the original diagnosis, Sacco (1888) described a central, slightly raised thread within the median groove, unlike the plain groove of hypichnial casts of *Didymaulichnus*. As well, this term was restricted (Andrews, 1955; Häntzschel, 1962) to tightly coiled or meandering bilobate trails, also unlike the open, gentle curves displayed by *Didymaulichnus*. Furrow-like varieties of Cruziana resemble *Didymaulichnus* except that the former exhibit V-shaped markings and fine lineations within the furrows, whereas D. furrows are smooth (Young, 1972). It is important to mention that Young (1972) considered only a part of *Fraena* Rouault, 1950 material as synonym of *Didymaulichnus* Young, 1972. The only species of *Didymaulichnus* genus presented in Young (1972) was *Didymaulichnus miettens* Young, 1972. The type-species of *Didymaulichnus* is *Fraena lyelli* Rouault, 1850 (*partim*), yet it was not presented wich part of the type-material of *Fraena lyelli* Rouault, 1850 should be considere as synonym of *Didymaulichnus lyelli* (Rouault, 1850). In fact, Rouault (1850) proposed four species for *Fraena* genus: *Fraena lyelli* Rouault, 1850, *Fraena furcifera* Rouault, 1850, *Fraena bronni* Rouault, 1850, *Fraena prevosti* Rouault, 1850. In fact, Young (1972) do not invalidated the *Fraena* genus, it was stated that only a part of the *Fraena* genus, probably *Fraena lyelli* material (information not clear in Young, 1972) should be considered as synonym of *Didymaulichnus lyelli* Young, 1972.

Didymaulichnus lyelli (Rouault, 1850)
(Fig. 13 c-d)

1850 *Fraena lyelli* n. sp. in Rouault, pp. 731
1981 *Didymaulichnus lyelli* (Rouault, 1850) in Bradshaw, pp. 635, fig. Fig. 23
1984 *Didymaulichnus lyelli* Rouault, 1850 in Pickerill et al., pp. 258
1998 *Didymaulichnus lyelli* Rouault, 1850 in Stanley & Pickerill, pp. 13, fig. 3:4
2012 *Didymaulichnus lyelli* Rouault, 1850 in Joseph et al., pp. 204, Pl. IV: b-c.
2013 *Didymaulichnus lyelli* Rouault, 1850 in Rajkonwar et al., pp. 23, fig. 2e
2017 *Didymaulichnus lyelli* (Rouault, 1850) in Parry et al., fig. 2: c-d.

Type-material: Not designated by Rouault (1850).

Type-locality: Guichen, Gauné, environ de Plélan, western Franc (Rouault, 1850).

Type-horizon: Ordovician Amorican sandstones of western France (Young, 1972)

Illustrated material: OUMNH ÁU.2 (Parry et al., 2017).

Description: Specimens straight to gently curving, bilobed ridges (3-5 mm wide, 2-3 mm high) and steep sided tracks; height varies by up to 5 percent of length; exposed lengths 47- 100 mm, limited by core diameter (approximately 100 mm); surfaces of lobes smooth or with faint transverse C-shaped (in plane view) ridges (0.6-0.8 mm wide), at 2 mm intervals; all specimens preserved as convex hypichnia and concave epichnia at interfaces between dark shales and thin sandstone beds (Vossler et al., 1989).

Diagnosis: Round, marked with a deep longitudinal groove; we could not distinguish any trace of oblique lateral streaks (Rouault, 1850).

Occurrence: Laginha quarry section, Guaicurus Formation, Corumbá Group, Cambrian, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Parry et al., 2017).

Geographic and stratigraphic distribution: Badhaura Formation, Permian Sakmarian of India (Kulkarni & Borkar, 2014). Terra Cotta Siltstone, Asgaard Range Table Mountain, Devonian, Antarctica AF227/1 CMu (Bradshaw, 1981). Bell Island and Wabana groups, Ordovician Arenig of Canada, Newfoundland (Fillion & Pickerill, 1990). Kaladongar Formation (Middle Jurassic), Patcham Island, Kachchh, Western India (Joseph et al., 2012). Guaicurus Formation, Corumbá Group, Cambrian, Corumbá Municipality, Mato Grosso do Sul State, Brazil (Parry et al., 2017).

ICHNOGENUS *Multina* Orłowski, 1968

Type-species: *Multina magna* Orlowski & Zvunska 1996

Diagnosis: Irregular network, passively filled, which can display appendices and string overlap within the same fossil trace (Uchman, 2001).

Remarks: The genus diagnosis presented in Uchman (2001) seems to be a new diagnosis for this genus presented by this author.

Multina minima Uchman, 2001
(Fig. 13: a-b)

2001 *Multina minima* isp. n., in Uchman, Pl. 13, figs. 4-5
2012 *Multina* isp. in Buatois & Mángano, Fig. 6.1-6.3.
2017 *Multina minima* Uchman, 2001 in Parry et al., fig. 2: a-b, e-h.

Type-material: Holotype is a well preserved specimen (specimen PJW1998VH 61) (Uchman, 2001).

Type-locality: Coming from the Aragon Valley, directly before the bridge, about 5 km north of Jaca locality 19, Pyrenees, northern Spain (Uchman, 2001).

Type-horizon: Upper Paleocene and Eocene Hecho Group (Uchman, 2001).

Illustrated material: OUMNH ÁU (Parry et al., 2017).

Description: As in diagnosis with the following additions: hypicimial form on a turbidite sandstone bed. The string is 0.6-1.0 m wide, and is filled with lighter-coloured, marlier sediment (Uchman, 2001).

Diagnose: *Multina mínima* presents very irregular nets, in which the meshes vary strongly in size but are less than 5 mm in diameter. The strokes exhibit various bumps and overlaps. Overlays can completely mask the traces and nets (Uchman, 2001).

Remarks: *Multina magna* displays more regular and larger meshes, in which strings are only slightly curved. Intensive sediment reworking in *Multina minima* suggests deposit-feeding (pascichnial) activity of the tracemaker, a few centimetres below the sea floor, along a sediment interface (Uchman, 2001).

Geographic and stratigraphic distribution: Tamengo and Guaicurus formations, Corumbá Group, Ediacaran, Mato Grosso do Sul, Brazil (Parry et al., 2017). Grupo Hecho Pirineus, Eocene in Northern Spain (Uchman, 2001). Very similar occurrences are presented for Puncoviscana Formation of Northwest Argentina, but those occurrences were attributed to *Multina* isp as illustrated by Buatois & Mángano (2012).

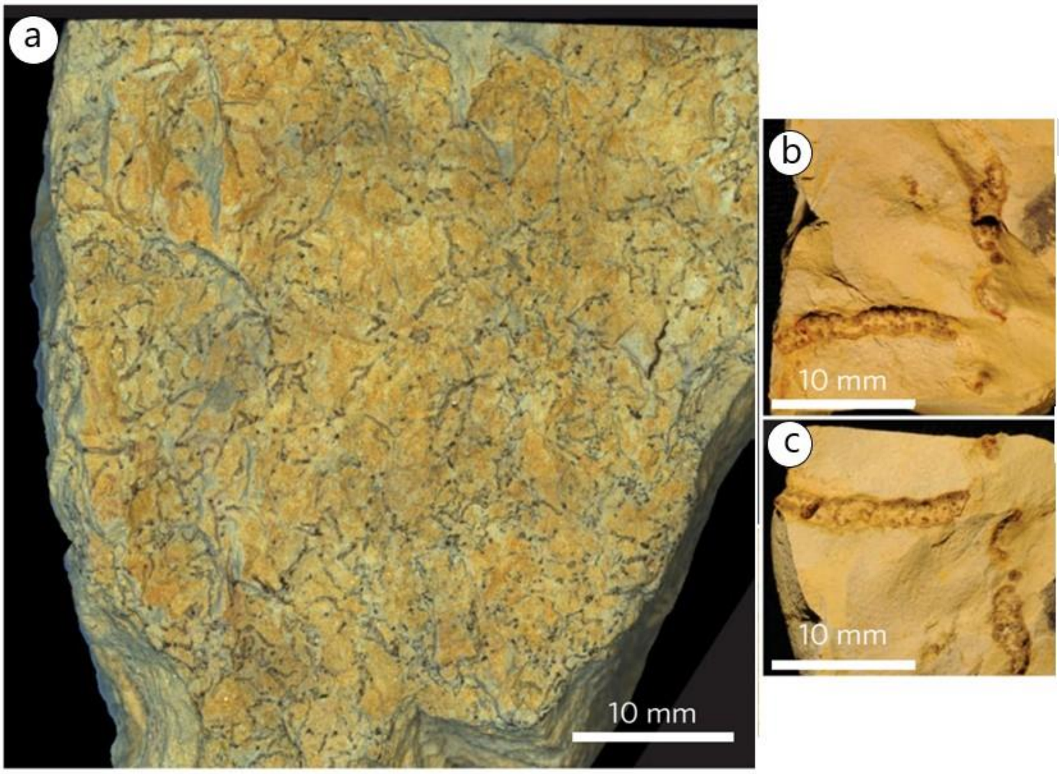


Figure 13. Photographs of hand samples and SEM images of the ichnofossils *Multina minima* (Uchman, 2001) from the Tamengo and Guaicurus Formation and *Didymaulichnus lyelli* (Rouault, 1850) from the Guaicurus Formation, Laginha quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil. a) *Multina minima* specimens; b-c) part and counterpart of bilobed traits of *Didymaulichnus lyelli* seen on the bedding surface (modified from Parry et al., 2017).

ICHNOGENUS *Gordia* Emmons, 1844

Type-species: *Gordia marina* Emmons, 1844.

Emended diagnosis: Smooth, unbranched, horizontal trails or burrows of uniform diameter throughout their length, winding but not meandering, with a marked tendency to level crossing. Burrow-fill massive (Fillion & Pickerill, 1990).

Remarks: Genus well stablished, an interesting discussion about Genus *Gordia* is presented in Fillion & Pickerill, 1990).

Gordia marina Emmons, 1844

(Fig. 14: 1-2)

1844 *Gordia marina* in Emmons, p. 24 pl. 2, fig. 2;
1847 *Gordia marina* Emmons, 1844 in Hall, p 264, pl. 7, fig. 1
1850 *Paleocorda minor* in M'Coy, pl. 1A-1, 1A-2;
1855 *Paleochorda marina* in Emmons, p. 103;
1867 not *Paleochorda marina* in Geinitz, p. 14-15, pl. 6, figs. 2-3.
1928 *Gordia marina* Emmons, 1844 in Shindewolf, p. 39;
1955 *Gordia marina* Emmons, 1844 in Andrews, p. 163;
1962 *Gordia marina* Emmons, 1844 in Häntzchel, p.W194;
1970 *Gordia marina* Emmons, 1844 in Andrews, p. 96;
1975 *Gordia marina* Emmons, 1844 in Häntzchel, p.W64;
1977 *Gordia marina* Emmons, 1844 in Chambernain, p. 11 Fig. 3G
1985 *Gordia marina* Emmons, 1844 in Crimes & Anderson, pp. 320, fig. Fig. 6.5, 6.6
1990 *Gordia marina* Emmons, 1844 in Fillion & Pickerill, Pl. 7 fig. 14.
1992 *Gordia marina* Emmons, 1844 in Pickerill, pp. 23, fig. 4D
1996 *Gordia marina* Emmons, 1844 in Orr, pp. 201, fig. 6a
1997 *Gordia marina* Emmons, 1844 in Keighley & Pickerill, Fig. 3G.
1998 *Gordia marina* Emmons, 1844 in Stanley & Pickerill, pp. 14, fig. 5:4
2000 *Helminthoidichnites* sp. in Hagadorn & Waggoner, Fig. 5.10.
2004 *Gordia marina* Emmons, 1844 in Knaust, pp. 13, fig. 6.1
2006 *Gordia marina* Emmons, 1844 in Gaillard & Racheboeuf, pp. 1209, fig. 5.3; 5.5; 5.6
2006 *Gordia marina* Emmons, 1844 in Davies et al., Fig. 3C.
2007 *Gordia marina* in Landing et al., pp. 288, fig. 1
2009 *Gordia marina* Emmons, 1844 in Wang et al., pp. 142, fig. Fig. 2, 3, 4
2012 *Gordia marina* Emmons, 1844 in Hofmann et al., pp. 937, fig. 7.2, 7.3
2016 *marina* Emmons, 1844 in Jensen & Palacios, pp. 85, 86, 87, figs. 3, 4, 5
2017 *Gordia marina* Emmons, 1844 in Gougeon et al., pp. 7, fig. Fig. 6.1
2018 *Gordia marnia* Emmons, 1844 (wrong spelling) in Hammersburg et al., pp. 20, fig. 12.1–12.4

Type-material: Not designated by Emmons (1844).

Tipe-locality: Bagging stone of Mr. M'Arthur's quarry, in Jackson, Washington county (Emmons, 1844).

Type-horizon: Not designated by Emmons (1844).

Illustrated material: Two samples (part and counterpart) under housed in collection prefix MAF, sample MF-517 in the laboratory of micropaleontology at the University of Brasilia.

Description: Slender burrows preserved in convex hyporelief or, more rarely, concave epirelief on surfaces of 15-40 mm thick, parallellaminated, flaser- or wavy-bedded and ripple cross-laminated siltstone and fine- to medium-grained sandstone beds, rarely with ooids or phosphatic pebbles. They wind irregularly and cross themselves up to three times, are smooth and 0.5-4.0 mm in diameter. Specimen GSC 78148 (Pl. 7, fig. 14 in Fillion & Pickerill, 1990) becomes bilobate, with faint transverse scratch marks along short segments while its surface is smooth along most of its course. Burrow may taper where the trace maker slightly crossed the interface. Burrow-fill is massive, similar to host rock (Fillion & Pickerill, 1990).

Diagnosis: *Gordia* in which level crossing is fully developed and meanders are unguided (Fillion & Pickerill, 1990).

Remarks: These traces are assigned to *Gordia marina* due to the lack of any distinguishing features such as sharp-angled turns, annulations, or arcuate shapes that would justify their assignment to one of the other ichnospecies of the genus. The species of *Gordia* are similar to *Helminthoidichnites* and *Helminthopsis*. But the specimens are closer to *Gordia* due to the presence of self-crossing and tendency to form loop. *Gordia* (and *Helminthoidichnites tenuis*) is a common trace fossil in late Ediacaran beds (Narbonne & Hofmann, 1987; Narbonne & Aitken, 1990), and its stratigraphic range extends throughout the Phanerozoic (Häntzschel, 1975). It is a facies-crossing form made by unknown organisms (Vidal et al., 1994). Regarding the occurrence recorded in Cambrian Spence Shale Member of the Langston Formation, Wellsville Mountains, Northern Utah, the United States of America (Hammersburg et al., 2018), there is a mistake in the spelling of this species name "*Gordia marnia* Emmons, 1844" instead of the correct name "*Gordia marina* Emmons, 1844".

Occurrence: Two samples (part and counterpart) under housed in collection prefix MAF, sample MF-517. Corcal quarry, Tamengo Formation, Corumbá Group, Ediacarano, Correira Quarry, Corumbá Municipality, Mato Grosso do Sul, Brazil.

Geographic and stratigraphic distribution: Tamengo Formation, Corumbá Group, Ediacarano, Correira Quarry, Corumbá Municipality, Mato Grosso do Sul, Brazil. Canada: -Member 2, Chapel Island Formation, lower Cambrian, Grand Bank Head; Random Formation, lower Cambrian, southwest of Grand Bank Head, Canada (Crimes & Anderson , 1985). The United States of America: Wood Canion Formation Upermost Ediacaran (Hagadorn & Wagoner, 2000); Moenkopi Group, Triassic of the United States of America (Lerner et al., 2007); Cambrian Spence Shale Member of the Langston Formation, Wellsville Mountains, Northern Utah, the United States of America (Hammersburg et al., 2018). Lower Alcudian strata, Uppermost Ediacaran of central Spain (Vidal et al., 1994). Ediacaran–Fortunian of Central Brittany, France (Gougeon et al., 2017). Precambrian-Cambrian boundary of Newfoundland, Canada and in the English Midlands but higher up at Meischucun in China (Crimes, 1987).

ICHNOGENUS *Pilichnus* Uchman, 1999

Type-species: *Pilichnus dichotomus* Uchman, 1999

Diagnosis: System of horizontal, straight, curved to irregularly winding, very thin sub-millimetric strings showing commonly dichotomous branches (Uchman, 1999).

Remarks: Genus well stablished.

Pilichnus cf. *P. dichotomus* Uchman, 1999
(Fig. 14: 3)

1999 *Pilichnus dichotomus* Uchman, 1999 in Uchman, Pl. 6, figs. 6, 8, Pl. 8, figs. 1-6.
2012 *Pilichnus dichotomus* Uchman, 1999 in Joseph et al., pp. 200, Pl. II: d

Holotype PIW19981V77, cotype PIW19981V74, 75. Material and Occurrence. 18 specimens. PIW19981V74-77, 143-144 from the Piesenkopf-schichten at Damüls; Zementmergelserie: Jenbach Valley (PIW19181V46A, 62, 81-83, II1-1 12, 115), Schmicdlaine Creek (PIW19981V50, 63A-B) (Uchman, 1999).

Type-locality: Jenbach Valley Damüls, Bregenz distric, Vorarlberg State, Austria (Uchman, 1999).

Type-horizon: Zementmergelserie, Piesenkopf-schichten limestone, Rhenodanubian Flysch (Aptian-Eocene).

Illustrated material: One sample with one specimens at the bedding surface (MAF-520).

Description: System of horizontal, straight, curved to irregularly winding, branched strings without wall, preserved m full-relief on parting surfaces 111 marlstones. The strings are 0.15-0.35 mm wide. They are filled with dark argillaceous substance. Dichotomous, Y-shaped branches are commonest and very characteristic; T-shaped branches, however, also occur. When crowded, the trace fossils may appear as irregular nets (Uchman, 1999).

Diagnosis: Same as for genus (Uchman, 1999).

Remarks: The ferruginous sediment in the track probably resulted from oxidation of pyrite. This is a deep-tier trace fossil described for the first time from uppermost Ediacaran Tamengo Formation. *Pilichnus* was proposed based on specimens from Cretaceous turbidites in Germany (Uchman, 1999). The stratigraphic and paleoenvironmental range of *Pilichnus* have been expanded to include Cambrian (e.g., Zhang et al., 2007; Mángano, 2011) and Ordovician shallow-marine deposits (e.g., Mikulás, 2003), and Carboniferous turbidites (e.g., Mikulás et al., 2004). It is most likely a feeding trace (fodinichnion). Now *Pilichnus cf. dichotomus* had occurrence recorded in the uppermost Ediacaran, extending its range to the Precambrian.

Occurrence: Hand sample MAF-520, Corcal quarry section, Tamengo Formation, uppermost Ediacaran, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: Cambrian of China (e.g., Zhang et al., 2007) and Argentina (Buatois & Mángano, 2012) and Canadá (Mángano, 2011) and Ordovician shallow-marine deposits (Mikulás, 2003), and Carboniferous turbidites of Czech Republic (e.g. Mikulás et al., 2004). Turonian-Lower Santonian Holovnia Siliceous Marls, Rybotycze, Poland (Leszczyński, 2003). Uppermost Ediacaran Tamengo Formation Brazil.

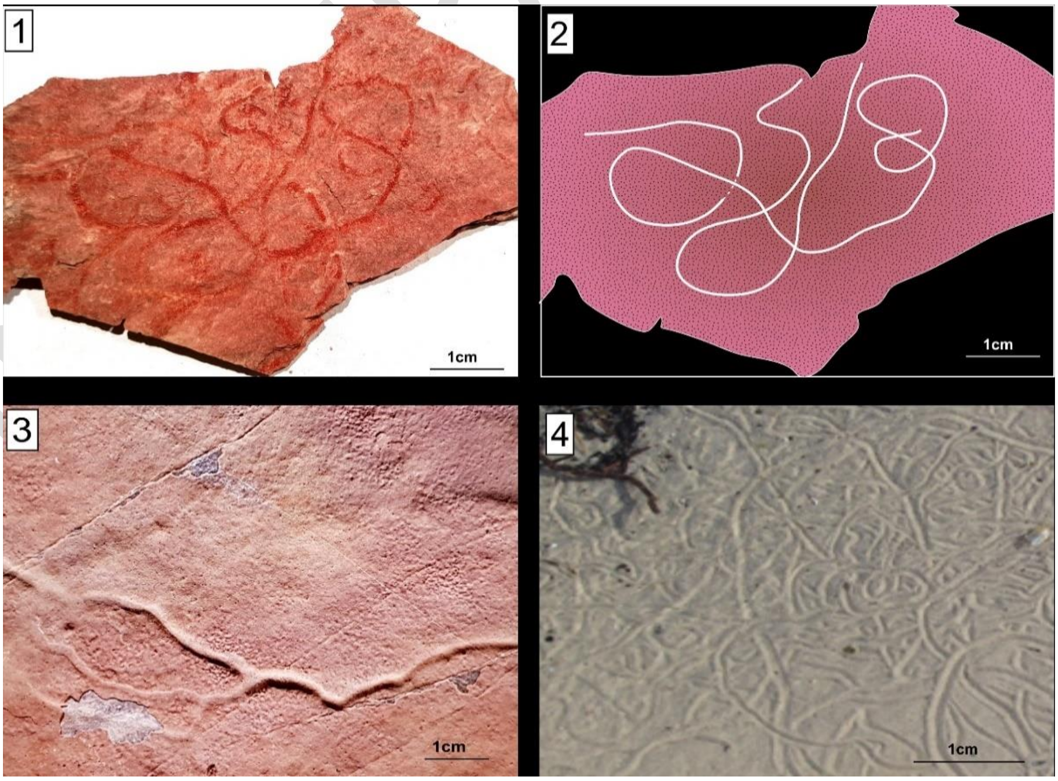


Figure 14. Trace fossils of the Tamengo Formation, Corcal quarry, Corumbá, MS. 1-2) *Gordia marina* Emmons, 1844; 1. Sample MAF-517; 2) schematic representation of the trace fossil 1; 3) *Pilichnus* cf. *P. dichotomus* Uchman, 1999, Sample MAF-520; 4) Wormtrack in recent beach sand.

Permineralized microfossils

Permineralized vesicles assigned to *Chuaria circularis* Walcott, 1899, were recovered from pelites of Tamengo Formation at Ecopoarque Cacimba section, Corumbá Municipality, Mato Grosso do Sul State, Brazil. This permineralized vesicles were assigned to *Chuaria circularis* considering the size of the specimens (between 500 and 600 µm), their subcircular morphology and the absence of surface ornamentation, it is assigned as *Chuaria circularis* (Ford & Breed, 1973; Gussow, 1973; Vidal et al., 1993). This species was already been reported in pelites of Tamengo Formation, in the locality of Ecoparque Cacimba (Pacheco, 2012). However, this occurrence was related to only one specimen preserved as a carbonaceous impression, reported to be associated with *Corumbella werneri* Hahn et al., 1982. In addition, few other specimens of *Chuaria circularis* were recovered from palynological macerations (Pacheco, 2012). Permineralized *Chuaria circularis* represents unprecedented preservation mode.

GROUP Acritarch Evitt, 1963
SUBGROUP Sphaeromorphitae Downie et al., 1963
"GROUP" Megasphaeromorphida Timofeev, 1969
FAMILY Leiospaheridae Einsenack, 1959
GENUS *Chuaria* Walcott, 1899 emended.

Type-species: *Chuaria circularis* Walcott, 1899.

Emended diagnosis: Acid-resistant, extremely robust, single-walled vesicle circular to subcircular in outline (originally spherical) after compaction. The external surface is psilate or chagrinate (Vidal & Ford, 1985).

Remarks: An emended diagnosis for the genus and the only species (type-species) are presented in Vidal & Ford (1985).

Chuaria circularis Walcott, 1899
(Fig. 15: 5-7)

1894 Unnamed, Wiman, p. 109–113, pl. 5 (1–5).
1899 *Chuaria circularis* nov. g. and sp. in Walcott, p. 234–235, pl.27 (12–13).
1941 *Chuaria wimani* n. nom. in Brotzen, p. 258–259.
1966 *Chuaria wimani* Brotzen in Eisenack (1966), p. 52–55 (1–2).
1970 *Kildinella magna* Timofeev in Timofeev (1970), pl. 1 (A, B).
1973 *Chuaria circularis* Walcott in Ford & Breed, p. 539, pl. 61 (1–7), pl. 62 (1–6), pl. 63 (1–4).
1974 *Chuaria circularis* Walcott, 1899 in Vidal, p. 6–8, pl. 1 (3–6).
1976 *Chuaria circularis* Walcott, 1899 in Vidal, p. 18–19, pl. 8 (A–H).
1977 *Chuaria circularis* Walcott in Hofmann, p. 3–5, Fig. 2.
1977 *Chuaria circularis* Walcott in Ford & Breed (1977), p. 171–173, pl. 1 (1–6).
1979 *Chuaria circularis* Walcott, 1899 in Vidal, p. 19–21, pl. 4 (a–b).
1981 *Chuaria circularis* Walcott, 1899 in Vidal, p. 23–25, pl. 11 (J–K).
1985 *Chuaria circularis* Walcott emend. Vidal and Ford, p. 355–359, pl. 3 (A).
1987 *Chuaria circularis* Walcott in Sun, p. 115, pl. 1 (1–8), pl. 4 (1–2).
1990 *Chuaria circularis* (Walcott) Vidal (1990); Vidal, p. 488, Fig. 1.
1993 *Chuaria circularis* (Walcott) Vidal & Ford (1985) in Vidal et al., p. 390–393, pl. 3 (A–D), pl. 4 (D).
1994 *Leiosphaeridia wimanii* (Brotzen, 1941) in Butterfield, et al., p. 42–43, fig. 13 (D–F).
1994 *Chuaria circularis* Walcott 1899 in Butterfield et al., p. 32–34, pl. 8 (G–H), pl. 13 (G–I).
1994 *Chuaria circularis* Walcott in Yin & Sun (1994), p. 99–100, pl. 4 (b).
1994 *Chuaria circularis* Walcott in Steiner, p. 95–101, pl. 1 (4–17), pl. 3 (1–7), pl. 4 (1–4), pl. 8 (2), pl. 9 (1–2), pl. 11(8–10), pl. 12 (4–11).

Type-material: A lectotype was designed by Ford & Breed (1973) catalogued under USNM 33800. Type-material was catalogued under U.S. National Museum no. 33800 and consists of six flakes of shale, each with one or more specimens. One flake is unfossiliferous, and there is also one small bottle that contains indeterminate fragments, again without any observable fossil. The original figure 13 in of Wacott (1899), cannot be identified in the collection. The original of his figure 12 is probably the specimen illustrated in Ford & Breed (1973) Pl. 61, fig. 1; this specimen is now designated lectotype and is still catalogued under USNM 33800. A number of specimens have been selected from the collections made by Ford & Breed (1969, 1972) and these have been added to the U.S. National Museum reference collection and are catalogued under USNM catalogue 36, no. 18 1859 (Ford & Breed, 1973).

Type-locality: A lgonkian, Chuar terrane, Kwagunt valley, within the Grand canyon of the Colorado, in Arizona, USA (Walcott, 1899).

Type-horizon: In the sandy, slightly argillaceous shale, 730 feet beneath the summit of the Chuar terrane (Walcott, 1899).

Illustrated material: Isolated permineralized specimen MP-1603 and MP-1607 (Fig. 15: 5-7).

Description: The specimens vary in size from 2 to 5 millimeters in diameter. They are concentrically wrinkled, as though a very thin, delicate, almost membranous conical shell had been compressed between the laminse of the shale. Usually a thin layer of dark bituminous matter covers the surface. When this is removed the shell is smooth and shiny, very much like the glistening surface of a phosphatic shell when slightly dulled by weathering (Walcott, 1899).

Emended diagnosis: Acid-resistant, extremely robust, single-walled vesicle circular to subcircular in outline (originally spherical) after compaction. The external surface is psilate or chagrinate (Vidal & Ford, 1985).

Remarks: In the original description (Walcott, 1899), no holotype was erected, so a lectotype was designed by Ford & Breed (1973) because of the original type-material of Walcott (1899; Fig. 13). In Brazil, this species had already been reported by Pacheco (2012), in the pelites of the Tamengo Formation, in the locality of Ecoparque Cacimba, in Corumbá. However, only one specimen preserved as a carbonaceous impression was reported to be associated with *Corumbella werneri* Hahn et al., 1982, as well as a few specimens recovered from palynological macerations. *Chuaria circularis* seems to be an unprecedented recovery from sedimentary fractions analyzed for mineralized microfossils. In this case, the grains appear to have been permineralized and therefore were recovered in sieve battery. Considering the size of the specimens (between 500 and 600 µm), their subcircular morphology and the absence of surface ornamentation, it is assigned as *Chuaria circularis* (Ford & Breed, 1973; Gussow, 1973; Vidal et al., 1993). However, the folded aspect due to the possible dryness and the carbonaceous composition of the wall, either by incrustation or permineralization, have not yet been reported in the literature, requiring caution in its classification. The appearance of the specimens suggests that originally, this vesicle was spherical, with an organic wall not rigid, which, before being buried, possibly underwent a drying process. Later, the organic wall was replaced or encrusted by mineral, since if the mineralization had occurred before the dryness, the convergence of the walls would result in the breaking of this fossil.

Occurrences: *Chuaria circularis* occurs in palynological preparations from the Corcal quarry samples (sample MP-1625), Corumbá, MS, and from slides (MP-1759 and MP-1763). They are permineralized cells recovered from samples MP-1603 and 1607 in the locality of Ecoparque da Cacimba, Porto Sobramil, Municipality of Corumbá, Mato Grosso do Sul (sample MP-1703).

Geographic and stratigraphic distribution: *Chuaria circularis* occurs in Mesoproterozoic occurs in Shallow Suket, Vindhyan Supergroup, India (Dutta et al., 2006); in the Edicaran units of Grupo Chuar, USA (Ford & Breed, 1973); Uinta Mountain Group, Utah, USA (Hofmann, 1977); Formation Franklinsundet Group Kapp Lord, Spitsbergen (Knoll, 1982); Akademikerbreen Group, Svanbergfjellet Formation, Spitsbergen (Butterfield et al., 1994); Shaler Supergroup, Wynniatt Formation, Victoria Island, Canada (Hofmann & Rainbird 1994); Little Dal Group, Mackenzie Mountain, Canada (Hofmann, 1985); formations Debengdin, Khajpakh & Khatyspyt, Yakutia (Vidal et al., 1993); Lachandin Formation, Uchur-Maja, Siberia (Pjatiletov, 1980); Tent Hill Formation, Arcoona Quartzite, South Australia (Damssa & Knoll 1986); Wessel Group, Raiwalla Shale, Maningrida, Australia (Haines, 1998); formations Liulaobei and Jiuliqiao, Shouxian, China (Sun, 1987); Changlongshan Formation, Xinglong and Huailai, Hebei, China (Du & Tian, 1985); Guotun formations, Diaoyutai, Nanfeng, S. Liaoning, China (Chen, 1991); Chichkan Series, Mali karatau, Kazakhstan (Ogurtsova & Sergeev, 1989); Shilu Group, Hainan Island, China (Zhang et al., 1991); Qingshuigou Formation, China (Dai & Peng, 1987); Shale Pusa, Spain (Brasier et al., 1979); Pendjari Formation, Benin & Burkina-Faso, East Africa (Amard, 1992); Soltanieh Formation, Chapoghlu Shale, Elburz Mountain, Iran (Ford & Breed, 1973); Nama Group, Namibia (Germs et al., 1986); Sierra Bayas Formation, Argentina (Baldis et al., 1983); Supergroup Vindhyan, Suket Shale, Rampura, India (Sahni, 1977; Kumar, 2001); Vindhyan Supergroup, Rewa Formation, Jhiri Shale, India (Rai et al., 1997); Vindhyan Supergroup, Bhander Limestone and Sirbu Shale, Maihar, India (Kumar & Srivastava, 1997); Vindhyan Supergroup, Rohtas Formation, Katni, India (Rai & Gautam, 1998); Bhima Group, Shale Gangurthi, South India (Suresh & Sundara Raju, 1983); Kurnool Group, Owk Shale, Andhra Pradesh, India (Sharma & Shukla, 1999); Robertson Bay Group, Northern Victoria Land, Antarctica (Cooper et al., 1982); Visingsö Group, Sweden (Vidal, 1974); Kanilov Formation, Podolia, Ukraine (Steiner, 1996); and in the Cambrian units Yanjahe Formation, Southern China

(Steiner, 1994), Pendjari Formation, West Africa (Amard, 1997) and Tamengo Formation, Corumbá Group, Brazil.

Sponge spicules
(Fig. 15: 1-4)

Illustrated material: MP-1713 Needle-shaped spicule fragment, Porto Sobramil; MP-1649 Corcal quarry section; MP-1710, Porto Sobramil section; MP-1667- Fragment acicular (spicule) fragment encrusted in rock, Laginha quarry section (Fig. 15: 1-4 and Fig. 15: 9.2).

Description: The probable sponge spicules from the Tamengo Formation in Corumbá area are megascleres. The spicules are 200–500 µm long and 10 µm in diameter. It is possible to note a regular polygonal net formed by the spicules (Fig. 15: 9.2).

Remarks: A question remains regarding its original composition, if it is calcareous or siliceous. Regardless of the original composition, these sponge spicules present a calcareous composition. Future works must be conducted in order to determine its original composition and its taxonomic determination.

Occurrence: MP-1713 Needle-shaped spicule fragment, Porto Sobramil; MP-1649 Corcal quarry section; MP-1710, Porto Sobramil section; MP-1667- Fragment acicular (spicule) fragment encrusted in rock, Laginha quarry section, Tamengo Formation, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: Tamengo Formation, Corumbá Group, uppermost Ediacaran, Porto Sobramil section, Municipality of Corumbá, Mato Grosso do Sul State, Brazil.

Incertae sedis
(Fig. 15: 9.3)

Illustrated material: specimen MP-1710, Fig. 15: 9.3.

Description: Vase-like chamber with an aperture at “oral” end. he typical specimens are small (30 µm in diameter), and have a hollow center and a smooth surface. The hollow is simple and does not have a collar. Only one specimen was find incrustated in the probable poriferous reticulum.

Remarks: This specimen is similar to that described by Du et al., 2014 as sponge gemmule. It differs basically by the smaller size (Doushantuo specimen is 30 µm in diameter). The basal end of the specimen is kneaded and not completely visible, the opening is not visible as well.

Occurrence: Residue of permineralized preparation, sample MP-1710, Porto Sobramil section, Municipality of Ladário/Corumbá, Mato Grosso do Sul State, Brazil, uppermost Ediacaran Tamengo Formation, Corumbá Group.

Geographic and stratigraphic distribution: Tamengo Formation, Corumbá Group, uppermost Ediacaran, Porto Sobramil section, Municipality of Ladário/Corumbá, Mato Grosso do Sul State, Brazil. Gemmules also occurs in the Doushantuo Formation, Ediacaran, China (Du et al., 2014).

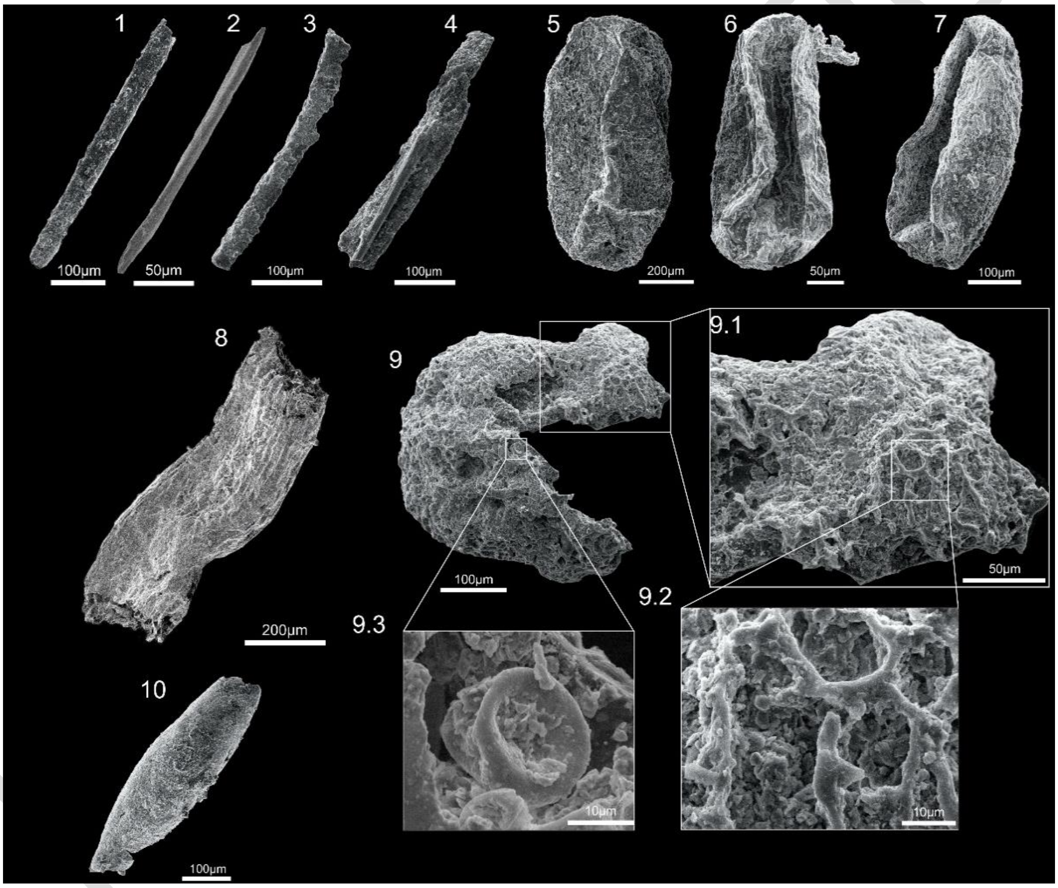


Figure 15. Mineralized and permineralized microfossils from the Tamengo Formation. 1-4 and 13) putative mineralized sponge spicules, 1) MP-1713 Needle-shaped spicule fragment, Porto Sobramil; 2) MP-1649 outcrop of Corcal quarry; 3) MP-1710, Porto Sobramil; 4) MP-1667- Fragment acicular (spicule) fragment encrusted in rock, Laginha quarry; 5-7) Permineralized *Chuaria circularis* Walcott, 1899, 5) MP-1603, Ecoparque Cacimba, 6-7) MP-1607 Ecoparque Cacimba. OBS: Note flattened and folded vesicular appearance on all three specimens; 8) Permineralized fragment of *Vendotaenia antiqua* Gnilovskaya, 1971 MP-1656 Corcal quarry, 9) MP-1710 putative mineralized sponge wall fragment, Porto Sobramil, 9.1 Enhanced for cross-linked appearance formed by needles (putative sponge mineralized spicules); 9.2. Even larger zoom showing detail reticulated structure; 9.3. Small microfossil chamber with uncertain taxonomic affinity (sponge gemmule?);10) Unnamed permineralized microfossil vase-shaped microfossil MP-1607 Ecoparque Cacimba.

Organic-walled microfossils

Fifteen species of organic-walled microfossils, probably from plankticic organisms, were identified from samples of the Tamengo Formation: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Navifusa* sp. and Gen1. Sp. 1 (chitinozoan like flask-shaped). Additionally, organic fragments of the species *Vendotaenia antiqua* Gnilovskaya, 1971 were recovered in palynological macerations.

Five species have occurences in both Tamengo and Dengying formations: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Ostiama microcystis*. Six of them also occur in the Nomtsas Formation, Namibia: *Bavlinella faveolata*, *Ostiama microcystis*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima*, *Leiosphaeridia minutíssima*. Four of the fifteen organic-walled microfossils of Tamengo Formation also occur in Tagatiya Guazu Formation, Paraguay: *Ostiama microcystis*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia minutissima* and Gen.1 sp. 1. These results increased the scarce record of species of organic-walled microfossils to the uppermost Ediacaran sections of these additional selected study sections.

KINDOM Eubacteria Woese & Fox, 1977

PHYLUM Cianobacteria Stanier et al., 1978

CLASS Hormogoneae Thuret, 1875

ORDER Nostocales Geither, 1925

FAMILY Nostocaceae? Kützing, 1843

GENUS *Arctacellularia* Hermann, 1976 in (Timofeev et al., 1976)

Type-species: *Arctacellularia ellipsoidea* Hermann, 1976 in (Timofeev et al., 1976).

Emended diagnosis: Single cell chain, without ornamentation, can be branched. Cells in the shape of spheres, sometimes cylindrical or similar in shape to polyhedra due to the branching. Cells are often crushed, evidenced by folds. The contact zones can be rectilinear or punctual between two cells, or even forming a triple contact between three cells. Cells may be present in short or long chains, may be associated with filaments, and sometimes isolated cells may occur, and may also have opaque point structure within them (Denezine, 2018).

Remarks: Genus well established.

Arctacellularia januarensis Denezine, 2018 *nomem nudum*

(Figs. 16: C-K)

2017 indetermined fossil flaments in Perrella-Junior et al., pp. 67, Fig. 7: H.
2018 *Arctacellularia januarensis* sp. nov. in Denezine, Fig. 9C, D-I, K, J.

Type-material: Holotype: Specimen CP-916 (Denezine, 2018, Fig. 9C). Paratype: CP919 (Denezine, 2018, Figs. 9D-I, K), CP920 (Denezine, 2018, Fig. 9J). Specimens housed in the Collection of Research, Museum of Geosciences, University of Brasília, Distrito Federal, Brazil.

Type-locality: Santa Luzia quarry, Sete Lagoas Formation, Bambuí Group, Municipality of Januária, State of Minas Gerais, Brazil.

Type-horizon: Intraclastic carbonate breccia from Sete Lagoas Formation, Bambuí Group, between 24.5 m to 48 m in the lithostratigraphic log.

Illustrated material: Palynologic slide CP-940 (original slide number 1706) and specimen [X31], Fig. 18: 6.

Description: Not available.

Diagnosis: Single cell chain, without ornamentation, can be branched. Cells in the shape of spheres, sometimes cylindrical or similar in shape to polyhedra due to the branching (Denezine, 2018: Fig. 9J). Cells are often crushed, evidenced by folds. The contact zones can be rectilinear or punctual between two cells, or even forming a triple contact between three cells. Larger cells diameters range from about 3 to 10 μm (Denezine, 2018).

Remarks: The specimens described in this paper resemble valid species of the genus *Arctacellularia* Hermann, 1976 in (Timofeev et al., 1976), which were described from Mesoproterozoic to Tonian material (Baludikay et al., 2016). However, they differ considerably in the size of their cells. The cells of *Arctacellularia ellipsoidea* Hermann, 1976 in (Timofeev et al., 1976) spans from 20 to 25 µm in diameter, *Arctacellularia kelleri* Hermann & Jankauskas, 1989 in Jankauskas et al (1989) range from 30 to 40 µm and *Arcracellularia tetragonala* (Maithy, 1975) from 40 to 70 µm. *Arctacellularia januarensis* as broadly discussed in Denezine (2018), has considerably smaller cells, varying from approximately 3 to 10 µm. In addition to size, another important feature for distinguishing this species is that there is evidence of branching of the cell chains, while in the other species previously described, this characteristic is absent. The present work extends the occurrence of this species to the uppermost Ediacaran Corumbá Group.

Occurrences: Tamengo Formation, Corumbá Group, Porto Sobramil, Corumbá, Mato Grosso do Sul, Sample CP-940 (original slide number 1706).

Geographic and Stratigraphic distribution: Mid to Uppermost Ediacaran Sete Lagoas Formation, Bambuí Group, Januária Municipality, State of Minas Gerais, Brazil (Denezine, 2018). Tamengo Formation, uppermost Ediacaran.

KINGDOM Protista? Whittaker, 1969
PHYLUM Incertae Sedis
CLASS Incertae Sedis
ORDER Incertae Sedis
FAMILY Leiospaheridae Einsenack, 1958
GENUS *Leiosphaeridia* Eisenack, 1958 emended.

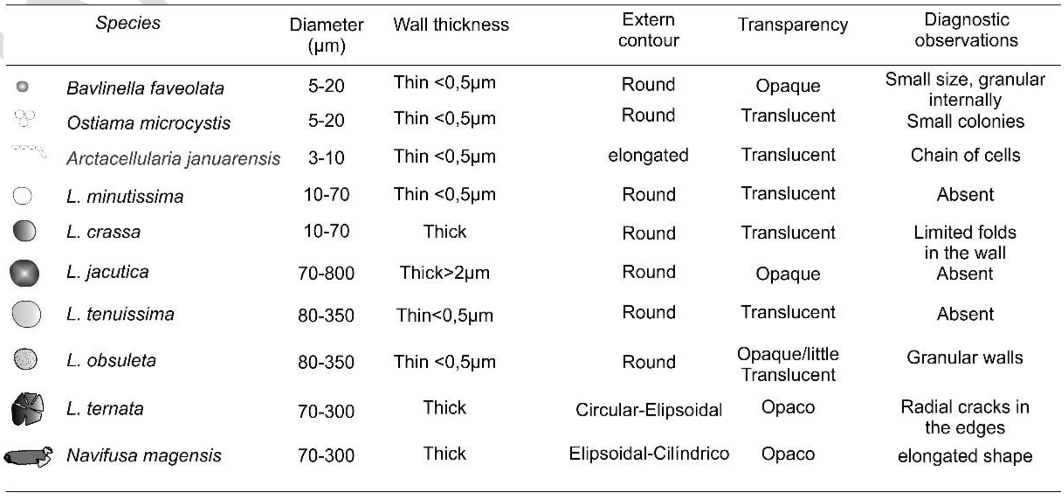
Type-species: *Leiosphaeridia baltica* Eisenack, 1958.

Original Diagnosis translated from German: Hollow-spherical, thin-walled cell, consisting of a very resistant, light yellow dark red-brown translucent organic substance, which can often be handed down in compressed state or irregularly folded wall (Eisenack, 1958).

Emended diagnosis: Organic remains of spherical shape, thin wall, resistant to acid attack, light yellow to dark brown. Generally flattened, like thin discs. The wall in the adult stage does not have pores, this being the main difference of this species with *Tasmanites* (Eisenack, 1958). Spherical, ellipsoid vesicle, without processes, often collapsed or bent, with or without a ficoma. Fine granular wall with dots or smooth. No divisions and no grooves or transverse or longitudinal waist (Downie & Sarjeant, 1963).

Remarks: Two emended diagnosis were presented for *Leiosphaeridia* Eisenack, 1958 (Downie & Sarjeant, 1963; Turner, 1984). The suprageneric classification presented here follows Sergeev & Schopf (2010) and Denezine (2018). Species of the genus *Leiosphaeridia* are very common in Proterozoic with a very wide stratigraphic distribution, from Paleoproterozoic to Mesozoic (Lamb et al., 2009). The literature used in this work as a reference for the taxonomy of the species of *Leiosphaeridia* treats this genus as possessing uncertain biological affinity; however, very similar to species of protists (Sergeev & Schopf, 2010). Fensome et al. (1990) reviewed the species of *Leosphaeridia* and listed 60 valid species. Jankauskas et al. (1989) divided the smooth wall species of *Leiosphaeridia* into four species according to the size and thickness of the wall. Stratigraphic distribution from Paleoproterozoic (Lamb et al., 2009; Peng et al., 2009) to the Miocene (Hannah et al., 2000).The parameters used for classification follow Jankauskas et al. (1989) and are presented in Table 4.

Table 4. General distinguishing features used in the identification of organic microfossils.



Species	Diameter (µm)	Wall thickness	Extern contour	Transparency	Diagnostic observations
Bavlinella faveolata	5-20	Thin <0,5µm	Round	Opaque	Small size, granular internally
Ostiama microcystis	5-20	Thin <0,5µm	Round	Translucent	Small colonies
Arctacellularia januarensis	3-10	Thin <0,5µm	elongated	Translucent	Chain of cells
L. minutissima	10-70	Thin <0,5µm	Round	Translucent	Absent
L. crassa	10-70	Thick	Round	Translucent	Limited folds in the wall
L. jacutica	70-800	Thick>2µm	Round	Opaque	Absent
L. tenuissima	80-350	Thin<0,5µm	Round	Translucent	Absent
L. obsuleta	80-350	Thin <0,5µm	Round	Opaque/little Translucent	Granular walls
L. ternata	70-300	Thick	Circular-Elipsoidal	Opaco	Radial cracks in the edges
Navifusa magensis	70-300	Thick	Elipsoidal-Cilíndrico	Opaco	elongated shape

(Sergeev et al. 2016; Sergeev et al. 2017; Denezine, 2018)

Leiosphaeridia ternata (Timofeev, 1966)

(Fig. 16: 9)

1966 *Turuchanica ternata* Timofeev, 1966; Timofeev: Pl. 9, Fig. 8;
1989 *Leiosphaeridia ternata* (Timofeev, 1966); Jankauskas et al.: Pl. XI, Figs. 2–4; Pl. XII, Figs. 4-5, 8;
1994 *Leiosphaeridia ternata* (Timofeev, 1966); Hofmann & Jackson: Figs. 17(5-7);
1992a *Leiosphaeridia ternata* (Timofeev, 1966); Zang & Walter: Pl. XII, Figs. F-I;
1992b *Leiosphaeridia ternata* (Timofeev, 1966); Zang & Walter: Pl. 53, Figs. A-E;
1995 *Leiosphaeridia ternata* (Timofeev, 1966): Zang: Figs. 28(K, L);
1997 *Leiosphaeridia ternata* (Timofeev, 1966): Cotter: Fig. 7(J);
2000 *Leiosphaeridia ternata* (Timofeev, 1966): Simonetti & Fairchild: Fig. 8(F);
2003 *Leiosphaeridia ternata* (Timofeev, 1966); Ragozina et al.: Pl. II, Fig. 1;
2016 *Leiosphaeridia ternata* (Timofeev, 1966); Baludikay et al.: Fig. 8(G);
2016 *Leiosphaeridia ternata* (Timofeev, 1966); Strother & Wellman: Figs. 7(A, F, G);
2016 *Leiosphaeridia ternata* (Timofeev, 1966); Sergeev et al.: Figs. 4(3-4);
2016 *Leiosphaeridia ternata* (Timofeev, 1966); Loron: Pl. IV, Figs. A-E;
2016 *Leiosphaeridia ternata* (Timofeev, 1966); Singh & Sharma: Pl. 1, Fig. 11;
2017 *Leiosphaeridia ternata* (Timofeev, 1966); Sergeev et al.: Fig. 3(8);
2017 *Leiosphaeridia ternata* (Timofeev, 1966); Javaux & Knoll: Fig. 4(9);
2017 *Leiosphaeridia ternata* (Timofeev, 1966); Beghin et al.: Pl. 2, Fig. K.
2018 *Leiosphaeridia ternata* (Timofeev, 1966); Denezine: Fig. 10G.

Type-material: Holotype: *Turuchanica ternata* Timofeev, 1966, Pl. 9, Fig. 8. IGGD USSR Academy of Sciences N° 49/59; Turukhansky District, Upper Riphean, Lectotype Pl. XII fig. 5 (Jankauskas 1989).

Type-locality: Turukhansky District, Lenigrad, Rússia (Jankauskas, 1989).

Type-horizon: Miroedihinskaya Suite Upper Riphean (Jankauskas, 1989).

Illustrated material: Palynologic slide and specimen Fig. 18: 6.

Description: Small and medium-sized (very rarely large) shells with a smooth surface, dense, opaque, fragile, cracking along the contour for more or fewer fragments. The dimensions of the flaps are 3–70 μm (usually 10–20 μm). The wall thickness is apparently less than 1 μm (Jankauskas, 1989).

Diagnosis: Not available.

Remarks: The suprageneric classification followed Sergeev & Schopf (2010). *Leiosphaeridia ternata* (Timofeev, 1966) emended. Mikhailova & Jankauskas (in Jankauskas et al., 1989) was originally called *Turuchanica ternata* Timofeev, 1966. Posteriorly, Mikhailova & Jankauskas in Jankauskas et al. (1989), changed the generic assignment to *Leiosphaeridia ternata* (Timofeev, 1966) emended Mikhailova & Jankauskas (in Jankauskas et al., 1989).

Occurrences: Tamengo Formation, Corumbá Group sample CP-943 (original slide number MP-1630), Corcal quarry section.

Geographic and stratigraphic distribution: Widely distributed in Late Mesoproterozoic to Neoproterozoic (Hofmann & Jackson, 1994), as well as in Cambrian (Zang & Walter, 1992a). Australia (Cotter, 1997; Zang & Walter, 1992b; Zang, 1995; Javaux & Knoll, 2017); Brazil: Conselheiro Mata Group, Municipality of Montalvânia, Minas Gerais State (Simonetti & Fairchild, 2000); Sete Lagoas Formation, Bambuí Group, Municipality of Januária, Minas Gerais State (Denezine, 2018), Canada (Hofmann & Jackson, 1994); China (Zang & Walter, 1992a); Scotland (Strother & Wellman, 2016); Mauritania (Beghin et al., 2017); Congo (Baludikay et al.,2016); Russia (Jankauskas et al., 1989; Ragozina et al., 2003; Sergeev et al., 2016; Sergeev et al., 2017); Sweden (Strother & Wellman, 2016; Loron, 2016).

Leiosphaeridia crassa (Naumova, 1949)

(Fig. 16: 1-5)

1949 *Leiotriletes crassus* Naumova, 1949 in Naumova, Pl. 1, Fig. 3;
1973 *Leiopsophosphaera crassa* in Pykhova, Pl. 2, Fig. 3;
1986 *Leiosphaeridia* spp. in Damassa & Knoll: Figs. 5(B-D, G);
1989 *Leiosphaeridia crassa* (Naumova, 1949) in Jankauskas et al.: Pl. 9, Figs. 5-10;
1992a *Leiosphaeridia crassa* (Naumova, 1949) in Zang & Walter: Pl. IX, Figs. A-K; Pl. XII, Fig. K; Pl. XIV, Figs. E, H;
1994 *Leiosphaeridia crassa* (Naumova, 1949) in Butterfield et al.: Figs. 16(F); 23(K);
1994 *Leiosphaeridia crassa* (Naumova, 1949) in Hofmann & Jackson: Figs. 15(19-29);
1999 *Leiosphaeridia crassa* (Pykhova, 1973) in Yin & Guan: Figs. 3(8); 4(5); 5(3, 5, 7, 11); 6(2-6, 9, 12);
2004 *Leiosphaeridia crassa* (Jankauskas et al., 1989) in Javaux et al.: Figs. 4(E-I);
2004 *Leiosphaeridia crassa* (Naumova, 1949) in Sergeev & Seong-joo: Pl. 3, Figs. 4-5;
2004 *Leiosphaeridia crassa* in Tiwari and Pant: Fig. 3(V);
2005 *Leiosphaeridia crassa* (Naumova, 1949) in Grey: Figs. 63(A-C); 64(A-D);
2005 *Leiosphaeridia crassa* (Naumova, 1949) in Marshall et al.: Fig. 1(E);
2006 *Leiosphaeridia crassa* (Naumova, 1949) in Sergeev & Seong-joo: Pl. 2, Figs. 2(AC); 5;
2006 *Leiosphaeridia crassa* (Pykhova, 1973) in Sergeev: Pl. 30, Figs. 4-5; Pl. 38, Figs. 2A(2, 4-5);
2008 *Leiosphaeridia crassa* (Naumova, 1949) in Moczydłowska: Fig. 7(A);
2009 *Leiosphaeridia crassa* (Naumova, 1949) in Bhat et al.: Figs. 5(A, N, P);
2009 *Leiosphaeridia crassa* (Naumova, 1949) in Yin et al.: Figs. 3(A, H, L); 4(D, F, H), 5(A, C);
2009 *Leiosphaeridia crassa* (Naumova, 1949) in Tiwari & Pant: Figs. 8(H, O-P);
2009 *Leiosphaeridia crassa* (Naumova, 1949) in Stanevich et al.: Pl. III, Figs. 3-4;
2010 *Leiosphaeridia crassa* (Naumova, 1949) in Sergeev & Schopf: Figs. 15(3-6);
2011 *Leiosphaeridia crassa* in Strother et al.: Figs. 1(A, E);
2011 *Leiosphaeridia crassa* (Pykhova, 1973) in Couëffé & Vecolii: Figs. 6(2), 7(1,7);
2013 *Leiosphaeridia crassa* (Naumova, 1949) in Tang et al.: Fig. 4(B);
2014 *Leiosphaeridia crassa* (Naumova, 1949) in Lottaroli et al.: Fig. 10(2);

2014 *Leiosphaeridia crassa* (Naumova, 1949) in Babu et al.: Fig. 3(F);
2014 *Leiosphaeridia crassa* (Pykhova, 1973) in Tobias: Fig. 19(A);
2015 *Leiosphaeridia crassa* (Naumova, 1949) in Tang et al.: Fig. 4(D);
2015 *Leiosphaeridia crassa* (Naumova, 1949) in Nagovitsin & Kochnev: Figs. 1(55, 56);
2016 *Leiosphaeridia crassa* (Naumova, 1949) in Baludikay et al.: Figs. 8(A-C);
2016 *Leiosphaeridia crassa* (Naumova, 1949) in Porter & Riedman: Figs. 13(2, 6);
2016 *Leiosphaeridia crassa* (Naumova, 1949) in Sergeev et al.: Fig. 4(2);
2016 *Leiosphaeridia crassa* in Tomescu et al.: Fig. 3.9(F);40
2017 *Leiosphaeridia crassa* (Naumova, 1949) in Javaux & Knoll: Figs. 4(4-6);
2017 *Leiosphaeridia crassa* (Naumova, 1949) in Agic et al.: Figs. 8(A-C);
2017 *Leiosphaeridia crassa* in Sergeev et al.: Fig. 3(14);
2017 *Leiosphaeridia crassa* in Beghin et al.: Pl. 2. Figs. C-D;
2017 *Leiosphaeridia crassa* in Suslova et al.: Figs. 3(1-4).
2018 *Leiosphaeridia crassa* (Naumova, 1949) in Denezine (Fig. 10E)

Type-material: Holotype: *Leiotriletes minustissimus* Naumova, 1949, Pl. I, Fig. 3; paleontological collection of the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, preparation no. 452/1; Lower Cambrian, Lontova Formation, Estonia (Sergeev & Seong-Joo, 2006). With the loss of the holotype, a neotype was erected by Jankauskas et al. (1989: Pl. 9: Fig. 5), LitNIGRI, nº 16-800-2942/9, specimen 2 (Grey, 2005).

Type locality: Bashkirian Peri-Urals (Jankauskas, 1989).

Type horizon: Vendian (Ediacaran), Redkino, Bashkibashev Formation, drill hole Sergeevsk-800, interval from 2.942,4 to 2.946,4 m (Grey, 2005).

Illustrated material: Palynological slides and specimens: Fig. 16: 1: CP-941 (original slide number MP-1632) L34[2]; Fig. 16: 2: CP-942 (original slide number MP-1626) Q43[3]; Fig. 16: 3: CP-942 (original slide number MP-1626) Y57[2]; Fig. 16: 4: CP-943 (original slide number MP-1630) T45; Fig. 16: 5: CP-944 (original slide number MP-1633) H54[1].

Description translated from Russian: Small and medium sized spheroidal shells with a smooth surface and a thickened wall. The dimensions of the shell are 10–70 µm (mean of 15–30 µm), the wall thickness is 0.7–1.5 µm. Holotype is 20-30 µm in diameter, lectotype - 34 µm. The contour is smooth and rounded. Folds are not numerous, distinct, lanceolate, with pointed endings, rarely fuzzy or absent (Jankauskas et al., 1989).

Diagnosis: Not available.

Remarks: The suprageneric classification followed Sergeev & Schopf (2010) and Denezine (2018). *Leiosphaeridia crassa* (Naumova, 1949) was originally assigned as *Leiotriletes crassus*

Naumova, 1949. It is worth noting that Pykhova (1973) described a new species of acritarch and named it *Leiopsophosphaera crassa*. Posteriorly, Jankauskas et al. (1989) reviewed all species of the genus *Leiosphaeridia* and transferred the species *Leiotriletes crassus* Naumova, 1949 to the genus *Leiosphaeridia* as well as changed the specific epithet naming the species proposed by Naumova (1949) as *Leiosphaeridia crassa* (Naumova, 1949) emended. Still on this work, a neotype for the species was erected; however, the change of the name of the species was not explained.

Occurrences: Ecoparque Cacimba, Municipality of Corumbá, Mato Grosso do Sul State, Brazil; Pedreira Corcal, Laginha, Porto Sobramil, uppermost Ediacaran, Tamengo Formation, Corumbá Group,in the Municipality of Corumbá, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: This species occurs in a time interval greater than 1 Ga, and extending to the Cambrian (Moczydlowska, 2008). By the other hand, Sergeev & Schopf (2010) restricts the occurrence of *Leiosphaeridia crassa* from assemblages from Meso to Neoproterozoic. Australia (Grey, 2005; Damassa & Knoll, 1986; Javaux et al., 2004; Marshall et al., 2005; Javaux & Knoll, 2017); Sete Lagoas Formation, Bambuí Group, Municipality of Januária, State of Minas Gerais (Denezine, 2018); Canada (Hofmann & Jackson, 1994); Kazakhstan (Sergeev & Schopf, 2010); China (Zang & Walter., 1992a; Yin & Guan, 1999; Marshall et al., 2005; Yin et al.,2006; Tang et al., 2013; Tang et al., 2015; Agic et al., 2017); Congo (Baludikay et al., 2016); Scotland (Stroter et al., 2011); the USA (Porter & Riedman, 2016); Ghana (Coueffe & Vecoli, 2011); India (Tiwari & Pant, 2004; Tiwari & Pant, 2009; Babu et al., 2014); Mauritania (Lottaroli et al., 2014; Beghin et al., 2017); Norway (Butterfield et al., 1994); Poland (Moczdlowska, 2008); Russia (Sergeev & Seong-Joo, 2004; Sergeev & SeongJoo, 2006; Stanevih et al., 2009; Nagovitsin & Kochnev, 2015; Sergeev et al., 2016; Sergeev et al., 2017; Suslova et al., 2017). Tamengo Formation, Corumbá Group, in the localities of Pedreira Corcal, Laginha, Porto Sobramil and Ecoparque da Cacimba in the Municipality of Corumbá, Mato Grosso do Sul State, Brazil.

Leiosphaeridia jacutica (Timofeev, 1966)

(Fig. 16: 13-14)

1966 *Kinidella jacutica* Timofeev; Timofeev; Pl. 7, Fig. 2;
1989 *Leiosphaeridia jacutica* (Timofeev, 1966); Jankauskas et al.: Figs. 3(A-B); 7; 9;
1994 *Leiosphaeridia jacutica* (Timofeev, 1966); Butterfield et al.: Fig. 16(H);
1994 *Leiosphaeridia jacutica* (Timofeev, 1966); Hofmann & Jackson: Figs. 17(1-4);
1995 *Leiosphaeridia jacutica* Jankauskas, 1989; Kumar & Srivastava: Fig. 11(K);
2001 *Leiosphaeridia jacutica* (Timofeev, 1966); Sergeev: Figs. 8(7-10);
2004 *Leiosphaeridia jacutica* (Jankauskas, 1989); Javaux et al.: Figs. 4(A-D, M);
2005 *Leiosphaeridia jacutica* (Timofeev, 1966); Grey: Fig. 63(G);
2005 *Leiosphaeridia jacutica*; Marshall et al.: Fig. 1(C);
2006 *Leiosphaeridia jacutica* (Timofeev, 1966); Sergeev & Seong-joo: Pl. 2, Fig. 6;
2006 *Leiosphaeridia jacutica*; Javaux & Marshal: Figs. 3(1-3);
2009 *Leiosphaeridia jacutica* (Timofeev, 1966); Stanevich et al.: Pl. III, Fig. 2;
2009 *Leiosphaeridia jacutica* (Timofeev, 1966); Vorob’eva et al.: Fig. 14(13);
2010 *Leiosphaeridia jacutica* (Timofeev, 1966); Nemerov et al.: Figs. 6(8, 9);
2010 *Leiosphaeridia jacutica* Mikhailova & Jankauskas; Prasad et al.: Pl. 1, Fig. 3;
2013 *Leiosphaeridia jacutica* (Timofeev, 1966); Tang et al.: Fig. 4(D);
2014 *Leiosphaeridia jacutica* (Timofeev, 1966); Babu et al.: Fig. 3(L);
2015 *Leiosphaeridia jacutica* (Timofeev, 1966); Chiglino et al.: Fig. 5(B);
2015 *Leiosphaeridia jacutica* (Timofeev, 1966); Tang et al.: Figs. 4(F-G); 5(A);
2015 *Leiosphaeridia jacutica* (Timofeev, 1966); Nagovitsin & Kochnev: Fig. 4(43);
2015 *Leiosphaeridia jacutica*; Vorob'eva et al.: Fig. 7(6);
2016 *Leiosphaeridia jacutica* Timofeev, 1966; Baludikay et al.: Fig. 8(D);
2016 *Leiosphaeridia jacutica* (Timofeev, 1966); Porter & Riedman: Fig. 13(3);
2016 *Leiosphaeridia jacutica*; Sergeev et al.: Figs. 4(1, 6-7);
2016 *Leiosphaeridia jacutica*; Tomescu et al.: Fig. 3.9(E);
2016 *Leiosphaeridia jacutica* (Timofeev, 1966); Singh & Sharma: Pl. 1, Figs. 9-10;
2017 *Leiosphaeridia jacutica* (Timofeev, 1966); Javaux & Knoll: Figs. 4(4-6);
2017 *Leiosphaeridia jacutica*; Sergeev et al.: Figs. 3(1, 9-11);
2017 *Leiosphaeridia jacutica*; Beghin et al.: Pl. 2, Figs. C-D;
2017 *Leiosphaeridia crassa* (Naumova, 1949); Tang et al.: Fig. 3(C).
2017 *Leiosphaeridia jacutica* (Timofeev, 1966); Tang et al.: Fig. 3(D).
2018 *Leiosphaeridia crassa* (Naumova, 1949); Denezine (Fig. 10F).

Type-material: Holotype: IGD Russian Academy of Sciences n.452/1 (Grey, 2005). Lectotype. IGD Russian Academy of Sciences n.1821/1 (Jankauskas et al.,1989).

Type-locality: Uchur-Maya region, Western Russia (Grey, 2005).

Type-horizon: Kumahinskaya, Lahandinskaya Stage (Grey, 2005).

Illustrated material: Sample and specimen: MP1626 T52 Corcal quarry section

Description: Large rigid vesicle, with thicker, dense, weakly transparent wall, with small to large lanceolate folds. Diameter 70-800 μm. Often the collapsed cytoplasm is observed inside the carapace. Compared with *Leosphaeridia crassa* differs only by the larger size (Jankauskas et al., 1989).

Diagnosis: Not available.

Remarks: The suprageneric classification followed Sergeev & Schopf (2010). The size of *Leiosphaeridia jacutica* corresponds to the finer specimens of *Chuaria circularis*, in the broadest sense of the latter diagnosis. However, Mikhailova & Jankauskas (1989 in Jankauskas et al., 1989) have limited the size of specimens of *Chuaria circularis* in 1.000 µm and maintained the smaller vesicles as *Leiosphaeridia jacutica*.

Occurrences: Tamengo Formation, uppermost Ediacaran Corumbá Group at Corcal quarry and Ecoparque Cacimba sections;

Geographic and stratigraphic distribution: Australia (Cotter, 1997; Javaux et al., 2004; Grey, 2005; Marshall et al., 2005; Javaux & Marshall, 2006; Javaux & Knoll, 2017); Brazil (Chiglino et al., 2015),Canada (Hofmann & Jackson, 1994; Hofmann & Jackson, 1996); China (Marshall et al., 2005; Tang et al., 2013; Tang et al., 2015); Congo (Baludikay et al., 2016); the USA (Porter & Riedman, 2016); Greenland (Hofmann & Jackson, 1996); India (Kumar & Srivastava, 1995; Prassad et al., 2010; Babu et al., 2014; Tang et., 2017); Mauritania (Beghin et al., 2017); Norway (Butterfield et al., 1994); Russia (Sergeev, 2001; Sergeev & Seong-Joo, 2006; Stanevich et al., 2009; Vorob'Eva et al., 2009; Nemerov et al., 2010; Nagovitsin & Kochev, 2015; Vorob'eva et al.,2015; Sergeev et al.,2016; Sergeev et al.,2017). Uppermost Ediacaran, Tamengo Formation, Corumbá Group, Corcal quarry and Ecoparque Cacimba sections;

Leiosphaeridia minutissima (Naumova, 1949)
(Fig. 16: 8, 16, 18, 20-23)

1949 *Leiotriletes minutissimus* Naumova, 1949; Naumova: Pl. 1, Fig. 1;
1989 *Leiosphaeridia minutissima* (Naumova, 1949); Jankauskas, Pl.9, Figs. 1- 4, 11;
1992 *Leiosphaeridia minutissima* (Jankauskas, 1989); Butterfield & Chandler: Figs. 3(A, I);
2003 *Leiosphaeridia minutissima* (Naumova, 1949); Gaucher & Germs: Figs. 6(10-12);
2005 *Leiosphaeridia minutissima* (Naumova, 1949); Grey: Fig. 63(D);
2005 *Leiosphaeridia minutissima* (Naumova, 1949); Blanco & Gaucher: Fig. 11(B)
2008 *Leiosphaeridia minutissima* (Naumova, 1949); Gaucher et al.: Fig. 3(A);
2008 *Leiosphaeridia minutissima* (Naumova, 1949); Moczydłowska: Fig. 8(H);
2009 *Leiosphaeridia minutissima* (Naumova, 1949); Bhat et al.: Fig. 5(D, L-M);
2010 *Leiosphaeridia minutissima* (Naumova, 1949); Nemerov et al.: Fig. 6(7);
2011 *Leiosphaeridia minutissima* (Naumova, 1949); Couëffé & Vecolii: Fig. 7(3);
2013 *Leiosphaeridia minutissima* (Naumova, 1949); Tang et al.: Fig. 4(A);
2015 *Leiosphaeridia minutissima* (Naumova, 1949); Chiglino et al.: Fig. 5(A);
2015 *Leiosphaeridia minutissima* (Naumova, 1949); Tang et al.: Fig. 4(C);
2015 *Leiosphaeridia minutissima* (Naumova, 1949); Nagovitsin & Kochnev: Figs. 4(57, 58);
2015 *Leiosphaeridia minutissima* (Naumova, 1949); Schopf et al.: Fig. 13(10);

2016 *Leiosphaeridia minutissima* (Naumova, 1949); Baludikay et al.: Fig. 8(E);
2016 *Leiosphaeridia minutissima* (Naumova, 1949); Porter & Riedman: Figs. 13(1, 5);
2017 *Leiosphaeridia minutissima* (Naumova, 1949); Javaux & Knoll: Figs. 4(7-8);
2017 *Leiosphaeridia minutissima*; Shi et al.: Figs. 11(6, 7);
2017 *Leiosphaeridia minutissima*; Beghin et al.: Pl. 2, Fig. G;
2017 *Leiosphaeridia minutissima* (Naumova, 1949); Tang et al.: Fig. 3(A).
2017 *Leiosphaeridia minutissima*; Suslova et al. Figs. 3(6-11);
2017 *Leiosphaeridia minutissima* (Naumova, 1949); Agic et al.: Figs. 8(G-H).
2018 *Leiosphaeridia minutissima* (Naumova, 1949); Denezine: (Fig. 10: A-C)

Type-material: Naumova 1949, Plate 1, Fig. 1, lower Cambrian, Lontova Suite. Lectotype. LITHIGRI, No. 16-800-2942/9, slide 1; Bashkirian Pre-Urals (Grey, 2005).

Type-locality: Drillhole Pre-Urals. Drillhole Sergeevsk-800, interval 2942- 2946.4 m; Vendian, Redkino horizon, Bashkibashev Suite. Lontova unit (Grey, 2005).

Type-horizon: Redkino Horizon, Bashkibashev Formation, Sergeevsk-800 drill hole, interval from 2.942,4 to 2.946,4 m (Grey, 2005).

Illustrated material: CP-941 (original slide number MP-1632) L40[2], Corcal quarry section; CP-950 (original slide number MP-2183) E50[3]; CP-951 (original slide number MP-2203) B42[1]; CP-952 (original slide number MP-4312)-II, U40; CP-952 (original slide number MP-4312)-II, H27[2]; CP-952 (original slide number MP-4312)-II F43; CP-952 (original slide number MP-4312)-II L41[4].

Description translated from Russian: Small and medium sized smooth-spheroidal shells with a very thin and thin wall. The diameter of the shells is 10–70 μm (usually 15–20 μm); the holotype is 25 μm, the lectotype is 36 μm. Wall thickness up to 0.7 microns. The contour is smooth, rounded. There are numerous, randomly located folds of folds of various shapes and sizes (Jankauskas, 1989, p. 80).

Diagnosis: Not available.

Remarks: The suprageneric classification followed Sergeev & Schopf (2010). *Leiosphaeridia minutissima* (Naumova, 1949) was originally assigned as *Leiotriletes minutissimus* Naumova, 1949. Jankauskas et al. (1989), besides altering the genus, changed the specific epithet, from then on, is now referred to as *Leiosphaeridia minutissima* (Naumova, 1949) emended.

Occurrences: Porto Sobramil, Laginha and Corcal quarries and Ecoparque Cacimba sections, Tamengo Formation, Corumbá Group uppermost Ediacaran;

Geographic and stratigraphic distribution: South Africa (Gaucher & Germs, 2003); Australia (Grey, 2005; Javaux & Knoll, 2017); Brazil: Ferrerinha Formation, Ubajara Group (Chiglino et al., 2015), Sete Lagoas Formation, Bambuí Group (Denezine, 2018), Canada (Butterfield & Chandler, 1992; Hofmann & Jackson, 1994); Kazakhstan (Schopf et al., 2015); China (Tang et al., 2013; Tang et al., 2015; Shi et al., 2017; Agic et al., 2017); Congo (Baludikay et al.,2016); the USA (Porter & Riedman, 2016); Ghana (Coueffe & Vecoli, 2011); India (Tang et al., 2017); Mauritania (Beghin et al., 2017); Namibia (Gaucher & Germs, 2003; Gaucher et al., 2005); Poland (Moczydłowska, 2008; Nagovitsin & Kochnev, 2015); Russia (Jankauskas et al., 1989; Nemerov et al., 2010; Suslova et al., 2017); Uruguay (Gaucher & Germs, 2003; Blanco & Gaucher, 2005; Gaucher et al., 2008). Widely distributed in Mesoproterozoic assembly to Cambrian (Grey, 2005).

Leiosphaeridia tenuissima Eisenack, 1958

(Fig. 16: 6)

1958 *Leiosphaeridia tenuissima* Eisenack, 1958; Eisenack: Pl. 2, Figs. 1-2;
1987 *Leiosphaeridia tenuissima* Eisenack, 1958; Gorka: Pl. IX, Fig. 11;
1994 *Leiosphaeridia tenuissima* Eisenack, 1958; Butterfield et al.: Fig. 16(I);
1994 *Leiosphaeridia tenuissima* Eisenack, 1958; Hofmann & Jackson: Fig. 15(16-18);
1998 *Leiosphaeridia tenuissima* Eisenack, 1958; Zhang et al.: Figs. 9(7, 9);
1998 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher et al.: Fig. 4.6;
1999 *Leiosphaeridia tenuissima* Eisenack, 1958; Turnau & Racki: Pl. V, Fig. 1;
2000 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher: Pl. 11, Fig. 5;
2003 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher & Germs: Fig. 6(6);
2004 *Leiosphaeridia tenuissima* (Jankauskas et al., 1989); Javaux et al.: Figs. 4(J-L);
2004 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher et al.: Fig. 4(D);
2005 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher et al.: Figs. 8(G-H);
2005 *Leiosphaeridia tenuissima* Eisenack, 1958; Blanco & Gaucher: Fig. 11(A);
2005 *Leiosphaeridia tenuissima* Eisenack, 1958; Grey: Figs. 63(H), 65;
2005 *Leiosphaeridia tenuissima* Eisenack, 1958; Marshall et al.: Fig. 1(D);
2006 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher & Germs: Figs. 7(D, F-G); 8(B-F);
2008 *Leiosphaeridia tenuissima* Eisenack, 1958; Gaucher et al.: Figs. 3(B-I);
2009 *Leiosphaeridia tenuissima* Eisenack, 1958; Stanevich et al.: Pl. III(5);
2009 *Leiosphaeridia tenuissima* Eisenack, 1958; Bhat et al.: Fig. 5(Q);
2010 *Leiosphaeridia tenuissima* Eisenack, 1958; Prasad et al.: Pl. 1, Fig. 1;
2013 *Leiosphaeridia tenuissima* Eisenack, 1958; Tang et al.: Fig. 4(C);
2014 *Leiosphaeridia tenuissima* Eisenack, 1958; Liu et al.: Figs. 101(1-6);
2014 *Leiosphaeridia tenuissima* Eisenack, 1958; Babu et al.: Figs. 3(D, K);
2014 *Leiosphaeridia tenuissima* Eisenack, 1958; Tobias: Fig. 21(C);
2014 *Leiosphaeridia tenuissima* Eisenack, 1958; Vorob'eva & Petrov: Fig. 6(B);
2015 *Leiosphaeridia tenuissima* Eisenack, 1958; Schopf et al.: Fig.13(9);

2015 *Leiosphaeridia tenuissima* Eisenack, 1958; Nagovitsin & Kochnev: Fig. 4(59);
2015 *Leiosphaeridia tenuissima* Eisenack, 1958; Chiglino et al.: Fig. 4;
2015 *Leiosphaeridia tenuissima* Eisenack, 1958; Tang et al.: Fig. 4(E);
2015 *Leiosphaeridia tenuissima*; Vorob'eva et al.: Fig. 7(8);
2016 *Leiosphaeridia tenuissima* Eisenack, 1958; Baludikay et al.: Fig. 8(F);
2016 *Leiosphaeridia tenuissima* Eisenack, 1958; Porter & Riedman: Fig. 13(4);
2016 *Leiosphaeridia tenuissima* Eisenack, 1958; Sergeev et al.: Fig. 4(2);
2016 *Leiosphaeridia tenuissima* Eisenack, 1958; Singh & Sharma: Pl. 1, Figs. 12, 15;
2017 *Leiosphaeridia tenuissima* Eisenack, 1958; Beghin et al.: Pl. 2, Fig. J.
2017 *Leiosphaeridia tenuissima* Eisenack, 1958; Tang et al.: Fig. 3(B);
2017 *Leiosphaeridia tenuissima* Eisenack, 1958; Agic et al.: Fig. 8(D-F);
2017 *Leiosphaeridia tenuissima*; Suslova et al.: Figs. 3(13, 14);
2017 *Leiosphaeridia tenuissima* Eisenack, 1958; Sergeev et al.: Pl. 1, Figs. 7, 9;
2017 *Leiosphaeridia minutissima* (Naumova, 1949); Sergeev et al.: Fig. 3(13);
2017 *Leiosphaeridia tenuissima* Eisenack, 1958; Javaux & Knoll: Figs. 4(7, 8).
2018 *Leiosphaeridia tenuissima* Eisenack, 1958; Denezine: (Fig. 10D)

Type-material: Holotype, Eisenack (1958) Plate 1, Fig. 2, Leningrad district, River Tosna (Grey, 2005).

Type-locality: Tosna River, Saint Petersburg, Russia (Eisenack, 1958).

Type-horizon: Dictyonema horizon, lower Ordovician (Grey, 2005).

Illustrated material: Palynological slide CP-793.

Description translated from Russian: Large smooth-walled shells with a thin wall and numerous, randomly arranged folds. The diameter is 1 - 15 microns. The opening of the shell was not observed (Jankauskas, 1989).

Diagnosis: Not available.

Remarks: The suprageneric classification followed Sergeev & Schopf (2010). Both species *Leiosphaeridia tenuissima* Eisenack, 1958 and *Leiosphaeridia minutissima* (Naumova, 1949) are simple sphaeromorphs, smooth, without any process and have a thin translucent wall. However, Jankauskas et al. (1989) differentiated them from the size of the vesicle and defined that specimens smaller than 70 μm are classified as *Leiosphaeridia minutissima* (Naumova, 1949) and specimens larger than 70 μm are classified as *Leiosphaeridia tenuissima* Eisenack, 1958.

Occurrences: Porto Sobramil, Ecoparque Cacimba and Corcal quarry sections, Tamengo Formation, Corumbá Group, uppermost Ediacaran;

Geographic and stratigraphic distribution: Widely geographically distributed in units of Mesoproterozoic to Cambrian (Grey, 2005). South Africa (Gaucher & Germs, 2006); Australia

(Grey, 2005; Damassa & Knoll, 1986; Javaux et al., 2004; Marshall et al., 2005; Javaux & Knoll, 2017); Brazil: Ferrerinha Formation, Ubajara Group (Chiglino et al., 2015); Canada (Hofmann & Jackson, 1994); Kazakhstan (Schopf et al. 2015); China (Marshall et al., 2005; Tang et al., 2013; Liu et al., 2014; Babu et al., 2014; Tang et al., 2015; Tang et al., 2017; Agic et al., 2017; Suslova et al., 2017); the USA (Porter & Riedman, 2016); Índia (Prassad et al., 2010; Tang et al., 2017); Mauritânia (Beghin et al., 2017); Namibia (Gaucher & Germs, 2003; Gaucher et al., 2005); Norway (Butterfield et al., 1994); Poland (Turnau & Racki, 1999); Congo (Baludikay et al.,2016); Russia (Stanevich et al., 2009; Vorob'eva & Petrov, 2014; Nagovitsin & Kochev, 2015; Vorob'eva et al., 2015; Sergeev et al., 2016, 2017); Suécia (Gorka, 1987); Uruguay (Gaucher & Germs, 2003; Gaucher et al., 2004; Blanco & Gaucher, 2005; Gaucher et al., 2008).

Leiosphaeridia obsuleta (Naumova, 1949)

(Fig. 15: 11-12, 19)

1949 *Trachytriletes obsuletes* Naumova, 1949 in Naumova, pp. 54, Pla I Fig. 7, Pl 2: fig 2.
1959 *Trachytriletum obsoletes* Naumova, 1949 Doweld, Pl X fig. 1-6.
1960 *Trachytriletes obsuletes* Naumova, 1949 in Timofeev,
1989 *Leiosphaeridia obsuleta* (Naumova , 1949) in Jankauskas, Pl. X figs. 1-3.

Type-material: Holotype in Naumova (1949) Table. 1, a FIG. 7 is lost. Lectotype: LitNIGRI, № 16-800-2942 / 15; Bashkiria. Sergeevskaya-800 drill hole, interval from 2942.4 to 2946,4 m; Ediacaran Jankauskas (1989).

Type-locality: See Jankauskas (1989).

Type-horizon: See Jankauskas (1989).

Illustrated material: MP 1714 N55[3], Porto Sobramil section; M1706 V53[4], Porto Sobramil section; M 2218 S41[4], Dengying Formation, China.

Description: Small and medium sized spheroidal shells with a shagreen (dotted or grainy) surface. The wall is very thin, thin or thickened. The dimensions of the shells are 10–70 μm (usually 15–30 μm), the holotype (Naumova, 1949) is 20–30 μm, the lectotype is 45 μm. Crease folds are more or less numerous misaligned randomly. The method of opening the shells was observed single by the median (Jankauskas, 1989 p. 80-81).

Diagnosis: Not available.

Remarks: *Leiosphaeridia obsuleta* (Naumova, 1949) was originally designated as *Trachytriletes obsuletes* Naumava, 1949, and later transferred to *Trachyoligotriletes obsuletes* (Naumova 1949) in Timofeev (1960). Several variations of spellings were presented e.g. **obsoletus* (Timofeev, 1960) or *obsoletum* (Timofeev and Bagdasaryan, 1964).

Occurrences: Here it is described in Corcal and Laginha quarries, Ecoparque da Cacimba and Porto Sobramil, Tamengo Formation, Corumbá Group, Brazil; Dengying Formation, China; Nomtsas Formation Nama Group, Namíbia; Tagatiya Guazu Formation, Itapucumi Group Paraguay.

Geographic and stratigraphic distribution: Tamengo Formation, uppermost Ediacaran, Brazil; Dengying Formation, uppermost Ediacaran, China; Nama Group, uppermost Ediacaran, Namibia; Tagatiya Guazu Formation, uppermost Ediacaran, Paraguay. Lena-Anabar Basin and north-western slope of the Olenek Uplift, Siberian Platform (Nagovitsin et al., 2015). Arymas and Debengda Formations, the Riphean of the Olenek Uplift, Siberia (Stanevich et al., 2009).

Incertae sedis

GROUP Acritarcha Evitt, 1963

GENUS *Bavlinella* (Schepeleva) Vidal, 1976

Type-species: *Bavlinella faveolatus* Shepeleva, 1962.

Emended diagnosis: Consists of 3 distinctive morphological subdivisions: (1) Small single coccoid cells, 3 to 5 microns in diameter, (2) larger coccoid cells, 5 to 16 microns in diameter occurring as individual cells or attached to similar cells to form rows or long chains; and (3) solid (?) globose masses 5 to 20 microns in diameter composed of coccoid subunits 0.1 to 2 microns in diameter (Moorman, 1974).

Remarks: The genus *Bavlinella* was erected by Shepeleva (1962), *Bavlinella faveolatus* being assigned as the type species. Subsequently, it was described once more by Shepeleva (1963) as a new genus, *Bavlinella faveolatus* being once more assigned as the type speeies of the genus. However, the specimen designated as holotype is the same as indicated in the earlier paper by Shepeleva (1962). Moorman (1974) erected the genus *Sphaerocongregus*. The type speeies, *Sphaerocongregus variabilis* was described as comprising a number of different mono- and pluricellular structures. The pluricellular structures are recognized by the present author (Vidal, 1976) as Shepeleva's species *Bavlinella faveolatus*. Therefore, in my opinion (Vidal, 1976), *Sphaerocongregus* may be considered as congeneric with *Bavlinella*. However, the diagnosis given by Moorman (1974) is, also in my opinion (Vidal, 1976), superior to that given earlier by Shepeleva (1962) and consequently adopted here as the valid diagnosis for the genus *Bavlinella* (Vidal et al. (1976).

Bavlinella faveolata Shepeleva, 1962
(Fig. 16: 15)

1962 *Bavlinella faveolatus* Shepeleva, 1962 pp. 170, Fig. 1.
1968 *Bavlinella faveolatus* Schepeleva, 1962 inVolkova, Pl. 9: 13.
?1973 *Microsphaera faveolata* Sin & Liu, pl. XIII, fig. 7
1974 *Favososphaera conglobata* Burmann, 1972 in Konzalova, pp. 43, Pl. 3: 4-5.
1974 *Sphaerocongregus variabilis* Moorman, pls 1–3.
1976 *Bavlinella faveolata* nom. correct. Vidal, fig. 7A–C.
1981 *Bavlinella* like Konzalová fig. 10 A–B.
1990 *Sphaerocongregus variabilis* (Vidal, 1976); Vidal & Nystuen, fig. 9A, B, D, E, G–L.
1992 *Sphaerocongregus* variabilis in Moorman, Plate VI, CJ; Plate XIV, G.
1992 *Bavlinella faveolata* (Vidal, 1976); Schopf, pl. 54J1–J3.
1996 *Bavlinella faveolata* (Vidal, 1976) in Gaucher, et al., figs 7.1–7.2.
2000 *Bavlinella faveolata* (Vidal, 1976) in Gaucher, pl. 9, pls 18.1–18.2.
2003 *Bavlinella faveolata* (Vidal, 1976) in Gaucher et al., figs 5C–H,6F.
2005 *Bavlinella faveolata* (Schepeleva) Vidal, 1976 in Gaucher et al., figs 6.

Type-material: The holotype of Shepeleva (1962), Volga-Urals region was lost. A Lectotype was proposed by German et al. (1989): Collection E. D. Shepeleva: ar. number 16/1893 drill holes. Kochevo-12, Interval from 474 to 476 m; Ediacaran the Eastern European platform; Table. XVIII, a FIG. 8a, b. Paratype in Shepeleva, 1963, pl. VII, a Fig. 10.

Type-horizon: Upper Bavlinskaya Series, Volga-Urals oil province, well Vyatskoye nº 4 (interval from 2927-2931 m) (Shepeleva, 1962).

Type-locality: Volga-Urals oil province, well Vyatskoye nº 4, Siberia, Russia, Perm Oblast', Borodulino stratigraphic reference well, depth interval 2927-2931 m (Shepeleva, 1962).

Illustrated material: Sample CP-948 (original slide number MP-1636), specimen O46[4] Corcal quarry section

Description: Sphaerical aggregate of numerous tightly packed spherical cells. Neither separating wall be tween each cell nor external wall on the cell aggregate is observed (Vidal, 1976).

Diagnosis: Same as for genus (Moorman, 1974).

Occurrences: Tamengo Formation, Corumbá Group in the localities of Ecoparque de Cacimba, Porto Sobramil and Pedreira Corcal, in Corumbá, State of Mato Grosso do Sul, was confirmed. Port Nolloth Group, Namibia (Gaucher et al., 2005a).

Geographical and stratigraphic distribution: *Bavlinella faveolata* presents a wide stratigraphic distribution, from the Mesoproterozoic to the Ordovician, being its acme in the Ediacaran (Gaucher et al., 2003). *Bavlinella faveolata* occurs in Russia: has been reported from the Upper Bavly Series (i.e. Lower Valdai) in the northern areas of the Volga-UraI oil province, wells Vyatskoye No. 4 (at 1 94 1 . 1-1947.9 m l , Severokamsk No. 1 2 (at 2847.2-2876.2 m l , Or'yebash No. 57 (at 2143-2148 m, Borodulino (at 2927-293 1 m) and Glazov (at 2141-2147 m). The rocks in which the species was found are reported to be greenish-grey micaceous argillites and fine-grained sandstones (Shepeleva, 1962). Other occurrences associated with organic-rich sediments in a number of Ediacaran basins worldwide (Konzalová, 1981; Germs, Knoll & Vidal, 1986; Palacios, 1989; Vidal & Nystuen, 1990; Gaucher, 2000; Gaucher et al. 2003; Gaucher & Germs, 2003). In black siliceous shales of the uppermost Proterozoic Hector Formation in southwestern Alberta, Canada (Moorman, 1974). It is recorded by from the Sinian Hsiamaling Formation in the Chih area, north China (Sin & Liu, 1973).

GENUS *Synsphaeridium* Eisenack, 1965

Type-species: *Synsphaeridium gotlandicum* Eisenack, 1965.

Diagnosis: See Eisenack (1965).

Remarks: The genus *Synsphaeridium* comprises four species, i.e. *S. gotlandicum* Eisenack, *S. tuberculatum* Eisenack, *S. conglutinatum* Timofeev and *S. sorediforme* Timofeev (Vidal, 1976). It was originally described from Sweden, Gotland, Silurian (Eisenack, 1965; pl. 23, fig. 1).

Synsphaeridium sp.

Not illustred

Illustrated material: Not illustred.

Description: Aggregates of thin-walled, compressed spheroidal vesicles. Vesicle walls psilate or slightly degraded, with common folds. Diameter of vesicles ranges between 10 and 30 µm.

Remarks: Morphological simplicity of these fossils and the lack of diagnostic features prevent a specific assignation of the material.

Occurrence: Tamengo Formation, Corumbá Group, uppermost Ediacaran, Corcal quarry section, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: Tamengo Formation, Corumbá Group, uppermost Ediacaran, Corcal quarry section, Municipality of Corumbá, Mato Grosso do Sul State, Brazil.

GENUS *Jacutianema* Timofeev & Hermann, 1979

Type-species: *Jacutianema solubila* Timofeev & Hermann, 1979.

Diagnosis: See Timofeev & Hermann (1979).

Remarks: Genus well stablished.

Jacutianema sp.

(Fig. 16: 10)

Illustrated material: Slide CP-945 (original slide number MP-1621) Specimen G43[3].

Description: Thick-walled, elongate, flat to round-ended cylindrical vesicles, 10 to 15 µm broad and 20 to 30 µm long, linked together in chain-like aggregates. Vesicle walls are opaque to translucent, fine-grained.

Remarks: These sphaeromorphs are left in open nomenclature because of the small number of specimens observed.

Occurrence: This species occurs in Tamengo Formation, Corumbá Group, Corcal quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: Tamengo Formation, Corumbá Group, uppermost Ediacaran, Corcal quarry section, Municipality of Corumbá, Mato Grosso do Sul State, Brazil.

GENUS *Lophosphaeridium* Timofeev, 1959

Type-species: *Lophosphaeridium rarum* Timofeev, 1959.

Diagnosis: See emended diagnosis in Lister (1970).

Remarks: Genus Diagnosis emended in Lister, 1970.

Lophosphaeridium sp.
(Fig. 16: 7)

Illustrated material: Slide MP1632, specimen K53[1].

Description: Robust-walled vesicle with verrucated, plicated surface. Diameter of specimen: 25 µm.

Remarks: These sphaeromorphs are left in open nomenclature because of the small number of specimens observed.

Occurence: This species occurs in Tamengo Formation, Corumbá Group, Corcal quarry, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: Tamengo Formation, Corumbá Group, uppermost Ediacaran, Corcal quarry section, Municipality of Corumbá, Mato Grosso do Sul State, Brazil.

GENUS *Ostiana* Hermann, in Timofeev et al., 1976

Type-species: *Ostiana microcystis* Hermann, in Timofeev et al., 1976

Diagnosis: See Timofeev et al., 1976

Remarks: Genus well stablished.

Ostiama microcystis Hermann in Timofeev et al., 1976
(Fig. 16: 20, 24 and Fig. 18: 10)

1976 *Ostiana microcystis* Hermann gen. et sp. nov. in Timofeev et al., p. 43, pl. XII, figs 5, 6, pl. XVII, fig. 8.
1976 *Ostiana microcystis* Hermann in Timofeev et al., 1976, p. 43, pl. 12, Figs. 5 and 6, pl. 17, Fig. 8;
1989 *Ostiana microcystis* Hermann in Jankauskas, p. 83, pl. 14, Figs. 1 and 2, and 6;
1990 *Ostiana microcystis* Hermann in Hermann pl. 3, Figs. 1 and 2;
1992 *Ostiana microcystis* Hermann in Schopf: pl. 23, figs. B and C1-C3;

1994 *Ostiana microcystis* Hermann in Butterfield et al.: p. 74, Figs. 5: F-I;
1994 *Ostiana microcystis* Hermann in Veis & Petrov: pl. 2, Fig. 11;
2006 *Ostiana microcystis* Hermann in Veis et al.: pl. 4, Fig. 12;
2009a *Ostiana microcystis* Hermann in Vorob’eva et al., p. 185, 186, Fig. 14.1;
2009b *Ostiana microcystis* Hermann in Vorob’eva et al., Fig. 4m;
2009 *Ostiana microcystis* Hermann in Butterfield, Fig. 1A-1C
2013 *Ostiana microcystis* Hermann in Tang et al., p. 163, fig. 5C–G
2015 *Ostiana microcystis* Hermann in Vorob’eva et al., pp. 211, Fig. 8: 2.
2016 *Ostiana microcystis* Hermann in in Baludikay et al., pp. 179, Fig. 12J.
2017 *Ostiana microcystis* Hermann in Loron & Moczydlowska, Plate 6, figures 3–5 pp, 27
2019 *Ostiana microcystis* Hermann in Loron et al., pp. 352, Fig. 2N.

Type-material: Timofeev et al. (1976), p. 43, table XII; figs 5, 6.

Type-locality: Yakutia, East Siberian Platform, Krasnoyarsk District, Turukhansk region, Miroedikha River (Timofeev et al., 1976).

Type-horizon: Miroedikha Formation, Upper Riphean (Timofeev et al., 1976).

Illustrated material: Sample and specimen, CP-952 (original slide number MP-4312)-II U40, 24. CP-952 (original slide number MP-4312)-II U24 and CP-955 (original slide number MP-2289) G44 [4].

Description: See Timofeev et al. (1976).

Diagnosis: See Timofeev et al. (1976).

Remarks: The observed specimens, in a similar way to *Synsphaeridium* Eisenack 1965, comprise individual vesicles, which if preserved individually would be identified as smaller leiospherids.

Occurrence: Brazil Tamengo Formation, Corumbá Group, uppermost Ediacaran. In the Nama Group, Namibia, assembled with *Cloudina lucianoi*. This speicies also occur in the Dengying Formation, China.

Geographic and stratigraphic distribution: Early Mesoproterozoic: Kotuikan Formation, Anabar Uplift, Siberia; latest Mesoproterozoic and Neoproterozoic (Tonian-Ediacaran): Burovaya and Miroedikha Formations, Turukhansk Uplift; Nureyen Formation, Uchur-Maya Uplift, Siberia (Vorob’eva et al., 2015); Svanbergfjellet Formation, Spitsbergen; Vychegda Formation, Timan Uplift, East European Platform (Vorob’eva et al., 2015); Meso–Neoproterozoic Mbuji-Mayi Supergroup, Democratic Republic of Congo (Baludikay et al., 2016).

Neoproterozoic lower Shaler Supergroup, Arctic Canada (Loron et al., 2019); Visingsö Group, Sweden (Loron, 2016); Uppermost Tamengo Formation, Corumbá Group, Brazil.

GENUS *Bambuites* Sommer, 1971

Type-species: *Bambuites erichsenii* Sommer, 1971

Diagnosis translated from Portuguese: Rounded morphotypes, opaque carbonaceous composition of irregular gaps, when observed, the transmitted light sometimes pops up the wall of denser contour; and diameter of dimensions variables (Sommer, 1971).

Remarks: See remarks for species.

Bambuites erichsenii Sommer, 1971

(Fig. 16: 14)

1971a *Bambuites erichsenii* Sommer, 1971 in Sommer, Pl. I: 1-15, holotype (Pl. I: 2).
1971b *Bambuites* sp. in Sommer, figs. 1-2.
2017 *Leiosphaeridia jacutica* (Timofeev, 1966) in Sanchez & Fairchild, fig. 8.

Type-material: Palynological slide number "S.70/1 - Section of Paleontology and Stratigraphy, D.G.M - D.N.P.M.", Museum of Earth Sciences, Rio de Janeiro, Rio de Janeiro State, Brazil (Sommer, 1971).

Type-locality: Limestone layer (top?) of the quarry at the cement factory Cauê, Pedro Leopoldo Municipality, Minas Gerais State, Brazil (Sommer, 1971).

Type-horizon: Upper? limestone layer, Sete Lagoas Formation, Bambuí Group.

Illustrated material: Specimen, palynological slide and England-Finde, CP-947 (original slide number MP-1714) M44 Porto Sobramil section (Fig. 16: 14).

Description translated from Portuguese: Carbonaceous, rounded, originally, perhaps, spherical morphotypes varying in their diameters and opaque (Sommer, 1971).

Diagnosis translated from Portuguese: Rounded morphotypes, between 70 and 200 micrometers in diameter; of the specimens found, 10 are between 100 and 140 micrometers in diameter; there are fragments that suggest a much larger diameter. Contour wall, when conspicuous, about 20 micrometers thick; in general, the individual is completely opaque, rarely whole, the margin always provided with crenellated ornamentation (Sommer, 1971).

Remarks: The main contribution to the original diagnosis of the species is the characterization of processes that prevent the insertion of *Bambuites erichsenni* in the group of spheromorphs, as proposed by Sanchez & Fairchild (2017), where they propose the synonymy with *Leiosphaeridia jacutica* (Timofeev, 1966). *Bambuites erichsenii* is included in the group of acantomorphs.

Occurrence: Porto Sobramil section, uppermost Ediacaran, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: *Bambuites erichsenni* Sommer, 1971 was described in rocks of the Sete Lagoas Formation, in the southeast region of the São Francisco Craton by Sommer (1971). Micro-fossils of acritarchs morphologically similar to Bambuites have been described in samples from rocks attributed to the Sete Lagoas Formation in the Rocinha Mine, in the western central region of the state of Minas Gerais (Baptista et al., 2010; Baptista et al., 2012; Baptista et al.,2013). Similar specimens were also described in drill hole samples and also related to the Sete Lagoas Formation, from the Montalvânia region, northern Minas Gerais state (Baptista, 2017). Porto Sobramil section, Tamengo Formation, Corumbá Group, uppermost Ediacaran, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

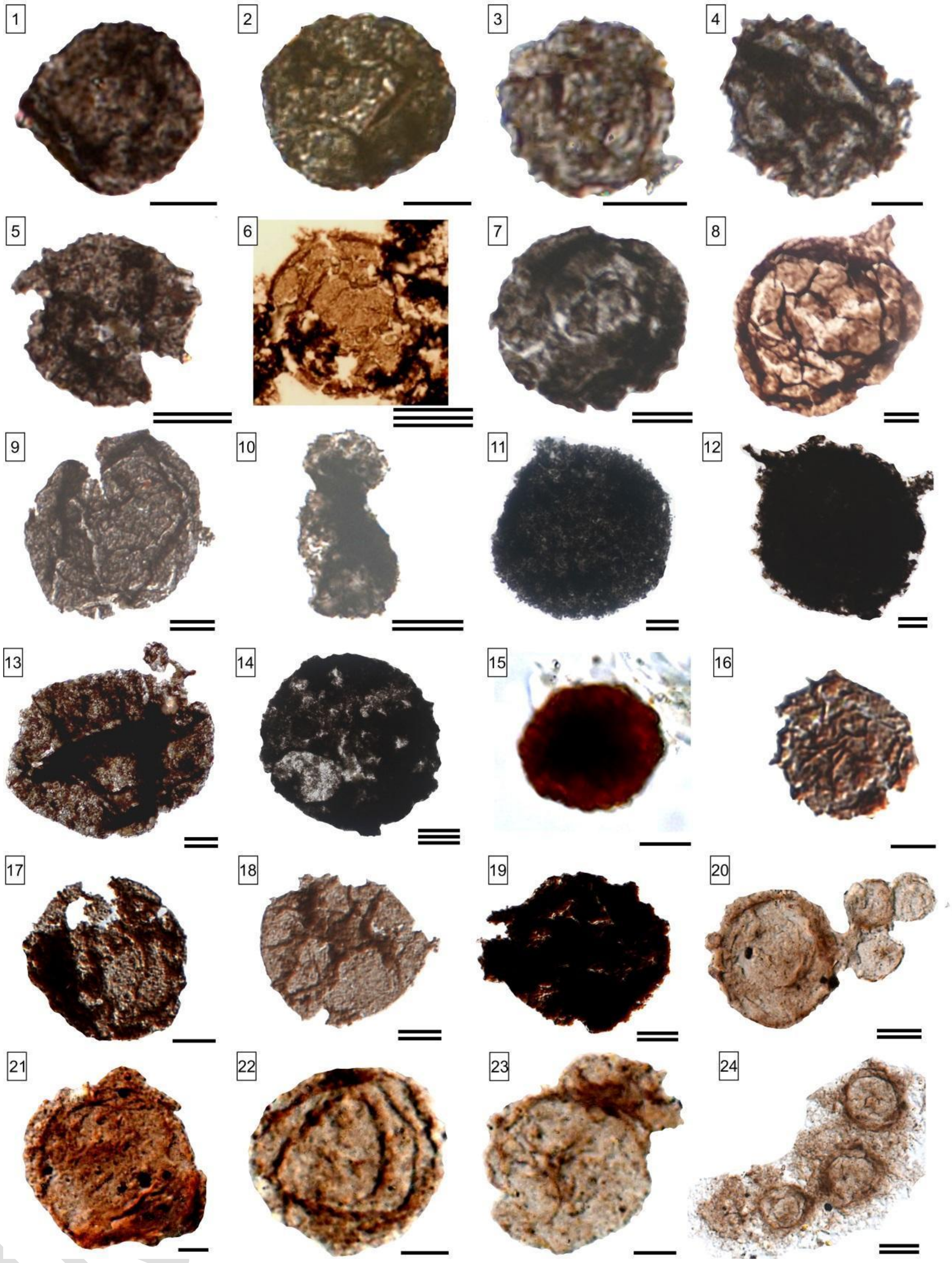


Figure 16. Sphaeromorph organic-walled microfossils from acidic macerations. 1-15) Coming from the Tamengo Formation, Corumbá Group (Brazil); 16-20) From Dengying Formation, China; 21-24) From Tagatiya Guazu Formation, Paraguay. 1-5) *Leiosphaeridia crassa* (Naumova, 1949), specimens and England Finder slide location: 1. CP-941 (original slide number MP-1632) L34[2]; 2. CP-942 (original slide number MP-1626) Q43[3]; 3 MP1626 Y57[2]; 4. CP-943 (original slide number MP-1630) T45; 5. CP-944 (original slide number MP-1633) H54[1]; 6) *Leiosphaeridia tenuissima* Eisenack, 1958: lâmina CP-793; 7) *Lophosphaeridium sp*.: CP-941 (original slide number MP-1632) K53[1]; 9) *Leiosphaeridia obsuleta* (Naumova, 1949): CP-943 (original slide number MP-1630) T45[3]; 10) *Jacutianema* sp.: CP-945 (original slide number MP-1621) G43[3]; 11-12, 19) *Leiosphaeridia obsuleta:* 11. CP-946 (original slide number MP-1714) N55[3], 12. CP-940 (original slide number 1706) V53[4], 19. CP-949 (original slide number MP-2218) S41[4]; 13-14) *Leiosphaeridia jacutica* (Timofeev, 1966): 13. MP1626 T52, 14. CP-947 (original slide number MP-1714) M44; 15) *Bavlinella faveolata* Vidal, 1976: CP-948 (original slide number MP-1636) O46[4]; 8, 16-18, 20-23) *Leiosphaeridia minutissima* (Naumova, 1949): 8. CP-941 (original slide number MP-1632) L40[2], 16. CP-950 (original slide number MP-2183) E50[3], 18. CP-951 (original slide number MP-2203) B42[1], 20. CP-952 (original slide number MP-4312-II) U40; 21. CP-952 (original slide number MP-4312-II) H27[2], 22) CP-952 (original slide number MP-4312-II) F43. 23. CP-952 (original slide number MP-4312-II) L41[4]; 20, 24) *Ostiama microcystis* * small vesicles: 20. CP-952 (original slide number MP-4312-II) U40, 24. CP-952 (original slide number MP-4312-II) U24. Scale bar: single= 5µm, double= 10 µm and triple=50µm.

Gen 1. Sp. 1

(Fig. 17: 1-2)

1992 chitinozoan like in Zang & Walter, pp. 298 Pl. XIII: F, K.
?2018 Gen. 1. Sp. 1 Denezine, Fig. 12 A.

Illustrated material: Two specimens were illustrated from different slides and samples: CP-953 (original slide number MP-1590) C37 [1] Cacimba section, Tamengo Formation, Corumbá Group (Brazil); 2) CP-952 (original slide number MP-4312)-Q24[2] from Tagatiya Guazu Formation (Paraguay).

Description: Flask-shaped organic-walled microfossil. The vesicle walls are opaque and thick. Some short unbranched processes can be observed. Maximum vesicle larger width are 20–30 µm and the longer length is about 50 – 70 µm. A short neck can be observed in some forms.

Remarks: Chitinozoans are organic-walled microfossils of uncertain systematic position whose stratigraphic range was until recently thought to be restricted to the Paleozoic or, more precisely, from the Cambrian to the Devonian (Jansonius, 1970). It was reported in Denezine et al. (2017) occurrences of organic-walled microfissils in vase-shaped or flask-shaped with similarities with chitinozoan from Sete Lagoas Formation, Bambuí Group. These chitinozoan-like forms appear to expand the range of occurrence of chitinozoan for at least to the uppermost Ediacaran, as previously suggested by Bloeser et al. (1977), Zang & Walter (1992), Binda & Bokhari (1980), Denezine et al. (2017) and Denezine (2018). Gen.1 sp. 1 have same size of the Chinese material described as chitinozoan like pl. XIII: F (Zang & Walter, 1992). The main difference between the Gen1 sp. 1 described here and the specimens described in Denezine, 2018 is the size, the specimens from Sete Lagoas are larger ~70µm and the Tamengo and Tagatiya Guazu Formation specimens are 20–30 µm maximum diameter.

Occurrence: Two specimens were illustrated from different slides and samples: CP-953 (original slide number MP-1590) C37[1], Tamengo Formation, Corumbá Group, uppermost Ediacaran, Brazil; Tagatiya Guazu Formation, Paraguay; 2) CP-952 (original slide number MP-4312)-Q24[2] from Tagatiya Guazu Formation (Paraguay). Ecopaque Cacimba section.

Geographic and stratigraphic distribution: Late Precambrian Chuar Group of the Grand Canyon, Arizona, USA (Bloeser et al., 1977). Jabal Rokham carbonates, Murdama Group, Arabian Shield Saudi Arabia (Binda & Bokhari, 1980). Zhaowei Formation and Liulaobei Formation, upper Ediacaran, Anhui region, China (Zang & Walter, 1992); Sete Lagoas Formation, Bambuí Group, Brazil (Denezine et al., 2017; Denezine, 2018).

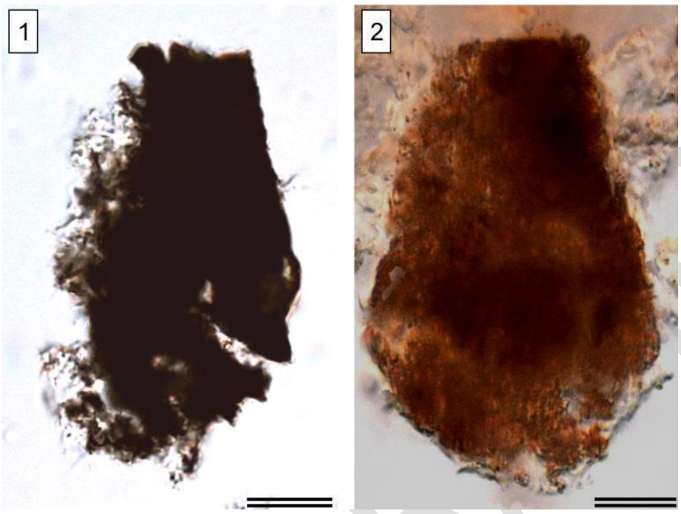


Figure 17. Gen.1 sp.1 flask-shaped organic-walled microfossils (Chitinozoa like) recovered from acidic maceration. 1) Specimen and England Finder slide location CP-953 (original slide number MP-1590) C37[1], Ecopaque Cacimba section, Tamengo Formation, Corumbá Group, Brazil; 2) CP-952 (original slide number MP-4312)-Q24[2] from Tagatiya Guazu Formation, Paraguay. Scale bar = 10μm.

GENUS *Navifusa* Combaz et al., 1967.

Type-species: *Leiofusa navis* Eisenack, 1938

Diagnosis translated from French: Shell in elliptical shape more or less elongated, or baton with rounded ends, without appendices; simple, smooth or ornamented membrane (Combaz et al., 1967).

Remarks: Genus well established.

Navifusa sp.
(Fig. 18: 2)

Illustrated material: Sample and specimen Englandfinder coordinate CP-942 (original slide number MP-1626) S56**.**

Description: Solitary single-layered nonseptate ellipsoidal baton with rounded ends. Vesicle walls translucent to opaque, coarse-grained, most likely a few micrometers thick. Ellipsoids 50–100μm long and 10–30 m wide.

Remarks: These ellipsoidal microfossils from the Lower Member of the Kotuikan Formation were identified in open nomenclature as *Navifusa* sp. These microfossils are larger than ellipsoidal akinetes of nostocalean cyanobacteria *Archaeoellipsoides* (=*Brevitrichoides*), that occur in many peritidal facies of the overlying Upper Member (Sergeev et al., 1995), and most likely are the remains of eukaryotic microorganisms. However, considering the poor preservation of the investigated material, we cannot exclude the possibility that *Navifusa* sp. in the Kotuikan microbiota are poorly preserved specimens of other microfossil taxa, e.g., *Chuaria circularis*.

Occurrence: Palynologic slide and specimen CP-942 (original slide number MP-1626) [S56] uppermost Ediacaran Tamengo Formation, Corcal quarry section, Corumbá Municipality, Mato Grosso do Sul State, Brazil.

Geographic and stratigraphic distribution: Uppermost Ediacaran Tamengo Formation, Corumbá Group.

Miscellaneous organic-walled microfossils
(Fig. 18: 1, 3, 8, 9)

Illustrated material: See figure 18.

Description: Several fragments were found in the acid maceration residue. It includes some likely cuticles (Fig. 12: 1, 3, 8, 9) and others which are more likely elongate tubular organic walled microfossils. The intense fragmentation of the material made it impossible to classify it in a secure way. So it is herein illustrated in Figure 18 to show the insoluble organic matter in wide view, and to make possible future work of comparison of these fossil fragments with some eventually extracted completely in future works.

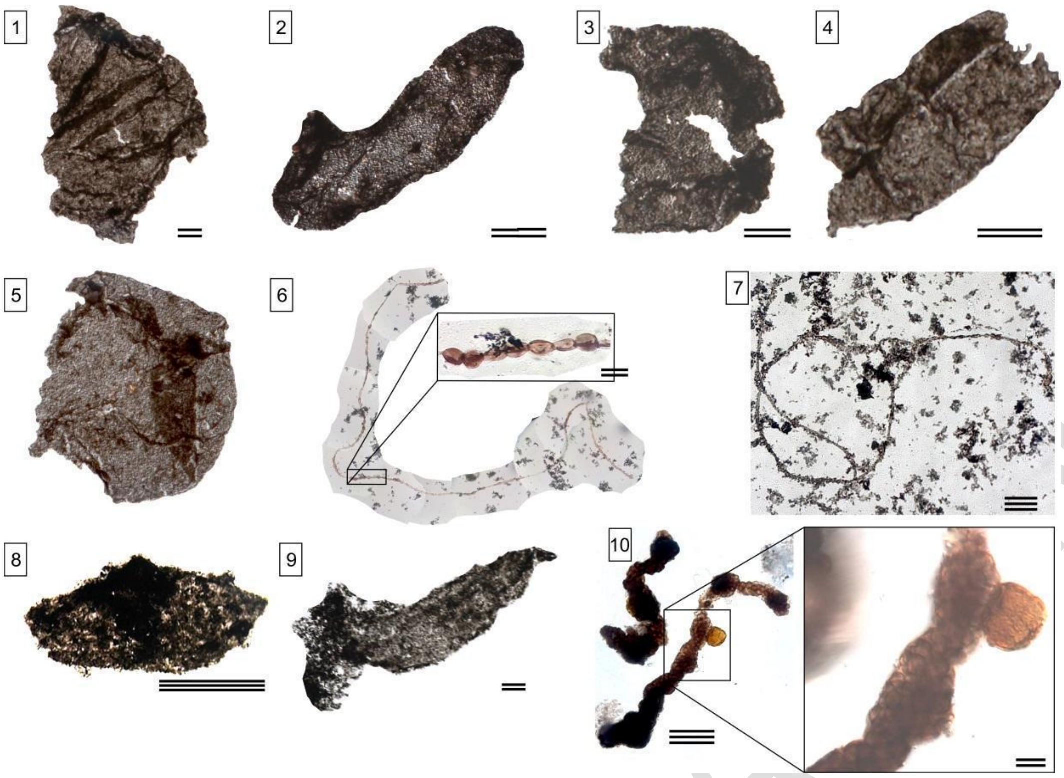


Figure 18. Miscellaneous organic-walled microfossils recovered from acidic macerations. 1-9) Samples from Tamengo Formation, Corumbá Group, Brazil; 10) Specimens from Nama Group, Namibia. 1, 3, 4, 5, 8 and 9) Unnamed forms from Corcal quarry section. 2) *Navifusa* sp.; 6) *Arctacellularia januarensis* Denezine, 2008 *nomem nudum;* 10) *Ostiama microcistis* Hermann, 1976 in (Timofeev et al., 1976). Specimens and England Finder slide location 1) CP-943 (original slide number MP-1630) V41[1]; 2) CP-942 (original slide number MP-1626) S56; 3) CP-943 (original slide number MP-1630) D52[2]; 4) CP-943 (original slide number MP-1630) EJ47[3]; 5) CP-943 (original slide number MP-1630) F39[4]; 6) CP-940 (original slide number 1706) X31; 7) CP-940 (original slide number 1706) T33; 8) CP-954 (original slide number MP-3189) S56[2]; 9) CP-947 (original slide number MP-1714) N32[1] Porto Sobramil section; 10) CP-955 (original slide number MP-2289) G44 [4]. Scale bar: double= 10 µm triple=50µm.

5. STRATIGRAPHIC DISTRIBUTION OF SPECIES

Tamengo Formation outcrops in all five studied sections: Ecoparque da Cacimba, Porto Sobramil, Porto Figueiras, Corcal and Laginha quarries. Laginha quarry outcrops both Tamengo and Guaicurus formations. The occurrences of the species were positioned in each log, in all five studied sections and for additional ones out of Brazil.

Based on the distribution of the species, it is possible to recognize two biotas: Tamengo biota and Guaicurus biota. The Tamengo Formation biota is represented by twenty-three species, as it is possible to note, yielding the greatest diversity of species for the upper Corumbá Group. The Guaicurus Formation biota is represented by four species, only one shared with Tamengo Formation, the ichnofossil *Multina minima* (Fig. 19).

This decrease on diversity is herein interpreted as an extinction event in the upper Tamengo Formation, materialized by the elimination of three epibenthic biomineralizing metazoan: *Cloudina lucianoi*, *Cloudina carinata* and *Corumbella werneri*. The extinction of these species is relatetad to Ediacaran-Cambrian extinction globally distributed (Amthor et al., 2003; Darroch et al., 2018).

Together with the extinction of the three basal cnidarian species, the disappearance of other nineteen epibenthic and planktic species of the Tamengo-Guaicurus transition: *Gordia marina* Emmons, 1844, *Pilichnus cf. P. dichotomus* Uchman, 1999 and *Vendotaenia antiqua* Gnilovskaya, 1971 plus fifteen species of small sphaeromorphs organic-walled microfossils that possibly represented marine planktic *Arctacellularia januarensis* Denezine, 2018 *nomem nudum*, *Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen 1. sp. 1 (chitinozoan like flask-shaped) was also observed. The disappearance of these nineteen species are herein interpreted as possibly a local response related to the Ediacaran-Cambrian extinction.

Particularly, considering that *Vendotaenia antiqua* and *Cloudina lucianoi* would be used in biostratigraphic framework, it seems interesting to make a remark about their extinction around the world. In Siberia, the extinction of *Vendotaenia antiqua* is concomitant with the extinction of *Cloudina lucianoi*, as it is observed at Corcal and Laginha quarries in Brazil. In China and Namibia, the extinction of *Vendotaenia antiqua* happens before the extinction of *Cloudina lucianoi* as observed in Ecoparque Cacimba in Brazil (Fig. 19). Further studies could evaluate if these extinctions are chronostratigraphically related, and if so, their significance for biostratigraphic purpose should be clarify.

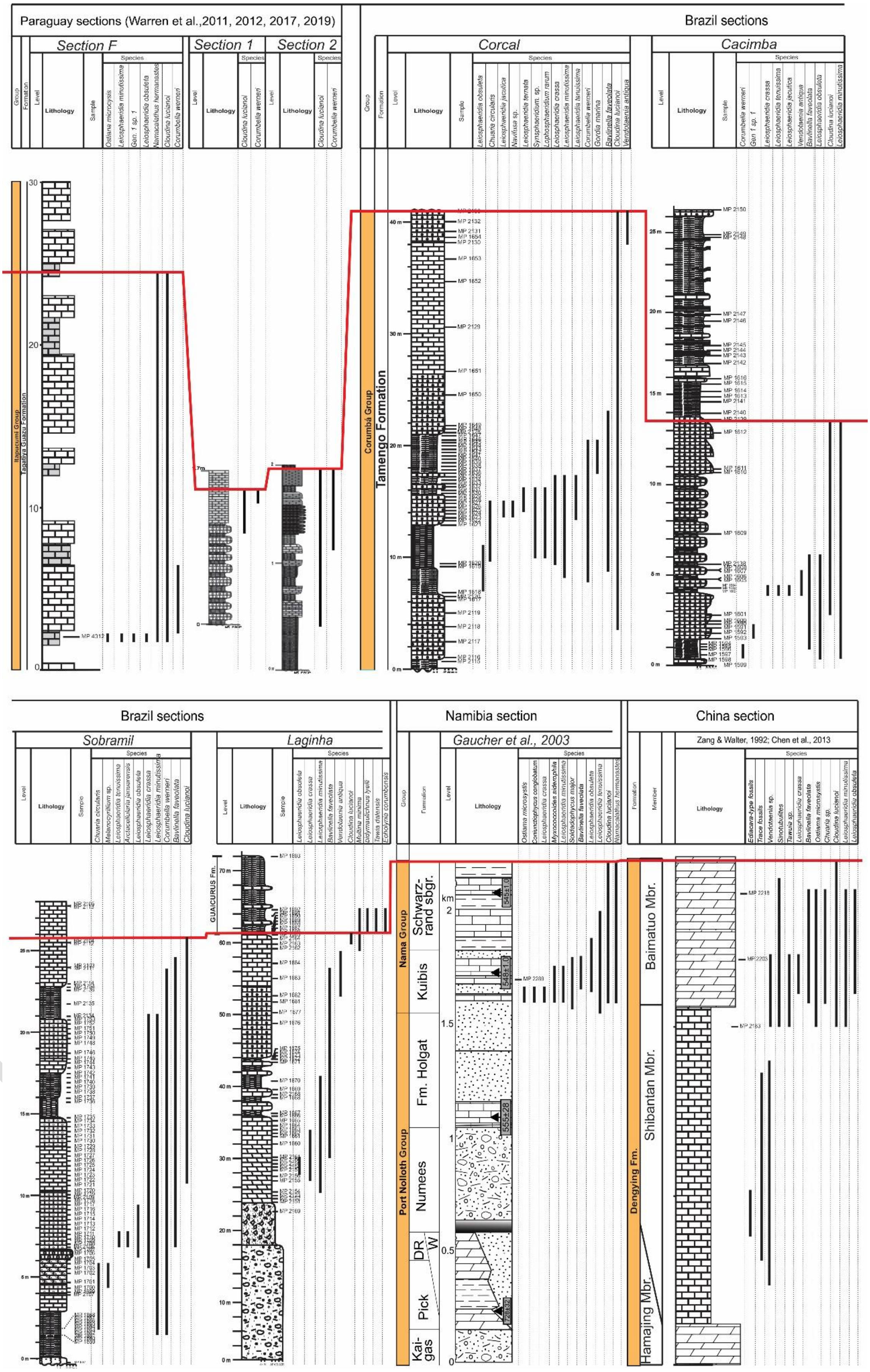


Figure 19. Stratigraphic distribution of the uppermost Ediacaran fossil assemblage of the Tamengo Formation and the additional complementary micropaleontology species for section in Paraguay (after Warren et al., 2011), Namibia (after

Gaucher et al., 2005) and China (after Chen et al., 2013). The red line marks the extinction of epibenthic biomineralizing metazoan: *Cloudina lucianoi, Cloudina carinata* and *Corumbella werneri*.

6. CONCLUSIONS

Five sections of the Tamengo Formation in the above-mentioned region had updated lithostratigraphic description: Ecoparque da Cacimba, Porto Sobramil, Porto Figueiras, Corcal and Laginha quarries. In addition to the updates of the lithostratigraphic logs, the occurrences of the species were positioned in each lithostratigraphic log, allowing future proposition of biostratigraphic essay and paleoecologic studies.

The fossil assemblage of the Tamengo and Guaicurus formations is composed of twenty-six species, of which three are benthic biomineralizing species of epibiont sessile habit: *Cloudina lucianoi* (Beurlen & Sommer, 1957), *Cloudina carinata* Cortijo et al., 2010, *Corumbella werneri* Hahn et al., 1982 and an indeterminate species of poriferous. Four ichnospecies represent activity of vagile organisms of benthic habit: *Didymaulichnus lyelli* (Rouault, 1850), *Multina minima* Uchman, 2001 both related to endobiont excavating organisms; *Gordia marina* Emmons, 1844 and *Pilichnus cf. P. dichotomus* Uchman, 1999 related to epibiont organisms, explorers of water-sediment interface. The microbiota of the Tamengo Formation consists of sixteen species, among which *Chuaria circularis* Walcott, 1899 and a small chamber microfossil (sponge gemmule?) with uncertain taxonomic affinity represent the permineralized microfossils. In addition, the microbiota of the Tamengo Formation also consists of fifteen species of small sphaeromorphs organic-walled microfossils: *Arctacellularia januarensis* Denezine, 2018 *nomem nudum, Leiosphaeridia ternata* (Timofeev, 1966), *Leiosphaeridia crassa* (Naumova, 1949), *Leiosphaeridia jacutica* (Timofeev, 1966), *Leiosphaeridia minutissima* (Naumova, 1949), *Leiosphaeridia tenuissima* Eisenack, 1958, *Leiosphaeridia obsuleta* (Naumova, 1949), *Bavlinella faveolata* Vidal, 1976, *Bambuites erichsenii* Sommer, 1971, *Synsphaeridium* sp., *Jacutianema* sp., *Lophosphaeridium* sp., *Ostiama microcystis* Hermann, 1976 in (Timofeev et al., 1976), *Navifusa* sp. and Gen 1. sp. 1 (chitinozoan like flask-shaped), as well as organic fragments of the species *Vendotaenia antiqua* Gnilovskaya, 1971.

The analysis of the stratigraphic distribution of the species and the changes in depositional paleoenvironment allow to consider that upper Tamengo Formation recorded the Ediacaran-Cambrian mass extinction. All three biomineralizing metazoans and other nineteen species disappeared from Tamento to Guaicurus Formation. Only one endobenthic ichnospecies survived, and other three new species appeared in Guaicurus Formation.

Additionally, five species of organic-walled microfossils were recovered and identified from samples of the Dengying Formation, China: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Ostiama microcystis*; Nine species from samples from Nama Group, Namibia: *Bavlinella faveolata*, *Ostiama microcystis*, *Leiosphaeridia crassa*, *Leiosphaeridia obsuleta* (Naumova, 1949), *Leiosphaeridia tenuissima*, *Leiosphaeridia minutissima*, *Soldadophycus major*, *Coniunctiophycus conglobatum* and *Myxococcoides siderophila*. Four species in the Tagatiya Guazu Formation, Paraguay: *Ostiama microcystis*, *Leiosphaeridia obsuleta* (Naumova, 1949) and *Leiosphaeridia minutissima* and Gen.1 sp. 1. The micropaleontological result for these additional sections complemented the scarce record of species of organic-walled microfossils from the uppermost Ediacaran.

Future studies involving paleoecology, paleogeography and biostratigraphy based on distribution of the uppermost Ediacaran fossil assemblage would be of great importance. In addition, studies on biology especially in the areas of phylogeny and compared morphology of uppermost Ediacaran metazoan, could help to present new diagnosis and description for *Corumbella werneri*. As already mentioned, the type-material of *Cloudina waldei* must be redescribed and a deep taxonomic revision must be performed.

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7. REFERENCES

All citations presented in this manuscript in preparation are included in the list of references presented in the thesis document.