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PRELIMINARY BIOSTRATIGRAPHIC CORRELATION OF THE ARROYO DEL SOLDADO GROUP (VENDIAN TO CAMBRIAN, URUGUAY) WITH THE CANGO CAVES AND NAMA GROUPS (SOUTH AFRICA AND NAMIBIA)

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ABSTRACT

A preliminary biostratigraphic correlation of the Arroyo del Soldado, Cango Caves and Nama Groups is postulated on the basis of organic-walled microfossils. The occurrence of a low-diversity, high abundance assemblage of organic-walled microfossils in the Cango Caves Group of South Africa is reported for the first time. The assemblage comprises the following species: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *L. tenuissima*, *Chuaria circularis*, *Micrhystridium* cf. *M. tornatum*, *Soldadophycus bossii*, *S. major*, *Myxococcoides* sp. A and B, *Glenobotrydion aenigmatis*, *Siphonophycus robustum* and *Coniunctiophycus conglobatum*. While the assemblage preserved in the Nooitgedagt Member is strongly dominated by *Bavlinella faveolata*, the association occurring in the overlying Kombuis Member is dominated by *Soldadophycus bossii*. Up section (Groenefontein and Huis Rivier Formations), sphaeromorphic acritarchs dominate. Around 70 % of the above mentioned species occur in the Arroyo del Soldado Group, allowing for a correlation of both units, which are roughly coeval and late Vendian in age. Palynomorphs previously reported for the Nama Group are taxonomically reassessed. The Nama assemblage is composed by (in order of decreasing abundance): *Leiosphaeridia minutissima*, *L. tenuissima*, *Chuaria circularis*, *Bavlinella faveolata*, *Siphonophycus solidum*, *S. kestron*, *S. typicum*, pseudoseptate filaments and aff. *Comasphaeridium* sp. Hence, the Nama acritarchs essentially represent the same association occurring in the Cango Caves and Arroyo del Soldado Groups, which is assigned to the Kotlin-Rovno assemblage of the East European Platform. Deposition of the Cango Caves Group took place entirely in the late upper Vendian. Palynofacies in that unit reflect the deepening-upward trend inferred from sedimentary facies. A broad connection of the Arroyo del Soldado, Corumbá, Nama and Cango Caves basins is envisaged, and may serve as a basis for future palaeogeographic reconstructions of SW-Gondwana.

Key words: Neoproterozoic, Vendian, Namibia, South Africa, Uruguay

RESUMEN

Se correlaciona de manera preliminar a los grupos Arroyo del Soldado, Nama y Cango Caves, en base a microfósiles de pared orgánica. Se reporta por primera vez la ocurrencia de una asociación de palinomorfos de baja diversidad y alta abundancia del Grupo Cango Caves de Sudáfrica, comprendiendo las siguientes especies: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *L. tenuissima*, *Chuaria circularis*, *Micrhystridium* cf. *M. tornatum*, *Soldadophycus bossii*, *S. major*, *Myxococcoides* sp. A y B, *Glenobotrydion aenigmatis*, *Siphonophycus robustum* y *Coniunctiophycus conglobatum*. Mientras la asociación de palinomorfos preservada en el Miembro Nooitgedagt del mismo grupo está dominada por *Bavlinella faveolata*, la microflora del sobreyacente Miembro Kombuis es dominada por

Soldadophycus bossii. Hacia el tope, en las formaciones Groenefontein y Huis Rivier, dominan las acritarcas esferomorfas. Cerca del 70 % de las especies mencionadas aparecen en el Grupo Arroyo del Soldado, permitiendo una correlación de esta unidad con el Grupo Cango Caves. Ambas se habrían depositado en el Vendiano superior. Los palinomorfos del Grupo Nama, descritos en la literatura, son revisados taxonómicamente, ocurriendo en esa unidad (en orden de abundancia decreciente): *Leiosphaeridia minutissima*, *L. tenuissima*, *Chuaria circularis, Bavlinella faveolata, Siphonophycus solidum, S. kestron, S. typicum,* filamentos pseudoseptados y aff. *Comasphaeridium* sp. Por tanto, la asociación de palinomorfos del Grupo Nama es esencialmente la misma que ocurre en los grupos Arroyo del Soldado y Cango Caves, la cual se asigna a la asociación Kotlin-Rovno de la Plataforma Este-Europea.
La depositación del Grupo Cango Caves tuvo lugar enteramente en el Vendiano superior alto. Las palinofacies presentes en esa unidad reflejan la tendencia progresivamente más profunda inferida de las facies sedimentarias. Se postula una amplia conexión de las cuencas de Arroyo del Soldado, Corumbá, Cango Caves y Nama, que puede servir de base para futuras reconstrucciones paleogeográficas del Gondwana sudoccidental.

Palabras clave: Neoproterozoico, Vendiano, Namibia, Sudáfrica, Uruguay

INTRODUCTION

The Arroyo del Soldado Group (ASG) occurs in Uruguay (Fig. 1) and was erected by Gaucher et al. (1996), to include a 5 km-thick platform succession comprising intercalated carbonates, siliciclastics, cherts and iron formations. From base to top, the following formations are distinguished (Gaucher et al. 1998, in press, Gaucher 2000, Fig. 2):

(a) Yerbal Formation, representing a fining-upward siliciclastic sequence, exceeding 1500 m in thickness;
(b) Polanco Formation, composed of up to 900 m of bluish gray, pure limestones, limestone/dolostone rhythmites and – more rarely- pure dolomites;
(c) Barriga Negra Formation, made up of 1500 m of conglomerates of differing composition, recording exposure and reworking of platform sediments;
(d) Cerro Espuelitas Formation, composed by a 1200 m thick intercalation of dark shales and chemical sediments, such as oxide-facies BIF and chert, representing renewed flooding of the shelf;
(e) Cerros San Francisco Formation, typically composed of quartz arenites and subarkoses ca. 300 m in maximum thickness; and
(f) Cerro Victoria Formation, with up to 400 m mainly stromatolitic limestones with trace fossils indicative of lowermost Cambrian age (Sprechmann et al., in press).

No volcanic, volcaniclastic or pyroclastic rocks occur in the ASG, confirming the interpretation of the unit as passive margin deposits (Gaucher et al. 1996, 1998, 2003, Gaucher 2000). The synrift deposits and volcanics that are commonly related to the opening of such basins are not represented in the ASG, indicating that the group already records the drift stage of the platform. An independent indication that a significant extensional event predated the ASG comes from the Nico Pérez mafic dyke swarm, which yielded Rb-Sr and K-Ar ages around 600 Ma (Rivalenti et al. 1995, Bossi et al. 1998).

Palaeontologic studies began relatively recently in the ASG. Montaña & Sprechmann (1993) reported the occurrence of stromatolites and ichnofossils in the Cerro Victoria Formation. Gaucher & Schipilov (1994) described the first acritarchs from BIF of the Cerro Espuelitas Formation. A number of publications by Gaucher et al. (1996, 1998) followed, describing organic-walled microfossils from almost the entire ASG. An assemblage of five genera and species of skeletal fossils including *Cloudina riemkeae*

Germs (1972 a) has been reported by Gaucher & Sprechmann (1999). Finally,

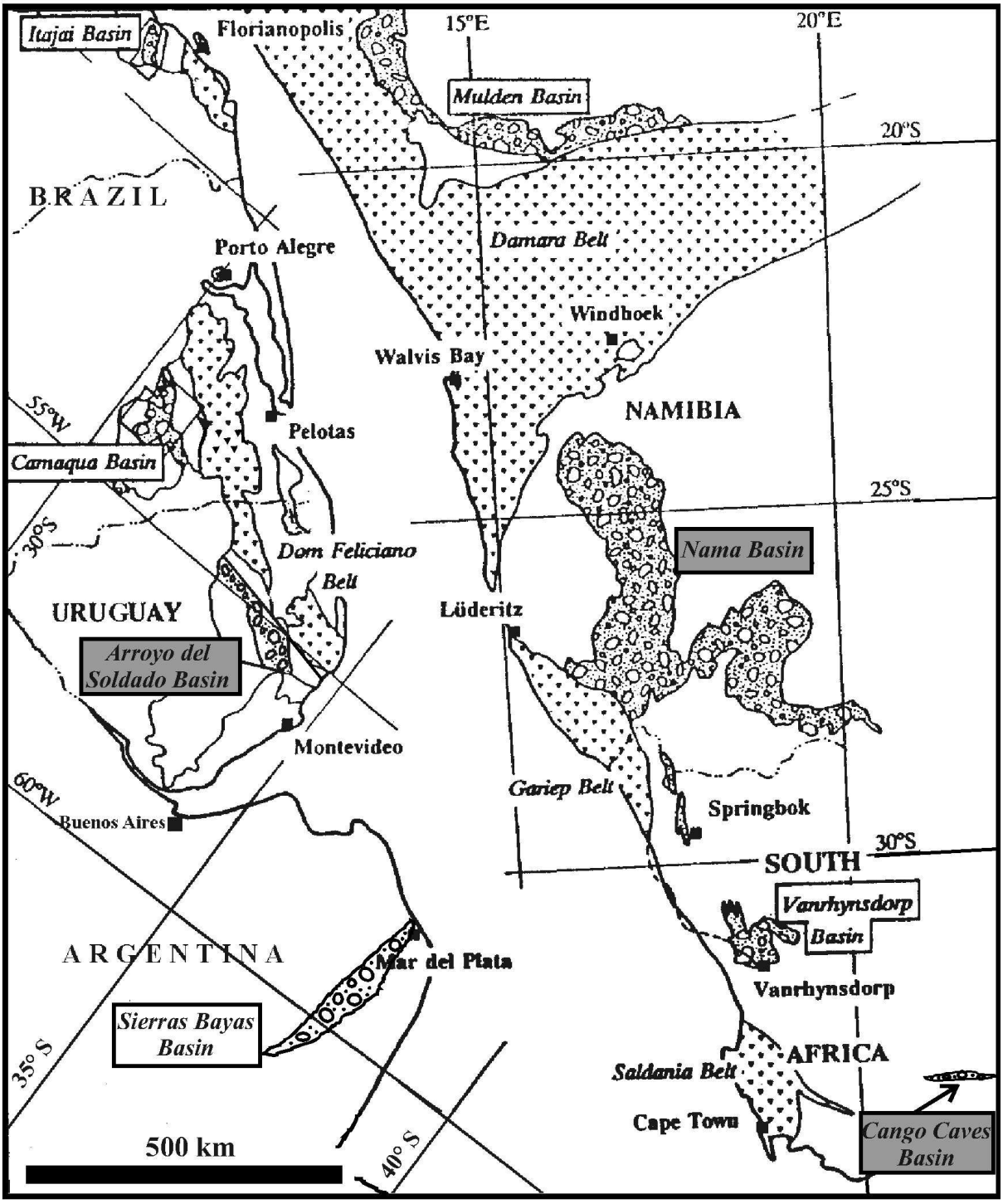


Fig. 1: Outcrop area of the Arroyo del Soldado, Cango Caves and Nama Groups, located on a pre-drift reassembly of Gondwana, modified after Gresse et al. (1996). Location of other late Neoproterozoic-Cambrian sedimentary basins and fold belts is also shown.

Gaucher (2000) presented detailed palaeontologic and biostratigraphic information for the ASG.

The ASG is a key unit for understanding the palaeogeographic evolution of western Gondwana in the Vendian-lowermost Cambrian, due to the strategic position of its outcrop area, great thickness and fair preservation of fossils. Correlations of the ASG with Vendian units from Brazil have been postulated by Teixeira & Gaucher (2001) and Gaucher et al. (2003), on a bio-, litho- and chemostratigraphic basis. In this paper, we review existing biostratigraphic data for the ASG and compare it with reported data from the Nama Group of Namibia (Fig. 1). Furthermore, we present the preliminary results of a micropaleontologic survey of the Cango Caves Group (South Africa, Fig. 1), and compare the microfossil assemblage occurring in the Cango Caves Group with the assemblages preserved in the Arroyo del Soldado and Nama groups.

AGE CONSTRAINTS

Arroyo del Soldado Group

Age of the ASG is geochronologically constrained by: (a) a maximum U/Pb SHRIMP age of 633 Γ 12 Ma for the Puntas del Santa Lucía pluton (Hartmann et al. 2002), which is overlain with erosional unconformity by the ASG; and (b) a minimum Rb/Sr isochron age for the Guazunambí Granite of 532 Γ 11 Ma (Ro=0.70624: Kawashita et al. 1999), which intrudes into the ASG causing contact-metamorphism. Additional data are provided by K/Ar ages ranging between 532 Γ 16 and 492 Γ 14 Ma for the recrystallization of pelites belonging to the group (Cingolani et al. 1990, Gaucher 2000). Finally, C-, O- and Sr-isotopic data also support a late Vendian age for the lower and middle ASG, the boundary between the Yerbal and Polanco Formations being placed at 580 Ma (Gaucher et al. in press). The Cerro Victoria and probably part of the Cerros San Francisco Formation have been placed on the basis of chemostratigraphic and trace fossils data in the lowermost Cambrian (Gaucher et al. 2003, Sprechmann et al. in press).

Nama Group

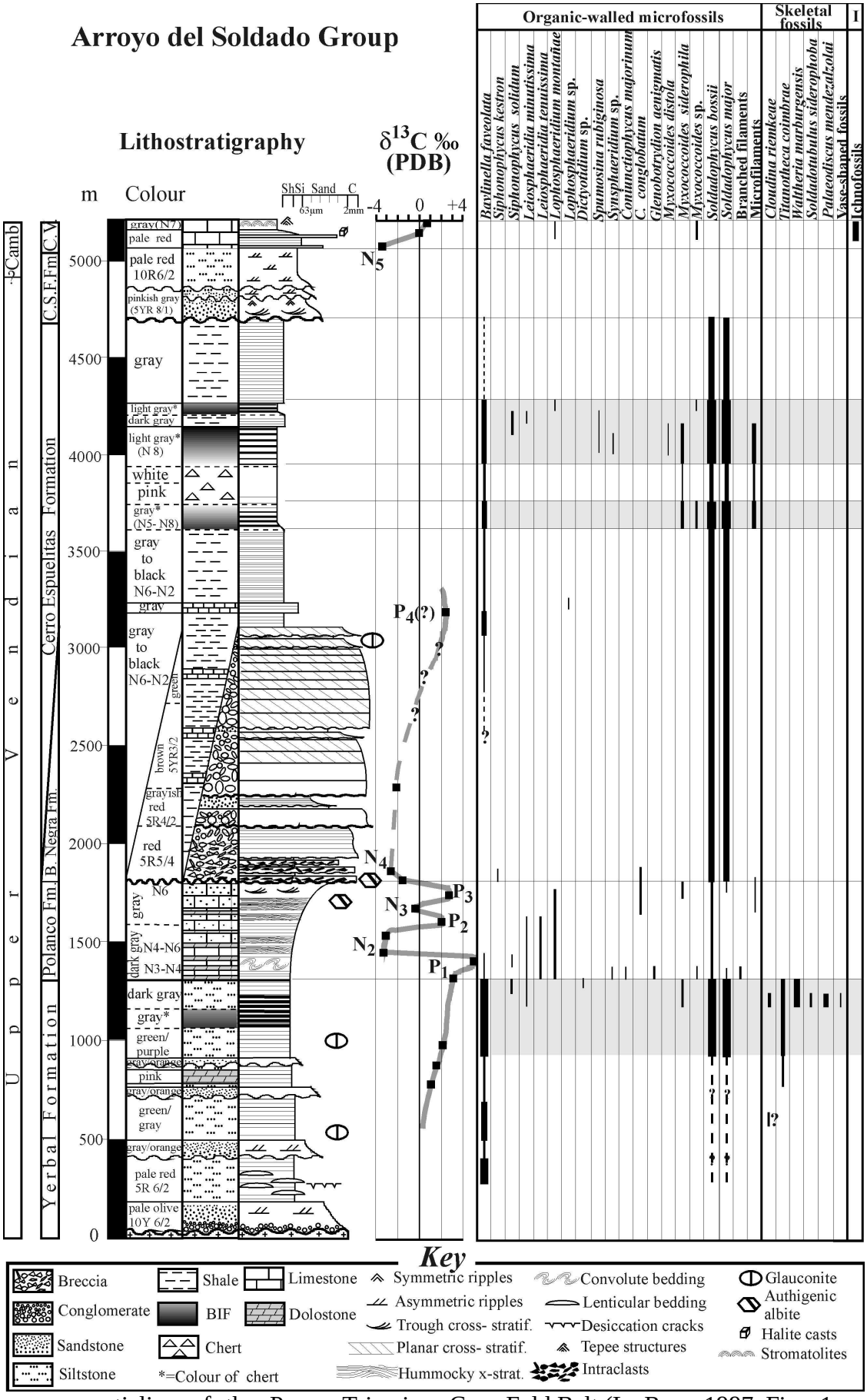
This unit, occurring in the central and southern parts of Namibia and the northwestern part of the Republic of South Africa (Fig.1), is one of the best dated Vendian successions worldwide. Grotzinger et al. (1995) provide U-Pb zircon datings of ash beds interbedded in the Kuibis and Schwarzrand Subgroups (Fig. 3). The bulk of these units was deposited according to the authors between 549 Γ 1 Ma (Zaris Formation) and 543 Γ 1 Ma (top of the Urusis Formation). The basis of the Nama Group is thus older than 549 Ma. An erosional unconformity spanning ca. 4 Ma occurs between the Urusis and Nomtsas Formations, as demonstrated by U-Pb datings of 539 Γ 1 Ma for the latter unit (Grotzinger et al. 1995).

High resolution C and Sr chemostratigraphic data presented by Kaufman et al. (1991) and Saylor et al. (1998) for the Nama Group are consistent with the above mentioned ages.

Independent, relative age constraints are provided by trace fossils described by Crimes & Germs (1982). Presence of *Treptichnus* (previously named *Phycodes*) *pedum* in the Nomtsas Formation and Fish River Subgroup (Fig. 3) indicates a Cambrian age for these units (Crimes & Germs 1982, Germs 1972b, 1995). Finally, a rich assemblage of Ediacaran fossils (Vendobionts) including *Pteridinium*, *Rangea*, *Cyclomedusa*, *Nasepia*, *Ernietta* and *Swartpuntia* among other genera (Germs 1995) is preserved in the Kuibis and Schwarzrand Subgroups (Germs 1995, Narbonne et al. 1997, Fig. 3), confirming a Vendian age for the lower Nama Group. Evidences provided by organic-walled microfossils and skeletal fossils will be discussed below.

Cango Caves Group

The Cango Caves Group (Le Roux 1999) is exposed as a basement inlier along the core



of a mega-anticline of the Permo-Triassic Cape Fold Belt (Le Roux 1997, Figs. 1 and

Fig. 2: Generalized stratigraphic column of the Arroyo del Soldado Group and C-isotopic composition of carbonates, modified after Gaucher (2000). Sources of $\delta^{13}C$-data: Boggiani (1998), Kawashita et al. (1999) and Gaucher et al. (2003a, b, in press). CSFFm: Cerros San Francisco Formation. CV: Cerro Victoria Formation.

4). The succession, previously named Goegamma Subgroup, is part of the Pan-African Saldania Belt, which marks the southern margin of the Kalahari Craton. From base to top, the Cango Caves Group includes (Fig. 5) the Matjies River, Groenefontein and Huis Rivier Formations (Le Roux 1997, 1999, Rozendaal et al. 1999; Fig. 5). The succession is made up of interbedded siliciclastic and carbonatic deposits at the base, which pass into siliciclastic turbidites up section (Fig. 5). Fig. 5 shows the main lithostratigraphic features of this unit, along with chemostratigraphic data reported by Fölling and Frimmel (2002) and microfossil occurrences first reported in this paper.

Reliable age constraints are scarce for the Cango Caves Group. Fölling et al. (2000) report a Pb-Pb double-spike isochron age of 553 Γ 30 Ma for carbonates of the Kombuis Member (Fig. 5). While detrital zircons of the Cango Caves Group yield ages around 1100 Ma, those from the overlying Kansa Group also contain a 518 Γ 9 Ma component (Barnett et al., 1997). These datings suggest a Vendian age for the Cango Caves Group, and a late Cambrian or younger age for the overlying Kansa Group. On the basis of C and Sr isotope chemostratigraphy, and a difference of 100 °C in thermal overprint between the Nooitgedagt and Kombuis members, Frimmel et al. (2001) and Fölling & Frimmel (2002) postulated a pre-Vendian age for the Nooitgedagt Member and a Vendian age for the rest of the Cango Caves Group.

MATERIALS AND METHODS

Palynological macerations of carbonates and pelites were prepared at the Micropalaeontology laboratories of the Facultad de Ciencias (Montevideo). Following crushing and digestion of samples (ca. 150 g) with concentrated HCl, 72% HF was applied for 24 hours to the silicate/organic residues. After neutralization, boiling, concentrated HCl was used to dissolve flourides. Remaining organic residues were recovered by means of a 5 µm sieve, stored in glass flasks and mounted with glycerin-gelatine on standard glass slides. Standard thin sections were prepared in the case of samples bearing skeletal fossils. Microfossils were determined and counted under a Leica DM LP polarizing microscope, using both transmitted and reflected light (in the latter case with oil immersion objectives). Microphotographs were taken with an attached Leica MPS-30 camera.

Repository. All palynological slides, containing specimens described here, are kept in the Precambrian collection of the Departamento de Paleontología, Facultad de Ciencias (Montevideo, Uruguay). Position of specimens in the slides are clearly marked in corresponding templates.

MICROPALEONTOLOGY

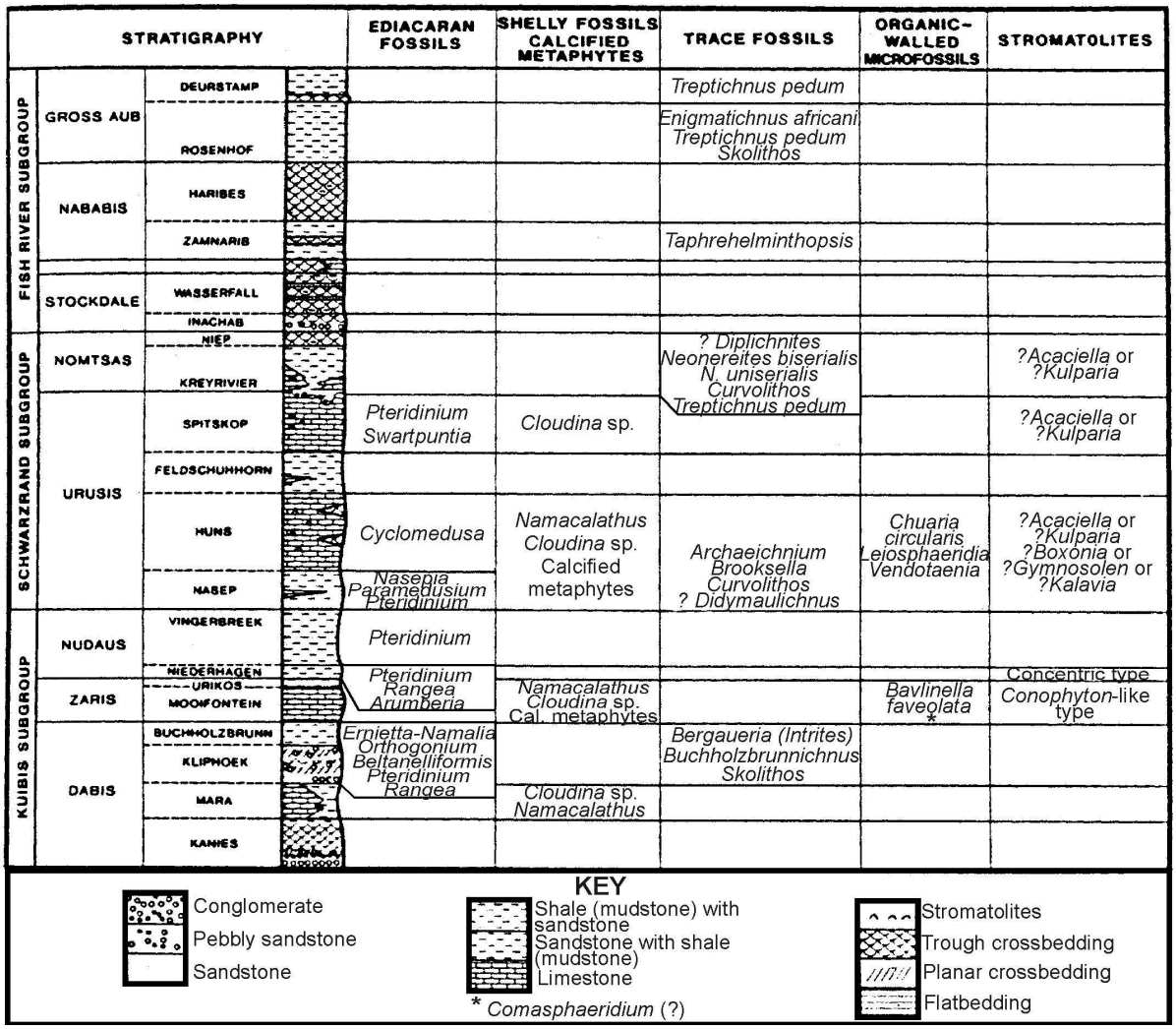
Arroyo del Soldado Group

An updated summary of the systematic palaeontology of organic-walled microfossils of the ASG is given by Gaucher (2000). Essentially, two different assemblages of organic-walled microfossils have been found in palynological macerations and thin sections. The two assemblages are facies controlled (Gaucher, 2000) and are the following (Fig. 2):

(1) An assemblage strongly dominated by the species *Bavlinella faveolata*, *Soldadophycus bossii* and/or *Soldadophycus major*, occurring in the Yerbal and Cerro Espuelitas formations. This assemblage includes less than 12 species of colonial spheroids, unbranched filaments and rare sphaeromorphic acritarchs. Among these, Gaucher et al. (in press) report the occurrence of *Dyctiotidium* sp. from the uppermost Yerbal Formation. Individual-richness is normally high, and strongly related to iron content of rocks.

(2) An assemblage including up to 15 species of spheromorphic acritarchs, colonial spheroids and large branched filaments characterizes the Polanco Formation. Samples of this unit are characterized by rather low concentration of microfossils and

Fig. 3: Schematic stratigraphic section of the Nama Group in Namibia (south of Osis) showing stratigraphic distribution of fossils, modified from Germs (1995). Range of



Namacalathus according to Grotzinger et al. (2000) and ranges of Ediacaran fossils partly taken from Narbonne et al. (1997).

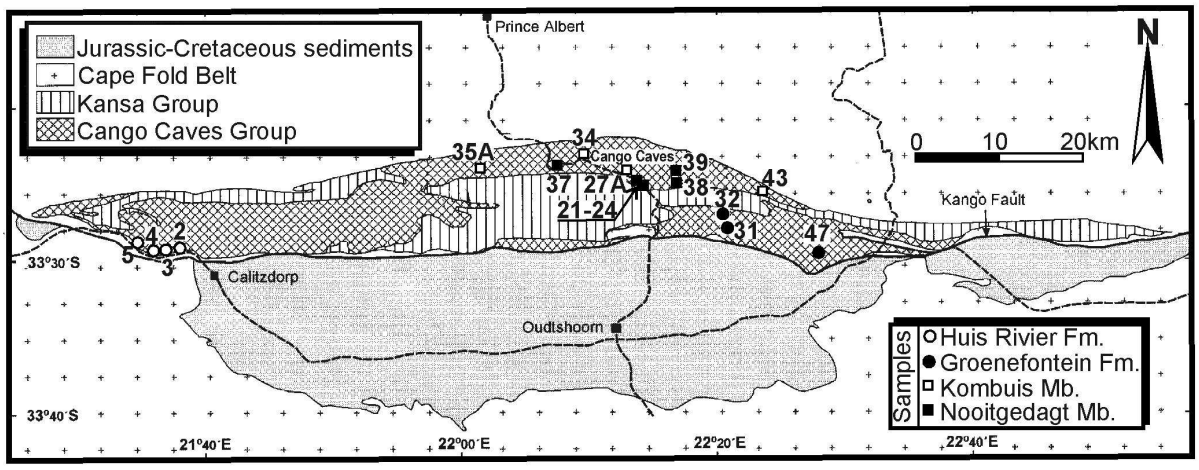


Fig. 4. Simplified geological map of the Kango Inlier, southern South Africa, modified from Frimmel & Fölling (2001). Location of fossiliferous samples is shown.

relatively higher diversity. *Bavlinella faveolata* and *Soldadophycus major* are rare in the Polanco Formation, and occur only as rare, fragmentary colonies. *Soldadophycus bossii* is quite common but not dominant, mainly represented by a few small colonies or colony-fragments per sample. The largest species of acritarchs and the largest individuals occur in this assemblage, namely *Leiosphaeridia tenuissima* and *Lophosphaeridium montañae*. These species are practically restricted to the Polanco Formation, as well as pseudoseptate, branched filaments, colonial spheroids of the genus *Coniunctiophycus* and *Glenobotrydion*. *Coniunctiophycus* represents the smallest colonial spheroids of the ASG.

Gaucher & Sprechmann (1999) and Gaucher (2000) described an assemblage of more than 5 species of skeletal micro-meiofossils occurring in the upper Yerbal Formation. Most important taxa are:

(1) *Cloudina riemkeae* Germs (1972 a), index fossil of the upper Vendian (Grant 1990). It occurs hematized, and in life position in banded siltstones of the Yerbal Formation.

(2) *Titanotheca coimbrae* Gaucher & Sprechmann (1999), an agglutinated foraminifer that built its test exclusively out of rutile crystals (Gaucher & Sprechmann 1999, Gaucher 2000). It represents the oldest forminifers currently known, and have been found recently in other Vendian successions of Brazil (Corumbá Group: Gaucher et al. 2003; Eleutério, Cajamar and Pico de Itapeva basins: Teixeira & Gaucher 2001).

(3) *Waltheria marburgenis* Gaucher & Sprechmann (1999), a tubular, septate fossil, probably with originally phosphatic test. The fossil occurs hematitized in siltstones of the upper Yerbal Formation, showing complex transitions between tubes, bundles of tubes and discs. They are often very abundant in the localities in which they occur.

Gaucher (2002) reported and illustrated three different, still undescribed skeletal species, namely:

(1) Conical, up to 3 cm long fossils with a test composed of secondary chamosite, occurring in bluish-gray siltstones of the Yerbal Formation (Quebrada de los Cuervos facies). Two or more conical units often join at the apex to give a "propeller shape". They occur in large numbers, mostly parallel to bedding-planes (event accumulations ?).

(2) Slightly curved, segmented fossils often showing branching. They also occur in the bluish-gray siltstones of the Yerbal Formation (Quebrada de los Cuervos

facies), sometimes associated with the conical fossils.

(3) Well-preserved, spongy fossils of still unknown composition, occurring in the chert-layers of BIF in the upper Yerbal Formation. It is not clear whether they are completely organic, or if they possessed a framework of spicules.

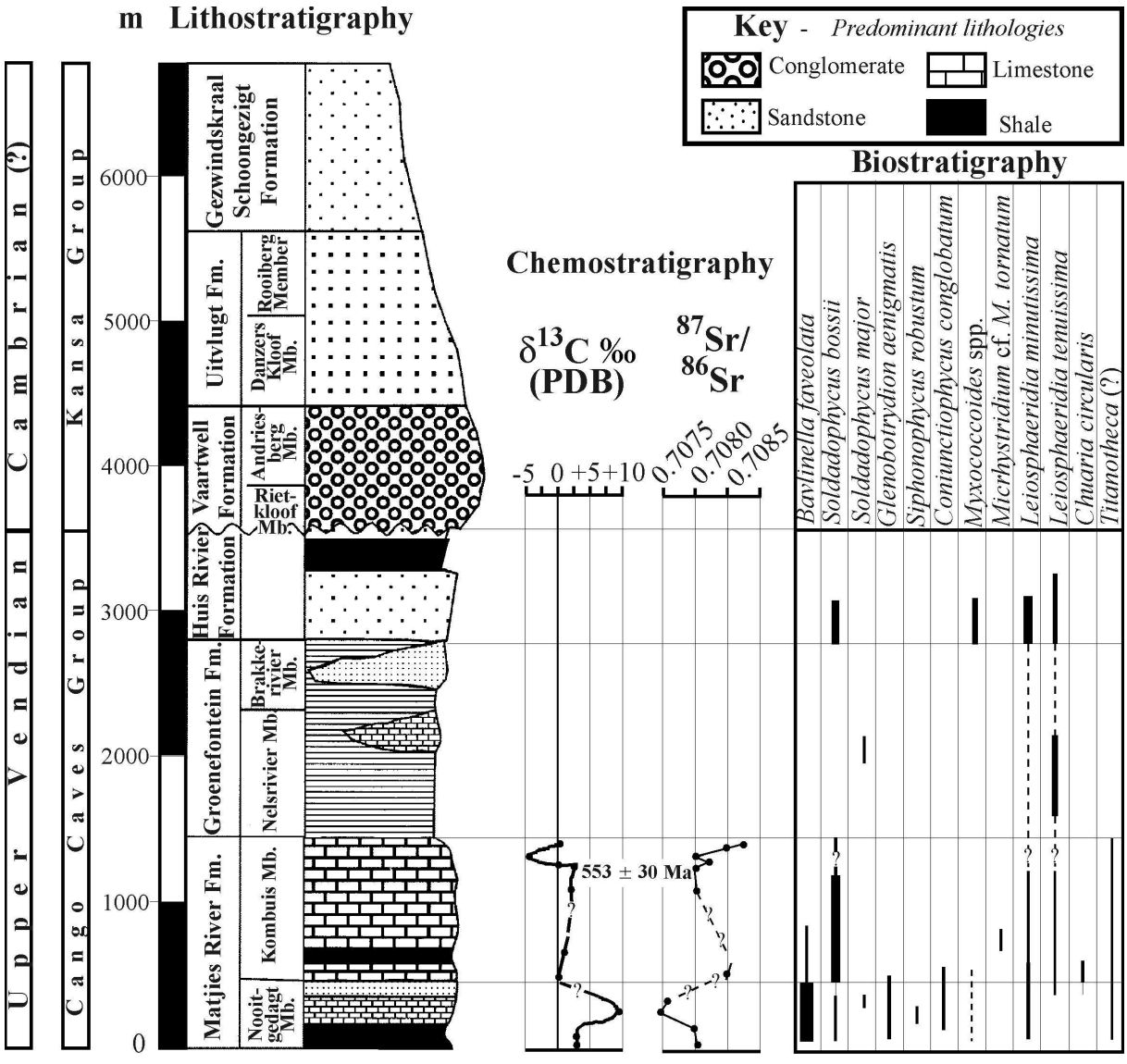
The diversity of the skeletal fossils is surprising, and they demonstrate that the evolutionary radiation of skeletal organisms started at least 40 Ma before the base of the Cambrian. Grotzinger et al. (2000: 348) arrived to similar conclusions while studying calcified metazoans of the Nama Group.

Distribution of different microfossil species in the ASG is shown in Fig 2.

Nama Group

Germs et al. (1986) reported the occurrence of a low-diversity assemblage of organic-walled microfossils from the Kuibis and Schwarzrand Soubgroups (Fig. 3) of the Nama Group (Namibia). The assemblage occurs in gray to black shales and is dominated by acritarchs assigned to the genus *Leiosphaeridia* and fragments of the ribbon-like macrofossil *Vendotaenia* (Germs et al. 1986). Further components of the assemblage reported by the authors are *Chuaria circularis*, *Bavlinella faveolata*, filamentous sheaths, and a single *Comasphaeridium*-like specimen. Considering thin-walled nature of the leiospherids, and there reported size between 10-16 µm and 30-70 µm (Germs et al. 1986),

Fig. 5. Generalized stratigraphic column of the Cango Caves and Kansa Groups modified after Le Roux and Gresse (1983) and Frimmel et al. (2001), showing chemo- and biostratigraphic data. Sources of $\delta^{13}C$- and $^{87}Sr/^{86}Sr$-data of Cango Caves carbonates: Fölling & Frimmel (2002). Pb-Pb dating shown for the Kombuis Member after Fölling et al. (2000).



they can be confidently assigned to *Leiosphaeridia minutissima* (Naumova) Jankauskas (1989) in accordance with currently accepted taxonomic schemes (Jankauskas 1989). On the other hand, at least one specimen figured by Germs et al. (1986: fig. 4.a) clearly exceeds the upper size limit of the mentioned species, and can be thus assigned to *Leiosphaeridia tenuissima* Eisenack. Thick-walled leiospherids 114-319 µm in diameter were grouped by Germs et al. (1986) under *Chuaria circularis* Walcott, and are at least in part equivalent to specimens of the Cango Caves Group here classified as *Leiosphaeridia jacutica* (Steiner 1994). *Bavlinella faveolata* (Schepeleva) Vidal (1976) is common in the Kuibis and Schwarzrand Subgroups, but not dominant (Germs et al. 1986). Nonseptate filamentous microfossils, described by Germs et al. (1986) from Kuibis and Schwarzrand samples, can be confidently assigned according to the most recent taxonomic schemes (Butterfield et al. 1994) to the genus *Siphonophycus*. Considering their reported width of 3-35 µm, the species represented are *S. solidum* (Golub) Butterfield, *S. kestron* Schopf (1968) and possibly also *S. typicum* (Hermann) Butterfield et al. (1994), although a detailed statistical study of the fossil material is needed to confirm this. Pseudoseptate, filamentous sheaths 20-40 µm in width also ocurring in the Nama Group (Germs et al. 1986) represent a separate taxon. Thus, the revised list of organic-walled microfossils of the Nama Group includes (in order of decreasing abundance): *Leiosphaeridia minutissima*, *Leiosphaeridia tenuissima*, *Chuaria circularis, Bavlinella faveolata, Siphonophycus solidum, S. kestron, S. typicum,* pseudoseptate filaments and aff. *Comasphaeridium* sp. Apart from these microfossils, microscopic remains of the macroscopic vendotaenid *Vendotaenia* sp. are also common in palynologic macerations of Nama shales (Germs et al. 1986).

Skeletal micro-meiofossils of the Nama Group (Fig. 3) include abundant *Cloudina riemkeae* Germs (1972 a) and *C. hartmannae* Germs (1972 a), the first skeletal fossils to be described from Precambrian successions, *Namacalathus hermanastes* Grotzinger et al. (2000), *Namapoikia rietoogensis* Wood et al. (2002), and still unnamed, tube-shaped fossils figured by Grotzinger et al. (2000). Composition of shells of the mentioned species is carbonatic (probably calcitic), fossils being commonly associated to thrombolite-stromatolite buildups.

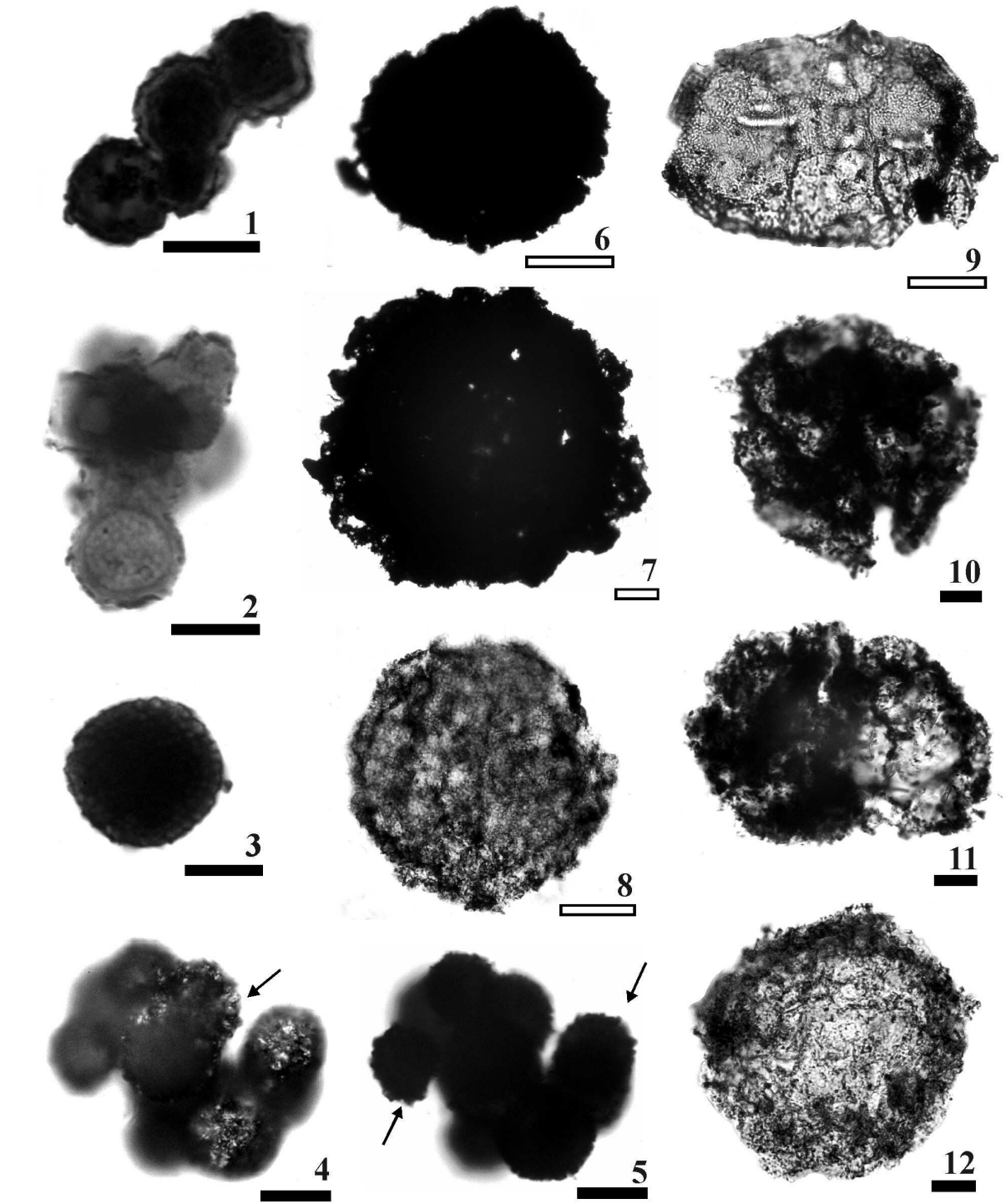
Cango Caves Group

Thirty-two samples of organic-rich shales and limestones of the Cango Caves Group were studied following standard palynological methods described above. Twenty-two samples yielded identifiable organic remains. While microfossils occuring in samples of the Matjies Rivier Formation (Nooitgedagt and Kombuis Members) were found to be mostly opaque and carbonized, microfossils of the Groenefontein and Huis Rivier Formations are predominantly middle to dark brown in colour. Thermal alteration index (TAI, Staplin in Hunt 1996) according to the schemes of Hunt (1996) and Teichmüller et al. (1998), is 5 for the Nooitgedagt Member, 4 to 5 for the Kombuis Member, and 3 for the Groenefontein and Huis Rivier Formations. These TAI values imply temperatures in excess of 250 °C for the Nooitgedagt Member, between 170-250 °C for the Kombuis Member, and 120-170 °C for the Groenefontein and lower Huis Rivier Formations (Hunt 1996, Teichmüller et al. 1998). Metamorphism temperatures calculated by Frimmel et al. (2001) using calcite-graphite carbon isotope geothermometry for the Nooitgedagt Member are considerably higher (388 Γ 8 °C) than those reported here. On the other hand, temperatures calculated by the same authors for the Kombuis Member are only slightly higher (less than 270 to 289 °C) than alteration temperatures inferred from palynomorphs. Though there is a difference in TAI between the Nooitgedagt and

Kombuis Members, a gap of 100 °C (Frimmel et al. 2001) seems excessive in view of TAI estimations reported above. Besides, there is some variation, ranging from slightly less than TAI 4 to TAI 5 in thermal alteration of Kombuis palynomorphs according to sample location, which is largely unrelated to stratigraphic height. Therefore, prudence is suggested while interpreting peak metamorphic temperatures of the Cango Caves Group, especially if the samples were taken from different sections.

Fig. 5 shows the stratigraphic distribution of organic-walled microfossils in the Cango Caves Group. The assemblage as a whole is characterized by relatively low diversity (12 species), high abundance of fossils and dominance of *Bavlinella faveolata* (Figs. 6.1-6.3), *Soldadophycus bossii* (Figs. 7.1-7.4), and *Leiosphaeridia* spp (Figs. 6.6, 6.8-6.12). The assemblage occurring in the Nooitgedagt

Fig. 6. Acritarchs of the Cango Caves Group. (1): *Bavlinella faveolata*, Nooitgedagt Member, sample 24 C (Fig. 4). (2): *Bavlinella faveolata*, Nooitgedagt Member, sample 37. (3): *Bavlinella faveolata*, Kombuis Member, sample 27 A. (4-5): *Micrhystridium* cf. *M. tornatum*, in reflected (4) and transmitted light (5), Kombuis Member (sample 27 A). Note short and robust processes (arrowed). (6): *Leiosphaeridia tenuissima*, Nooitgedagt Member, sample 24 C. The same specimen could be classified under *Chuaria circularis* Walcott, depending on the lower



size limit accepted for the taxon (see Butterfield et al. 1994). (7): *Chuaria circularis*, Kombuis Member, sample 34 B. Concentric folding of the relatively thick wall is visible in reflected light. (8): *Leiosphaeridia tenuissima*, Huis Rivier Formation, sample 2. Note less thermal alteration than preceding specimens. (9): *Leiosphaeridia tenuissima*, Groenefontein Formation, sample 31 B. (10-11) *Leiosphaeridia minutissima*, intensely corroded, Kombuis Member, sample 34 B. Specimen illustrated in (11) shows possible cell division (compare with Grey et al. 2003: fig. 4G). (12) *Leiosphaeridia minutissima*, Huis Rivier Formation (sample 2). The specimen shown is less carbonized than *L. minutissima* from the Kombuis Member (specimens 10-11) and has a distinctly corroded vesicle wall. Solid scale bars represent 10 µm and hollow scale bars 50 µm.

Member is strongly dominated by *Bavlinella faveolata*, which becomes rarer up section, the assemblage of the Kombuis Member being dominated by mainly spheroidal and saucer-shaped colonies of *Soldadophycus bossii* (Gaucher 2000; Figs. 7.2-7.3). This *Soldadophycus*-dominated assemblage is replaced up section (Groenefontein and Huis Rivier Formations) by an essentially *Leiosphaeridia*-dominated microflora. The only acanthomorphic acritarchs found in the Cango Caves Group are rare *Micrhystridium* cf. *M. tornatum* Volkova (Figs. 6.4-6.5) occurring in the Kombuis Member. Sphaeromorphs are mostly of modest size (< 150 µm), diameter increasing with stratigraphic height. Largest sphaeromorphs reach diameters between 200 and 400 µm, and occur in the Kombuis, Groenefontein and Huis Rivier Formations (Figs. 6.7-6.9). Thick-walled, opaque sphaeromorphs with concentric folds ca. 400 µm in diameter are here classified as *Chuaria circularis* Walcott (Fig. 6.7), following the criteria of Butterfield et al. (1994). Some thick-walled sphaeromorphs of the Nooitgedagt Member assigned to *Leiosphaeridia tenuissima* could be placed under *Chuaria circularis* if the lower size limit suggested by other authors is used (Ford & Breed 1973). A common feature of all acritarchs occurring in the Cango Caves Group is an advanced corrosion of vesicle walls, as also reported for the Nama Group (Germs et al., 1986).

The depauperate assemblage described above is characteristic for the upper Vendian (see chapter "Biostratigraphy"). Moreover, occurrence of fossils in the different units of the Cango Caves Group is to a certain extent controlled by palaeobathymetry and facies. While in the shallower deposits represented by the Matjies River Formation filament mats and larger spheroid colonies occur (Fig. 7), the assemblage occurring in the turbiditic Groenefontein and Huis Rivier Formations is composed of planktonic sphaeromorphs (Fig. 6) and relatively, small, spheroidal and saucer-shaped *Soldadophycus bossii*-colonies (Fig. 7.4).

Skeletal fossils have not been described from the Cango Caves Group so far. Spherical to flask-shaped bodies 20-60 µm in diameter, consisting of probably agglutinated, fine-grained rutile crystals occur in palynological macerations of samples from the Matjies River Formation (Nooitgedagt and Kombuis Members). The structures resemble *Titanotheca coimbrae* from the ASG in being composed of rutile-grains (Gaucher & Sprechmann 1999). However, they are significantly smaller, made up of finer rutile-crystals and do not show the characteristic test shapes of that species. Therefore, we regard these structures with doubts to *Titanotheca* sp., until more data are available.

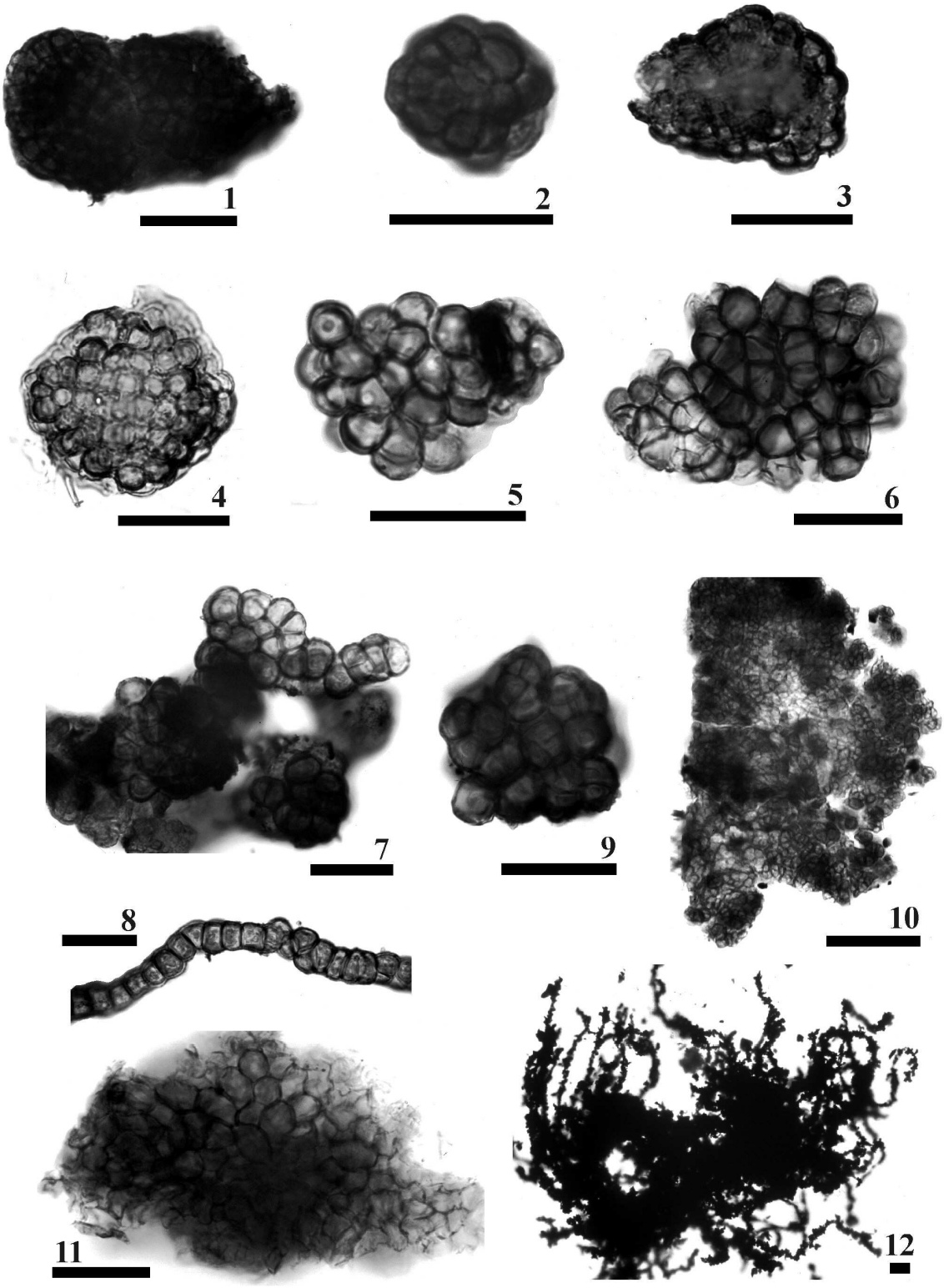
BIOSTRATIGRAPHY AND CORRELATIONS

Biostratigraphy

The depauperate palynomorph assemblages preserved in the Arroyo del Soldado, Nama and Cango Caves Groups are typical for the Vendian. Similar low-diversity, high-abundance microfloras were also reported for the Vendian of the East European Platform (Volkova 1985), France (Chauvel & Schopf 1978, Mansuy & Vidal 1983), Norway (Vidal & Nystuen 1990), Spain (Palacios 1989, Vidal et al. 1994), Spitsbergen (Knoll & Sweet 1985, 1987), Sweden (Vidal 1976), Shackleton Range of Antarctica (Weber 1991), Australia (Grey et al. 2003), Brazil (Gaucher et al. 2003a), Canada (Moorman 1974) and China (Zang 1992). The microflora matches the Kotlin-Rovno assemblage of Vidal & Moczydlowska (1997), which is characterized by low

diversity, abundance of *Bavlinella faveolata*, rarity or absence of acanthomorphs and absence of large (> 500 µm) sphaeromorphs (Vidal & Knoll 1983, Volkova 1985, Vidal & Moczydlowska 1997). Neoproterozoic, pre-Vendian assemblages (R3 and R4 of Vidal & Moczydlowska 1997) are more diverse and distinctly different from Vendian assemblages (Allison & Awramik 1989, Vidal et al. 1993, Vidal & Moczydlowska 1997, Knoll 2000). A more refined biostratigraphic scheme for the Vendian has

Fig. 7. Colonial spheroids and filamentous microfossils of the Cango Caves Group. (1): A flat, bilobate colony of *Soldadophycus bossii*, Nooitgedagt Member, sample 23 B (Fig. 4). (2): *Soldadophycus bossii*, small spheroidal colony, Kombuis Member, sample 23 B. (3): *Soldadophycus bossii*, flat colony, Kombuis Member (sample 27 A). (4): Saucer-shaped colony of *Soldadophycus bossii*, Huis Rivier Formation, sample 2. (5):



Myxococcoides sp. A, Huis Rivier Formation, sample 2. (6) *Myxococcoides* sp. B, Huis Rivier Formation, saample 3. (7-8): *Myxococcoides* sp. A (?), Kombuis Member, sample 35 A. Note pseudofilamentous habit of spheroids. (9) *Glenobotrydion aenigmatis*, Nooitgedagt Member, sample 21. (10): *Coniunctiophycus conglobatum*, flat, irregular colony. Nooitgedagt Member, sample 21. (11): Soldadophycus major, colony fragment. Groenefontein Formation, sample 47. (12): *Siphonophycus robustum*, mat fragment consisting of pyrite-encrusted filaments. Nooitgedagt Member, sample 21. Scale bars represent 20 µm for all specimens.

been recently proposed, which recognizes three informal acritarch-biozones between the Varangerian/ Marinoan glacials and the base of the Cambrian (Knoll 2000, Grey et al. 2003). The Varangerian/Marinoan and strata immediately above are characterized by a simple leiosphere palynoflora, followed by a complex acanthomorph palynoflora (CAP) described from Australia (Zang & Walter 1992, Grey et al. 2003), Siberia (Moczydlowska et al. 1993) and China (Zang 1992). In the uppermost Vendian, plankton diversity decreased dramatically, leading again to a depauperate assemblage dominated by small sphaeromorphs (Grey et al. 2003). The age of the CAP is estimated to be 570-580 Ma. Absence of this palynoflora in the Arroyo del Soldado, Nama and Cango Caves Groups is probably due to different factors, and can be explained as follows: (1) the Kuibis and Schwarzrand Subgroups (Nama Group) were deposited entirely in the latest Vendian (ca. 550-543 Ma), as demonstrated by U/Pb zircon datings of interbedded ash beds (Grotzinger et al. 1995). These ages place the lower Nama Group entirely within the Kotlin-Rovno assemblage of Vidal & Moczydlowska (1997). (2) According to Sr and C isotopic data, the ASG was probably deposited between 585 Ma and the basal Cambrian (Gaucher et al. in press, Gaucher et al. 2003a, b). Age of the CAP is roughly equivalent to the lower Polanco Formation, but a *Leiosphaeridia-Lophosphaeridium* assemblage devoid of acanthomorphs occurs there (Gaucher 2000). Absence of acanthomorphs could be due to preservational bias, palaeoecological or palaeogeographic reasons. (3) The Cango Caves Group does not contain acritarchs attributable to the CAP either. Considering a Pb-Pb double-spike age of 553 Γ 30 Ma reported by Fölling et al. (2000) for carbonates of the Kombuis Member and the palynomorph assemblage described here, the Cango Caves Group is probably younger than the CAP and records only the Kotlin-Rovno acritarch assemblage. Occurrence of *Micrhystridium* cf. *M. tornatum* in the Kombuis Member suggests a latest Vendian age for the unit, as reported from the Kotlin type region in Russia and elsewhere (Volkova 1985, Knoll & Sweet 1987).
Occurrence of *Cloudina*, index fossil of the upper Vendian (Valdaian/Ediacaran, Grant 1990), confirms a Vendian age for the Kuibis and Schwarzrand subgroups and the lower ASG.

Correlations

There is a striking similarity between the palynomorph assemblages preserved in the ASG and those recovered from the Nama and Cango Caves Groups. Almost 70 % of the species occurring in the Nama and of those recovered from the Cango Caves Group occur in the ASG. This implies that apart from being roughly coeval and having similar lithologies, these units were deposited in basins that had an ample connection and in similar climatic zones. The same is true for the Corumbá Group of Brazil, which hosts a similar palynomorph assemblage (Gaucher et al. 2003).

On the other hand, the Nama assemblage is best compared to the microflora preserved in the Kombuis Member and Groenefontein and Huis Rivier Formations. This assemblage is characterized by common leiospherids and occurrence of subordinated *Bavlinella faveolata*. *Soldadophycus bossii*, common in the middle-upper Cango Caves Group, is not known from the Nama Group (Germs et al. 1986), but since *Soldadophycus* was first described in 1996 (Gaucher et al. 1996), a reassessment of the palynoflora could eventually reveal these fossils. As for the *Bavlinella faveolata*-dominated assemblage preserved in the Nooitgedagt Member, it can

be confidently assigned to the Vendian because no *Bavlinella*-dominated assemblages pre- or postdate this period (Knoll & Sweet 1985, 1987). The corresponding assemblage in the Nama Group probably occurs in the lower Kuibis Subgroup, which was only coarsely sampled by Germs et al. (1986). However, with the available data we cannot definitely rule out a correlation of the Nooitgedagt Member with Vendian, pre-Nama units. Fölling & Frimmel (2002) proposed a correlation of the Nooitgedagt Member with the Hilda Subgroup of the Port Nolloth Group (Gariep Belt), which underlies tillites of the Numees Formation. Since data presented here do not support a pre-Vendian age for the Nooitgedagt Member, the Numees tillites might represent a post-Varangerian/Marinoan glacial event (Moelv glaciation?) . A Pb-Pb isochron age of 555 Γ 28 Ma obtained by Fölling et al. (2000) for the corresponding cap carbonates (Bloeddrif Member of the Holgat Formation) is consistent with this hypothesis.

CONCLUSIONS

The occurrence of a low-diversity, high abundance assemblage of organic-walled microfossils occurring in the Cango Caves Group of South Africa is reported for the first time. The assemblage comprises the following species: *Bavlinella faveolata*, *Leiosphaeridia minutissima*, *L. tenuissima*, *Chuaria circularis*, *Micrhystridium* cf. *M. tornatum*, *Soldadophycus bossii*, *S. major*, *Myxococcoides* sp. A and B, *Glenobotrydion aenigmatis*, *Siphonophycus robustum* and *Coniunctiophycus conglobatum*. While the assemblage preserved in the Nooitgedagt Member is strongly dominated by *Bavlinella faveolata*, the association occurring in the Kombuis Member is dominated by *Soldadophycus bossii*. Up section (Groenefontein and Huis Rivier Formations), leiosphaerids dominate. Around 70 % of the above mentioned species occur in the ASG, allowing for a correlation of both units, which are roughly coeval and late Vendian in age. Palynomorphs previously reported for the Nama Group by Germs et al. (1986) are taxonomically reassessed. The Nama assemblage is composed by (in order of decreasing abundance): *Leiosphaeridia minutissima*, *Leiosphaeridia tenuissima*, *Chuaria circularis*, *Bavlinella faveolata*, *Siphonophycus solidum*, *S. kestron*, *S. typicum*, pseudoseptate filaments and aff. *Comasphaeridium* sp. Hence, the Nama acritarchs essentially represent the same association occurring in the Cango Caves and Arroyo del Soldado Groups, which is assigned to the Kotlin-Rovno assemblage of Vidal & Moczydlovska (1997). Therefore, deposition of the Cango Caves Group took place entirely in the late upper Vendian. This is in disagreement with Frimmel et al (2001) who assigned a post-Sturtian, pre-Marinoan age (ca. 740-600 Ma) to the Nooitgedagt Member of the Cango Caves Group. A broad connection of the Arroyo del Soldado, Corumbá, Nama and Cango Caves basins is envisaged, and may serve as a basis for future palaeogeographic reconstructions of the Brazilides and Adamastor oceans. If the proposed chemostratigraphic correlation of the Kombuis Member with the Holgat Formation of the Port Nolloth Group (Gariep Belt, Fölling & Frimmel 2002) is correct, then this suggests a post-Varangerian/Marinoan age for the glaciomarine Numees Formation, in view of the biostratigraphic data presented here for the Cango Caves Group. This implies that the Numees glacial event took place contemporaneously with the Moelv glaciation.

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