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The West African salt-bearing rifted margin—Regional structural variability and salt tectonics between Gabon and Namibe

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Abstract

Salt-bearing rifted margins comprise some of the most structurally complex and economically important sedimentary basin settings such as the South Atlantic and the Gulf of Mexico salt basins. They are also involved with some of the largest uncertainties regarding the crustal and syn-rift basin architecture and supra-salt tectonic evolution, as well as the link between rifted margin architecture with salt deposition and post-rift gravity-driven salt tectonics. We thus conduct a margin-scale study along nearly the entire West African salt basin, from South Gabon to Namibe, combining a vast data set of 2D and 3D seismic and well data with gravimetric and magnetic data to analyse its along-strike rift and salt tectonic structural variability. We construct regional structural and thickness maps of key salt and post-salt intervals to depict the history of individual margin segments and to investigate (1) how rifting and rifted margin architecture influences post-rift salt tectonics evolution, (2) how these vary through time and space and (3) what are the controls between their different salt tectonic styles. We show that rifting and rift structures controlled the salt basin geometry, thickness and base-salt relief in different ways for the different margin segments, and drastically influenced their post-rift salt tectonic evolution. Differences in post-salt sediment supply and continental uplift also had a role in their salt tectonic evolution. The results also have general implications to understand the interplay between rifted margin architecture with post-rift salt tectonics for salt-bearing rifted margins.

KEYWORDS

Gliding, Gravitydriven deformation, Rifted Margins, Salt Basins, Salt tectonics, Spreading

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1 | INTRODUCTION

Highlights

- We analyse the styles and controls on structural variability of salt tectonics along the West Africa rifted margin
- Rifting and rifted margin architecture exert a strong control on salt basin geometry and thickness and its post-rift salt tectonic evolution
- There is a significant partition of salt flow seaward and along the margin due to variations in base-salt relief and post-salt sedimentation history

Rifted continental margins are a consequence of lithospheric extension and rifting and, ultimately continental breakup, which leads to the generation of oceanic crust at newly formed spreading axes (Buck, 1991; Huismans & Beaumont, 2011, 2014; McKenzie, 1978; Peron-Pinvidic et al., 2013). The style of rifting and the width, and geometry of rifted margins are influenced by several factors including crustal and lithospheric mantle rheology, thickness, temperature, composition and inherited fabrics as well as magmatism, surface processes and variations in time and space in 3D rift kinematics (Brune et al., 2014; Buck, 1991; Huismans & Beaumont, 2003; Lavier & Manatschal, 2006; Neuharth et al., 2022; Sapin et al., 2021; Theunissen & Huismans, 2019). Another important control on passive rifted margin architecture and evolution is the occurrence of thick (generally >2 km) and widespread evaporite (i.e. salt) deposits. These are typically highly mobile, deforming in a ductile viscous manner and producing remarkably complex structural styles and basin evolution (cf. Jackson & Hudec, 2017; Pichel et al., 2022a, 2022b; Rowan, 2014).

Salt-bearing rifted margins comprise some of the most hydrocarbon-prolific and prospective basin settings owing to the exceptional sealing capacity and thermal conductivity of thick salt layers and/or to the presence of salt structures (e.g. diapirs and pillows), which control the development of depocentres and produce excellent structural traps (Callot et al., 2016; Jackson & Hudec, 2017). Notwithstanding, salt-bearing margins are commonly associated with significant uncertainties, among which their post-rift salt tectonic evolution (cf. Hudec et al., 2013; Hudec & Norton, 2019; Jackson, Jackson, & Hudec, 2015; Jackson, Jackson, Hudec, & Rodriguez, 2015; Pichel, Huuse, et al., 2019; Pichel et al., 2020; Pichel & Jackson, 2020), and the characterization of the underlying rifted margin nature and tectonostratigraphic architecture (cf. Epin et al., 2021; Fernandez et al., 2020; Izquierdo-Llavall et al., 2022; Kumar et al., 2013; Norton et al., 2016; Pichel et al., 2022a, 2022b; Sapin et al., 2021; Zalán et al., 2011). The first type of uncertainty is related to the ability of the salt to flow and its high seismic velocity, producing complex and often sub-vertical geometries, which hamper seismic imaging. The second relates to the fact that thick, often highly deformed and heterogeneous salt bodies obscure the imaging of sub-salt rocks (Davison et al., 2012; Jackson & Hudec, 2017; Jones & Davison, 2014; Rowan et al., 2004). For those reasons, salt-bearing margins are typically more challenging and less well-understood than their salt-poor or salt-free counterparts (cf. Lentini et al., 2010; Sapin et al., 2021).

Examples of salt-bearing rifted margins include the Gulf of Mexico (Hudec & Norton, 2019; Izquierdo-Llavall et al., 2022; Rowan, 2020), Nova Scotia-Newfoundland, SW Iberia and NW Africa in the Central Atlantic (Alves et al., 2003; Deptuck & Kendell, 2017; Tari et al., 2017), the Brazilian and West African margins in the South Atlantic (Kukla et al., 2018; Lentini et al., 2010; Marton et al., 2000; Pichel et al., 2021; Rowan, 2020) and the Red Sea (Augustin et al., 2014; Mohriak & Leroy, 2013). In the majority of these examples (except for Iberia and Newfoundland), the salt was deposited during the latest stages of rifting, that is after most of the crustal extension had migrated towards the future distal margin and prior to continental breakup (cf. Araujo et al., 2022; Davison et al., 2012; Epin et al., 2021; Hudec & Norton, 2019; Rowan, 2014). In this case, the salt is deposited as a contiguous basin across both conjugate margins and is later stretched and split into two basins with continental breakup and oceanic spreading (cf. Kukla et al., 2018; Lentini et al., 2010; Pichel et al., 2022a, 2022b; Wardlaw & Nicholls, 1972).

Some of the most outstanding questions in salt-bearing rifted margins revolve around: (1) How do rifting and rifted margin architecture influence their post-rift salt tectonic evolution? (2) How do these vary through time and space across each margin and/or along strike between different margin segments? (3) What are the controls between their different salt tectonics structural styles? and, (4) What is the relative timing between rift-related extension, salt deposition and tectonics? These issues are especially relevant for the largest and most complex of these margins, the circum-Gulf-of-Mexico and circum-South-Atlantic, as these are likely to involve greater variability in rift kinematics, crustal rheologies, syn- to post-rift magmatism and basin infill. Nonetheless, few studies have attempted to correlate margin-scale rift architecture with the style and evolution of post-rift salt tectonics along these margins, from either subsurface data (cf. Epin et al., 2021; Izquierdo-Llavall et al., 2022; Rowan, 2020) or modelling (Pichel et al., 2022b).

We, thus, conducted a regional, margin-scale study along nearly the entire West African salt-bearing margin (ca. 1600 km long and up to 400 km wide) to analyse its along-strike rift and salt tectonic structural variability, its controls and evolution (Figure 1). We combine state-of-the-art

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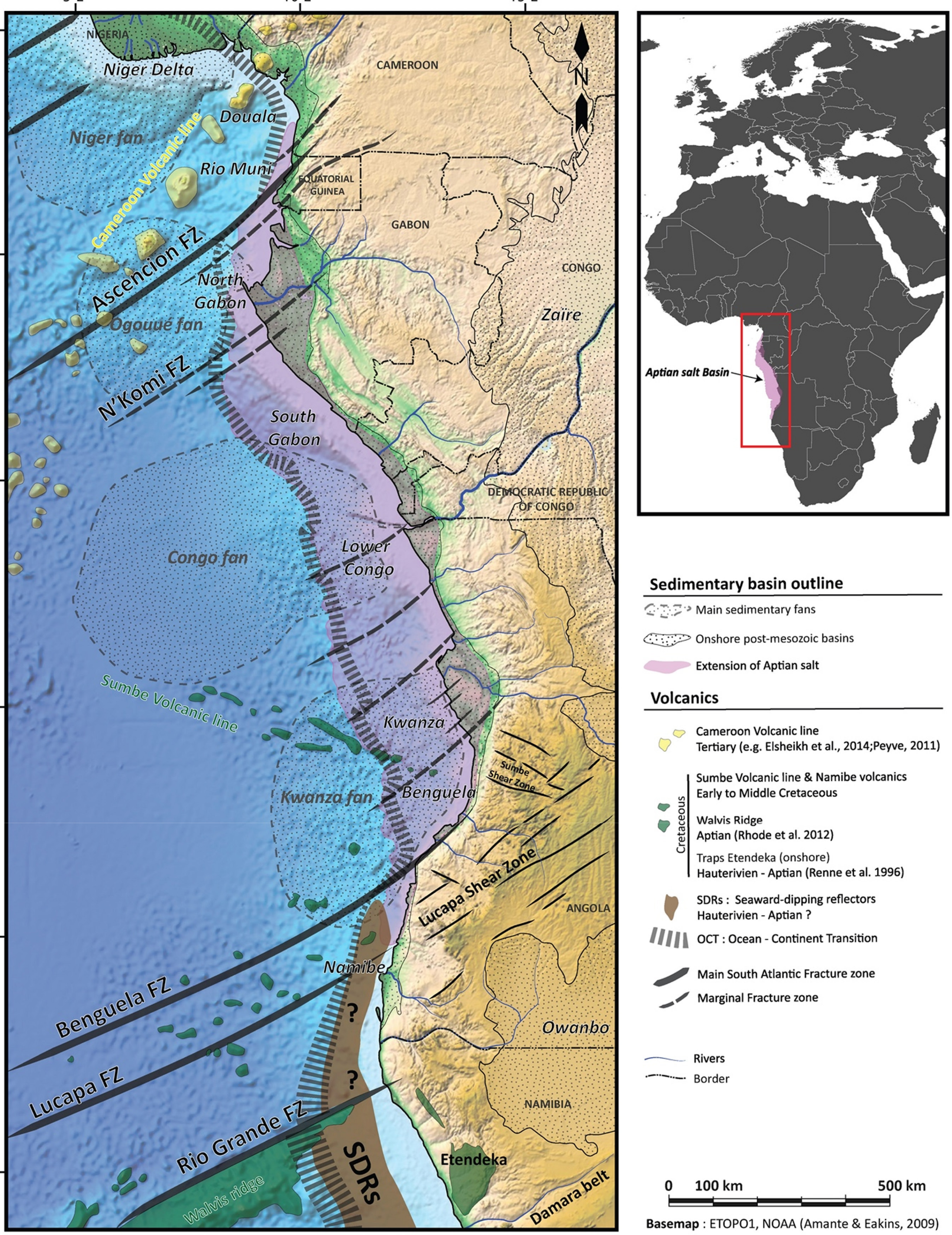

FIGURE 1 Regional map showing the extent and distribution of the Aptian salt basin along the West Africa rifted continental margin, its relationship with transform fault zones, syn-rift SDRs and volcanics and the post-rift Congo and Kwanza fans.

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regional 2D seismic profiles and 3D seismic data (both time- and depth-migrated) with gravimetric and magnetic data and a large set (>100 wells) of proprietary/public/traded wells and internal reports resulting from several decades of exploration by TotalEnergies® along the margin. We examine seven margin-scale transects intersecting key areas in the different salt basin segments along West Africa, namely, from north to south: South Gabon, Lower Congo, Kwanza, Benguela and Namibe Basins (Figure 1). We integrate this large data set and then construct regional structural and thickness maps of key salt and post-salt intervals along these basins to depict their history, structural variability and eventually the link between salt tectonics and rifted margin architecture. This aims to answer, at least, some of the aforementioned questions for the West African margin, but the results presented here have also broader implications, in particular for the understanding of their conjugate margins in Brazil and the Gulf of Mexico.

2 | GEOLOGICAL SETTING

The South Atlantic is typically divided into three segments: Equatorial, Central and Austral segments, which formed during the diachronous, northward-propagating rifting of the supercontinent Gondwana during the Late Jurassic to Early Cretaceous (Heine et al., 2013; Moulin et al., 2005). In the Central South Atlantic, the area of interest in this paper, rifting occurred during the Early Cretaceous times (ca. 143–112 Ma), creating the conjugate continental margins of West Africa and East Brazil (Figure 2, e.g. Heine et al., 2013; Kukla et al., 2018; Lentini et al., 2010; Reston, 2010).

Rifting resulted in the early deposition (ca. 143 to 127 Ma), of a ca. 2–3 km thick syn-rift fluvio-continental succession over tilted fault blocks and half-grabens associated with thinned and stretched continental crust. A late (ca. 127 to 113 Ma), ca. 1–2 km thick syn-rift sequence was deposited in lacustrine to shallow marine environments after most of the fault activity ceased locally and rifting migrated seawards towards the future distal margin. This late syn-rift, a predominantly post-tectonic sequence is often referred to in the literature as the 'sag' sequence (Kukla et al., 2018; Lentini et al., 2010; Unternehr et al., 2010). Rifting also produced various amounts of magmatism and salt deposition on both conjugate continental margins (Buiter & Torsvik, 2014; Chauvet et al., 2021; Davison, 1999, 2007; Planke et al., 2000). The Western Africa salt-bearing rifted margins span laterally for ca. 1700 km between Namibe and Rio Muni (Figure 1). The main thick (>2 km) and wide (>100 km) salt basin occurs between the Ascencion and Benguela Fracture Zones, in between Benguela and North Gabon, with salt deposition being very limited away from these boundaries (Figure 1). A thick, on average 2–2.5 km and locally up to 4 km, Aptian salt (ca. 120–110 Ma) was deposited along most of the Central South Atlantic (Figure 2) (cf. Davison et al., 2012; Hudec & Jackson, 2004; Lentini et al., 2010; Pichel et al., 2020; Rowan, 2020). The relative timing of salt deposition is debatable. Some authors suggest that the salt is post-breakup (cf. Dupre et al., 2007; Norton et al., 2016), but most recent works suggest the salt was late syn-rift to syn-breakup, so that most of the salt was deposited prior to continental breakup and oceanic spreading, but after most of the crustal extension had occurred (Davison et al., 2012; Kukla et al., 2018; Lentini et al., 2010; Rowan, 2014). Salt is, in some places, observed directly on top of tilted blocks on the initial oceanic crust (e.g. Gabon, Epin et al., 2021, Brazil, Araujo et al., 2022). This suggests that it could have been locally deposited during the development of the early oceanic crust or that it was emplaced as allochthonous salt by a combination of crustal extension and seaward salt flow.

In these margins, the post-salt (post-rift) is characterized by deposition of up to ca. 1.5 km thick platform carbonate sequence and deep-water equivalents during Albian (possibly Late Aptian) to Cenomanian following the onset of oceanic spreading and thermal subsidence (Marton et al., 2000, Figure 3). During most of the Late Cretaceous and Cenozoic, sedimentation was dominated by siliciclastic progradation (Figure 3). Volumes and rates of sedimentation, as well as flexural subsidence, varied significantly along strike during this time, owing to (i) variable distribution of sediment pathways, especially in the Congo and Kwanza fan deltas and (ii) the onset of differential continental uplift and erosion during the Oligocene (Hudec & Jackson, 2004; Jackson & Hudec, 2009; Marton et al., 2000). All these factors, coupled with the original salt basin architecture, salt thickness and base-salt relief controlled the post-rift salt tectonics, which was pronounced for all West African salt-bearing margin segments, although highly variable in terms of styles and magnitude.

Both Central South Atlantic conjugate margins display significant along-strike variability in terms of crustal architecture, magmatism, the presence and thickness of Aptian salt, and its post-rift evolution and related salt tectonics (Epin et al., 2021; Kukla et al., 2018). The rift-related variations are attributed to several controlling factors, including inheritance (Salazar-Mora et al., 2018; Stanton et al., 2019), contrasting crustal rheologies (Clerc et al., 2018; Sapin et al., 2021; Theunissen & Huismans, 2019), magmatic budgets (Tugend et al., 2020) and 3D variability in rift kinematics (Brune et al., 2018; Heine et al., 2013). Their post-rift variability is related to variable styles and magnitudes of gravity-driven salt tectonics, which in turn were controlled by their post-rift

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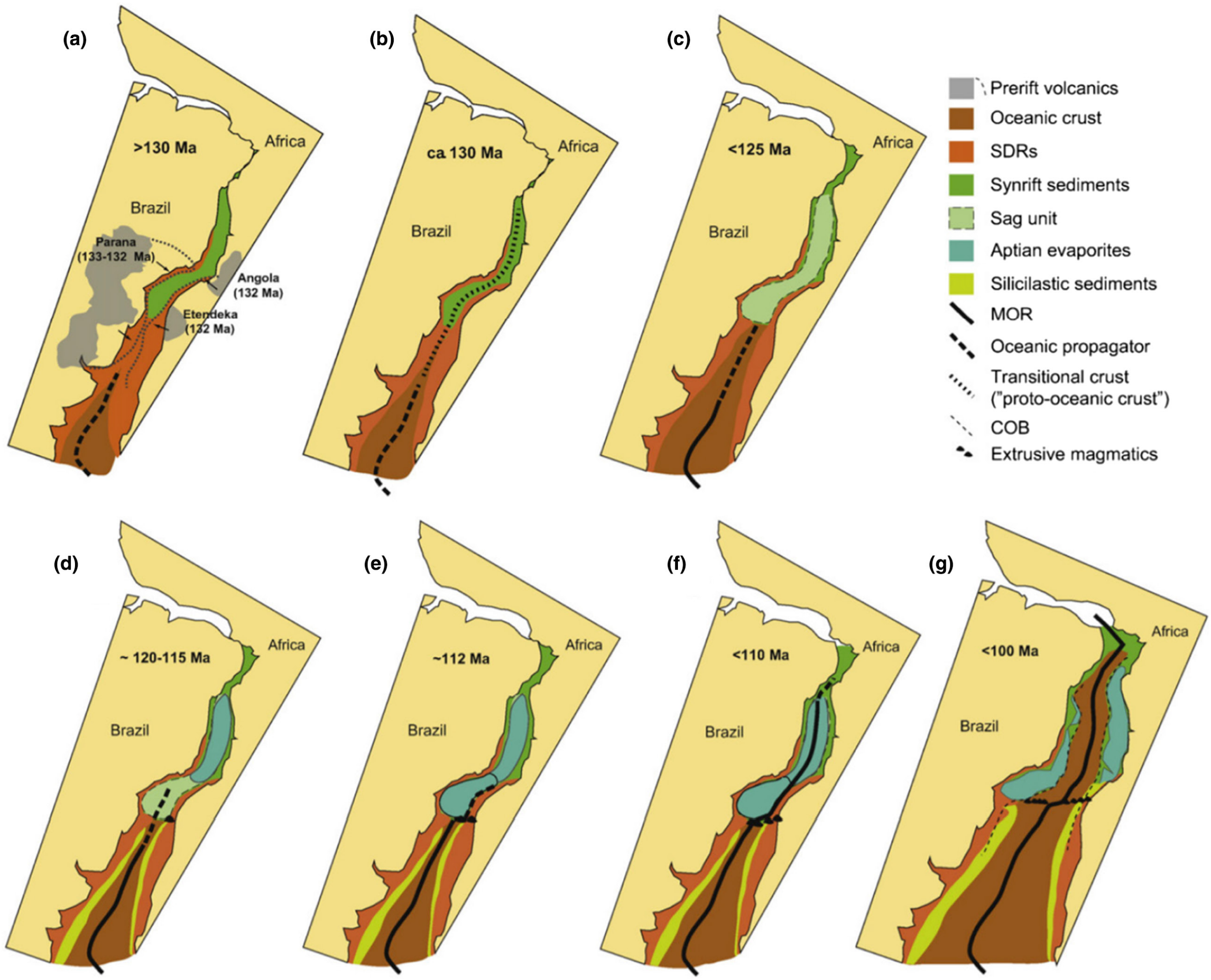

FIGURE 2 Synthetic maps of the South Atlantic geodynamic evolution showing the rift to drift transition and the formation of the conjugate rifted margins between Brazil and West Africa (Kukla et al., 2018). (a) Rifting and syn-rift graben fill in the central segment, initiated by Parana plume onshore Brazil at about 138 Ma (Quirk et al., 2013). (b) Propagation of spreading from the southern segment and emplacement of intrusive magmatic rocks in the central rift basins. (c) Sag basin deposition on top of rifted continental crust (proximal basins) and intrusive magmatics (distal basins). (d) Advancement of the spreading propagator towards the central Santos Basin; onset of the offshore Walvis Ridge; increased siliciclastic deposition in the southern segment; deposition of the older Aptian salt province in the northern part of the central segment. (e) Jump of the embryonic spreading centre towards the African margin; salt deposition in the Santos/Campos Basins. (f) Advancement of the spreading centre through the entire Aptian salt province and breakup. (g) Final post-breakup configuration.

sedimentation and uplift history, and their original salt basin geometries (Figure 3).

3 | DATA SET AND METHODS

3.1 | Data set

This study integrates regional 2D seismic surveys (ION GXT 2D CongoSPAN I & II), comprising ca. 200 lines and a total length of coverage of 14,360 and 30,000 km, respectively (Supporting Information Figure S12). The surveys include both time and depth-migrated seismic, dip and strike-oriented 2D profiles and several 3D seismic surveys covering the Kwanza and Lower Congo margin segments. For this regional study, we focus on the regional GXT 2D lines while complementing our interpretations locally with the intersecting 3D surveys where available. We also integrated gravimetric and magnetic data with the 2D seismic lines to help constrain the deep crustal geometries and domains (see Supporting Information figures). We describe the seismic interpretation and restoration workflow in the Supporting Information.

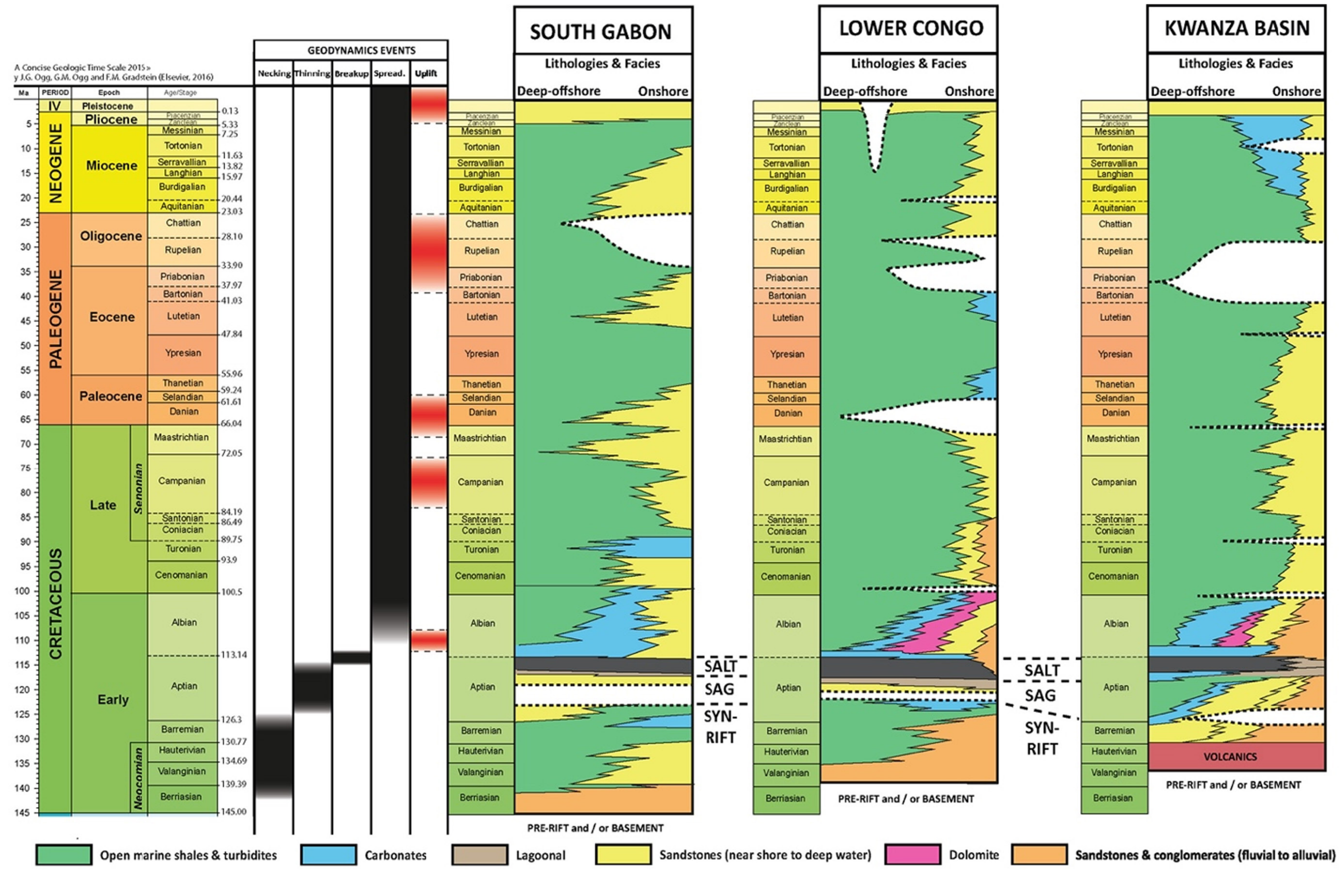

FIGURE 3 Synthetic stratigraphic column for the main salt basins in the study area (Gabon, Lower Congo and Kwanza) and the relationship of sedimentary basin fill with major geodynamic events.

In order to establish the link between salt structural style and rifted margin geometries, we distinguish five main crustal domains (based on Sapin et al., 2021) along the regional profiles (Figure 4 and see Supporting Information). We define the width of the rifted margins by summing the width of each continental crust and OCT domains, not including the oceanic crust domains. The seafloor slope profile and the sediment accommodation across the margin are controlled by the isostatic response of the different domains to the gradual removal of the thermal plume (thermal isostasy) and by the load of sediments and water, and crustal elastic thickness (flexural isostasy).

4 | RESULTS

We define five partially connected but distinct salt basins along the West African rifted margin (Figure 5). These are from north to south:

- The Rio Muni Basin (small-sized, north of Ascension Fracture Zone),
- The Gabon Basin (North and South domains, separated by the N'Komi Fracture Zone),
- The Lower Congo Basin,
- The Kwanza Basin, limited to the south by the Sumbe volcanic ridge,
- The Benguela Basin, limited to the South by the Benguela Fracture Zone,
- The Namibe Basin,

we further divide the Lower Congo Basin, the most complex and structurally variable of these into three segments, namely the Northern, Central and Southern Lower Congo. For simplicity and because we lack similar data coverage there, we do not discuss the North Gabon and Rio Muni basins in this study.

The strike-oriented geoseismic transect extends from the North Gabon Basin near the Ascension Fracture Zone to the northern part of the Namibe Basin (Figure 5). The transect does not run in the same crustal domain but intersects mostly the hyperextended crust (locally, near–exhumed mantle) and the middle-lower slope of the margin. It also intersects the distal part of the salt tectonic domains that are broadly comparable between the different basins. This allows us to describe the first-order along-strike variations in the margin architecture, pre- and post-salt sediment thickness and salt tectonics.

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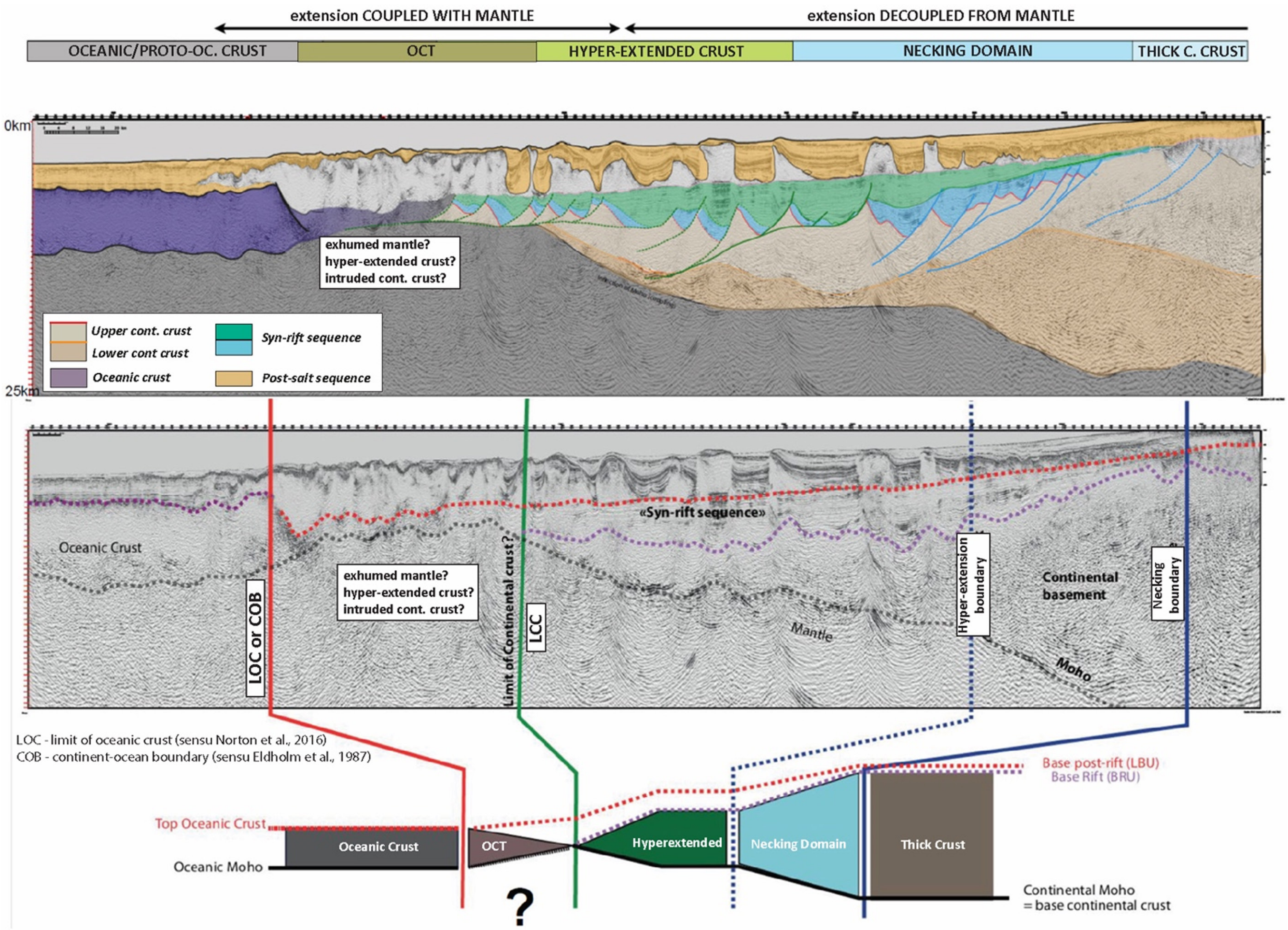

FIGURE 4 First-order rifted margin crustal architecture and domains typical of West African passive margins in the study area: thick-crust domain, necking domain, hyperextended domain, ocean-continent-transition (OCT) and oceanic and/or proto-oceanic domain. The seismic profile is equivalent to the fully interpreted profile from Southern Lower Congo in Figure 7.

Continental crustal thickness is broadly similar along the profile from the Gabon to the Kwanza basins, although second-order variations are observed owing to structural compartmentalization along transfer zones and fault blocks (Figure 5d). In addition, exhumed and/or near-exhumed mantle occur in the Benguela and Namibe basins, and a thicker continental crustal high defining the Benguela Fracture Zone separates Benguela from the Namibe Basin to the south. Pre-salt syn-rift sediment thickness also varies locally over rift faulted blocks but there is a general trend of increasing sediment thickness from the Lower Congo, both towards Kwanza and South Gabon (Figure 5). Post-salt sediment thickness exhibits an opposite trend with the thinnest post-salt in South Gabon and the thickest in Lower Congo (Figure 5d). As for the salt, there is a general increase in salt thickness towards the Benguela Basin in the south (Figure 5c,d). The distal salt is thus broadly thicker in the southern Lower Congo, Kwanza and Benguela basins, but there is greater diapir complexity and a prominent allochthonous salt level in the central portion, between the Central Lower Congo and Kwanza Basins (Figure 5). The salt basin also becomes wider from South Gabon towards Lower Congo and Kwanza, narrowing again towards Benguela until nearly disappearing in Namibe (Figure 5a–c). Base-salt complexity is also generally greater in the central Lower Congo and Kwanza segments (Figure 5a). We describe these structural variations across (i.e. downslope) each basin segment in more detail in the following sub-sections.

4.1 | South Gabon

The South Gabon is characterized by a ca. 180–200 km wide margin defined by predominantly landward-dipping normal faults in the necking domain and seaward-dipping normal faults in the hyperextended domain (Figure 6). Syn-rift faults and basin infill become generally younger and thicker seaward. The faults also tend to become more gently dipping and to detach at broadly deeper crustal levels oceanward towards a ca. 30 km wide OCT with localized near-exhumed to exhumed mantle (cf. Epin et al., 2021).

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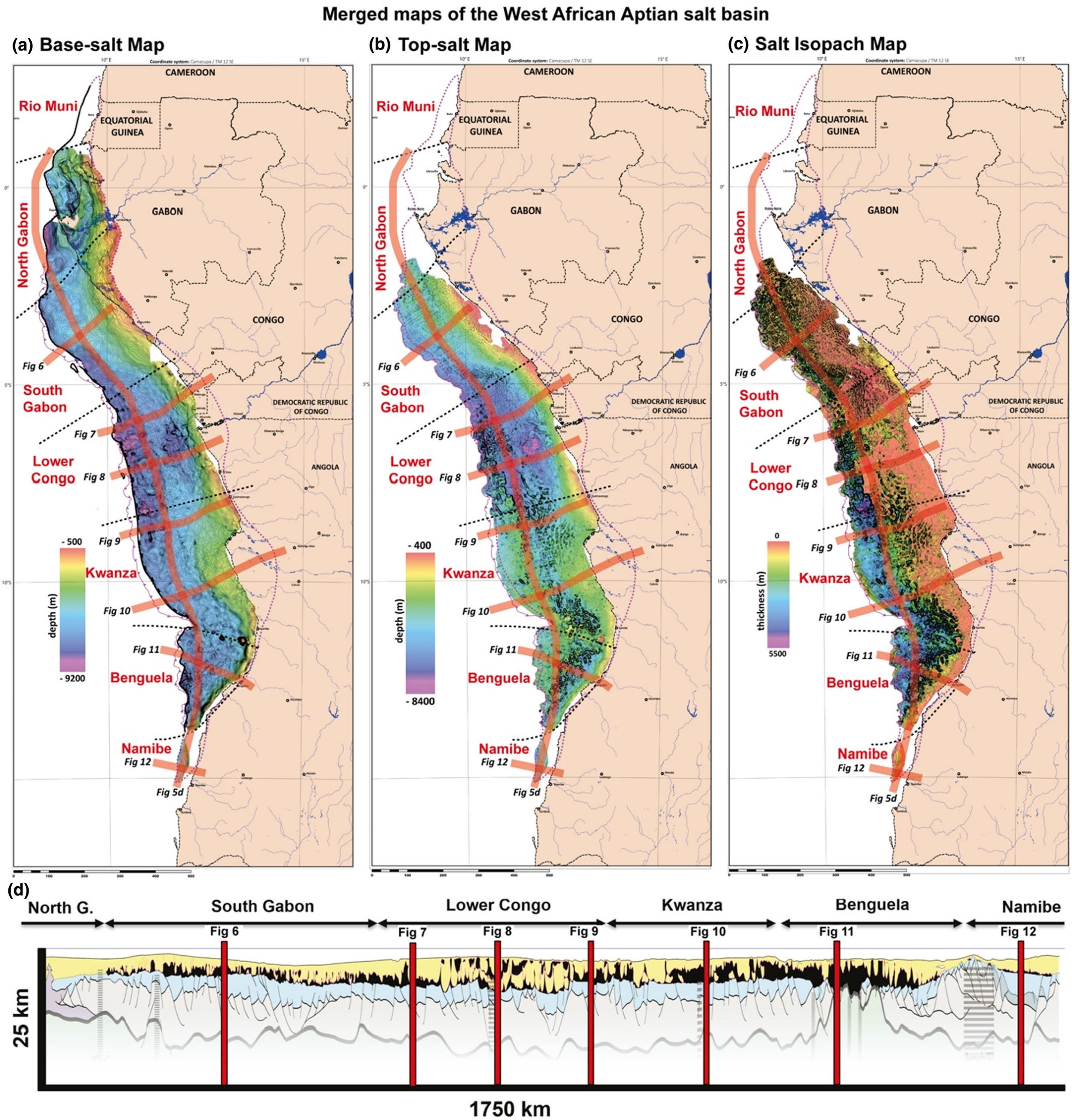

FIGURE 5 Regional maps of the West African Aptian salt basin in depth: (a) base-salt, (b) top-salt and (c) salt isopach. Dashed black lines represent the salt sub-basins limits and the purple dashed line corresponds to the onshore limit of the salt basin. (d) Strike-oriented profile showing the variability of crustal, syn-rift, salt and supra-salt thickness and geometries along the margin. Vertical dashed lines/zones of various widths in (d) correspond to the main transfer zones. Pale green: mantle; pale brown: continental crust; purple: oceanic crust; blue: pre-salt deposits; black: salt; yellow: post-salt deposits.

The syn-rift sequence has an approximate average thickness of 4 km, but it reaches up to ca. 6 km in between the necking and hyperextended domains until drastically thinning and pinching out against the newly formed oceanic crust. The salt basin is ca. 200 km wide in this profile, with the distal ca. 20 km corresponding to an allochthonous salt nappe overriding both pre- and younger post-salt sediments over the OCT and oceanic crust domains (Figure 6). The base-salt is broadly smooth across most of the margin owing to the generally very thick pre-salt sediments fully filling (fill-to-spill) the rift-related depocentres (Figure 6). A few exceptions occur such as between 180 and 200 km

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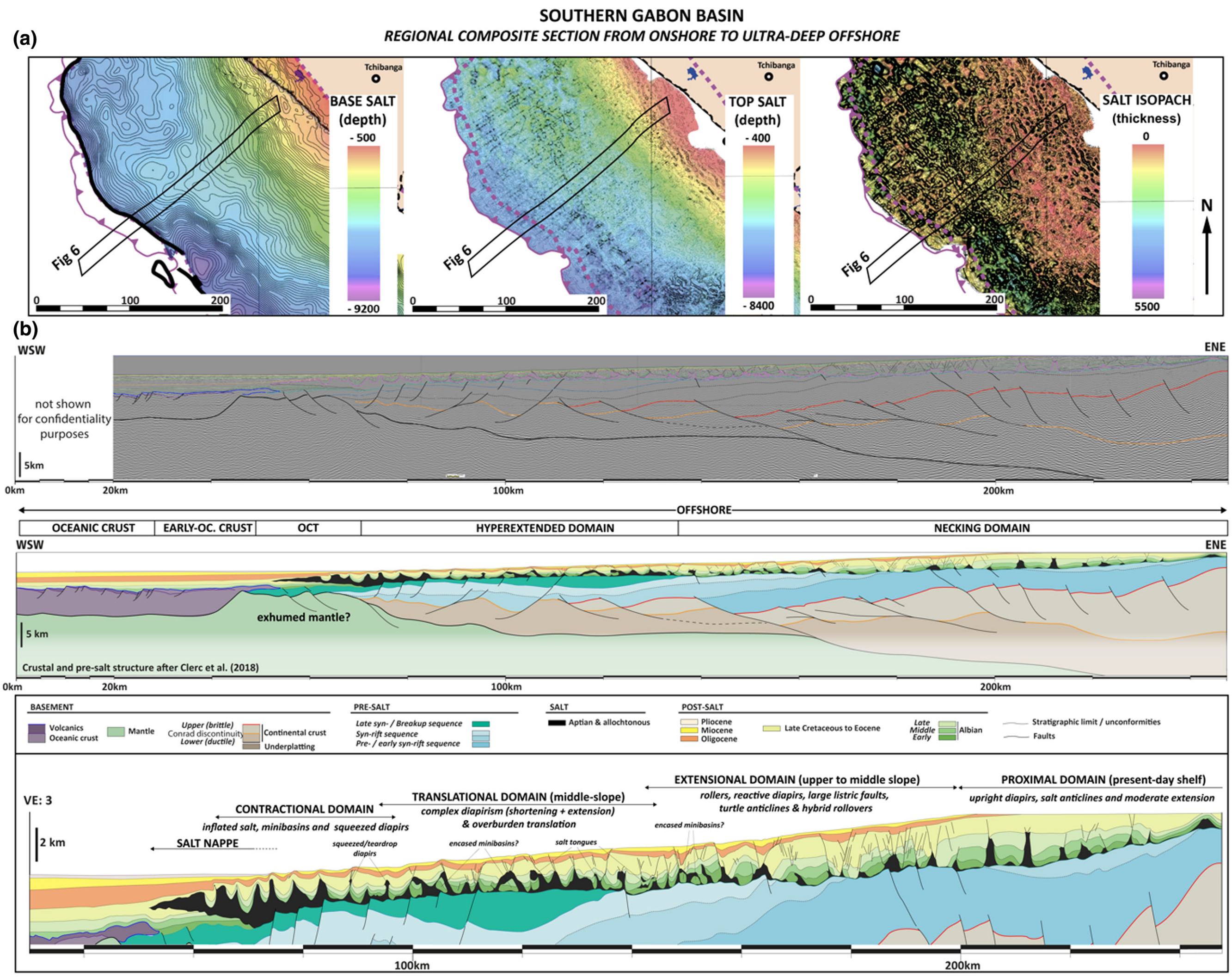

FIGURE 6 South Gabon panel with (a) base-, top- and isopach salt maps and (b) the key regional profile across the margin. The profile display follows a partially interpreted seismic profile, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note that the OCT domain is characterized by higher uncertainty and complexity owing to the juxtaposition of various crustal lithologies, possible mantle exhumation and magmatism, with potential highly thinned continental crust preserved. The final profile shows a zoom of the salt basin with the definition of the main salt-related structural domains and a description of their key salt structures with a vertical exaggeration of 3:1. The approximate profile location is given in (a).

along the profile where a broad, <1 km tall base-salt high is observed, and at the most distal edge of the salt basin, where the base- and lower section of the salt sequence is faulted by a set of seaward-dipping normal faults affecting the late syn-rift sediments (Figure 6).

Underneath the present-day shelf, the proximal salt basin is characterized by small (<1 km tall) reactive diapirs associated with small extensional rafts, turtles and/or rollovers and predominantly seaward-dipping normal faults (Figure 6). The autochthonous salt level is largely depleted in between the salt structures, although a few salt anticlines and larger (ca. 3 km tall) diapirs are also observed further seaward. Albian-Upper Cretaceous growth strata indicate the timing of the development of these structures. Seaward, underneath the upper-middle slope, there is another set of reactive diapirs, which are broadly more symmetric and associated with either landward- and/or seaward-dipping normal faults and rollovers (Figure 6) These faults are also larger, extend vertically for >5 km, and younger, offsetting Albian to Paleogene-Neogene strata. In a few locations, there is an absence of Albian strata indicating significant, >5 km of extension and/or the presence of earlier, Albian-age salt diapirs that later collapsed under post-Albian extension (Figure 6). The largest post-Albian rollovers in this area dip seaward and are either bounded by landward-dipping listric faults or collapsed diapirs, occasionally forming turtle structures, all indicating a hybrid salt expulsion-extension origin.

Under most of the lower slope, there is a series of narrow, squeezed, ca. 2–3 km tall diapirs associated

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with minibasins of Albian-Late Cretaceous age, some of which are also offset by Paleogene-Neogene normal faults (Figure 6). Some of these diapirs also appear to develop teardrop geometries and/or allochthonous salt tongues in their seaward flanks and significant near-diapir strata upturn. The degree of Paleogene-Neogene extension decreases seaward until disappearing towards the abyssal plain. Conversely, the size and complexity of the diapirs in the lower slope increase seaward, with many of them becoming more seaward-leaning and fully squeezed (i.e. vertically welded), occasionally forming salt tongues. They also tend to present greater stratal upturn and uplift associated with slightly rotated and occasionally encased minibasins (Figure 6). In the abyssal plain, the distal domain is mainly characterized by thick (ca. 2–3 km) and inflated salt above a base-salt low. This domain displays broadly simpler, upright diapirs with bowl-shaped minibasins of mostly Late Cretaceous-Neogene age, before transitioning into the distal ca. 20 km wide salt nappe (Figure 6). The nappe presents similar, albeit smaller diapirs and subtle buckle-folding and/or thrusts at its distal edge.

4.2 | Northern Lower Congo

The Northern Lower Congo margin is ca. 240–250 km wide offshore, with an additional ca. 30 km onshore. It is defined by sets of seaward- and landward-dipping normal faults in the proximal domain and predominantly seaward-dipping normal faults in the necking and hyperextended domains (Figure 7). The widespread occurrence of the early syn-rift interval suggests that rifting was broadly coeval across the proximal and necking domains (ca. 180 km) but with a late abrupt migration towards the hyperextended and OCT domains (Figure 7). This indicates that rifting was in general more widely distributed than in Gabon. The margin contains a ca. 2 km thick pre-salt syn-rift succession on average, with a maximum of ca. 3.5 km in the distal trough in the transition between the necking domain and the distal high, before passing into a ca. 1–1.5 km thick succession over the OCT.

The salt is widespread along the margin, forming a ca. 300 km wide salt basin from which the most distal ca. 30–40 km corresponds to an allochthonous salt nappe overriding post-rift Albian sediments over the near-exhumed mantle and early oceanic crust. The nappe overlies a moderately deformed, ca. 20 km wide and ca. 1 km thick salt layer directly on top of the early oceanic crust (Figure 7b). The base-salt is broadly smooth in the proximal domain, but it becomes gradually more rugose towards the necking domain over inherited rift topography and underfilled half-grabens (Figure 7). There are also large (ca. 1 km) offsets of the base-salt over relatively larger and younger syn-rift faults near the distal high and the outer trough, suggesting these were active, at least during, but possibly after, salt deposition (Figure 7).

The proximal salt is relatively thick (ca. 1 km) and undeformed apart from very subtle folding in the transition to the necking domain (Figure 7b). In the necking domain, the base-salt dips gradually seaward and seaward-dipping listric normal faults associated with salt rollers and extensional rollovers and/or turtles become widespread. These structures were mostly active during the Albian and Late Cretaceous as indicated by their equivalent-age growth strata. The faults located approximately in the middle of this area appear to have been active also throughout most of the Cenozoic, forming a Cenozoic Trough (Figure 7b). This ca. 100 km wide extensional domain is delimited seaward by a ca. 6 km tall, nearly welded and broadly upright diapir located directly above a major base-salt step (Figure 7b). The diapir shows evidence of early (ca. Albian-Upper Cretaceous) rise driven by sediment loading and late (ca. Paleogene-Neogene) diapir squeezing by shortening with significant near-diapir strata upturn and overburden uplift.

Seaward, over the distal high, there is a contractional domain characterized by an early fold-thrust belt with inflated salt anticlines and a series of seaward-verging, ca. 2 km tall thrust-fed diapirs (Figure 7b). These were active predominantly during the Albian and Late Cretaceous as indicated by their growth strata. The most distal of these thrust-fed diapirs show evidence of Paleogene reactivation with normal faulting and development of prominent seaward-dipping extensional rollovers (Figure 7b). The contractional domain passes seaward, beyond the distal high, into a zone of inflated, thick (ca. 1–2 km) salt. This zone displays proximal salt anticlines and large (ca. 4–6 km tall) distal diapirs and minibasins (Figure 7b). The diapirs show evidence of early (ca. Albian), load-driven diapirism and late (ca. Late Cretaceous-Neogene) squeezing, with the development of both seaward- and landward-verging geometries with slightly rotated minibasins. Some of these diapirs develop roof-thrusts and/or uplift their ca. 1–2 km thick roofs. The distal end of the salt basin is characterized by a <1 km thick salt nappe overlain by salt-cored buckle folds and/or thrusts of Albian-Neogene age.

4.3 | Central Lower Congo

The Central Lower Congo margin presents a similar crustal-scale margin architecture and width to the Northern Lower Congo, although with a slightly thicker, ca. 3 km thick on average, pre-salt syn-rift succession (Figure 8a). The main difference corresponds to the near-complete absence of an exhumed mantle domain, with

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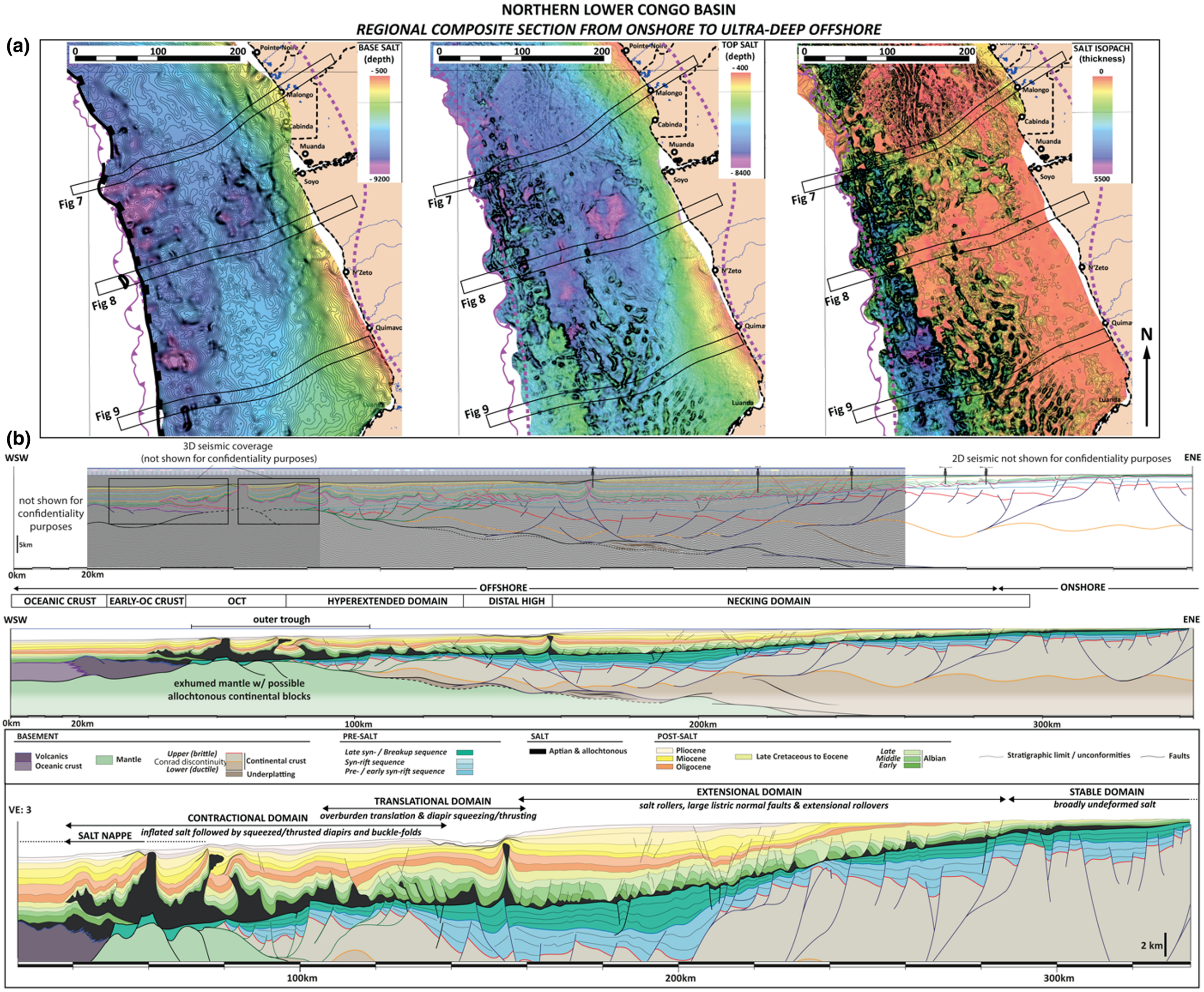

FIGURE 7 Northern Lower Congo panel with (a) base-, top- and isopach salt maps and (b) the key regional profile across the margin. The maps show the approximated location of three profiles for all Lower Congo segments (see Figures 10 and 11). The profile display follows a partially interpreted seismic profile, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note that the OCT domain is characterized by higher uncertainty and complexity owing to the juxtaposition of various crustal lithologies, possible mantle exhumation and magmatism, with potential highly thinned continental crust preserved. The final profile shows a zoom of the salt basin with the definition of the main salt-related structural domains and a description of their key salt structures with a vertical exaggeration of 3:1.

the domain of hyper-thinned continental crust passing directly into early oceanic crust (Figure 8a). The salt basin is only slightly narrower, being ca. 260 km wide, of which ca. 20 km corresponds to the distal allochthonous salt nappe (Figure 8). The style and distribution of deformation are, however, notably different (Figure 8b).

The proximal margin domain has very thin, <0.5 km thick salt, which is also broadly undeformed, apart from very subtle, long-wavelength folding (Figure 10b). Similar to the Northern Lower Congo segment (cf. Figure 7), the bulk of updip salt deformation initiates in the necking domain with the development of large, predominantly seaward-dipping listric normal faults associated with extensional rollovers and small salt rollers. These extensional structures were active mainly during the Paleogene-Neogene, as indicated by their growth strata, and little record of Albian-Upper Cretaceous overburden extension (Figure 8b). There is ca. 45 km wide area where the Albian-Upper Cretaceous strata are absent that is bounded seaward by a large landward-dipping normal fault and underlain by a highly depleted salt. This system is analogous to the Albian Gap in the Santos Basin, Brazil in which early extension was accommodated cryptically by diapir widening (cf. Pichel & Jackson, 2020; Rowan et al., 2022).

Further seaward, towards the hyperextended crust domain, the Albian-Late Cretaceous sequence reappears with

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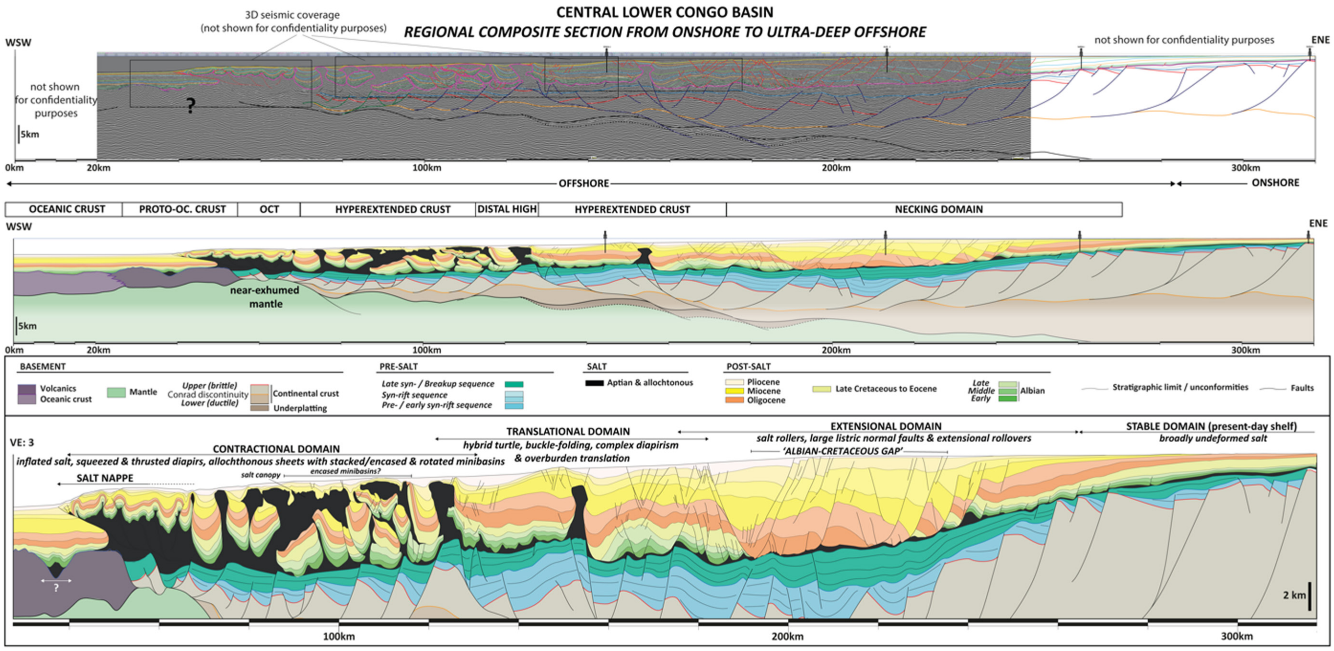

FIGURE 8 Central Lower Congo profile, for location, see Figure 7. The display follows a partially interpreted seismic profile, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note that the OCT domain is characterized by higher uncertainty and complexity owing to the juxtaposition of various crustal lithologies, possible mantle exhumation and magmatism, with potential highly thinned continental crust preserved. The final profile shows a zoom of the salt basin with the definition of the main salt-related structural domains and a description of their key salt structures with a vertical exaggeration of 3:1.

significant thickness (up to ca. 2 km) and growth strata. These together with the Paleogene-Oligocene strata form a prominent (ca. 5 km thick and ca. 20 km wide) turtle anticline (Figure 8b). This turtle is hybrid, with a large seaward-dipping normal fault and associated extension rollover defining its extensional proximal side and an expulsion rollover on its distal side, at the flank of a ca. 5 km tall, moderately squeezed diapir (Figure 8b). Both the bounding normal faults and diapir occur above prominent base-salt highs, the fault above a ca. 0.5 km seaward-dipping ramp and the diapir over a ca. 1 km tall landward-dipping step at the edge of the distal high (Figure 8). There, over the distal high, there are Albian-Upper Cretaceous salt-cored buckle folds associated with, on average, a ca. 0.5 km thick salt. At the distal edge of this high, there is another ca. 5 km tall diapir overlying another prominent (ca. 1 km tall) base-salt step. This diapir displays a more complex geometry associated with a multiphase evolution characterized by early (ca. Albian-Paleogene) load-driven diapirism and, possible minor extension, followed by late (Paleogene-Neogene) shortening and diapir squeezing.

Seaward, over a ca. 40 km wide area in the hyperextended crust domain, there is a drastic increase in structural complexity (Figure 8b). This area is characterized by stacked, commonly rotated ca. 3–4 km thick, encased minibasins associated with squeezed diapirs, thrust-welds and salt tongues as well as large, ca. 25 km wide allochthonous salt sheets. There are possibly two levels of salt sheets, a primary one formed around the Albian-Upper Cretaceous boundary and another around the Oligocene-Miocene (Figure 8b). There is evidence of both overburden shortening and extension in this area, which occasionally overlap vertically with sub-salt sheet shortening and diapir squeezing, and supra-salt extension (Figure 8b). The largest of these sheets occurs seaward and forms a ca. 20 km wide Miocene-age canopy by coalescence of 4 to 5 diapirs, being ca. 2–2.5 km thick. This canopy passes seaward into two highly squeezed, ca. 4 km tall teardrop diapirs that are laterally connected with the canopy by a ca. 1.5 km thick salt at their base (Figure 8b). The most distal of these diapirs is bounded seaward, in the transition to the distal salt nappe, by a ca. 6 km thick bowl-shaped minibasin before passing into a ca. 30 km wide area of highly inflated, ca. 4.5 km thick salt associated with salt-cored buckle folding and thrusting. The entire distal area, beyond the distal high, shows long-lived multiphase deformation spanning from the Albian to the present (Figure 8b). It occurs over a base-salt low that is associated with a more rugose, likely faulted base-salt and an originally thicker salt.

4.4 | Southern Lower Congo

The Southern Lower Congo presents a similar crustal-scale margin geometry to the other Lower Congo segments, with a ca. 260 km wide margin and a similar style of faulting but a thicker (ca. 4–5 km) pre-salt syn-rift succession over

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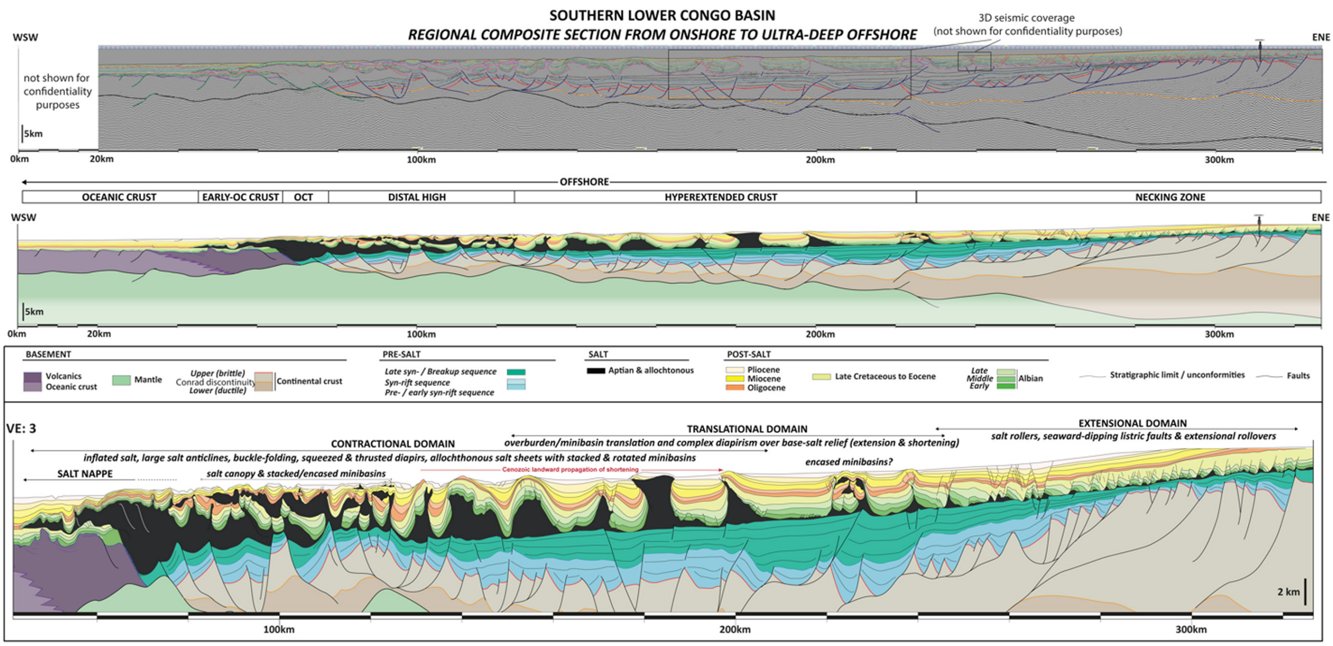

FIGURE 9 Southern Lower Congo profile, for location, see Figure 7. The display follows a partially interpreted seismic profile, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note that the OCT domain is characterized by higher uncertainty and complexity owing to the juxtaposition of various crustal lithologies, possible mantle exhumation and magmatism, with potential highly thinned continental crust preserved. The final profile shows a zoom of the salt basin with the definition of the main salt-related structural domains and a description of their key salt structures with a vertical exaggeration of 3:1.

the necking and hyperextended domains (Figure 9a). The main difference is the absence of exhumed mantle at the OCT. There is negligible base-salt relief over the necking and most of the hyperextended domains. The distal part of the hyperextended domain, however, displays several base-salt highs and lows with up to ca. 1.5 km of relief, many of which appear to indicate syn-salt extension (Figure 9). The salt basin is ca. 280 km wide, of which the most distal 35 km corresponds to the distal salt nappe (Figure 9b).

There is evidence of widespread Albian extension from the proximal and necking domains to the hyperextended crustal domain, over >150 km wide area. The necking domain is characterized by a series of predominantly seaward-dipping normal faults and salt rollers overlain by landward-dipping rollovers, most of which being active only during the Albian and Late Cretaceous. Extension becomes longer-lived seaward with a few normal faults remaining active until the Mio-Pliocene (Figure 9b). This extensional domain is bounded seaward by a set of complex salt structures and minibasins that show evidence of early (Albian) extension and later (ca. Cenozoic) inversion associated with diapir squeezing, thrusting and buckle-folding. This inversion is also associated with a prominent, but localized base-Cenozoic erosional unconformity on the flank of the squeezed diapirs. The most distal ones present a set of complex teardrop diapir geometries overlying Albian salt rollers and extensional rollovers over a ca. 0.5 km high base-salt step (Figure 9b).

Seaward, there is a ca. 80 km wide domain with large, up to ca. 10 km wide and 5 km tall, broadly simple diapirs with equally wide intervening minibasins that show little to no visible post-Albian deformation (Figure 9b). These minibasins occur above extended Albian strata associated with small normal faults and salt rollers above highly depleted (<0.2 km) salt. Overburden deformation in this domain is restricted to the flanks and/or roofs of diapirs and is primarily characterized by Albian extension and post-Albian shortening in the flanks and/or uplift and outer-arc extension over their roofs (Figure 9b). The degree of diapir and minibasin complexity increases seaward, towards the distal high, where we interpret a series of squeezed and/or thrusted, seaward-leaning diapirs associated with rotated and/or stacked and encased minibasins (Figure 9b).

Seaward, beyond the distal high, there is the development of a ca. 30 km wide salt canopy domain and a further increase in structural complexity, as in the Central Lower Congo (cf. Figures 8 and 9). The distal portion of this canopy overlies partially a ca. 2–4 km thick salt above a highly faulted base-salt This lower salt level shows evidence of Albian-Neogene shortening associated with buckle-folding and thrusting and distal salt inflation against a ca. 2 km base-salt high at the transition to the distal salt nappe (Figure 9). The nappe overlies the early oceanic crust and post-salt sediments, displaying only simple buckle-folding and thrusting, and a single, <1 km thick minibasin at its distal end.

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4.5 | Kwanza

The Kwanza is the widest, ca. 320 km, rifted margin in West Africa (Figure 10). Its proximal, onshore crustal domain is characterized by grabens and half-grabens passing seaward into the necking domain to predominantly seaward-dipping low-angle normal faults and associated half-grabens. At the transition between the proximal and necking domains there is also evidence of significant syn- to post-rift magmatism and development of a pronounced, up to 1 km tall, volcanic base-salt high referred to as Cabo Ledo. A ca. 20 km wide distal high marks the transition between the necking and hyperextended domains, the latter being characterized by predominantly landward-dipping normal faults detaching at the Moho and a highly thinned crust with near-exhumed mantle (Figure 10). The pre-salt syn-rift sequence is ca. 1–2 km thick in the proximal and necking domains, thickening seaward into the hyperextended domain where it reaches up to 4 km of thickness. The salt basin is ca. 360 km wide, ca. 40 km of which corresponds to the distal allochthonous salt nappe that lies, in parts, directly on top of early oceanic crust and, further seaward, above early post-salt sediments (Figure 10). The base-salt is flat and smooth throughout most of the proximal, onshore domain, steepening near the necking domain where it forms a large (ca. 30 km wide) relatively steep (ca. 5°–10°) seaward-dipping base-salt ramp. This ramp then passes into a gentler seaward-dipping and highly rugose base-salt over the distal high and hyperextended crust domain (Figure 10).

In the proximal domain, the salt basin exhibits a simple style of deformation characterized by Albian-Upper Cretaceous listric normal faults with little associated diapirism in their footwalls and with slightly dominant seaward-vergence (Figure 10). This proximal domain of limited diapirism and minor extension occurs over a narrow, ca. 25 km wide area where the base-salt dips seaward before passing into an area of broad and simple salt anticlines of similar age above a flat base-salt area (Figure 10). A large, ca. 5 km tall, squeezed, hourglass-shaped diapir of Albian-Paleogene age forms in the transition to the necking domain and directly above the Cabo Ledo High before passing into another extensional domain of Albian-Miocene age. It displays large, ca. 1–2 km tall salt rollers and ca. 4–5 km thick extensional rollovers associated with either seaward- or landward-dipping normal faults (Figure 10). This second extensional domain occurs over an area of rugose base-salt defined by a series of seaward- and landward-dipping steps, in which there seems to be a direct correlation between the location of seaward-dipping post-salt faults

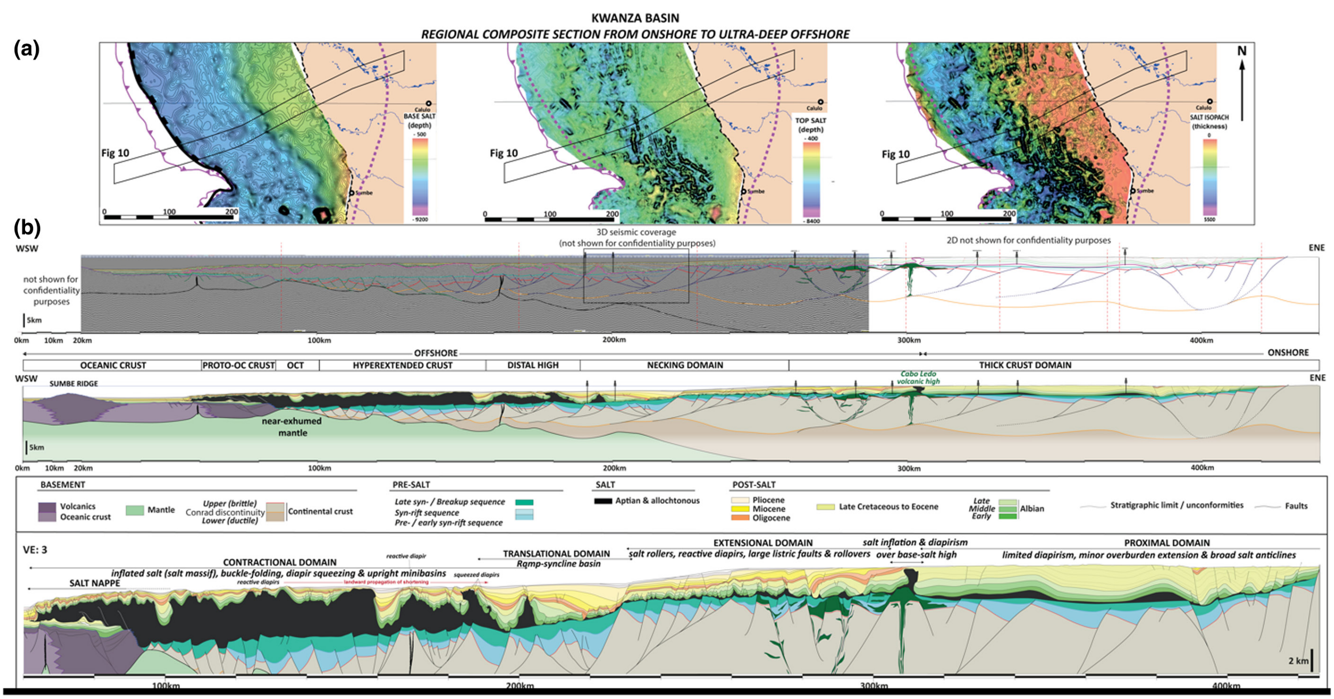

FIGURE 10 Kwanza panel with (a) base-, top- and isopach salt maps and (b) the key regional profile across the margin. The profile display follows a partially interpreted seismic profile, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note that the OCT domain is characterized by higher uncertainty and complexity owing to the juxtaposition of various crustal lithologies, possible mantle exhumation and magmatism, with potential highly thinned continental crust preserved. The final profile shows a zoom of the salt basin with the definition of the main salt-related structural domains and a description of their key salt structures with a vertical exaggeration of 3:1. The approximate profile location is given in (a).

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with seaward-dipping base-salt ramps and vice-versa. Immediately seaward of this domain (between ca. 230 and 250 km mark), there is a series of smaller and shorter-lived (ca. Albian-Paleogene) salt rollers and extensional rollovers, most of which are controlled by seaward-dipping normal faults over the smoother and gentler seaward-dipping base-salt (Figure 10).

A ca. 30 km wide ramp-syncline basin (cf. Jackson & Hudec, 2005) forms where the base-salt steepens seaward in the necking domain (Figure 10). This ramp-syncline minibasin is ca. 5 km thick and characterized by landward-dipping sigmoidal Upper Cretaceous-Miocene growth strata. It records ca. 28 km of salt and overburden seaward translation over the base-salt ramp during Late Cretaceous (possibly Late Albian) to Pliocene times (cf. Evans & Jackson, 2020). This minibasin is bounded seaward by a large, ca. 3 km tall salt anticline of similar age before passing into a domain of highly inflated salt (ca. 3 km thick on average) (Figure 10). This inflated salt domain is ca. 35 km wide and occurs over a highly rugose base-salt distal high. This domain contains a series of salt-cored buckle folds and squeezed, seaward-leaning diapirs in its proximal portion but also a reactive, extensional diapir in its distal portion (Figure 10). A large, ca. 4 km thick wedge-shaped minibasin occurs at its seaward edge above a ca. 1 km thick salt before passing into a remarkably wide (>50 km) and thick (up to 4.5 km) inflated salt plateau (Figure 10). This salt plateau is characterized by salt-cored buckle folds and simple, ca. 1 km tall diapirs and associated minibasins before passing into a ca. 2 km thick minibasin and the distal salt nappe. The salt nappe varies in thickness from ca. 4 to 1 km seaward and presents a similar style of deformation to the adjacent inflated salt plateau, although with shorter-wavelength folds (Figure 10).

4.6 | Benguela

The Benguela rifted margin is significantly narrower than the previous ones, only ca. 160 km wide and characterized by a well-defined, ca. 35 km wide zone of exhumed (or near-exhumed) mantle at its most distal portion, at the OCT (Figure 11). We note there may be potentially a few allochthonous continental crustal blocks preserved in this domain (dashed lines in Figure 11). The margin is dominated by seaward-dipping normal faults, which become generally younger with gentler dips seaward. The pre-salt syn-rift sequence varies from ca. 2 to 5 km thick, being generally thicker over half-grabens in the necking domain (Figure 11). The salt basin is significantly wider than the margin itself, being ca. 230 km wide, of which ca. 45 (possibly ca. 70) km corresponds to an allochthonous salt nappe that overlies exhumed mantle, early oceanic crust and associated volcanic additions (Figure 11). The base-salt is broadly smooth across most of the proximal and thinned crust domains, with only a few, very subtle (<0.5 km tall) base-salt steps owing to the relatively thick pre-salt succession and infilled rift topography. There is a general increase in base-salt relief seaward, with up to ca. 1 km of relief over the distal high and exhumed mantle domains (Figure 11). There is also a general relatively steep (ca. 3°) seaward-dipping base-salt for the entire salt basin.

The proximal salt is very thin (<200 m) with only a few small, relatively low-displacement seaward-dipping normal faults, mostly of Albian age and without any significant diapirism in their footwalls (Figure 11). Extensional deformation becomes greater and longer-lived (ca. Albian-Miocene) seaward, over a ca. 50 km wide area underneath the present-day upper slope, where large (up to ca. 4 km tall), predominantly seaward-dipping normal faults develop (Figure 11). These faults have up to ca. 1 km tall salt rollers in their footwall, occasionally forming Albian rafts and Upper Cretaceous- Miocene extensional rollovers that overlie a highly depleted salt. This extensional domain passes seaward into a broad Albian-Upper Cretaceous turtle structure and further seaward to a ca.10 km wide seaward-dipping expulsion rollover bounding two closely spaced, ca. 4 km tall upright diapirs above the distal high (Figure 11). These diapirs are separated by a ca. 3 km thick bowl-shaped minibasin and from another large diapir seaward by a ca. 10 km wide, ca. 4.5 km thick load-driven turtle structure overlying highly depleted to welded salt (Figure 11). Both the minibasin and the turtle structure are of Albian-Pliocene age.

The distal diapir occurs over a base-salt high at the boundary with exhumed mantle and a steep seaward-dipping base-salt ramp (Figure 11). This diapir is simple, broadly upright in its proximal portion, but it is connected on its distal flank to a strongly squeezed, seaward-verging diapir overlying a highly rotated (ca. 90° seaward), 3 km thick Albian-Paleogene minibasin located directly above the base-salt ramp (Figure 11). This rotated minibasin is overlain by a broadly unrotated Oligocene-Pliocene wedge-shaped minibasin and is bounded seaward by a ca. 60 km wide inflated salt plateau that connects with the distal salt nappe. The inflated salt plateau and nappe have an average of ca. 4.5 km of thickness and are overlain by subtle buckle folds and minibasins of Albian-Paleogene age that are occasionally reactivated by normal faults and reactive diapirs (Figure 11).

4.7 | Namibe

The Namibe margin is the narrowest in West Africa, being ca. 90 km wide, with a ca. 40 km wide necking zone and hyperextended crust domains passing to normal oceanic

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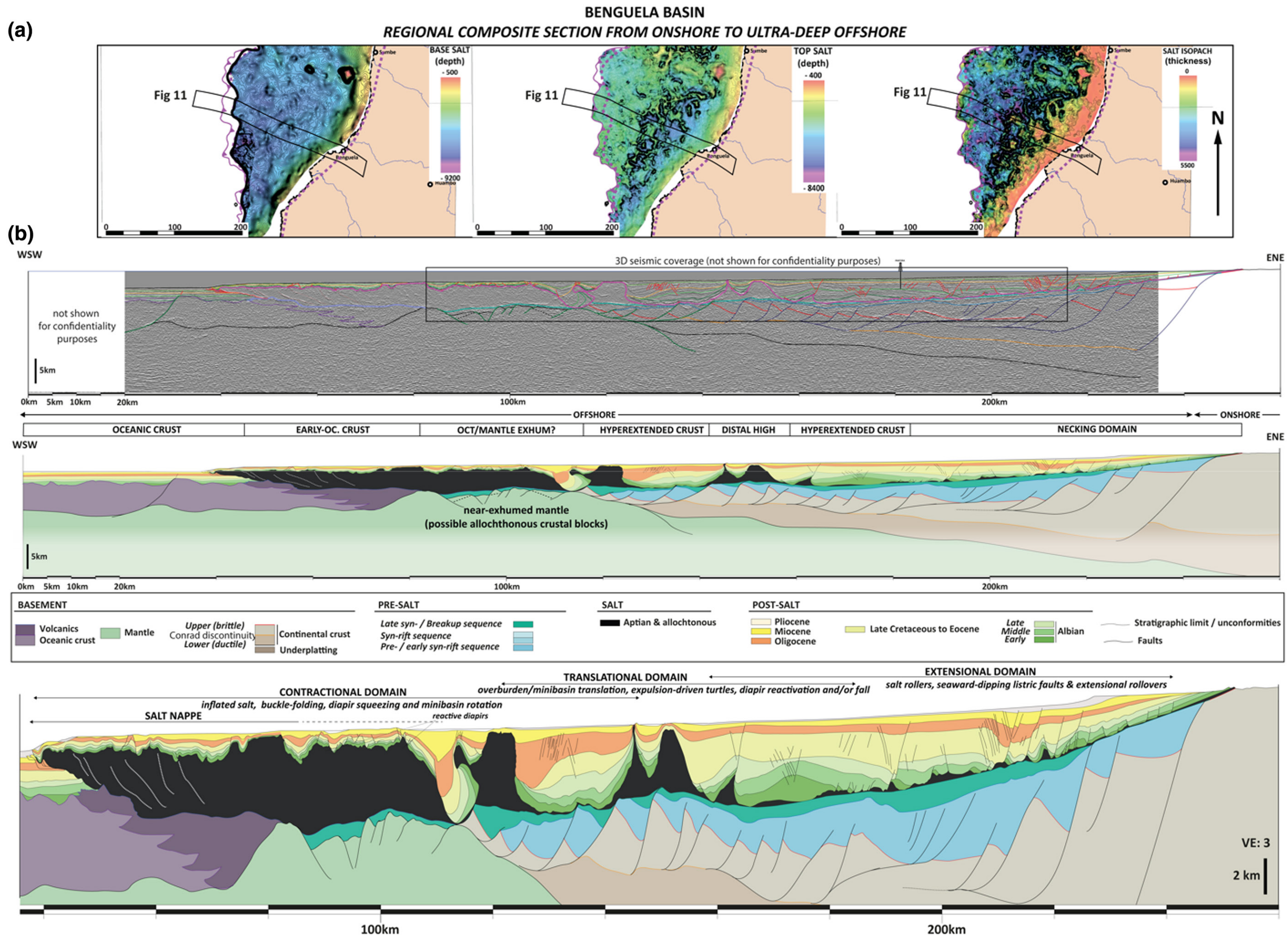

FIGURE 11 Benguela panel with (a) base-, top- and isopach salt maps and (b) the key regional profile across the margin. The profile display follows a partially interpreted seismic profile, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note that the OCT domain is characterized by higher uncertainty and complexity owing to the juxtaposition of various crustal lithologies, possible mantle exhumation and magmatism, with potential highly thinned continental crust preserved. The final profile shows a zoom of the salt basin with the definition of the main salt-related structural domains and a description of their key salt structures with a vertical exaggeration of 3:1. The approximated profile location is given in (a).

crust over a ca. 5 km wide zone of near-exhumed mantle (Figure 12). The margin is dominated by low-angle landward-dipping normal faults, most of which detach at mid-lower crustal levels. They are commonly overlain by thick, ca. 2–4 km of early syn-rift volcanics and/or SDRs before passing into ca. 1–2 km thick late syn-rift sediments (Figure 12). The rotated crustal fault blocks exhibit superb evidence of dykes (i.e. steep high-amplitude seismic events with broadly equal spacing and dimensions, Figures 12 and 13a) that despite being emplaced sub-vertically are rotated by subsequent movement along these faults allowing them to be seismically imaged (cf. Clerc et al., 2018; Phillips et al., 2018; Pindell & Heyn, 2022). The dykes are observed mostly in the lowermost half of the syn-rift sequence, which can be attributed to them not being imaged in the uppermost and significantly less rotated late syn-rift sequence, or that they simply do not penetrate it. The relatively magma-richer nature as well as the geometry of the margin are notably different from the previous examples. Nonetheless, the margin also develops a late syn-rift salt basin, although this is significantly narrower, <40 km wide. In this profile, the salt is localized over the hyperextended crust domain and shows only limited updip extension associated with small Albian-Oligocene normal faults over a highly depleted to welded salt (Figure 12). We note, however, there is also the occurrence of salt further landward and onshore (Gindre-Chanu et al., 2022; Moragas et al., 2023), so that some of the most proximal salt may have been drained downdip or dissolved. The narrow (ca. 10 km wide) extensional domain passes seaward into a ca. 1.5 km thick, ca. 20 km wide salt anticline with Upper Cretaceous-Oligocene growth strata and little additional deformation. Further seaward, at the distal end of the salt basin, there are also two small (<1 km tall) buckle folds

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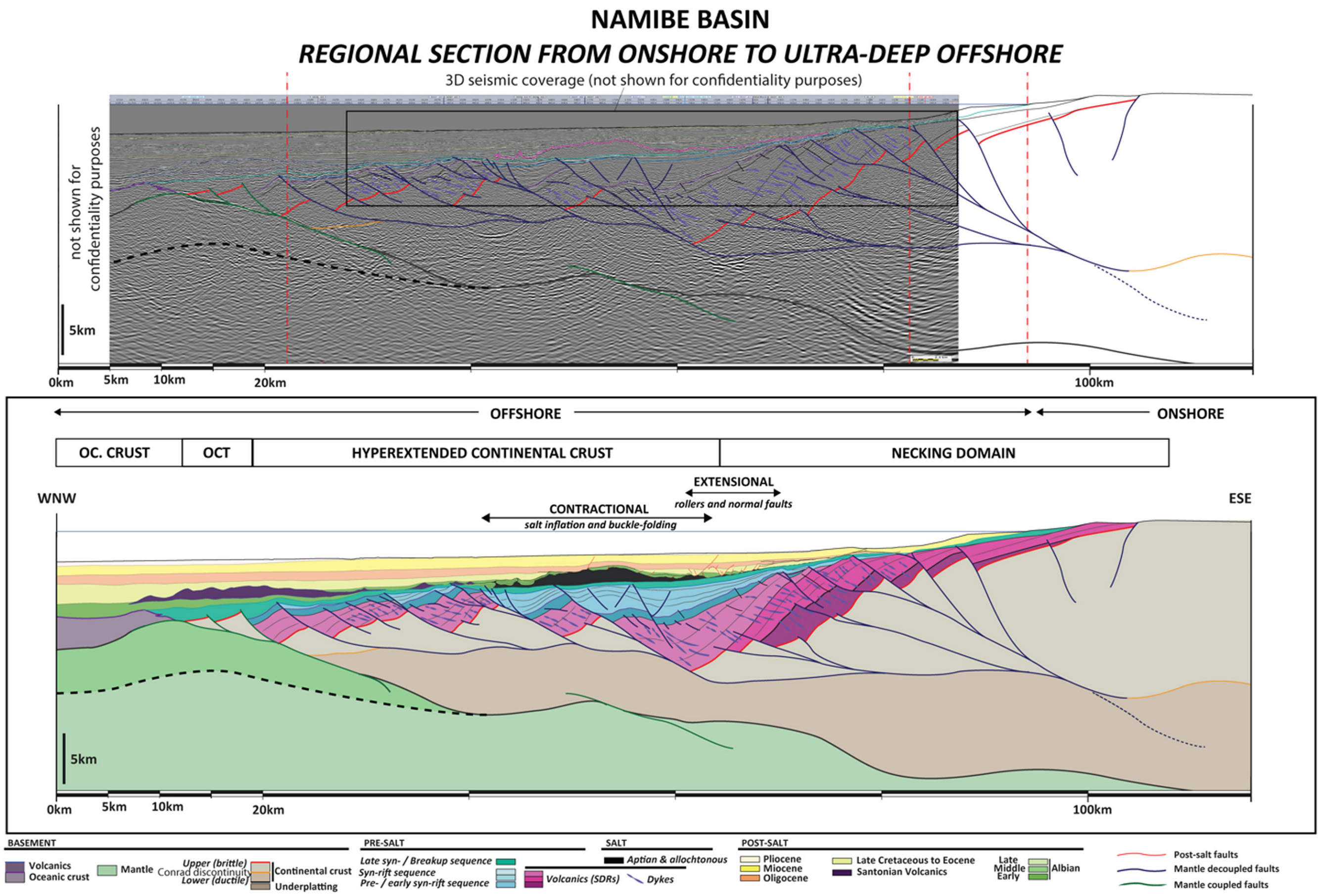

FIGURE 12 Namibe profile, for location, see Figures 7 and 15. The display follows a partially interpreted seismic profile and, a regional geoseismic profile showing both crustal-scale rifted margin domains and structure as well as salt and post-salt structure. Note the presence of thick SDRs and dykes within syn-rift graben and the narrow and simple salt basin compared to the other margin segments. The white box refers to the zoomed image in Figure 13a.

with squeezed diapirs at their crest (Figure 12). There is no salt nappe or significant seaward salt flow in the basin.

4.8 | Salt basin restorations and palaeogeography

Restoration of the original, Aptian salt basin geometry demonstrates how rifted margin width, geometry and structural compartmentalization controlled the salt distribution and thickness along the West African continental margin (Figure 14). This restoration depicts the end of salt deposition time. This occurs during the final stages of continental breakup when the distal margin already underwent a significant thinning of the continental crust (to <8 km of thickness) and/or mantle exhumation, and significant magmatism had begun. The salt is interpreted to have been deposited in shallow waters (ca. 200 m) in the proximal margin but at ca. 1–2 km of water depth in its most distal portion so that the top-salt has a seaward-dipping slope of ca. 0.5–1° at the end of salt deposition (Figure 14) (cf. Epin et al., 2021; Pichel & Jackson, 2020; Rowan, 2020). This is done so that the restored salt thickness in the distal margin is not excessive (>4 km) and inconsistent with the present-day salt area/volume. The top-salt slope is likely a consequence of late syn-rift thermal and tectonic, rift-related subsidence and possible variations in water salinity and/or evaporation across the margin. This is also in agreement with recent models and observations from Hudec and Norton (2019), Rowan (2020), Epin et al. (2021) and Pichel et al. (2021) for the South Atlantic and Gulf of Mexico. The restoration of the salt basin geometry across the Kwanza profile (Figure 10) is comparable to the one presented in Hudec and Jackson (2004). Our restored profile, however, includes a more detailed representation of the rifted margin and base-salt as well as a relatively thinner distal salt due to the initial top-salt slope, which was not included by these authors.

The width of the salt basin and overall 2D salt thickness (volume in 3D) were directly controlled by the width of the rifted margin, with wider margins displaying wider

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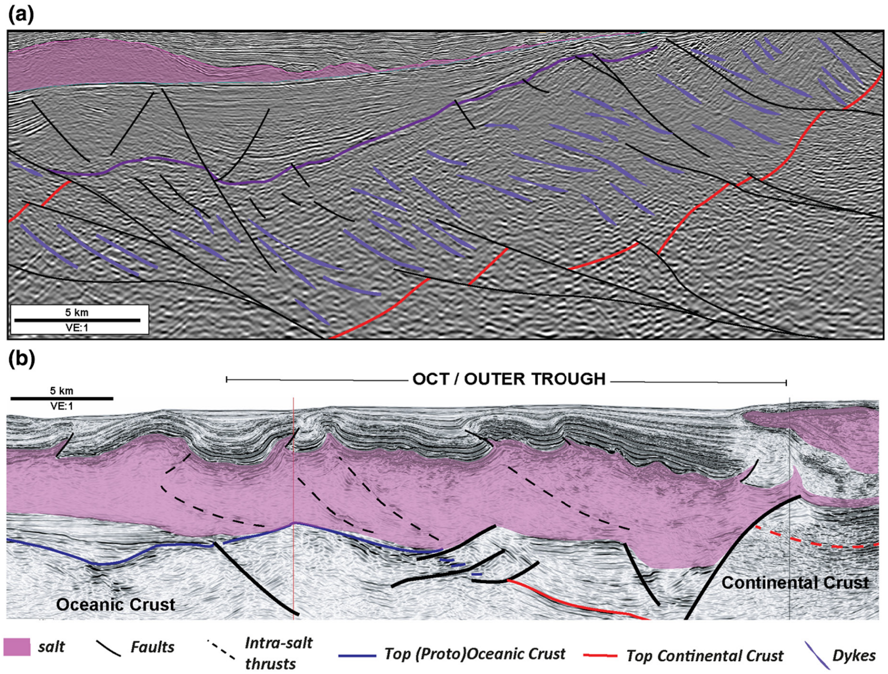

FIGURE 13 (a) zoom of syn-rift dykes and volcanic basin fill (SDRs) in the Namibe Basin from Figure 13. (b) 3D seismic zoom (location undisclosed) from the Lower Congo basin showing key elements of the distal salt basin along the margin: allochthonous salt nappe overlying magmatic/oceanic crust with salt inflation, buckle-folding, intra- and supra-salt thrusts; as well as faulted base-salt in the outer trough (data courtesy from SLB Multiclient and ANPG).

salt basins and greater overall salt volume. Underfilled rift structures such as grabens, half-grabens and structural highs produced base-salt relief that, in turn, created second-order variations in salt thickness across and along the margin (Figures 5 and 14). The base-salt relief may also be associated to a smaller extent with post-salt (i.e. possibly post-rift) fault reactivation, as observed on the other side of the Atlantic, in Brazil (cf. Pichel et al., 2021). In West Africa, the salt over the proximal and necking domains was deposited primarily over inactive rift structures, being generally thin (<1.5 km) and with little (<0.5 km) base-salt relief, as also along most of the Brazilian conjugate margin (Araujo et al., 2022; Pichel et al., 2018).

The structural relief and number of base-salt steps tend to increase seaward from the necking to the hyperextended crust domains where prominent (ca. 1 km tall) base-salt highs and troughs are observed. These are also associated with several smaller base-salt steps and/or ramps (Figure 14). In the outermost trough between South Gabon and Benguela, the salt thickens rather abruptly (from <1 km over the distal high to >2.5 km in the distal trough) and displays a significantly faulted base-salt (Figures 13b and 14). This is particularly more pronounced in the Lower Congo and Kwanza Basins and indicates that the distal salt was deposited during the final stages of crustal extension, which created additional accommodation and likely stretched the most distal salt (cf. Pichel et al., 2022a). This pattern of proximal post-tectonic and distal syn-tectonic salt is consistent with the seaward migration of rifting through time during the various stages of margin building (Araujo et al., 2022; Reston, 2010; Ribes et al., 2020) and has also been observed in other salt-bearing rifted margins (cf. Hudec & Norton, 2019; Pichel et al., 2021; Rowan, 2014).

The distal edge of the salt basin is often marked by an abrupt (>1 km tall) landward-dipping step, between Central Lower Congo and Benguela, which is related to the onset of magmatic accretion and early oceanic crust (Figures 13 and 14). This suggests an important interplay between rift-related stretching, salt deposition and magmatism. It is noteworthy that the most distal salt may be partially allochthonous and associated with lateral salt flow by the latest syn-rift stretching as suggested by recent geodynamic models (cf. Pichel et al., 2022a, 2022b) and observed from modern analogues (i.e. salt namakiers along the Red Sea, Augustin et al., 2014). Some of the distal salt geometries observed in the restoration such as the abrupt top-salt slope in the outer trough (South Gabon, Lower Congo and Kwanza), and thinning and compartmentalization of the outer ca. 10–15 km of the salt (Lower Congo), also support this idea.

5 | DISCUSSION

5.1 | Salt tectonic evolution and gravity-driven processes

We here compare and discuss the temporal evolution of salt tectonics for the entire West African salt-bearing margin.

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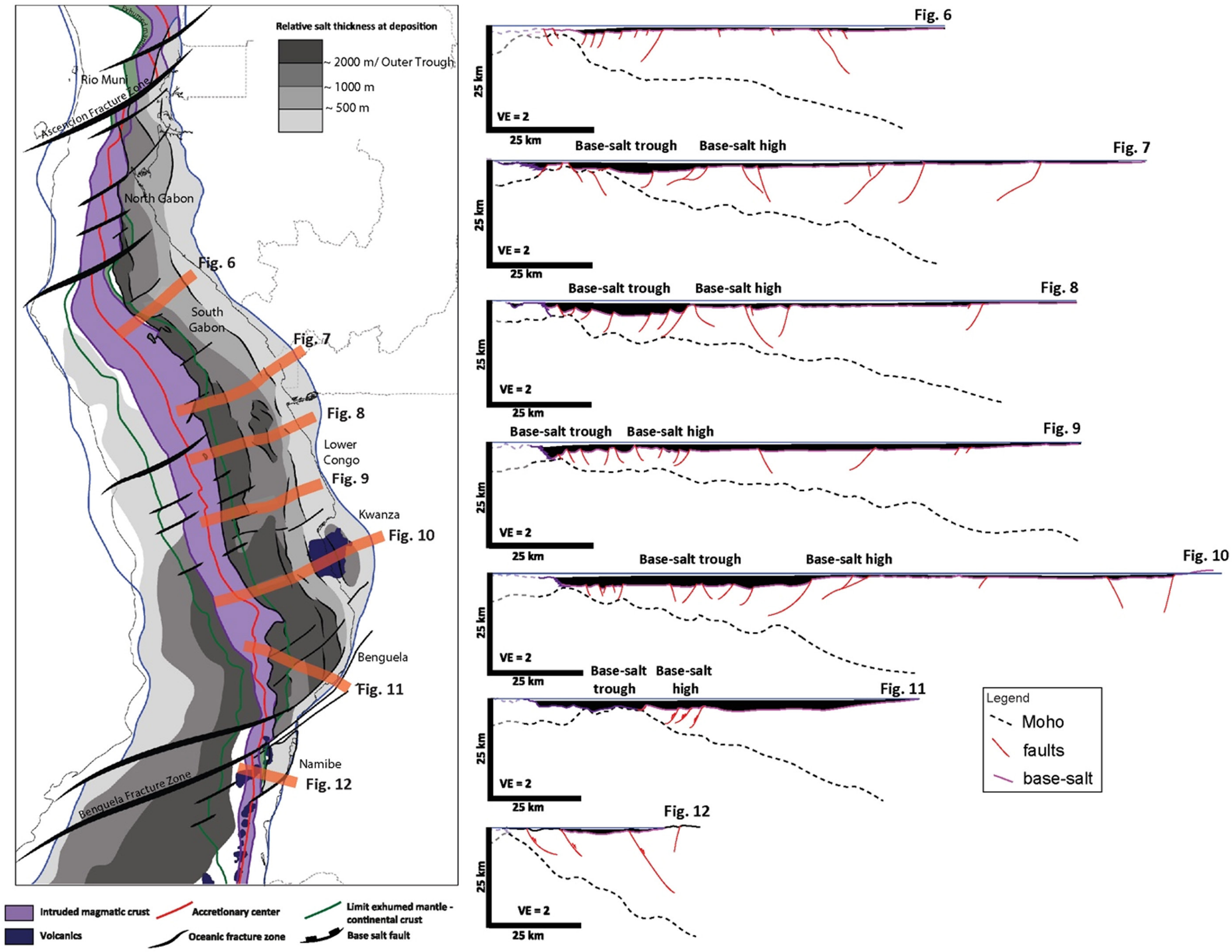

FIGURE 14 Reconstruction of the Aptian salt basin geometry along the West African margin (this work) and the conjugate Brazilian salt basin (based on Lentini et al., 2010) at the time of the end of salt deposition, which corresponds to the final stages of continental breakup and onset of magmatic accretion and development of oceanic crust. The African salt basin extends from the Ascencion to the Benguela Fracture zones. Profiles show the crustal-scale rift architecture and its controls on salt basin geometry, and salt thickness variability along strike and downdip for all margin segments presented in this study. The paleobathymetry at the end of the salt deposition is estimated between 1 and 2 km in the distal part of the South Gabon Basin by Epin et al. (2021) and thus applied to the other sections in these restorations. Note that some of the smaller faults were removed from the profiles for simplification purposes.

For this, we combine our interpreted regional profiles with paleogeographic and structural maps, whilst using a detailed, multi-stage restoration of the Central Lower Congo profile as a template for their first-order kinematics.

5.1.1 | Aptian

Salt deformation is likely to have started during the salt deposition in the distal, hyperextended domain associated with the latest syn-rift (Late Aptian) stretching and continental breakup. This is supported by the evidence of base-salt faulting and abrupt salt thickening in the outer margin and hyperextended crustal domains (Figures 13b–16), as well as by structures such as intra-salt minibasins suggestive of syn-salt-deposition flow in these locations (Figure 16). In more proximal crustal domains, we only recognize evidence of post-salt deformation, even though we cannot rule out the possibility of syn-depositional salt flow there as well. The lateral juxtaposition of the latest syn-rift magmatic additions, SDRs and/or volcanoes with the distal salt at/near the OCT is also likely to have influenced distal salt flow (Figure 16). This could occur by hydrothermal alteration of evaporites (Gindre-Chanu et al., 2022), heat-enhanced salt flow (cf. Magee et al., 2021; Schofield et al., 2014), as well as mechanically buttressing or displacement of salt by magma accretion (cf. Ferrer et al., 2017; Pichel et al., 2020).

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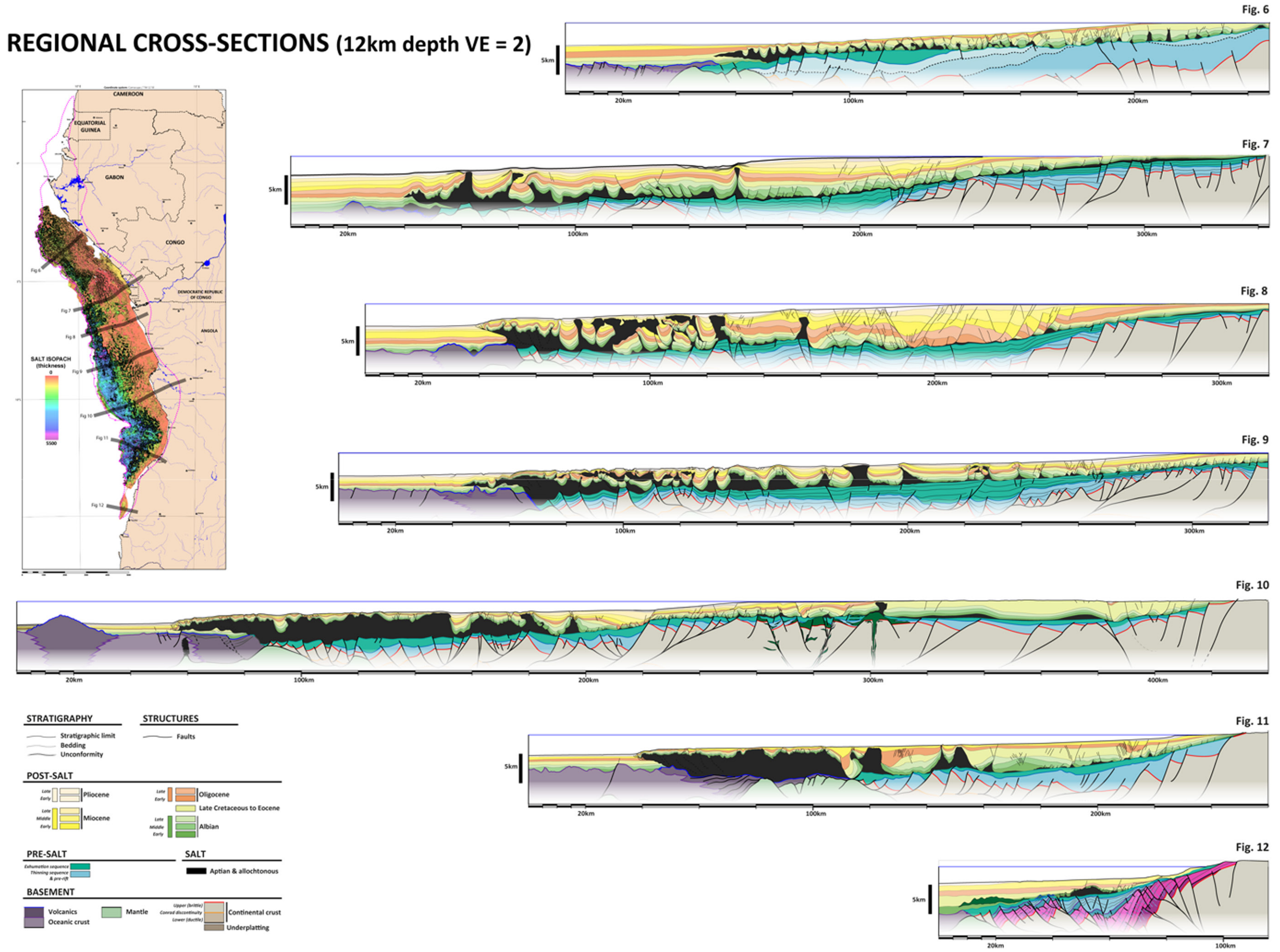

FIGURE 15 Comparison panel of all profiles presented in this study (maximum depth of 12 km) focusing on salt and post-salt structural architecture and variability.

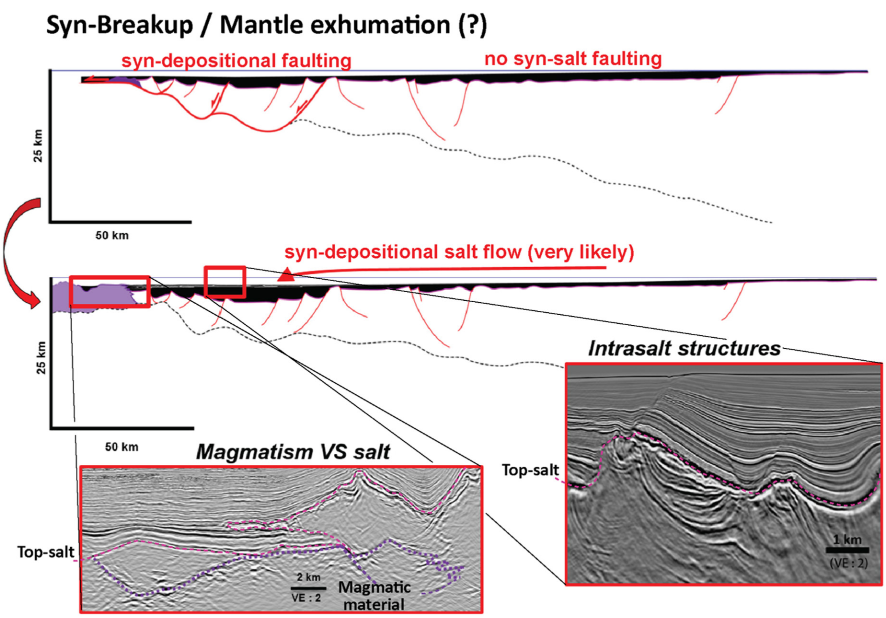

FIGURE 16 Top-salt restoration of the Central Lower Congo profile (Figure 8) demonstrating evidence of syn-breakup and syn-salt-deposition extension at the most distal margin with the associated seaward salt flow towards the base-salt through. Insets show evidence of intra-salt minibasins based on 3D seismic that support this observation, as well as evidence of the juxtaposition and likely interaction of salt deposition and flow with magmatic accretion at the oceanic crust.

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5.1.2 | Albian-Late Cretaceous

In the proximal-necking domains, salt deformation started soon after salt deposition (ca. Early-Middle Albian). This deformation was characterized primarily by the development of listric normal faults, rafts, extensional rollovers and turtles associated with reactive salt walls and rollers, with a few occasional minibasins in between (Figures 15 and 17a). Albian-aged normal faults were predominantly seaward-dipping, with only a few landward-dipping normal faults in South Gabon and Benguela (Figure 15). The early (Albian-Upper Cretaceous) extensional domain coincides with an area of gently dipping (ca. 1°–2°) base-salt that varies in width from ca. 30 km (Kwanza) to ca. 140 km (Northern Lower Congo). This area coincides also with the Albian-Neogene shelf and upper slope domains (Figure 15). In some segments, however, where the base-salt was broadly flat and the salt relatively thin (e.g. Northern-Central Lower Congo and Kwanza), there was limited to no salt deformation in the proximal domain (i.e. stable domain, Figure 17).

Seaward, in the hyperextended crust domain, Albian-Late Cretaceous deformation was largely variable across and in between the different margin segments. There was downdip overburden shortening in the form of buckle folds and thrusting over mid- to distal base-salt highs (deep-water fold-thrust-belts, Figure 17a) and salt inflation with the development of diapirs and minibasins over base-salt troughs and/or flats (inflated salt domain, Figure 17a). At the distal edge of the salt basin, deformation was characterized by salt inflation and frontal nappe advance associated with additional thrusting and buckle-folding (Figures 15 and 17a). In the areas of originally thicker distal salt (e.g. Kwanza-Benguela and Central Lower Congo, Figures 14 and 15), there was an intervening domain dominated by Albian-Late Cretaceous salt inflation, load-driven diapirism and minibasin subsidence with little evidence of shortening (Figures 15 and 17a).

Downdip shortening occurs in response to updip extension (cf. Jackson, Jackson, Hudec, & Rodriguez, 2015; Rowan et al., 2004), the latter of which happens mainly over the wide seaward-dipping base-salt domains during the Albian-Upper Cretaceous in West Africa (Figure 15). This suggests that Albian-Late Cretaceous extension and shortening were mainly driven by *gliding* (Figure 18a). Deformation at this stage was nonetheless also influenced by spreading under an incipient prograding slope, and by minibasin downbuilding and passive diapirism in areas of initially thicker salt such as the outer base-salt troughs (Figures 14, 16 and 17a).

5.1.3 | Late Cretaceous-Paleogene

By the Late Cretaceous-Paleogene, extension ceased in the proximal domains and migrated seaward towards the necking domain (Figures 15, 17b and 18b), as most of the proximal salt was continuously expelled towards the necking and hyperextended domains. This produced extensional reactivation of earlier-formed structures in these mid-margin domains, such as Albian reactive and/or passive diapirs, which developed diapir-fall geometries and hybrid (i.e. expulsion-extensional) turtles and/or rollovers (Figure 17). Landward-dipping normal faults and expulsion and/or hybrid rollovers became increasingly more important at this stage (Figures 6–11).

Seaward, large-scale salt inflation associated with load-driven diapirism and minibasin subsidence continued over the hyperextended crust and OCT domains (Figures 15 and 17b). There was also localized salt extrusion and development of allochthonous salt sheets in the Central and Southern Lower Congo segments (Figure 15). There seems to be less evidence of Late Cretaceous-Paleogene overburden shortening relative to the Albian-Upper Cretaceous, which suggests downdip shortening was accommodated mainly cryptically by diapir squeezing (cf. Jackson, Jackson, & Hudec, 2015) and salt extrusion. Downdip diapir shortening occurred predominantly above and around the distal and/or mid-margin highs (Figures 15, 17b and 18b). Previous mid-margin contractional structures were largely inactive at this stage owing to the depletion of the intervening salt layer and the general increase in overburden thickness (Figure 15). At the distal edge of the basin, there was further seaward salt nappe advance with continuous salt inflation and minibasin development, buckle folds and occasionally thrusts (Figures 13b, 15, 17b and 18b). The area in between the downdip shortening and updip extension was dominated by seaward salt flow and overburden translation (i.e. translational domain, Figure 17b) with little additional diapirism and overburden deformation, for example, wide turtle anticlines of various types (Figures 8 and 9) and ramp-syncline basins (Figure 10), similar to the Brazilian conjugate margin (cf. Pichel et al., 2018).

The seaward migration of both updip extension and downdip shortening coupled with the increasing occurrence of landward-dipping normal faults and seaward-dipping expulsion rollovers in the proximal and necking domains (Figure 15), increasing diapirism and salt inflation in the distal domain suggest that *spreading* became increasingly more important. This was a consequence of continuous sediment progradation and overburden

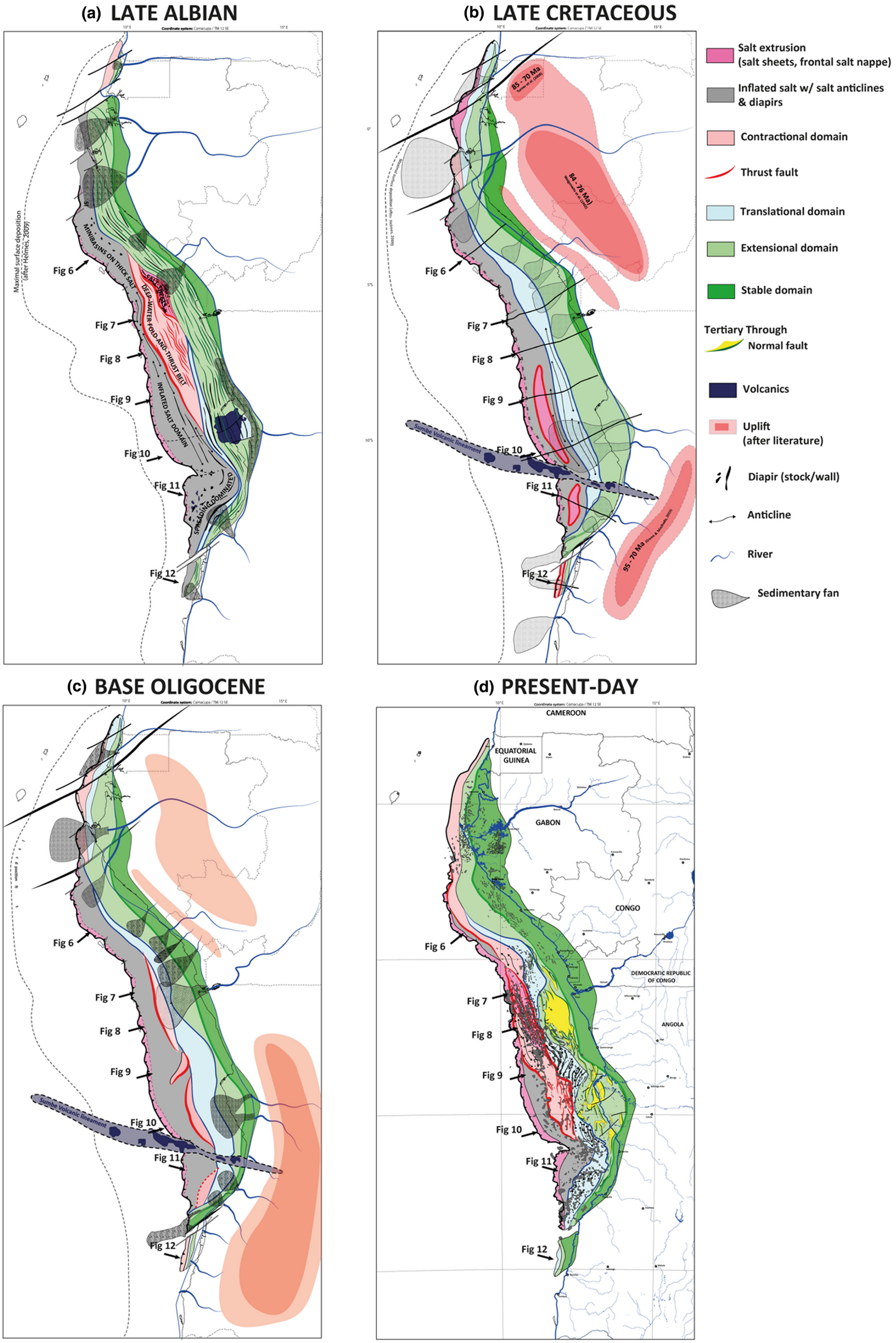

FIGURE 17 Maps of post-salt tectonic domains along the West African salt basin, (a) Albian, (b) Late Cretaceous, (c) Oligocene and (d) present-day.

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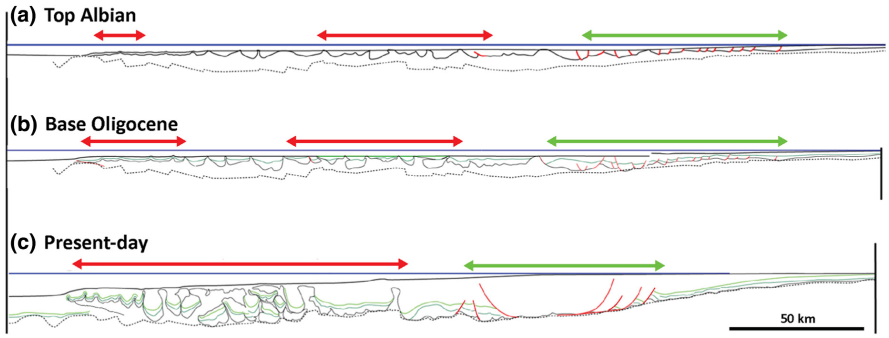

FIGURE 18 Restoration at (a) Top Albian and (b) Base Oligocene from (c) present-day structure across the central Lower Congo profile using the line length conservation and minimal displacement demonstrating distribution and migration of extension (green) and shortening (red) domains through time.

thickening. In addition, during the latest Cretaceous (ca. Santonian-Campanian), the southern and northern parts of the margin also experienced continental uplift (cf. Green & Machado, 2017; Turner et al., 2008), which increased both the sediment supply (i.e. spreading) and seaward tilt of the basin (i.e. gliding) (cf. Hudec & Jackson, 2004), likely contributing to sustain and possibly amplify, seaward salt flow and overburden translation.

5.1.4 | Palaeocene-Oligocene

Continuous continental uplift throughout Paleogene-Oligocene times produced significant erosion of the shelf, further development of the Lower Congo and Kwanza fans and consequent redistribution of sediments towards the slope and deep basin (Figure 17c). These were more pronounced in the south, towards the Southern Lower Congo, Kwanza and Benguela Basins. During this time, there was the development of large expulsion and/or hybrid (extensional-expulsion) rollovers and turtles across most of the necking domain and upper-middle slope (Figure 15). This was associated with an increase in seaward salt expulsion, frontal nappe advance, and pronounced downdip salt inflation but limited additional updip extension and downdip shortening (Figures 17c and 18c). These factors suggest salt deformation at this stage was largely driven by *spreading* in response to an increase in sediment flux towards the deep basin with limited additional gliding.

The moderate downdip shortening was accommodated mainly by diapir squeezing, which in the Lower Congo produced further salt extrusion and development of salt canopies with complex, stacked minibasins formed by encasement of primary minibasins by the allochthonous salt sheets over the hyperextended crust domain (Figure 17). At this stage, the distal minibasins formed above the extruded allochthonous salt sheets/canopies and were translated seaward over the earlier-formed (Albian-Paleogene) minibasins producing the observed stacked pattern (Figure 15). We also observe evidence of downdip shortening propagating landward from the distal edge of the basin towards the distal high due to gradual buttressing of frontal nappe by increasing overburden thickness above and beyond the nappe, in particular between the Lower Congo and Kwanza segments (late mid-margin diapir squeezing in Figures 8–10 and 15).

5.1.5 | Miocene—Recent

The present-day configuration of salt tectonic domains reflects an increase of seaward salt flow and salt tectonics during Late Oligocene-Pliocene times due to continued continental uplift (e.g. Guiraud et al., 2010; Hudec & Jackson, 2004) (Figure 17d). The necking domain and upper-middle slope are characterized by several listric normal faults, some of which with multi-km offsets and/or Cenozoic troughs (Kwanza, Lower Congo and Benguela) (Figure 17). Consequently, there was significant additional downdip diapir shortening associated with minibasin rotation and/or stacking, inflation and thickening of the allochthonous salt sheets in the lower slope and deep basin, but little to no additional salt nappe advance by this stage.

5.2 | Lateral variability and controls of salt tectonics in West Africa

The style, magnitude and dynamics of salt tectonics vary significantly along and across the West African continental margin (Figure 19). The relative timing and distribution of controlling processes, such as gliding, spreading, overburden translation, nappe advance and diapirism also vary. For example:

- A relatively undeformed domain occurs over the proximal, thick-crust domain along most of Kwanza and Lower Congo, but not in Benguela and Gabon, despite the originally thicker salt on the latter (Figure 14).
- Albian updip deformation is characterized primarily by overburden extension with the development of rafts

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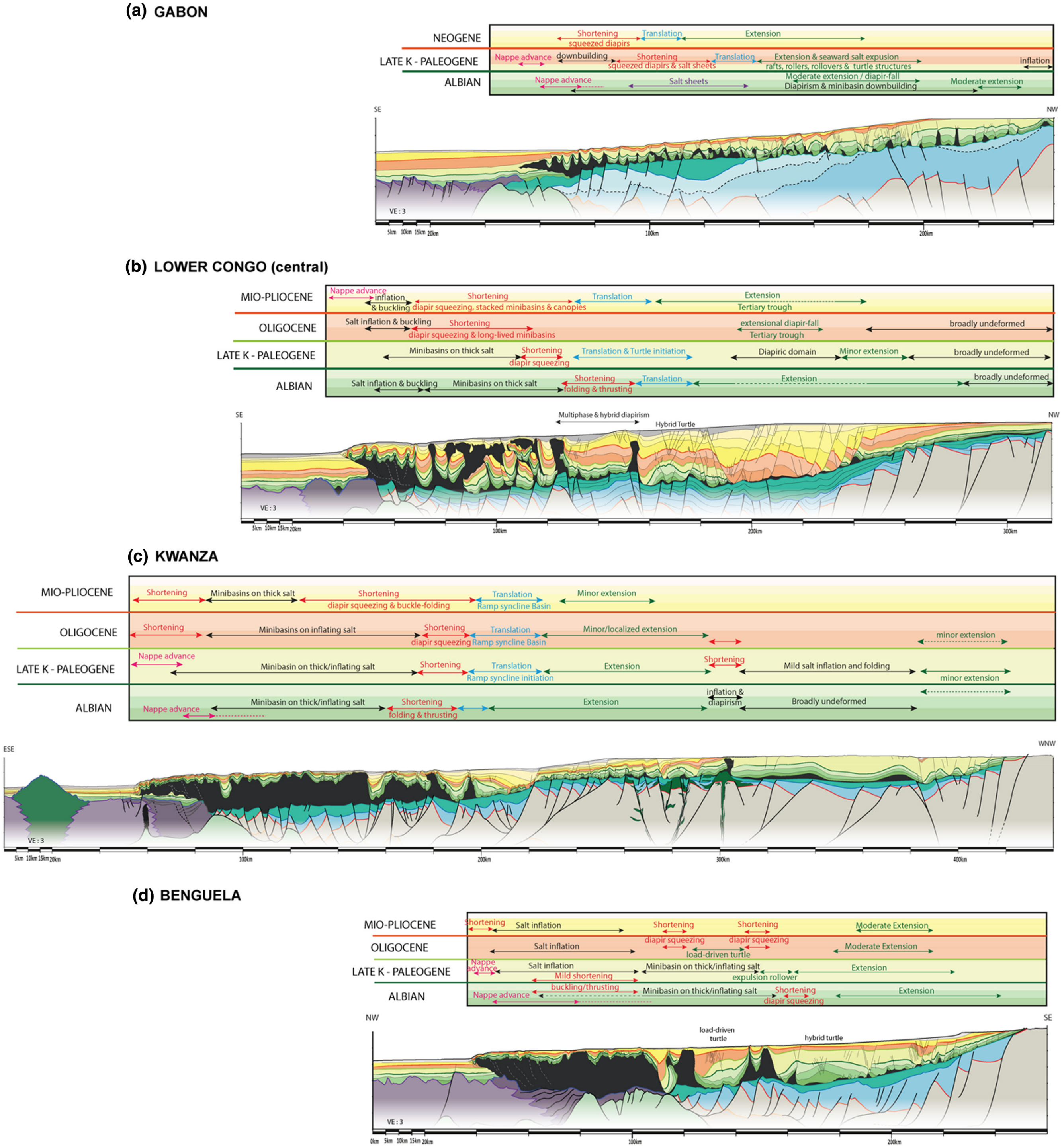

FIGURE 19 Panels showing the variability of salt-related structural styles and processes through time and space for (a) South Gabon, (b) Central Lower Congo, (c) Kwanza and (d) Benguela.

and extensional rollovers over a regionally seaward-dipping base-salt on most of Lower Congo, Kwanza and Benguela segments, but in Gabon Albian updip deformation was dominated by updip diapirism and minibasins driven by differential sediment loading with negligible extension or shortening across nearly the entire margin (Figure 19).

- Updip extension was greater during the Albian-Paleogene in Kwanza, Benguela and Northern Lower Congo, whereas in Gabon and Central Lower Congo the greater extension occurred during the Paleogene-Oligocene onwards when there was only limited extension in Kwanza. The Northern Lower Congo margin exhibited the largest and best-expressed gliding system

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with a wide domain of updip extension characterized by salt rollers and extensional rollovers above a regionally seaward-dipping base-salt (Figure 15).

- Mid-margin overburden translation was accommodated by the development of a prominent ramp-syncline basin in wider margins, such as Kwanza (cf. Jackson & Hudec, 2005). In narrower margins such as Lower Congo and Benguela, mid-margin translation was mainly accommodated by hybrid turtle anticlines and multi-stage diapirism associated with both shortening and extension over base-salt relief (Figures 15 and 19).
- Downdip shortening propagated primarily seaward in the Central Lower Congo with significant diapir shortening and salt extrusion, but in Kwanza and Benguela it propagated both seaward and landward from the areas with originally thicker salt over the distal base-salt troughs and resulted primarily in salt inflation and buckle-folding with only limited diapir squeezing (Figure 19).
- Post-rift nappe advance occurred in all margin segments, but its timing and magnitude varied. In Gabon, Kwanza and Benguela it occurred from Albian to Paleogene times resulting in significantly wide (ca. 20–40 km) nappes, whereas in the Central Lower Congo, the distal salt was pinned during this time, only advancing <10 km after the Oligocene (Figure 19).

In the next section, we discuss what are the main controls on this structural variability and salt tectonics evolution.

5.2.1 | Salt basin thickness, width and base-salt relief

Restoration of the original salt basin geometry and its correlation with the present-day structure demonstrates an important control of rifted margin architecture and base-salt relief on the salt thickness and ultimately salt tectonics for all margin segments (Figures 16 and 17). The more proximal base-salt relief is interpreted to have predated salt deposition and thus consisted of inherited rift structures that defined salt depocentres. This base-salt relief helped to localize salt diapirs (cf. Dooley et al., 2017, 2020; Ge et al., 1997; Pichel, Finch et al., 2019), such as in Kwanza and Gabon where large diapirs formed directly above base-salt steps (Figure 19). Seaward-dipping base-salt ramps promoted the development of the largest extensional rollovers in more proximal extensional domains (e.g. Gabon, North-Central Lower Congo) and ramp-syncline basins in mid-margin translational domains for wider margins such as in Kwanza (cf. Evans & Jackson, 2020; Jackson & Hudec, 2005; Figure 19). Proximal landward-dipping base-salt steps seem to have also nucleated and influenced the location of post-salt counter-regional, landward-dipping normal faults in the proximal domain as most of these faults occur near or directly above landward-dipping base-salt steps such as in Gabon (Figure 6). This is supported by recent findings from both analogue (cf. Pichel et al., 2021) and numerical modelling (Pichel et al., 2022b).

The most distal base-salt relief, mainly above the OCT and distal hyperextended domains was formed partially during salt deposition by ongoing rifting and tectonic subsidence, which produced an initially thicker salt (>2.5 km) and segmented the salt basin (Figures 16 and 20a,b). The typically rapid salt deposition is likely to have provided positive feedback by increasing the differential sediment load in rift depocentres, amplifying the growth of normal faults and their relief in the distal margin (cf. Allen et al., 2020; Davison et al., 2012).

In general, the largest diapirs formed around areas where the Aptian salt was originally thicker (Figures 14–16). In the proximal domains, this corresponds to the largest and relatively underfilled pre-salt grabens such as in proximal Gabon (Figure 6) and mid-margin Kwanza (Figure 10), both areas with a relatively flat base-salt. In the Southern Lower Congo and Benguela, where the proximal salt was also relatively thick (ca. 1 km) but with a significant base-salt slope (>1°) there was only limited diapirism due to efficient seaward salt flow, thus producing significant overburden extension, normal faults, rafts and rollovers instead (Figure 15). In distal domains, the areas with the largest diapirs correspond to pre-salt outer troughs at/near the OCT and distal hyperextended domain, such as most of Lower Congo, Kwanza and Benguela (Figure 19). Other large diapirs also occur in intermediate areas with relatively flat base-salt owing to gradual seaward salt evacuation onto these areas, such as most of Lower Congo (Figures 8 and 9).

The intervening, mid-margin areas often formed significant base-salt highs at the time of salt deposition and thus had an originally thinner salt (except for Benguela, Figure 14), which ultimately resulted in smaller diapirs and minibasins (Figure 15). These areas nonetheless formed barriers to early (Albian-Paleogene) salt flow and gravity gliding, partially segmenting the salt basin into smaller sub-basins with different evolution and styles of salt deformation (Figure 20a,b). Early (Albian-Paleogene) downdip shortening and salt inflation was focused primarily against and/or above these distal base-salt highs for the margins with more prominent structural relief such as Kwanza (cf. Erdi & Jackson, 2021) and most of the Lower Congo (Figure 19). The distal part of these basins had originally thicker salt and evolved largely independently during this time, being characterized by significant vertical salt tectonics, passive diapirism and minibasin downbuilding (Figure 20b,c). There was only little to no

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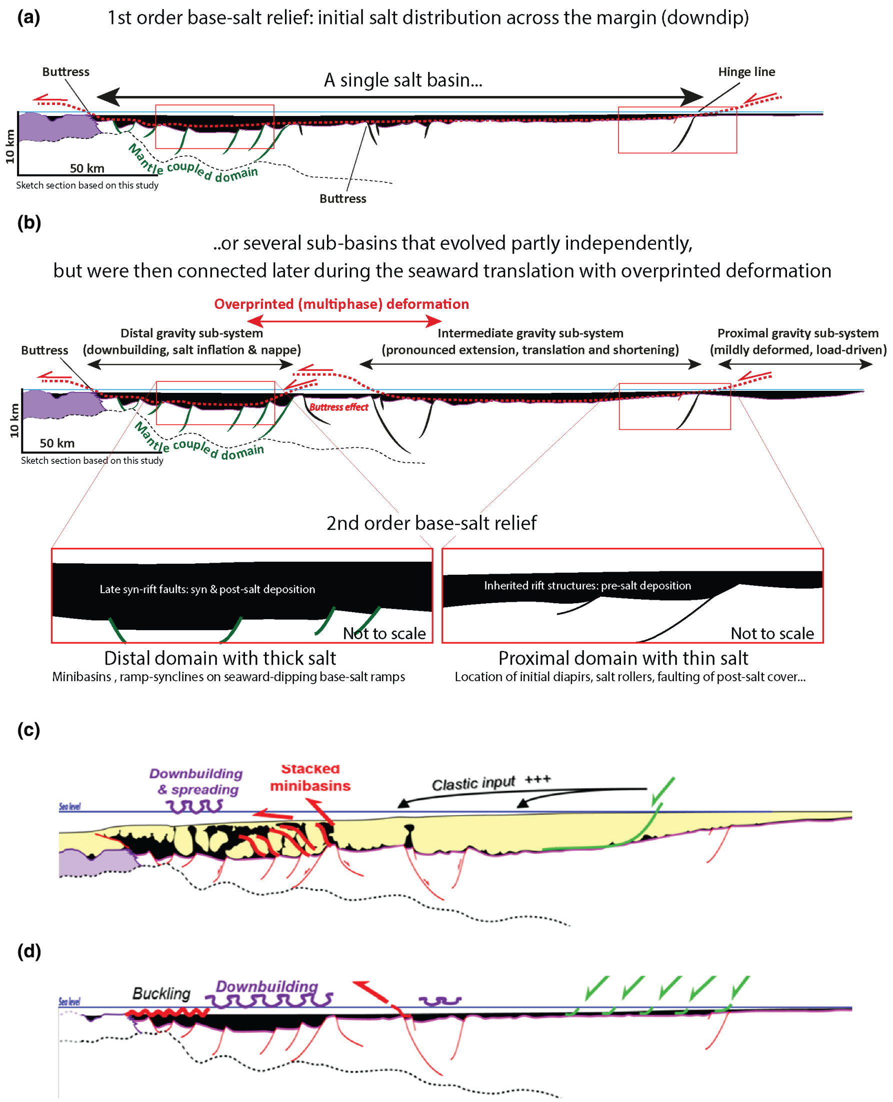

FIGURE 20 Schematic conceptual diagrams showing the first-order controls on the initial salt distribution and salt basin geometry along the West African margin. (a) A single salt basin in which the post-salt gravity-driven deformation is entirely linked across the margin. (b) A series of salt sub-basins segmented by base-salt highs and lows that evolve partially independently at the initial stages of gravity-driven deformation and may be subsequently linked by progressive salt flow over the structural highs, connecting the sub-basins. Second-order controls associated with base-salt ramps and steps inherited from rift structures are shown in insets. Example of the evolution of salt deformation with early (c) and late (d) post-salt gravity-driven deformation of two partially isolated sub-basins from the Central Lower Congo segment. Early deformation is not fully kinematically linked due to the presence of a distal base-salt high that acts as a buttress to regional seaward salt flow. Intervening base-salt lows favour minibasin downbuilding and load-driven diapirism. During the late stages, the two sub-basins are partially connected by progressive salt flow and diapirism associated with margin progradation. Extension in green, shortening in red and downbuilding and/or load-driven processes in purple.

early downdip shortening at these distal portions. Margin segments such as Kwanza, Gabon and Northern Lower Congo had also an additional proximal sub-basin each that was broadly flat and not kinematically linked to the remaining salt (Figures 14 and 19). These proximal sub-basins thus remained relatively undeformed or with mild, predominantly load-driven salt tectonics (Figure 20b).

With continued margin progradation and regional salt tectonics, mid-margin shortening-driven structures were reactivated during Upper Cretaceous-Oligocene times by extension and developed diapir-fall geometries with turtle structures and/or rollovers on their crests (Figure 19). Some of the earlier-formed structures and inflated salt were able to translate seaward over the outer trough and OCT domain in the form of allochthonous salt canopies forming stacked and complex minibasin patterns whilst partially connecting the two salt sub-basins, such as in the Lower Congo (Figures 8, 9 and 20c).

Not only the geometry of the salt basin but also its width played a major role in the salt tectonic evolution

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along the margin. Wider salt basins such as the ones in Lower Congo and Kwanza had wider and more developed systems of updip extension, overburden translation and downdip shortening (Figures 7, 8 and 10). Narrower margins such as Gabon (Figure 6) and Benguela (Figure 11) were conversely relatively more influenced by lateral salt expulsion and distal salt inflation, vertical diapirism and minibasin subsidence with more moderate updip extension and downdip shortening. The Namibe segment was notably different from the other relatively salt-rich and magma-poor segments as there was only localized salt deposition and, therefore, limited salt tectonics due to most of the rift-related accommodation being filled by magmatic additions and SDRs.

5.2.2 | Post-rift sedimentation and uplift history

The West African salt-bearing margin also displays significant along-strike differences in post-salt thickness, in particular for the Cenozoic succession (Figure 19). Low post-salt sedimentation rates and sediment thickness in Gabon (ca. 4 km on average) allowed for more intense diapirism, minibasin downbuilding and the greater number of diapirs in the proximal and necking domain compared to other margin segments. This in turn was associated with less seaward salt evacuation and less salt nappe advance (Figure 19). The Gabon margin was thus associated with limited early (Albian-Upper Cretaceous) gliding and spreading, even though spreading became important at later stages (Paleogene onwards) in distal areas, that is the hyperextended and OCT domains. Conversely, the nearly double post-salt sediment thickness (ca. 8 km) in Northern and Central Lower Congo produced significantly greater seaward salt evacuation from the proximal and necking domain and thus greater gravity spreading with updip overburden extension and downdip shortening associated with intense diapirism and salt extrusion.

Other margin segments presented a more intermediate behaviour and evolution, although additional effects such as continental uplift and differences in the timing of sedimentary input towards the deep basin produced second-order and/or shorter-lived variations. Continental uplift was, for example, more pronounced in Kwanza resulting in significant erosion of post-rift sediments from the proximal, thick-crust domain and additional seaward tilting of the salt basin along the necking domain as well as additional sediment input towards the deep basin. This produced renewed gliding and spreading over the necking and hyperextended domain and significant seaward salt evacuation, updip overburden extension and translation, as well as downdip salt inflation and nappe advance, both being the greatest along this margin.

5.3 | The interplay between rifted margin and salt tectonics domains

Our analysis shows a direct link between rifted margin architecture and its associated crustal domains with the salt tectonics domains and prograding sedimentary slope (Figure 21), as follows:

- The thick-crust domain underlies the present-day shelf and presents a broadly flat base-salt with typically thin salt with little to no salt deformation. Where the salt is locally thicker over undefiled proximal rift-related depocentres there is load-driven diapirism and minibasins but little lateral salt tectonics.
- The necking domain underlies the shelf and upper slope and displays a regionally seaward-dipping base-salt. It is dominated by extension, salt rollers, rollovers and listric normal faults, with occasional diapirs over larger, predominantly landward-dipping base-salt steps.
- The hyperextended domain spans the upper to lower slope and is characterized by a rugose base-salt, occasionally pronounced base-salt highs and a more variable style of salt deformation. There is generally a complex salt deformation over the highs with early shortening followed by late extension and/or diapir fall, whereas large seaward-dipping ramps control the development of ramp-syncline basins. The distal part of this domain typically presents large diapirs with early load-driven rise and minibasins development followed by late shortening and occasional salt extrusion with the development of allochthonous salt sheets and stacked minibasins
- The OCT is located underneath the lower slope and deep basin. There, the originally thick salt is characterized by syn-rift salt thickening followed by early post-rift load-driven diapirism and downbuilding, salt inflation and mild late shortening. It is similar to the distal hyperextended domain but with less shortening and wider, simpler diapirs.
- At the oceanic crust domain and deep basin, there is salt nappe advance associated with buckle-folding, thrusting and diapirism over the oceanic crust. There are occasional pieces of salt interlayered with magmatic bodies directly overlying the early and extended oceanic crust. The distal edge of the autochthonous salt basin is often characterized by a prominent base-salt relief that resulted from the interaction between rift-related extension, magmatism and salt deposition.

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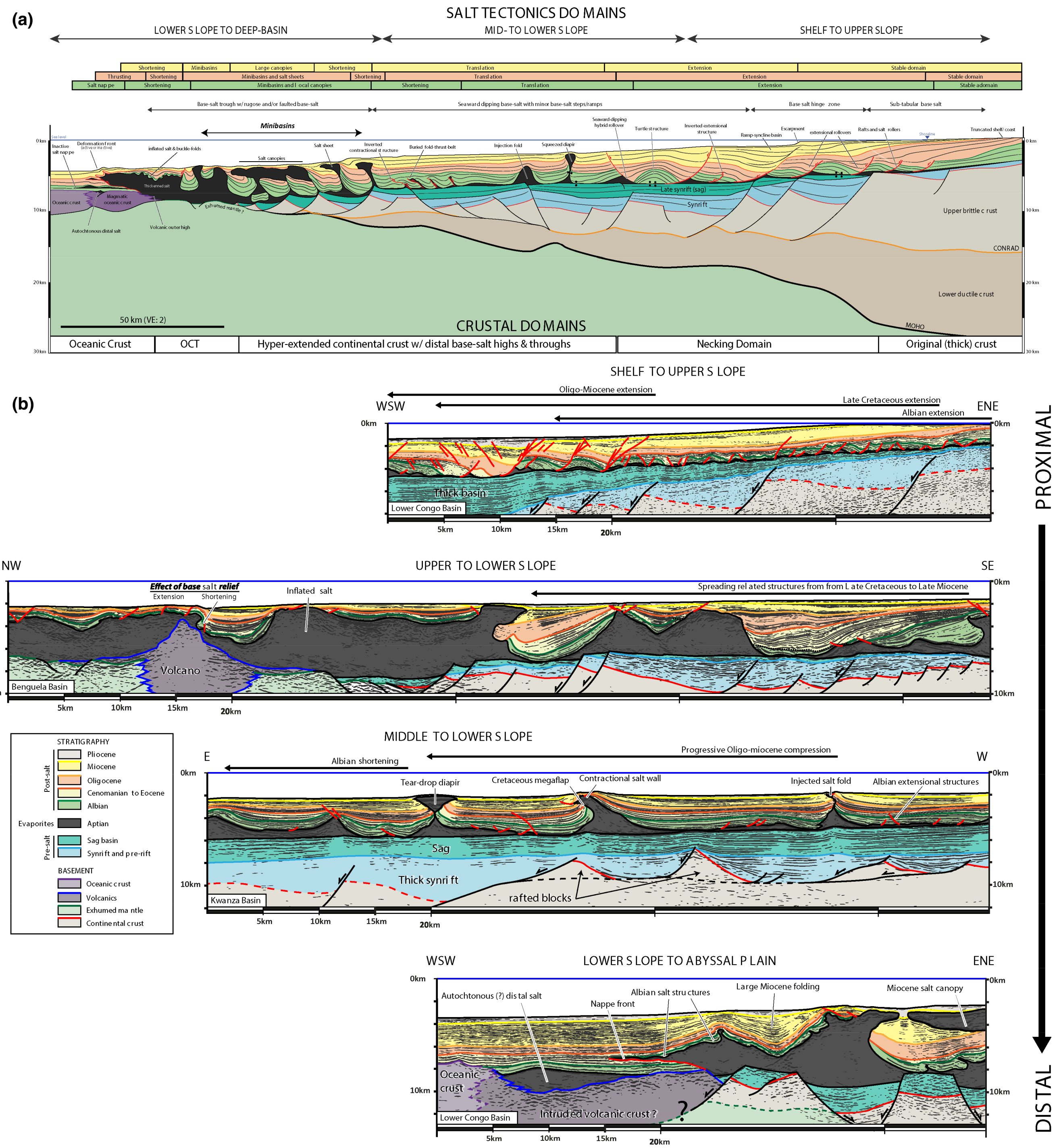

FIGURE 21 (a) Synoptic cross-section of the West African salt-bearing rifted margin showing the relationship between crustal domains, post-rift sedimentary slope and salt tectonics domains. (b) Zoom on each of these domains from proximal to distal showing the typical salt structures and kinematics for each of these domains using different examples including Kwanza, Benguela and Lower Congo basins.

6 | CONCLUSIONS

We have conducted a margin-scale analysis of salt tectonics along nearly the entire West African salt-bearing rifted margin, from Namibe to Gabon. We combined 2D and 3D seismic data with gravimetric-magnetic (Supporting Information Figure S1) and well data to constrain the crustal-scale rift geometries and their impact on salt distribution, thickness and base-salt relief along the margin. This was aimed to understand how rifted margin architecture controlled salt deposition and subsequent post-rift salt tectonics, whilst also

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addressing the role of variable rates and thicknesses of post-rift sediment progradation. The study shows there is significant along-strike variability in initial salt thickness and salt basin geometry as well as rifted margin architecture, although a few first-order features are broadly similar.

Proximal deformation is usually focused over the necking crustal domain and characterized by gravity-driven extension with normal faults and rollovers, although some margins present a broadly undeformed or a load-driven proximal salt tectonic domain where the base-salt is roughly horizontal. Mid-margin deformation is often associated with significant seaward salt flow and overburden translation over variable base-salt relief which produce multiphase, hybrid diapirs and/or turtle structures as well as ramp-syncline basins. Distal deformation is characterized by downdip shortening with diapir squeezing, salt inflation and associated minibasin downbuilding as well as buckle-folding over most of the hyperextended crust domain. The most distal deformation is associated with early downbuilding and load-driven diapirism over large base-salt troughs, being later overprinted by seaward propagation of shortening associated with sediment progradation. An allochthonous salt nappe occurs at the distal edge of the salt basin overlying magmatic proto-oceanic crust and/or post-salt sediments for all margin segments, although its dimensions, degree and timing of advance and the style of deformation vary. The only exception for this distribution of structural styles and evolution is the magma-rich and salt-poor Namibe margin. Most margins exhibit a prominent distal or mid-margin base-salt high that act as a buttress to the early stages of salt flow partially segmenting the salt basin. All margins present an outer base-salt trough overlying the OCT domain where the salt was originally thicker (>2.5 km) and deposited during ongoing extension related to the final stages of breakup. Salt is likely to have started flowing seaward and onto the newly formed seafloor (i.e. exhumed mantle or proto-oceanic crust) during this stage (i.e. syn-depositionally) as shown by localized intra-salt minibasin geometries. These observations contribute to the understanding of the dynamics and styles of gravity-driven salt tectonics along salt-bearing rifted margins worldwide, in particular to the comprehension of the interaction between rifting and rifted margin architecture with salt deposition and tectonics.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from TGS. Restrictions apply to the availability of these data, which were used under licence for this study. Data are available from the author(s) with the permission of TGS.

PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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