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**Sedimentology and chemostratigraphy of the late Neoproterozoic carbonate
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and the C5 Formation (western central Democratic Republic of Congo):
Record of the late post-Marinoan marine transgression on the margin of
the Congo Craton**

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Abstract

The Neoproterozoic Marinoan climatic event corresponded to the Snowball Earth-type glaciation, and is commonly marked by the deposition of diamictites and by a negative carbon isotope anomaly. This event was followed by a sudden return to a greenhouse climate and a rapid post-glacial transgression with deposition of cap carbonates. Although the cap carbonates and marine carbonate sediments at the base of the post-glacial period are well known in the literature, few studies focused on the end of the marine transgression, which is a prelude to the Pan-African Orogeny in Central Africa. In this paper, we present new descriptions of these carbonate rocks and a sedimentological study from key cores and outcrops in the Otavi Mountainland (Namibia) and West Congo belt (DRC) of the Httenberg Formation and the C5 Formation, respectively. Both successions show five main facies: (i) microbial ‘mounds’ and pinnacles, (ii) ooid-shoal barrier, (iii) evaporitic brackish lagoon, (iv) beach and (v) coastal sabkha. The Httenberg Formation consists of an open-marine mid-inner carbonate ramp setting including microbial mounds and pinnacles, and oolitic shoal-barrier islands. The C5 Formation exhibits a hypersaline inner carbonate ramp including an ooid- shoal barrier, an evaporitic brackish lagoon, a beach and a coastal sabkha plain. Sedimentological, chemostratigraphical and biostratigraphical comparisons between the C5 and Httenberg formations suggest these are coeval carbonate shelf deposits on the margins

of the Congo Craton, with a depositional age between 580 Ma and 540 Ma for both formations.

Introduction

The Ediacaran Httenberg Formation, the youngest stratigraphic unit in the Otavi Group of the Damara Supergroup in northwest Namibia, comprises a 900 m-thick succession of shales, dolomitic limestones, oolitic limestones, and cherty dolostones. These were deposited in shallow marine environments on the southern and northern passive margins of the Congo-So Francisco (hereafter, C-SF) and Kalahari cratons respectively (Kamona and Gnzel, 2007; Figure 1). The sedimentary succession of the C5 Formation of the Cataractes Group (former West Congolian Group), similar to that developed in the Otavi Platform, is also present along the western flank of the Congo Craton in the Democratic Republic of Congo (DRC) (Delpomdor et al., 2018). Both successions record the end of the marine transgression, following Snowball Earth-type Marinoan glaciation (Kirschvink, 1992; Hoffman, 1999; Hoffman et al., 1998; Kennedy et al., 2001; Hoffman and Schrag, 2002). They predate the shutdown of the carbonate factory before the deposition of molasse sequences of the Mulden Group in Namibia and the Mpioka Subgroup in DRC. No datable intrusive or volcanic rocks and biostratigraphic fossils have so far been directly reported from these stratigraphic units and the age of sedimentation of the sedimentary succession in this part of the Ediacaran sedimentary cover of the C-SF and Kalahari cratons remains largely unconstrained. Nevertheless, the Httenberg and C5 formations were constrained by carbon isotopes, which reveal an upwards-increasing trend suggesting a depositional age between 635 and 580 Ma (Halverson et al., 2005; Frimmel et al., 2006). Recent chemostratigraphic and biostratigraphic re-interpretation of the C5 Formation attributed a maximum depositional age of 540 Ma

(Delpomdor et al., 2018). However, a previous study focusing on the temporal carbon isotope trend of Httenberg Formation carbonates has considered this to be a Sturtian to Marinoan interglacial interval (Kaufman et al., 2010).

The principal objective of this paper is to contribute to the debate on the age of the Httenberg Formation. We present the results of a detailed study on two key sections in the Httenberg Formation and the C5 Formation which record the ultimate postglacial marine transgression, before the terminal Neoproterozoic Pan-African orogeny. Here, we describe the depositional characteristics of these two carbonate ramps with a focus on the litho- and microfacies, geometry, and stratigraphic architecture. Based on the new inferred depositional environments of the stratigraphic-equivalent C5 Formation in the DRC, an age for the Httenberg and C5 formations can be estimated.

Geological setting and stratigraphy

Regional geological setting

Widespread shearing and tectonic escape, post-tectonic magmatism, extension, rifting, and intracontinental mobile belt formation were common on the margin of the C-SF cratons in the period ~1000-720 Ma (Stanistreet et al., 1991; Tack et al., 2001; Kamona and Gnzel, 2007). These tectonic events postdated the assembly of Rodinia and predated the breakup of this supercontinent. Rifting of the Rodinia supercontinent occurred successively as a series of eastward younging rift basins formed between 1100 and 950 Ma (Unrug, 1995) (Figure 1A). Separation of the C-SF cratons from Rodinia supercontinent started with the opening of Araua Basin between the C-SF cratons at ca. 1000 Ma (Pedrosa-Soares et al., 2001), and between 999 ± 7 Ma and 912 ± 7 Ma along the western margin of the Congo Craton with the deposition of volcano-sedimentary units and intrusion of peralkaline granitoids of the Matadi

and Tshela/Seke Banza groups (Tack et al., 2001; Baudet et al., 2014) (Figure 1B). Rifting and opening of the Adamastor Ocean, between the Kalahari, C-SF and Rio de la Plata cratons, was initiated between 900-760 Ma and was marked by voluminous volcanic effusions and intrusions (Hoffman et al., 1996; McGhee et al., 2012; Miller, 2013). Rifting occurred as transtensional and transpressive events between the Kalahari and C-SF cratons, extended into the Zambezi rift basin, which opened the Khomas-Mozambique Oceans with the deposition of fluvial clastics, intrusion of granitoids and outpouring of lava flows at 880 Ma (Martin, 1965; Hedberg, 1979; Porada and Berhorst, 2000; Armstrong et al., 2005; Li et al., 2008). Rifting spread westwards into the Zambezi and Damara rift basins, and thereafter northwestwards into the area of the Katanga rift Basin (Porada and Berhorst, 2000). Between 920 Ma and ~600 Ma, a series of passive margins with deposition of fluvio- to marine siliciclastic and carbonate sediments developed along the margins of the C-SF cratons. The Amazonian–West African–Rio de la Plata cratons (East Gondwana) collided with West Gondwana, creating the Pan-African–Brasiliano orogenic belts on the margin of the C-SF cratons between ~650 Ma and ~515 Ma (Alkmim et al., 2006; Pedrosa-Soares and Alkmim, 2011) (Figures 1D, E). West Gondwana was amalgamated with Amazonia, West Africa and C-SF plates at about ~600 Ma (Brito-Neves et al., 1999; Cordani et al., 2003) initiating the earlier Pan-African–Brasiliano tectonic episode of the Araua-West Congo Belt (e.g., Alkmim et al., 2006; Pedrosa-Soares and Alkmim, 2011) (Figure 1E). With the final amalgamation of India to Australia–East Antarctica (e.g., Meert, 2003; Collins and Pisarevsky, 2005), the Pan-African orogeny ended. The polyphase assembly of the Gondwana supercontinent during the East Africa, Brasiliano, Kuungan and Damaran orogenic events thus extended from about 1000 Ma to at least the end of the Cambrian (~540 Ma to 490 Ma; Porada, 1989; Stanistreet et al., 1991; Meert, 2003; Begg et al., 2009; Nascimento et al., 2016).

Neoproterozoic stratigraphy in Namibia and DRC

The West Congo Supergroup rests unconformably on the ~2.1 Ga polymetamorphic Kimezian basement. It consists of up to 10 km thick siliciclastic and carbonate sequences with decreasing regional metamorphism from amphibolite facies in the west, through to unmetamorphosed rocks in the east (Frimmel et al., 2006). The metamorphosed rocks formed in the aulacogen thrust-and-fold belt, whereas the unmetamorphosed units represent deposition in the foreland basin. In Namibia, the Damara Supergroup is up to 14 km thick and consists of greenschist facies siliciclastics and carbonates deposited on a polymetamorphic Palaeoproterozoic basement.

The Neoproterozoic sedimentary successions in the West Congo and Damara belts are remarkably similar (Figure 2). Both record a long-lived initial rift - between ~900-750 Ma for the West Congo Supergroup (Tack et al., 2001; Frimmel et al., 2006), and between 770-750 Ma for the Damara Supergroup (McChee et al., 2012; Miller, 2013), followed by a passive margin including carbonate platform deposits, and final continental collision between the Rio de la Plata and C-SF cratons approximately between 600 to 550 Ma (Merdith et al., 2017). Rift deposition is generally recorded by continental and rift-related volcano-sedimentary rocks. These are overlain by fluvio-deltaic siliciclastic and marine carbonates deposited on a passive margin. Continental collision and foreland basin deposition are recorded in the red bed facies of the 580-535 Ma Mulden Group in Namibia (Clauer and Krner, 1979; Hedberg, 1979; Miller, 2008; Germs et al., 2009) and in the 566-490 Ma Mpioka Subgroup in DRC and Angola (Frimmel et al., 2006; Moni et al., 2012) (Figure 2).

In the West Congo Supergroup, up to two diamictite units, the Lower Diamictite Formation and the Upper Diamictite Formation (Lepersonne, 1951) have been interpreted, respectively,

as Sturtian (U–Pb age on baddeleyite single-grains: 694 ± 4 Ma; Straathof, 2011) and Marinoan in age (Frimmel et al., 2006; Tait et al., 2011). In Namibia, glacial diamictites and associated cap carbonates occur at the base of the Abenab (Sturtian) and Tsumeb (Marinoan) subgroups, the Varianto and Ghaub formations respectively (Figure 2). The maximum age of the Varianto Formation is 746 ± 2 Ma based on U-Pb ages in a tuff of the Naauport Formation west of the Otavi Mountainland (Hoffman et al., 1994; Hoffmann and Prave, 1996.). A coeval depositional age of 760 ± 1 Ma was obtained from zircon grains (U-Pb TIMS) in a tuff of the Devede Formation (Ombombo Subgroup) in the Summas Mountains (Halverson et al., 2005). The Marinoan-equivalent Ghaub Formation yielded U-Pb zircon ages between 639.3 ± 0.3 Ma and 635 ± 1.2 Ma, based on zircon grains of an ash layer in the Ghaub Formation in northwestern and south-central Namibia respectively (Hoffmann et al., 2004; Prave et al., 2016). An age of 635.2 ± 0.6 Ma obtained from an ash bed in the basinal equivalent of the Ghaub Formation in south-central Namibia constrains the top of the Ghaub Formation (Prave et al., 2016).

Our study will focus on the open-marine to lagoonal carbonates of the Httenberg Formation (Tsumeb Subgroup) and the stromatolitic and oolitic C5 Formation of the Lukala Subgroup in Namibia and DRC, respectively. The Httenberg Formation is constrained by the stratigraphically-equivalent Kuiseb Formation in south-central Namibia, which yielded U-Pb detrital zircon ages between 606 ± 24 Ma and 587 ± 9 Ma (Foster et al., 2015). ^{40}Ar – ^{39}Ar metamorphic ages of 590 Ma were obtained in the Kuiseb Formation in the Austerlitz area (Lehmann et al., 2016). The C5 Formation is constrained between ~ 575 Ma and 566 ± 42 Ma, based on $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in carbonate rocks of the underlying C4 Formation (Poidevin, 2007) and ^{40}Ar – ^{39}Ar metamorphic ages obtained in the Mpioka Subgroup (Frimmel et al., 2006) respectively. Recently, the age of the C5 Formation was refined between 575 and 540 Ma based on new chemostratigraphic and biostratigraphic data (Delpomdor et al., 2018).

Methods

This study is based on detailed facies descriptions and petrographic analyses of the Httenberg and C5 formations (Figure 3A). Six cores and two outcrop sections around the towns of Tsumeb and Abenab (Namibia) (Figure 3B) and two cores from Bamba Kilenda village (Figure 3C), located 150 km southwest of Kinshasa (DRC) are described in detail. Outcrop sections are located in the Tsumeb mine and west of Tsumeb along the B1 Road (Figures 3C and 4). Cores were sampled at the Tsumeb Mine (core S#66), Vogelsang 284 Farm (core MJNM#5-10), Guinab Farm (core MJNM#6-9), and Bombay Farm (core MJNM#12) located to the northwest of Abenab (Figures 3C and 5). In addition, two cores (Gx6c and GN7/9a) from the northern side of the Bamba Kilenda anticline were sampled at the Royal Museum for Central Africa, Belgium (Figures 3B and 6). A total of 406 samples encompassing the T7 and T8 Httenberg Formation in Namibia, and the C5 Lukala Formation in DRC were collected at intervals of approximately ~5 m and ~50 cm respectively. Drawings from photographic sketches are used to detail the geometry and internal sedimentary structures of beds.

Forty-eight samples were selected for whole rock carbon isotopic analyses. Carbonate powders were reacted with 100% phosphoric acid (density >1.9, Wachter and Hayes, 1985) at 75 C using a Kiel III online carbonate preparation line connected to a ThermoFinnigan 252 mass spectrometer. All values are reported in per mil relative to V-PDB by assigning a $\delta^{13}\text{C}$ value of +1.95 to NBS19. The reproducibility of $\delta^{13}\text{C}$ V-PDB measurements is 0.04 (1).

Three samples were selected for Sr isotopes analyses. Sr values were measured using a VG54 multicollector mass spectrometer at the Universit libre de Bruxelles (Belgium). The $^{87}\text{Sr}/^{86}\text{Sr}$ values were normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$.

Stratigraphic framework of the studied successions

Httenberg Formation, Namibia

The thickness of the Httenberg Formation is approximately 900 m (Porada, 1983). The lower part of the Httenberg Formation consists of up to 15 m-thick, light to dark grey-blue coloured, finely bedded shaley and laminar dolostone with *Conophyton*-type stromatolite, dolarenite, cherts and local breccia (Figure 4A).

The middle part of the Httenberg Formation contains, from base to top, (1) yellow to brown dolomitic shale with dark chert, (2) dark blue-grey laminar limestone, locally dolomitic, (3) yellow to brown dolomitic shales overlain by dark grey dolostone with breccia and brown shale interbeds, and (4) light blue-grey dolostone with white bluish nodules of anhydrite (Figure 4B). The uppermost part of this unit contains shallowing-upward sequences of dark grey dolostone, passing to grey planar to wavy laminar dolostone, overlain by blue-grey oolitic dolostone, often silicified, with planar and crossed laminations. Beds of blue-grey medium- to coarse-grained dolarenites and interbeds of dark cherts are also present.

The upper part of the Httenberg Formation is up to 250 m-thick and dominated by pale to dark blue-grey bedded laminar dolomitic limestone and dolostone interbedded with red to yellow dolomitic shale, blue-grey impure shaley limestone, and blue-grey oolitic limestone. Breccia and blue-grey calcarenite are also common (Figure 4C). Up to 9 m-thick evaporite beds with nodules of anhydrite and gypsum are locally observed (Kamona and Gnzel, 2007).

The top of the Httenberg Formation consists of up to 200 m-thick pale greenish/brownish to dark grey massive to laminar dolomitic limestone with interbeds of reddish to greenish-yellow dolomitic shale, locally dark-grey silicified oolitic limestone, passing to pale brownish to dark grey fine- to medium-grained dolostone interlayered by reddish brown dolomitic shale (Figures 5A-E). Horizons and nodules of dark chert and white talc are also common. Massive dolerite 0.70 m in thickness locally intrudes this unit (Figure 5D).

C5 Formation, Lukala Subgroup, DRC

The C5 Formation (estimated thickness between 150 m and 300 m; Lepersonne, 1973) is divided, from the oldest to youngest, into C5a, C5b and upper C5b members. The C5a member consists of 20-40 m-thick light grey lime conglomerate and breccia, light- to dark-colored oolitic limestone and dolomitized limestone with cyanobacterial mats, evaporitic (anhydrite after gypsum) and chert horizons. The C5b Member is an approximately 40 m-thick dominant dark greenish to dark grey massive to laminar limestone, often dolomitic. It locally contains small-scale LLH-type stromatolites, and cm- to dm-thick well sorted dark grey to dark oolitic limestone including *Obruchevella parva* in the nucleus, e.g., the “Kisantu Oolite”, which is locally silicified (Figures 6A-B). Low-angle cross-laminations, rare ripples, erosional gutter casts and desiccation cracks are present. Dark grey lime mudstone with whitish nodules of calcite pseudomorphs of anhydrite and gypsum, yellow to reddish brown hardgrounds and desiccation crack surfaces are associated. Filamentous cyanobacterium *Obruchevella parva* was identified in the “Kisantu Oolite” in the stratigraphic-equivalent SCIII Formation in the Republic of Congo (RC) (see Alvarez et al., 1995).

The overlying upper C5b Member is subdivided into C5b1 and C5b2 submembers (Lepersonne, 1973). The C5b1 submember, locally 95-135 m-thick, consists of approximately 40 m of light to dark greyish laminar to nodular dolomitic limestone, locally dolostone, with frequent ripples, yellow to reddish brown hardgrounds, desiccation cracks and calcretes. It is interbedded with reddish to dark grey dolomitic shale, and dark grey lime mudstone (Figure 6B). Nodules of calcite pseudomorphs of anhydrite and gypsum are common in this submember.

The C5b2 submember comprises 30-50 m-thick light greyish to whitish dolomitic limestone including cm-thick beds of silicified oolites, locally with talc. In the study area, it was eroded by the overlying Mpioka Subgroup and was not investigated in detail.

Lithofacies and microfacies associations

Twelve microfacies (MF1 to MF12) are recognized from outcrop and core sections and thin-section examination in the T7-T8 Httenberg and C5 formations. Lithology, sedimentary structures and textures, and fossil contents allow a grouping into nine lithofacies associations, LFA-H1 to LFA-H4 and LFA-C1 to LFA-C5 for the Httenberg and C5 formations respectively. Lithofacies associations and microfacies are summarized in Table 1, and shown in Figures 4-6.

Httenberg Formation (Namibia)

Lithofacies association H1 (LFA-H1)

Lithofacies association H1 only includes argillaceous (dolo)mudstone (MF1). In outcrop and core sections, LFA-H1 is dark blue-grey, microcrystalline and commonly dolomitic, with

argillaceous seams and stylolites. With increasing degree of dolomitization, the lithofacies may grade into medium to coarse grained dolomitic calcarenite and dolarenite. The massive micritic matrix (4-15 μm in size) is recrystallized to neomorphic microspar (15-20 μm in size) (Plate 1A). The dolomitic microfacies is composed of medium to coarse crystalline euhedral to anhedral dolomitic rhombs (50-100 μm in size) with rare intercrystalline clay seams. Silt- to sand-sized grains of quartz (>10% wt.), feldspars (>5% wt.) and micas (>20% wt.) are observed. No sedimentary structures were observed in this microfacies. LFA-H1 is interpreted as low-energy lime muds deposited in a subtidal open-marine environment with detrital contributions. The absence of evaporites excludes protected conditions like lagoons. An open lagoon connected to the open sea via tidal inlets and with normal salinity is unlikely due to the low variety of sediment types and the absence of distinct tidal features.

Lithofacies association H2 (LFA-H2)

Lithofacies association 2 contains laminated (dolo)mudstone (MF2) and calcimicrobial (dolo)bindstone (MF3). The former consists of millimeter-scale laterally continuous light to dark brown, planar to wispy parallel, thin- to non-laminated mudstone. The matrix of the thin- to non-laminated mudstone is composed of fine micrite (5-10 μm in size) (Plate 1B), replaced by a neomorphic microspar (15-30 μm in size). Dolomitization is fairly common. The contact between the laminations is gradual.

Calcimicrobial bindstone (MF3) consists of submillimetric-scale, irregular and continuous, thin planar to wavy parallel microbial tubular filaments in a dark brown micrite matrix.

Locally, the microfacies shows a closely-packed texture of randomly oriented tubular filaments and clumps of cyanobacteria micro-organisms. The filaments are dominantly non-

branched, non-septate, discrete tubules with a diameter between 50 μm and 500 μm (Plate 1C). Tubules with a diameter between 5 μm and 20 μm display dark-colored micritic walls (4-8 μm of thickness) often filled with equant sparry crystals (10-20 μm in size). Clumps are irregular and elongate, and form ellipsoid patches rimmed by a diffuse dark-colored micrite. Clumps rarely contain discrete remnants of tubular filaments.

With increasing degree of dolomitization, the matrix shows fine crystalline euhedral to anhedral dolomitic rhombs (4-20 μm in size) in equigranular mosaic fabrics. Swallowtail twins, platy rectangular laths and nodules filled by calcite, replacing gypsum and anhydrite, are fairly common in these both microfacies. Silt- to sand-sized grains of quartz (>5% wt.), feldspars (>5% wt.) and micas (>2% wt.) were observed.

Microfacies 2 and 3 are interpreted to have accumulated in low to moderate energy environments in the photic zone, which facilitated the seasonal carbonate production by cyanobacteria (Gerdes et al., 1994). Locally, the cyanobacteria formed small-scale calcimicrobial biostromes that are common on a carbonate mid-ramp setting (Turner et al., 2000).

Lithofacies association H3 (LFA-H3)

Two microfacies, peloidal (dolo)wackestone-(dolo)packstone (MF4) and stromatolitic (dolo)boundstone (MF5) form lithofacies association 3. In outcrop and core sections, MF4 only occurs in the T8 unit of the Httenberg Formation. Stromatolites of LLH-type, and locally spheroidal structures, *Conophyton* stromatolites are identified in this lithofacies. In thin section, MF4 consists of silt- to sand-sized irregular micritic peloids, locally cemented by radiaxial spar (Plate 1D), in a fine microcrystalline micritic matrix. The microfacies is characterized by abundant irregular pseudo-fenestrae, filled by an equant calcite cements.

MF5 displays thin sub-millimetric-scale, irregular, horizons of stromatolitic mats and clumps of cyanobacterial micro-organisms in a micritic to microsparitic matrix. Stromatolitic mats are planar to wavy and consist of dark micritic laminae up to 50 μm in thickness. The grumeaux consist of irregular and dark micritic rounded patches of stromatolites up 300 μm in size (Plate 1E), often filled by equant calcite cements (up to 50 μm in size). This microfacies locally shows vugs, veins, and desiccation cracks filled by bladed calcite cements associated with botryoidal and radiaxial cements. Both microfacies contain silt-to-sand-sized grains of quartz (10 to 50 μm of size, >2% wt.), fine-grained pyrites (less than 10 μm of diameter, >5% wt.) and remnant of tubular filaments are observed. The lithofacies association 3 is variably dolomitized, forming dolomudstone and dolorenite, with original textures obscured in outcrop and core sections, but commonly visible in thin sections. The lithofacies association 3 corresponds to stromatolitic pinnacles in low- to moderate-energy conditions. Similar lithofacies have been described in the Neoproterozoic sedimentary successions from Canada (Batten et al., 2004; Thomson et al., 2014). Peloids formed the base of the stromatolitic buildups through the encrustations of micrite (probable aragonite mud) around cyanobacteria or as decomposition products of various algae (Flgel, 2010). The occurrence of pseudo-fenestrae associated with subspherical fenestrae suggests a shallow near-coastal peritidal environment (Flgel, 2010). Botryoidal cements are usually marine, and are common in cavities of reefs and in steep seaward dipping slopes (James and Ginsburg 1979).

Lithofacies association H4 (LFA-H4)

Lithofacies association 4 only includes oolitic (dolo)packstone-(dolo)grainstone (MF6). The microfacies displays light blue-grey, medium- to well-sorted calcarenites and dolarenites with

indistinct cross laminations. In thin sections, MF6 consists of 1-2 mm-thick layers of medium- to well-sorted (dolomitized) oolitic packstone-grainstone (Plates 1F-H). The oolites occur either in a tightly packed dark brown lime matrix (packstone) or in coarse-crystalline lighter-coloured drusy sparry cements (grainstone). Sedimentary structures include wedge-shaped planar or trough cross laminations. The oolites are predominantly spherical to ovoid with a dark microcrystalline micritic fabric in the cortex. Alternatively, they consist of concentric tangential grains, or are grouped in coarse-grained grapestones (up to 1 mm). These latter are moderately elongated, flattened and stretched. Silicified yellow-colored oolites are locally observed. Associated with oolites, coalescent flattened peloids, debris of probable cyanobacterial mats (microbial chips) and vertical desiccation cracks are also observed.

In the Httenberg Formation, oolites represent a beach-barrier island environment. Trough cross-laminations indicate deposition in high-energy environments such as sandy carbonate shoals. Concentric oolites are common of high-energy in shorefaces and shoals (Burchette and Wright, 1992). Oolites and microbial chips result from reworking of fore- to back-barrier sediments (e.g., muds, cyanobacterial mats) by fair-weather waves, storms and/or tides.

C5 Formation (DRC)

Lithofacies association C1 (LFA-C1)

This lithofacies association includes argillaceous mudstone (MF7) and laminated mudstone (MF8). Argillaceous mudstones (MF7) consist of dark-grey, locally pale pinkish, massive limestone with thin argillaceous seams and stylolites. In thin section, the microfacies is characterized by a fine micritic matrix (Plates 1H-I), locally neomorphosed to microspar (15-20 μ m in size). Where dolomitized, the matrix displays fine-grained hypidio- to xenotopic

dolomitic rhombs (5-10 μm in size). Wispy microbial mats, microbial chips, and isolated peloids, are also present observed. Mudstones (MF8) consist of laterally continuous dark grey, planar to wavy parallel, thin laminated limestone. Oblique and cross-laminations are also present. The laminations display dark brown micrite (up to 10 μm in size), locally with peloidal fabric (Plates 1I-J). The matrix is partially neomorphosed to microspar (15-30 μm in size) or, replaced by idio- to hypidiotopic dolomicrosparitic crystals (up to 50 μm in size). This lithofacies association contains silt-sized quartz, irregular and flattened peloids (up to 20 μm of diameter), randomly oriented swallowtail twins and platy rectangular laths of replaced gypsum, stratabound nodules and enterolithic anhydrite replaced by calcite cements. The argillaceous mudstone (MF7) is interpreted as low-energy lime muds deposited in subtidal environments. The occurrence of anhydrite pseudomorphs points to protected lagoonal conditions, probably barred by sandy shoals and reefs. The association with the laminated mudstone (MF8) is also inferred to low energy inter- to supratidal lagoonal settings colonized by cyanobacterial mats periodically reworked by intertidal currents. Arid conditions are recorded by the precipitation of stratabound gypsum and anhydrite.

Lithofacies association C2 (LFA-C2)

Lithofacies association C2 is abundant in the C5b Member of the C5 Formation and consists of dark coarse grained, well-sorted, crossed laminated oolitic grainstone (MF9). Grainstone contains tightly-packed spheroidal to ellipsoidal siliceous ooids and pisoids up to 50 μm in diameter (Plates 1K-L) within wedge-shaped planar or low angle crossed laminations. Oolites are dominantly composed of multiple-coated and tangentially arranged laminations with either calcite or quartz in the cortex. Intergranular pores are occluded either by lighter-

coloured drusy sparry calcite cements, or by micro- to megacrystalline quartz cements. Desiccation cracks and rare lamellar and meniscus sparry cements are present. This lithofacies association represents oolitic sands deposited on beach separating the supratidal mudflat and sabhka sediments from the evaporitic lagoon. Our interpretation is similar to the depositional model of the stratigraphically-equivalent oolitic shoals in RC (Alvarez, 1995). Coated grains are well sorted by tidal currents during the abrasion, reworking and transport of lagoonal sediments. This grainstone lithofacies is also periodically subjected to subaerial exposures with desiccation cracks.

Lithofacies association C3 (LFA-C3)

Lithofacies association C3 consists of microbially laminated mudstone (MF10). MF 10 is dark gray, submillimetric, irregular and continuous, thin microbially laminated, planar and wavy parallel limestone. In thin section, the microfacies displays dark brown microcrystalline micritic laminations in light dark gray-brown micritic or neomorphosed microsparitic matrix (Plate 1M). Fenestrae characterized by small spar-filled cavities and larger irregular voids are present. Platy rectangular laths of replaced gypsum, stratabound nodules and enterolithic structures filled by calcite pseudomorphs of anhydrite are also visible. Subvertical desiccation cracks, locally forming *in-situ* breccias, filled by sparry cements cut-across the microbial laminations.

The lithofacies association C3 represents shallow inter- to supratidal settings in evaporitic environments. Fenestrae and desiccation cracks indicate episodic subaerial exposures in intertidal settings (Grotzinger, 1986; Pratt et al., 1992).

Lithofacies association C4 (LFA-C4)

Lithofacies association C4 only includes the evaporitic dolomudstone microfacies (MF11). This microfacies is a mud-supported dark-grey dolomitic limestone dominantly composed of brownish to bluish white nodular anhydrite and interbeds of anhydrite. Anhydrite is commonly replaced by a light drusy sparry cement, but microcrystals of anhydrite are occluded in these cements. Various types of gypsum crystals such as lenticular, lozenge-shaped, swallowtail twinned, and platy rectangular forms are fairly common (Plates 1M-O). Small-sized nodules and chicken-wire structure show loosely packed aggregates of tiny platy rectangular laths and stellate crystals (Plate 1N). Locally, 1-2 cm-thick layers of massive anhydrites are mixed with dolomudstone. The matrix is composed of equigranular xeno- to hypidiotopic dolomitic crystals (5-15 μm in size) in non-planar fabrics. Desiccation cracks (20-200 μm of width) filled by drusy sparry cements, and hardgrounds are also present. This lithofacies association represents supratidal evaporitic environments. Such sediments are encountered in the recent shallow peritidal shelf and coastal sabkha of Abu Dhabi (Shearman, 1978). Lenticular, swallowtail twins and lath patterns are indicative of saline intertidal diagenesis (Cadwell, 1976) while nodules and chicken-wire structures are common in sabkha and are the result of the replacement of gypsum by anhydrite crystals in soft sediments by capillarity- dehydration processes (Kinsman, 1969). Periodical emersions were recorded and form polygonal desiccation cracks or non-deposition throughout inter- and supratidal beachrocks (see lithofacies association C5 for explanation).

Lithofacies association C5 (LFA-C5)

In the C5 Formation, the lithofacies association C5 is rare, and only includes the calcrete microfacies (MF12). MF12 consists of dark, rarely yellowish-orange, millimetric-thick crusts

of slightly undulated laminations, and *in-situ* brecciation of dolomitized limestone. Abundant desiccation cracks are also common. In thin section, the microfacies shows light grey brown fine- to medium-grained dolomitic mudstone, locally dolomitized wackestone with coated grains, composed of oolites and peloids, with dense dolomicrite concentrated into crusts (Plate 10). Veins of sparite form an *in-situ* brecciation. Sand-sized dense dolomicritic ‘glaebules’ and dolomicrite coatings are also associated with this microfacies. The matrix exhibits hypidiotopic dolomitic crystals (20 µm in size). Rare laminations are planar parallel to crossed. Calcite pseudomorphs after anhydrite (rosettes, laths, or fibrous replaced gypsum) are fairly common. Meniscus sparry cements are observed on the rims of coated grains. This lithofacies association is interpreted as near-surface soil horizons or paleosoils, formed by the accumulation of CaCO₃ and the oxidation of beachrock surfaces by iron hydroxides in semi-arid climate conditions under sparse rainfall (Adatte et al., 2005). Occurrences of evaporites and brecciation indicate that the sediment was affected by desiccation, emersion, and periods of dissolution. Such processes are common in supratidal and continental environments. The presence of meniscus sparry cements indicates vadose conditions.

Depositional framework interpretation

The lithofacies associations (LFA-H1 to LFA-H4 and LFAC1 to LFA-C5) of the Httenberg and C5 successions integrate the variations in sea level, energy and salinity in the carbonate ramp. In both the Httenberg and C5 formations, lithofacies associations are arranged in up to 4 m-thick depositional cycles showing an upsection trend from marine to restricted deposition, which is broadly followed by an upsection increase in energy level (Figure 7). The lithofacies associations comprise six main belts described here from a distal to proximal gradient recording the different levels of the hydrodynamic energy: (i) microbial ‘mounds’,

(ii) stromatolitic reefs, (iii) ooid-barrier shoals, (iv) evaporitic brackish lagoons, (v) beaches and (vi) coastal sabkhas (Figure 8). The type-1 cycle is characterized by a LFA-H1 to LFA-H4 succession of lithofacies associations, while the type-2 cycle contains a LFA-C1 to LFA-C5 succession.

The gradual transitions between lithofacies associations and the general increase of depositional energy upsection, suggest that both formations represent deposition in a mid- to inner carbonate homoclinal ramp. A beach-barrier/island-lagoon model could be applied to both successions, due to the moderate to high wave energy, a relatively high tidal range estimated at ~1.8 m for the C5 Formation (see Delpomdor et al., 2018), a high carbonate sand production, and the high contents of evaporites. An oolitic sand shoal-barrier separated an open-marine sea with stromatolitic pinnacle reefs from a back-reef carbonate-evaporitic lagoon bordered by a coastal sabkha plain (Figure 8).

The assemblage of lithofacies associations LFA-H1 and LFA-H2 form the lower domain of the middle carbonate ramp, and records low- to moderate-energy open-marine conditions as revealed by the lime mud content and the microbial patch mounds deposited on gently dipping slopes. Cyanobacterial micro-organisms were associated with outer ramp LLH-type stromatolitic buildups forming small-scale mounds and pinnacles (LFA-H3). These stromatolites grew in moderate- to high-energy shallow waters around an active wave base. The ooid shoal lithofacies (LFA-H4) form a barrier island, and represent high-energy sediments related to tidal and wave agitation. The ooids indicate 'warmer' and possibly aragonite-saturated waters, preferentially dolomitized by brines percolating from the lagoonal and evaporitic environments during dry to arid climatic episodes (van Smeerdijk Hood and Wallace, 2018). The middle-inner carbonate ramp profile and its geometry are observed on homoclinal shelf margins of other Neoproterozoic successions (Batten et al., 2004; Cozzi et al., 2004; Thomson et al., 2014).

The Httenberg units of our study were deposited in the post-rift Khomas sea along the southern margin of the Congo Craton. They represent the development of a shallow-water carbonate epicontinental platform (Stanistreet et al., 1991; Kamona and Gnzel, 2007). However, the presence of dessication cracks and breccia indicates that during deposition, the sediment was periodically subjected to subaerial exposure. Locally, lagoonal sediments were affected by hypersaline conditions, with microbial mats, evaporites (horizons of 9-14 m of thickness) and cherts resulting (Kamona and Gnzel, 2007). These conditions are confirmed by typical marine REE +Y signatures, and highly variable enrichment in ^{13}C (reaching several plateaux of +8‰ to +12‰) due to elevated evaporation rates in a restricted basin (Frimmel, 2009, 2010).

In the C5 Lukala Formation, the lagoonal belt shows a typical blackened dolomitized limestone lithofacies association (LFA-C1 to -C4) with a relatively high organic content suggesting possible periods of dysoxia/anoxia in the lagoon. The reducing waters were followed by well-oxygenated waters, which facilitated the development of benthic cyanobacterial mats in the nearshore zones of the lagoon. The coastal shoreline zone (LFA-C3) was marked by waves, tides and elevated salinity. Off-shore sand bars on a beach-strandplain belt were probably dominated by high wave energy and low tidal range as shown by ripples, cross laminations, and reworking and transport of cyanobacteria fragments living in the foreshore and backshore environments. Beachrock formed due to rapid cementation of sand-sized grains by aragonite and Mg-calcite crystals growing in the interparticular spaces. Beachrock is a common feature of low-latitude warm-water beaches in tropical and temperate environments and formed during cessation of sedimentation or periods of low sedimentation rate (Scoffin and Stoddard, 1983). The sabkha evaporites, dolomitization, and caliche crusts (LFA-C4 to -C5) can be used as paleoclimatic markers of semi-arid normally low-latitude deposition. The evaporites, dolomitization, and caliche crusts (LFA-C4 to -C5), point to an

520 arid climate of deposition instead. Extensive dolomitization, locally capped by caliche
521 surfaces at the top of evaporitic cycles, occurred between the coastal and the reefal zones. The
522 upper parts of sections of the carbonate-evaporitic lagoon were seasonally subjected to
523 precipitation with formation of caliche surfaces, containing vadose pisoids, pseudo-peloids,
524 and breccias.

525 The distribution of open-marine type-1 cycle of the Httenberg Formation follows a thin
526 peritidal cycle with an average cycle thickness of approximately 4 m (in this paper), while the
527 type-2 cycle of the C5 Formation shows an average thickness of ~1.8 m (Delpomdor et al.,
528 2018). Such thicknesses are frequent in peritidal environments (Catuneanu et al., 2011;
529 Franseen and Byrnes, 2012; Delpomdor et al., 2015). The open-marine type-1 cycle of the
530 Httenberg Formation preludes the lagoonal and near-shore type-2 cycle of the C5 Formation,
531 and locally present in the T8 unit of the Httenberg Formation. Although the Httenberg
532 Formation and the C5 Formation were deposited in two distinct basins on the southwestern
533 and western margin of the C-SF cratons, there are similar patterns of lithofacies associations
534 that reflect similar deposition on passive margins during the global post-Marinoan sea-level
535 transgression.

537 **Carbon and strontium isotopes**

538
539 The carbon and strontium isotopic data for the C5 Formation (DRC) are shown in Table 2.
540 Analysis of major and trace elements demonstrate that the samples retained their original
541 marine isotope signature (Delpomdor and Prat, 2013). Carbon isotope data for the
542 Httenberg Formation from a previous study on Tsumeb core S86A (Kaufman et al., 2010)
543 are compared with our results for stratigraphic correlation.

The C5a/C5b boundary is marked by a positive shift in $\delta^{13}\text{C}$ values from +1.5‰ to +7.5‰, followed by an upwards-decrease in $\delta^{13}\text{C}$ values from +7.5‰ to +1.3‰. A second positive shift occurs in the middle C5b, with $\delta^{13}\text{C}$ values varying from +1.3‰ to +10.8‰, followed by a significant upwards-decreasing of $\delta^{13}\text{C}$ until +3.1‰. The C5b/upper C5b boundary is marked by positive isotopic shift in $\delta^{13}\text{C}$ from +3.1‰ to +5.6‰ directly overlain by a rapid return to negative isotopic shift in $\delta^{13}\text{C}$ around +1.7‰. The upper C5b Formation displays higher $\delta^{13}\text{C}$ values than the C5a and C5b formations with a mean value ranging around +6.2‰. At the top of the succession $\delta^{13}\text{C}$ values fall sharply to near +3.5‰, just before being truncated by the molasse of the Mpioka Subgroup in this part of the DRC. One sample of the C5b Formation has a strontium isotope ratio of 0.7081, while $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the upper C5b Formation range between 0.7084 and 0.7090 ($n = 2$). Overall $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are altered by diagenetic fluids directly after deposition, as evidenced by the low Sr concentrations above the cut-off of 300 ppm (Halverson et al., 2007), and cannot therefore be used as a proxy for correlation (Delpomdor et al., 2018). However, samples from the same unit published by Frimmel et al. (2006), close of the cut-off of 300 ppm plot in the same $^{87}\text{Sr}/^{86}\text{Sr}$ ranges (0.7074-0.7075) and are considered as unaltered samples, representative of the seawater composition.

The Httenberg Formation carbonates revealed a significantly higher positive carbon isotope excursion than at any other time in the Neoproterozoic Era (Kaufman et al., 2010). The lower part of the Httenberg Formation shows a range of values between +8‰ and +10‰. The middle and upper parts are marked by isotopic shifts of $\delta^{13}\text{C}$ values from +12‰ to +4‰ and from +10‰ to +2‰ respectively. The lowest $\delta^{13}\text{C}$ values between +0‰ and +2‰ are encountered in the middle part of this unit. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the Httenberg Formation range between 0.7076 and 0.7086 ($n = 2$) with Sr concentrations between 60 and 1220 ppm ($n = 2$) (Frimmel et al., 1996).

The $\delta^{13}\text{C}$ data of both Httenberg and C5 formations are significant with the carbon isotopic values published by Frimmel et al. (1996) and Halverson et al. (2005), in the same range.

Stratigraphic correlations

Current regional correlations of Cryogenian and Ediacaran glaciogenic successions in central east Brazil, northwestern Namibia and west central DRC rely on chemostratigraphic and radiometric age constraints (Figure 10; Pedrosa-Soares et al., 2008; Kaufman et al., 2010; Tait et al., 2011; Caxito et al., 2012; Cailteux et al., 2015). Numerous correlations between the carbonate successions of the Bambu Group (central east Brazil; ~750-540 Ma in age) and the West Congo Supergroup (west central DRC) have been suggested (Alkmim and Martins-Neto, 2012; Caxito et al., 2012; Cailteux et al., 2015) but are hampered by lack of precise radiometric dating of both successions (Santos et al., 2000; Caxito et al., 2012; Paula-Santos et al., 2017). Both sedimentary successions are considered as coeval with the Damara Supergroup (Cailteux et al., 2015). Based on lithostratigraphic and radiometric data, the Tsumeb Subgroup in Namibia and the Gombela Subgroup of the Central Africa Copperbelt (CAC) in DRC and Zambia were considered as coeval (Miller, 2013). The Tsumeb Subgroup succession is constrained by an U-Pb zircon age of 635 ± 1.2 Ma on an ash layer interbed in the Ghaub Formation (Hoffmann et al., 2004), and U-Pb detrital zircon ages on metasediments between 606 ± 24 Ma and 587 ± 9 Ma in the Kuiseb Formation (Foster et al., 2015; Lehmann et al., 2016), considered as stratigraphic-equivalent with the Httenberg Formation (Miller, 2008). The youngest age is confirmed by ^{40}Ar - ^{39}Ar metamorphic ages of 590 Ma obtained in the Kuiseb Formation (Lehmann et al., 2016). A minimum deposition age for the top of the Swakop Group in Northern Zone of Namibia, intruding the Karibib and Kuiseb formations, is constrained by granite and metamorphic age determinations of ~585-

570 Ma (Bergemann et al., 2014; Milani et al., 2014; Forster et al., 2015). In the CAC, the oldest metamorphic ages are 592 ± 22 Ma (U–Pb monazite) and 585.8 ± 0.8 Ma Ar–Ar plateau age for biotite (Rainaud et al., 2005). Recently, Cailteux et al. (2015) correlated the lower part of the Lukala Subgroup (C1–C3 formations) of the West Congo Supergroup with the Gombela Subgroup, which displays a strongly comparable sedimentary succession, in particular the similarity between the oolitic limestone of the Lubudi and C3 formations. However, this correlation is still debated due to the lack of chemostratigraphic and radiometric constraints.

In the absence of temporally significant fossils and radiometric constraints, carbon isotope stratigraphy was specifically applied to the correlation of carbonates above and below the Namibian “Marinoan-age” glacial deposits, e.g., Ghaub Formation (Kaufman et al., 1991). Composite carbon-isotope profiles spanning the inferred Marinoan and Pan-African deformation events in northwestern Namibia, west central DRC, and central east Brazil show two carbon-isotope trends. The first trend (arrow 1) is marked by a positive to negative shift in $\delta^{13}\text{C}$ values in the dolostones of the Maieberg in Namibia and C1 formations in DRC, and the Pedro Leopoldo Member, lowermost unit of the Sete Lagoas Formation in Brazil (Santos et al., 2000; Halverson et al. 2005; Straathof, 2011; Caxito et al., 2012; Delpomdor and Prat, 2013; Cailteux et al., 2015; Paula-Santos et al., 2017). This isotopic “event” is followed by a positive excursion in $\delta^{13}\text{C}$ values, which is marked by a rapid marine transgression as a result of extensional tectonic processes directly after the Marinoan-age glaciation event (Halverson et al., 2005; Delpomdor et al., 2016; Caxito et al., 2012; Paula-Santos et al., 2017). Such glaciations are recorded in the Ghaub Formation in Namibia, Jequita Formation in Brazil, and periglacial deposition in the Niari Formation in Gabon, stratigraphic-equivalent of the distal gravity deposited sediments in the Upper Diamictite Formation in DRC (Prian et al., 2009; Busfield and Le Heron, 2013; Uhlein et al. 2013, 2016; Delpomdor et al., 2016, 2017;

Nascimento et al., 2016; Rodler et al., 2017). The second trend (arrow 2) is marked by a negative to positive excursion in $\delta^{13}\text{C}$ values in the Elandshoek and Httenberg formations in Namibia, comparable to carbon-isotope values of the C4 and C5 formations in DRC and the upper part of the Sete Lagoas (Santa Lagoa Member) to Lagoa do Jacar formations in Brazil (Kaufman et al., 1991, 2010; Frimmel et al., 1996; Santos et al., 2000; Halverson et al., 2005; Frimmel et al., 2006; Straathof, 2011; Caxito et al., 2012; Delpomdor and Prat, 2013; Cailteux et al., 2015; Paula-Santos et al., 2017; Delpomdor et al., 2018). The contact between the C3/C4 formations in DRC, as well as in the stratigraphic-equivalent SCI-SCII in the Republic of Congo (A.P.- Ackouala, 2018, pers. comm.), shows abrupt lithological changes and negative carbon-isotope shift related to a possible Gaskiers-age event (Cailteux et al., 2015; Delpomdor et al., 2018). The second carbon-isotope trend corresponds to a second marine transgression, which flooded the Damara, West Congo, and So Francisco basins in Namibia, DRC and Brazil respectively (Martins-Neto et al., 2001; Cailteux et al., 2015; Prat et al., 2011; Reis and Alkmim, 2015; Delpomdor et al., 2018). This transgression eventually gave rise to a restricted basin without an efficient mixing with external seawater. Because of the stagnant dysoxic to anoxic water columns the organic matter was preserved in the evaporitic shallower environments (e.g., the Httenberg, C5, and Lagoa do Jacar formations). We suggest that the second marine transgression favoured regional-scale exchange with other basins accompanied by flora migration and development of benthic helicoidal cyanobacteria *Obruchevella parva* in the C5 Formation (Alvarez et al., 1995; Delpomdor et al., 2018) and *Cloudina* and *Corumbella* in the Sete Lagoas Formation (Warren et al., 2015), and unknown cyanobacterial organisms in the Httenberg Formation (this study). *Obruchevella parva* is commonly considered as an index fossil for the terminal Ediacaran (Yakschin and Luchinina, 1981) or Cambro-Ordovician (Reitlinger, 1959). *Cloudina* and *Corumbella* are considered as index fossils for the terminal Ediacaran (Warren

et al., 2015), which is recently supported by maximum deposition ages (U-Pb zircon dating) of ~ 557 Ma for most of the Sete Lagoas Formation (Paula-Santos et al., 2015). Although the index fossil *Cloudina* is absent in the C5 and Httenberg formations, probably due to a later closure of the marine interconnection between the C-SF and Kalahari cratons, the abundance of cyanobacterial organisms might be considered as a coeval biological marker for stratigraphic correlations between the uppermost parts of the Sete Lagoas to Lagoa do Jacar formations, and the C5 Formation (Cailteux et al., 2015; Delpomdor et al., 2018), thereby allowing the debatable Late Ediacaran age (e.g., 580-540 Ma) of the Httenberg Formation to be applied to the Sete Lagoas and Lagoa do Jacar formations.

In this paper, $\delta^{13}\text{C}$ values of the C5 and Lagoa do Jacar carbonates are compared with the carbon isotope values from the Tsumeb core S86A, (Kaufman et al., 1991) (Figures 9 and 10), and the published data from Halverson et al. (2005). The C5 Formation shows seven upwards-increasing trends of $\delta^{13}\text{C}$ that may be correlated to the lower and middle parts of the Httenberg Formation. A distinct negative shift of $\delta^{13}\text{C}$ values at the top of the Httenberg Formation is currently not recognized at the top of the C5 Formation due to lack of data resulting from erosion by the Mpioka Subgroup (Figure 9). This negative $\delta^{13}\text{C}$ shift can be correlated to the Gaskiers (580 Ma) or Moelv (560 Ma) isotope shifts linked to the Numees Formation diamictite in southern Namibia (Kaufman et al., 1991), or to the Basal Cambrian Isotope Excursion (BACE; see Alvaro et al., 2008). In Brazil, the Lagoa do Jacar Formation shows comparable $\delta^{13}\text{C}$ values, to the Httenberg and C5 formations (Figure 10).

All formations are overlain by molasse-type sediments related to the collision of the Rio de la Plata Craton with the C-SF cratons and closure of the Adamastor Ocean along the 575–540 Kaoko-Gariep-Araua-West Congo belts (e.g. Frimmel and Frank, 1998; Frimmel et al., 2006; Konopsek et al., 2014; Merdith et al., 2017), and the closure of the Khomas Ocean

between C-SF and Kalahari cratons around 550 Ma with the development of the Damara-Lufilian-Zambezi Orogen (e.g. Naydenov et al., 2014; Merdith et al., 2017). Independent of the absolute ages, the similarity in chemostratigraphy, their similar stratigraphic position, sedimentology and sea level evolution, suggest that Httenberg and C5 formations might be coeval deposits on the margins of the C-SF cratons. In this paper, we consider the age of the C5 Formation, and its stratigraphic-equivalent Httenberg Formation, as terminal Ediacaran (e.g., 580-540 Ma). However, the current knowledge of the depositional ages of these sedimentary successions through the Damara and West Congo basins is very limited which limits more precise prediction of stratigraphic correlations.

Conclusions

New descriptions and sedimentological study of key cores and outcrops in the Httenberg Formation in northwestern Namibia show that this unit formed in an open-marine mid-inner carbonate ramp setting with organic mounds, pinnacles and oolitic shoal-barrier islands. The mid ramp includes shallow-water microbial and stromatolitic patch mounds and pinnacles, respectively, formed on gentle slopes at the outer edges of the shelf on the southern margin of the Congo-So Francisco cratons. Inner ramp deposits are composed of oolitic shoals and lagoonal muds, locally subjected to hypersaline conditions, behind a wide gently sloping shelf. Sedimentology establishes similar lithofacies associations in the C5 Formation of the Democratic Republic of Congo, with four main belts recording different levels of hydrodynamic energy following a distal to proximal gradient from: (i) an ooid-barrier shoal, (ii) an evaporitic brackish lagoon, (iii) a beach, and finally (iv) a coastal sabkha. The carbonate ramp represented by the Httenberg Formation is considered as regionally correlative of the C5 carbonates. In term of geochronology, the Httenberg Formation is

constrained by U-Pb zircon ages of ~635 Ma and ~590 Ma in the Ghaub and Kuiseb formations in Central Namibia. Due to the lack of radiometric data in the Tsumeb Subgroup in northwestern Namibia, carbon-isotope stratigraphy was tentatively applied to the correlation as reference curves for worldwide carbonate successions (Halverson et al., 2005). Two $\delta^{13}\text{C}$ trends were identified as the result of a marine transgression, interconnected with global extensional tectonic processes, directly after the Marinoan-age glaciation event. The first carbon-isotopic trend is marked by a strong negative anomaly in $\delta^{13}\text{C}$ values, followed by a negative to positive excursion, probably coeval with the Maieberg Formation in Namibia, the C1 to C3 formations (Kwilu unit) in DRC, and the lower part of the Sete Lagoas Formation (Pedro Leopoldo Member) in Brazil. A second negative to strongly positive excursion in $\delta^{13}\text{C}$ values is recognized in the Elandshoek-Httenberg succession in Namibia, comparable to the carbon-isotope values in the C4-C5 formations in DRC, and in the upper part of the Sete Lagoas (Santa Lagoa Member) and Lagoa do Jacar formations in Brazil. This carbon-isotope excursion records a second marine transgression, which gave rise to regional-scale exchange with other basins accompanied by flora migration and development of Late Ediacaran benthic cyanobacterial micro-organisms, abundantly present in the Httenberg and C5 formations. The convergence of chemostratigraphic data and biostratigraphy suggest a Late Ediacaran age - e.g., 580-540 Ma - of deposition for the both Httenberg and C5 formations, comparable to the Lagoa do Jacar Formation in Brazil.

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References

- Adatte, T., Keller, G., Stben, D., Harting, M., Kramar, U., Stinnesbeck, W., Abramovich, S. and Bemjamini, C., 2005. Late Maastrichtian and K/T palaeoenvironment of the eastern Tethys (Israel): mineralogy, trace and platinum group elements, biostratigraphy and faunal turnovers. *Bulletin de la Socit Gologique de France*, 176 (1), 37-55.
- Alkmim, F.F. and Martins-Neto, M.A., 2012. Proterozoic first-order sedimentary sequences of the So Francisco craton, eastern Brazil. *Marine and Petroleum Geology*, 33, 127-139.
- Alkmim, F.F., Marshak, S., Pedrosa-Soares, A.C., Peres, G.G., Cruz, S. and Whittington, A., 2006. Kinematic evolution of the Araua-West Congo orogen in Brazil and Africa: Nutcracker tectonics during the Neoproterozoic assembly of Gondwana. *Precambrian Research*, 149, 43-64.
- Alvarez, Ph., 1995. Les facteurs de contrle de la sdimentation du Supergroupe Ouest-Congolien (Sud-Congo). *Rampe Carbonate et activit biologique au Protrozoique Suprieur*. Edition BRGM, 239, 286pp
- Alvarez, Ph., Chauvel, J.-J. and van Vliet-Lano, B., 1995. *Obruchevella*, cyanobactrie fossile du Protrozoique suprieur du Congo. Implications sur l'ge du Groupe Schisto-Calcaire et de la glaciation fini-Protrozoique. *Comptes Rendus de l'Acadmie des Sciences, Serie 2, Sciences de la Terre et des Plantes*, 320 (7), 639-646.

- 741 lvaro, J.J., Bauluz, B., Pierre, C., Subas, I. and Vizcano, D., 2008, Carbon
742 chemostratigraphy of the Cambrian–Ordovician transition in a mid-latitude mixed platform,
743 Montagne Noire, France. *Geological Society of America Bulletin*, 120, 962–975.
- 744 Armstrong, R.A., Master, S. and Robb, L.J., 2005. Geochronology of the Nchanga Granite
745 and constraints on the maximum age of the Katanga Supergroup, Zambian Copperbelt.
746 *Journal of African Earth Sciences*, 42, 32–40.
- 747 Batten, K.L., Narbonne, G.M. and James, N.P., 2004. Paleoenvironments and growth of early
748 Neoproterozoic calcimicrobial reefs: platformal Little Dal Group, northwestern Canada.
749 *Precambrian Research*, 133, 249–269.
- 750 Baudet, D., Kant-Kabalu, F. and Fernandez-Alonso, M., 2014. Carte gologique de la
751 Rpublique du Congo, Province du Bas-Congo, avec notice explicative. Centre de
752 Recherches Gologiques et Minire (CRGM), Kinshasa, RDC et Muse royal de l’Afrique
753 Centrale (MRAC), Tervuren, Belgique, ISBN 978-9-4916-1535-1.
- 754 Begg, G.C., Griffin, W.L., Natapov, L.M., O’Reilly, S.Y., Grand, S.P., O’Neill, C.J., Hronsky,
755 J.M.A., Poudjom Djomani, Y., Swain, C.J., Deen, T. and Bowden, P., 2009. The
756 lithospheric architecture of Africa: seismic tomography, mantle petrology, and tectonic
757 evolution. *Geosphere*, 5 (1), 23–50.
- 758 Bergemann, C., Jung, S., Berndt, J., Stracke, A. and Hauff, F., 2014. Generation of
759 magnesian, high-K alkali-calcic granites and granodiorites from amphibolitic continental
760 crust in the Damara Orogen, Namibia. *Lithos*, 198–199, 217–233.
- 761 Brito-Neves, B.B., Campos-Neto, M.C. and Fuck, R.A., 1999. From Rodinia to Western
762 Gondwana: An approach to the Brasiliano-Pan African cycle and orogenic collage.
763 *Episodes*, 22, 155–199.
- 764 Burchette, T.P. and Wright, V.P., 1992. Carbonate ramp depositional systems. *Geology*, 79,
765 3–57.

- 766 Busfield, M.E. and Le Heron, D.P., 2013. Glacitectonic deformation in the Chuos Formation
767 of northern Namibia: implications for Neoproterozoic ice dynamics. *Proceedings of the*
768 *Geologists' Association*, 124 (5), 778–789.
- 769 Cadwell, R.A., 1976. Holocene gypsum deposits of the Bullara Sunkland, Carnarvon basin,
770 Western Australia. Unpublished PhD thesis, University of Western Australia, Perth,
771 Australia. 123pp
- 772 Cailteux, J.L.H., Delpomdor, F.R.A. and Ngoie Ndobami, J.-P., 2015. The Neoproterozoic
773 West Congo ‘Schisto-Calcaire’ sedimentary succession from the Bas-Congo region
774 (Democratic Republic of the Congo) in the frame of regional tentative correlations.
775 *Geologica Belgica*, 18 (2-4), 126-146.
- 776 Catuneanu, O., Galloway, W.E., Kendall, C.G.S.C., Miall, A.D., Posamentier, H.W., Strasser,
777 A. and Tucker, M.E., 2011. *Sequence Stratigraphy: Methodology and Nomenclature*.
778 *Newsletters on Stratigraphy*, 44 (3), 173-245.
- 779 Caxito, F.A., Halverson, G.P., Uhlein, A., Stevenson, R., Dias, T.G. and Uhlein, G.J., 2012.
780 Marinoan glaciation in east central Brazil. *Precambrian Research*, 200-203, 38-58.
- 781 Clauer, N. and Krner, A., 1979. Strontium and argon isotopic homogenization of pelitic
782 sediments during low-grade regional metamorphism: the Pan-African upper Damara
783 sequence of Northern Namibia (SouthWest Africa). *Earth and Planetary Science Letters*, 43,
784 117–131.
- 785 Collins, A.S. and Pisarevsky, S.A., 2005, Amalgamating eastern Gondwana: The evolution of
786 the circum-Indian orogens. *Earth-Science Reviews*, 71, 229–270.
- 787 Cordani, U.G., Brito-Neves, B.B., D’Agrella, M.S. and Trindade, R.I.F., 2003. Tearing-up
788 Rodinia: the Neoproterozoic paleogeography of South American cratonic fragments. *Terra*
789 *Nova*, 15, 343-349.

- 790 Cozzi, A., Grotzinger, J.P. and Allen, P.A., 2004. Evolution of a terminal Neoproterozoic
791 carbonate ramp system (Buah Formation, Sultanate of Oman): Effects of basement
792 paleotopography. *Geological Society of America Bulletin*, 116 (11-12), 1367-1384.
- 793 Delpomdor, F. and Prat, A., 2013. Early and Neoproterozoic C, O and Sr isotope
794 chemostratigraphy in the carbonates of West Congo and Mbuji-Mayi supergroups: A
795 preserved marine signature? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 389, 35-
796 47.
- 797 Delpomdor, F., Tack, L., Cailteux, J. and Prat, A., 2015. The C2 and C3 formations of the
798 Schisto-Calcaire Subgroup (West Congo Supergroup) in the Democratic Republic of the
799 Congo: An example of post-Marinoan sea-level fluctuations as a result of extensional
800 tectonisms. *Journal of African Earth Sciences*, 110, 14-33.
- 801 Delpomdor, F., Eyles, N., Tack, L. and Prat, A., 2016. Pre- and post-Marinoan carbonate
802 facies of the Democratic Republic of the Congo: Glacially- or tectonically-influenced deep-
803 water sediments? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 457, 144-157.
- 804 Delpomdor, F.R.A., Tack, L. and Prat, A.R., 2017. Facies and micromorphology of the
805 Neoproterozoic Upper Diamictite Formation in the Democratic Republic of Congo: new
806 evidence of sediment gravity flow. *Geologica Belgica*, 20 (1-2), 69-79.
- 807 Delpomdor, F., Van Vliet, N., Devleeschouwer, X., Tack, L. and Prat, A., 2018. Evolution
808 and Estimated Age of the C5 Lukala Carbonate-Evaporite Ramp Complex in the Lower
809 Congo region (Democratic Republic of Congo): New perspective in Central Africa. *Journal*
810 *of African Earth Sciences*, 137, 261-277.
- 811 Flgel, E., 2010. *Microfacies of Carbonate Rocks, Analysis Interpretation and Application*,
812 Springer-Verlag, Berlin, Heidelberg. 976pp
- 813 Foster, D.A., Goscombe, B.D., Newstead, B., Mapani, B., Mueller, P.A., Gregory, L.C. and
814 Muvangua, E., 2015. U–Pb age and Lu–Hf isotopic data of detrital zircons from the

- 815 Neoproterozoic Damara Sequence: implications for Congo and Kalahari before Gondwana.
816 Gondwana Research, 28, 179–190.
- 817 Franseen, E.K. and Byrnes, A.P., 2012. Arkuckle Group Platform Strata in Kansas: A
818 synthesis. In: J.R. Derby, R.D. Fritz, S.A. Longacre, W.A. Morgan and C.A. Sternbach
819 (Editors.), The great American carbonate bank. The geology and economic resources of the
820 Cambrian-Ordovician Sauk megasequence of Laurentia. American Association of
821 Petroleum Geologists Bulletin, Memoir 98, 1031-1047.
- 822 Frimmel, H.E., 2009. Trace element distribution in Neoproterozoic carbonates as
823 palaeoenvironmental indicator. Chemical Geology, 258 (3–4), 338–353.
- 824 Frimmel, H.E., 2010. On the reliability of stable carbon isotopes for Neoproterozoic
825 chemostratigraphic correlation. Precambrian Research, 182 (4), 239-253.
- 826 Frimmel, H.E. and Frank, W., 1998. Neoproterozoic tectono-thermal evolution of the Gariep
827 Belt and its basement, Namibia and South Africa. Precambrian Research, 90 (1), 1–28.
- 828 Frimmel, H.E., Deane, J.G. and Chadwick, P.J., 1996. Pan-African tectonism and the genesis
829 of base metal sulfide deposits in the northern foreland of the Damara Orogen, Namibia. In:
830 D.F. Sangster (Editor), Carbonate-Hosted Lead-Zinc Deposits. Society of Economic
831 Geologists, Special Publication No. 4, 204–217.
- 832 Frimmel, H.E., Tack, L., Basei, M.S., Nutman, A.P. and Boven, A., 2006. Provenance and
833 chemostratigraphy of the Neoproterozoic West Congolian Group in the Democratic
834 Republic of Congo. Journal of African Earth Sciences, 46, 221-239.
- 835 Gerdes, G., Dunajtschik-Piewak, K., Riege, H., Taher, A.G., Krumbein, W.E. and Reineck,
836 H.E., 1994. Structural diversity of biogenic carbonate particles in microbial mats.
837 Sedimentology, 41, 1273-1294.
- 838 Germs, G.J.B., Miller, R.McG., Frimmel, H.E. and Gaucher, C., 2009. Syn- to late-orogenic
839 sedimentary basins of southwestern Africa. Neoproterozoic to Early Palaeozoic evolution of

- 840 Southwestern Africa. In: C. Gaucher, A.N. Sial, G.P. Halverson and H.E. Frimmel
841 (Editors), Neoproterozoic-Cambrian Tectonics, Global Change and Evolution: A Focus on
842 Southwestern Gondwana. Developments in Precambrian Geology, volume 16, Elsevier,
843 183–203.
- 844 Grotzinger, J.P., 1986. Cyclicity and paleoenvironmental dynamics, Rocknest platform,
845 northwestern Canada. Geological Society of America Bulletin, 97, 1208-1231.
- 846 Halverson, G.P., Dudas, F.O., Maloof, A.C. and Bowring, S.A., 2007. Evolution of the
847 $^{87}\text{Sr}/^{86}\text{Sr}$ composition of Neoproterozoic seawater. Palaeogeography, Palaeoclimatology,
848 Palaeoecology, 256, 103–129.
- 849 Halverson, G.P., Hoffman, P.F., Schrag, D.P., Maloof, A.C. and Rice, A.H.N., 2005. Towards
850 a Neoproterozoic composite carbon isotope record. Geological Society America Bulletin,
851 117, 1181–1207.
- 852 Hedberg, R.M. 1979. Stratigraphy of the Ovamboland Basin, South West Africa. Bulletin of
853 Precambrian Research Unit, volume 24, University of Cape Town, Cape Town, South
854 Africa. 325pp
- 855 Hoffman, P.F., 1999. The break-up of Rodinia, birth of Gondwana, true polar wander and the
856 Snowball Earth. Journal of African Earth Sciences, 28 (1), 17-33.
- 857 Hoffman, P.F. and Schrag, D.P., 2002. The snowball Earth hypothesis: testing the limits of
858 global change. Terra Nova, 14, 129–155.
- 859 Hoffman, P.F., Swart, R., Eckhardt E.F. and Guowei, H. 1994. Damara orogen of northwest
860 Namibia. Geological Excursion Guide Geological Survey of Namibia, 55 p.
- 861 Hoffman, P., Kaufman, A., Halverson, G. and Schrag, D., 1998. A Neoproterozoic snowball
862 Earth. Science, 281, 1342–1346.

- 863 Hoffmann, K.H. and Prave, A.R., 1996. A preliminary note on a revised subdivision and
864 regional correlation of the Otavi Group based on glaciogenic diamictites and associated cap
865 dolostones. *Communication of the Geological Survey of Namibia*, 11, 77-82.
- 866 Hoffmann, K.H., Condon, D.J., Bowring, S.A., and Crowley, J.L., 2004. A U-Pb zircon date
867 from the Neoproterozoic Ghaub Formation, Namibia: Constraints on Marinoan glaciation.
868 *Geology*, 32, 817–820.
- 869 James, N.P and Ginsburg R.N., 1979. The seaward margin of Belize barrier and atoll reefs
870 *International Association of Sedimentology, Special Publication*, volume 3. 173pp
- 871 Kamona, A.F. and Gnzel, A., 2007. Stratigraphy and base metal mineralization in the Otavi
872 Mountain Land, Northern Namibia – a review and regional interpretation. *Gondwana*
873 *Research*, 11, 396-413.
- 874 Kant-Kabalu, F., Kadja-Wongudi, G., Mujinga-Mulemba, E., Nseka-Mbemba, P., Phambu-
875 Landu, J., Kanda-Nkula, V., Baudet, D., Dewaele, S., Eekelers, K., Fernandez, M.,
876 Laghmouch, M., Theunissen, K. and Tack, L., 2016. New 1/500.000 scale GIS-based
877 geological and mineral resources maps for Bas-Congo province (DRC) with an updated
878 lithostratigraphy of the Neoproterozoic West Congo Supergroup. 5th International Geologica
879 Belgica 2016 Congress, University of Mons, Mons, Belgium, 42-43.
- 880 Kaufman, A.J., Hayes, J.M., Knoll, A.H. and Germs, G.J.B., 1991, Isotopic compositions of
881 carbonates and organic carbon from upper Proterozoic successions in Namibia:
882 Stratigraphic variation and the effects of diagenesis and metamorphism. *Precambrian*
883 *Research* 49, 301–327.
- 884 Kaufman, A.J., Sial, A.N., Frimmel, H.E. and Misi, A., 2010, Neoproterozoic to Cambrian
885 Paleoclimatic Events in Soutwestern Gondwana. In: C. Gaucher, A.N. Sial, G.P. Halverson
886 and H.E. Frimmel (Editors), *Neoproterozoic-Cambrian Tectonics, Global Change and*

- 887 Evolution: a focus on southwestern Gondwana. *Developments in Precambrian Geology*,
888 volume 16, Elsevier, 369-388.
- 889 Kennedy, M.J., Christie-Blick, N., Sohl and L.E., 2001. Are Proterozoic cap carbonates and
890 isotopic excursions a record of gas hydrate destabilization following Earth's coldest
891 intervals? *Geology*, 29, 443–446.
- 892 Kinsman, D.J.J., 1969. Modes of formation, sedimentary associations and diagnostic features
893 of shallow-water and supratidal evaporates. *American Association of Petroleum Geologists*
894 *Bulletin*, 53, 830–840.
- 895 Kirschvink, J.L., 1992. Late Proterozoic Low-Latitude Global Glaciation: the Snowball Earth.
896 In: J.W. Schopf and C. Klein (Editors), *The Proterozoic Biosphere: a Multidisciplinary*
897 *study*. Cambridge University Press, Cambridge, United Kingdom, 51-52.
- 898 Konopsek, J., Kosler, J., Slma, J. and Janousek, V., 2014. Timing and sources of pre-
899 collisional Neoproterozoic sedimentation along the SW margin of the Congo Craton (Kaoko
900 Belt, NW Namibia). *Gondwana Research*, 26, 386–401.
- 901 Lehmann, J., Saalmann, K., Naydenov, K.V., Milani, L., Belyanin, G.A., Zwingmann, H.,
902 Charlesworth, G. and Kinnaird, J.A., 2016. Structural and geochronological constraints on
903 the Pan-African tectonic evolution of the northern Damara Belt, Namibia. *Tectonics*, 35 (1),
904 103–135.
- 905 Lepersonne, J., 1951. Donnes nouvelles sur la stratigraphie des territoires anciens du Bas-
906 Congo. *Bulletin belge de Gologie, Palontologie, Hydrologie*, LX-2, 169-189.
- 907 Lepersonne, J., 1973. Carte gologique l'chelle 1/200000. Notice explicative de la feuille
908 Ngungu (Degr carr S6/14 = SB 33.9). Rpublique Dmocratique du Congo. Dpartement
909 des Mines, Direction du Service Gologique. 61pp
- 910 Li, Z.X., Bogdanova, S.V., Collins, A.S., Davidson, A., DeWaele, B., Ernst, R.E., Fitsimons,
911 I.C.W., Fuck, R.A., Gladkochub, D.P., Jacobs, J., Karlstom, K.E., Lu, S., Natapov, L.M.,

- 912 Pease, V., Pisarevsky, S.A., Thrane, K. and Vernikovsky, V., 2008. Assembly,
913 configuration, and break-up history of Rodinia: a synthesis. *Precambrian Research*, 160 (1–
914 2), 179–210.
- 915 Martin, H., 1965. The Precambrian geology of South West Africa and Namaqualand.
916 Precambrian Research Unit, volume 24, University of Cape Town, Cape Town, South
917 Africa. 159pp
- 918 Martins-Neto, M.A., Pedrosa-Soares, M.A. and Lima, S.A.A., 2001. Tectono-sedimentary
919 evolution of sedimentary basins from late Paleoproterozoic to late Neoproterozoic in the
920 So Francisco craton and Araua Fold Belt, eastern Brazil. *Sedimentary Geology*, 141–142,
921 343–370.
- 922 McGee, B., Halverson, G.P. and Collins, A.S., 2012. Cryogenian rift-related magmatism and
923 sedimentation: South-western Congo Craton, Namibia. *Journal of African Earth Sciences*,
924 76, 34–49.
- 925 Meert, J.G., 2003. A synopsis of events related to the assembly of eastern Gondwana.
926 *Tectonophysics*, 362, 1–40.
- 927 Merdith, A.S, Collins, A.S., Williams, S.E., Pisaversky, S., Foden, J.D., Archibald, D.B.,
928 Blades, M.L., Alessio, B.L., Armistead, S., Plavsa, D., Clark, C. and Mller, R.D. 2017. A
929 full-plate global reconstruction of the Neoproterozoic. *Gondwana Research*, 50, 84–134.
- 930 Milani, L., Kinnaird, J.A., Lehmann, J., Naydenv, K.V., Saalman, K., Frei, D. and Gerdes,
931 A., 2014. Role of crustal ontribution in the early stage of the Damara Orogen, Namibia: new
932 constraints from combined U-Pb and Lu-Hf isotopes from the Goas Magmatic Complex.
933 *Gondwana Research*, 28, 961–986.
- 934 Miller, R.M., 2008. The Geology of Namibia, volume 3. Geological Survey of Namibia,
935 Windhoek, Namibia.

- 936 Miller, R.M., 2013. Comparative stratigraphic and geochronological evolution of the
937 Northern Damara Supergroup in Namibia and the Katanga Supergroup in the Lufilian Arc
938 of Central Africa. *Geoscience Canada*, 40 (2), 118–140.
- 939 Moni, P., Bosch, D., Bruguier, O., Vauchez, Y., Nsungani, P. and Neto, A.B., 2012. The
940 Late Neoproterozoic/Early Palaeozoic evolution of the West Congo Belt of NW Angola:
941 geochronological (U-Pb and Ar-Ar) and petrostructural constraints. *Terra Nova*, 24, 238-
942 247.
- 943 Nagel, R., 1999. Eine Milliarde Jahre geologischer Entwicklung am NW-Rand des Kalahari
944 Cratons. Unpublished PhD thesis, University of Gttingen, Gttingen, Germany. 169pp
- 945 Nascimento, D.B., Ribeiro, A., Trouw, R.A.J., Schmitt, R.S. and Passchier, C.W., 2016.
946 Stratigraphy of the Neoproterozoic Damara Sequence in northwest Namibia: Slope to basin
947 sub-marine mass-transport deposits and olistolith fields. *Precambrian Research*, 278, 108-
948 125.
- 949 Naydenov, K.V., Lehmann, J., Saalmann, K., Milani, L., Kinnaird, J.A., Charlesworth, G.,
950 Frei, D. and Rankin, W., 2014. New constraints on the Pan-African Orogeny in Central
951 Zambia: a structural and geochronological study of the Hook Batholith and the Mwembeshi
952 Zone. *Tectonophysics*, 637, 80–105.
- 953 Paula-Santos, G.M., Babinski, M., Kuchenbecker, M., Caetano-Filho, S., Trindade, R.I. and
954 Pedrosa-Soares, A.C. 2015. New evidence of an Ediacaran age for the Bambu Group in
955 southern So Francisco craton (eastern Brazil) from zircon U-Pb data and isotope
956 chemostratigraphy. *Gondwana Research*, 28 (2), 702-720.
- 957 Paula-Santos, G.M., Caetano-Filho, S., Babinski, M., Trindade, R.I.F. and Guacaneme, C.,
958 2017. Tracking connection and restriction of West Gondwana So Francisco Basin through
959 isotope chemostratigraphy. *Gondwana Research*, 42, 280-305.

- 960 Pedrosa-Soares, A.C. and Alkmin, 2011. How many rifting events preceded the development
961 of the Araua-West Congo orogen? *Geonominos*, 19 (2), 244–251.
- 962 Pedrosa-Soares, A.C., Noce, C.M., Wiedemann, C.M. and Pinto, C.P., 2001. The Araua-
963 West- Congo Orogen in Brazil: an overview of a confined orogen formed during
964 Gondwanaland assembly. *Precambrian Research*, 110 (1), 307–323.
- 965 Pedrosa-Soares, A.C., Alkmin, F., Tack, L., Noce, C., Babinski, M., Silva, L. and Martins-
966 Neto, M., 2008. Similarities and differences between the Brazilian and African counterparts
967 of the Neoproterozoic Araua-West Congo Orogen. In: J. Pankhurst, R. Trouw, B. Brito-
968 Neves, and M. De Wit (Editors), *West Gondwana: Pre-cenozoic Correlations Across the*
969 *South Atlantic Region 294*. Geological Society of London, Special Publications, London,
970 United Kingdom, 153–172.
- 971 Poidevin, J.-L., 2007. Stratigraphie isotopique du strontium et datation des formations
972 carbonates et glaciogniques noproterozoiques du Nord et de l’Ouest du craton du Congo.
973 *Comptes Rendus Geoscience*, 339, 259-273.
- 974 Porada, H., 1983. Die Geosynklinalentwicklung des Damara-Orogens in Namibia und ihr
975 geodynamischer Rahmen. Unpublished habilitation thesis, Universitt von Gttingen,
976 Gttingen, Germany. 209pp
- 977 Porada, H., 1989. Pan-African rifting and orogenesis in southern to equatorial Africa and
978 eastern Brazil. *Precambrian Research*, 44, 103–136.
- 979 Porada, H. and Berhorst, V., 2000. Towards a new understanding of the Neoproterozoic-Early
980 Paleozoic Lufilian and northern Zambezi Belts in Zambia and DRC. *Journal of African*
981 *Earth Sciences*, 30, 727–771.
- 982 Pratt, B.R., James, N.P. and Clinton, A.C., 1992. Peritidal carbonates. In: R.G. Walker and
983 N.P. James (Editors), *Facies Models: Response to Sea Level Change*. Geological
984 Association of Canada. 409pp

- 985 Prave, A.R., Condon, D.J., Hoffmann, K.H., Tapster, S. and Fallick, A.E., 2016. Duration and
986 nature of the end-Cryogenian (Marinoan) glaciation. *Geology*, 44 (8), 631-634.
- 987 Préat, A., Prian, J.P., Thiéblemont, D., Mabicka Obame, R. and Delpomdor, F., 2011. Stable
988 isotopes of oxygen and carbon compositions in the Neoproterozoic of South Gabon
989 (Schisto-Calcaire Subgroup, Nyanga Basin): Are cap carbonates and lithoherms recording a
990 particular destabilization event after the Marinoan glaciation? *Journal of African Earth*
991 *Sciences*, 60 (4), 273-287.
- 992 Prian, J.P., Thiéblemont, D., Préat, A., Goujou, J.C., Simo Ndounze, S. and Ekogha, H., 2009.
993 Notice explicative de la Carte géologique de la République du Gabon à 1/ 200 000, feuille
994 Ndendé. Editions DGMG – Ministère des Mines, du Pétrole, des Hydrocarbures, Libreville.
- 995 Rainaud, C., Master, S., Armstrong, R.A., Phillips, D. and Robb, L.J., 2005. Monazite U–P
996 dating and ^{40}Ar – ^{39}Ar thermochronology of metamorphic events in the Central African
997 Copperbelt during the Pan-African Lufilian Orogeny. *Journal of African Earth Sciences*, 42
998 (1), 183–199.
- 999 Reis, H.L.S. and Alkmim, F.F., 2015. Anatomy of a basin-controlled foreland fold-thrust belt
1000 curve: the Três Marias salient, São Francisco basin, Brazil. *Marine Petroleum Geology*, 66
1001 (4), 711–731.
- 1002 Reitlinger, E.A., 1959. Atlas des restes microscopiques et des Problemática des couches
1003 anciennes de Sibérie. *Travaux de Géologie, Atlas Nauka Acad. Sci., URSS*, 25, 1-63.
- 1004 Rodler, A.S., Frei, R., Gaucher, C., Korte, C., Rosing, S.A. and Germs, G.J.B., 2017.
1005 Multiproxy isotope constraints on ocean compositional changes across the late
1006 Neoproterozoic Ghaub glaciation, Otavi Group, Namibia. *Precambrian Research*, 298, 306-
1007 324.

- 1008 Santos, R.V., S. de Alvarenga, C.J., Dardenne, M.A., Sial, A.N. and Ferreira, V.P., 2000.
1009 Carbon and oxygen isotope profiles across Meso-Neoproterozoic limestones from central
1010 Brazil: Bambu and Parano groups. *Precambrian Research*, 104, 107-122.
- 1011 Scoffin, T.P. and Stoddard, D.R., 1983. Beachrock and intertidal cements. In: A.S. Goudie
1012 and K. Pye (Editors), *Chemical sediments and geomorphology*. Academic Press, London,
1013 United Kingdom, 401-425.
- 1014 Shearman, D.J., 1978. Evaporites of coastal sabkhas. *Society and Economist Paleontologists*
1015 *and Mineralogists Short Course*, volume 4, 6–42.
- 1016 Stanistreet, I.G., Kukla, P.A. and Henry, G., 1991. Sedimentary basinal responses to a Late
1017 Precambrian Wilson Cycle: the Damara Orogen and Nama Foreland, Namibia. *Journal of*
1018 *African Earth Sciences*, 13 (1), 141-156.
- 1019 Straathof, G.B., 2011. Neoproterozoic Low Latitude Glaciations: An African Perspective.
1020 Unpublished PhD. Thesis, University of Edinburgh, Edinburgh, Scotland. 283pp
- 1021 Tack, L., Wingate, M.T.D., Ligeois, J.-P., Fernandez-Alonzo, M. and Deblond, A., 2001.
1022 Early Neoproterozoic magmatism (1000-910 Ma) of the Zadinian and Mayumbian groups
1023 (Bas-Congo), onset of Rodinia rifting at the western edge of the Congo Craton. *Precambrian*
1024 *Research*, 110, 277-306.
- 1025 Tait, J., Delpomdor, F., Prat, A., Tack, L., Straathof, G. and Kanda Nkula, V., 2011.
1026 Neoproterozoic sequences of the West Congo and Lindi/Ubangi Supergroups in the Congo
1027 Craton, Central Africa. In: E. Arnaud, G.L. Halverson and G. Shields-Zhou (Editors), *The*
1028 *Geological Record of Neoproterozoic Glaciations*. Geological Society Memoir, volume 36,
1029 London, United Kingdom, 185–194.
- 1030 Thomson, D., Rainbird, R.H. and Dix, G., 2014. Architecture of a Neoproterozoic
1031 intracratonic carbonate ramp succession: Wynniatt Formation, Amundsen Basin, Arctic
1032 Canada. *Sedimentary Geology*, 299, 119-138.

- 1033 Turner, E.C., James, N.P. and Narbonne, G.M., 2000. Taphonomic Control on Microstructure
1034 in Early Neoproterozoic Reefal Stromatolites and Thrombolites. *Palaios*, 15 (2), 87-111.
- 1035 Uhlein, G.J., Carvalho, J.F.M.G., Uhlein, A., Caxito, F.A., Halverson, G.P. and Sial, A.N.,
1036 2013. Estratigrafia e sedimentologia da Formao Carrancas, Grupo Bambu, nas regies de
1037 Belo Horizonte e Pitangui – MG. *Geonomos*, 20(2), 79-97.
- 1038 Uhlein, G.J., Uhlein, A., Halverson, G.P., Stevenson, R., Caxito, F.A., Cox, G.M. and de
1039 Carvalho, J.F.M.G., 2016. The Carrancas Formation, Bambu Group: A record of pre-
1040 Marinoan sedimentation on the southern So Francisco craton, Brazil. *Journal of South*
1041 *American Earth Sciences*, 71, 1-16.
- 1042 Unrug, R., 1995. Rodinia and Gondwana: A record of supercontinent configuration change.
1043 In: M. Yoshida and M. Santosh (Editors), *India and Antarctica during the Precambrian*.
1044 *Geological Society of India Memoir*, volume 34, 1–9.
- 1045 Van Smeerdijk Hook, A. and Wallace, M.W., 2018. Neoproterozoic marine carbonates and
1046 their paleoceanographic significance. *Global and Planetary Change* 160, 28-45.
- 1047 Wachter, E. and Hayes, J.M., 1985. Exchange of oxygen isotopes in carbon-dioxide
1048 phosphoric acid systems. *Chemical Geology* 52, 365–374.
- 1049 Warren, L.V., Quaglio, F., Riecomini, C., Simoes, M.G., Poir, D.G., Strikis, N.M., Anelli, A.
1050 and Strikis, P.C. 2014. The puzzle assembled: Ediacaran guide fossil *Claudina* reveals an
1051 old proto-Gondwana seaway. *Geology*, 42 (5), 391-394.
- 1052 Yakschin, M.S. and Luchinina, V.A., 1981. New materials of fossil alga Family
1053 *Oscillatoriaceae* (KIRCHN.) Elenkin. In *Boundary strata between the Precambrian and*
1054 *Cambrian in Siberian Platform*. Novosibirsk, *Scienca*, 28-34.
- 1055
- 1056 Editorial Handling: S. McCourt
- 1057

1058 **Table**

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1060 **Table 1:** *Summary of lithofacies association characteristics of the Httenberg Formation*

1061 *(Namibia) and the C5 Formation (Democratic Republic of Congo)*

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1063 **Table 2:** *C-, O- and Sr-isotopic and elemental geochemical data.*

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Figures

Figure 1: Cartoon illustrating the Neoproterozoic palaeogeographic reconstruction of the Congo-So Francisco (C-SF) cratons (modified after Stanistreet et al. 1991; Alkmim et al. 2006). (A) Reworked 1.1 Ga-950 Ma Rodinia Supercontinent centered on the present-day Africa and South America continents. (B) Continental rifting at ~1 Ga. (C) Opening of the Khomas Ocean separating shelves on the C-SF and Kalahari continental margins. (D) Initial closure of the Adamastor Ocean, at ~720 Ma, as a consequence of the C-SF, Rio de la Plata, Kalahari interaction. (E) Pan-African-Brasiliano orogen on the Gondwana Supercontinent at ~540 Ma. Abbreviations: Craton - Am, Amazonia; RP, Rio de la Plata; WA, West Africa; Co, Congo; SF, So-Francisco; Ka, Kalahari, Ta, Tanzania block (Congo craton); AR, Arequipa; Ho, Hoggar; In, India; EAn, East Antarctica; Was, West Australia; NAs, North Australia; Ga, Gawler. Pan-African-Brasiliano orogens – RP, Rio Preto, BR, Brasiliano; SP, Sierra Pampeanas; WC, West Congo; KK, Kaoko; DA, Damara; GA, Gariep; LF, Lufilian; ZB, Zambezi; MO, Mozambique; SA, Saldania; CF, Cape Fold; RO, Ross; KA, Kanmatoo. Stars: C5 Formation in the Democratic Republic of Congo, Httenberg Formation in Namibia.

Figure 2: (A) Regional geological sketch map of the study area. (B) Geological map of the section Lukala-Mbanza Ngungu (after Cailteux et al., 2015). (C) Geological map of the Damara belt (after Kamona and Gnzel, 2007). Location of the studied outcrops and core sections in yellow stars.

Figure 3: Lithostratigraphy and chronostratigraphy of the (A) Damara Supergroup and (B) the West Congo Supergroup (see text for discussion). New and previous terminology of the

1107 *West Congo Supergroup falls outside the scope of this paper but is briefly discussed in Kant-*
1108 *Kabalu et al. (2016).*

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1110 **Figure 4:** Detailed lithostratigraphy coupled with microfacies analyses. (A) Tsumeb Mine
1111 (GPS coordinate: S1914'07.80/E1743'49.40). (B) Tsumeb town (GPS coordinate: S
1112 1915'60.60/E1742'44.30). (C) S#66 drillcore (GPS coordinate: N304893/E76412).

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1114 **Figure 5:** Detailed lithostratigraphy coupled with microfacies analyses. (A) MJNM#5
1115 drillcore, farm Vogelsang 284 (GPS coordinate: S1910'00.86/E1821'42.01). (B) MJNM#6
1116 drillcore, farm Guinab 277 (GPS coordinate: S1911'11.57/E1822'48.53). (C) MJNM#9
1117 drillcore, farm Guinab 277 (GPS coordinate: S1910'10.46/E1822'47.86) (D) MJNM#10
1118 drillcore, farm Vogelsang 284 (GPS coordinate: S912'51.38/E1757'28.12). (E) MJNM#12
1119 drillcore, Farm Bombay 670 (GPS coordinate: S1912'51.38/E1757'28.12).

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1121 **Figure 6:** Detailed lithostratigraphy and lithology coupled with microfacies analyses and C
1122 isotopes. (A) GX6c drillcore (RMCA serial number RG40421-40466). (B) GN7/9a drillcore
1123 (RMCA serial number RG40178-40198).

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1125 **Figure 7:** Vertical changes of microfacies (MF1 to MF12) represented by type-1 and -2
1126 cycles of open marine- to restricting-upward carbonate sequences. The type-1 cycle is
1127 characterized by a LFA-H1 to LFA-H4 succession of complete cycles that begin with LFA-
1128 H1, while the type-2 cycle contains a LFA-C1 to LFA-C5 succession that begin with LFA-C1
1129 (see text for discussion).

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Figure 8: Carbonate ramp geometry and facies distribution of the Httenberg Formation in Namibia and the C5 Formation in DRC. (A-C) Middle- to inner carbonate ramp of the Httenberg Formation. (A) Middle carbonate ramp of the Httenberg Formation with (dolo)mudstone (MF1-2) overlain by mounds and pinnacles of microbial and SH/LLH-type stromatolitic buildups (MF3-5). High-energy oolitic (dolo)packstone-grainstone (MF6) form barrier shoals. (B) Inner carbonate ramp of the Httenberg Formation exhibits a temporary emerged hypersaline lagoon with desiccation cracks and breccias (see MF10). (C-D) Inner carbonate-evaporite ramp of the C5 Formation. (C) Shoal-barrier and lagoonal ramp settings of the C5a Member (MF7-9). (D) Nearshore carbonate-evaporite ramp setting with beach and coastal sabkha plain (MF10-12).

Figure 9: Attempt at carbon-isotope correlation between the C5 carbonate rocks and the high-resolution $\delta^{13}\text{C}$ data from the Tsumeb core S86A drilled in the Httenberg Formation (data after Kaufman et al. 2010).

Figure 10: Composite carbon-isotope profiles and simplified stratigraphic columns spanning the inferred Marinoan and Pan-African deformation events in northwestern Namibia, west central DRC, and central east Brazil. The three sedimentary successions are marked by two marine transgressions, after the Marinoan-age glaciation. Two carbon-isotope trends show (i) a very negative anomaly, directly after the Marinoan glaciation, marked by the deposition of the Ghaub Formation in Namibia, Upper Diamictite Formation in DRC, and Carrancas/Jequita formations in Brazil, (ii) a negative to positive excursion in $\delta^{13}\text{C}$ values in the Maieberg Formation in Namibia, comparable to the C1-C3 formations in DRC, and the lower part of the Sete Lagoas in Brazil, and (iii) a second negative to strong positive excursion in $\delta^{13}\text{C}$ values in the Elandshoek-Huttenberg formations in Namibia, comparable to

1156 *the C4-C5 formations in DRC, and the upper part of the Sete Lagoas Formation to the Lagoa*
 1157 *do Jacar Formation in Brazil. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are here indicative. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from –*
 1158 *Namibia: Frimmel et al. (1996) and Halverson et al. (2007); DRC: Frimmel et al. (2006),*
 1159 *Poidevin (2007), and Delpomdor and Prat (2013); Brazil: Caxito et al. (2012) and Paula-*
 1160 *Santos et al. (2015, 2017).*

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1162 **Plate**

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1164 **Plate 1:** *Microfacies analysis. (A) Homogeneous mudstone (MF1). (B) Planar to wispy*
 1165 *parallel laminated mudstone (MF2). (C) Tightly-packed microbial tubular filaments in a*
 1166 *bindstone texture (MF3). (D) Silt- to sand-sized peloidal wackestone/grainstone (MF4). (E)*
 1167 *stromatolitic boundstone with fenestral fabric filled by equant calcite cements (MF5). (F)*
 1168 *Tightly packed fine-grained concentric tangential to radial oolites in a packstone texture*
 1169 *(MF6). (G) Reworked stromatoclasts in an oolitic grainstone cemented by calcite cements*
 1170 *(MF6). (H) Thin-levels of oolitic and peloidal packstone (MF6) alternating with*
 1171 *homogeneous mudstone (MF7). (I) Vertical desiccation crack in a homogeneous mudstone*
 1172 *(MF7) capped by thin wavy parallel laminated mudstone (MF8). (J) Thin planar to oblique*
 1173 *parallel microbial laminations. (K) Oolitic grainstone (MF9) in calcite cements. (L)*
 1174 *Occurrence of helicoidal cyanobacteria, attributed to *Obruchevella parva* Reitlinger (1959),*
 1175 *in the nucleus of oolites ('Kisantu Oolite', see Alvarez et al. 1995). (M) Alternations of planar*
 1176 *to wavy parallel microbial laminites (MF10) and evaporitic mudstone (MF11). (N) Small-*
 1177 *sized nodules showing loosely packed aggregates of tiny platy rectangular laths and stellate*
 1178 *crystals (MF11). (O) Dolomitized lime mudstone (MF12) capped by evaporitic mudstone*
 1179 *(MF11).*

GEOCHRONOLOGY: NAMIBIA: ¹Kamona and Günzel (2007), ²Hoffmann et al. (1994), ³Halverson et al. (2005), ⁴Hoffman et al. (1996), ⁵Hoffmann et al. (2004), ⁶Nagel (1999). **DRC:** ¹Tack et al. (2001), ²Frimmel et al. (2006), ³Straathof (2011), ⁴Poidevin (2007)

Type-1 cycle - open marine

Environment		Lithofacies association		
~4 m in thickness	Intertidal shoal barrier		Oolitic (dolo) packstone/ grainstone (MF6)	LFA-H4
	Sub- to intertidal organic mounds and pinnacles		Stromatolitic (dolo) boundstone (MF5)	LFA-H3
		Peloidal (dolo) wackestone/ packstone (MF4)	
	Shallow subtidal open-marine		Microbial (dolo) bindstone (MF3)	LFA-H2
		Laminated (dolo) mudstone (MF2)	
	Subtidal open-marine		Argillaceous (dolo) mudstone (MF1)	LFA-H1

Type-2 cycle - lagoon to nearshore

Environment		Lithofacies association		
0.9 to 2.6 m in thickness	Soil		Calcrete (MF12)	LFA-C5
	Supratidal sabhka		Evaporitic dolomudstone (MF11)	LFA-C4
	Inter- to supratidal mudflat		Microbially laminated mudstone (MF10)	LFA-C3
	Intertidal beach		Oolitic grainstone (MF9)	LFA-C2
	sub- to intertidal lagoon		Laminated mudstone (MF8)	LFA-C1
Argillaceous mudstone (MF7)

Hüttenberg Formation: lower-upper members

- Dolomitic limestone with oolites (upper member)
- Dolomitic limestone with stromatolites and oolites (lower-middle member)
- Dolomitic shale

- Oolitic grainstone
- Cyanobacterial bindstone
- Encrusted dolomitic limestone
- Calcareneite
- Stromatolitic framestone/bindstone
- Calcimicrobial boundstone

C5 Formation: C5a-upper C5b members

- Calcareous and dolomitic shale (C5a)
- Dolomitic limestone with stromatolites and oolites (C5b-upper C5b)
- Dolomitic shale

- LLH-type stromatolite
- Cyanobacterial mat
- Obruchevella parva*
- Oolites
- Evaporites
- Mud cracks

THIS PAPER

MPIOKA SUBGROUP

LUKALA SUBGROUP
CIII (BANGU) UNIT
C5 FM.

UPPER

C5b

C5b

C5a

C4 FM.

TSUMEB CORE S86A (AFTER KAUFMAN ET AL., 2010)

- DOLOSTONE
- STROMATOLITIC DOLOSTONE
- OOLITIC DOLOSTONE
- SHALEY DOLOSTONE
- DOLOMITIC LIMESTONE
- OOLITIC LIMESTONE
- SHALEY LIMESTONE
- SANDSTONE
- SHALE
- CHERT

Lithofacies associations	Microfacies	General descriptions	Depositional environment
<i>Hüttenberg Formation (Namibia)</i>			
LFA-H1	MF1	Dark blue-grey microcrystalline massive argillaceous mudstone; locally dolomitization; detrital grains; stylolites	Subtidal open-marine
LFA-H2	MF2	Light to dark blue-grey, planar to wispy parallel, thin- to non-laminated mudstone; microcrystalline micrite, locally dolomitization; detrital grains; rare replaced gypsum and anhydrite crystals	Shallow subtidal open-marine
	MF3	Thin planar to wavy parallel bindstone, brownish to bluish-grey, closely-packed tubular filaments and clumps of fragments of micro-organisms; microcrystalline micrite, locally dolomitization; detrital grains; rare replaced gypsum and anhydrite crystals	
LFA-H3	MF4	Light blue-grey, fine- to medium-grained, moderately-sorted, peloidal wackestone-packstone; microcrystalline micritic matrix, locally dolomitization	Sub- to intertidal organic mound and pinnacle
	MF5	Light blue-grey, stromatolitic boundstone stromatolitic mats and clumps of fragments of micro-organisms; SH- to LLH-type <i>Conophyton</i> ; microcrystalline micritic matrix, locally dolomitization; fenestrae; locally mudcracks	
LFA-H4	MF6	Light blue-grey, medium- to well-sorted, oolitic packstone-grainstone; planar or trough cross laminations; peloids; locally dolomitization; interparticular calcite cements; mudcracks	Intertidal shoal barrier
<i>C5 Formation (Democratic Republic of Congo)</i>			
LFA-C1	MF7	Thin-bedded dark-grey, locally pale pinkish argillaceous mudstone; microcrystalline micrite, locally dolomitization; argillaceous seams and stylolites; abundant replaced gypsum and anhydrite crystals	Sub- to intertidal lagoon
	MF8	Dark grey planar to wavy parallel, thin laminated mudstone; oblique and cross-laminations; microcrystalline micrite, locally dolomitization; abundant replaced gypsum and anhydrite crystals	
LFA-C2	MF9	Coarse grained, well-sorted, tightly-packed oolitic grainstone; planar or low angle crossed laminations; locally dolomitization or silicification; interparticular calcite cements; mudcracks	Intertidal beach
LFA-C3	MF10	Thin microbially planar and wavy parallel laminated mudstone; microcrystalline micrite, locally dolomitization; fenestrae; abundant replaced gypsum and anhydrite crystals; mudcracks; pedogenic crusts	Inter- to supratidal mudflat
LFA-C4	MF11	Evaporitic dolomudstone; equigranular xeno- to hypidiotopic dolomititic matrix; brownish to bluish white replaced gypsum crystals, nodular anhydrite and interbeds of anhydrite, chicken-wire structure; mudcracks; hardgrounds	Supratidal sabhka
LFA-C5	MF12	Dark, rarely yellowish-orange, millimetric-thick crusts of slightly undulated laminations; in-situ brecciation of dolomitized limestone; locally oolites and peloids; abundant replaced gypsum and anhydrite crystals; mudcracks	Paleosoil

Sample	Drillcore	Member	$\delta^{13}\text{C}$ (‰, VPDB)	$\delta^{18}\text{O}$ (‰, VPDB)	$^{87}\text{Sr}/^{86}\text{Sr}$
BCK112	GN7/9a	upper C5b	5.8	-7.7	-
BCK99	GN7/9a	upper C5b	7.0	-3.7	0.708374
BCK61	GN7/9a	upper C5b	6.0	-4.0	
BCK44	GN7/9a	upper C5b	4.0	-8.6	0.708118
BCK43	GN7/9a	upper C5b	-	-	-
BCK41	GN7/9a	upper C5b	-	-	-
BCK34	GN7/9a	upper C5b	5.6	-4.4	-
BCK32	GN7/9a	upper C5b	-	-	-
BCK22	GN7/9a	upper C5b	2.8	-2.8	-
BCK002	GN7/9a	upper C5b	1.1	-2.8	0.708982
BCK290	GX6c	C5b	1.3	-4.2	-
BCK252	GX6c	C5b	4.1	-3.9	-
BCK206	GX6c	C5b	7.5	-2.9	-
BCK201	GX6c	C5a	1.5	-3.2	-