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Paleoenvironments in Meso–Neoproterozoic carbonates of the Mbuji-Mayi Supergroup (Democratic Republic of Congo) – Microfacies analysis combined with C–O–Sr isotopes, major-trace elements and REE + Y distributions

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A B S T R A C T

The Meso- and Neoproterozoic Mbuji-Mayi Supergroup (1155 Ma to ca. 800 Ma) was deposited in the SE–NW trending siliciclastic-carbonate failed-rift in the Sankuru-Mbuji-Mayi-Lomami-Lovoy Basin. Drillcore- and outcrop-derived microfacies, isotope (C, O and Sr) compositions of carbonates and REE + Y distributions are integrated to unravel the paleoenvironmental and chemical conditions prevailing during deposition and alteration (or contamination) of the Mbuji-Mayi carbonates. The carbonate succession (BIe subgroup and BIIa to BIIe subgroups), composed of 11 microfacies (MF), records the evolution of a marine ramp submitted to evaporation, with basinal and low-energy outer-ramp environments (MF1–MF5), biohermal mid-ramp (MF6) and restricted tide-dominated lagoon inner-ramp (MF7–MF9) settings, overlain by lacustrine (MF10) and sabkha (MF11) environments. The ramp margin is characterized by thick stacks of stromatolitic bioherms. δ^{13}C and δ^{18}O relationships in the Mbuji-Mayi carbonates allow discrimination between meteoric (δ^{13}C: −7.5‰ to +0.0‰, δ^{18}O: −7.0‰ to −1.0‰) and burial lithifications (δ^{13}C: −1.5‰ to +0.0‰, δ^{18}O: −15.1‰ to −7.0‰), that overprinted a primary marine signal (δ^{13}C: −1.5‰ to +2.0‰, δ^{18}O: −3.0‰ to +0.5‰) partially preserved in the subgroups. Unaltered pristine signals are found in the Mbuji-Mayi carbonates with ^{87}Sr/^{86}Sr ratios (0.7065–0.7082) similar to those of the marine-preserved strontium signatures of the early Neoproterozoic oceans. The PAAS-normalized REE + Y distributions indicate that the BIe carbonates were altered by Fe-oxide-rich hydrothermal fluids. BIIb and BIIe carbonates exhibit uniform light REE depleted patterns suggesting inputs of detrital river material whereas a marine seawater, highlighted by the REE + Y distributions is preserved in BIIc and BIId carbonates. The pattern of carbon, oxygen and strontium isotopic variations in the Mbuji-Mayi carbonates reflects deposition and early diagenesis in variety domains in marine, evaporitic and meteoric conditions. Almost all Mbuji-Mayi carbonates display discrete seawater REE + Y distributions, reflecting influences of particulate and colloidal materials derived from riverine inputs or hydrothermal fluids. Our systematic REE + Y approach allows also to infer the nature of the dolomitization processes operating in each carbonate subgroup, i.e. dolomitization may be attributed to evaporative reflux of groundwater or mixing zones of freshwater lenses. The internal architecture and evolution of the carbonate Mbuji-Mayi succession are similar to many Phanerozoic ramps submitted to sealevel variations, climatic changes and episodic detrital inputs.

1. Introduction

The span of geologic time that stretches from the late Mesoproterozoic through the early–middle Neoproterozoic (1300–800 Ma) heralded extraordinary climatic and biological changes related to the tectonic changes that resulted in the assembly and the break-up of Rodinia. However, the end of the Mesoproterozoic Era (ca. 1300–1250 Ma; e.g. in the early Upper Riphean to Middle Riphean Uchur-Maya and Turukhansk Uplift in Siberia; Bartley et al., 2001) is characterized by a subsequent δ^{13}C increase related to the change in the atmospheric oxygen content associated with the break-up of Rodinia (Des Marais et al., 1992; Canfield, 1999). Moreover, the early and the lower middle Neoproterozoic periods (1000–800 Ma) were marked by greenhouse conditions, with

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deposition of evaporites in hot and arid environments (Hill et al., 2000; Delpomdor et al., 2013), with circulation of equatorial currents favouring the exchange of tropical and polar waters. However, the knowledge of paleoenvironmental and chemical conditions prevailing during the late Mesoproterozoic and early–middle Neoproterozoic are still limited.

It is common to interpret the past environments with tools such as macro- and microfacies analyses and stable isotope geochemistry (Halverson et al., 2005, 2007; Nédelec et al., 2007; Shields et al., 2007; Caron et al., 2010), in order to infer the primary depositional conditions and their alteration during diagenesis and burial. This primary information is of great importance in the Precambrian carbonate genesis, as it can preserve the geochemical and diagenetic signatures of the rocks themselves despite their antiquity (Préat et al., 2010). Another way to interpret the paleoenvironments is revealed by studies on chemical sedimentary rocks, such as carbonates, banded iron formations, cherts and phosphates, which showed that certain trace element patterns in water are useful proxies in sedimentology (Nothdurft et al., 2004; Frimmel, 2009). Systematic differences in the properties of the lanthanide series (REE) and Y are particularly useful to discriminate various input sources, such as marine, continental and hydrothermal. (e.g. Bolhar et al., 2004; Nothdurft et al., 2004; Bolhar and Van Kranendonk, 2007). Seawater REE + Y distributions in sediments appear independent of age (Shields and Webb, 2004; Bolhar and Van Kranendonk, 2007). This distribution is normalized with Post-Archean Australian Shales (PAAS), showing a typical uniform light REE depletion, an enrichment in La, a depletion in Ce, a slight enrichment in Gd and a positive Y anomaly (Zhang and Nozaki, 1996). The Ce deficiency is commonly related to the oxygen levels, with oxidized Ce^{4+} facilitating solubilization and absorption onto particles (De Baar et al., 1991). PAAS-normalized REE + Y patterns of reduced and acidic hydrothermal fluids display positive Eu anomaly and light (LREE) to middle (MREE) REE-enrichment patterns. In contrast, PAAS-normalized REE + Y distributions of river water have flat REE + Y patterns with slight uniform LREE depletion and no distinct elemental anomalies (Goldstein and Jacobsen, 1988; Lawrence et al., 2006; García et al., 2007).

In this paper, we highlight, combining microfacies with C–O–Sr isotopes, major-trace elements and REE + Y distributions; that (i) all Mbuji-Mayi carbonates kept their marine isotopic signatures; (ii) almost all Mbuji-Mayi carbonates display a discrete seawater REE + Y distribution, locally influenced by particulate and colloidal materials derived from riverine inputs or hydrothermal fluids; (iii) the shale contamination of the Mbuji-Mayi carbonates ranges between 2% and 4%; and (iv) the microfacies analysis and REE + Y geochemistry are complementary tools, providing an opportunity to state both regional (e.g. hydrodynamics, clastic supplies) and global (e.g. tectonics, subsidence) implications during late Mesoproterozoic and early–middle Neoproterozoic times.

2. Geological setting

The Sankuru-Mbuji-Mayi-Lomami-Lovoy (SMLL; Fig. 1a) Basin is located between 6°S and 8°S latitude and 23°E and 26°E longitude (Kasai-Oriental Province, Democratic Republic of Congo), along with the Archean-Paleoproterozoic Kasai Craton and the southern and eastern part by the Mesoproterozoic Kibaran Belt. The Mbuji-Mayi sedimentary sequence is weakly or no affected by regional metamorphism, with a maximum dip of 3° and between 20° and 45°, respectively, in the western and southeastern parts of the SMLL Basin (Cahen, 1954). The Mbuji-Mayi Supergroup is divided, from oldest to youngest, into siliciclastic BI and carbonate BII groups (Raucq, 1970). In the Sankuru-Mbuji-Mayi area, the lower siliciclastic series or BI group of the Mbuji-Mayi Supergroup is ~500 m thick and consists of five subgroups: BIb, BIc, BId, BIE (only in the Kafuku region) and BIe. The BIa subgroup is missing in the Sankuru-Mbuji-Mayi area, but has been observed near Makululu and Kiankodi villages in the southern part of the SMLL Basin (Cahen and Mortelmans, 1947).

The BI group consists of red quartzites and shales with an interbedded pink chert horizon. The BII group consisting of ~1000 m-thick carbonates with thin organic-rich shale levels, is subdivided into five subgroups: BIIa, BIIb, BIIc, BIId and BIIe. Basic igneous rocks are identified as (i) basaltic lavas overlying the BII group at the confluence of the Mbuji-Mayi and Sankuru rivers (Cahen et al., 1984); (ii) dolerite sills emplaced within the succession close to the BI/BII contact in the Lomami area; and (iii) sills of dolerite and amygdaloid lavas in the BI group along Kiankodi and Lovoy rivers (Cahen and Mortelmans, 1947). Polymictic conglomerates (Kabele and Kabenga Conglomerates) with more than 50% of clasts derived from the Mbuji-Mayi carbonates along the Kibaran Belt (southern part of the SMLL Basin), were attributed to the 'Grand Conglomérat' Formation of the Katanga Supergroup (Cahen and Mortelmans, 1947).

3. Geochronology (Fig. 1b)

The northern oldest siliciclastic BI group rests unconformably on 2648 ± 22 Ma migmatitic gneisses of the Dibaya Complex (Delhal et al., 1976) with granitic to tonalitic compositions, while the south SMLL Basin overlies the 1155 ± 15 Ma Kibara Belt (KIB) Supergroup (Delhal et al., 1966). An upper limit to the depositional age of the Mbuji-Mayi Supergroup is provided by a multi-mineral K–Ar age of 1152 ± 15 Ma (Delhal et al., 1989, recalculated to 1118 ± 15 Ma using the decay constants from Steiger and Jäger, 1977) on biotite, pyroxene and amphibole from E–W trending syenodiorite dykes outcroping in the eastern part of the Lulua Complex. Recently, youngest U–Pb ages on detrital zircon grains from the BId subgroup yielded 1174 ± 22 Ma, concordant with the maximum K–Ar age of 1152 ± 15 Ma (Delpomdor et al., 2013). The BI and BII transition, constrained by $^{207}Pb/^{206}Pb$ ages on presumed syngenetic galena, ranges between 1040 Ma and 1065 Ma (Cahen, 1954; Holmes and Cahen, 1955). Recent data from primary $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ chemostratigraphical analyses on BII carbonates (Fig. 1b), showed that primary marine signals are preserved and are coeval with the Bitter Springs negative anomaly around ca. 810 Ma (Delpomdor et al., 2013). Amygdaloid basaltic pillow lavas overlying the Mbuji-Mayi Supergroup at the Sankuru-Mbuji-Mayi confluence yielded an age of 948 ± 20 Ma. New ^{40}Ar–^{39}Ar dating on dolerite in the eastern part of the SMLL Basin gave 888.2 ± 8.8 Ma, but the geochemical analyses revealed an enrichment in K and Ca (Delpomdor et al., 2013).

4. Methodology

4.1. Samples

The sites of the studied drillholes are situated within the Sankuru-Mbuji-Mayi area between the Lubi and Luembe rivers (Fig. 1a). The cores are stored in the Geological Department from the Royal Museum for Central Africa (RMCA) in Belgium. A detailed lithological description of these drillcores is provided by Raucq (1957, 1970), which allowed recognition of corresponding stratigraphic units. The overall studied drillcores (Fig. 2) covers a thickness of ~525 m, and intersects the BIb to BIId succession. In our paper, we use the lithological descriptions of Raucq (1957, 1970) for the siliciclastic series (BI group), and for the carbonate series, we updated the descriptions using a new nomenclature to control the degree of diagenetic alteration. A total of 755 samples