



Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: <https://atbu.edu.ng/science-forum/>



Seismic Geomorphology of Submarine Channels Using Spectral Decomposition Techniques Offshore Angola-West Africa

Byami A. Jolly^{1*}, Ahmed I. Isiaka¹ and Tuvieri Omeru², Mohammed Mohammed³

¹Department of Geology, Ahmadu Bello University, Zaria – Nigeria

²Department of Geosciences, University of Lagos, Akoka, Lagos – Nigeria

³Department of Applied Geology, Abubakar Tafawa Balewa University, Bauchi – Nigeria

ABSTRACT

The use of advanced spectral decomposition techniques and Red-Green-Blue (RGB) blending of 3D seismic data from the transitional slope domain offshore Angola have provided high resolution imaging of both structural and stratigraphic elements with great insight into the spatio-temporal distribution of these elements. The depositional and structural elements observed include sand/mud-filled channels, sand-rich splays and faults including sub-seismic scale faults. The splays are usually expressed as bright lobate features (characterized by high amplitude seismic reflectors) that are up to 10 km wide and 15 km long and deposited at the distal parts of the turbidite channel systems within unconfined mini-basins. Earlier splay-deposits are often eroded by subsequent channels cutting through them, with the products of such erosion deposited as splays within the next mini-basin further downslope. These eroding channels, once abandoned, are filled with mud – which are characterized by low amplitude and negative differential compaction in seismic section. The channels and consequently, the depositional elements appeared to be controlled by the time-integrated movement of salt – which also creates the mini-basins. Analysis shows that channels are mostly confined upslope, flowing through salt walls or salt-cored highs and are mostly erosive but on getting to unconfined intra-slope mini-basins, these channels spread through the process of avulsion to deposit splays. In essence, this study has greatly improved our understanding of the geometry and architecture of depositional elements within the study area, and can aid in exploration efforts in deepwater settings such as offshore Angola.

ARTICLE INFO

Received 12 November 2023

Received in Revised Form

14 November 2023

Accepted 15 November 2023

Published 15 January 2024

Available online 15 January 2024

KEYWORDS

Seismic-geomorphology,
Spectral-decomposition,
Channels,
Splays,
Angola,
Mini-basins

Introduction

The continued availability of high-quality 3D seismic data and the advent of seismic geomorphology discipline have made it possible for submarine channels to be studied in great details in the offshore Gulf of Mexico, Niger Delta, Nile Delta, Offshore Australia and offshore Angola. Seismic geomorphology has been used to study channels by many workers (e.g., Kolla et al., 2001; Posamentier and Kolla, 2003; Gee et al., 2007; Deptuck et al., 2007; Othman et al., 2016; Pattison, 2018;

Mahon and Wallace 2022 amongst others). The advantage of seismic geomorphology is the ability to integrate it with seismic stratigraphic analysis as a means of deriving better insight in to the seismic data. This help in constraining the geometry of geobodies especially submarine channels that have been poorly understood in the past. In this study, we take advantage of this unique methodology for better imaging of submarine channels – including subseismic scale channels that are difficult to identify purely from seismic stratigraphic analysis. The study also analyses the interaction between these channels and salt diapirism within the study area.

1. Study Area and Geological Setting

The study area is located in License 'Block X' (identity not revealed), offshore Angolan slope in water depth of about 1500 m to 2000 m (Fig. 1). The Angolan passive margin is part of the West Africa passive continental margin. The basin evolution resulted from the early Cretaceous rifting 130 Ma (Jansen et al., 1985; Marton et al., 2000) that led to the development of continental rift comprising the syn-rift and the post-break-up mega-Sequences. The tectono-stratigraphic sequence of the Angolan Passive margin is shown in Figure 2. There are three main stratigraphic units, which correlates with three tectonic phases: pre-rift continental deposits (Jurassic), syn-rift fluvio-lacustrine deposits (Lower Cretaceous), and the post-break-up unit with a large accumulation of salt (Middle-Late Aptian) covered by thick marine successions (Albian to

present) (Bruno et al 2009; Anka et al., 2008). The post-break-up sequence includes the Miocene submarine channels and associated turbidite fans at the distal end of the slope. Large volume of sandy sediments was supplied through submarine channels during the Oligocene-Miocene along the Angolan slope due to regional tectonic uplift and structural deformation on land, humid climatic and worldwide Sea level lowstand during later Cenezoic (Cramez and Jackson, 2000). Sandy turbidites were deposited in mostly slope environments as highly productive amalgamated channel complexes with sinuous depositional patterns (Kolla et al., 2001). Many discoveries of hydrocarbon fields in deep water offshore Angola are related to the deep-marine channels deposited between the Oligocene and Miocene (Amaral et al., 1998; Kolla et al., 2001).

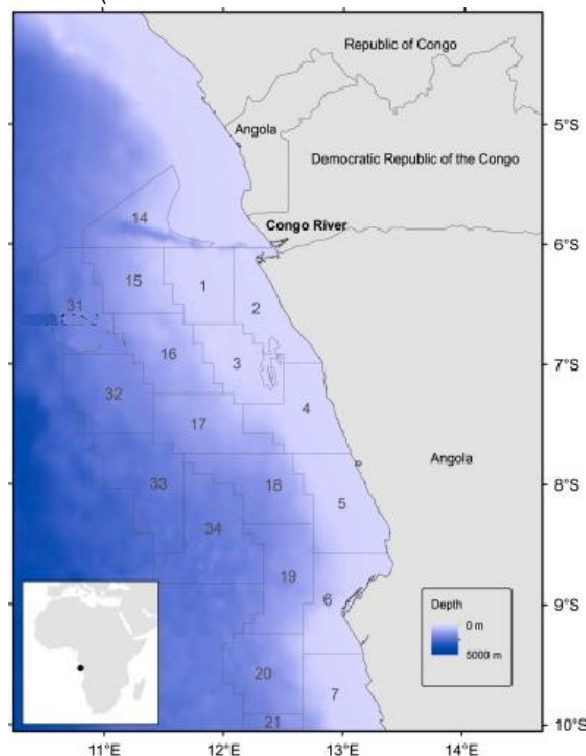


Fig. 1: Shows the location of Angolan Passive Margin and Licence Blocks (Numbered) – our study area remains confidential but located in water depth of between 1500m to 2000m (Water depth is shown in different shades of blue). Black dot on Inset map of Africa shows the position of Angolan margin (Figure adapted from Jones et al., 2014)

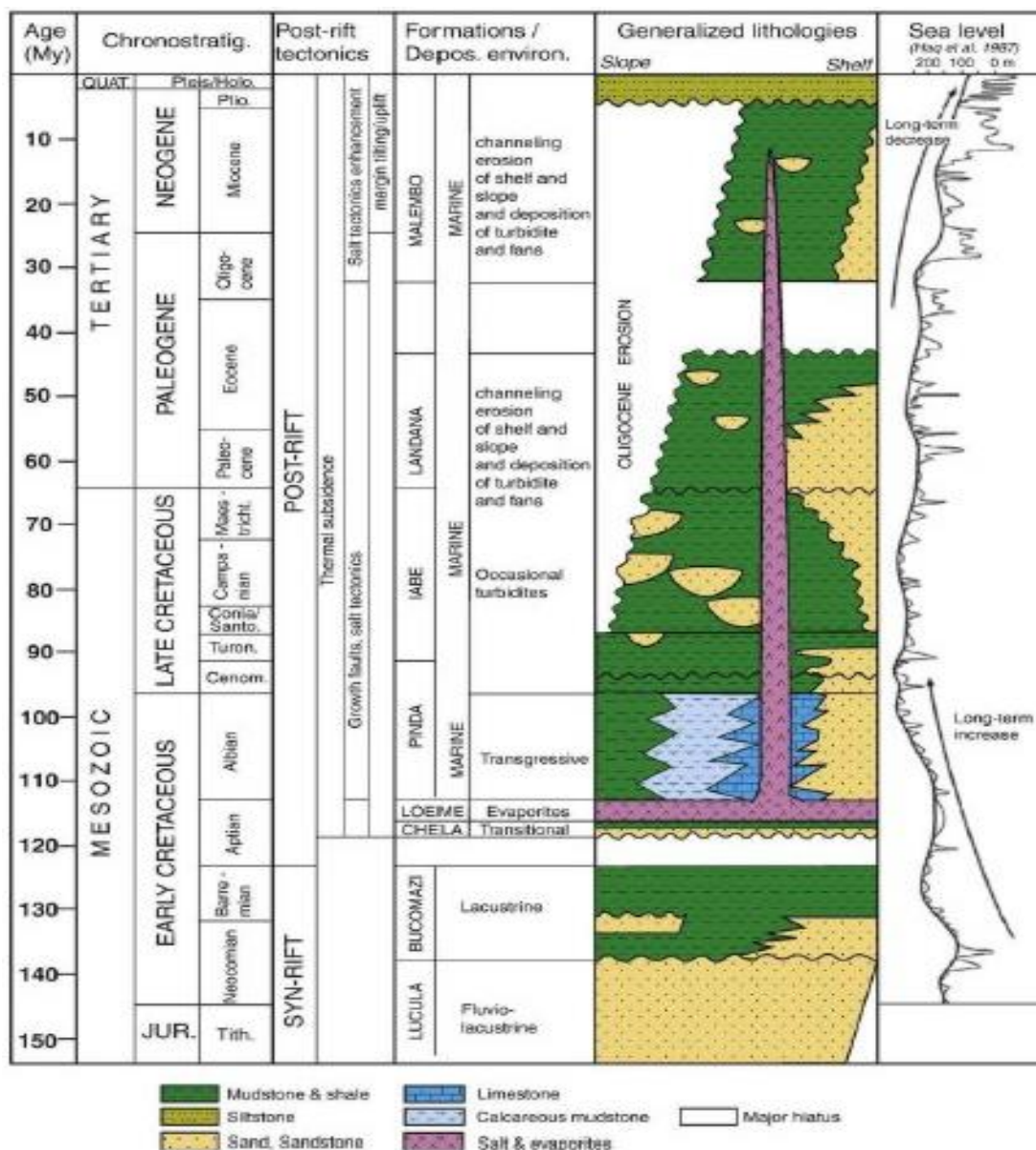


Fig. 2: Generalized litho-stratigraphy and main post-Rift tectonic events on the shelf and upper slope of Angolan Passive Margin (after Anka et al., 2007).

2. Aim of study

The aim of this study is to analyse the temporal and spatial distribution of submarine channels belts along a segment of the Angolan margin subject to salt tectonics in order to determine the 3-D arrangement of depositional elements and to predict the distribution of reservoir facies.

3. Data and Methods

The data available for the study is a 3-D seismic survey of a block (identity not revealed) located offshore Angola. Data was provided by PGS. The methods used in this study include the manual interpretation of key surfaces especially those bounding the channel complex interval (cf. Fig. 4)

using Petrel software. These bounding surfaces were used to generate iso-proportional slices in Petrel in order to enable 3D studies of the spatial relationship of the laterally and vertically aggrading channels through time. Spectral decomposition techniques (attribute) was applied to the interpreted seismic data using SVI-PRO software to image channels in order to analyse the 3D perspective views of the channel-valley morphology. Spectral decomposition uses the Fourier transform workflow to transform the seismic data from the time domain in to the frequency domain using the Red-Green-Blue (RGB) blending tool. This is achieved through the decomposition of the seismic data in to its individual spectral frequencies inherited as the seismic wavelet travels through a media (geobody) with variable lithological characteristics. This makes it possible to delineate different seismic facies including subtle features such as sub-seismic scale faults. In essence, this method has better definition of structural and stratigraphic features especially in the aspect of imaging and mapping temporal bed thickness and geological discontinuities over a large area of 3-D seismic survey (Partyka et al., 1999).

4. Results and Discussion

Figure 3 is a Two-Way-Time (TWT) map of the base of the channel interval (see Fig. 4), and is a surface that defines a regional dip direction in the NE-SW which overall, deepens to the SW from 2600 ms to 3400 ms (tw) over a distance of 40 km. The surface can be broadly divided in to: (1) a "high" (averages 2300 ms (tw)) to the NE and (2) a "low" (averages 3200 ms (tw)) to the S and NW of the mapped area. The high is separated from the low by a major salt wall with a normal fault adjacent to the salt wall (Fig. 4). The low areas are made up of mini basins (1, 2, 3 and 4) bounded by salt walls and salt cored highs/diapirs (Figs. 3, 4). The mini basins display two main orientations: (a) Mini basin 1 to the NW is parallel to the strike of the slope and is about 15.6 km long and 8 km wide on average. It is the deepest of the mini basins up to 3700 ms in its deepest parts. (b) Mini basins 2, 3 and 4 located to the S and SE of the map, are parallel to the dip of the slope with 5.2 km, 7 km and 6 km average width respectively. The average depth of these basins is 3000 ms (tw). Mini basin 2 and 4 are 40 km and 20 km long respectively but can be more than that since they extend beyond the mapped area down slope. Mini basin 3 (3a & 3b), is almost compartmentalized by salt walls and salt cored highs, and is about 37 km long and sub-divided in to 3a (deep) and 3b (shallow) indicated by the twt.

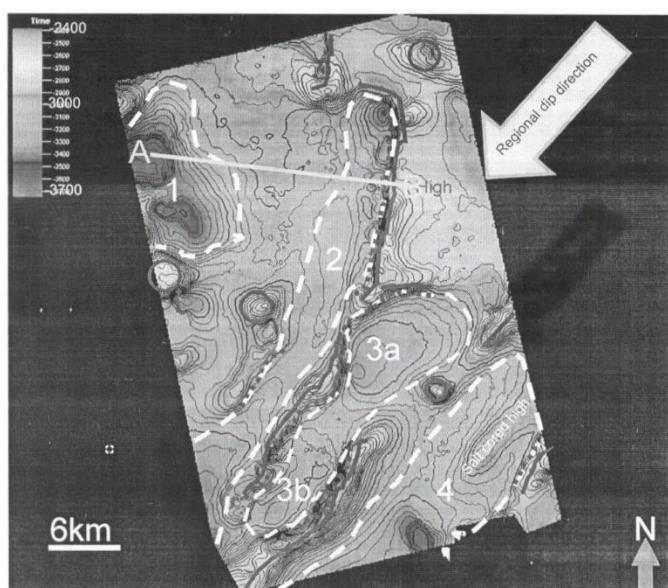


Fig. 3: Time structure map of the base of multiple channel interval showing mini-basins oriented parallel to regional slope (white dash lines). The depo-centres are numbered 1 to 4. Dark/thicker lines are salt walls; circles are salt cored highs. Section line AB is described in Figure. 4.

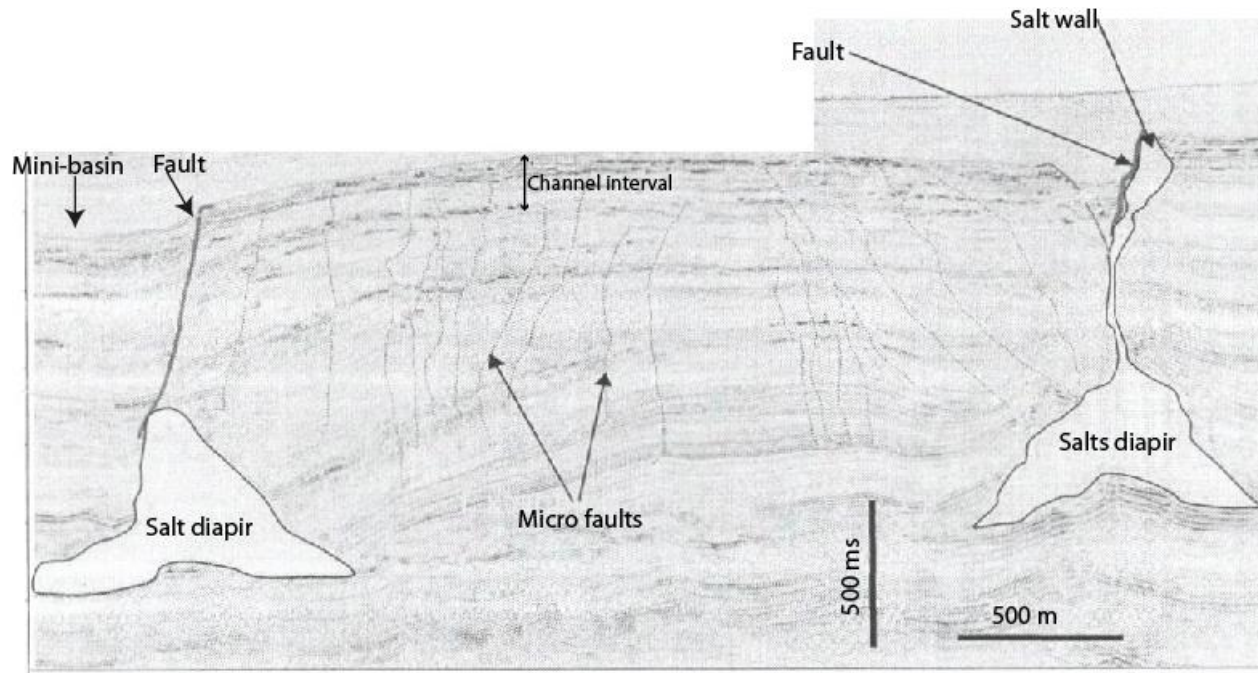


Fig. 4: Seismic section line AB (position shown on Fig.3) showing the seismic expression of salt and associated structures, faults and the interval of occurrence of the studied channels. Note also the development of mini-basin in response to salt diapirism.

The result of RGB blend on iso-slices revealed a great deal of depositional elements and structural features. For example, Figures 5 reveals many features including mud-filled channels (dark on RGB blend with characteristic low amplitude fill and negative differential compaction in seismic section AB), sand-filled channels/splays (bright-white on RGB blend with characteristic moderate-high amplitude in seismic sections AB and CD), and faults that have offset the earlier deposited splays (seen both on the RGB blend and on seismic section AB). The negative differential compaction exhibited by the dark channel on Figure 5 couple with the low amplitude channels-fill suggests the channel is filled with mud (Fig. 5, section AB). Channels that are filled with sandy facies display characteristic high amplitude, chaotic seismic reflections within the channel (Fig. 6, section AB). The splays form bright fan-like (lobate) features on the RGB blend and are approximately 8 km wide and up to 12 km long (Fig. 5). The splays are made up of small-scale channels with moderate-high amplitude fill (Fig. 6, section CD) and occur at the same

stratigraphic level with the high amplitude, parallel and flat reflectors that have been interpreted as the splays (see Figs. 5 and 6). This high amplitude, parallel reflectors are often deposited at the front of the incoming channels as smaller-scale distributary channels once the incoming channel enters into an unconfined part of a mini-basin (Fig. 6). As a result of this observation, the splays have been interpreted in this study as sand-rich deposits in a relatively unconfined areas of the mini-basin where there is little to no restriction by the growth of salt diapirs/walls. These kind of splays have previously been interpreted by Posamentier and Kolla (2003) as 'Frontal Splays' which are distinguishable from crevasse splays that are normally small, and often deposited at the outer bend of a meander loop. The faults must have cut-through previously deposited splays prior to the development of the now abandoned mud-fill channel because the channel appeared structurally controlled – developing very high sinuosity as it crosses the fault zone (Fig. 5).

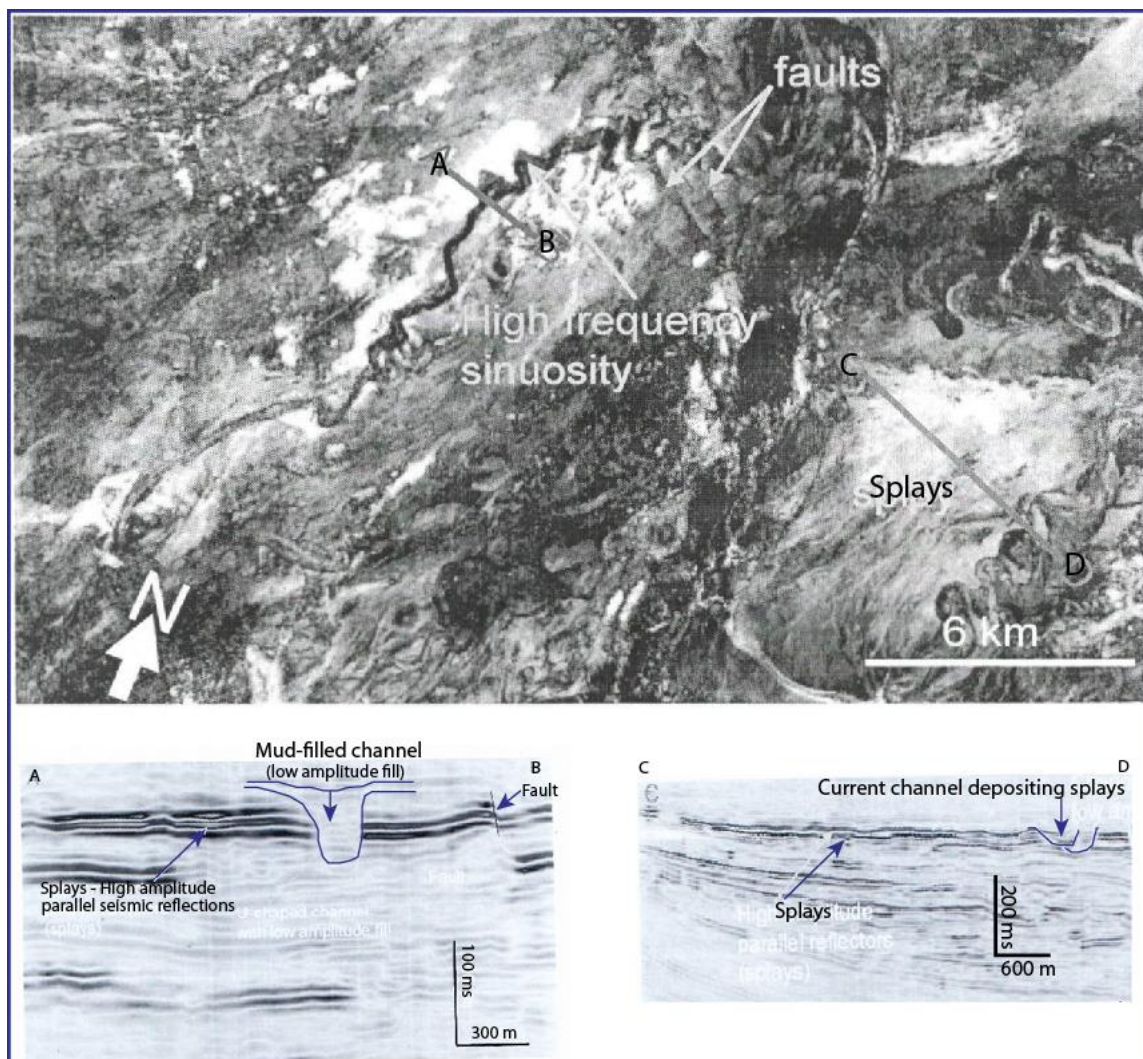


Fig.5: RGB blend and section line AB and CD revealing structural and stratigraphic features within the study area. Note, the mud-filled dark cut through very bright fan-like shaped feature (splays) that has been distorted by faults.

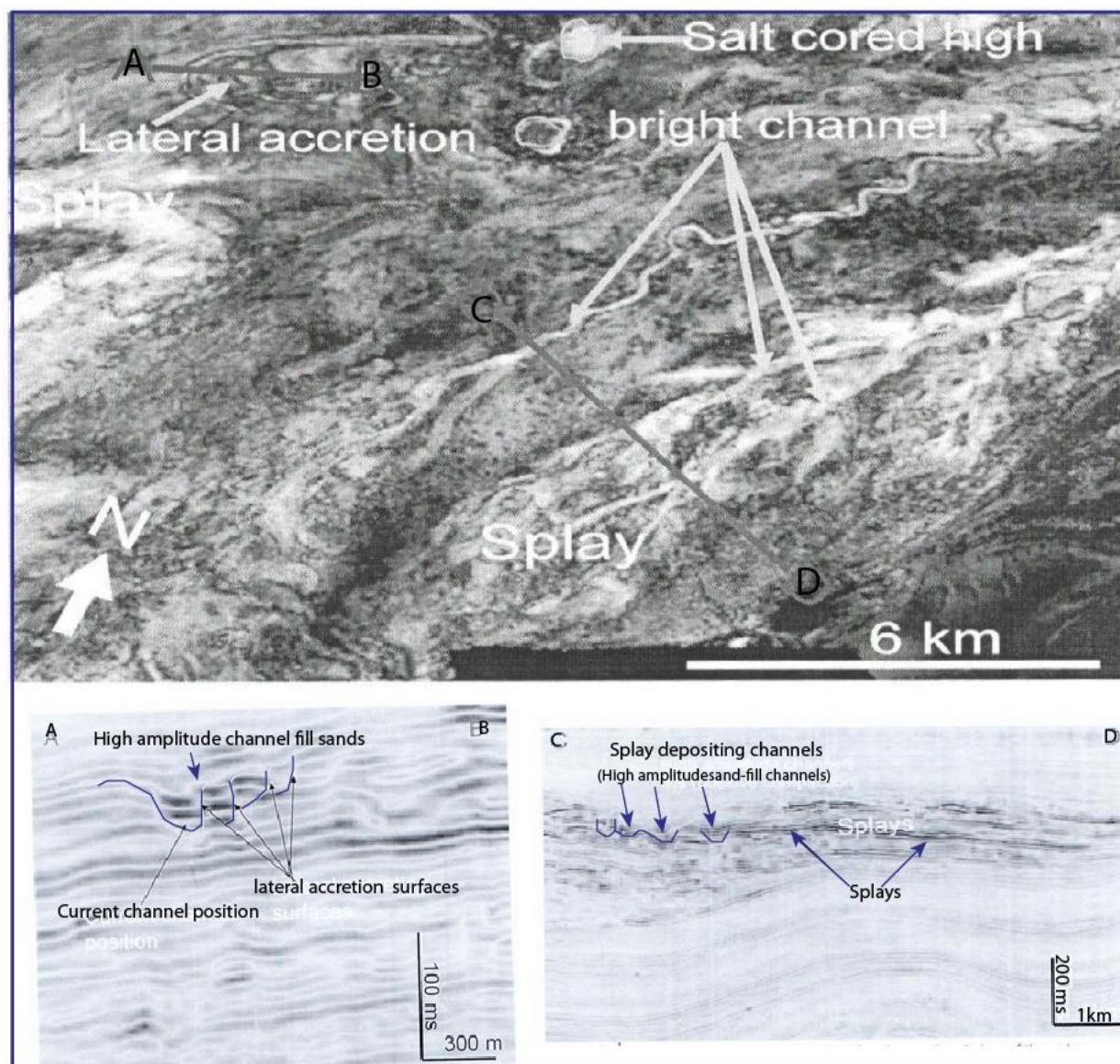


Fig. 6: RGB blend and section line AB and CD revealing structural and stratigraphic features within the study. Note that splays develop from series of avulsion by sand-filled bright channels within the unconfined mini-basin.

In essence, our analysis within the study area reveals how salt movement has created mini-basins that have been filled with sediments supplied through submarine channels. These depo-centres (Mini-basins) gradually become less active upslope once they are filled, thereby shifting depositional activities to the next mini-basin downslope. Our work also shows that the splays develop from avulsions by sand-rich channels (*cf.* Fig. 6) and are present only in the distal parts of the channels system within mini-

basins. These splays are often cut through and eroded by subsequent channels – which if abandoned, are filled with mud and are imaged as dark channels on the RGB blend (*cf.* Fig. 5). These eroding channels eventually deposit their entrained sands in form of new splays in the next mini-basins downslope.

It is therefore, interpreted (see Fig. 7) that the channels upslope are mostly confined either by deep incision or by salt constriction and are characterized by erosion and bypass in those

areas. Confinement of turbidity current due to deep incision with less overspill have been documented offshore Angola (Gee et al., 2007). Coarse sediments (sands and gravels) are probably entrained at the lower part of the turbidity current with only occasional overspill of the upper part of the turbidity current leading to the deposition of silt and mud on the overbank (Babonneau et al., 2002). The entrained coarse sediments are then deposited by series of avulsions – forming splays downslope after the channels exit constrictions in to more unconfined mini-basins. When the mini-basin gets filled, incoming channels will bypass it and erode part of the earlier sediments

and depositing in the next mini-basin downslope. This same process has been observed in the intra-slope mini basins of the Gulf of Mexico (Beaubouef and Friedmann, 2000). This study also has implication for hydrocarbon exploration in structurally complex deepwater settings modified by salt tectonics. For instance, our methodology can help delineate sand bodies (splays and sand-rich channel complexes) that can be potentially high quality reservoirs especially when the right traps are set in place by salt diapirism.

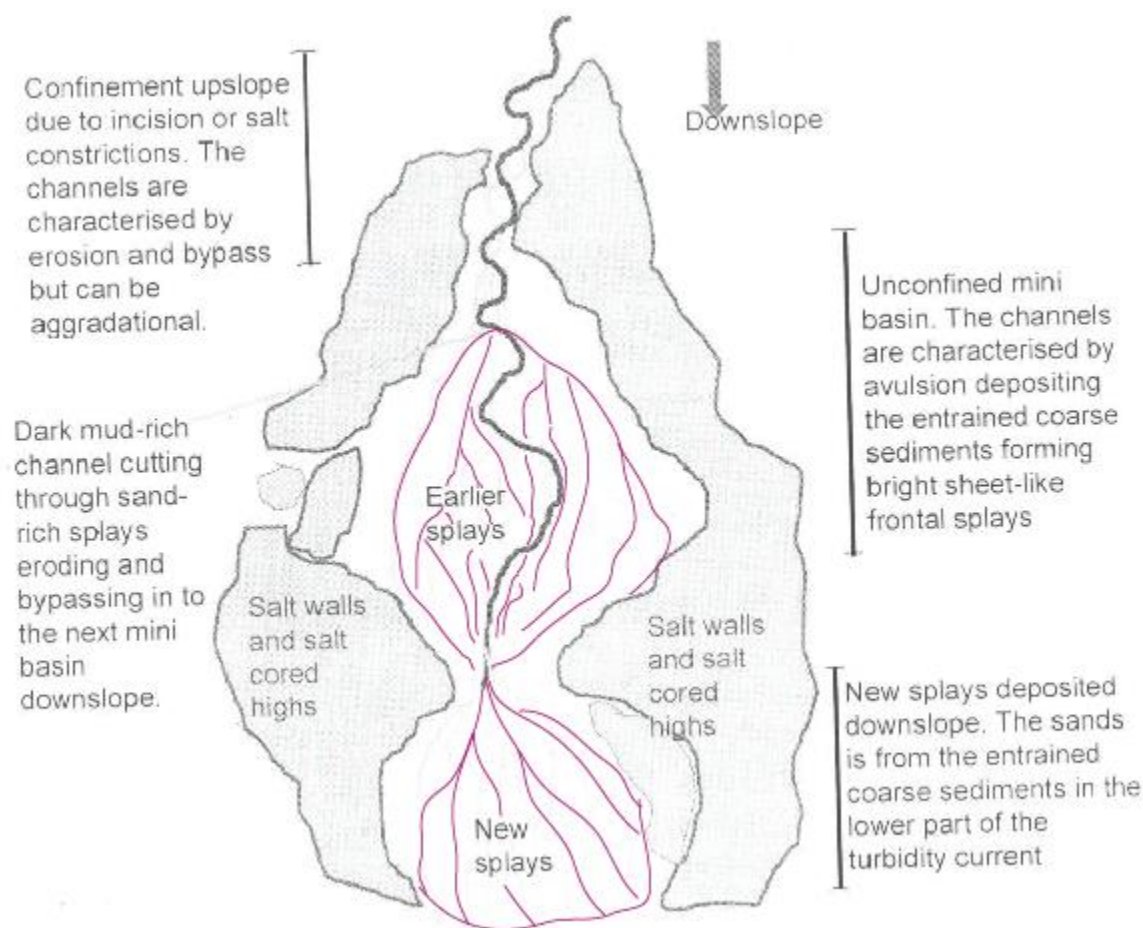


Fig.7: A model developed for the study area showing the relationship between the various depositional elements and how the depo-centres prograde downslope. When a depo-centre upslope gets filled, incoming channels will bypass to the next mini-basin downslope.

5. Conclusions

- This study combines the use of seismic geomorphology and spectral decomposition techniques (RGB blend) to analyze submarine channels offshore Angolan slope subject to salt tectonics. Our analysis shows that RGB blend is a powerful tool and is better at unravelling depositional elements architecture and geometry than conventional seismic attribute analyses. This technique also has the ability to unravel structural details including sub-seismic scale structures.
- Depositional elements unraveled are channels (both sand-filled and mud-filled) and sand-rich splays that developed from series of avulsion by sand-rich channels once they entered into unconfined mini-basins created by salt tectonics.
- These splays are often eroded by subsequent channels cutting through them, with the products of such erosion deposited as newer splays within the next mini-basin further downslope. Once these channels become inactive (abandoned) they are usually filled with mud, and are imaged on the RGB blend as dark channels.
- Overall, the channels and associated depositional element are controlled by the time-integrated movement of salt – which also creates the mini-basins. Our study has provided great insight into the interaction between salt tectonics and submarine channels which in turn, can aid in the exploration efforts in offshore Angola and similar deepwater settings.

Acknowledgement

Special thanks to Petroleum **Geo-Services (PGS)** for providing the seismic data used for this study. Thanks also to Schlumberger for the **Petrel software** used in seismic interpretation; and Software ventures International for

provision of the **SVI Pro software** used for spectral decomposition blending.

References:

- Amaral, J., Biteau, J.J. and Zaroslinska, P., 1998. Angola— The lower Congo Basin Tertiary petroleum systems hydrocarbon distribution in relation with structural and sedimentary evolution (abs.): AAPG International Conference and Exhibition Extended Abstracts, p. 924– 925.
- Anka, Z., Sèranne, M., Lopez, M., Scheck-Wenderoth, M., and Savoye, B., 2008, The long-term evolution of the Congo deep-sea fan: A basin-wide view of the interaction between a giant submarine fan and a mature passive margin (ZaiAngo project): *Tectonophysics*, 470, P. 42-56.
- Babonneau, N., Savoye, B., Cremer, M., and Klein, B., 2002, Morphology and architecture of the present canyon and channel system of the Zaire deep-sea fan: *Marine and Petroleum Geology*, v. 19, p. 445–467.
- Beauboeuf, R.T., and Friedmann, S.J., 2000. High-resolution seismic/sequence stratigraphic framework for the evolution of Pleistocene intra slope basins, Western Gulf of Mexico: depositional models and reservoir analogs, *in* Weimer, P., Slatt, R.M., Coleman, J., Rosen, N.C., Nelson, H., Bouma, A.H., Styzen, M.J., and Lawrence, D.T., eds., *Deep-Water Reservoirs of the World: Gulf Coast Society of the Society of Economic Paleontologists and Mineralogists Foundation, 20th Annual Research Conference*, p. 40–60.
- Cramez, C. and Jackson, M.P.A., 2000. Superposed deformation straddling the continental-oceanic transition in deep-water Angola. *Marine and Petroleum Geology*, 17: 1095-1109.
- Deptuck, M.E., Sylvester, Z., Pirmez, C., O'byrne, C., 2007, Migration-aggradation history and 3-D seismic geomorphology of submarine channels in the Pleistocene Benin-major Canyon, western Niger Delta slope: *Marine and Petroleum Geology*, v. 24, p. 406-433.

Gee, M.J.R., and Gawthorpe, R.L., 2006, Submarine channels controlled by salt tectonics: Examples from 3D seismic data offshore Angola: *Marine and Petroleum Geology*, v. 23, p. 443–458.

Gee, M.J.R., Gawthorpe, R.L., Bakke, K., and Friedmann, S.J. 2007, Seismic Geomorphology and Evolution of Submarine Channels from the Angolan Continental Margin: *Journal of Sedimentary Research*, V. 77, P. 433-446.

Gee, M.J.R. and Gawthorpe, R.L. 2007. Early evolution of submarine channels offshore Angola revealed by three-dimensional seismic data in press. In: Davies, R.J., Posamentier, H.W., Wood, L.J. and Cartwright, J.A. (eds.), /*Seismic Geomorphology: Applications to Hydrocarbon Exploration and Production/ Geological Society Special Publication*, 277, 223-235.

Jones, D.O.B., Walls, A., Clare, M., Fiske, M.S., Weiland, R.J., O'Brien, R., Touzel, D.F. 2014. Asphalt mounds and associated biota on the Angolan margin: *Deep-sea research*, v. 194, p. 124 – 136.

Kolla, V., Bourges, P., Urruty, J.M., and Safa, P., 2001, Evolution of deep-water Tertiary sinuous channels offshore Angola (West Africa) and implications for reservoir architecture: *American Association of Petroleum Geologists, Bulletin*, v. 85, p. 1373–1405.

Mahon, E.M. and Wallace, M.W. 2022. 3D seismic geomorphology of Early Cenozoic incised channels, Gippsland Basin, SE Australia: Evidence for submarine origin: *Sedimentary geology*, 430 (2022) 106092.

Marfurt, K.J., and R. L. Kirlin, 2001, Narrow-band spectral analysis and thin-bed tuning: *Geophysics*, 66, 1274-1283.

Othman, A.A.A., Fathy, M., and Maher, A. 2016. Use of spectral decomposition technique for delineation of channels at Solar gas discovery, offshore West Nile Delta, Egypt: *Egyptian Journal of Petroleum*, v. 25, p. 45 – 51.

Partyka, G.A., J. Gridley, and J. Lopez, 1999, Interpretational applications of spectral decomposition in reservoir characterization: *The Leading Edge*, 18, 353-360.

Pattison, S.A.J., 2018. Rethinking the incised-valley fill paradigm for Campanian Book Cliffs strata, Utah-Colorado, USA: evidence for discrete parasequence-scale, shoreface-incised channel fills. *Journal of Sedimentary Research*, v. 88, p. 1381–1412.

Posamentier, H.W., and Kolla, V., 2003, Seismic geomorphology and stratigraphy of depositional elements in deep-water settings: *Journal of Sedimentary Research*, v. 73, p. 367–388.

Posamentier, H.W. et al. 2007. Seismic Geomorphology – an overview. In: Davies, R.J., Posamentier, H.W., Wood, L.J. and Cartwright, J.A. (eds.), /*Seismic Geomorphology: Applications to Hydrocarbon Exploration and Production/ Geological Society Special Publication*.