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Origin and diagenetic evolution of gypsum and microbialitic carbonates in the Late Sag of the Namibe Basin (SW Angola)

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ABSTRACT

Ephemeral evaporitic conditions developed within the uppermost part of the transgressive Late Sag sequence in the Namibe Basin (SW Angola), leading to the formation of extensive centimetre- to metre-thick sulphate-bearing deposits and correlative microbialitic carbonates rich in pseudomorphs after evaporite crystals. The onshore pre-salt beds examined in this study are located up to 25 m underneath the major mid-Aptian evaporitic succession, which is typified at the outcrop by gypsiferous Bambata Formation and in the subsurface by the halite-dominated Loeme Formation.

Carbonate–evaporite cycles mostly occur at the top of metre-thick regressive parasequences, which progressively onlap and overstep landward the former faulted (rift) topography, or fill major pre-salt palaeo-valleys. The sulphate beds are made up of alabastrine gypsum associated with embedded botryoidal nodules, dissolution-related gypsum breccia, and are cross-cut by thin satin-spar gypsum veins. Nodular and fine-grained fabrics are interpreted as being diagenetic gypsum deposits resulting from the dissolution and recrystallisation of former depositional subaqueous sulphates, whereas gypsum veins and breccia result from telogenetic processes.

The carbonates display a broader diversity of facies, characterised by rapid lateral variations along strike. Thin dolomitic and calcitic bacterial-mediated filamentous microbialitic boundstones enclose a broad variety of evaporite pseudomorphs and can pass laterally over a few metres into sulphate beds. Dissolution-related depositional breccias are also common and indicate early dissolution of former evaporite layers embedded within the microbialites. Sulphate and carbonate units are interpreted as being concomitantly deposited along a tide-dominated coastal supra- to intertidal- sabkha and constitute high-frequency hypersaline precursor events, prior to the accumulation of the giant saline mid-Aptian Bambata and Loeme Formations.

Petrographic and geochemical analyses reveal successive dissolution, recrystallisation and cementation phases that occurred during burial, uplift and exhumation, implying a complex diagenetic evolution of both gypsum and carbonates, influenced by pore fluids of diverse composition which distinctly varied from meso- to telogenetic domains.

1. Introduction

Platform carbonates that commonly precede marine basinwide salt occur as assemblages of stromatolites and evaporites deposited in shallow water hypersaline environments (Pope et al., 1990; Perri et al., 2013; Caruso et al., 2015). They often constitute regressive subtidal carbonates that concomitantly form in response with (1) a progressive oceanic isolation of the basin caused by either the initiation of a significant sea level drawdown (Rouchy and Caruso, 2006), (2) the restriction of a tectonically active basins (Warren, 2010), (3) a drastic climatic changes with the pre-dominance of semi-arid to arid conditions (Warren, 2006), and/or (4) an increase of water saturation and salinity due to hydrothermal influx (Hovland et al., 2006). The pre-salt to salt transition is often typified inboard by a regional erosional unconformity. Few examples deal with transitional stromatolites that initiate during a relative sea level rise through which hypersaline shallow water conditions are permanently sustained over the end of a basin-wide salt deposition. The parameters that control the spatial facies distribution,

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the style of deposition model and the diagenesis of these transgressive deposits are therefore poorly known.

In the Namibe Basin of SW Angola, stromatolites rich on evaporite pseudomorphs that conformably underlay the mid-Aptian gypsum Bambata Formation (onshore equivalent of the Loeme Salt Formation), indicate precursor hypersaline conditions prior to the main salinity crisis (Gindre-chanu et al., 2014) and are known to be correlatively deposited over hundreds to thousands of kilometres along the West African margin during a major transgression. The question of whether the original depositional setting of these carbonates constituted an open freely tide-controlled sabkha (Shearman, 1963; West et al., 1979; Park, 2010; Strohmenger et al., 2011), a resurging marine water-fed coastal isolated salina (Warren, 1982a; Handford et al., 1984) or an intermediate semi-restricted embayment fed by mixed-marine resurgence and surface recharge (Aref et al., 1997; Rouchy et al., 1998), is critical. Their fundamental differences mainly reside in the spatial distribution of fabrics, their lateral arrangement across the coastal area, and also the hydrological connectivity with the open-marine setting (Warren and Kendall, 1985). Moreover, owing to the paucity of subsurface data and difficult access to key outcrops, sedimentary facies, as well as diagenetic phases resulting from fluid–rock interaction during the burial-uplift-exhumation cycle, are poorly documented.

In this paper, we describe in detail thin gypsum and microbialitic transgressive carbonates belonging to the Late Sag sequence cropping out in the Namibe Basin that form the transition with the gypsum Bambata Formation. A depositional model for the sulphate/carbonate units is suggested based on mapping and petrographic analysis. Particular emphasis was placed on micro-textural description in order to document phases of dissolution, recrystallisation and cementation. Additionally, with the support of isotopic and trace element analysis, the different paragenetic sequences accounting for the diagenetic evolution of both mineralogies from deposition, throughout burial until final exhumation on uplift are highlighted.

2. Geological setting

The onset of continental rifting in the South Atlantic occurred during the Late Berriasian–Early Valanginian, circa 140 m.y. according to (Gradstein and Ogg, 2004). A series of rift-related horsts and en-echelon normal fault-bounded grabens half-grabens were formed on both the Brazilian and West African margins (Rabinowitz and LaBrecque, 1979; Karner et al., 2003; Karner and Gambôa, 2007; Torsvik et al., 2009; Guiraud et al., 2010).

The Namibe Basin, formerly called the Mocâmedes or Mossamedes basin, is an elongate marginal depression located in SW Angola and N Namibia, ranging from 50 to 100 km wide (east–west) and circa 570 km long (Fig. 1). It lies along an interpreted orthogonal to oblique rifted segment of the African margin of the South Atlantic, bounded to the north by the NE–SW left-lateral Lucapa and Benguela transform fault complexes (Guiraud et al., 2010) and to the south by the volcanic Walvis Ridge, which is adjacent to the major NE–SW oriented Namibe transform fault. Whereas the exposed crystalline basement marks its eastern flank in onshore Angola, its western border remains imprecise basinward because the continent-ocean boundary is still poorly defined.

The pre-salt to salt architecture in West Africa results in three successive major rift-related tectono-stratigraphic units that control the structures along and across the margin: the two first correspond to s.s. syn-rift sequences, whilst the last is interpreted as being a subsiding Sag without significant fault activity (McHargue, 1990; Bate et al., 2001; Karner et al., 2003; Karner et al., 2003; Karner and Gambôa, 2007;).

Based on seismic observations and ostracod and palynomorph zonations in northern Angola, Gabon and Congo, the Sag can be subdivided into three higher frequency sequences, dated Early to Late Barremian, Late Barremian to Early Aptian and Early to Mid-Aptian (Grosdidier et al., 1996; Braccini et al., 1997; Steven and Abreu, 1998; Bate, 1999; McHargue, 1990; Harris, 2000; Karner et al., 2003; Karner and Gambôa, 2007) The last Late Sag sequence, typified by evaporitic carbonates and anhydrite, is interpreted as being the result of a widespread shallow-marine incursion and represents the onset of the 2nd-order marine transgression that includes the Salt Loeme Formation and ends with the post-salt Albian succession (Grosdidier et al., 1996; Braccini et al., 1997).

3. Stratigraphy of the Namibe Basin

Extensive volcanic complexes, called the Bero Volcanics, unconformably overlie the basement at the surface in the south of the Namibe Basin. They consist of tholeitic basalts and quartzites that interlayer with metre-thick volcaniclastic and aeolian to fluvial sandstones (Fig. 2). Onshore, the volcanics are believed to be temporal correlative to the Parana-Etendeka igneous provinces dated around 130 ± 2 M.y. (Rennes et al., 1996; Marsh et al., 2001). Oblique rift faulting and rotations have created a highly segmented topography in the upper part of the Bero volcanics, which are locally characterised by tilted blocks and half-grabens, and are cross-cut by many incised palaeo-valleys. As a result of this inherited rift-related tilting morphology and incisions, the upper Bero Volcanics are interpreted as having been largely removed, as indicated by a regional unconformity at the surface that implies a significant time gap within the “pre-salt” stratigraphy.

Dolomitic and siliceous hot spring travertine and tufa associated with water-lain lacustrine marlstones and limestones overlie the Bero volcanics, forming a carbonate-bearing unit, called the Cangulo Formation (Fig. 2). The Cangulo Formation is overlain by the hundreds of metres thick heterolithic Tumbalunda Formation, the base of which consists of gravelly fluvial to alluvial fan facies. The fans pass upward into conglomeratic mouth deltaic bars that are overlain by metre-thick siltstone and organic matter-rich mudstone forming thin-laminated paper-like deposits reminiscent of diatomites. The uppermost part is mainly composed of siliciclastics, evaporites and carbonate beds (Figs. 2, 3). Hydrothermal vents, 5 to 6 m high, are preserved in the northern Tumbalunda area.

Three main correlative centimetre- to metre-thick carbonate and evaporite units, respectively, named from base to top Unit 1, 2 and 3, can be regionally mapped out between Bero and Lucira areas (Figs. 1, 2, 3). Carbonates mostly consist of thinly laminated stromatolites, whereas evaporites show gypsum and mudstone beds. Metre- to decametre-thick coarsening-upward units made up of sandy marlstone and cross-bedded pebbly to cobbly sandstones constitute interbedded units and are interpreted as marine shallowing-upward deltaic packages influenced by mixed flood and tidal processes.

The Tumbalunda Formation displays an overall transgressive fining-upward trend that progressively onlaps and oversteps landward the former faulted topography of the Bero Volcanics and the older palaeo-valleys initiated during the Permo-Jurassic (Fig. 2). It is also conformably overlain by the mid-Aptian “Salt” Bambata Formation, which is interpreted as mainly being dissolution-related secondary gypsum beds at outcrop (Gindre-chanu et al., 2014) but occurs as massive halite seaward, called the Loeme Formation.

Thinly laminated to nodular whitish to reddish gypsum beds (1- to 5-m-thick) can be locally observed at Bero, Gaio and Tumbalunda. Gypsum beds of Unit 1 are preserved up to 25 m beneath the Bambata Formation (Figs. 3, 4A), whereas the gypsum beds of Unit 3 are located just beneath it (Fig. 4B, D). They either often pass laterally into or are interbedded with carbonates. Clastic interbeds are conformable and gradational with gypsum beds (Figs. 3, 4A, C). Substantial amounts of chalky whitish alunite ($KAl_3(SO_4)_2(OH)_6$) are preserved over the underlying sandstone of gypsum Unit 2 in Tumbalunda (Fig. 4D). At some locations, the pre-salt to salt transition is marked by organic matter and native sulphur (Fig. 4E).

The carbonate beds of Unit 3 are thin, ranging from 5 to 10 cm thick, whereas the carbonate beds in Units 1 and 2 reach up to 4 m thick.