PS Outcrop Analogues for Reservoir Characterization - Examples from Lusitanian Basin's Post-Rift Units*

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Abstract

Reservoir units are usually identified and characterized based on their seismic imaging, trying to extract geological and petrophysical properties from geophysical large-scale and low-resolution attributes. The access to outcropping real-scale analogues is therefore a crucial tool for such approaches and to improve the accuracy of the interpretations. The Late Jurassic deposits of the Lusitanian Basin (Western Iberian Margin) are excellent examples of outcropping syn- to post-rift siliciclastic sequences with carbonate and mixed intercalations, allowing to know in detail their characteristics as potential reservoir units. Kimmeridgian syn-rift sediments correspond mainly to siliciclastic turbidites (Abadia Formation) filling-up subsiding axial depocenters, laterally fed by alluvial inputs (Alcobaça Formation). The post-rift sequences record strata deposited in shallow-water carbonate platform, with coral barriers and nearshore brackish bays and lagoons (Late Kimmeridgian, Amaral Formation), overlain by fluvial-deltaic with a few marginal marine intercalations until the end of the Tithonian (Lourinhã Formation). North of Lisbon, 20-30 m high coastal cliffs continually expose for around 30 km the Late Kimmeridgian to Tithonian mainly siliciclastic succession, around 1 km thick. From the fort of Consolação to the beach of Areia Branca, a 7 km long continuous outcrop shows the lower half of this succession, around 600 meters thick and gently dipping to the South. Several fourth-order and a few third-order sequences may be defined within this broadly progradational package. Field-based multi-scale analyses may be used to characterize these units, including high-resolution sequence stratigraphic framework, reservoir 3D geometries and connectivity, facies and petrophysical properties, etc. Detailed logging is available and reservoir characterization and modelling has been developed at various scales, namely to serve as analogues for the Lower to Middle Jurassic Statfjord, Dunlin, and Brent Groups (North Sea). This contribution presents the overall characteristics of this outcropping succession and its potential for high-resolution sequence stratigraphy application to support production development projects both within the scope of scientific research projects and/or as part of technical field-trip training.

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OUTCROP ANALOGUES FOR RESERVOIR CHARACTERIZATION - examples from Lusitanian Basin´s post-rift units

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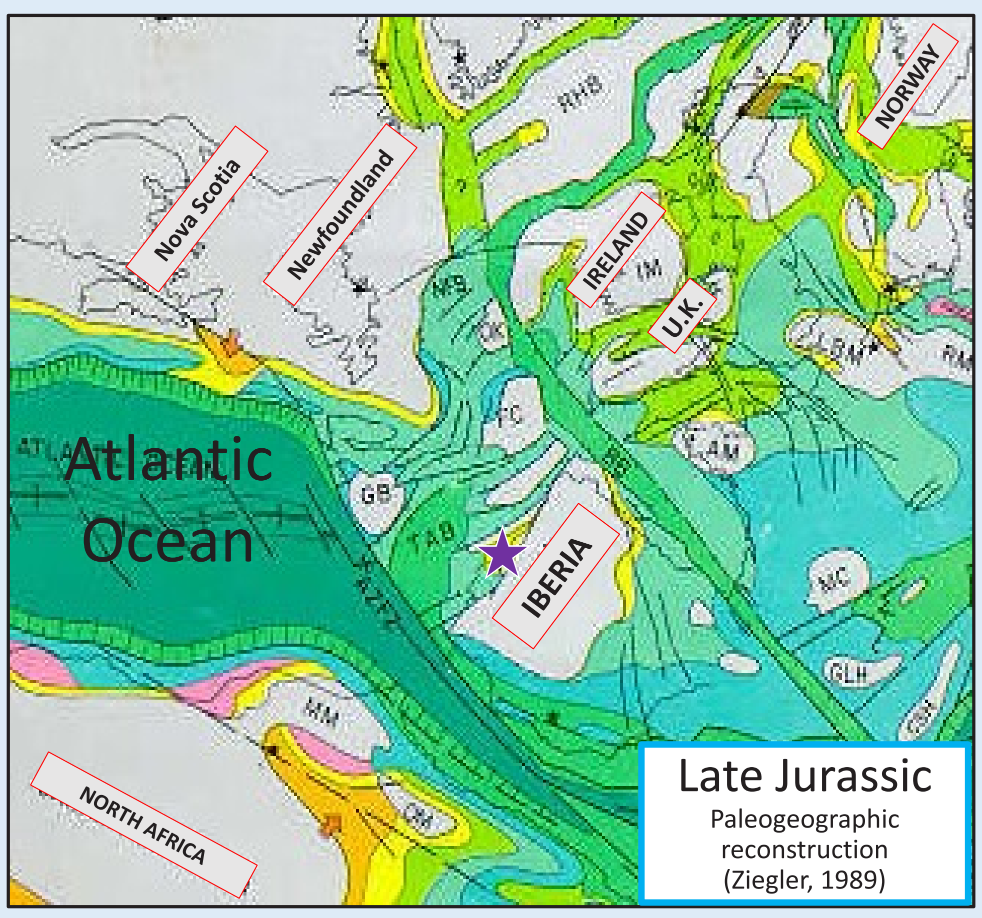
The Late Jurassic deposits of the Lusitanian Basin (North Atlantic, Western Iberian Margin) are excellent examples of outcropping syn- to post-rift siliciclastic sequences with carbonate and mixed intercalations, allowing to know in detail their characteristics as potential reservoir units.

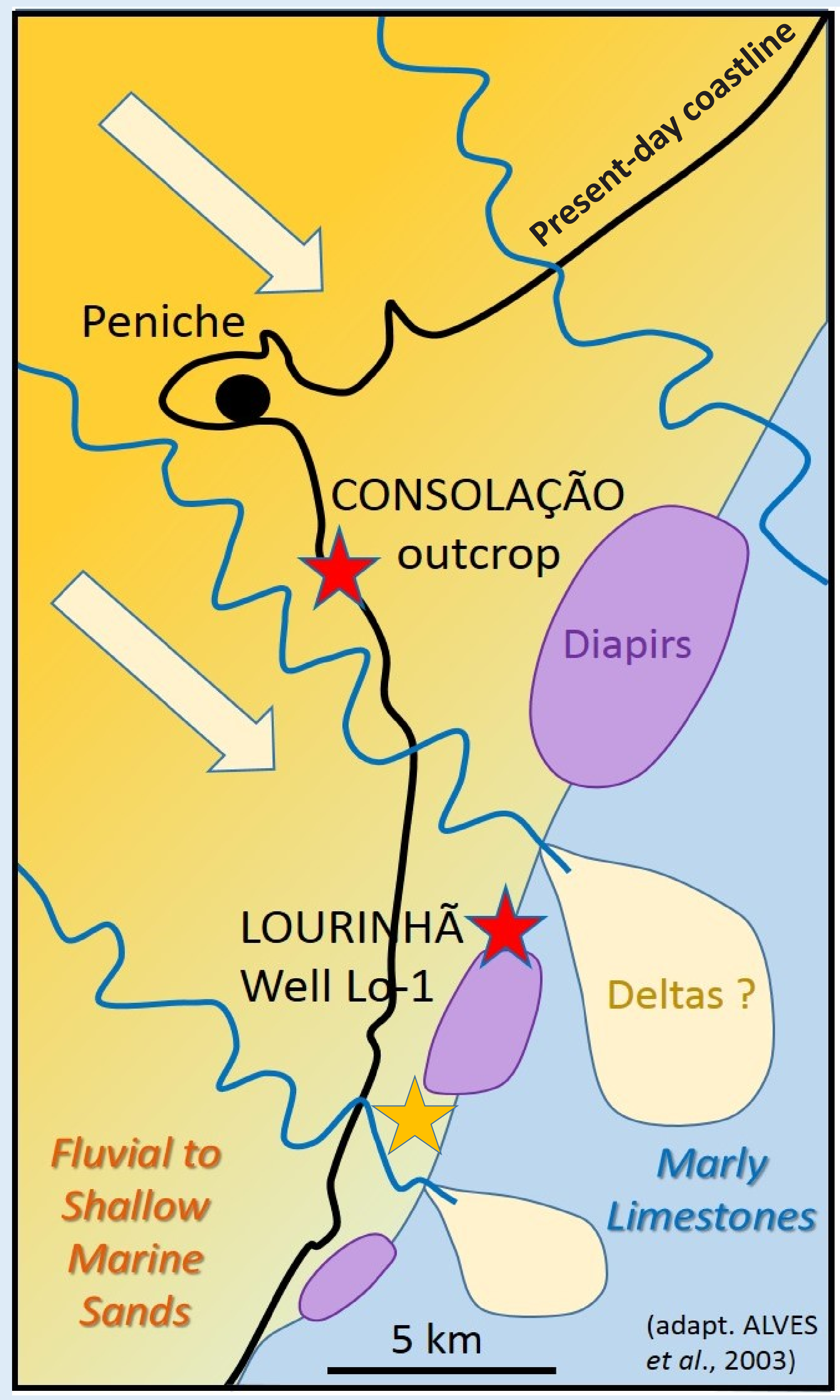
The outcrops are located North of Lisbon, where 30 km long coastal cliffs continually expose around 1 km thick Late Kimmeridgian to Tithonian succession.

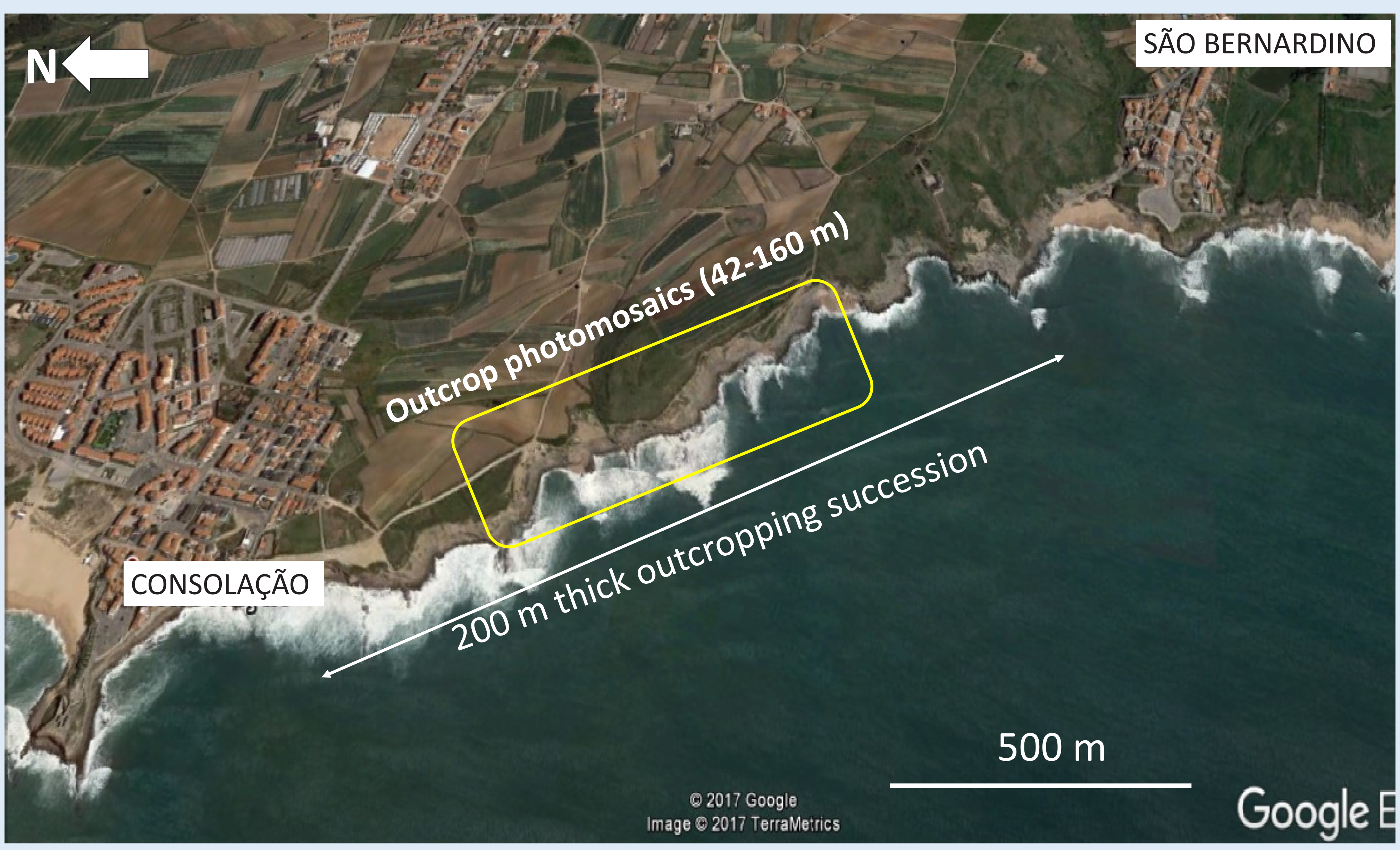
Late Oxfordian to Kimmeridgian syn-rift sediments correspond mainly to siliciclastic turbidites (**Abadia Fm**) filling-up the subsiding axial depocenters, laterally fed by alluvial inputs (Alcobaça Fm).

A shallow marine succession developed in Late Kimmeridgian with carbonate, mixed and siliciclastic deposits (**Amaral Fm**). At the top, the basin was filled up by fluvial to coastal siliciclastic sediments, punctuated by few major marine floodings (Tithonian, **Lourinhã Fm**).



Berriasian	DRIFT	Torres Vedras
Tithonian	Post-RIFT	LOURINHÃ
Kimmeridgian		AMARAL
		ABADIA / Alcobaça
Oxfordian	Rift climax	
	RIFT initiation	Montejunto
		Cabaços
Callovian	SAG	Candeeiros

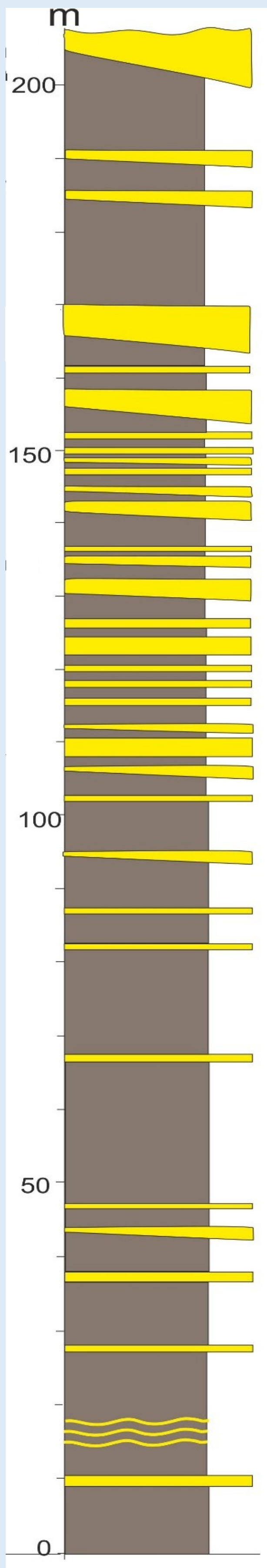




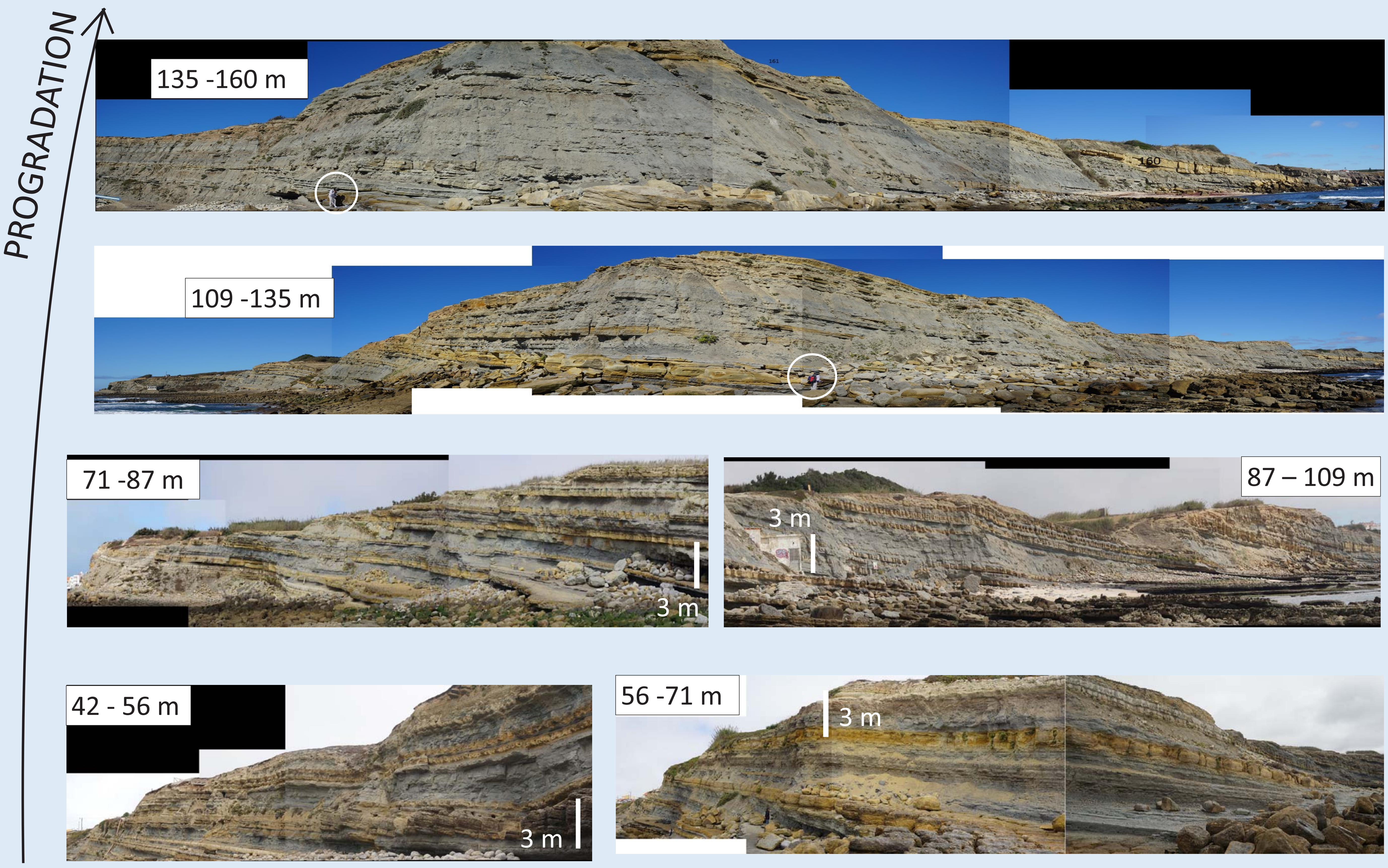
Paleogeographic reconstructions for the Kimmeridgian show the influence of the western border of the Lusitanian basin, nowadays represented by the Paleozoic outer high of the Berlengas Islands. Sedimentary transport direction was broadly from NW to SE, with the most distal and depocentric areas located around 20 km SE of the studied area.

In this study, we detailed the medium portion of the Amaral Fm, 200 m thick shallow marine outcropping succession, between the fort of Consolação and the beach of São Bernardino. This interval has been correlated with a nearby exploration well (Lo-1), drilled 10 km to the SE in 1959.

STUDIED SUCCESSIONS / Outcrop and Well

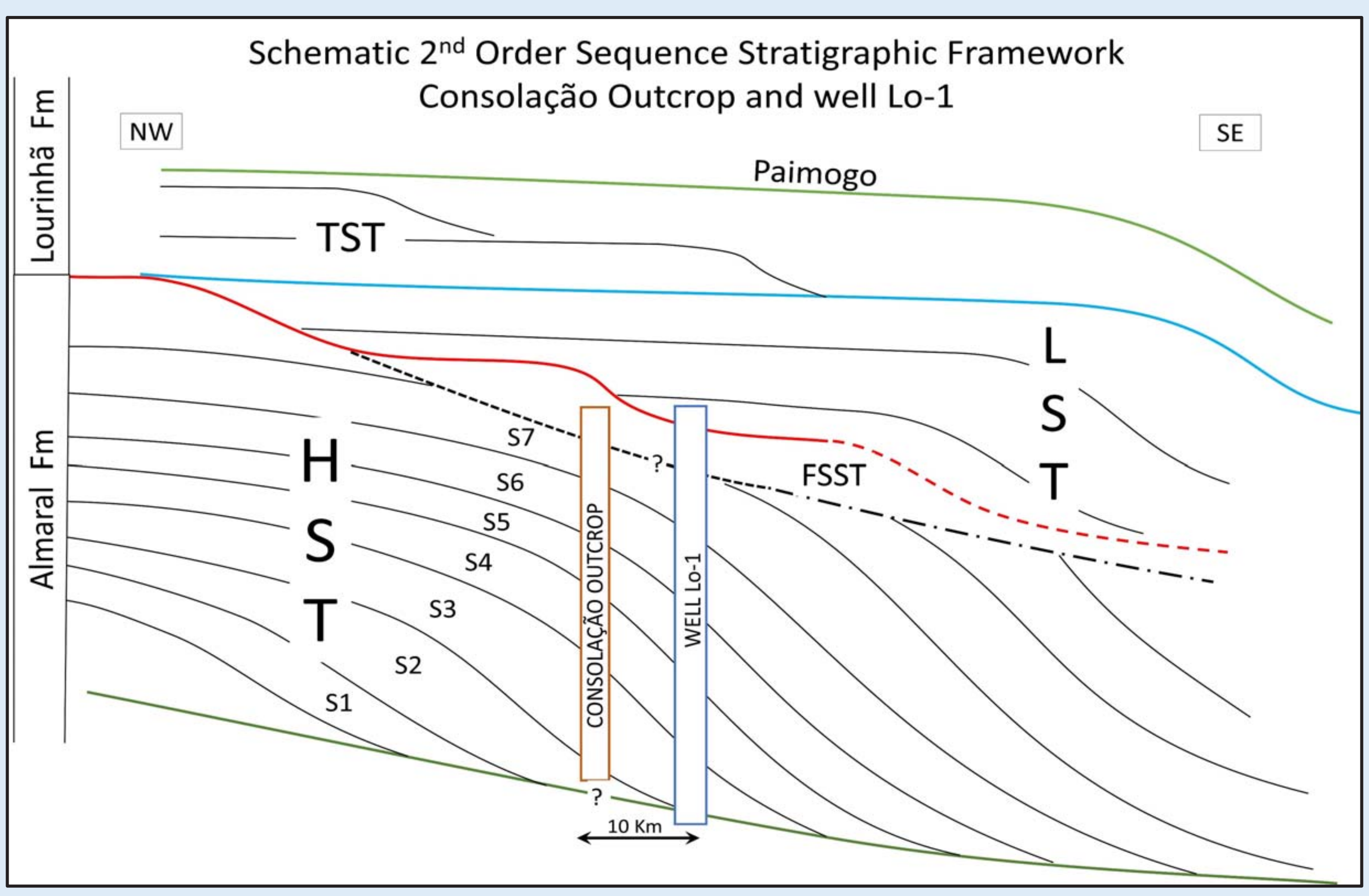


(Werner, 1996)



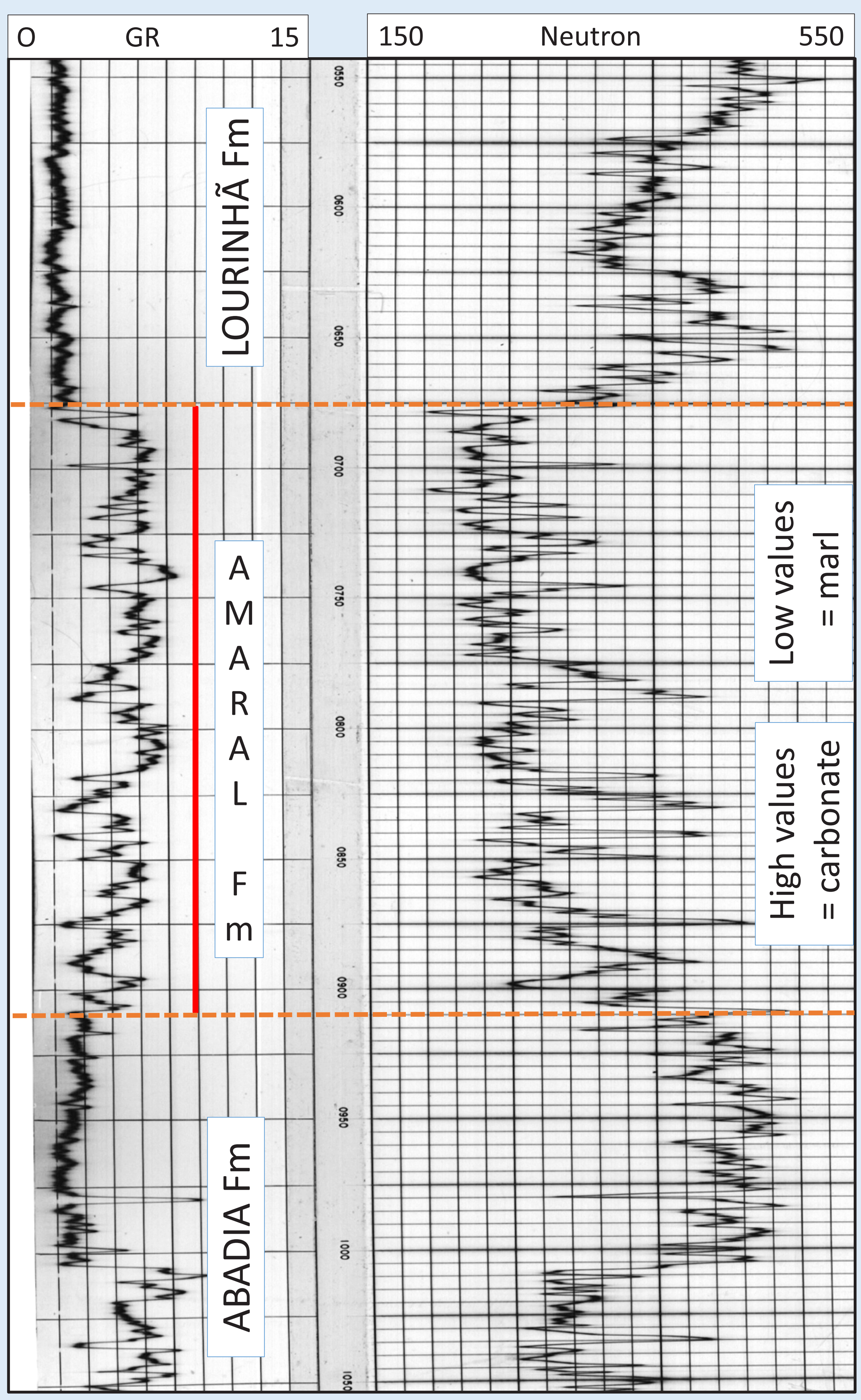
The magnificent 20-30 m high coastal cliffs in Consolação expose Amaral Fm. shallow marine successions gently dipping to the South that clearly show progradational stacking pattern. Towards the depocenter, where the well Lo-1 is located, the proximal facies observed in Consolação give place to predominantly inner shelf carbonate (mudstone) and marl.

In the well, the Amaral Fm. is clearly noticeable (**red line**) and both the GR and the Neutron log indicate concentration of carbonate mudstone layers towards the base and marly intervals towards the top, thus corroborating the progradational pattern.

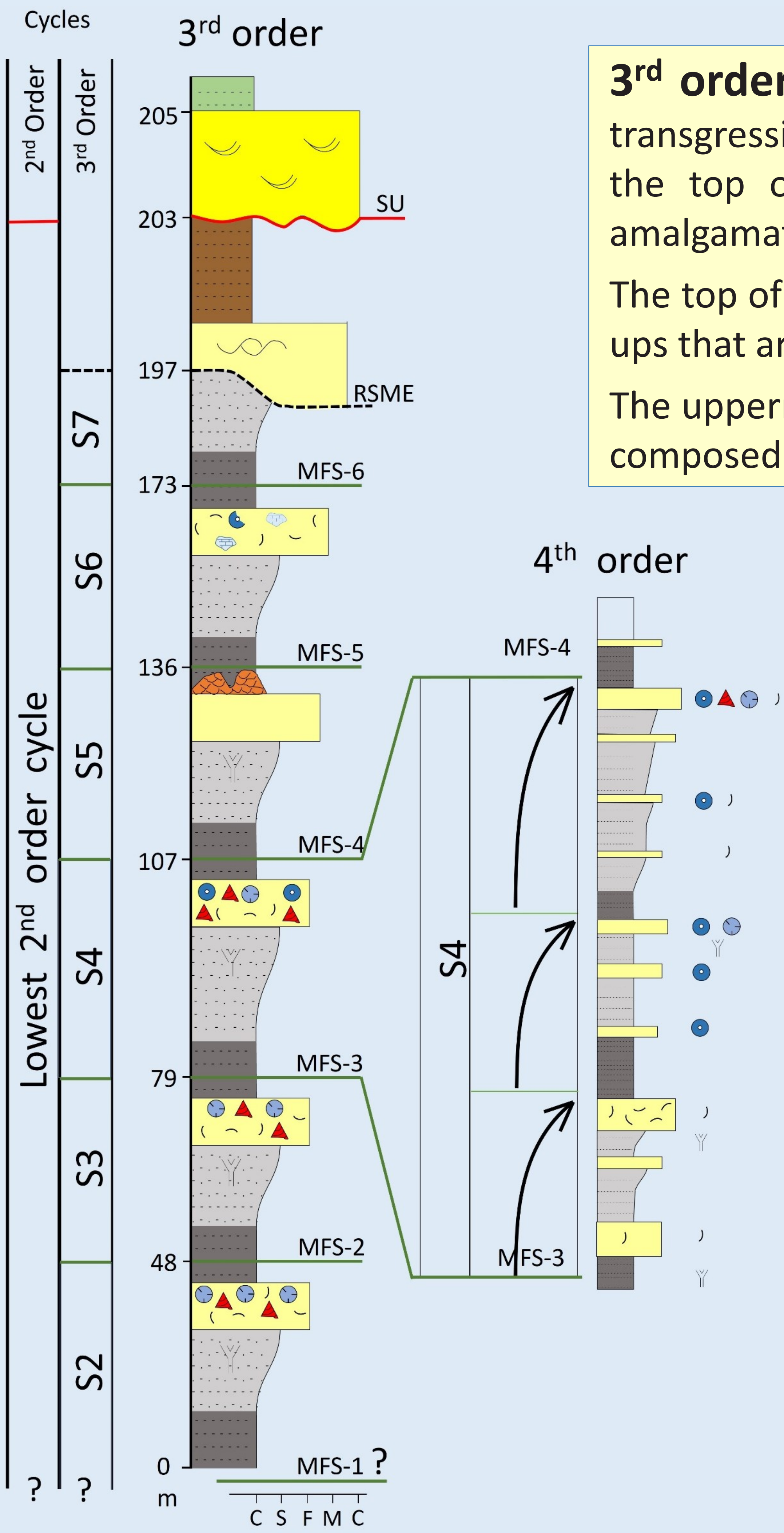


Overall, the Amaral and Lourinhã formations contain four 2nd order genetic sequences bounded by MFSs identified, from the bottom to the top, in Paimogo (**green line**), Praia Azul, and Assenta marine flooding intervals. Both studied intervals, outcrop and well, are here interpreted as belonging to the HST in the lowest 2nd order genetic sequence.

Well Lo-1, 10 km SE of Consolação



3rd and 4th Order Cycles

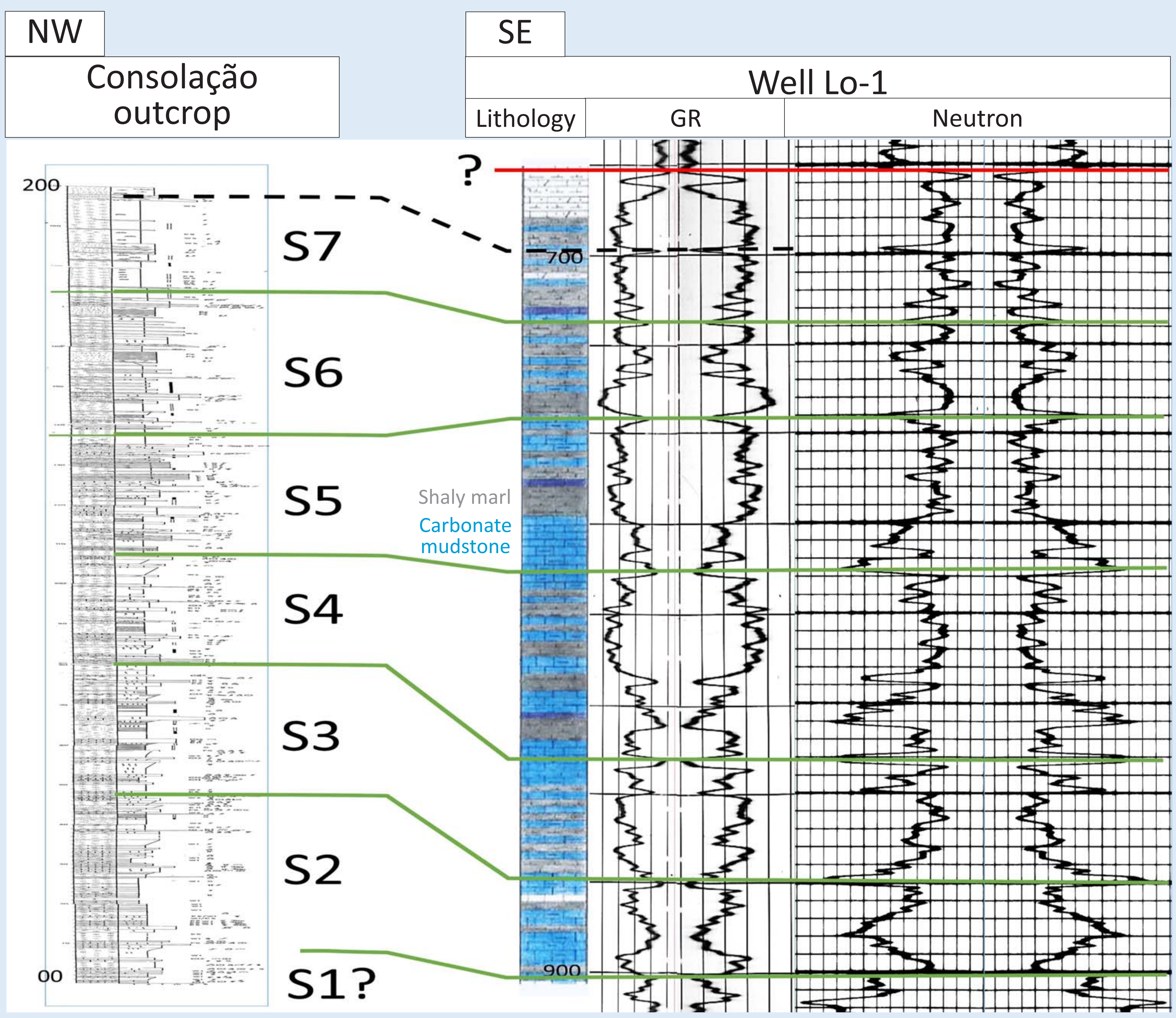


3rd order cycles reflect changes in stratal stacking pattern observed at 30-40 m scale. The transgressive interval mainly consists of thin (< 1m thick) inner shelf clay-rich marl. Towards the top of the succession, the regressive facies become gradually more proximal and amalgamated.

The top of each progadational stacting pattern is characterized by coral, bivalve or oyster build ups that are placed on top of shallow marine sandstone.

The uppermost 3rd order cycle (S7) is truncated at the top by a RSME. Each third order cycle is composed of three to five fourth order cycles.

4th order cycles are characterized by changes in stratal stacking pattern at 8-10 m scale. A typical cycle exhibits beds of clay-rich marl at the base that is overlain by thickening upwards siltstone to sandstone layers. Each fourth order cycle is formed by three to four five order cycles.



3rd order Outcrop – Well correlation

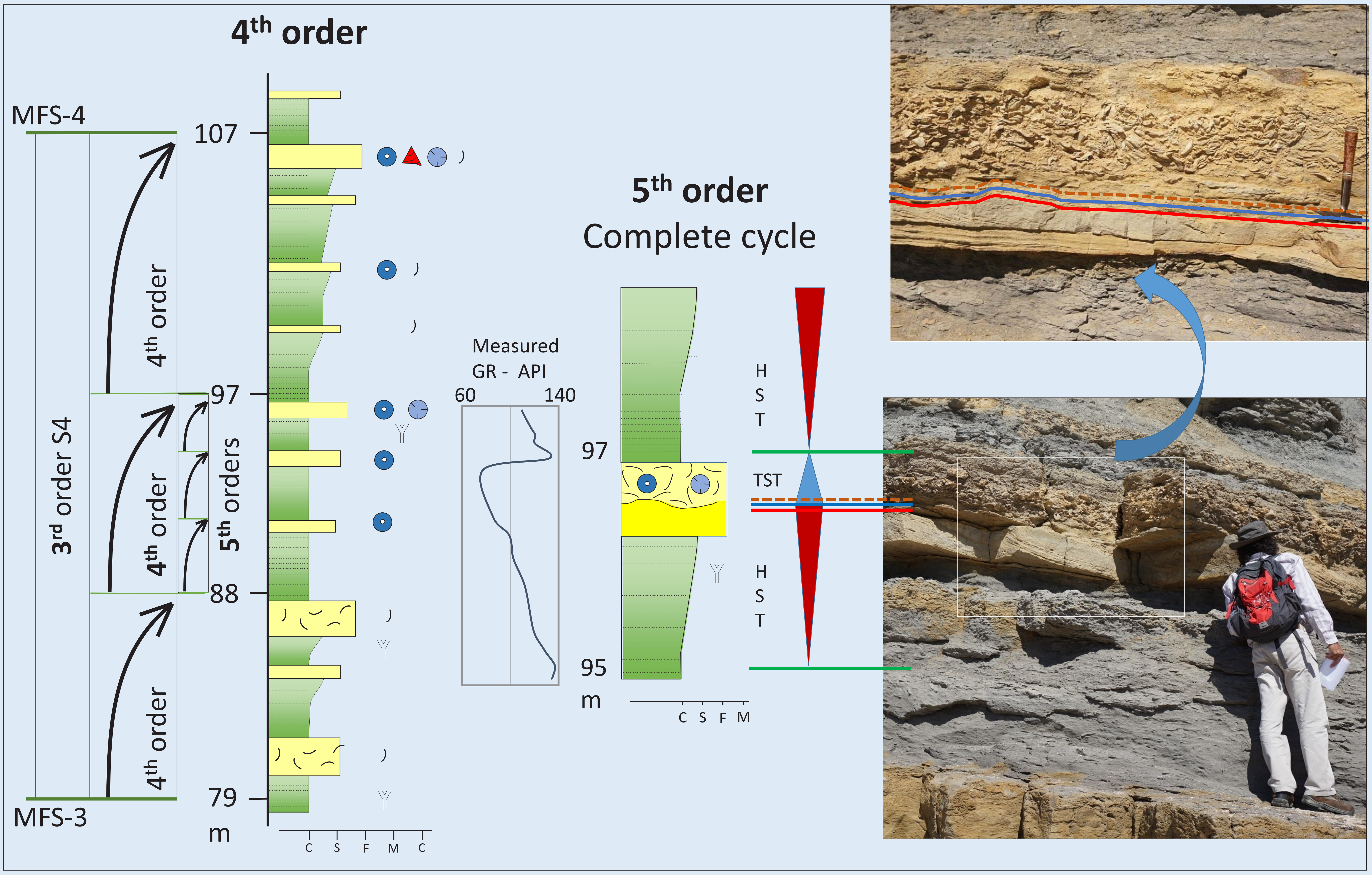
3rd order cycles correspond to genetic sequences, which may be correlated from the outcrop to the well.

At Lo-1 well, the transgressive intervals are marked by outer shelf carbonates, defined by low GR and high Neutron values. The regressive intervals consist of shaly marls related to the terrigenous input, showing high GR and low Neutron values.

At the outcrop, the proximal shaly marls are chronoequivalent to carbonate mudstones in dip direction (Lo-1), and hence they both contain MFSs.

Seven 3rd order sequences have been identified. Among them, sequence S4 is further detailed, including the definition of 4th and 5th order cycles.

5th Order Cycle – the reservoir scale

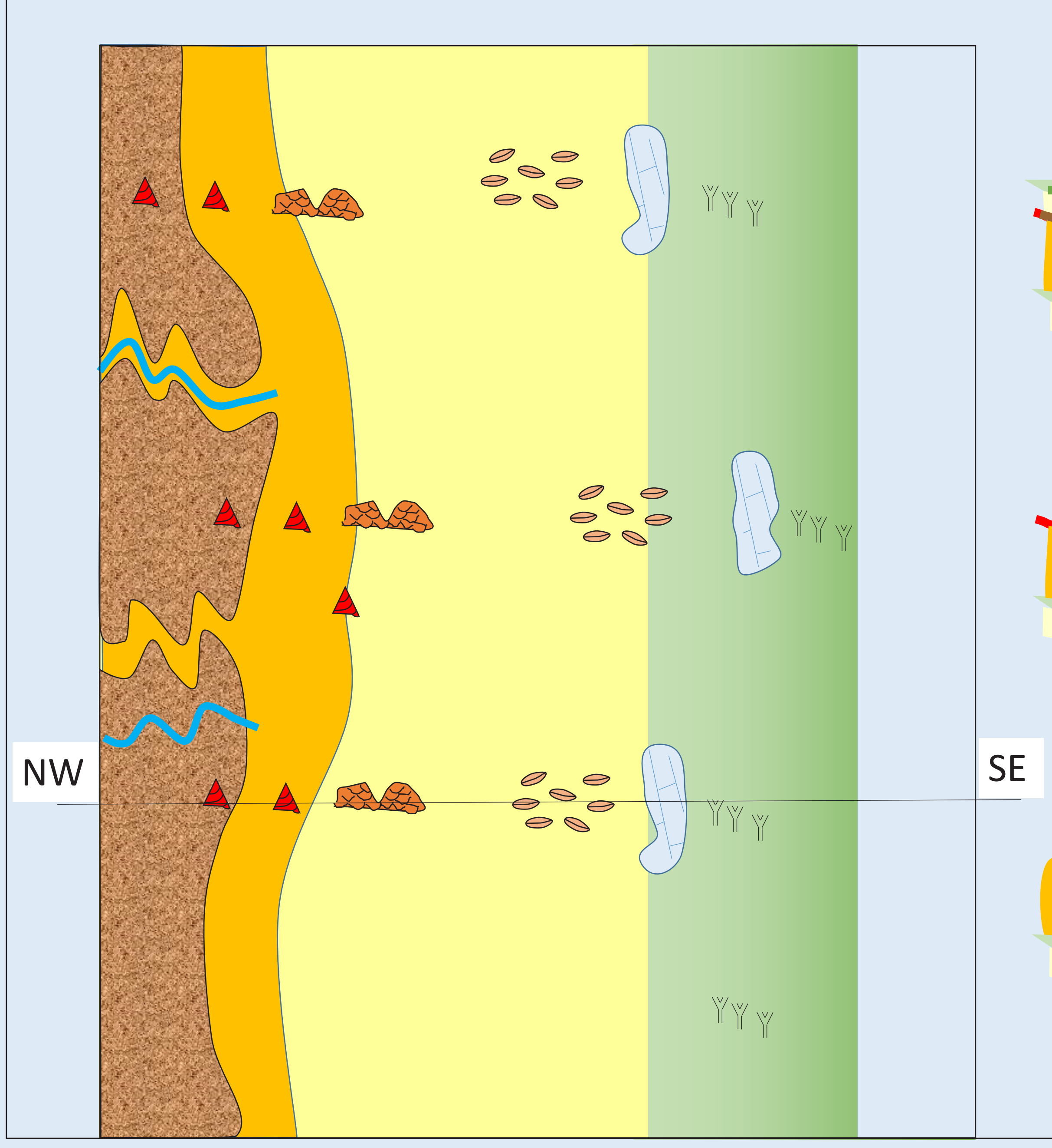


5th order cycles reflect changes in stratal stacking patterns at 2-4 m scale. At the outcrop, the high-frequency complete cycle (5th order) is bounded by MFSs, which are placed within inner shelf clay-rich marl interval. The bioclastic sandy layer, bounded at the base by a superimposed surface (SU/MRS/WRS), marks the beginning of the TST.

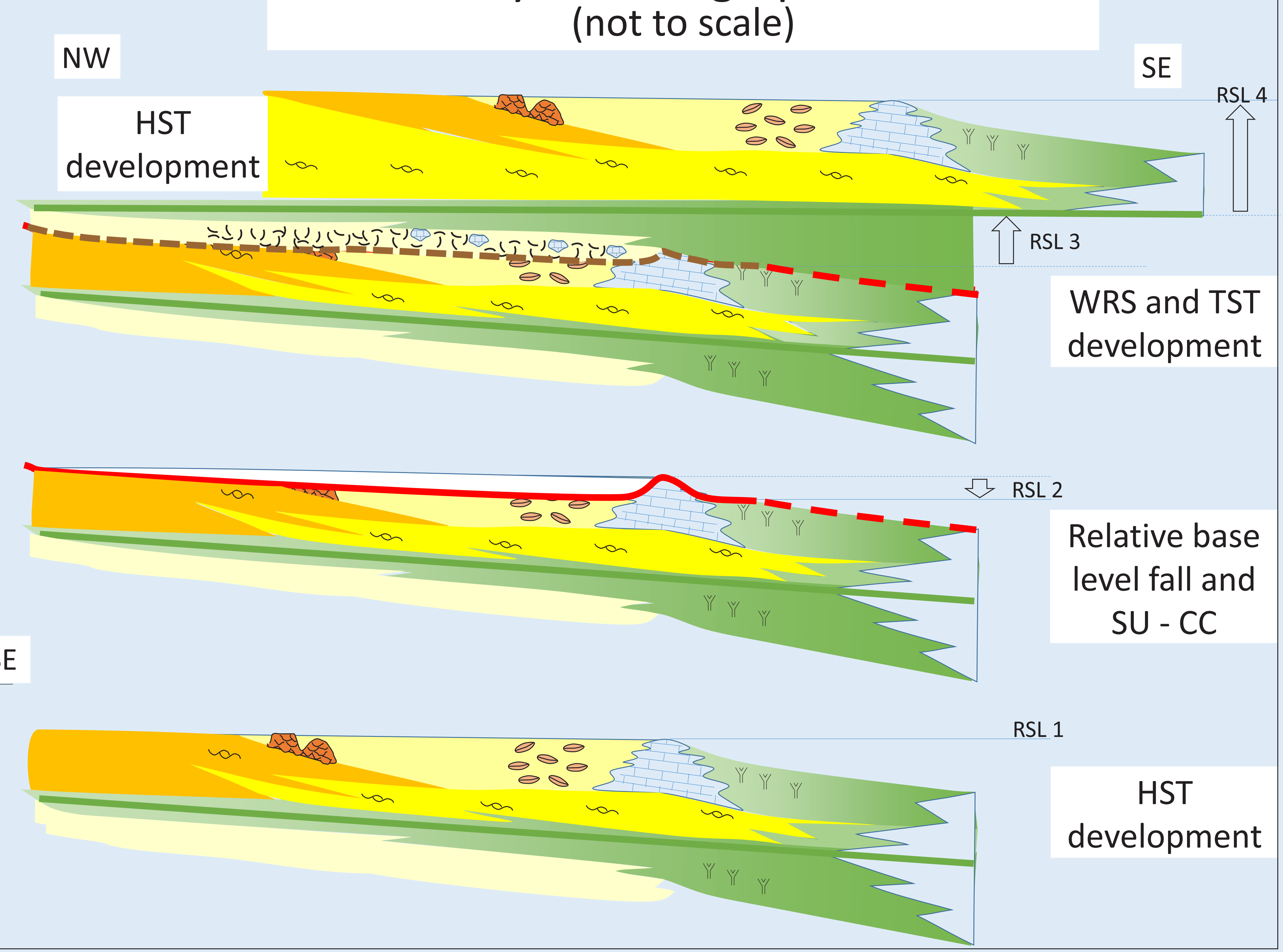
The HST is characterized by the coarsening up trend from mudstone to fine- to medium-grained, massive to wave-rippled sandstone. Facies analysis was also supported by available petrographic, macrofossil and ichnofacies characterization (Werner, 1996; Hanganu, 2017).

The GR log of the outcrop resembles the stacking pattern and allowed the correlation of the stacking patterns observed at Consolação outcrop and the well Lo-1.

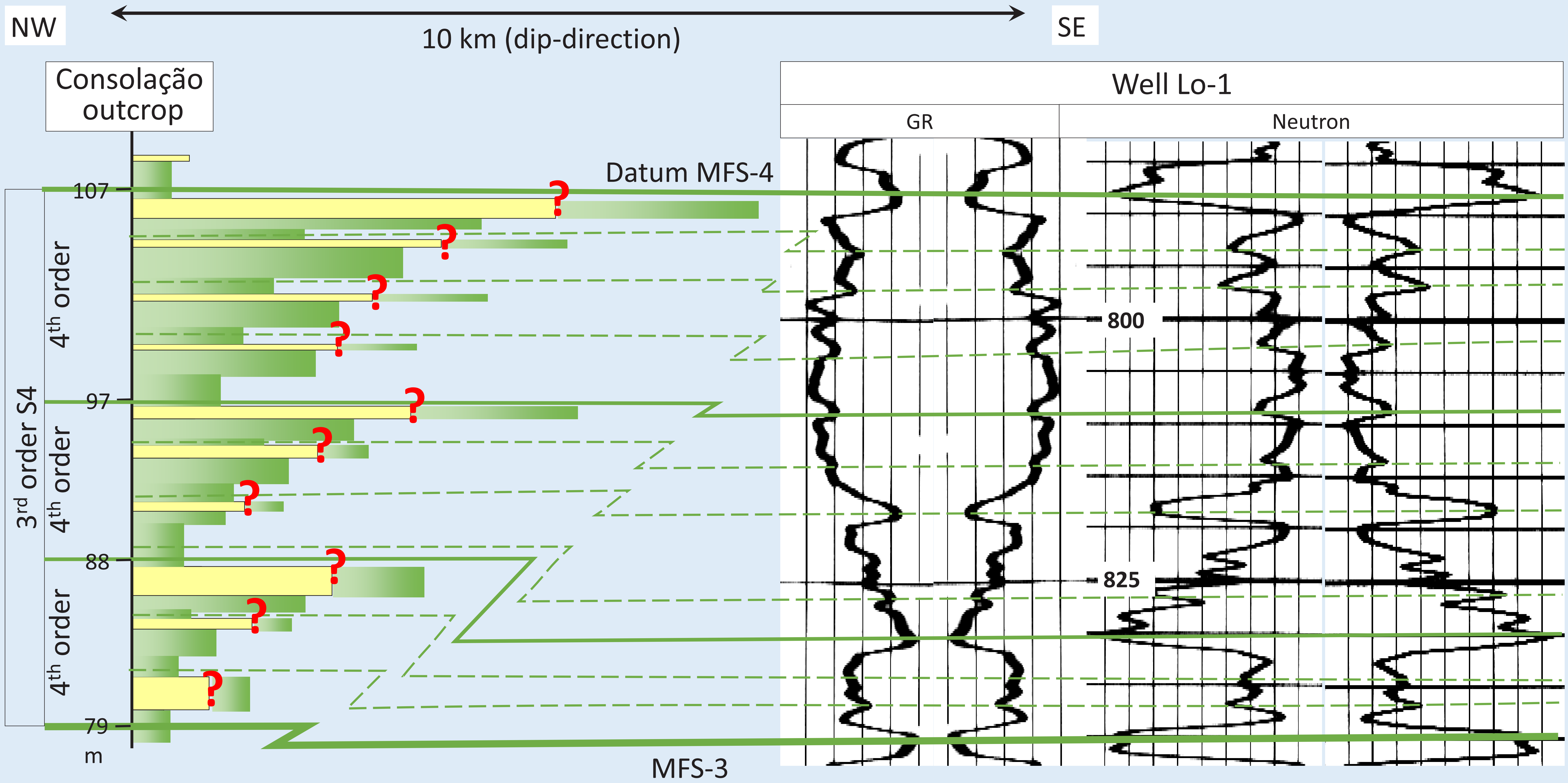
Paleogeographic reconstruction
(not to scale)



5th order cycle stratigraphic evolution
(not to scale)



Reservoir application: chronostratigraphic correlation



The chronostratigraphic correlation is based on the precise location of the MFSs, starting from the 3rd into the 5th order. Note that, in this example (sequence S4), the thickness in the well is about twice the thickness at the outcrop. Once the high-resolution framework is established, the reservoir zoning is achieved because the high-frequency MFSs are the zone boundaries (Magalhães et al. 2015). The next step is the correlation of architectural elements including those that contain reservoir facies (i.e. sandstone in yellow). This is even more challenging because of the shift of facies which occurs along the stratigraphic surfaces. The uncertainty related to the lateral extent of reservoir facies (? In the cross-section) is extremely important as it controls facies and petrophysical modelling and determines, at least, the volume of oil and the production strategy of the field.

CONCLUSIONS

The magnificent exposure of shallow marine mixed/siliciclastic succession in Consolação exhibits different facies associations, sedimentary structures and fossil content, supporting detailed sedimentological and paleoenvironmental interpretations.

The available data-base (outcrop description, well log, petrographic analysis, macrofossil and ichnofacies characterization) turns this area into a world-class analogue for reservoir characterization. The observed cyclicity reflects changes in the stratal stacking patterns at 30-40 m, at 8-10 m, and at 2-4 m scales respectively related to 3rd, 4th, and 5th order hierarchies. Altogether, these observations make easy the practice of high-resolution sequence stratigraphy and its immediate application to 3D geological modelling within this chronostratigraphic framework.

Zone boundaries equal to high-frequency MFSs (5th order) and they highlight not only the reservoir external geometry, areal occurrence, and both vertical and horizontal connectivity, but also the main uncertainties that may impact the volume of oil and the production strategy of the field.

Therefore, this area is a robust field laboratory that can be used within the scope of scientific research projects and/or as part of technical field-trip training on reservoir characterization and high-sequence stratigraphy application to reservoir studies.

Legend

- Subaerial Unconformity (SU)
- Maximum Regressive Surface (MRS)
- 3rd order Maximum Flooding Surface (MFS)
- Correlative Conformity (CC)
- Basal Surface of Forced Regression (BSFR)
- Regressive Surface of Marine Erosion (RSME)
- Wave Ravinement Surface (WRS)
- 5th order MFS

Reservoirs:
- Coarse- to medium-grained sandstone
- Fine- to medium-grained bioclastic sandstone

- Marl to clay-rich marl
- Open marine marl and limestone

- Oolith, Oncolith
- Gastropode
- Coral
- Bivalve in situ
- Bioclastic
- Oyster build up
- Coral reef build up
- Thalassinoides
- Wave-ripple

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OUTCROP ANALOGUES

FOR RESERVOIR CHARACTERIZATION

- examples from Lusitanian Basin´s post-rift units

HIGHLIGHTS

- *Late Jurassic units of the Lusitanian Basin may be used as analogues for the Lower to Middle Jurassic Statfjord, Dunlin and Brent Groups (North Sea). Detailed logging is available and reservoir characterization and modelling have already been developed at various scales.*
- *In this study, high-resolution sequence stratigraphic analysis has been applied to a Late Jurassic post-rift climax shallow marine succession, outcropping 50 km NNW of Lisbon.*

- *Correlation with a nearby exploration well is presented through a 10 km long dip-oriented chronostratigraphic cross-section with 3rd to 5th order sequences.*
- *Paleogeographic reconstruction, reservoir geometry and connectivity, and implications for 3D geological modelling and production strategy are discussed.*
- *The favourable exposure conditions and the robust associated data-base, make this section an excellent case-study and a natural laboratory to exercise high-resolution sequence stratigraphy applied to reservoir characterization.*