

PS Cenozoic Turbidite Systems in the Onshore Angola: Facies Analysis and Paleoenvironmental Interpretation of the Massambala Heavy Oil Accumulation*

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Abstract

The Congo Fan in the Lower Congo Basin of Angola began its development at the end of the Cretaceous. In the offshore, it has been the primary exploratory objective since the 1960s, with discovered STOIP of more than 5300 MMBOE. The fan has been less explored onshore; however, discoveries such as the Massambala Field (Cabinda South Block) demonstrate that the paleo-Congo fluvial system supplied sediments to an area located on the present-day shoreline during the Eocene-Oligocene.

The objective of this contribution is to propose a sedimentary paleo-environment for the clastic reservoirs of the Eocene-Oligocene Malembo Formation in the Massambala heavy oil accumulation, based on an integrated analysis of cores, logs, borehole images, seismic and regional publications, in order to better understand the prospectivity of the onshore Congo Fan.

The Malembo Formation is an unconsolidated siliciclastic unit composed mainly by blocky and thick coarse-grained turbidite sandstones intercalated with less abundant thin claystone layers. The sands have very high porosities and permeabilities ($\Phi \sim 30\%$ and $K = 0.05\text{--}4.3 \text{ D}$). Sediment deposition in the field area was controlled by NW-SE extensional faults located towards the east of the field. These structures are related to halokinesis involving underlying evaporites.

Two facies associations (FA) are recognized in the Massambala Field. FA-1 corresponds to a shoreface setting composed by bioturbated sandstones and fine-grained sediments formed by settling and tractive flows. FA-2 contains most of the heavy oil and corresponds to turbidites related deposits in which sediment gravity flows are more common than tractional ones.

FA-2 has the highest reservoir quality. 3D seismic data suggests that this FA is composed of two major lobed features that are interpreted as proximal turbidite lobes developed on the shoreface. Both features appear to have feeder systems located to the east-northeast. FA-1 has oil in stains or patches, and it is considered a secondary reservoir due to its reduced petrophysical conditions.

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CENOZOIC TURBIDITIC SYSTEMS IN THE ONSHORE ANGOLA: FACIES ANALYSIS AND PALEOENVIRONMENTAL INTERPRETATION OF THE MASSAMBALA HEAVY OIL ACCUMULATION

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Malembo Formation is an unconsolidated siliciclastic unit composed mainly by blocky and thick coarse-grained turbidite sandstones intercalated with less abundant thin claystone layers. The sands have very high porosities and permeabilities ($\Phi \sim 30\%$ and $K = 0.05-4.3$ D). Sediment deposition in the field area was controlled by NW-SE extensional faults located towards the east of the field. These structures are related to halokinesis involving underlying evaporites.

Two facies associations (FA) are recognized in Massambala Field. FA-1 corresponds to a shoreface setting composed by bioturbated sandstones and fine grained sediments formed by settling and tractive flows. FA-2 contains most of the heavy oil and corresponds to turbidites related deposits in which sediment gravity flows are more common than tractional ones. FA-2 has the highest reservoir quality. 3D seismic data suggests that this FA is composed of two major lobed features that are interpreted as proximal turbidite lobes developed on the shoreface. Both features appear to have feeder systems located to the east-northeast. However, as FA-1 has oil in stains or patches, it is considered a secondary reservoir due to its reduced petrophysical conditions.

1- LOCATION



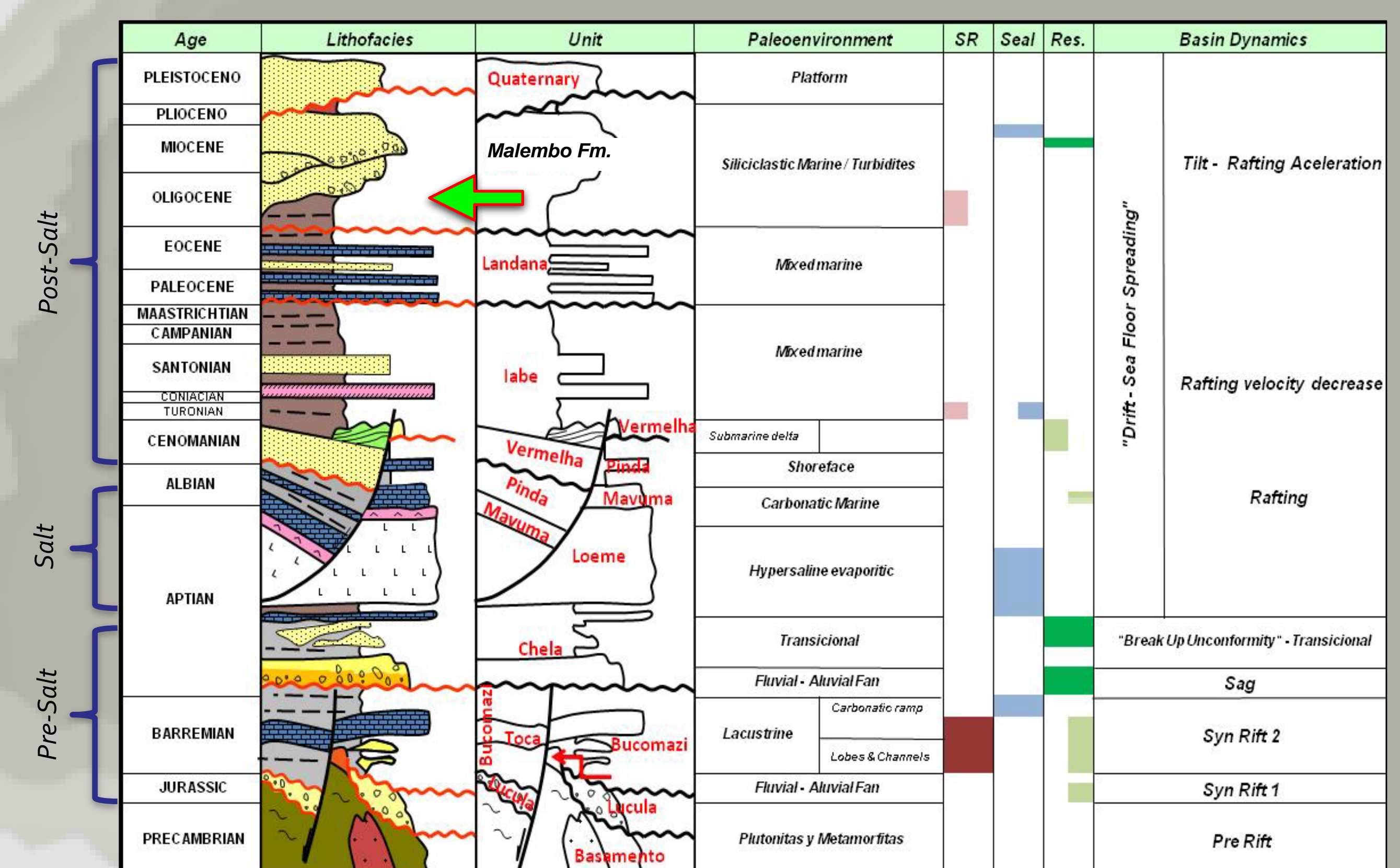
The Cabinda South Block is located in the onshore eastern portion of the Lower Congo Basin, in the Cabinda Province, North Angola, and has a total area of 1035 km².

Massambala heavy oil accumulation in Malembo Tertiary sandstones was discovered by ROC Oil in 2007.

The block is operated by PLUSPETROL since 2009.

The Lower Congo Basin is part of the West Central Africa Coastal Province, formed as a consequence of the Triassic and Jurassic rifting processes, which initiated due to Gondwana super continent break-up and which led to the opening of the South Atlantic Ocean.

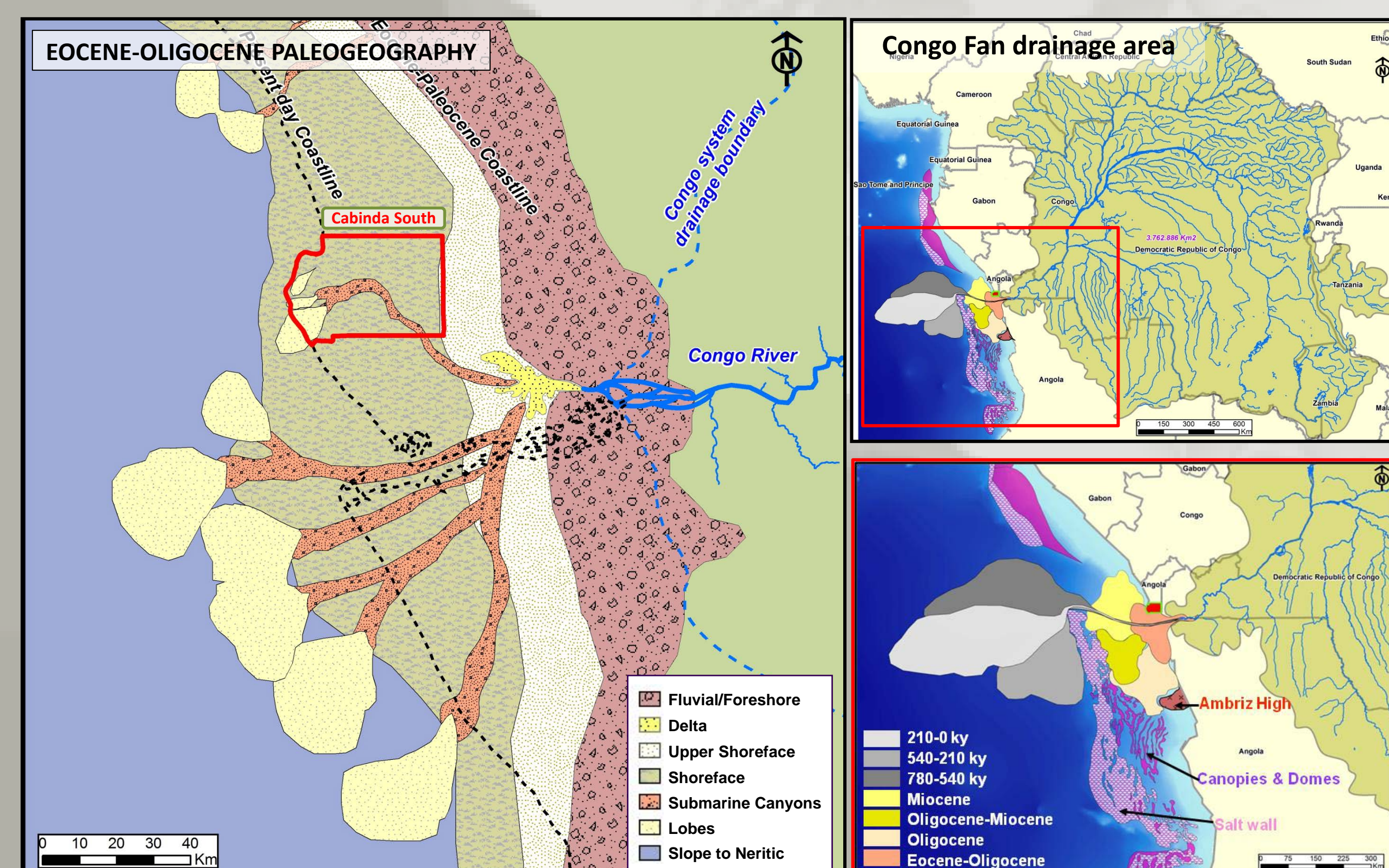
2- STRATIGRAPHY AND BASIN EVOLUTION



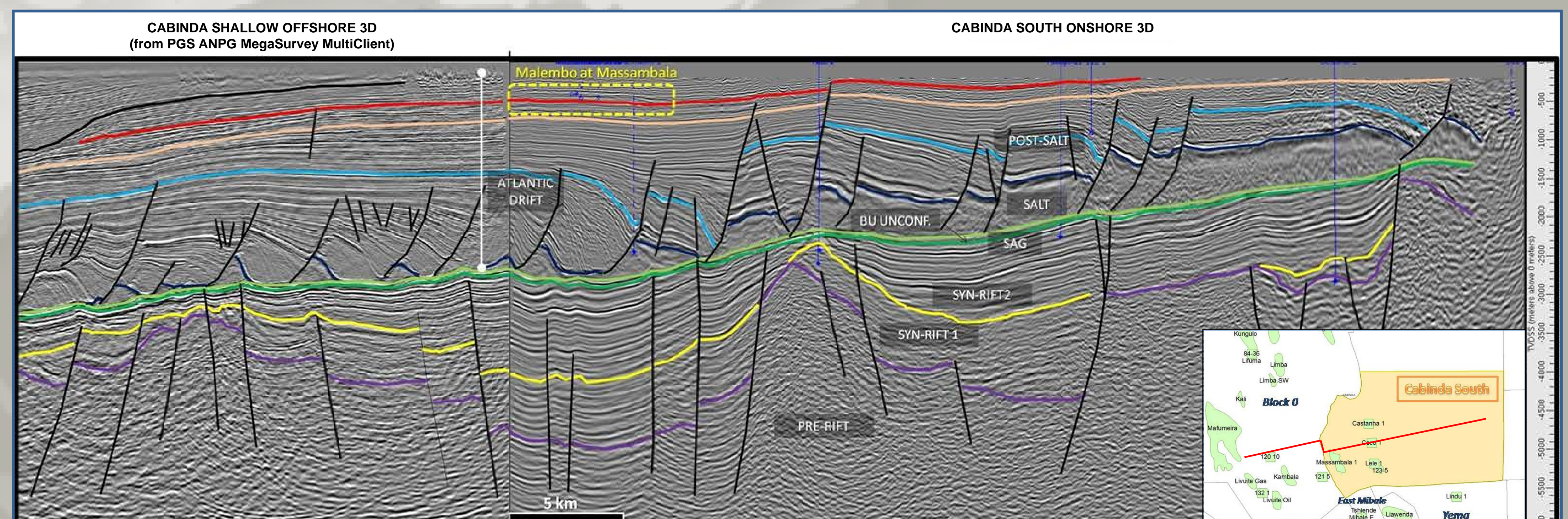
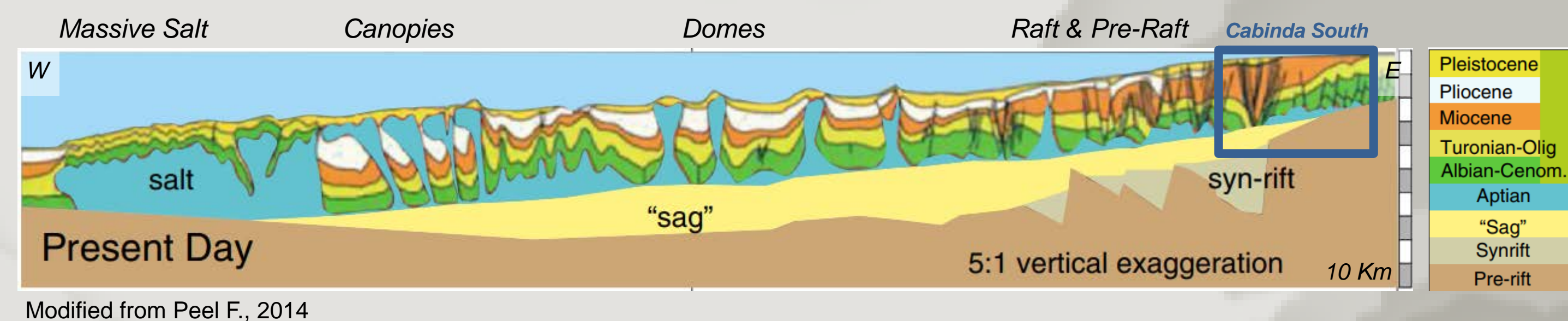
Stratigraphy corresponds to Upper Jurassic/Lower Cretaceous Syn-rift clastics and carbonates, followed by Aptian Sag sandstones and evaporites, and capped by Post-rift clastics and carbonates of the Atlantic drift phase.

Malembo turbidites constitute the lithostratigraphic unit which forms the Congo Fan.

3 - THE CONGO FAN



The deep-water Congo Fan has been developing in SW Gabon, W of the Democratic Republic of Congo and NW Angola since the end of the Cretaceous. This system is the second biggest of the modern fans in the world and drains almost 1/3 of the African Craton (3.8 MM Km²). It has been formed mainly by deep-water turbidity currents. The reservoirs associated with this Tertiary Fan in offshore Angola have been the main exploratory objective of the biggest companies in the world for the last decades, discovering more than 5300 MBOE in place. However, the system has been less explored onshore where shelf lobes are recognized.



“Post-salt” sedimentation is related to “Halokinesis” or “Salt Tectonics Events”. The related “raft” deformation favored the development of listric faults detached in the evaporites, which influenced and controlled the dispersion and accumulation of sediments during the Upper Cretaceous and Cenozoic Atlantic drift phase, and also the vertical migration of hydrocarbons from the pre-salt into the post-salt section.

4 – MASSAMBALA HEAVY OIL ACCUMULATION

OVERVIEW

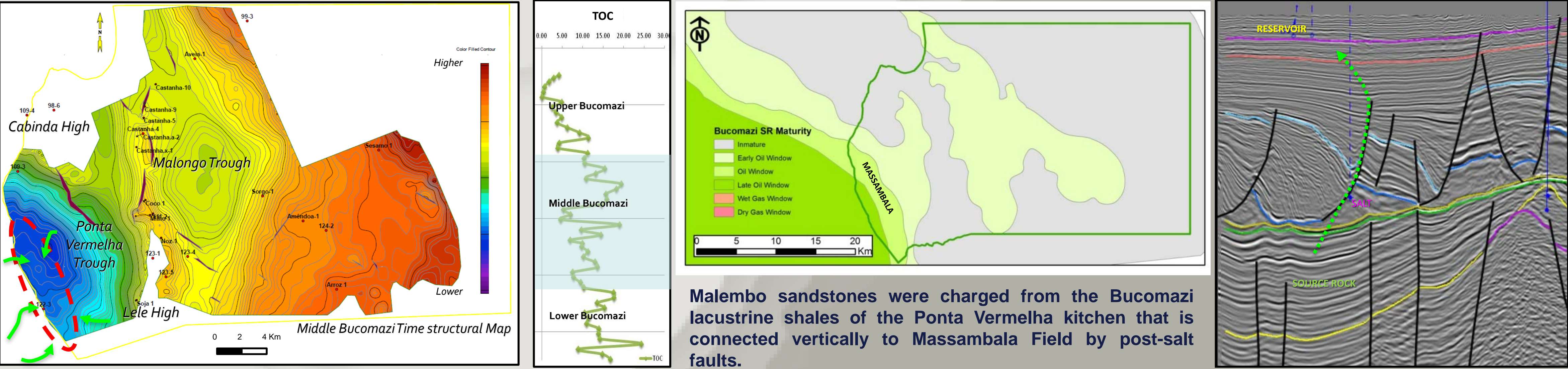
Massambala is a shallow heavy oil accumulation (around 400 mbsl) discovered by Roc Oil Company in 2007; PLUSPETROL estimates STOOIP around 300 MMBO.

This field is located around 3.5 km SW of the Cabinda City, with five appraisal wells drilled to total depths of 400 m, including a 400m horizontal branch borehole, which was completely cored and tested.

- The accumulation remains non-commercial:
- Low °API density and high viscosity of the oil, which is a result of severe in-situ biodegradation.
 - Large volumes of fresh-water production with little hydrocarbons during test of Mass-4 and 5H (included water heating), indicating severe water coning.
 - High cost of production technology expected for this type of heavy oil.

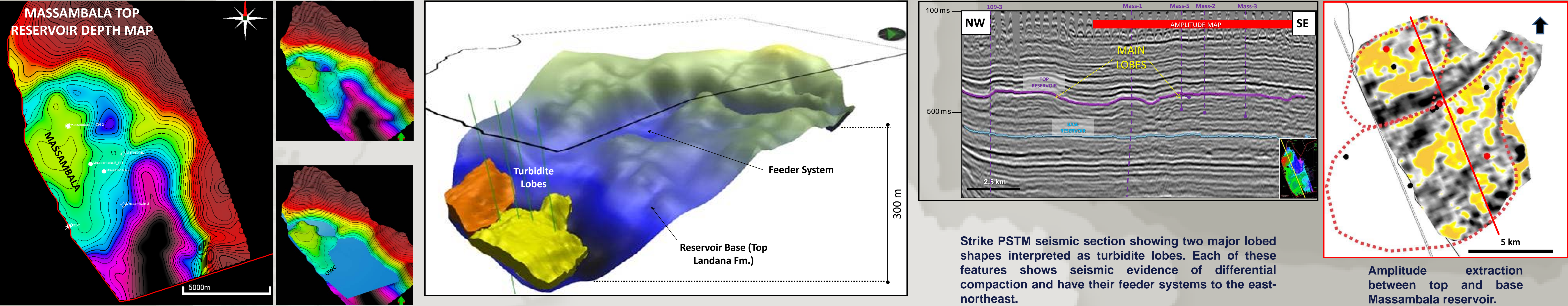
However, the Massambala field could be economic in the future when new technologies and oil prices are appropriate to produce this shallow accumulation.

OIL CHARGE



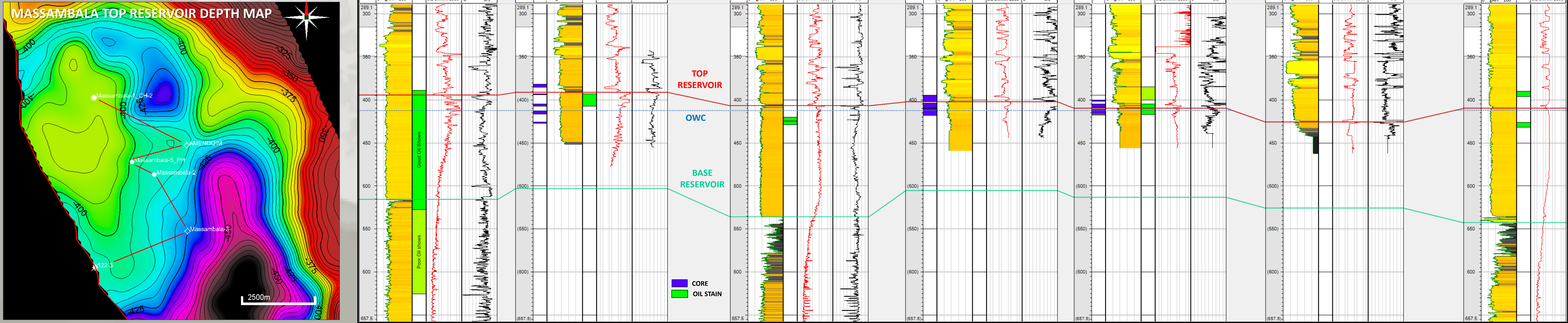
TRAP & SEAL

4WDC structure at Malembo turbidite sandstones, given by a combination of differential compaction and rafting processes. Top seal given by shoreface fine-grained facies plus carbonate-cemented sandstones.



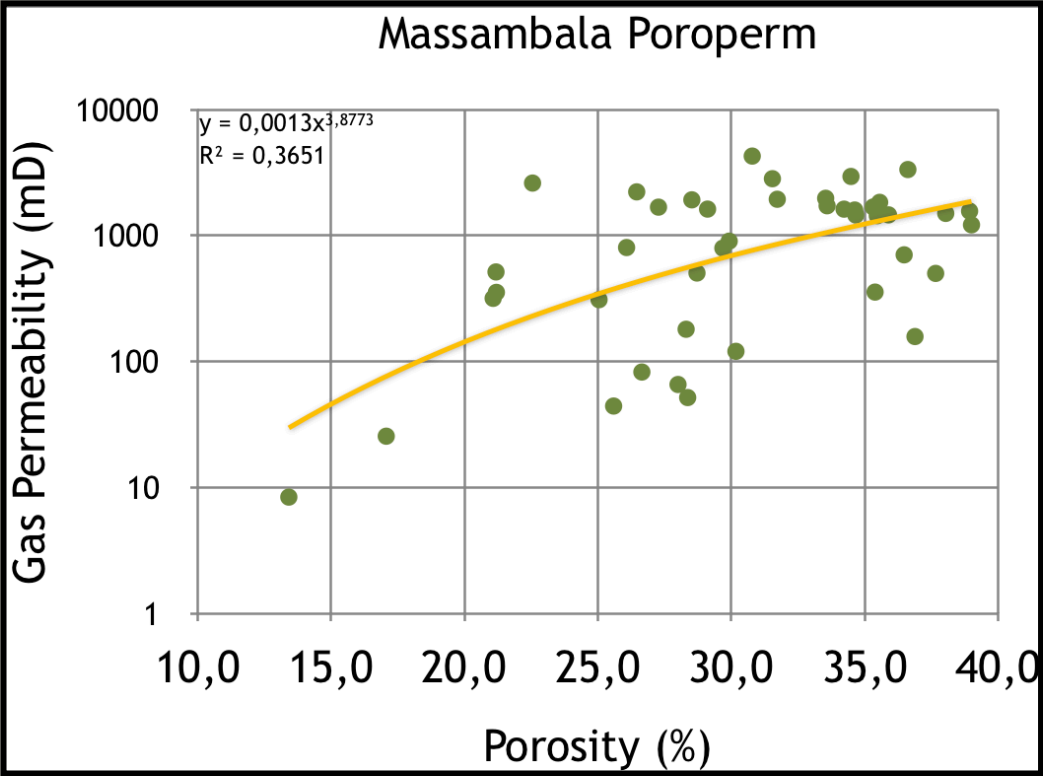
STRUCTURAL CROSS SECTION

Structural cross section in strike orientation showing top and base reservoir with well-defined OWC.



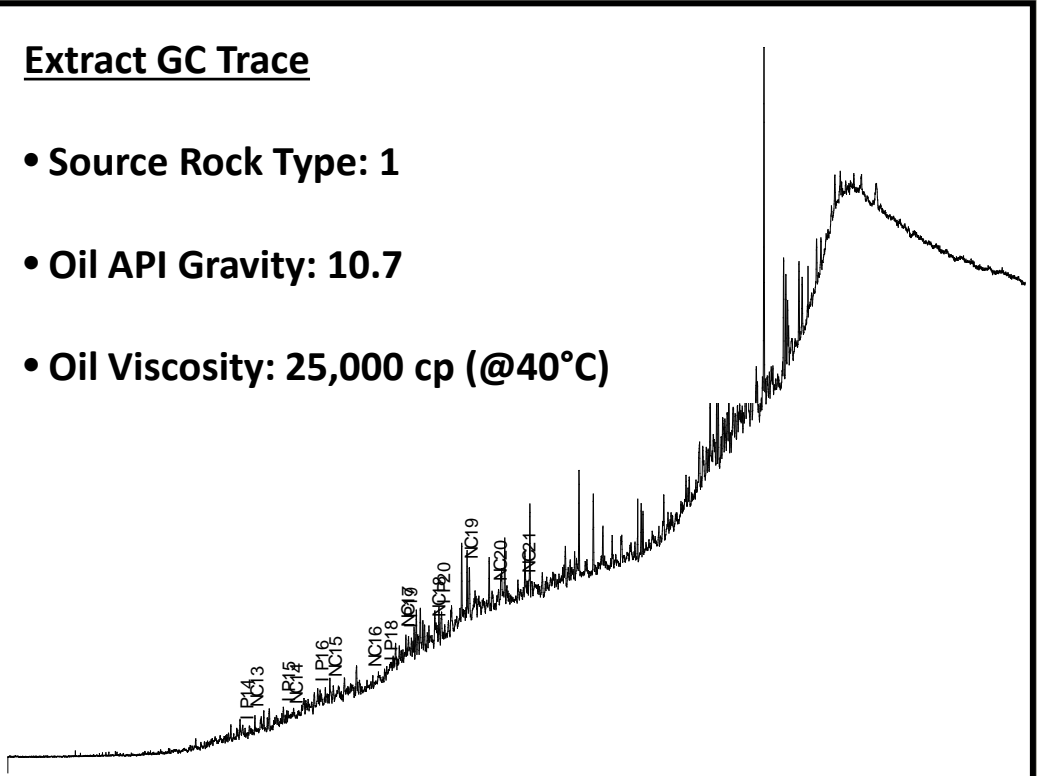
RESERVOIR

Eocene-Oligocene unconsolidated blocky and thick coarse sandstones intercalated with lesser thin claystone layers. These deposits correspond mainly to sediment gravity flows with very high porosity and permeability (Φ ~30% and K 0.05 to 4.2 D).



FLUID TYPE

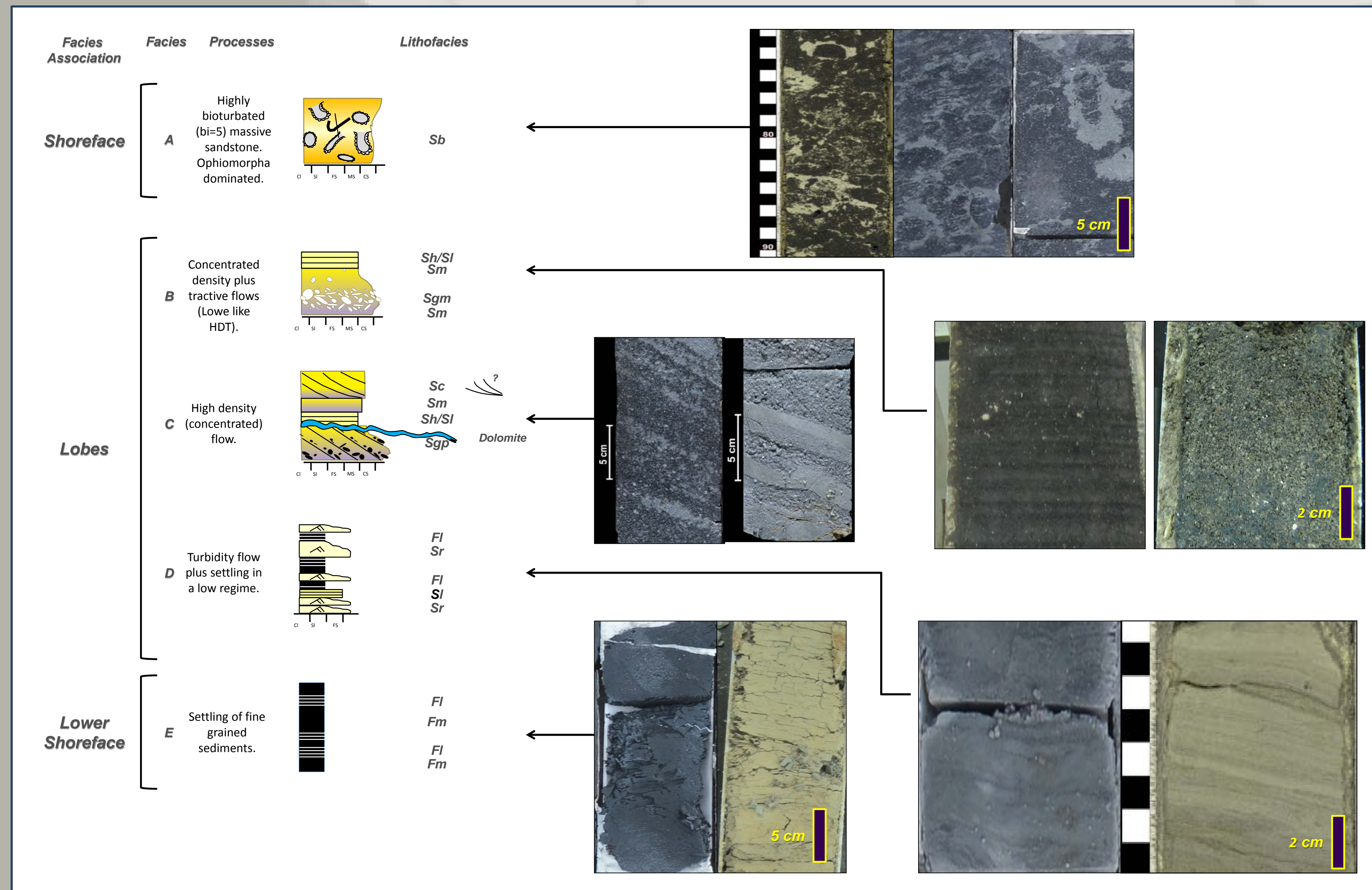
Heavy oil samples (10.7° API) from cores and wells tests, together with geochemical analysis, show typically high viscosity values and strongly biodegraded chromatographic profiles.



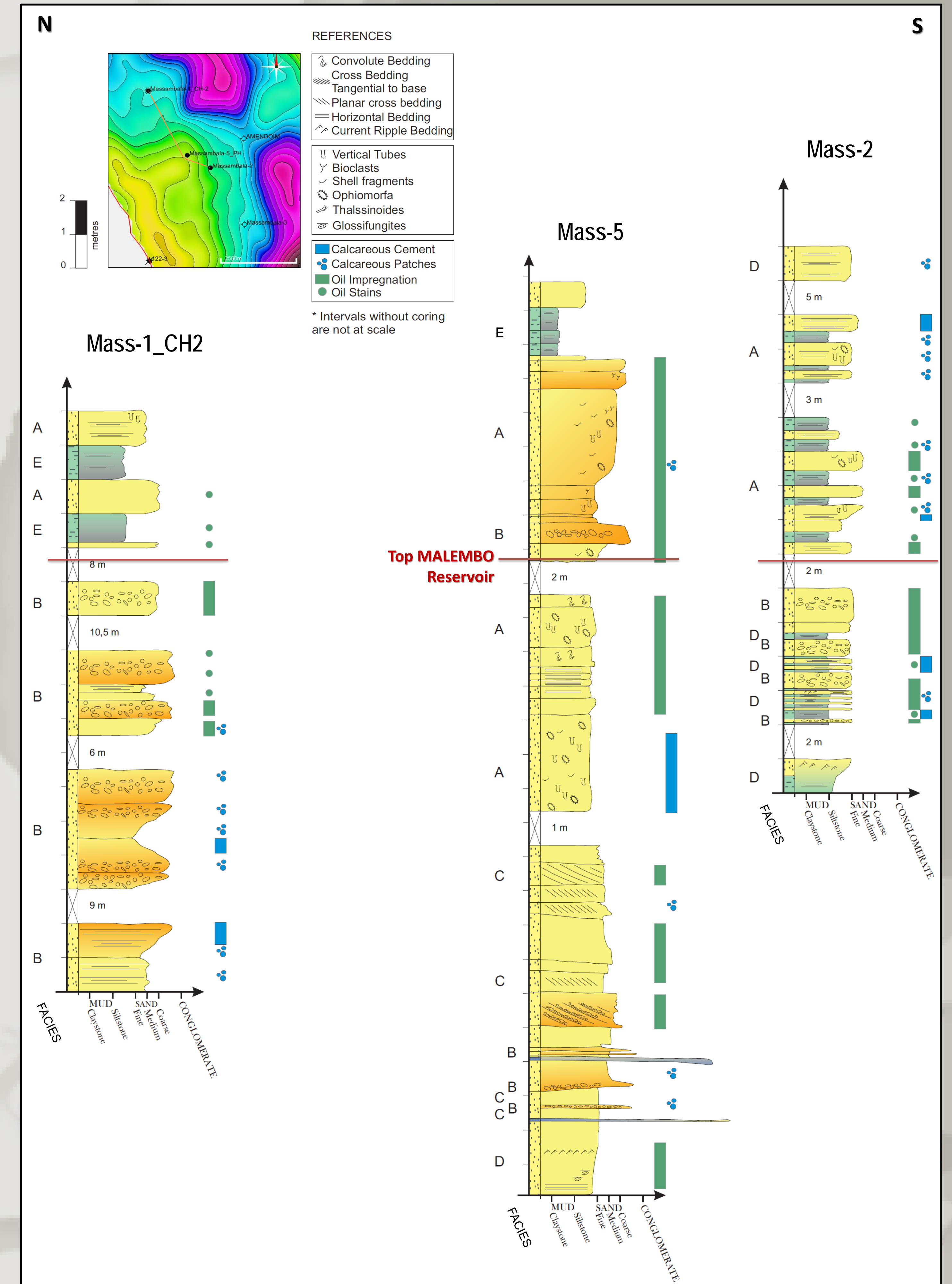
5 – MALEMBO Fm. FACIES AND PALEOENVIRONMENT ANALYSIS

LITHOFACIES DESCRIPTION

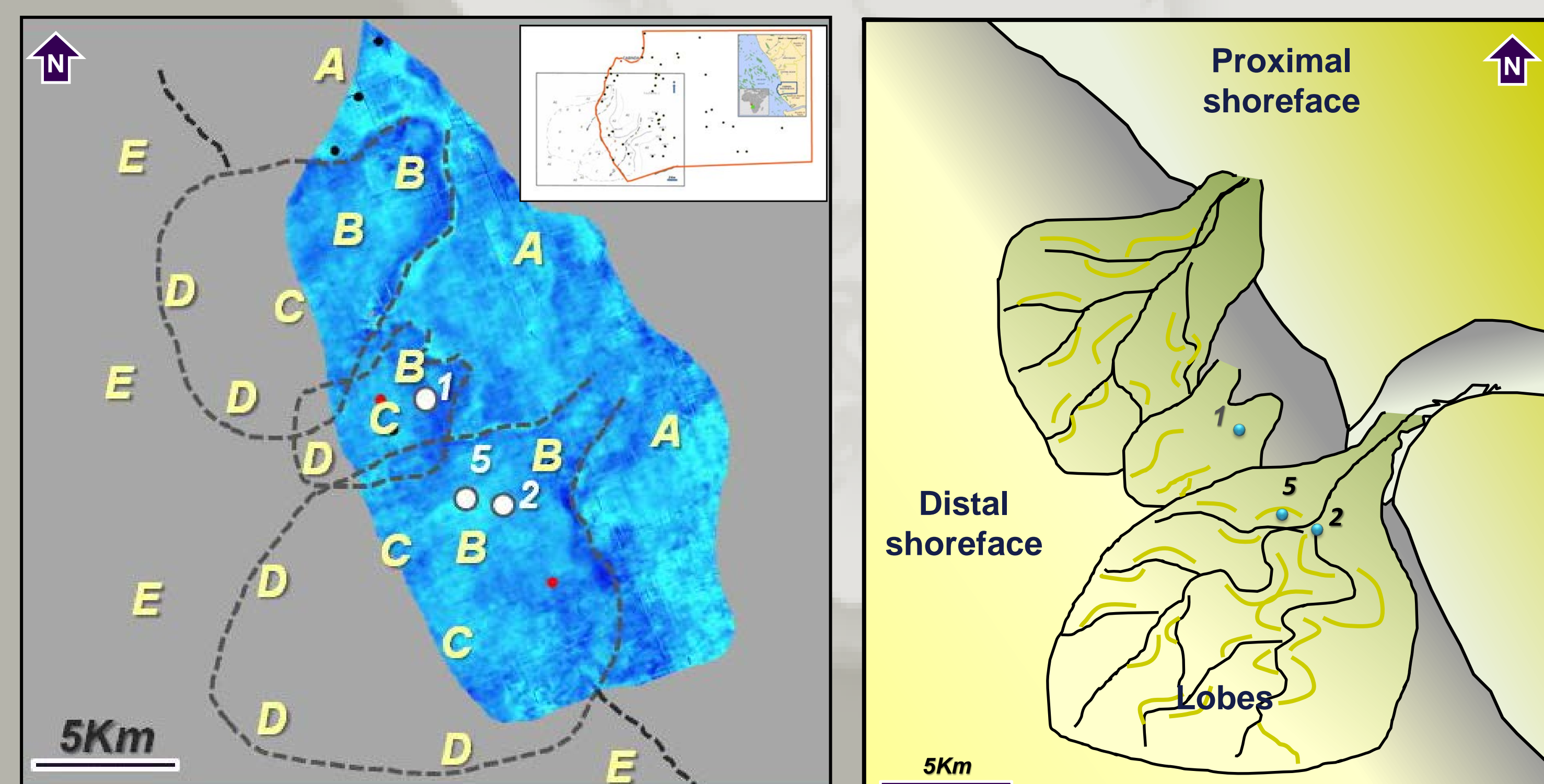
Five wells have been drilled at Massambala Field. Three of them have cores (Mass-1, Mass-2 & Mass-5). For the cores description, Miall's lithofacies classification (1978) was used. They were grouped in facies and two facies associations were defined: FA1 = shoreface and FA2 = lobes.



SEDIMENTOLOGICAL LOGS



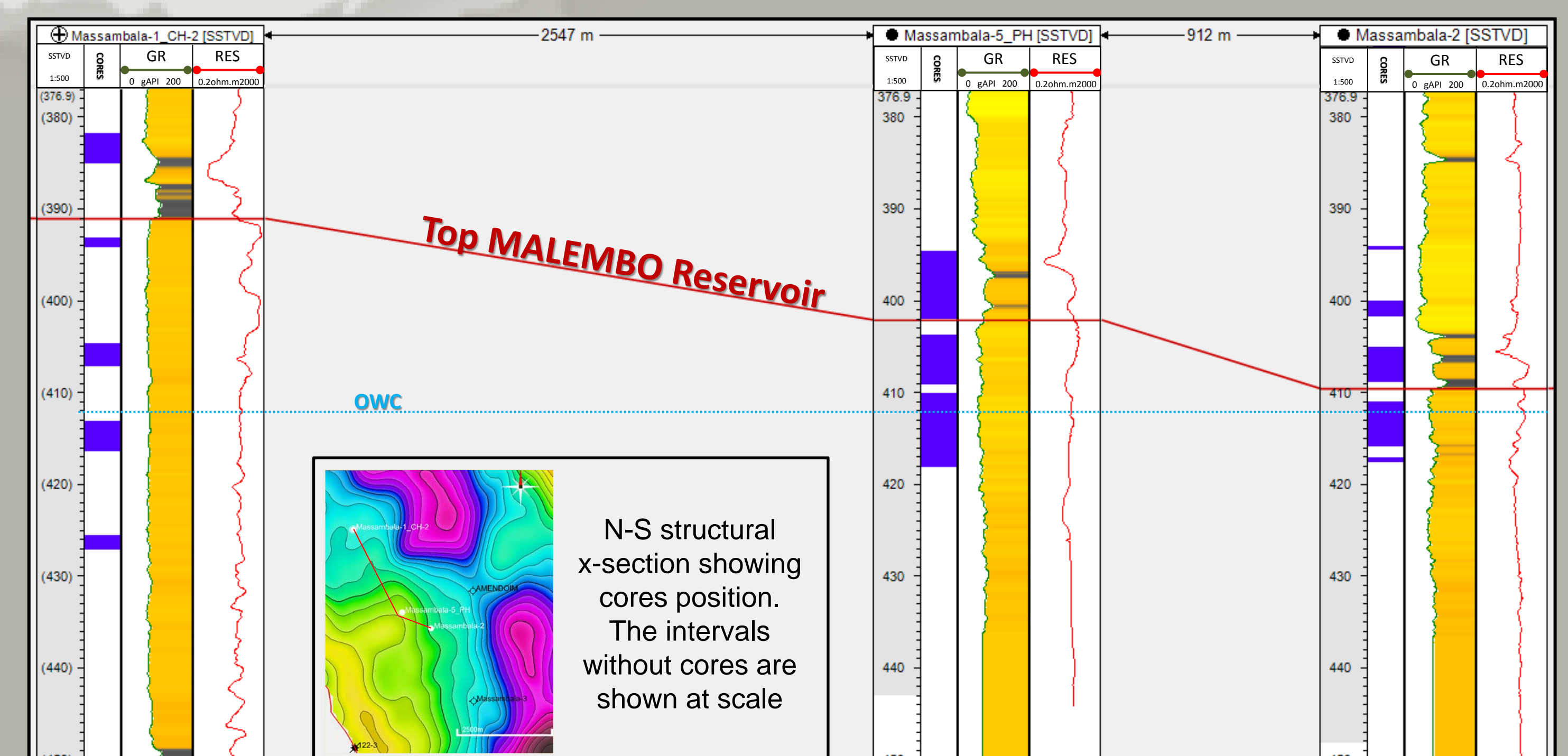
FACIES ASSOCIATIONS & SEDIMENTARY MODEL



In a facies tract conception for FA2, these sandy and conglomeratic sandstones came from the east and northeast first as sediment gravity flows (Facies B) and then turned into fluid tractive flows (Facies C & D) by dilution or sediment charge losses. This facies association has excellent petrophysical conditions where Massambala heavy oil is hosted.

Within the Malembo reservoir spot facies B and C are totally oil impregnated, constituting a very important hydrocarbon reservoir. Facies A are strongly bioturbated, which reduces their sandy reservoir quality. Although facies A and D have oil in stains or patches, due to their poor petrophysical conditions, they are considered a secondary reservoir.

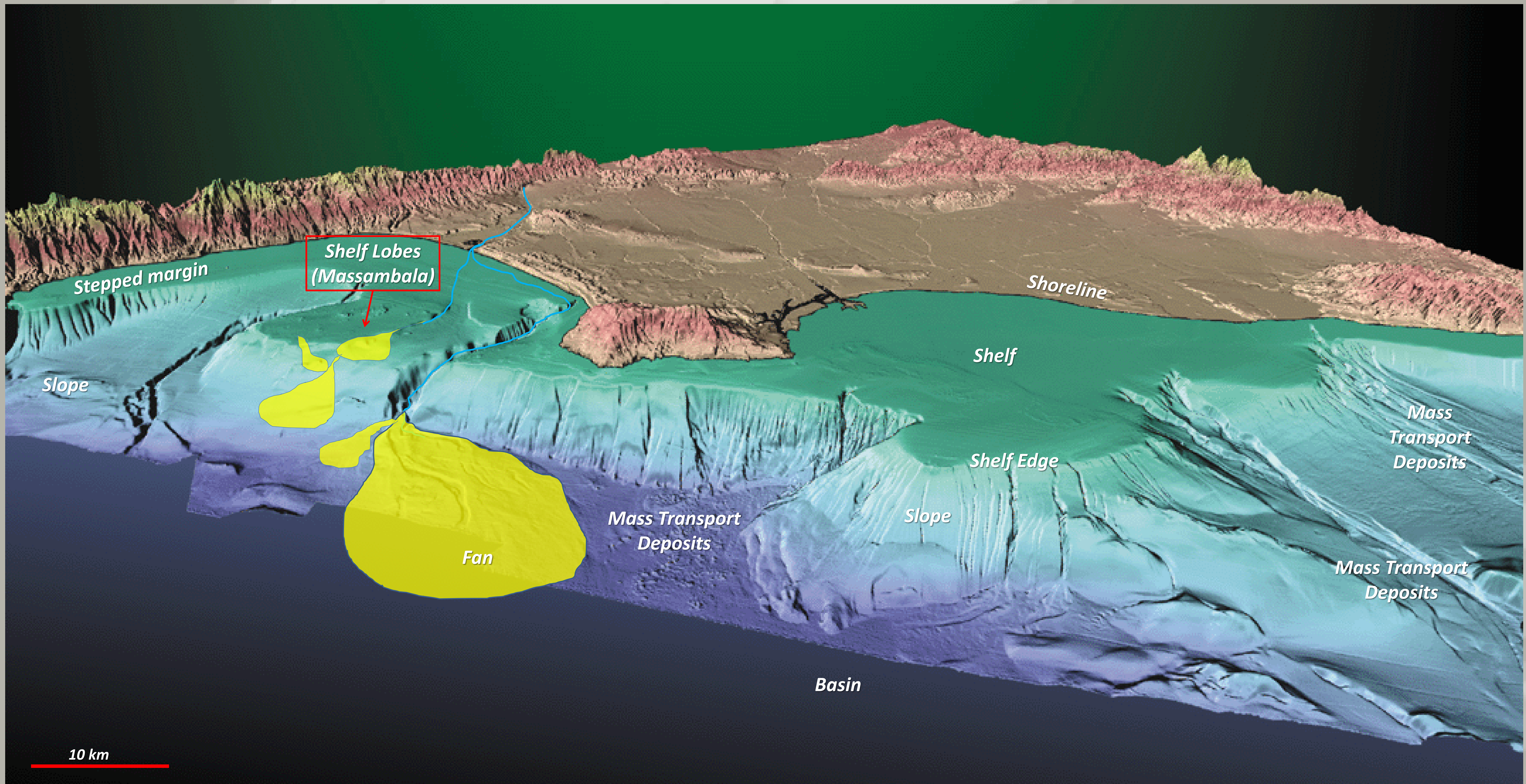
WELL CORES CORRELATION



6 – CONCLUSIONS

- Turbidite systems are described and interpreted for the Massambala Field by the integration of cores, logs, seismic and regional data.
- Ichnofacies assemblages suggest a shoreface marine setting where turbidite systems developed.
- Two major lobed shapes are interpreted in 3D seismic as turbidite lobes with feeder canyons to the NE.
- These lobes are part of the early Congo Fan system developed during Eocene-Oligocene times.

**STEPPED MARGIN CONCEPTUAL MODEL
FOR MALEMBO FM. IN MASSAMBALA OIL ACCUMULATION
(BASED ON MODERN MARINE ENVIRONMENT OF WESTERN USA)**



Modified and adapted picture from USGS Pacific sea floor mapping project, Los Angeles offshore multibeam bathymetric image (2007, 2018)