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Contourite vs Turbidite Outcrop and Seismic Architectures

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The hydrocarbon exploration of oceanic depositional systems demands a better understanding of the role of bottom currents and their implications for petroleum systems such as reservoir and sealing rocks. Deep-marine bottom-current reworked sands (sandy contourites) have been recognized in hydrocarbon-bearing sands of the Kwanza Basin. Such understanding implies additional alternatives for the definition of exploration targets and prospect risk reduction. The southernmost part of the Kwanza Basin (Miradouro da Lua zone) comprises one of the best outcrops of contourites deposits, formed during the Miocene and Pliocene age. Laterally, coeval sandy deposits are found offshore Kwanza Basin along the continental margin, and have been one of the great challenges for the oil companies operating in Angola. Therefore, the aim of the current proposal is to characterize sandy contourite deposits at Miradouro da Lua and compare them with offshore deep-water sandy deposits, evaluating their conceptual and economic implication. Modern field sedimentology technique merged with reflection seismic data and other geographic information system (GIS) techniques, allow the characterization and proposal of a stratigraphic architecture diagram that explains the interaction of the deep-marine processes, especially gravitational (down-slope) and bottom current (along-slope) processes as well as its vertical and spatial association. Sonangol (Angolan State Oil Company) and Total (French Multinational Company) explore similar deposits in Block 48 in Ultra deep-sea, and they will also reactivate the exploration of the Iabe Formation in Block 4. The Tertiary Stratigraphic Architecture in Blocks 6, 7, 8, 19 and 20 are similar to the Lower part of the Miradouro da Lua zone. All these observations and data are very important to calibrate oil reservoir models.

1. Introduction

The recognition of contourite deposits implies that bottom currents were active and responsible for the accumulation of sediments. Their occurrence is linked to particular conditions of ocean circulation, which are directly related to climate characteristics, and their interaction with local margin physiography and sediment availability [11, 33, 35, 40].

The lack of good outcrops with contourites and the lack of detail sedimentary facies association based on outcrops for analogs can make it difficult to recognize contourite deposits in seismic in different scale.

The stratigraphic architecture exposed on the lower part of the cliffs at Miradouro da Lua – Sangano, 58-100 km south of Luanda, represents an exceptional geometry of sedimentary bodies, showing vertical and lateral facies changes as well as sedimentary stacking pattern from deep sea (contourite and turbidite) to shallow systems (costal deltaic), during the Miocene age (Fig. 2). The Kwanza Basin is divided into an eastward raised part in the inland domain, the Inner Kwanza Basin, and a westward shelf to the deep marine domain, the Outer Kwanza Basin [20]. The inner portion rose along the coastal margin at approximately 100 m during the Cenozoic period; however, the mechanisms controlling these movements, such as tectonics [16, 17], salt gravitational deformation [20], and general thermal doming remain poorly constrained [22, 26]. In the coastal domain of the Inner Kwanza Basin, particularly around the Luanda area, the Neogene deposits have been the subject of much discussion due to the lack of stratigraphical constraints and correlations [4]. The top of the series, corresponding to the Miradouro da Lua outcrop (Luanda Fm., Cacuaco Fm. and Quelo Fm.), has been described in detail in some pioneer sedimentological papers.[4, 5] Similarly, there is neither a detailed facies description nor vertical and lateral correlations to constrain the sedimentary processes as well as the pile stacking mechanisms, to better understand and elaborate the best offshore geological model (Blocks 5, 6, 7, 19 and 20, Fig.1).

The objectives of this paper are to (1) analyze the stratigraphic architecture (sedimentology and biostratigraphy) of the Tertiary deposits to clarify the depositional processes; (2) constrain the facies partitioning and the relationship between turbidite deposits and contourite network on seismic and outcrops and; (3) the impact on the reservoir model in the Kwanza Basin.

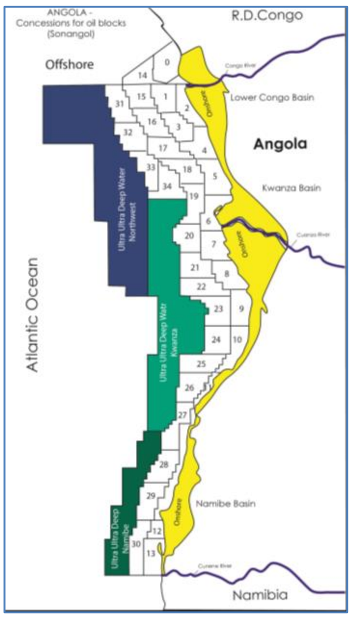

Fig. 1: Block Map of the Angolan margin, illustrating the outcrop of the study zone and the Ultra Ultra basins.

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2. Geological setting

The exceptional countourite geometries crossing the turbidite deposits, seen at Miradouro da Lua outcrops, were discovered in the northern part of the Cuanza River estuary (Inner Kwanza basin), 20 km south of Luanda (Fig.2). The Inner Kwanza basin corresponds to a salt-controlled mobile margin submitted to an overall uplift during the late Neogene that led to the continentalization of the domain and the outcropping of shelf to slope deposits along wellexposed coastal cliffs.[20, 16, 17] During the Cenozoic period, the eastern part of the basin was submitted to an overall southward differential uplift that led to the present-day sub-continuous outcrop along the coastal cliffs, from southern Upper Eocene/Lower Miocene turbidites and deep-sea deposits to northern Late Miocene/Pleistocene braided-delta and coastal plain deposits. The Miocene contourite in West Africa was also described in Morocco by. [3] This paper focuses on the paleo-conditions for the development of the sedimentary prism in the northern zone of the Kwanza basin from Miocene to Pliocene-Quaternary age.

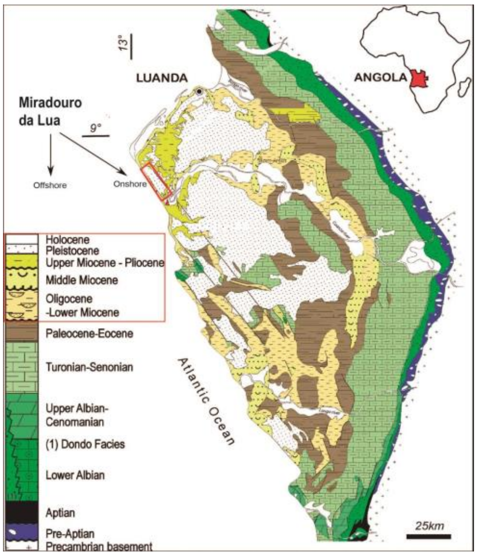

Fig. 2: Location map of Miradouro da Lua and geological overview of the discovery zone of contourite vs turbidite deposits in the Kwanza basin, Angola; modified from Cauxeiro [4].

The upper part of the sequence in Kwanza basin is mainly composed of about 20 m of intensely bioturbated, greenish-grey clayey silt to fine sands. The exact age of the upper sands remains relatively uncertain; the fossil skeleton found in these sands helps to place these deposits in the Tortonian-Messinian interval.

Some authors[29] describe the existence of one regional marine erosional surface in south part of Cuanza River, which can be correlate, towards the northern area of Miradouro da Lua (Fig.3). In the southern part of the cliff, the top of the sedimentary pile is characterised by a 20-30 m thick coarsening upward sequence of poorly sorted fine to coarse sand. Towards the north of the cliff, the top is represented by the Miradouro da Lua Bird foot Delta[5].

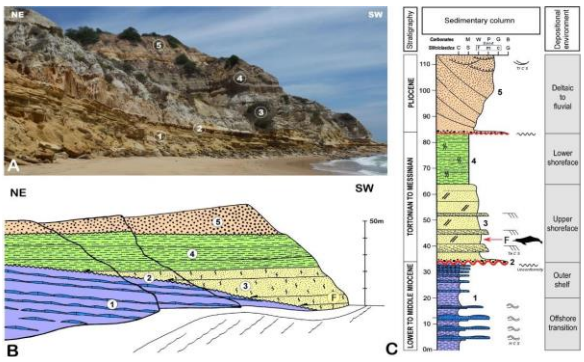

Fig. 3: Stratigraphical architecture and conceptual sedimentary log of the cliff located south of Barra do Kwanza where the holotype of K. khoisani was discovered. (A) Panoramic view; (B) interpreted line drawing; and (C) sedimentary column showing the main facies assemblage. In the lower part of the cliff, alternating hummocky cross stratified sandstones, mudstones, and black shales from the lower to middle Miocene (sequence 1) are slightly tilted southwards and obliquely truncated by the major erosional unconformity (sequence 2). This erosional surface is onlapped by an overall fining upward sequence dated from the late Miocene. This sequence shows upper shoreface sand burrowed by Ophiomorpha (sequence 3) passing upwards to burrowed fine sand to clayey silt from lower shoreface environment (sequence 4). The upper part of the cliff is composed of an upward coarsening sequence, from fine to coarse sand and gravel (sequence 5), which marks the overall progradation of the paleo-Cuanza delta during the Pliocene. This sequence is floored by a marine ravinement lag deposit. Abbreviations: F fossil locality (see also Fig. 3); M mudstone;Wwackestone; P packstone; G grainstone; B boundstone; C clay; Si silt; f fine sand; m medium sand; c coarse sand; G gravel; HCS hummocky cross stratification; TaCS tabular cross stratification; TrCS trough cross stratification.[29]

3. Data and Methods

The available dataset for this study consists of several fieldworks dating from 2015 which include detailed outcrop studies, sample analysis as well as 2D seismic data.

The field data allowed, for the first time, the characterisation of different sedimentological facies, depositional environments and key surfaces that led to the reconstruction of the main stratigraphic architecture, stacking pattern and dimensioning of the paleo-geographic landscapes of the Kwanza Basin succession using time and space correlations.

To constrain the large-scale geometry of the sedimentary bodies and to localise the key working-areas, a helicopter and drone survey was previously performed, which allowed the selection of the outcrop sections. The cliff sections were carefully analysed from base to top using particularly climbing techniques developed by Cauxeiro.[5] In this technical methodology the unconsolidated material observed in the outcrop needs to follow a particular workflow; cleaning techniques were used to obtain a better section to describe the facies association: (1) Partial excavation with a hoe and removal of collapsed material to obtain a vertical plane. (2) Scraping off the surface with a machete to obtain a flat regular surface for detailed observations. (3) Brushing off the surface with a large paint brush to elucidate the internal fabric of the sedimentary structures.

At a later stage, seismic profiles were used to understand the deep-water architectures in order to build the first stratigraphic architecture approach model in different scales.

4. Sedimentology - Fieldwork

The undertaken fieldwork covered the area between the southern part of Miradouro da Lua and the northern part of Barra do Kwanza. The zones corresponding to the Luanda Formation (Upper Miocene-Pliocene ages) and the stratigraphic unit, is overlaid by the Quelo Formation (Pleistocene) in some places. According to Cauxeiro[5], this zone can be considered as an excellent natural laboratory which provide a unique opportunity to learn and understand more about the formation of contourite and turbidite sequences.

Recently, studies about the economic potential of these deposits have taken off with great potential for hydrocarbon exploration. The central most part of the Kwanza Basin (Miradouro da Lua zone) is characterized by the best outcrops of contourite deposits, formed during the Upper Miocene to Pliocene age.

4.1. Sedimentological descriptions - Facies

The outcrops Parede area, namely "Pescadores Village" (Fig.4), are characterized by a very complex system of sand and mud sequences showing different periods of interaction. According to the flow characteristics, sediment nature, texture and origin, a large variety of contourite facies have been recognized in the modern oceans.[33, 34, 35] This depositional processes depend on the bottom-current velocity: slow velocity currents allow vertical settling of the suspended particles from the nepheloid layer; high-velocity currents have more bedload transport and deposition. The latter generate largescale winnowing and erosion, resulting in a lag deposit. Chemical processes (dissolution and authigenesis) can be associated with the physical processes. Contourite grain size varies from sand (more rarely gravel) to mud. The nature of the sediment can be terrigenous siliciclastic, volcaniclastic or biogenic (siliceous or calcareous), and is commonly mixed. Despite the grain size and nature, the various contourite facies show three common diagnostic features.[10, 15] These contourites features are: (1) Abundant bioturbation with several types of burrows as the benthic fauna depends on the current intensity. This bioturbation may help in distinguishing muddy contourites from hemipelagites with homogenous burrows and from fine-grained turbidites where bioturbation is usually restricted to the uppermost part of the bed.[43] (2) Bad preservation of the dynamic sedimentary structures, due to bioturbation. These structures are well preserved in fine-grained turbidites. (3) Irregular vertical variation in grain size. Superposition of well-developed coarsening-upward and fining-upward units is the main difference with fining-upward turbidites, but could be mistaken for hyperpycnites[27].

The Parede outcrop is represented by alternating cm-thick packages of ripple-laminated, finegrained sand and bioturbated muddy units with sandy bodies at the base (Fig.4). Laterally, these facies are eroded by coarse to very coarse-gravel sands, showing some shale clasts within the sediment. The coarser facies are localized in particular sectors. The geometries of these alternating packages are very well displayed in the village zone.

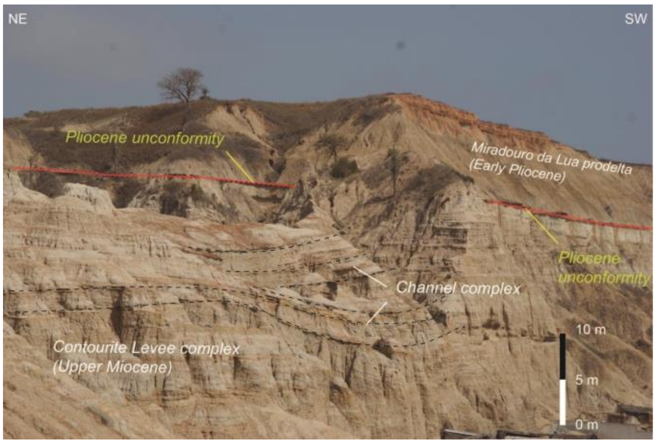

Fig. 4: North part of the Parede outcrop (Pescadores zone - Miradouro da Lua), illustrating the contourite and turbidite deposit geometries and the relationship between Upper Miocene and Pliocene facies.

The middle part of the Parede series is represented by an unconformity surface that marks the early Pliocene.[4] Below of this surface, there is a fining upward sequence, with clean gravel to coarse sand, poorly sorted with shale clasts, going from fine to very fine sand on top; these facies are confined by erosional surfaces which show wave geometries. The top of this zone, is clearly represented by meters thick wellsorted fine sands with large ripples showing internal sigmoidal structures within a wave geometry that rework the sand sediments of the gravity deposit. In Palmeira Real area toward to south, it is possible to see multicycle of wave geometries in opposite phase, showing wave lamination structures built by sub-critically climbing ripples that indicate flow direction[30, 31, 38] .

Coarser contourite sand deposits are mainly observed in the southern part of the Palmeira Real. It´s characterized by coarse clean sand, with some granules scattered within the sands and Ophiomorpha bioturbation; gravel to coarse sands with shale clasts; gravel to coarse sands with cross-trough bedding and very coarse to coarse sands showing high regime parallel laminae.

4.2. Contourite Geometry

The offshore (seismic) and onshore (outcrops) geometries in Miradouro da Lua, gave the excellent examples of the continuity of the Kwanza Basin onshore sedimentary series toward seaward. The images below are a well-detailed geometries representation of the contourite system in the Parede and Palmeira Real area (Fig. 5). The contourite sandstone facies suggest that these deposits were reworked by bottom currents from the located gravity flow travel points. Understanding the palaeo-environmental conditions and consequently the sedimentological processes associated with the formation of contourite deposits, is one of the most efficient ways to recognize such deposits and avoid confusions with turbidite deposits in dynamic reservoir models shown by oil industry.

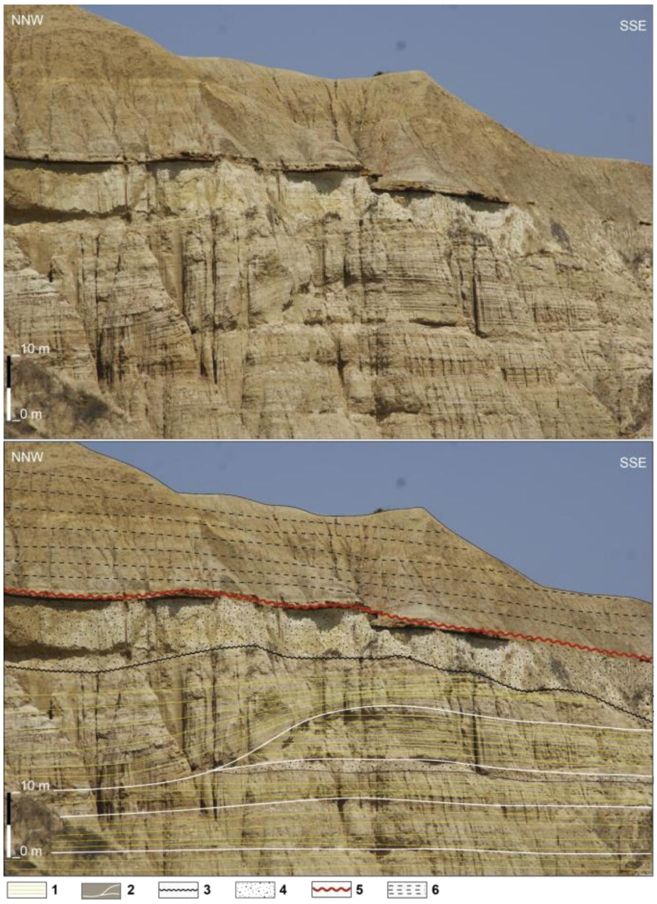

Fig. 5: Southern part of the Parede outcrop showing the great contourite geometries and the contact with turbidite flow deposits; **1**: silt and clay intercalation forming 50 cm of increase and decrease energy current velocity; **2**: Erosional contourite surfaces indicating the alternation of contour cycles; **3**: erosional channel surface of the turbidite flow; **4**: Gravel to clean sand, poorly sorted with granule sediments and shale clasts; **5**: Early Pliocene erosional surface;[5] **6**: Miradouro da Lua bottom set facies.

4.3. Inferences at palaeodepth

Contourites are generally considered to be deposited by bottom currents at depths greater than 300 m.[36] The water depth at the time of deposition of the Miradouro Da Lua contourite deposits (estimated from clinoform height, sedimentary facies and Chondrites bioturbation) is about 400 to 300 m. The representation of the internal structure of the up-slope migrating mounds is very clear, and it is represented in perpendicular direction to the coast. Observing that at southern Palmeira Real zone, the bottom current was responsible for erosion. The scours on the Palmeira outcrops have a clear two preferential alignment, i.e. one perpendicular to the slope and other parallel to the slope. This implies a stronger current influence during the Upper Miocene times, perhaps suggesting that a tidal-circulation current was operating along-slope rather than in parallel with density-laden currents down-slope.

In this particular case, we would be in an area where the “along-slope” and “down-slope” processes would alternate simultaneously to allow the deposition of gravity and contours deposits. This indicates an overlapping / drifting spectrum: “overlapping fan / drift”.[23] The flow direction associated with these contour deposits are clearly visible along a perpendicular section which appears on this last outcrop (southern part of Palmeira). It is observed that the alternation between the coarse silts-clay drapes and intense bioturbation of Chondrites, is organized according to a set of wave geometry that display clearly and locally the laminae showing very clear the truncations shapes between the bundles. The middle part of the outcrop shows a succession of overlapping mega ripple sets with very fine sands migrating towards to northwest, climbing the paleo-slope topography.

This association of facies and the geometries observed in Miradouro da Lua, are similar to those described by some authors.[1, 3, 13, 19, 29] Their studies confirm that these depositional processes are associated with bottom currents (Contourites) which go from abyssal zones towards the platform (upwelling).

5. Results

Our detailed fieldwork analysis merged with seismic profile interpretations made it possible to highlight two main results: stratigraphic architecture and geological model.

5.1. Stratigraphic Architecture

The main feature that allowed the understanding on contourites stratigraphic architecture deposits is the sediment drift. According to Mulder,[27] contouritic sediment waves are frequent in deep-seas because they can form on a relatively flat sea-floor, despite the water-depth. These giant depositional bedforms with wavelengths can ranging from 0.5 to 10 km and heights ranging from 10 to 150 m. They form widespread undulated fields at the top of most of the giant-mounded contourite drifts and flat contourite sheets. The waves can also cover terraces located along deep channel flanks or continental slopes. Contouritic sediment waves may be parallel, perpendicular or oblique to the current direction. On a relatively flat seafloor, they are more or less perpendicular to the current direction (transversal waves), with a symmetric or asymmetric cross-section. Propagation of asymmetrical waves can be either downstream or upstream. These geometries are controlled by parameters such as current velocity, sea-floor topography, Coriolis force and the amount and nature of transported sediment.

The Southern Palmeira Real's stratigraphic geometry is a confined drift, represented by a geometry mainly influenced by the morphology and sustainable contour current, which led to sediment deposition in the negative relief. The bottom boundary of confined drifts is distinct with a flat and smooth top, accompanied with moats, either parallel or subparallel. These drifts are also characterized by moderate to low continuity and moderate to high amplitude seismic reflections. Convergence and erosion are formed in the moats[32, 42].

In the northern part of Palmeira Real, the different asymmetric facies can be very well observed on the left and right side - an erosive structure, whit several hundred meters to kilometers long. This suggests giant elongated drifts which are a typical type of contourites, usually mounded and elongated shapes along the slope associated with moats. Seismic images show that these drifts have distinct boundaries that are either concave to smooth upward features, or parallel to sub-parallel structures with upslope migration, low continuity, and moderate to low amplitude seismic reflection, usually converging in the high energy moats. Furthermore, multi-depositional stages can be identified in a number of drifts. Giant elongated drifts display wavy seismic reflection patterns, with migration paths in the seismic profile, which can be sub-parallel to the slope. [32, 42]

The contourite series on north of the Palmeira Real outcrop, show variations from mud-silt and very fine to fine laminated sands, with bioturbated levels. However, on the south of this outcrop, the drift is characterized by clean fine to medium laminated sands. This asymmetric geometry shows one of the major sediment drift directions, dipping towards the north, probably related to Benguela currents. Both sides are eroded by another bottom current cycle, showing an alternation between clay-silt and some fine sand layers. 3D view of this geometry is clearly exposed in Palmeira Real zone. The combination between vertical and lateral facies variation, erosive geometries and seismic interpretation, allow us to better understand the complexity of this reservoir. The outcrop display the key to build a 3D view as well as constrains the size of the contourite versus turbidite sedimentary bodies (Fig. 6 and 7). The local point of turbidite flow is located laterally of the drift geometry, represented by a poorly sorted gravel to coarse sand with shale clasts. This stratigraphic organization was very well studied in the Pleistocene Faro Drift by Molina[18] and Alonso.[1] In this part of the Kwanza basin the coarse-grained and thick-bedded turbidite sands were trapped in delta-fed slope channels, structurally-controlled by depressions (intraslope basins) and channel-terminus lobate features. Fine-grained sediment transported in suspension by turbidity currents was almost entirely removed by bottom currents during and immediately after deposition and transported northward, away from their turbidite feeder systems, to form spectacular fields of fine-grained and very well-sorted contourite low-relief sand drifts, characterized by very distinctive facies in cores, which are highly prolific oil reservoirs.[28] Similar structures was discovery in this in offshore part of Miradouro da Lua (Figs. 6 and 7).

The Upper Miocene contourite stratigraphic architecture in Miradouro da Lua outcrops, showing 3D geometries formed by the combination of vertical and lateral facies variations and erosive geometries. This model allows us to better understand the complexity of this type of reservoir and it is the key to build a 3D view and constraint the size of these sedimentary bodies. **1**: fine to medium laminated sands alternating with silt layers and with poorly sorted gravel to coarse sand elongated drift; **2**: mud-silt and very fine to fine laminated sands indicating the variation in the wave period of the bottom current on Offshore (Fig. 7).

The contourite deposits can greatly improve the qualities of sandy reservoirs. For example, in the Ewing Bank Block 826 field, the type I (L-1) reservoir with 80% sand exhibits higher permeability values (100-1800 md) than the type 2 (N-1) reservoir with 26% sand (50-800 md)[41].

In Brazilian margin, giant oil fields were discovered (e.g. Marlim, Albacora and Roncador oil fields) leading to a very fast growth of the Brazilian proved reserves in contourites deposits. In opposite margin (Angola) the Kwanza Basin show several stratigraphic architecture and sedimentary facies, which can be interpreted as a complex network between contourite and turbidite systems, which rework and improve reservoir quality in Kwanza basin.

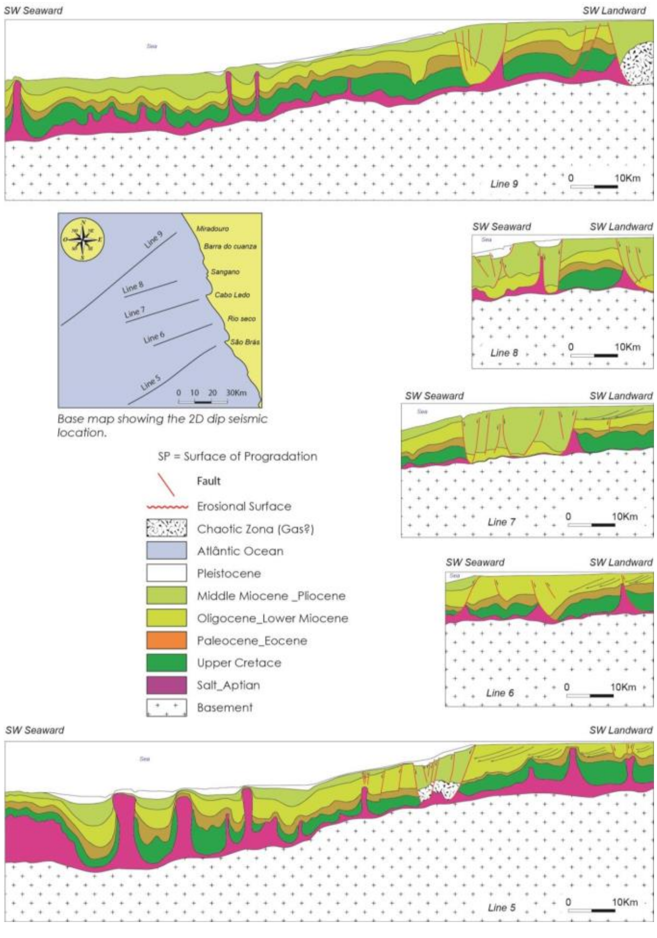

Fig. 6: General setting from the Miradouro da Lua to São Brás, showing the stratigraphic architecture crossing to coast line, displaying the major sedimentary depocenter filling with Oligocene to Pliocene and Quaternary progradding sequences, modified from Cauxeiro.[4]

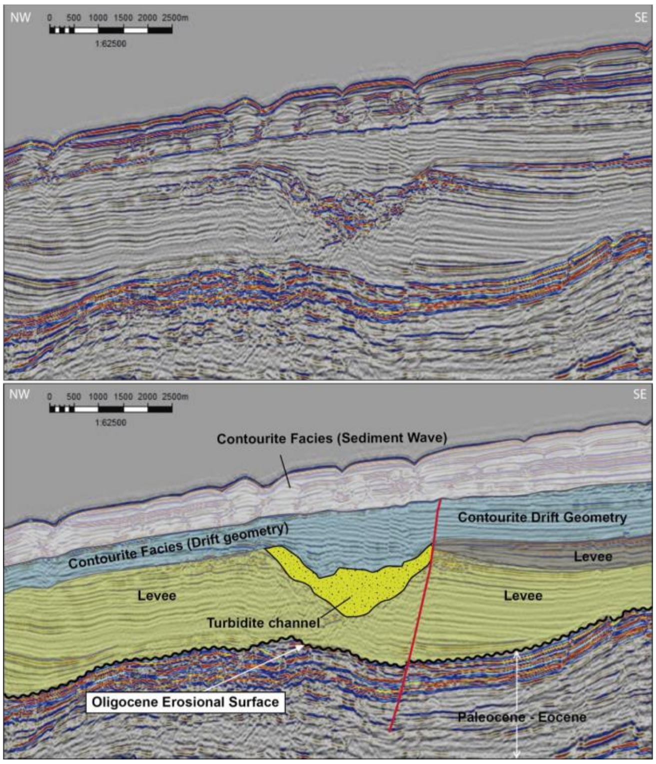

Fig. 7: Offshore Kwanza Basin seismic (section of line 9, in Fig.15), showing the stratigraphic section displaying the major sedimentary deposits (Turbidite vs Contourite) from Oligocene, Pliocene and Quaternary ages, modified from Alzira.[2]

5.2 Geological Model Approach

Building geological models based on field study and subsurface data is a typical and hard task in geological studies as it involves natural resource evaluation and hazard assessment. This paper aims to understand the sedimentological evolution of Miradouro da Lua's outcrops in the Kwanza Basin, based on data integration such as seismic profiles, photographies, outcrop analysis as well as structural interpretation. All of these analysis culminated in a pioneer construction of a geological model of the Upper Miocene – Pliocene Miradouro's formations (Fig. 8).

Results from seismic data and field analysis show that the Upper Miocene-Pliocene sands are divided into contourite and turbidite facies. Both contourite and turbidite sands are good reservoir units as they show excellent petrophysical properties. Cross section of the coastal outcrops shows the vertical and horizontal distribution of facies and suggest their depositional environment (Fig. 6 and 7).

Seismic section from offshore Miradouro da Lua suggests that salt diapirs flowed along listric faults zones, forming mini-basins structures in the area (Fig. 6). Such type of structures have also been studied in other areas by Gee and Gawthorpe [14].

This paper also suggests that the sedimentary directions of the Miradouro turbiditic systems was probably influenced by the rapid rise of salt domes. As in the case of the Kwanza Basin, these salt walls and domes developed parallel to the coast, forcing the turbiditic system to bypass and migrate laterally. The barrier formed by the diapir could lead to avulsion processes and variation of syn-sedimentary geometries.[14, 24] These processes are evident in the Lower Congo Basin, and was confirmed by Cauxeiro [4].

The seismic architecture on offshore Miradouro da Lua area, allowed to constrain the canyon formations that diverted the turbiditic channels to the pits. This process was combined with deltaic supply, gullies, tidal currents and platform landslides. The turbidite sands were reworked by bottom current that circulated into the pit. The architecture of all this complex depositional system, from lower to upper slope, could also be controlled by fault systems striking NW-SE and NE-SW.

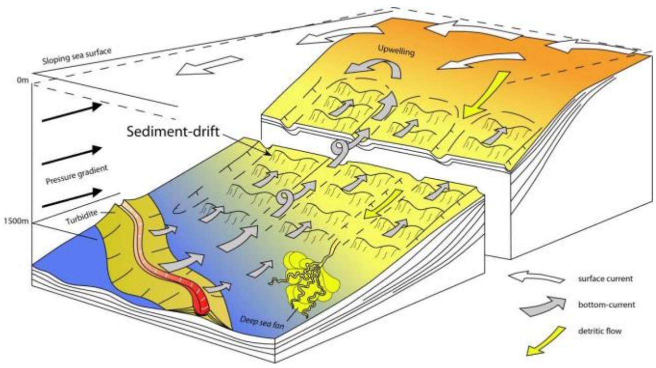

Fig. 8: Block diagram of the southern part of Miradouro da Lua (Kwanza Basin), showing the geological model approach, illustrating the processes of mixing littoral and platform deposits in deep turbidite sands. It processes combined with tectonic events was the responsible for the structural architecture from the Oligocene-Miocene to Pliocene.

6. Conclusions

The Upper Miocene - Pliocene contourite and turbidite deposits of the Miradouro da Lua, Kwanza Basin study, was made based on sedimentological fieldwork, photography interpretation and detailed seismic data analysis from Onshore and Offshore of Kwanza Basin. The combination of these technics allowed the understanding of the stratigraphic architecture, sedimentary processes and potential reservoir of these deposits. Therefore, the main findings of this study are as follows:

a) The detailed outcrop studies in metric and kilometric scales unveiled giant contourite geometries as well as stratigraphic relationship between turbidite and contourite facies. These observations show the complexity of the Tertiary clastic deposits of the Kwanza Basin.
b) The quality of these facies found in these deposits resulted from the reworking of the turbidite currents by the contourite currents. These deposits are characterized by having high NTG and clean well-sorted sands making good reservoirs;
c) This sedimentological study of the Miradouro da Lua, leads to a great understanding of how subsurface reservoir models work, leading to more realistic geological results when looking into the petroleum system of the Kwanza Basin.

References

[1] Belén, Alonso; Gemma, Ercilla; David, Casas; Dorrik, A. V. Stowc; Francisco, J. Rodríguez-Tovar; Javier, Dorador D.; Francisco-Javier, Hernández-Molina. Contourite vs gravity-flow deposits of the Pleistocene Faro Drift (Gulf of Cadiz): Sedimentological and mineralogical approaches. Marine Geology. (2016).

[2] Benvindo, Alzira and Cauxeiro, Cirilo. Interacção entre depósitos contouríticos e turbidíticos (Miocénico Médio-Superior) – Implicação na exploração dos reservatórios de hidrocarbonetos. Miradouro da lua – Bacia do Kwanza, Angola. Dissertação de mestrado. Departamento de Geologia, Faculdade de Ciências, Universidade Agostinho Neto. Angola. (2016).

[3] Capella, W.; Hernández-Molina, F. J.; Flecker, R.; Hilgen, F. J.; Hssain, M.; Kouwenhoven, T. J.; van Oorschot, M.; Sierro, F. J.; Stow, D. A. V.; Trabucho-Alexandre, J.; Tulbure, M. A.; de Weger, W.; Yousfi, M. Z.; Krijgsman, W.; Sandy contourite drift in the late Miocene Rifian Corridor (Morocco): reconstruction of depositional environments in a foreland-basin seaway. In: Sedimentary Geology, Vol. 355, p. 31-57. (2017).

[4] Cauxeiro, Cirilo. Architecture stratigraphique du prisme Neogene de la Cuanza, Angola et relations avec les mouvements verticaux. Thèse de Doctorat. SIBAGHE: Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydrosciences, Environnement. Université de Montpellier2, France. (2013).

[5] Cauxeiro, Cirilo; Durand, Jacques and Lopez, Michel. Stratigraphic architecture and forcing processes of the late Neogene Miradouro da Lua sedimentary prism, Cuanza Basin, Angola.Journal of African Earth Sciences, 95, 77–92. (2014).

[6] Cauxeiro, Cirilo; Barros, António A. Chivanga; Lundungo, Wilson; Lopes, Alípio; Ferreira, Hercinda and Bernardo, Domingos. Contourites versus Turbidites Evidences from the Eocene of the Kwanza basin, Angola: Sedimentary architecture and depositional processes. Fied trip, Sonangol Academy. (2017).

[7] Cauxeiro, Cirilo; Lopez, Michel; Hernandez-Molina, Francisco-Javier; Miguel, Artur; Cauxeiro, Gizela and Caetano, Áurea. Contourites versus Turbidites source rock - Eocene of the Kwanza Basin, Angola: Fied trip, Sonangol Academy. (2018).

[8] Cauxeiro, Cirilo; Lopez, Michel; Hernandez-Molina, Francisco-Javier; Miguel, Artur; Cauxeiro, Gizela and Caetano, Áurea. Contourites versus Turbidites Reservoir - Eocene of the Kwanza basin, Angola: Stratigraphic architecture and oil system. Fied trip, Sonangol Academy. (2018).

[9] F. Javier, Hernández-Molina; Anna, Wåhlin; Miguel, Bruno; Gemma, Ercilla; Estefanía, Llave; Nuno, Serra; Gabriel, Roson; Pere, Puig; Michele, Rebesco; David, Van Rooij; David, Roque; César, González-Pola; Francisco, Sánchez; María, Gómez; Benedict, Preu; Tilmann, Schwenk; Till, J.J. Hanebuth; Ricardo, F. Sánchez Leal; Jesús, García-Lafuente; Rachel, E. Brackenridge; Carmen, Juan; Dorrik, A.V. Stow and José María, Sánchez-González. Oceanographic processes and morphosedimentary products along the Iberian margins: A new multidisciplinary approach. Marine Geology. (2015).

[10] Faugères; J.C.; Gonthier, E.; Stow; D.V. Contourite drift molded by deep Mediterranean outflow. Geology 12, p. 296-300. (1984).

[11] Faugères, J. C. and Stow, D. V. Bottom-current-controlled sedimentation: a synthesis of the contourite problem. Sedimentary Geology. Volume 82, Issues 1–4, January, Pages 287-297. (1993).

[12] Faugères, J. C.; Stow, D. A. V.,. Contourite drifts: nature, evolution and controls. In: Rebesco, M., Camerlenghi, A. (Eds.), Contourites, Developments in Sedimentology, vol. 60. Elsevier, pp. 271, 283. (2008).

[13] Faugères, J. C.; Stow, D. A. V.; Imbert, P.; Viana, A. R. Seismic features diagnostic of contourite drifts. Marine Geology, 162, 1–38. (1999).

[14] Gee, M. J. R. and Gawthorpe, R.L. Submarine channels controlled by salt tectonics: Examples from 3D seismic data offshore Angola. Marine and Petroleum Geology (23), pp. 443-458. (2006).

[15] Gonthier, E.; Faugères, J. C. and Stow, D. A. V. Contourite facies of the Faro Drift, Gulf of Cádiz, In: Stow, D.A.V., Piper, D.J.W. (eds.), Fine Grained Sediments, Deep-Water Processes and Facies. Geological Society, London, Special Publication 15, pp. 275-291. (1984).

[16] Guiraud, R., Buta-Neto, A., Quesne, D., 2010. Segmentation and differential post-rift uplift at the Angola margin as recorded by the transform-rifted Benguela and oblique-to-orthogonalrifted Kwanza basins. Marine Petrol. Geol. 27, 1040–1068. (2010).

[17] Guiraud, R. and Maurin, J. C. Early Cretaceous rifts of western and central Africa: an overview. Tectonophysics 213, 153–168.Duval, B., Cramez, C., Jackson, M.P.A., 1992. Raft tectonics in the Kwanza Basin, Angola. Marine Petrol. Geol. 9, 389–404. (1992).

[18] Hernández-Molina, Francisco-Javier; Llave, Estefania; Preu, Benedict; Ercilla, Gemma; Fontan, Antia; Bruno, Miguel; Serra, Nuno; Pascual, Gomiz; Juan, Jesus; Brackenridge, Rachel E.; Sierro, Francisco J.; Stow, Dorrik A. V.; García, Marga; Juan, Carmen; Sandoval, Nicolas and Gimenez, Alvaro Arnaiz. Contourite processes associated with the Mediterranean Outflow Water after its exit from the Strait of Gibraltar: Global and conceptual implications. Geology, 42, 227-230. (2014).

[19] Hernández-Molina, F. J.; Soto, M.; Piola, A.R.; Tomasini, J.; Preu, B.; Thompson, P.; Badalini, G.; Creaser, A.; Violante, R.A.; Morales, E.; Paterlini, M. and De Santa Ana, H. A contourite depositional system along the Uruguayan continental margin: Sedimentary, oceanographic and paleoceanographic implications. Mar. Geol. 378, 333-349. (2016).

[20] Hudec, M. R. and Jackson, M. P. A.. Structural segmentation, inversion, and salt tectonics on a passive margin: evolution of the inner Kwanza Basin, Angola. Geol. Soc. Am. Bull. 114, 1222 – 1244. (2002).

[21] Jennifer, Y. Stuart and Mads, Huuse. 3D seismic geomorphology of a large PlioPleistocene delta e 'Bright spots'and contourites in the Southern North Sea. J.Y. Stuart, M. Huuse / Marine and Petroleum Geology 38. Pp. 143-157. (2012).

[22] Lavier, L. L.; Steckler, M.S. and Brigaud, F.. Climatic and tectonic control on the Cenozoic evolution of the West African margin. Mar. Geol. 178, 63–80. (2001).

[23] Locker, S. D. and Laine, P. Paleogene–Neogene depositional history of the middle, US Atlantic continental rise: mixed turbidite and contourite depositional systems. Mar. Geol. 103, 137–164. (1992).

[24] Lopez, M. Siliciclastic sedimentary environments. Montpellier 2 University. France. (2010).

[25] Lopez, M. Contourites versus Turbidites from the Upper Miocene of the Kwanza basin, Angola: Sedimentary architecture and depositional processes. Total internal report. Angola. (2018).

[26] Lunde, G.; Aubert, K.; Lauritzen, O. and Lorange, E. Tertiary uplift of the Kwanza Basin in Angola. Geologie Africaine, Colloques de Geologie de Libreville 6–8 Mai, edited by R. Curnelle, Bull. Cent. de Rech. Explor. Product. Elf Aquitaine, Mém. 13, 99 – 117. (1992).

[27] Mulder, T.; Voisset, M.; Lecroart, P.; Le Drezen, E.; Gonthier, E.; Hanquiez, V.; Faugères, J. C.; Habgood, E. L.; Hernández-Molina, F. J.; Estrada, F.; Llave-Barranco, E.; Poirier, D.; Gorini, C.; Fuchey, Y.; Voelker, A.; Freitas, P.; Lobo Sanchez, F. J.; Fernandez, L. M.; Kenyon, N. H. and Morel, J. The Gulf of Cadiz: an unstable giant contouritc levee. Geo-Marine Letters 23, 7–18. (2003).

[28] Mutti, Emiliano; Rogério, S. Cunha; Élvio, M. Bulhoes; Luci, M. Arienti and Adriano, R. Viana. Contourites and Turbidites of the Brazilian Marginal Basins. (2014).

[29] Olivier, Lambert; Camille, Auclair; Cauxeiro, Cirilo; Michel, Lopez and Sylvain, Adnet. A close relative of the Amazon River dolphin in marine deposits: a new Iniidae from the late Miocene of Angola. PeerJ, DOI 10.7717/peerj.5556. (2018).

[30] Reading, H. G.; Sedimentary Environments and Facies. Second ed.; Blackwell Scientific Publications, Oxford, 615p. (1986).

[31] Reineck, H.E. and Singh, I. B. Depositional Sedimentary environments, Second Edition. Springer Verlag, Berlin, 549p. (1980).

[32] Shao, L.; Li, X. H.; Wei, G. J.; Liu, Y. and Fang, D. Y. Provenance of a prominent sediment drift on the northern slope of the South China Sea. Science in China Series D: Earth Science 44, 919, 925. (2001).

[33] Stow, D. A. V. Contourite watch, IGCP 432 Project Newsletter, Southampton Oceanography Centre, Southampton, UK, Issue 1 (January 1999), 8 pp. (1999).

[34] Stow, D.A.V. and Faugères, J. C. Contourite facies and the faciesmodel. Developments in Sedimentology, 60, 223–256. (2008).

[35] Stow, D. A. V.; Faugères, J. C.; Howe, J. A.; Pudsey, C. J. and Viana, A. R. Bottom currents, Contourites and deep-sea sediment drifts: current state-of-the-art. In: Stow, D.A.V., Pudsey, C.J., Howe, J.A., Faugères, J.-C., Viana, A.R. (eds.), Deep-Water Contourite Systems: Modern Drifts and Ancient Series, Seismic and Sedimentary Characteristics. Geological Society, London, Memoirs 22, 7-20. (2002b).

[36] Stow, D. A. V.; Kahler, G. and Reeder, M.; Fossil contourites: type example from an Oligocene palaeoslope system, Cyprus. In: Stow, D.A.V., Pudsey, C.J., Howe, J.A., Faugères, J.-C., Viana, A.R. (Eds.), Deep-water Contourite Systems: Modern Drifts and Ancient Series, Seismic and Sedimentary Characteristics. Geological Society, London, Memoir, 22, pp. 443455. (2002).

[37] Stow, D.A.V.; Reading, H. G. and Collinson, J. Deep seas. In: Reading, H.G. (Ed.), Sedimentary Environments, third ed. 395–453. (1996).

[38] Suguio, K. Geologia Sedimentar. Primeira edição, Edgard Blucher LTDA, Brasil, 400p. (2003).

[39] Susanne, Lil Rasmussen and Finn, Surlyk. Facies and ichnology of an Upper Cretaceous chalk contourite drift complex, eastern Denmark, and the validity of contourite facies models. Journal of the Geological Society 169(4):435-447. (2012).

[40] Viana, A. R.; Faugères, J. C. and Stow, D. A. V.; Bottom-current controlled sand deposits: a review from modern shallow to deep-water environments. Sediment. Geol. 115, 53–80. (1998).

[41] Viana A. R.; Almeida, Jr, W.; Nunes, M. C. V.; and Bulhões, E. M. The Economic Importance of Contourites. Petrobras, E&P Exploration, Rio de Janeiro, RJ 20031-912, Brazil. (2007).

[42] Wang, P. X.; Prell, W. L.; Blum, P. and Baldauf, J. Proceedings of the Ocean Drilling. (2000).

[43] Wetzel, A.; Werner, F. and Stow, D. A. V. Bioturbation and biogenetic sedimentary structures in contourites. In: reBesco, M. & cAmerlenghi, A. (eds) Contourites. Developments in Sedimentology, 60, 223–256. (2008).