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Oligocene to Miocene Turbidite Deposits of the Cabo Ledo, Inner Kwanza Basin, Angola: Stratigraphic Architecture and Sedimentary Processes

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The stratigraphic architecture of the deep to upper sedimentary processes and reservoir geometry in Angola ma was well displayed in Cabo Ledo area. During the Cenozoic time, the eastern part of the Kwanza basin was submi to an overall uplift that led to the continentalization of the domain and the outcropping of slope to deep deposits along well exposed coastal cliffs. This so-called Inner Kwanza basin represents an exceptional are calibrate and accurate the sedimentary architecture of the time-equivalent turbidite complexes imaged on seis and drillholes from the deep offshore. In particular, in the central domain, the series is slightly tilted toward north showing an overall shallowing upward sequence from Oligocene lower slope to Miocene shelf deposits. this area, the turbidite deposits display two mains stratigraphic architectures clearly linked to the geodynamic of margin. In the South from Cabo de São Braz to Cabo Ledo, the Oligocene to Lower Miocene series corresponds lower slope channel-levee network clearly controlled by the growth of diapirs. Constructional and erosional syst are both visible with typical facies assemblages, including mass-transported deposits linked to the destabilizatio the flanks of the diapirs. The channel margins show a peculiar bioclastic sandstone facies intensely burrowe *Thalassinoïdes* and *Ophiomorpha*, which indicate carbonate sand cascading from the shelf edge and pa colonization by conveyed resistant fauna.

1. Introduction

The Cabo Ledo area, is located north of Cassamba, and extends toward north to the limit with the Sangano. The study in this area aimed to determine the relationship between diapirs and turbidites deposits (Fig 1). The Cabo Ledo zone have divided into two sub-sectors: Sub-sector 1: Zone going from the village of Fishermen to the Ponta Feixe; Sub-sector 2: Cabo Ledo village area toward to south part of Sangano; in total 47 waypoints ware heavily studied.

In this area, the cliffs are essentially composed by alternating green to grey-blue marls with fading ripples, with levels of brown marl at the base. This unit passes upwards to channeled sandy facies. This clayey-sandstone series in the the outcrops about 50 m thick, has been attributed to the Quifangondo Formation (Oligocene-Lower Miocene) at the base and Luanda (Upper Miocene, even in some cases to the Pliocene), without knowing the exact age and stratigraphic relationships (Brognon and Verrier, 1959; Schlumberger 1991; MacMillan et al., 1999; Morais et al., 2000). This is the reason why we carried out a sampling in the key sedimentary levels which surmount the channel facies to do the biostratigraphic study.

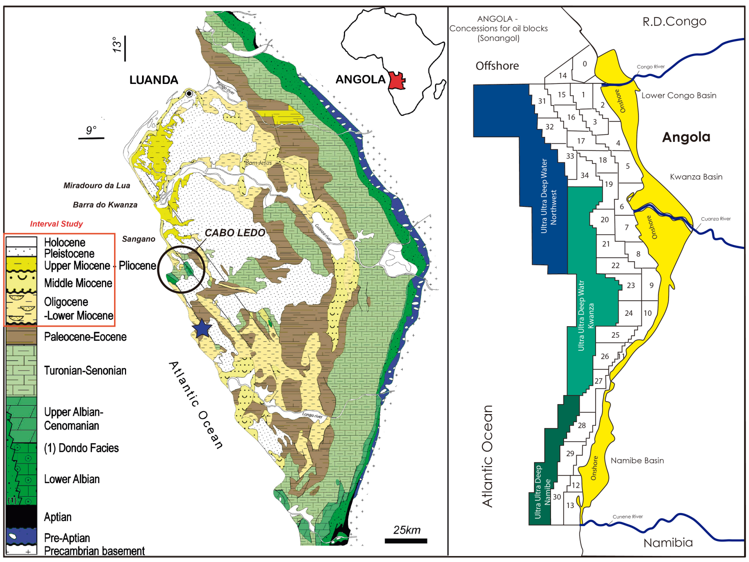

Figure 1. Location of the study zone on a Geological chart of the Kwanza Basin and their relation with Angola offshore oil blocks. (Modified from Cauxeiro et al, 2020).

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1.1. Geological Setting

Deep-water slope channel systems are one of the most important reservoir types in the hydrocarbon system of the Angola margin. The Kwanza Basin is a Cretaceous to Holocene sedimentary basin developed on the West African continental margin which origin is related initially to the Early Cretaceous break-up of Gondwana (M. L. Porter et al., 2006; Anderson et al., 2000). The turbidite deposits of this basin rests on a series of three main sedimentary units deposited along the formation of the Atlantic continental margin (G. Turakiewicz, 2004; N. Babonneau et al., 2002; B. Savoye et al., 2009): pre-rift continental deposits (Jurassic), syn-rift lacustrine deposits (Lower Cretaceous), the post-rift unit with a large accumulation of salt (middle Aptian) covered by a thick marine succession (Albian to present), Fig.1.

The Cabo Ledo zone represents the segmented portion of a central area oh the Inner Kwanza basin particularly mobile salt-controlled locally of the general margin. The eastern part of the basin during the Cenozoic period, was submitted to an overall southward differential uplift that led to the present-day. The consequence of these processes was the greats outcrop along the coastal cliffs, from southern Upper Cretaceous/Lower Miocene turbidites and deep-sea deposits to northern Late Miocene/Pleistocene braid-delta and coastal plain deposits (Cauxeiro et al, 2014). This paper focuses on the development of the Oligocene-Miocene Turbidite systems of the Palaeo-Cuanza sedimentary prism in the central zone of the inner Kwanza basin.

2. Data and Methods

The dataset used in this paper was collected during field works and includes detailed outcrop studies, drone panoramas and samples analysis. All this data was use to analyse sedimentary sequences at different spatial scales to characterize the stratigraphic architectures of the sedimentary geobodies and to build the analogies with deep series in subsurface.

To constrain the large-scale geometry of the sedimentary bodies and to localise the key working-areas, drone survey was previously performed, which allowed the selection of 47 outcrop sections (waypoints). Only some of them, the most representative, are described in this paper.

3. Results and Discussions

3.1. Sedimentary Facies and Facies Association

The Cabo Ledo sedimentary pile is characterised by 14 main facies associations identifiable by the combination of remarkable lithologies and sedimentary fabric that constrains the depositional processes and environment into genetic sequences (Fig.2, and Fig.3).

Facies AF1: This facies association is mainly composed of unsorted very coarse conglomerate with blocks of Cretaceous platform, showing carbonate cement.

Facies AF2: Composed poorly conglomerate showing oblique bedding underlined by quartz draggers indicating the hydrodynamic transition between a mass transport and a current tractive.

Facies AF3: These facies surmounted the previous AF2 facies and is mainly represented by coarse sandstone, with very coarse microconglomeratic with well-differentiated trough bedding at the base.

Facies AF4: Composed by coarse to very coarse sandstone with flat parallel bedding following small cycles with a graded tendency of the order of 10 m thick. It facies evolves towards a fine sandstone dominating at the summit which reflects the deceleration of a tractive current.

Facies AF5: These facies represent the upper part of the outcrop, formed by coarse silts with ripples current which alternate with centimetric to pluri-centimetric horizons of green silty clay. This last facies marks an alternation of low current intensity and the decanting processes when the channel/canyon is abandoned.

Facies AF6: The channel sequence is sealed by 5-6 m of green silty clays with dying ripples, which mark the complete abandonment of the system dominated by decanting processes with occasional distal turbiditic inputs. This facies locally shows tearing and slump structures which indicate the permanence of a certain instability in the system.

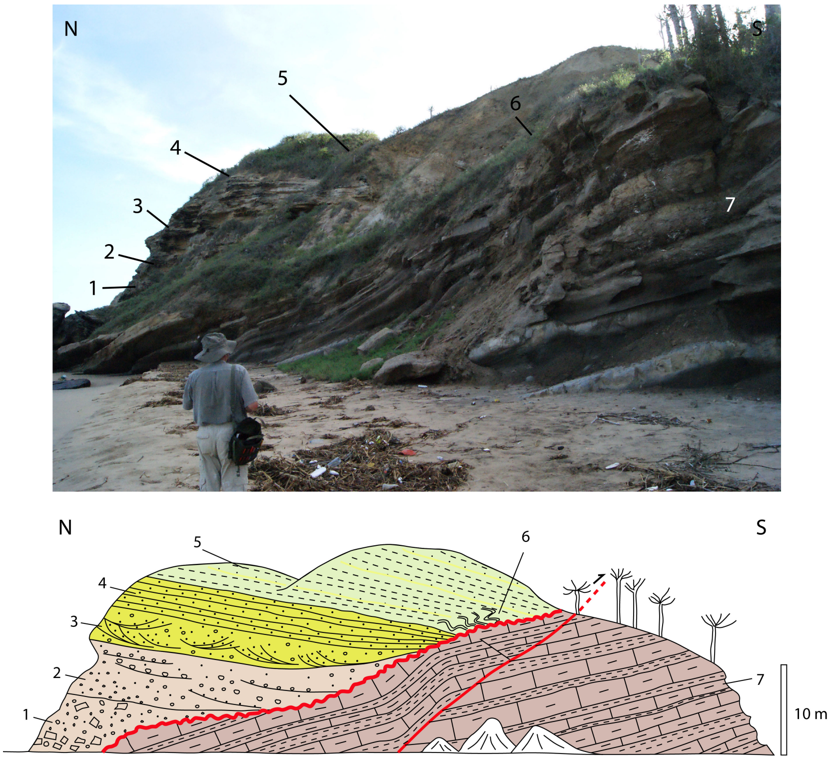

Figure 2: General view of the Ponta Feixe outcrop, showing the Upper Cretaceous diapir, incised on the flank by a turbidite canyon of Oligocene-Miocene Age. (1): Very coarse conglomerate with blocks of Cretaceous carbonates; (2): Coarse conglomerates with rough organization; (3): Misclassified very coarse conglomeratic sandstone; (4): Coarse sandstone to coarse past/microconglomeratic following flat parallel bedding; (5): Green silty clays with fine sand and fading-ripples; (6): Slumped area at the edge of the diapir; (7): Yellow marl-limestone alternations (Fm. Teba, Upper Cretaceous).

The facies association from AF1 to AF6 is interpreted as a flow stream channelized by the pre-existing morphology of the seabed with dominant incision processes at the base of the sequence and the remobilization of material from the flanks of the diapir. This situation is compatible with a canyon dynamic.

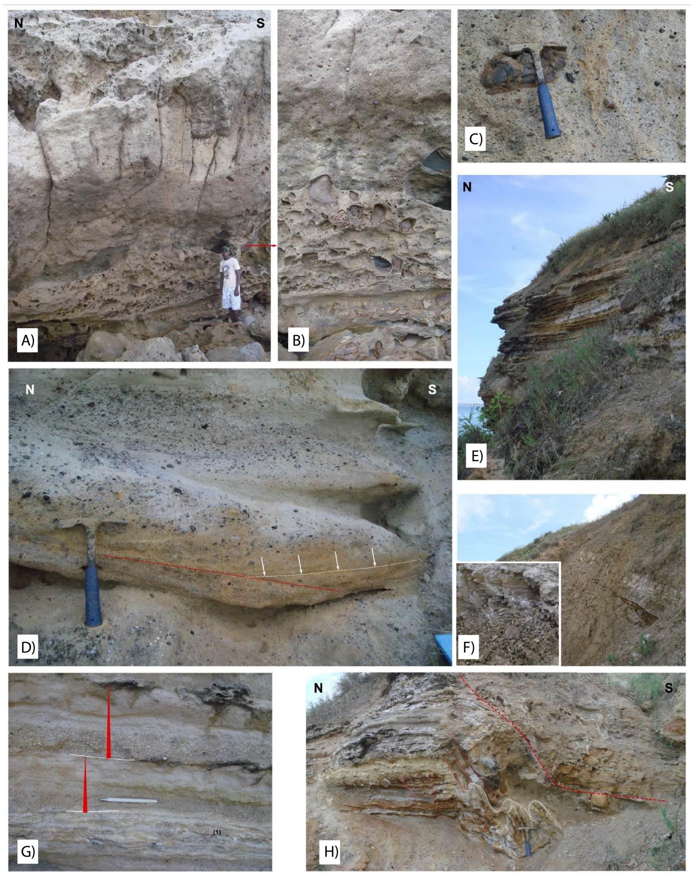

Figure 3: Detail of the filling of the turbiditic channel-canyon of Ponta Feixe. A, B, C: Conglomerate with clayey limestone clasts from the Upper Cretaceous; D: Very coarse sandstone with very rough trough bedding; E: Upper part of the channel/canyon abandonment sequence showing the alternation of siteous clay and fine sandstone with current ripples; F: Silty clays with fadding-ripples; G: Coarse sandstone with granules and rough grading alternating with fine sandstones in the middle part of the cycle; H: Transition facies with slumped/sheared levee deposits. See text for detail description.

The facies in the Fisherman's Village is mainly composed by an unsorted middle to coarse brown to dark red iron-rich clayey sand, forming the last 6 m on the top of the cliff and developing extensively on the surface of the plateau. In total more 7 facies ware described in this outcrop (Figs. 4 and 5).

AF7: Poorly sorted very coarse to microconglomerate sand at the base, passing up toward the top with massive fine sand; in the limit of the microconglomerate and the fine sand show the shale clast. This clast sediments represent the power erosion of the channel margin by the turbidite flow.

AF8: Fine sand with beds of granules.

AF9: Represented by a fine sand showing some plane gravel levels.

AF10: Fine sands alternated by silt clays showing ripples current.

AF11: Mainly composed by dark silt clays finely laminated, with fading-ripples, which marks the abandoned sediments of the channel flow.

This facie association (Figs. 4 and 5) is interpreted as the vertical and lateral superposition of a set of turbidity channel-levee in a deep submarine system in the lower slope.

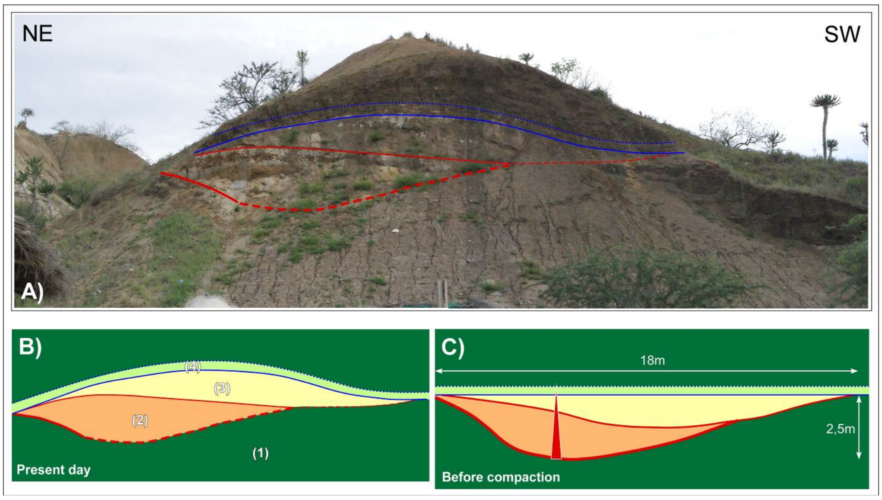

Figure 4: General view of the turbidite channel of the "Fisherman's Village". (1): Dark silty clays with fading-ripples and fine sand wrinkles; (2): Microconglomerate with very coarse poorly classified sands; (3): Fine sand intersected by shale clasts levels; (4): Level of abandonment marked by current ripples.

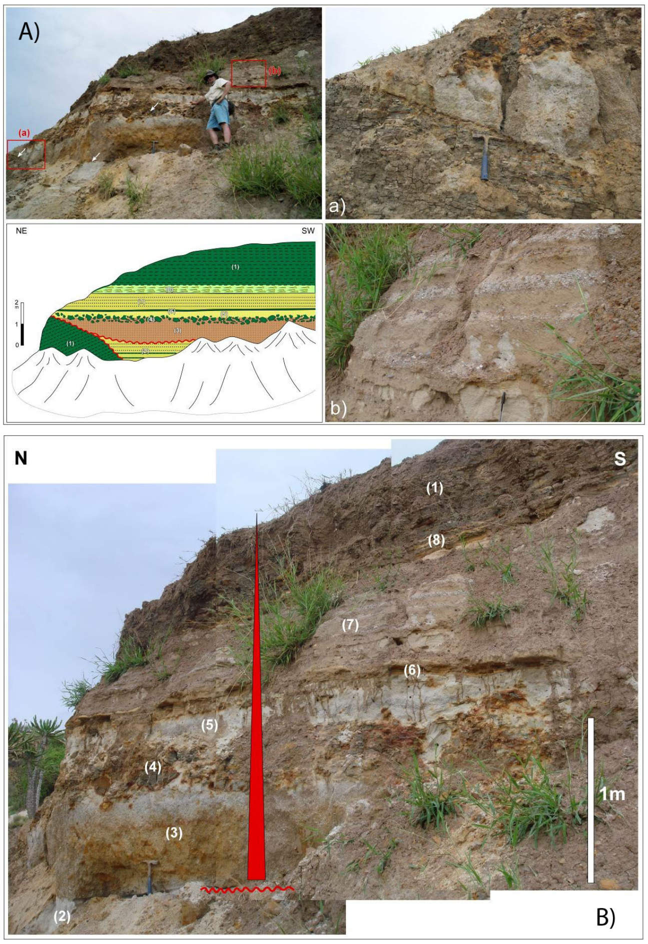

Figure 5: Detail view of the turbidite channel of the "Fisherman's Village". A: Lithology and geometry of the channel with (a) erosional truncation of the edge and (b): fine sand facies at plane level parallel to granules; B: Detail of the succession of the filling sequence with: (1) dark silty clays with fading-ripples, (2) fine to flat past sand with granules, (3): very coarse misclassified microconglomeratic sand, (4) layer of soft pebbles, (5) massive fine sand, (6) draping of dark clays, (7) fine sand with beds of granules, (8) alternation of fine sands with current ripples and silty clays.

In the North part of the Cabo Ledo, zone called Military, show a new and particularly facies assemblage (Fig. 6) that was identified locally.

Facies AF12: Composed by quartz-feldspar to microconglomerates with carbonate blocs from Eocene platform.

Facies AF13: This facies is mainly formed by microconglomerates with rhodolites et bioclasts fauna, that marks the instability of the flank in the borders of the diaper;

Facies AF14: Conglomerates to microconglomerates with trough cross stratification and plans-parallel layer of the upper regime, showing rhodolites and bioclastes at the base.

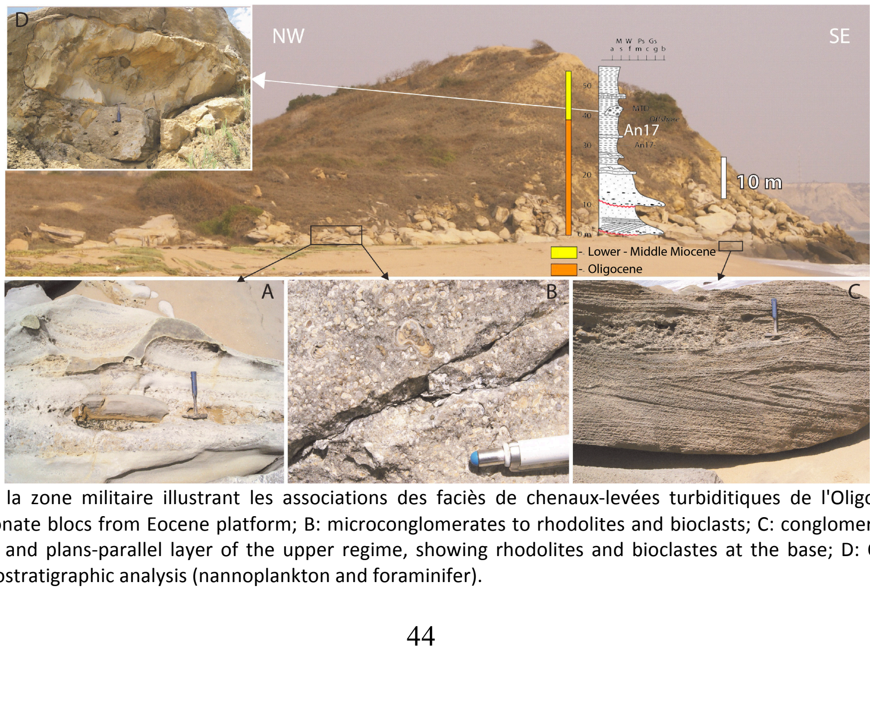

Figure 6: Sous-secteur Sud de la zone militaire illustrant les associations des faciès de chenaux-levées turbiditiques de l'Oligocène. A: quartz-feldspar to microconglomerates with carbonate blocs from Eocene platform; B: microconglomerates to rhodolites and bioclasts; C: conglomerates to microconglomerates with trough cross stratification and plans-parallel layer of the upper regime, showing rhodolites and bioclastes at the base; D: Olistolithe (Eocene) into the Oligocene green marl; AN17: biostratigraphic analysis (nannoplankton and foraminifer).

3.1. Evolution of Post-Diagenetic Processes in Turbiditic Grainstone Beds at Military Zone

The sandstone beds, which form the base of the turbidity channels, detailed above (Fig. 7), are in the form of balls (Chaos of blocks). These objects do not correspond to depositional structures; but are the result of a series of late digenetic processes that the beds have undergone during the geological history of the margin. To explain this situation a simplified diagram is proposed (Fig. 7).

This process would be linked to the physical, visible translation of one of the combined processes of haloclasty and hydrolysis associated with the penetration of saline solutions into the rock through the network of joints and the porosity of the rock. When this water evaporates, the salts crystallize. The salt crystals then exert significant pressure on the walls of the pores, which can lead to a micro-rupture of the grain boundaries and the separation of the mineral assemblies. A repetition of this cycle would lead to both grain-to-grain mechanical breaking of the rock (honeycombing) and its desquamation.

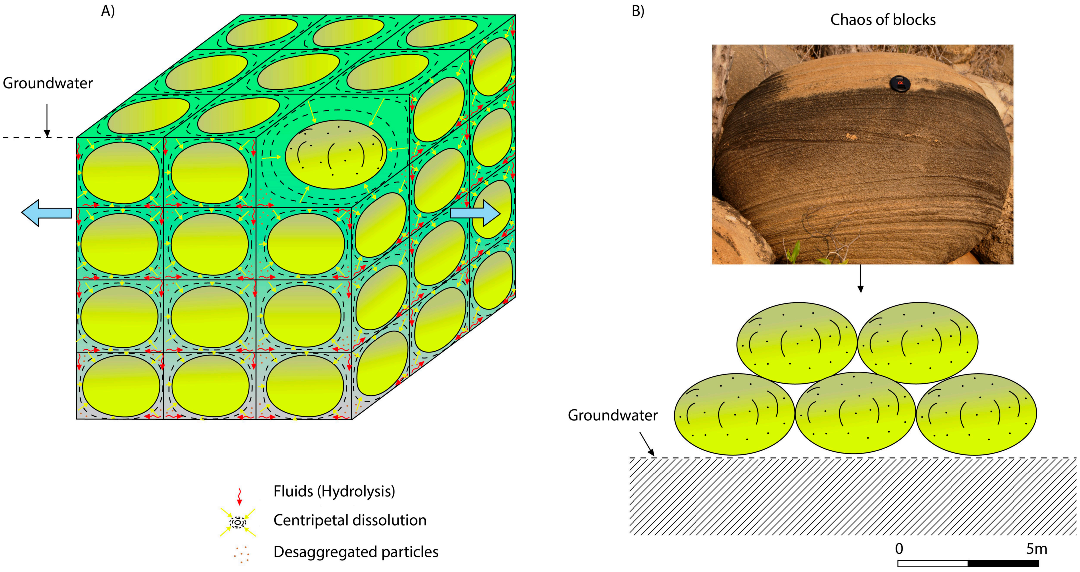

Figure 7: Diagram of late diagenetic evolution in the grainstone beds that make up the base of the turbiditic channels, during the phase of exhumation and decompaction of the sedimentary series of the margin. A) block diagram illustrating the centripetal action of fluids (saline solutions) in the network of fractures below the water table; B) chaos of blocks resulting from intense weathering processes (haloclasty, desquamation and hydrolysis) well illustrated at the foot of cliffs in the Military zone (modified from Cauxeiro 2013).

3.2. Analysis of Turbidity System

Turbidity system activity can occurs in mixes depositional processes in the basin, (Zoê Cumberpatch et al, 2021), the evolution in this basin forms different sequence types according to the systems tract record (Posamentier & Weimer, 1993) predominantly during periods of falling sea-level and sea-level low stand.

The sea floor topography and the instability of the platform can exert a potentially influence on the sedimentary processes and organization (Pickering et al., 1989).

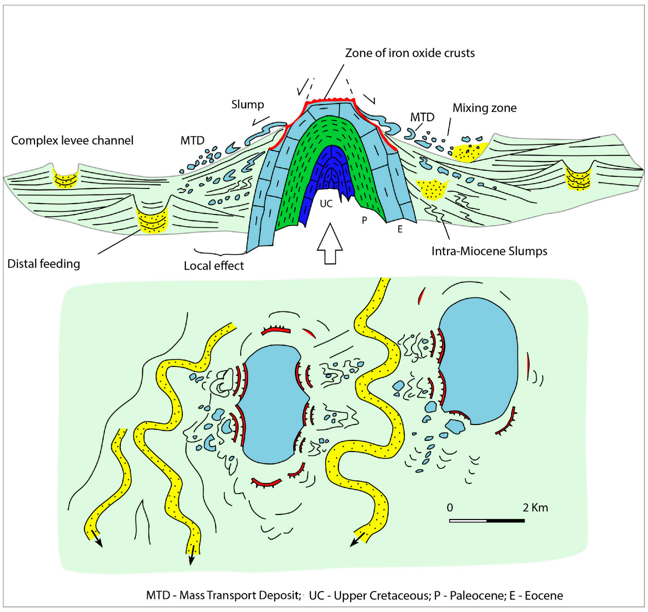

Figure 8: Theoretical model of the geometric relationships between the diapiric domes on the seabed and the turbiditic channels in the area of the Cabo Ledo zone.

The local structures (diaper, sliding and volcanism) changes or modify the driving buoyancy force of turbidity flows, erosion and redisposition of the sediments (Gray et al., 2005).

The Cabo Ledo area illustrates the impact of the tectonically instability influence on the complex turbidite deposits during the Oligocene – Miocene (Fig. 8). Due to the lack of seismic, core and biostratigraphic data the mechanisms of formation and the sedimentary processes are still poorly understood. The turbidite series studied here (Oligo-Miocene interval) are located in a complex zone highly affected by salt tectonics. Salt tectonics remained active during this period as evidenced by the presence of inter-diapir basins with complex slope geometry, creation of large depocenters, the growth and deformation of salt diapirs, the lateral migration and complex geometry of channels (Fig. 8).

These processes made controlled the location some deep-sea fan depocenters, in particular the conduit orientation for the turbidite flow and the overall basinward progradation of the fan in late Miocene- early Pliocene according with curtains authors (Z. Anka, 2004; Z. Anka, M. Séranne, 2004).

The Olistoliths and the rodolites can be sourced from either collapse on top of the diapir or its flanks, or from failures of the shelf-edge and/or slope (Doughty-Jones et al. 2019; Rodriguez et al. in press; Wu et al. 2020). Its sediments are more common during initial development of diapir (Wu et al. 2020).

4. Conclusion

In this work, we investigated the architecture of two major turbiditic systems of the Kwanza Basin during the Oligocene to Miocene period, using field woks and seismic and biostratigraphic data.

The studied turbiditic systems can be described by two main depositional architectures: (1) a constructive morphology characterized by levee channel and (2) an erosive morphology characterized by mixing sediments from clast supply and carbonate platform blocks and organisms' assemblage (rhodolites and bioclasts). 14 facies types ware identified AF1 to AF14, from the base of the system to the abandoned turbidite flow.

The facies association of the Oligocene and Miocene turbiditic systems are related to both regional and local deformation.

The regional deformation, related to the Miocene West African margin uplift, interplay between sediment supply and salt tectonics, explains the more erosive character of the system in the regional slope.

The turbidite channel levee closed to the diapir structure present more sediments supply of the platform than the distal systems which show the abundance of clastic sediments typically of the single turbidite event.

The late digenesis processes create conditions for the dissolution of particles and cementation, resulting in the disaggregation of the sandstone layers into blocks and the reduction of porosity and permeability of these turbiditic sand packages.

These systems are analogous to those found on the offshore of Kwanza Basin.

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