PS Portugal Prospective Petroleum Basins, Offshore Edge of Iberia Peninsula*

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Abstract

The continental margin edge of the Western Iberian Margin is marked by the Portuguese rifted sedimentary margin basins. These rifted basins originated from the closure of the Tethys Ocean and opening of the North Atlantic Ocean and they all have similar characteristics. The best known of these basins is the mostly onshore Lusitanian Basin where exploratory work has been consistent. The basins evolved as part of the Mesozoic evolution of the Iberia Peninsula, the petroleum geology history of the Lusitanian Basin being known through the detailed stratigraphic mapping of outcrop exposures and legacy exploratory drilling. Exploratory work have also been conducted in the onshore and shallow offshore wells have been drilled in the Algarve Basin. The lesser known basins are the western offshore basins of Porto, Peniche, and Alentejo and the southernmost basins of Sagres and Algarve deeper offshore. In the last decade state of the art seismic surveys were conducted in the Peniche, in the Alentejo, and in the Algarve basins. Interpretation mapping of these surveys uncovered attractive structural and stratigraphic prospects in deep-water shaped by salt tectonics.

This paper describes an overall G & G view of these marginal basins based on seismic, gravity, and magnetics data. The better-known onshore Lusitanian Basin developed over a Paleozoic basement terrane amalgamated during the Variscan Orogeny. Triassic rift siliciclastic infill was followed by thick salt-rich clays deposited in continental and coastal evaporitic sabkhas. Marly and carbonate deposition were predominant during the Early and Middle Jurassic with marine sediments of ramp and platform environments. The Late Jurassic characterizes a new rifting episode with realignment of old basement structures and erosion of the margin rift shoulders. Early Cretaceous sedimentation was marked by the break-up of the North Atlantic whereas the Late Cretaceous marks the tectonic inversion of the basin and its continued deformation. Salt pillows deforming the Late Triassic date back from Early to Mid-Jurassic, whereas Late Jurassic tectonics and basin inversion are contemporaneous with the rise of salt diapirs and the massive corridor salt walls of the Lusitanian Basin. The Late Cretaceous piercing of diapirs and the deformation of the buried and piercing salt features are related to the Alpine compressive events. These deformations continued until recent times with the diapirism being regionally defined by seismic and basin outcrop exposures. The Peniche and Alentejo basins offshore also display thick sections of Triassic (with massive salt in the Peniche Basin), Jurassic, and Lower Cretaceous sediments whereas the Algarve Basin has influences from the Atlantic and from the Pelagian Platform of North Africa in resemblance with oblique slip features of a transform margin.

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UNIVERSIDADE DE COIMBRA

LISBOA UNIVERSIDADE DE LISBOA

Abstract

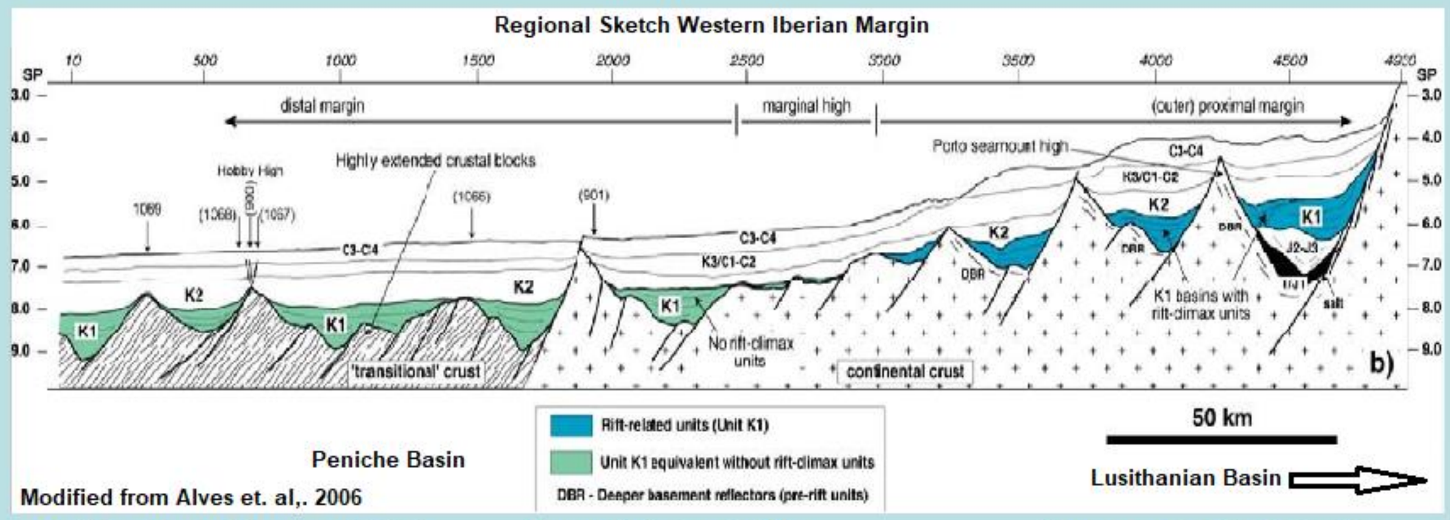
The continental margin edge of the Western Iberian Margin is marked by the Portuguese rifted sedimentary margin basins. These may be distinctively grouped as inner basins such as the Porto, Lusitanian and Algarve and outer basins such Peniche, Alentejo and Sagres offshore basins. All of these rifted basins originated from the closure of Thetis Ocean and opening of the North Atlantic Ocean and they all have similar characteristics. The best known of these basins is the mostly onshore Lusitanian Basin where exploratory work has been consistent. The basins evolved as part of the Mesozoic evolution of the Iberia Peninsula, the petroleum geology history of the Lusitanian Basin being known through the detailed stratigraphic mapping of outcrop exposures and legacy exploratory drilling. Exploratory work have also been conducted in the onshore and shallow offshore wells have been drilled in the Algarve Basin. The lesser known basins are the western offshore basins of Porto, Peniche and Alentejo and the southernmost basins of Sagres and Algarve deeper offshore. In the last decade state of the art seismic surveys were conducted in the Peniche, in the Alentejo and in the Algarve basins. Interpretation mapping of these surveys un-covered attractive structural and stratigraphic prospects in deep-water shaped by salt tectonics.

This paper describes an overall G & G view of these marginal basins based on seismic, gravity and magnetics data. The better known onshore Lusitanian Basin developed over a Paleozoic basement terrane amalgamated during the Variscan orogeny. Triassic rift siliciclastic infill was followed by thick salt-rich clays deposited in continental and coastal evaporitic sabkhas. Marly and carbonate deposition were predominant during the Early and Middle Jurassic with marine sediments of ramp and platform environments. The late Jurassic characterizes a new rifting episode with realignment of old basement structures and erosion of the margin rift shoulders. Early Cretaceous sedimentation was marked by the break-up of the North Atlantic whereas the late Cretaceous marks the tectonic inversion of the basin and its continued deformation. Salt pillows deforming the Late Triassic date back from Early to Mid-Jurassic, whereas Late Jurassic tectonics and basin inversion are contemporaneous with the rise of salt diapirs and the massive corridor salt walls of Lusitanian Basin. The late Cretaceous piercing of diapirs and the deformation of the buried and piercing salt features are related to the Alpine compressive events. These deformations continued until recent times with the diapirism being regionally defined by seismic and basin outcrop exposures. The Peniche and Alentejo basins offshore also display thick sections of Triassic (with massive salt in the Peniche Basin), Jurassic and Lower Cretaceous sediments whereas the Algarve Basin has influences from the Atlantic and from the Pelagian Platform of North Africa in resemblance with oblique slip features of a transform margin. The interpretation of regional seismic lines over these diverse Portuguese basins outlines the main events such as the breakup unconformities, the pre-salt section, the Triassic salt, the early and Upper Jurassic carbonates and the Lower and Upper Cretaceous sediments.

REGIONAL DIP CRUSTAL MODELS- WESTERN IBERIAN MARGIN

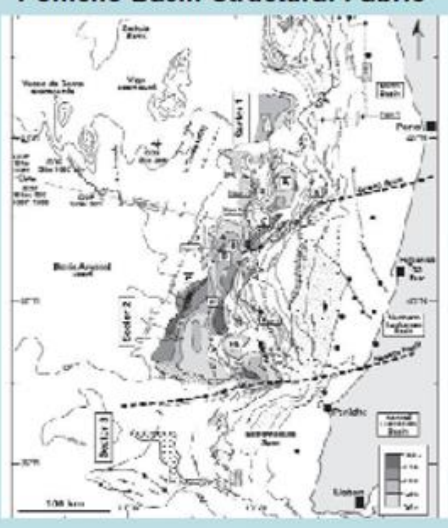
The onshore and offshore western Iberian basin may be grouped as follows:

Modified from Fainstein and Duarte, 2017

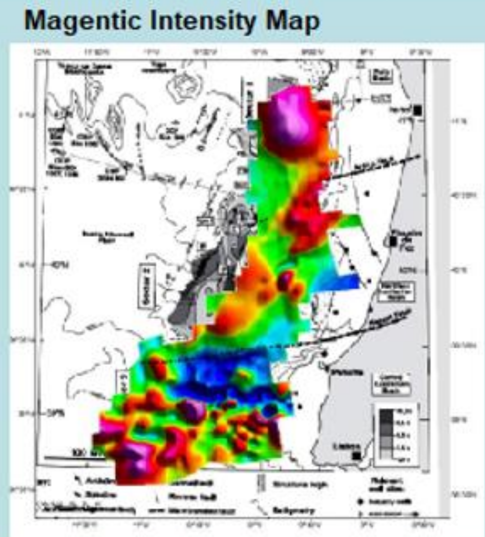


Modified from Alves et. al,. 2006

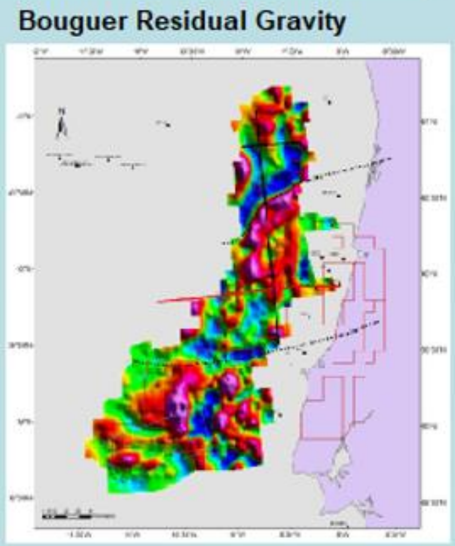
Peniche Basin Structural Fabric



Magentic Intensity Map



Bouguer Residual Gravity

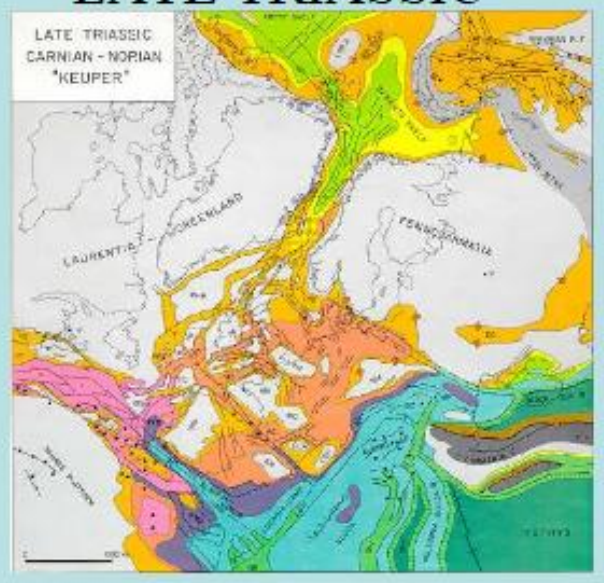


Modified from Fainstein and Duarte, 2017

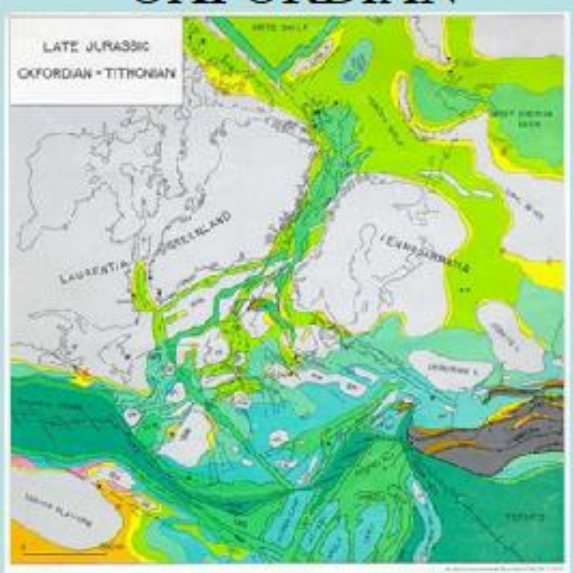
TECTONIC EVOLUTION- THE PORTUGUESE ATLANTIC MARGIN

The tectonic evolution of the western edge of the Iberian Margin involves several episodes of structural alignments as per diagram below.

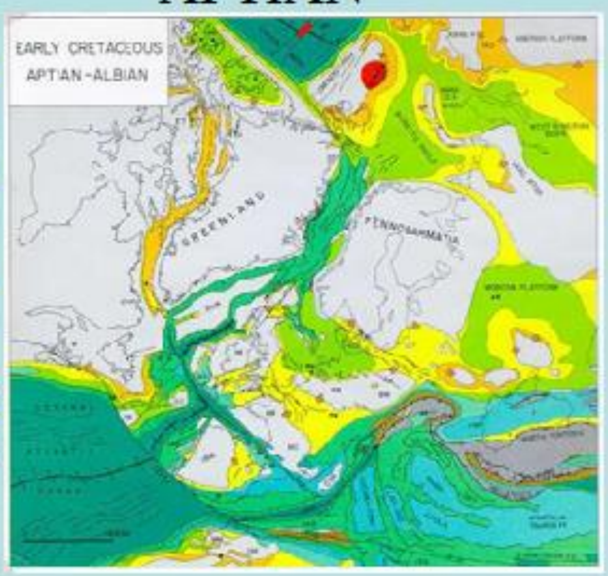
LATE TRIASSIC



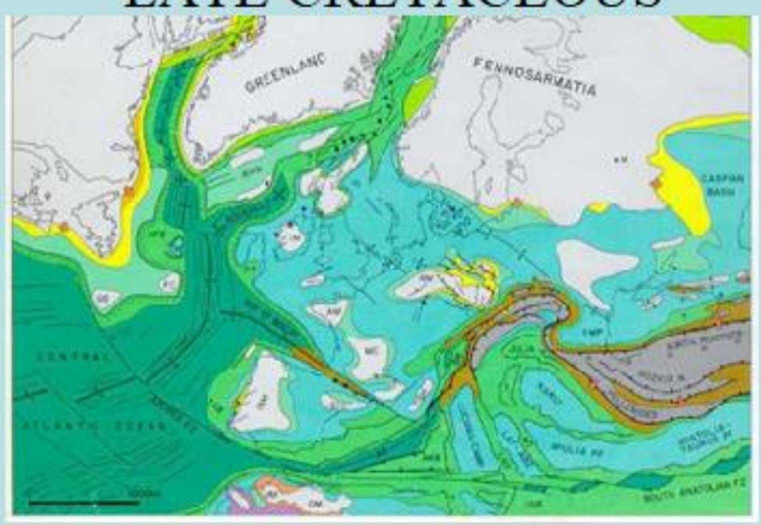
OXFORDIAN



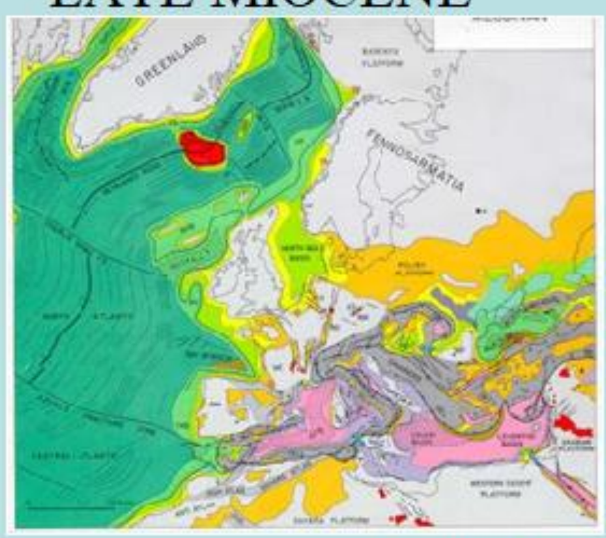
APTIAN



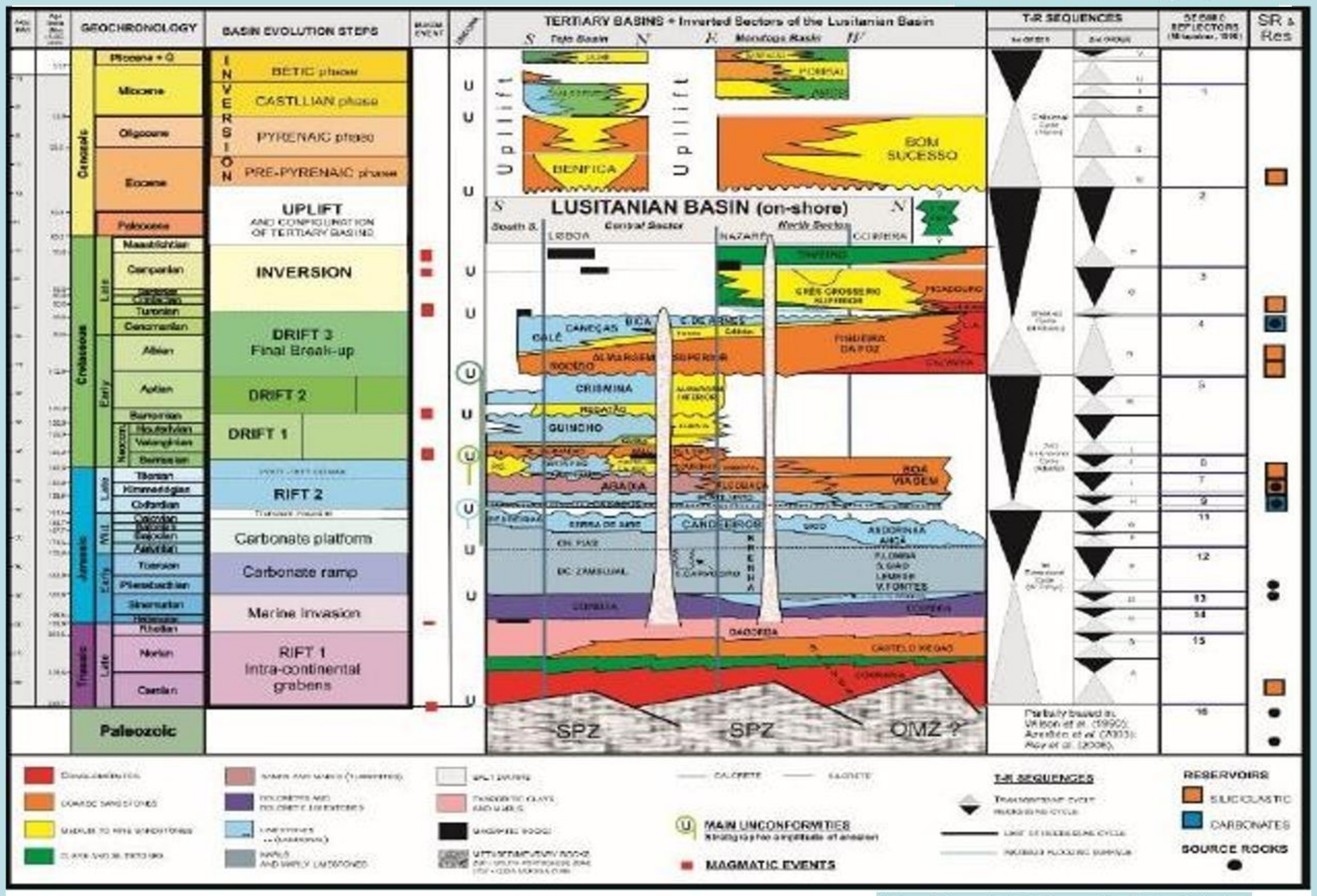
LATE CRETACEOUS



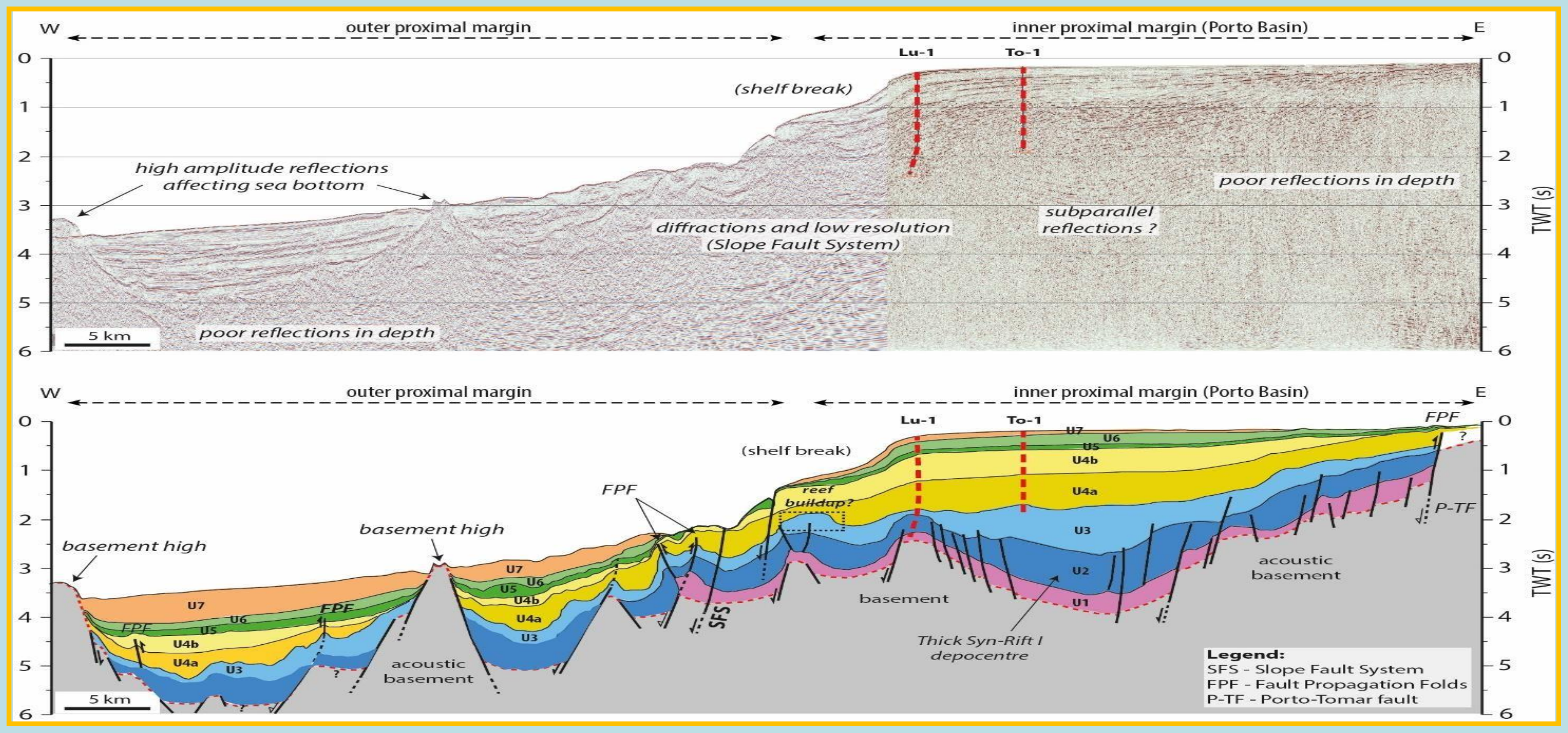
LATE MIOCENE

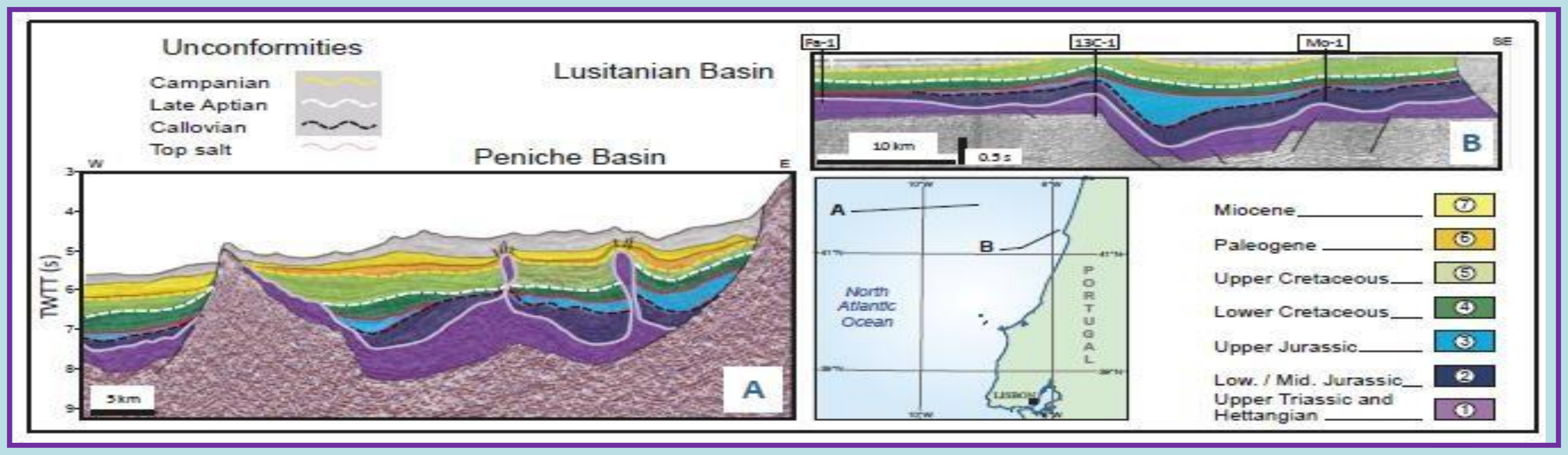


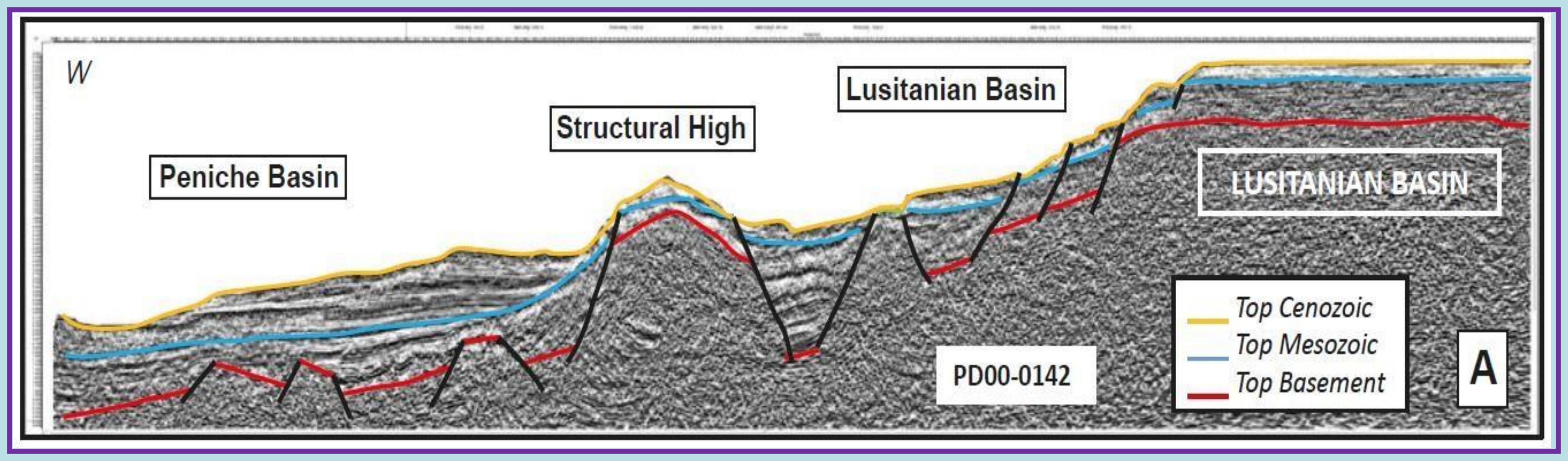
Modified from Ziegler, 1999

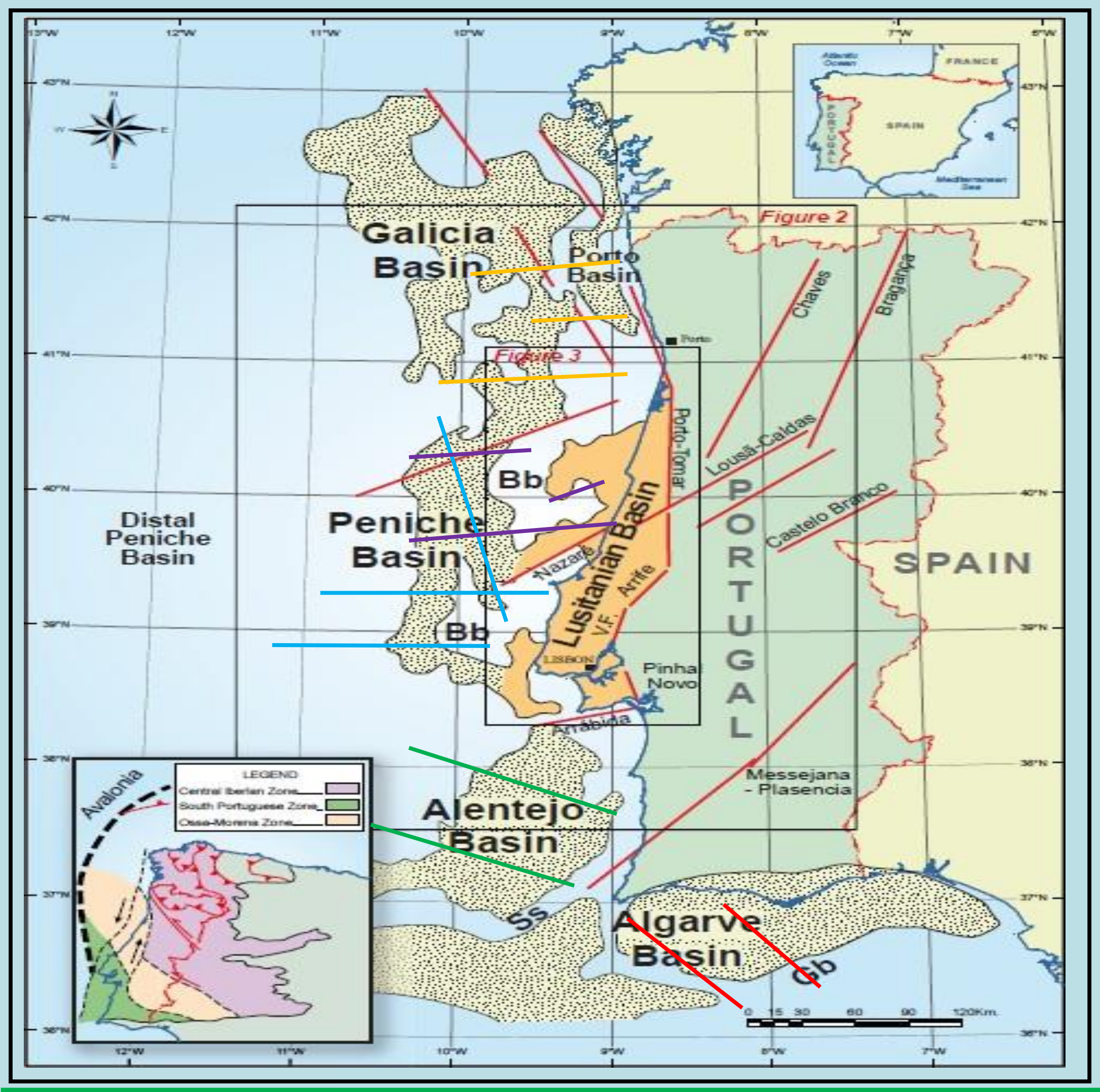


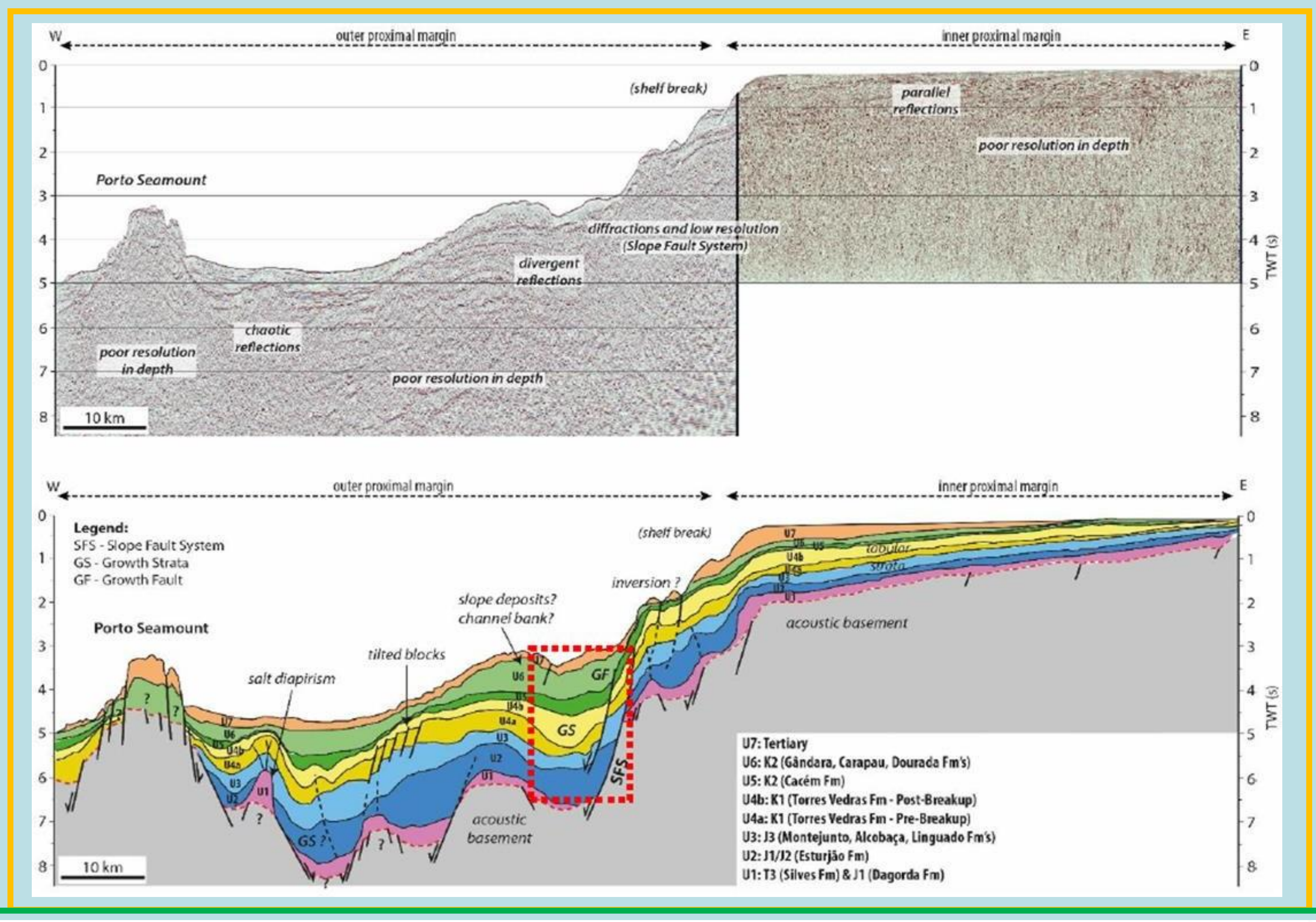
After Pimentel & Pena dos Reis, 2016

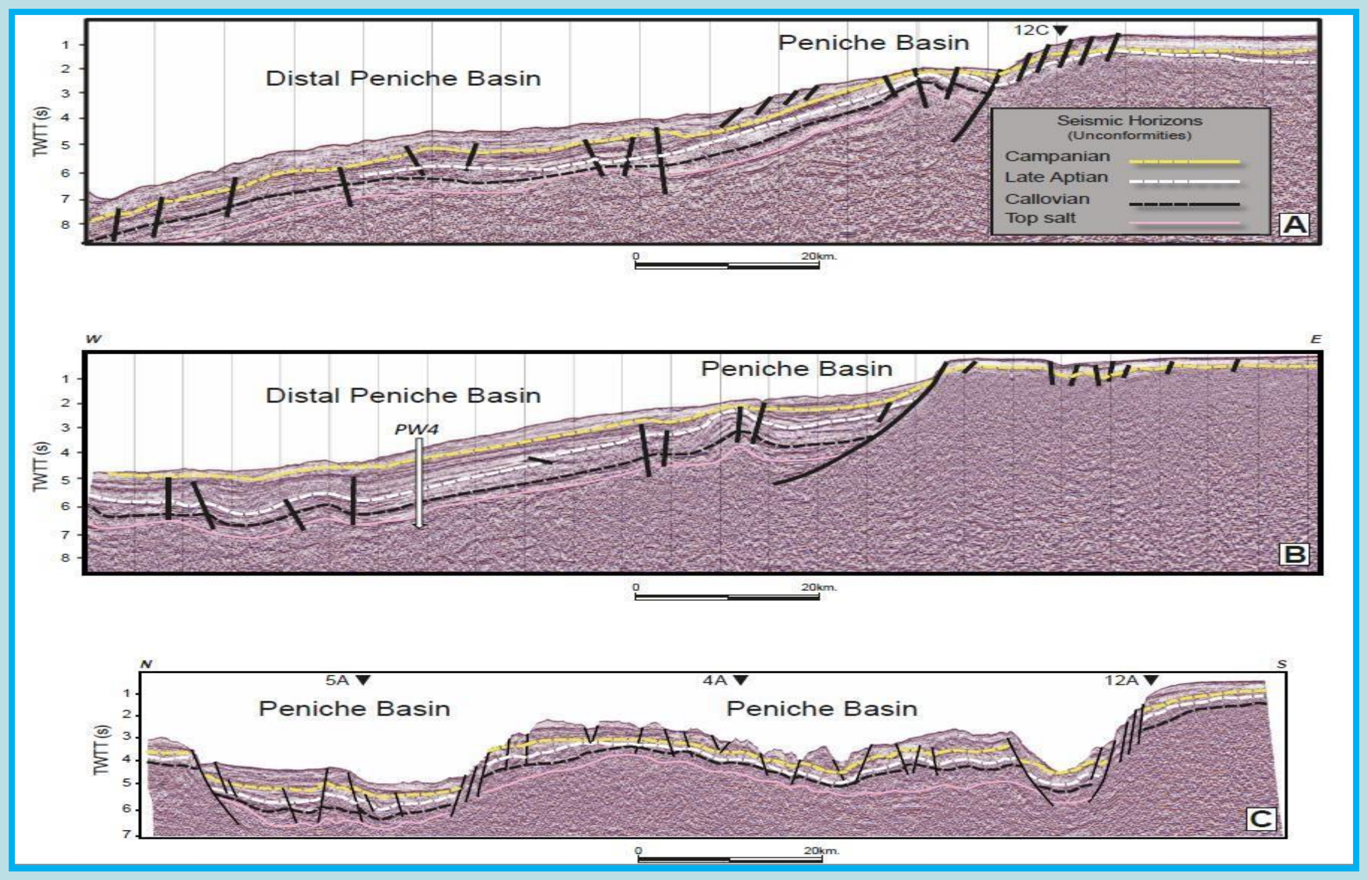

W
outer proximal margin
inner proximal margin (Porto Basin)
E
Lu-1
To-1
(shelf break)
high amplitude reflections affecting sea bottom
diffractions and low resolution (Slope Fault System)
subparallel reflections ?
poor reflections in depth
poor reflections in depth
5 km
TWT (s)
basement high
basement high
FPF
reef buildup?
SFS
acoustic basement
basement
Thick Syn-Rift I depocentre
acoustic basement
P-TF
Legend:
SFS - Slope Fault System
FPF - Fault Propagation Folds
P-TF - Porto-Tomar fault

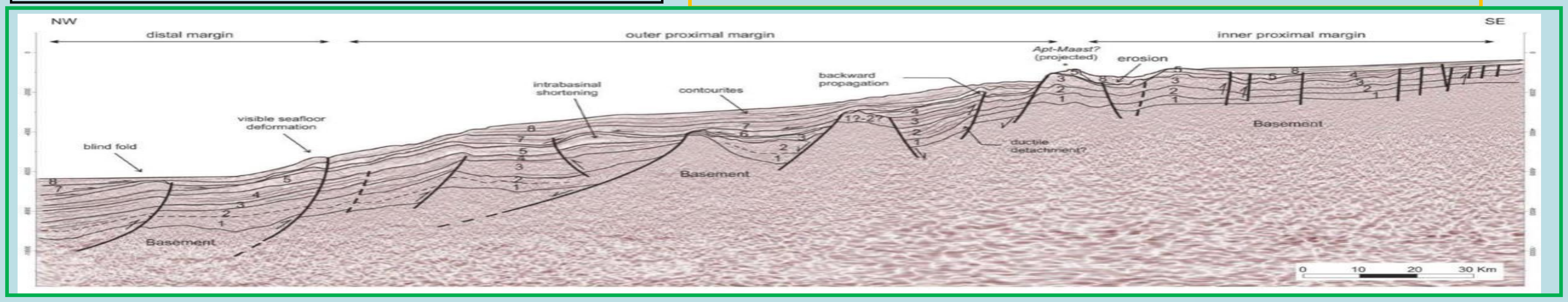

Unconformities
Campanian
Late Aptian
Callovian
Top salt
Lusitanian Basin
Peniche Basin
TWTT (s)
5 km
A
B
10 km
North Atlantic Ocean
PORTUGAL
Miocene
Paleogene
Upper Cretaceous
Lower Cretaceous
Upper Jurassic
Low. / Mid. Jurassic
Upper Triassic and Hettangian

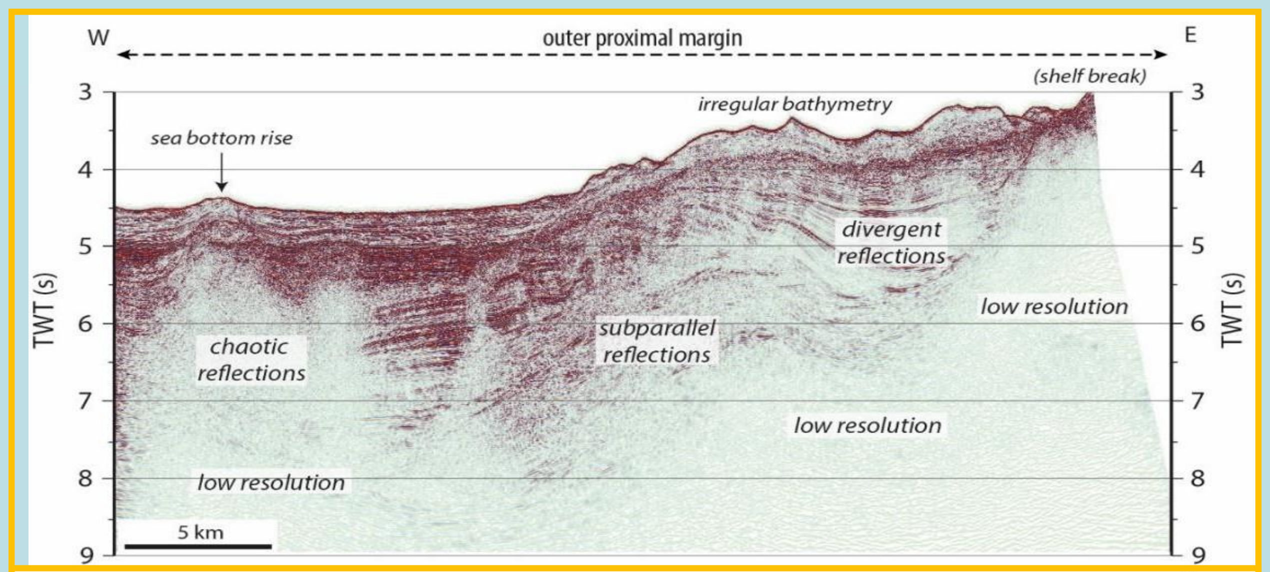

W
Peniche Basin
Structural High
Lusitanian Basin
LUSITANIAN BASIN
Top Cenozoic
Top Mesozoic
Top Basement
PD00-0142
A

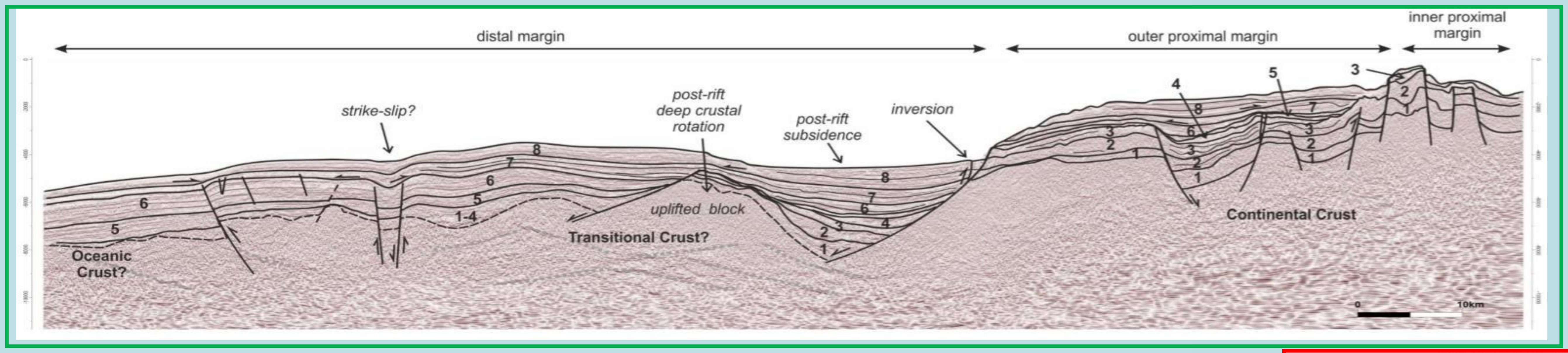

Galicia Basin
Porto Basin
Figure 2
Distal Peniche Basin
Peniche Basin
Bb
Lusitanian Basin
PORTUGAL
SPAIN
Pinhal Novo
Alentejo Basin
Algarve Basin
Gb
LEGEND
Central Iberian Zone
South Portuguese Zone
Ossa-Morena Zone

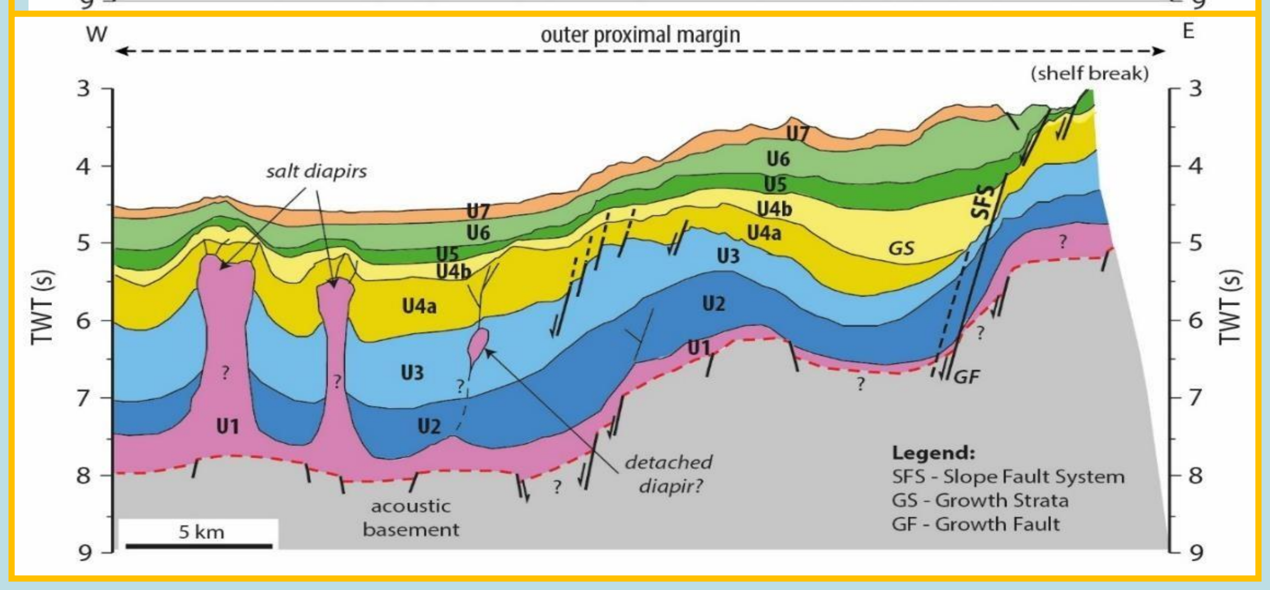

outer proximal margin
inner proximal margin
(shelf break)
Porto Seamount
parallel reflections
poor resolution in depth
diffractions and low resolution (Slope Fault System)
divergent reflections
chaotic reflections
poor resolution in depth
10 km
Legend:
SFS - Slope Fault System
GS - Growth Strata
GF - Growth Fault
salt diapirism
tilted blocks
slope deposits? channel bank?
inversion !
acoustic basement
U7: Tertiary
U6: K2 (Gândara, Carapau, Dourado Fm's)
U5: K2 (Cacém Fm)
U4b: K1 (Torres Vedras Fm - Post-Breakup)
U4a: K1 (Torres Vedras Fm - Pre-Breakup)
U3: J3 (Montejunto, Alcobaça, Linguado Fm's)
U2: J1/J2 (Esterção Fm)
U1: T3 (Silves Fm) & J1 (Dagorda Fm)

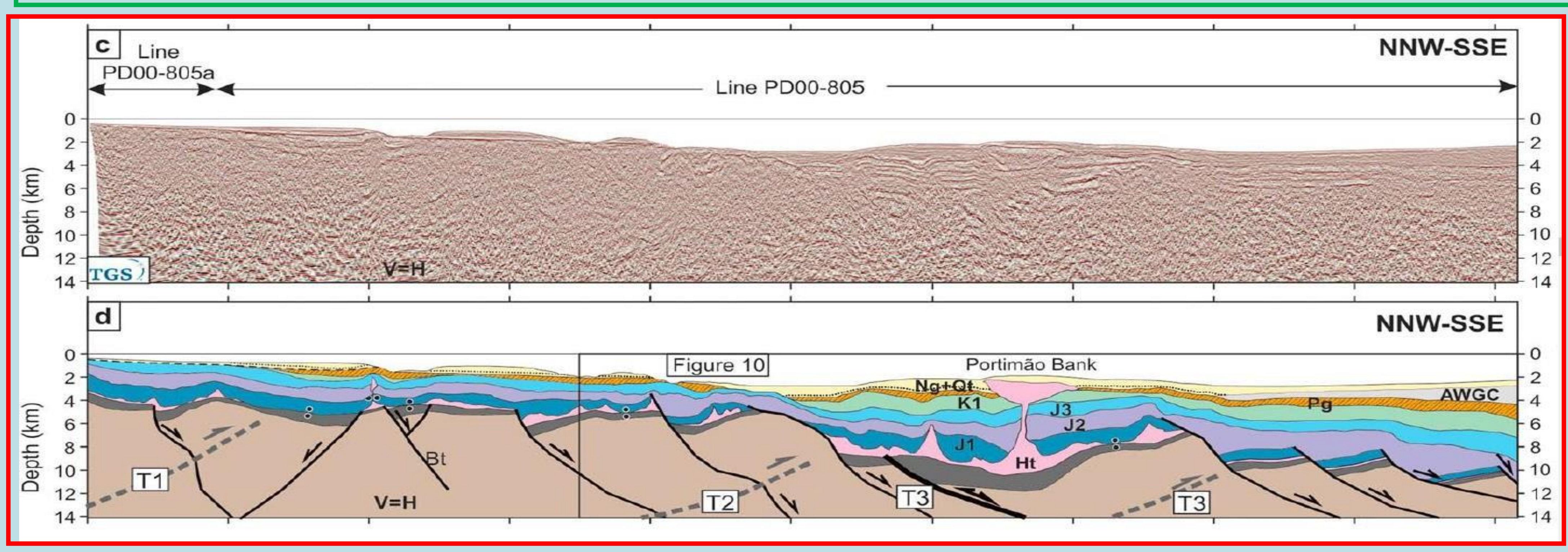

Distal Peniche Basin
Peniche Basin
12C
Seismic Horizons (Unconformities)
Campanian
Late Aptian
Callovian
Top salt
A
W
E
Distal Peniche Basin
Peniche Basin
PW4
B
N
S
5A
4A
12A
Peniche Basin
Peniche Basin
C

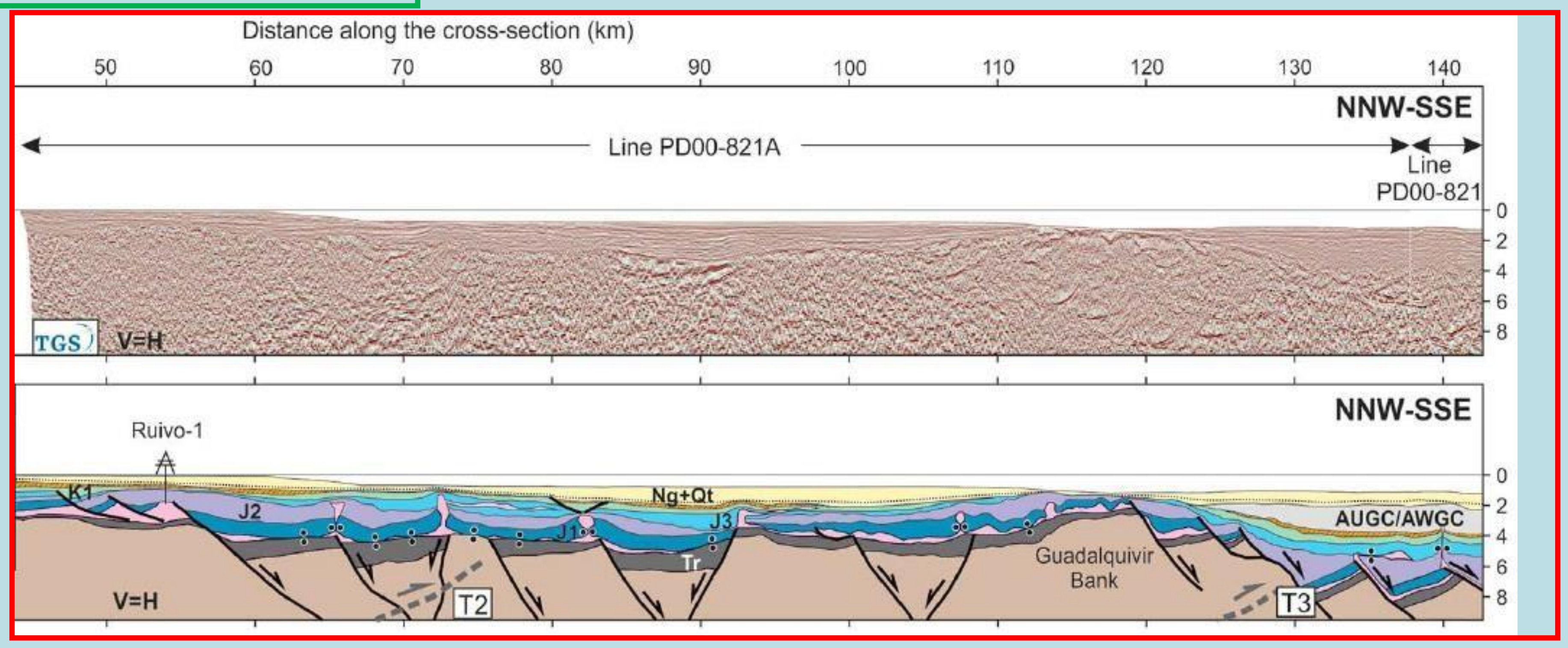

NW
SE
distal margin
outer proximal margin
inner proximal margin
Apt-Maast? (projected)
erosion
intrabasinal shortening
contourites
backward propagation
blind fold
visible seafloor deformation
Basement
Basement
Basement
ductile detachment?


W
outer proximal margin
E
(shelf break)
irregular bathymetry
sea bottom rise
divergent reflections
low resolution
chaotic reflections
subparallel reflections
low resolution
low resolution
TWT (s)
5 km


distal margin
outer proximal margin
inner proximal margin
strike-slip?
post-rift deep crustal rotation
post-rift subsidence
inversion
uplifted block
Oceanic Crust?
Transitional Crust?
Continental Crust
10km


W
outer proximal margin
E
(shelf break)
salt diapirs
U7
U6
U5
U4b
U4a
U3
U2
U1
GS
SFS
GF
detached diapir?
acoustic basement
TWT (s)
5 km
Legend:
SFS - Slope Fault System
GS - Growth Strata
GF - Growth Fault


c
Line PD00-805a
Line PD00-805
NNW-SSE
Depth (km)
TGS
V=H
d
NNW-SSE
Figure 10
Portimão Bank
Ng+Qt
K1
J3
J2
J1
Ht
Pg
AWGC
Bt
T1
T2
T3
T3
V=H


Distance along the cross-section (km)
NNW-SSE
Line PD00-821A
Line PD00-821
TGS
V=H
NNW-SSE
Ruivo-1
K1
J2
J1
Ng+Qt
J3
Tr
AUGC/AWGC
Guadalquivir Bank
T2
T3
V=H

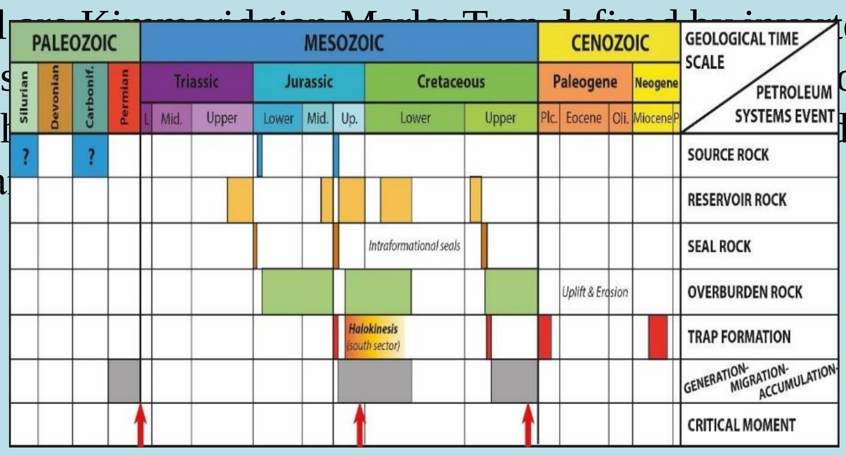
PETROLEUM SYSTEMS

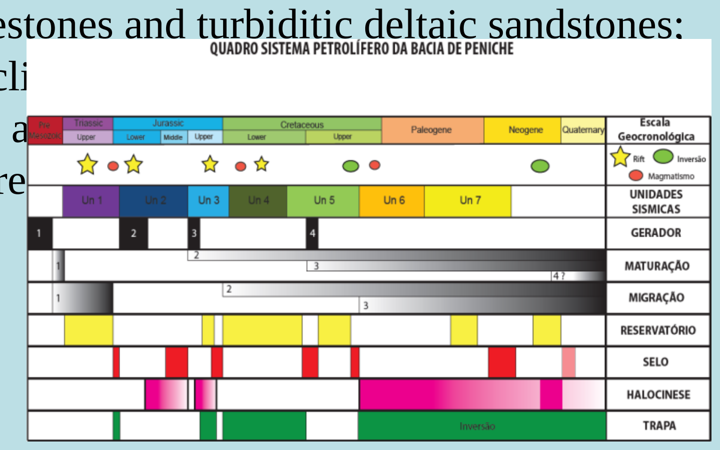
In the Portuguese basins petroleum source rocks and live migrated hydrocarbons are encountered in the pre-salt and in the post-salt sequences.

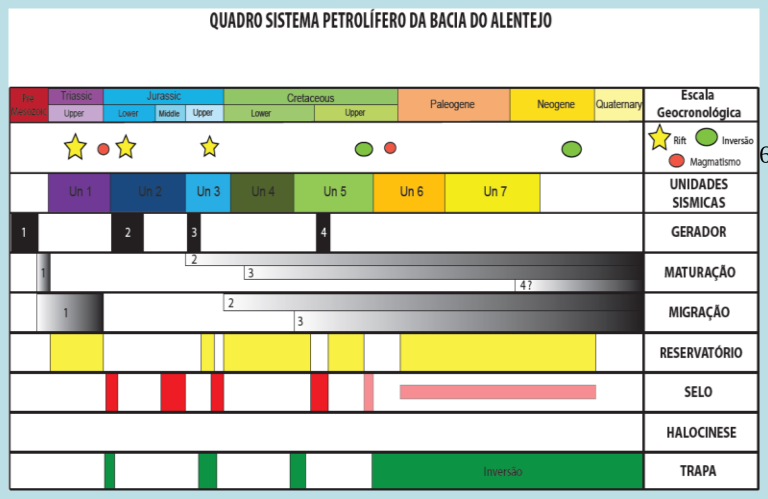
.a) Pre-salt: Source Rocks are Silurian and Carboniferous Shales; Reservoir Rocks are Late Triassic Alluvial Sandstones; Regional Seals are Hettangian Marls and Evaporites.

b) Lower Jurassic Petroleum System: Source Rocks are Pliensbachian marine marls; Reservoir Rocks are Cretaceous Alluvial Sandstones; Seal made by Maastrichian transitional clays; Trap delineated by salt architecture.

c) Upper Jurassic Petroleum System .Source Rocks are Middle Oxfordian lagoonal limestones; Reservoir Rocks are Oxfordian/Kimmeridgian fractured limestones and turbiditic deltaic sandstones: Seal are Kimmeridgian Marls; Trap defined by inverted anticli
Thes ... onshore a
offsh ... l shifts re
rega







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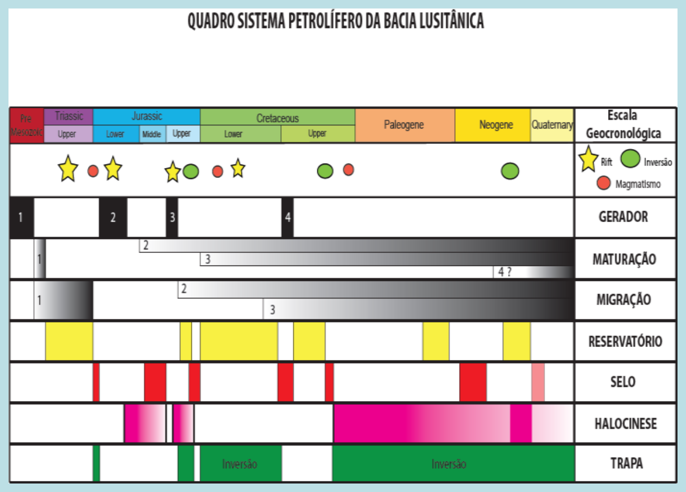

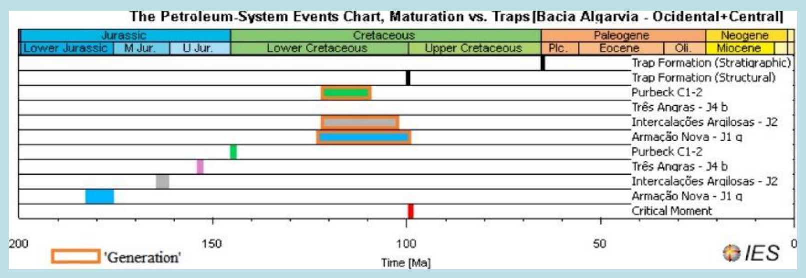

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Unpublished.

MARGIN’S OVERVIEW

Amongst the several un-explored basins that developed along the western Iberia margin, the most important are the Lusitanian Basin and the offshore Peniche Basin, geographically linked and parallel to each other and both being the focus of contemporaneous exploratory efforts. They are situated along the western Portuguese coast and their origin are related to the opening of the North Atlantic Ocean. These basins formed as a rifted, essentially non-volcanic, Atlantic continental margin type, trending dominantly on an N-S orientation. The basins are geographically near and roughly parallel to each-other, corresponding to the inner and outer marginal sectors. Sedimentary infill comprises siliciclastic, carbonate and hybrid sediments, with deposition and unconformities related to major tectonic events. Among these, the Late Triassic intra-continental rifting, the Early and Middle Jurassic sag basin development, the Callovian Unconformity, the following Late Jurassic rifting and intense subsidence, the Early Cretaceous siliciclastic progradation, the Late Aptian Break-up Unconformity and the Campanian early inversion Unconformity, may be identified with different signatures all over the margin’s basins. Tertiary deposits are significant in most of the offshore basins and tectonic inversion affecting these basins had Late Eocene and Late Miocene alpine climaxes.

In the western Iberian Portuguese Margin evaporites sequences are seen throughout the whole of Lusitanian Basin on outcrop exposures and concepts inferred from these deposits may be extended towards the overall view of basin architecture both onshore and offshore. Interpreting these offshore deep-water basins with modern data recently acquired for seismic exploration leads to an overall comprehensive view of the salt tectonics in the Peniche Basin and in the offshore continuation of the Lusitanian Basin. Towards south the Algarve´s Basin structural shaping is also strongly affected by active salt motions.

SALT TECTONICS

Evaporites accumulation in the Western Iberian Margin, took place since the Late Triassic (Norian?) until the Early Jurassic. Salt resulted from intra-continental playa lakes and mudflats with evaporites and clays, gradually passing into costal sabkhas with evaporites and dolomites. Original thickness of this salt-rich unit (Dagorda Formation) is believed to have reached hundreds of meters, eventually up to 1 km or more in some depocentric areas. Massive salt originated below the Jurassic originated salt diapirs rise through basement rooted fractures, crossing and deforming the whole Mesozoic sequence.

Salt tectonics may have started since the Early to Middle Jurassic, as salt irregular pillows accommodating differential subsidence. This incipient stage has been strongly incremented during the Late Jurassic, in relation with the rifting phase and intense extension, subsidence, infill and overburden. Salt pillows have been accentuated and significant salt motion begun. The role of late-hercynean basement faults, affecting the Mesozoic cover, has been crucial in defining the locus of the salt pillows. Salt withdrawal and vertical up-rise of the salt units. Vertical motion continued throughout the Cretaceous and in some diapirs piercing has been attained. The timing of this piercing is well constrained by onshore lithostratigraphic references and may be dated from the Maastrichtian. This indicates that piercing is mostly related with the beginning of tectonic inversion that continued throughout the Cenozoic.

The relationships between salt and hydrocarbon accumulations were recognized from the very beginning of oil and gas exploration. Basin’s architecture clearly reflects the influence of salt tectonics, including structural anticlinal traps and stratigraphic facies variations traps. Salt pillows may have acted as regional seals for underlying units, whereas diapirs’ walls have been important migration pathways, as observed in several oil-seeps.

CONCLUSIONS

Regional 2D and prospect focused 3D seismic surveys have been conducted recently in the offshore basins off Portugal. It would appear that the most prospective areas are the offshore extension of the Lusitanian Basin and beyond the limited ridge border the deepwater region of Peniche Basin, both basins with plays delineated by intense salt tectonics. Salt is also present in the offshore Porto Basin, but apparently with no major influence. In the Alentejo Basin deepwater, where salt does not prevail, plays are mainly related to Cretaceous reservoirs with alpine inversion and active exploration led to deepwater drilling scheduled for 2017. Further south the architecture of the Algarve Basin is also strongly affected by salt tectonics, including allochtonous tongues, with most attractive prospects in shallower water.

In the Portuguese onshore, best prospects are in the Lusitanian Basin, within the mini-basins corridors delimited by rail-road track salt diapirs.

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