CENTRAL & NORTH ATLANTIC

CONJUGATE MARGINS CONFERENCE
DUBLIN 2012

THIRD CONJUGATE MARGINS CONFERENCE 2012

"The Mesozoic Evolution of South-Western Portugal"

ALGARVE AND ALENTEJO BASINS, PORTUGAL - FIELD TRIP GUIDE

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(Field Trip Leaders)

The Mesozoic Evolution of South-Western Portugal

FIELD TRIP GUIDE

Financial support

FOREWORD

This volume corresponds to a field-trip guide for a 3-day visit to South-West Portugal, as part of the III Central & North Atlantic Conjugate Margins Conference (Dublin, 2012).

The field-trip starts in the Algarve Basin, a south facing Atlantic Basin, close to the Mediterranean and the former Tethys influence. In the western part of the basin, most of the Upper Triassic to Upper Jurassic sequence can be seen. We opted to look in detail at a restricted number of outcrops, representing the main facies and events of that time interval. Cretaceous deposits also occur and will be seen, although they are better exposed towards the East andare mostly covered by Tertiary deposits. The first day will take us through the Jurassic evolution of the basin and the second day through the Cretaceous and Tertiary evolution. The main elements and moments of the petroleum system will also be addressed, although the best potential of this basin lies in the offshore area to the South-East.

The second day will take us to the Alentejo Basin, facing the Atlantic to the west. The only outcrops are around Santiago village, where an uplifted block has brought up the base of the Mesozoic sequence. The Upper Triassic to Lower Jurassic sequence is well exposed, whereas the Middle and Upper Jurassic may be seen only in small windows below the Tertiary cover, between Santiago and the coastline.

The third day will be dedicated to the southern edge of the Lusitanian Basin, which extends for over 200 km to the North and for over 100 km offshore to the West. This edge of the basin corresponds to the Arrabida chain, showing intense alpine uplift related to the Tertiary inversion. Jurassic and Cretaceous facies will be seen, as well as the effects of the extensional and compressive regional tectonics.

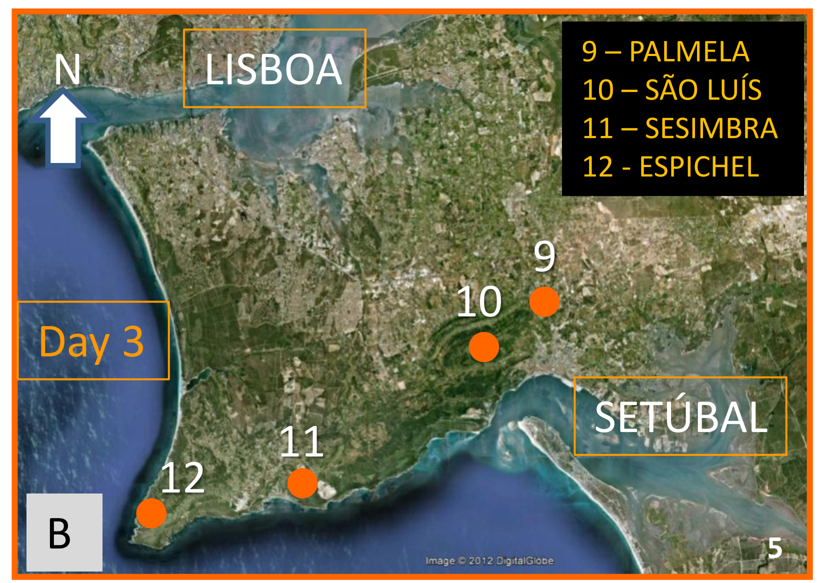
This field trip is intended to give an overview of the main geodynamic phases and sedimentary infill packages, leading to discussions about basin evolution and regional petroleum systems.

We hope you'll enjoy the geology, the landscapes, and especially the places and the moments to take with you in your memories!

Rui Pena dos Reis & Nuno Pimentel (Field-trip Leaders)

Contents

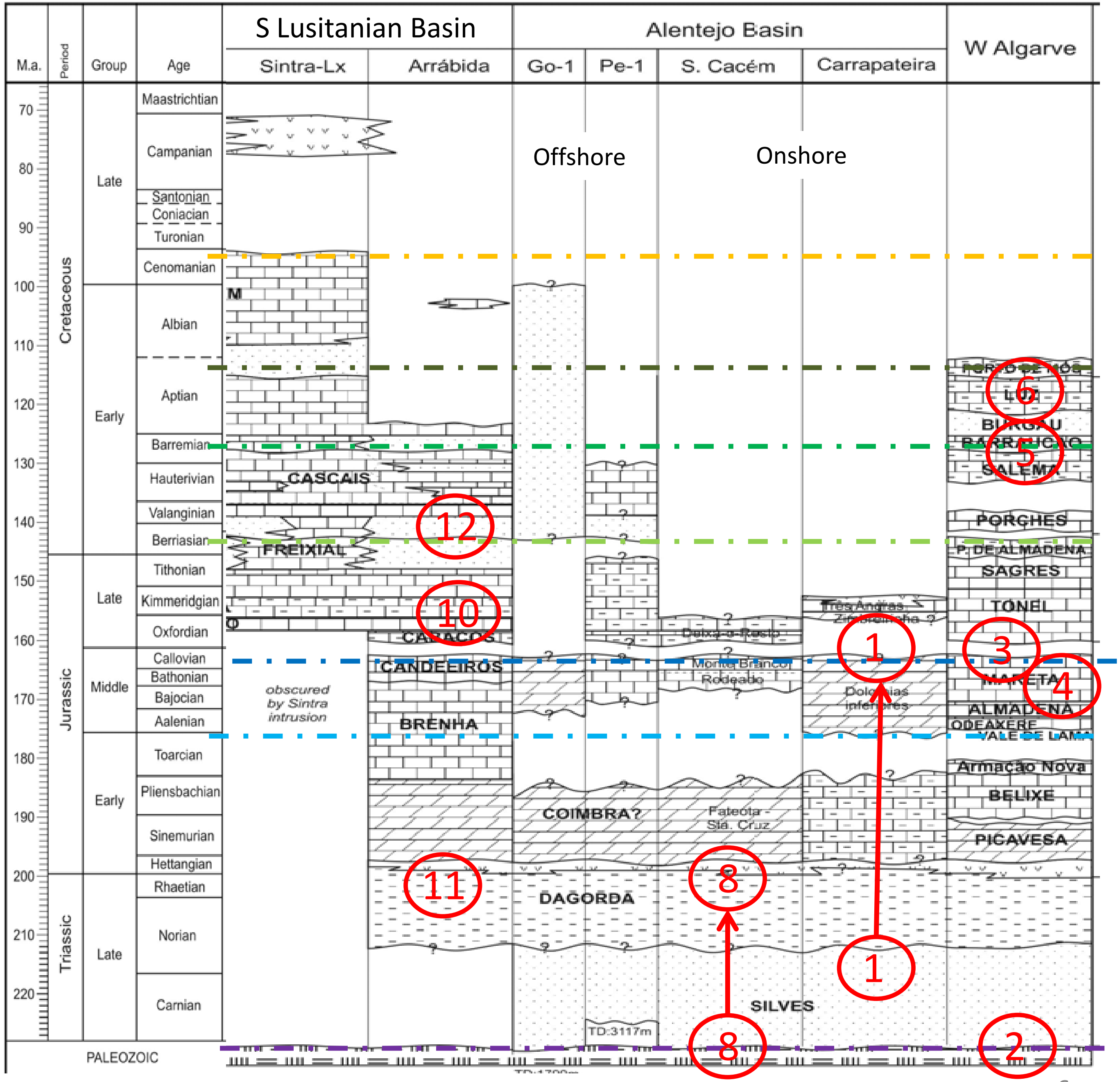
Itinerary & Stops



Correlation of the W Algarve, Alentejo and S Lusitanian Basins

The Western Algarve Basin presents a late Triassic to Early Cretaceous Mesozoic infill, which may be correlated with the infill of the onshore Alentejo Basin and the southern Lusitanian Basin.

The main depositional sequences and hiatus may be recognised in all these basins, with some regional unconformities

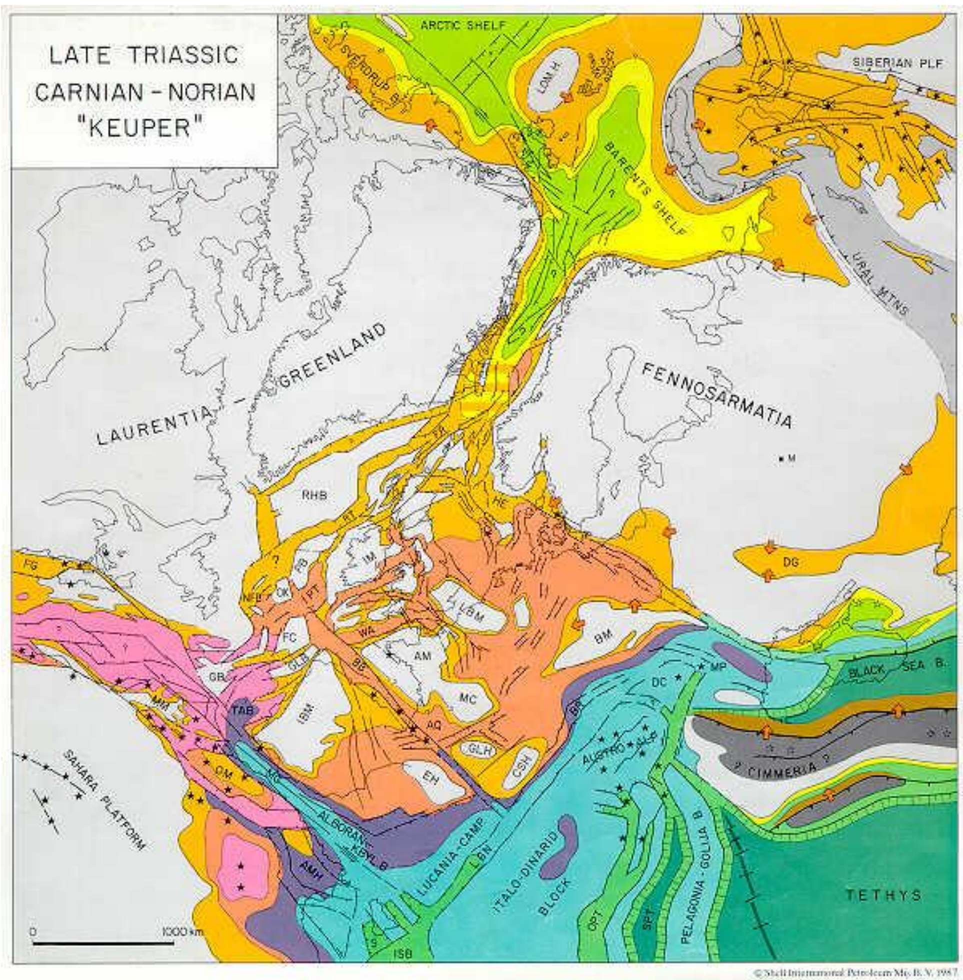


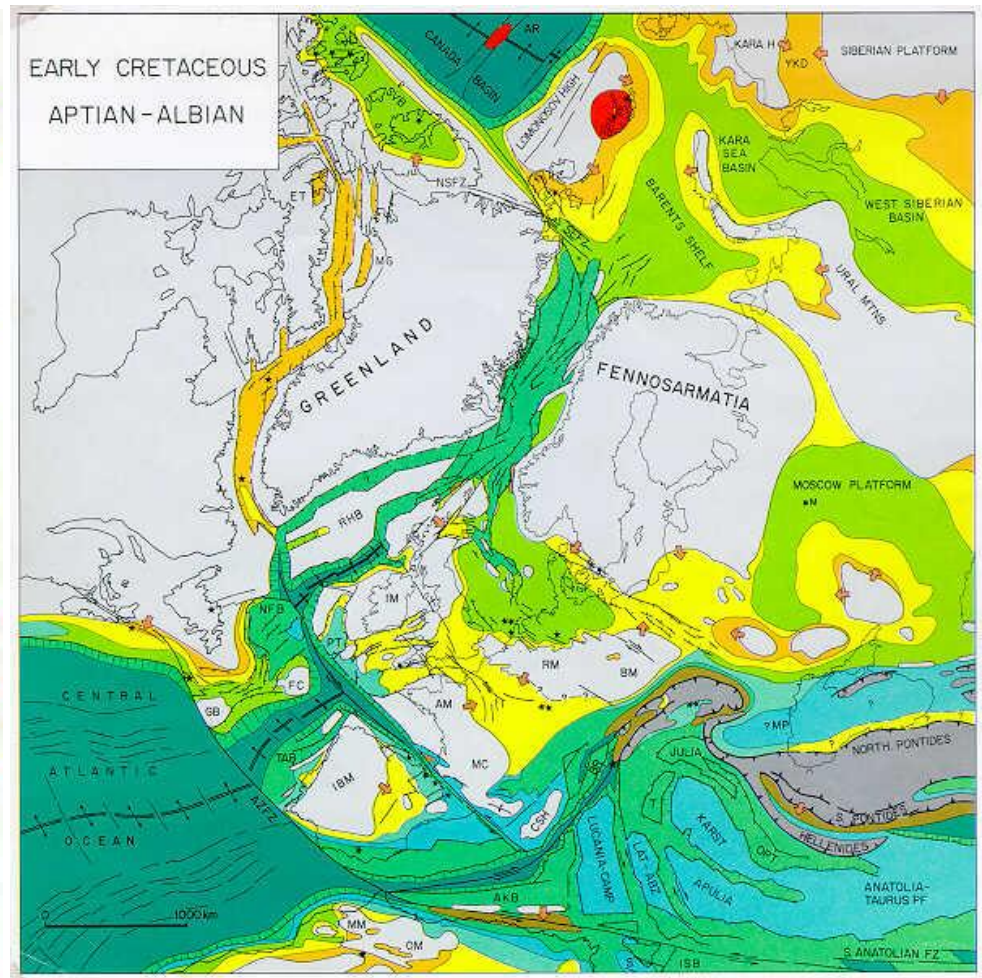
Stratigraphical position of the field trip stops 2

(adapted from Pereira & Alves, 2011)

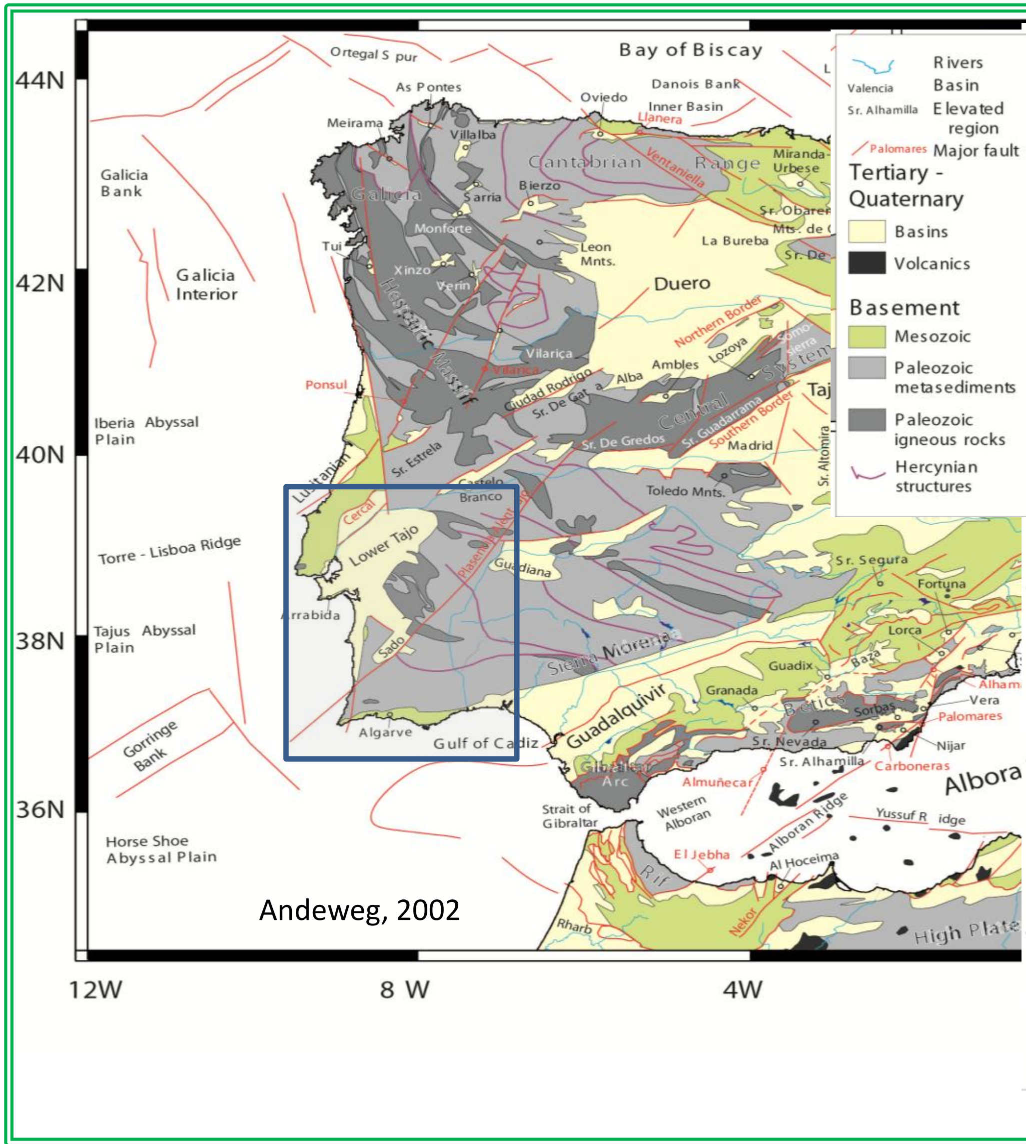
Palaeogeographic reconstruction of the Iberia microplate

The change from a Triassic/Jurassic Tethys realm to a Cretaceous Atlantic realm (Ziegler, 1999).

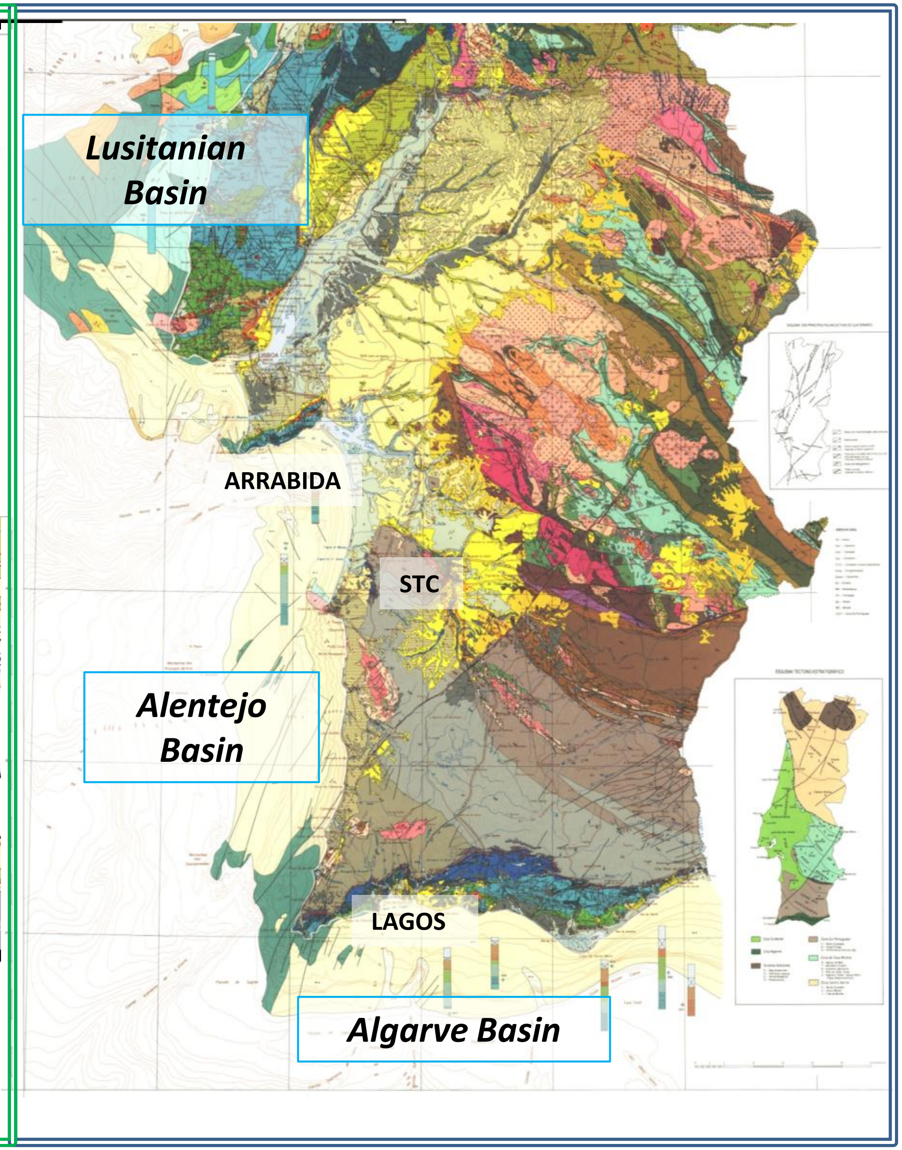




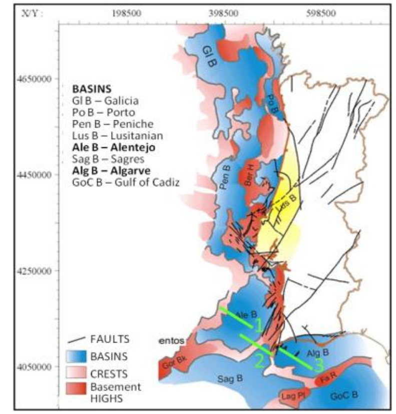
Regional framework of the SW Iberian basins



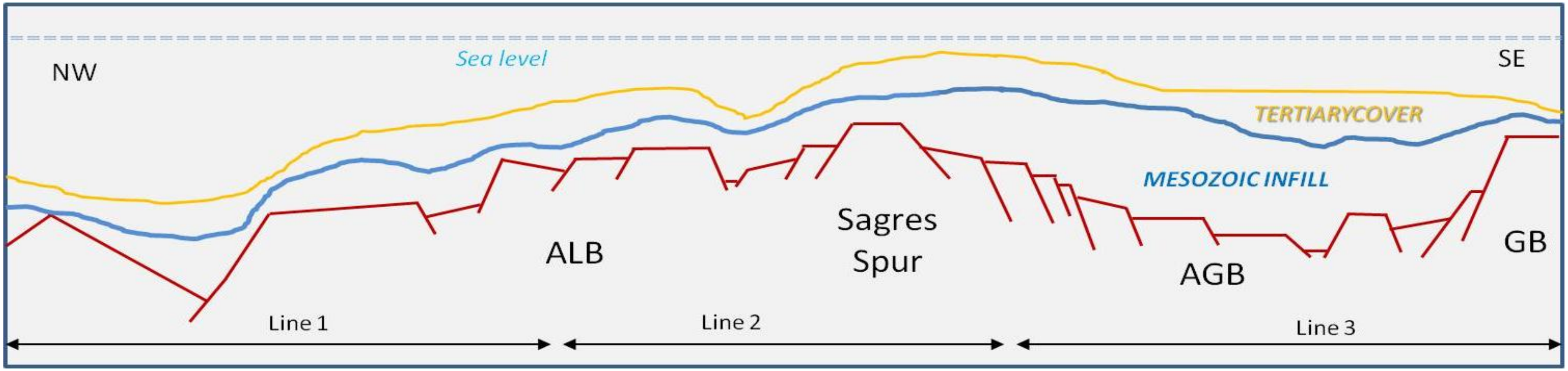
Andeweg, 2002

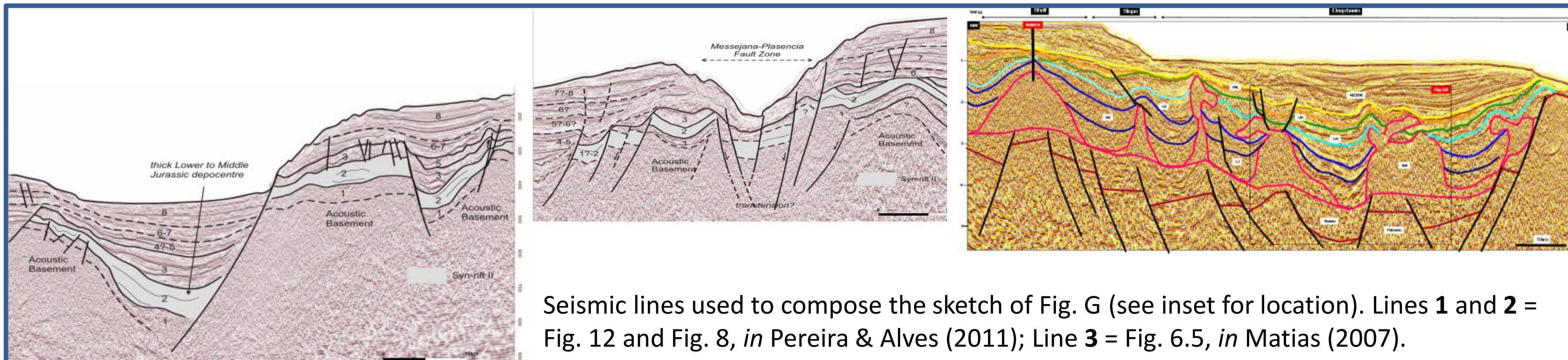


Offshore structure of the Algarve and Alentejo basins



Sketch of the basement structures and Meso-Cenozoic infill of the Alentejo Basin (ALB) and Algarve Basin (AGB), based on the composition of three interpreted seismic lines (see inset for location). ALB – Alentejo Basin; ABG – Algarve Basin; GB – Guadalquivir Bank. (Pimentel & Pena dos Reis, 2012).



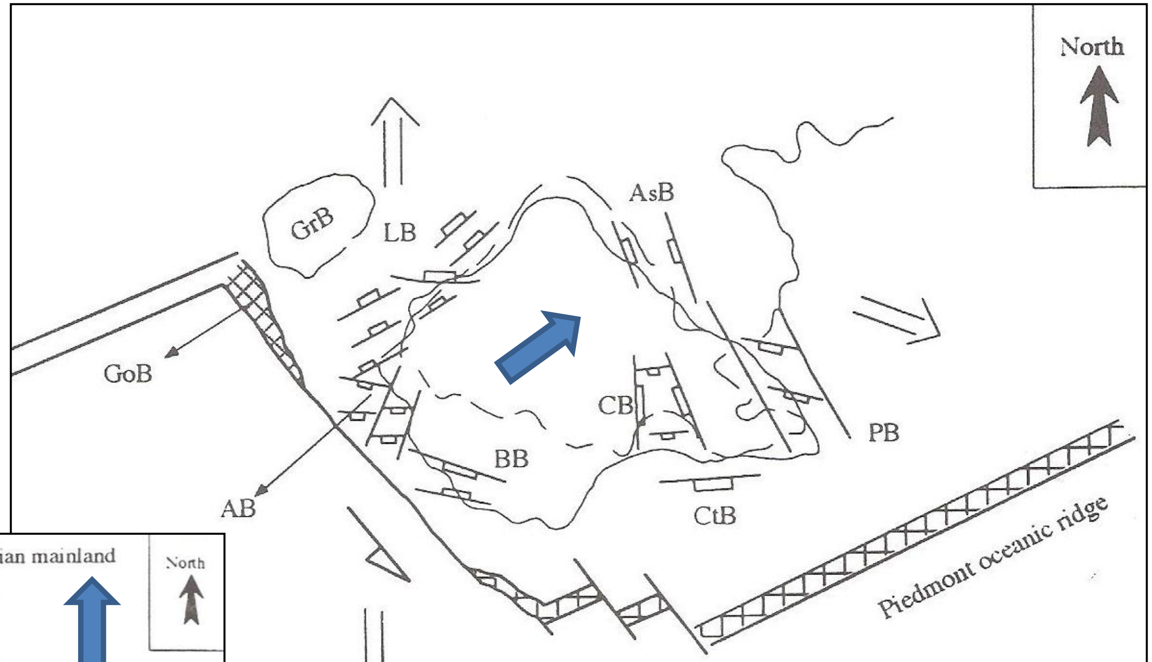


Seismic lines used to compose the sketch of Fig. G (see inset for location). Lines **1** and **2** = Fig. 12 and Fig. 8, *in* Pereira & Alves (2011); Line **3** = Fig. 6.5, *in* Matias (2007).

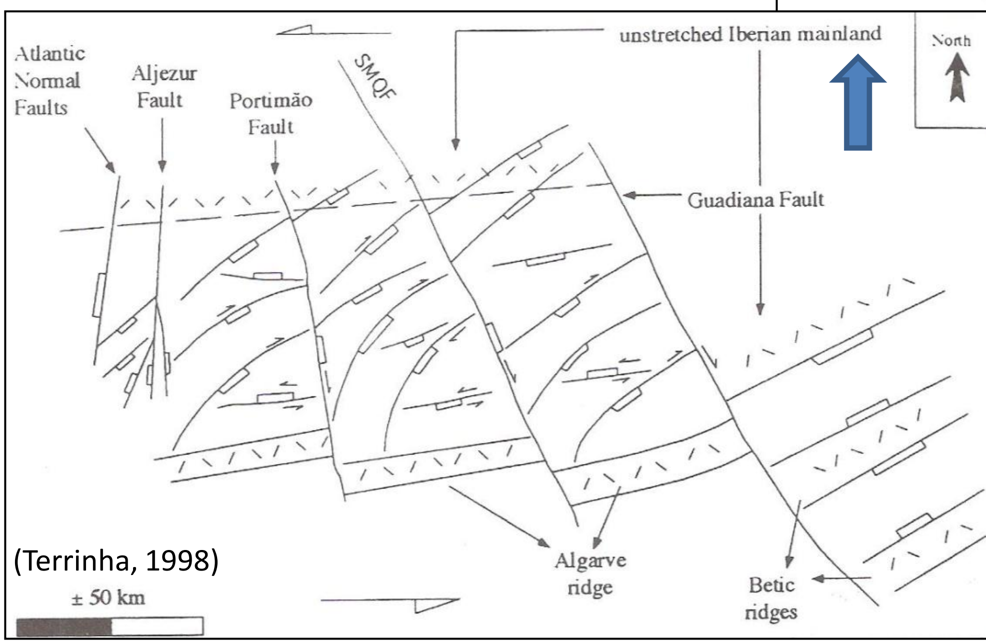
Geodynamic framework of the Algarve Basin

The Algarve Basin's Mesozoic evolution is controlled mainly by the extension related with its position between the western Tethys and the Central Atlantic opening, causing differential movement of Africa with respect to Eurasia.

This tectonic framework promoted a left lateral transtension shear-zone and the extensional re-activation of NE-SW late-Variscan faults.



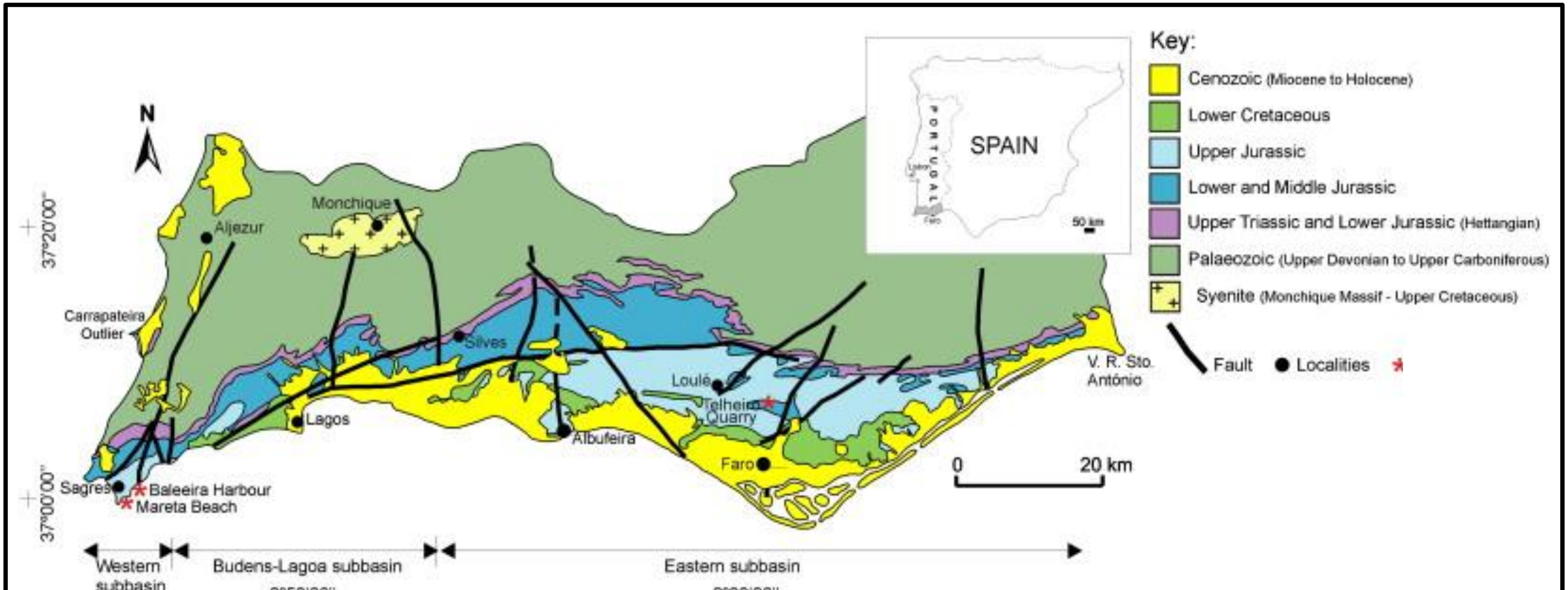
(Terrinha, 1998)



(Terrinha, 1998)

During Mesozoic extension, N-S to NW-SE faults acted as right lateral transfer faults, separating elongated tectonic blocks. These two directions, NE-SW dip-slip faults and NNW-SSE transfer faults, may also be recognised in the palaeogeographic evolution of the Algarve Basin during the Jurassic and Cretaceous.

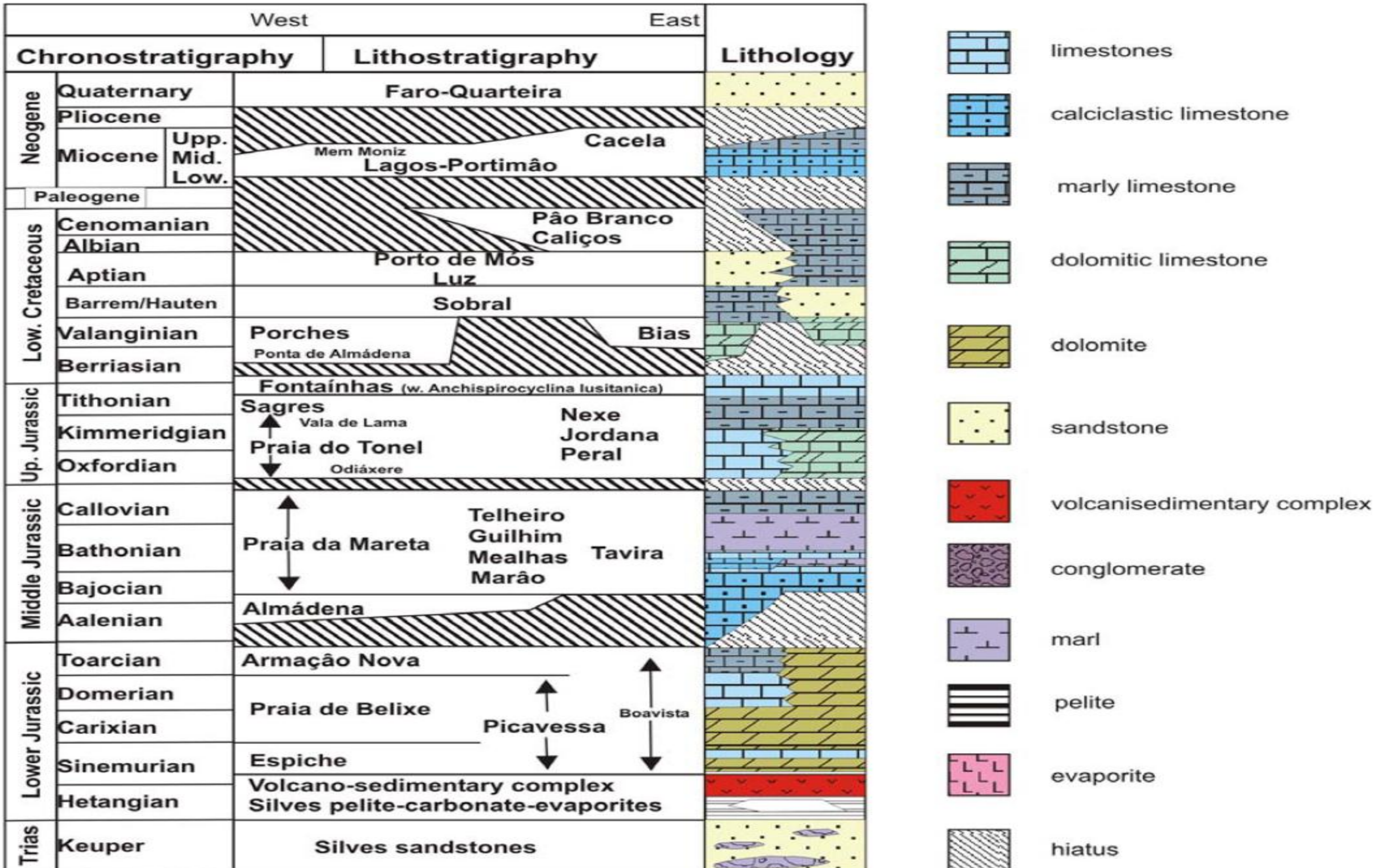
Simplified geological map of the Algarve region, southern Portugal



(Borges et al., 2012)

The Algarve presents a broad monoclynal structure dipping to the south.
At the northern margin, Upper Triassic units overlie Palaeozoic basement, followed by Lower to Middle Jurassic and Upper Jurassic units, outcropping mostly in the western and central parts of the Basin. Cretaceous units outcrop mainly in the central part of the basin. A Cenozoic basin covers the southern margin of the Algarve Basin.

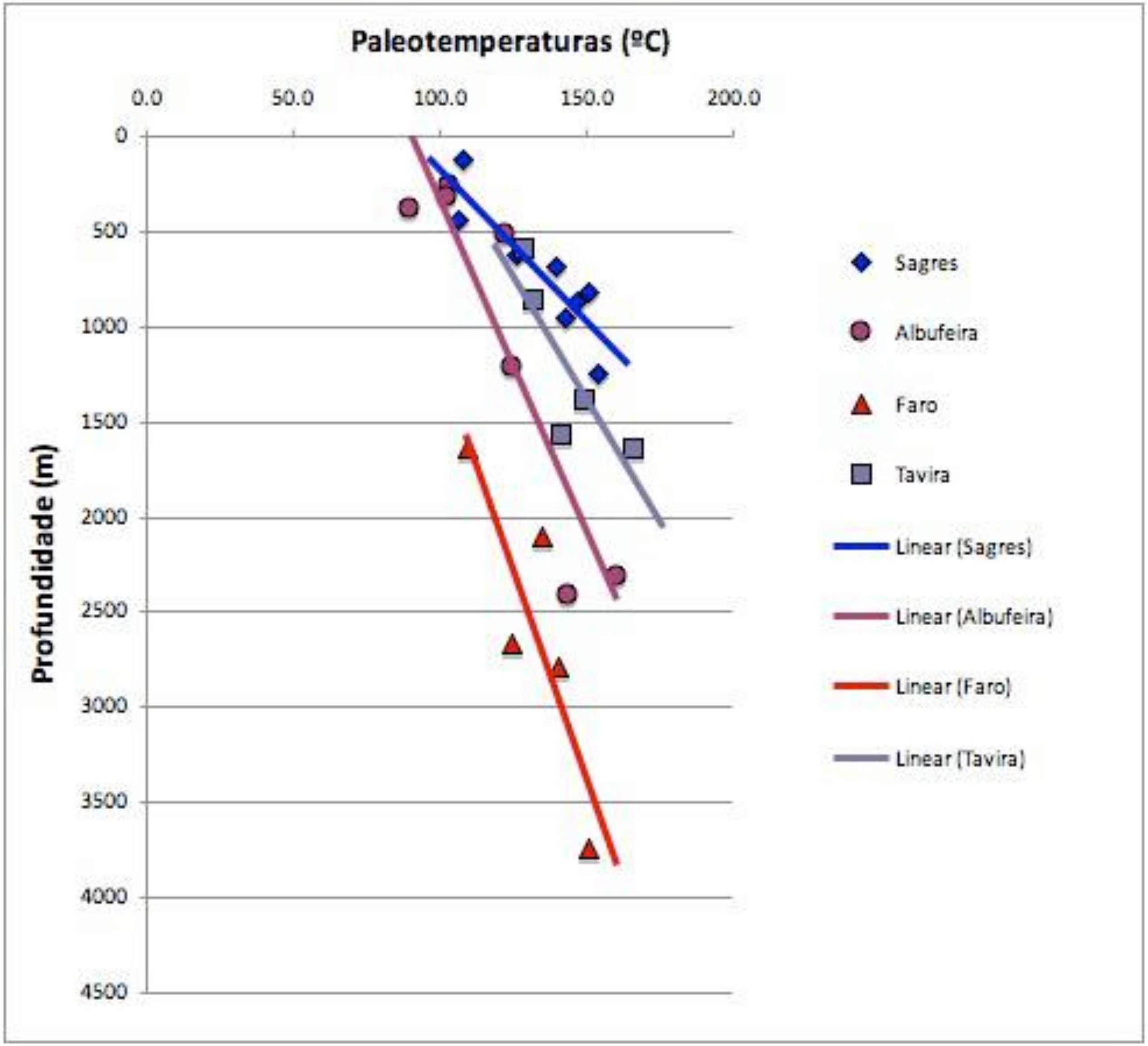
Lithostratigraphy of the Algarve Basin (Terrinha, 1998)



Palaeotemperatures in the Algarve Basin

The palaeotemperature studies in the Algarve Basin (Fernandes et al., 2012) point to a higher geothermal gradient in the Western Algarve (c. 60ºC).
In the Sagres area, palæotemperatures around 90ºC at present-day surface, point to uplift and erosion of more than 1 km of sediments.

These facts underline the importance of local and regional tectono-thermal evolution to understand the maturation of potential source rocks in this basin .

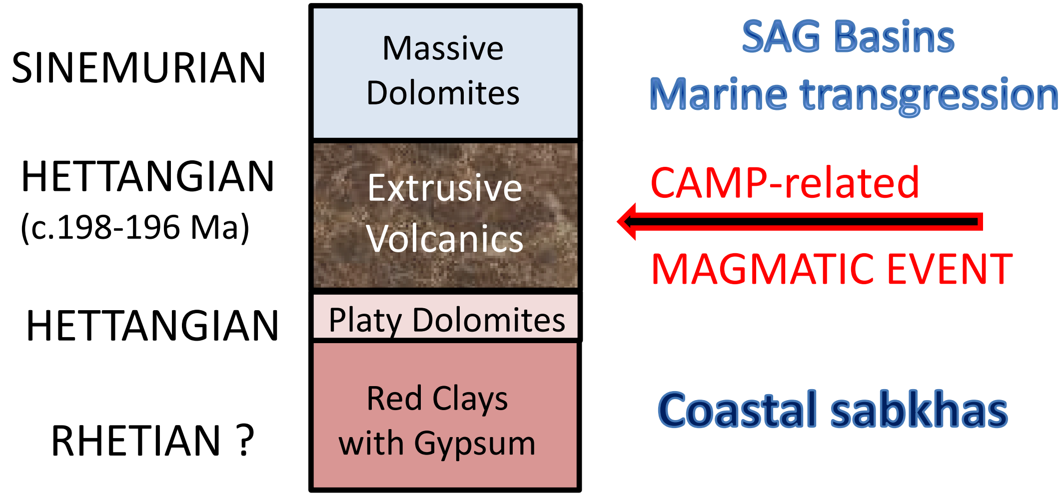


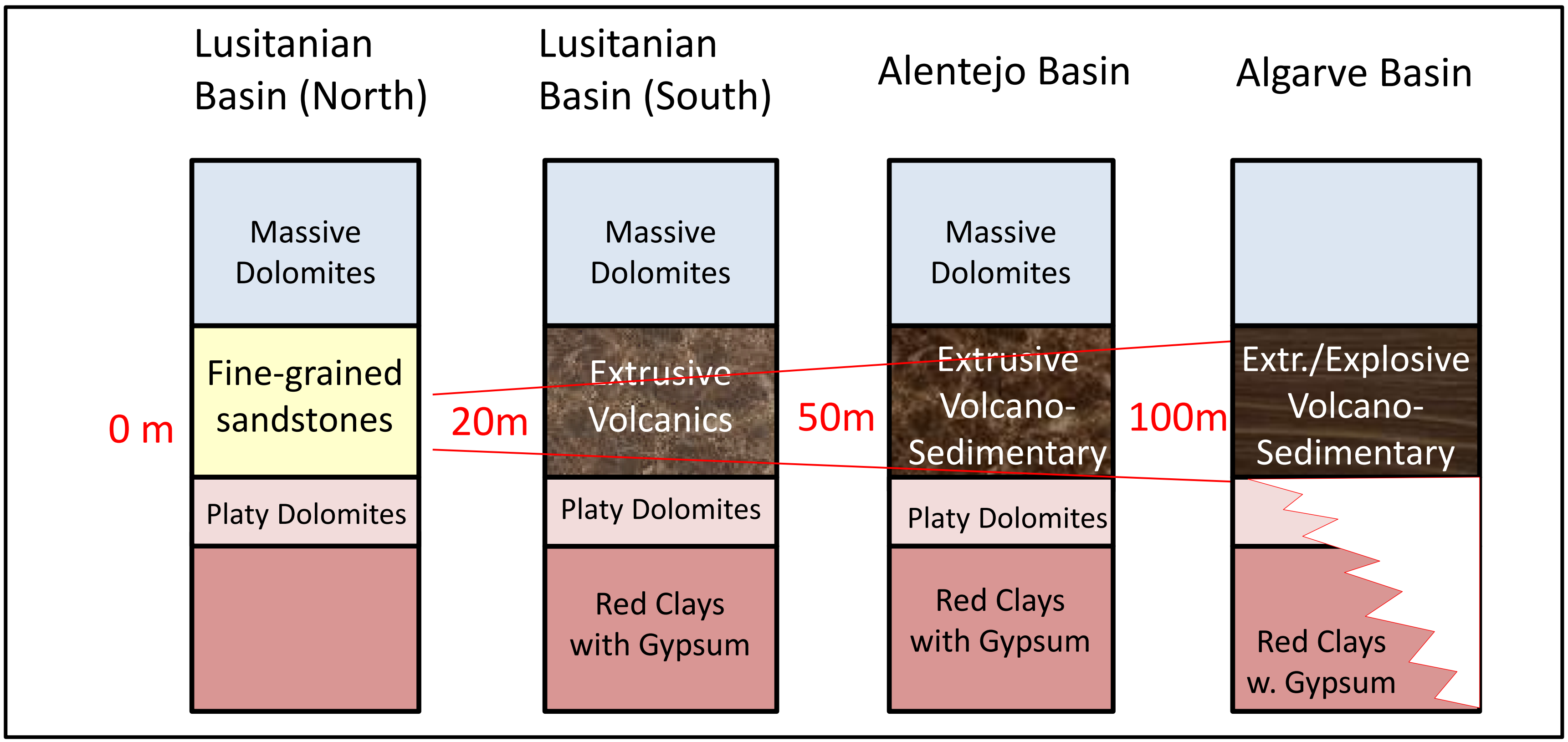
Palaeotemperature vs. dept profiles for the Western Algarve (Sagres), Central Algarve (Albufeira) and eastern Algarve (Faro and Tavira). Palaeotemperature values have been calculated from %Ro data, according to the empirical equation of Barker (1988). *In* Fernandes *et al.*, 2012 acessed at http://www.associacaodpga.org/vi_alen_alg_moura.html

The CAMP record in West Iberian Basins

(Pena dos Reis & Pimentel, 2011)

The onshore geological record of Late Triassic to Early Jurassic on the West Iberian Margin may be studied in three different basins: the Lusitanian Basin (to the North), the Alentejo Basin (to the SW) and the Algarve Basin (to the South). The CAMP event, largely recorded in Morocco and Western Canada, is also present in these basins.





Atlantic NW Morocco – Agadir-Essaouira Basin

Davison et al., 2010

REGIONAL EVOLUTION

(Hafid et al., 2010)

Tertiary infill and intense compressional folding

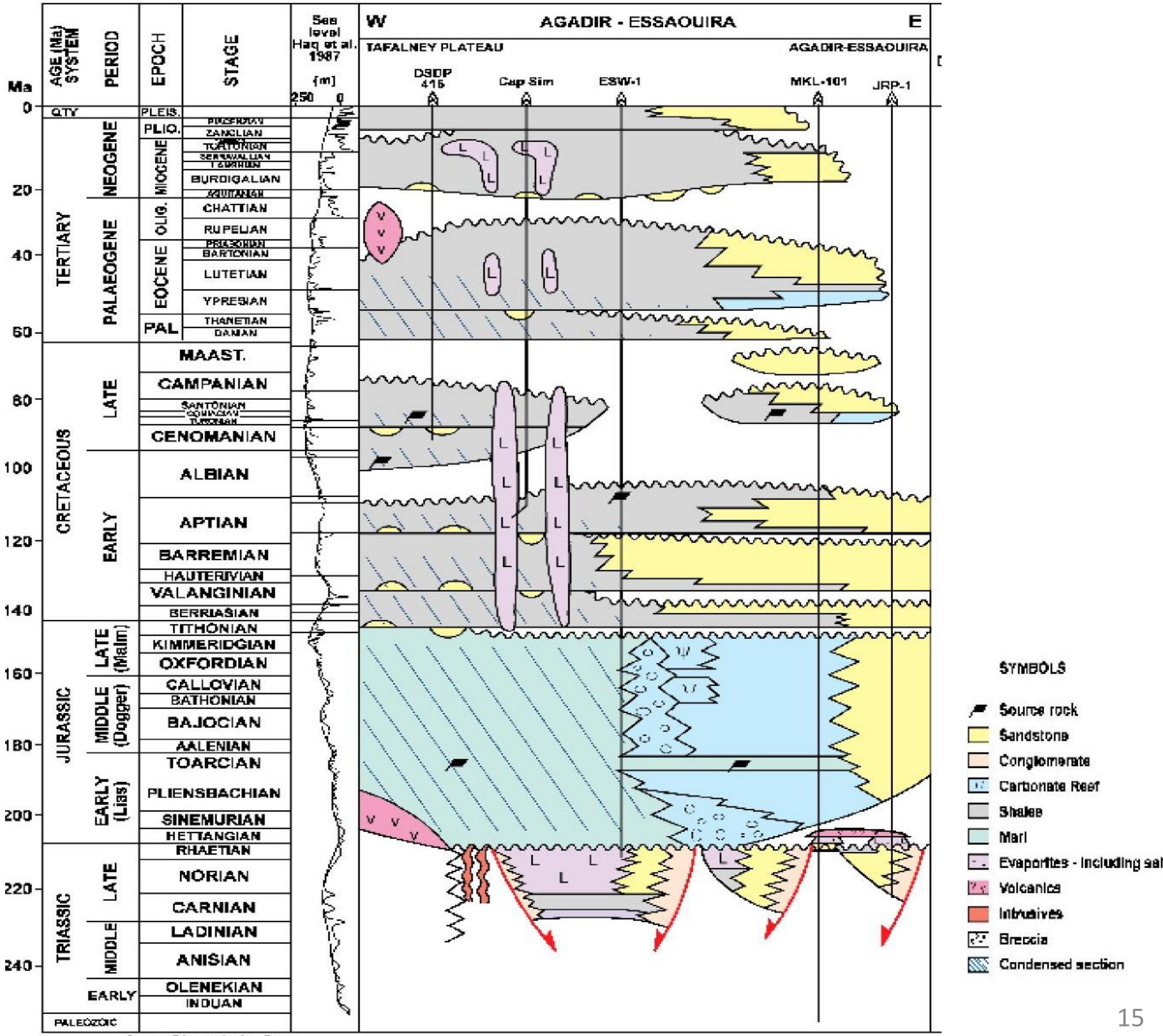
Eur-Africa collision and basin's mild inversion

Transgression; Marine platform development; Berriasian-Barremian regression.

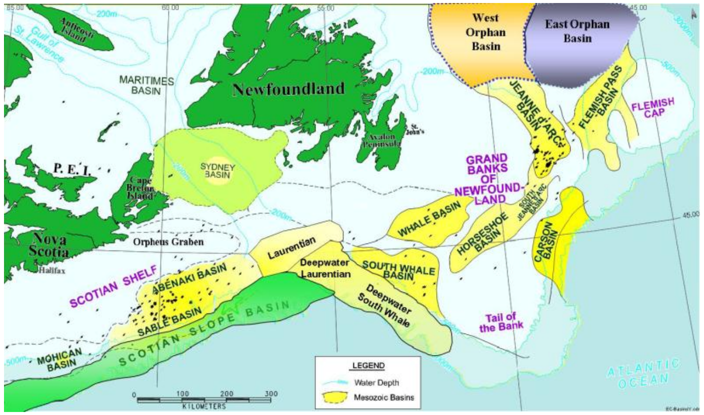
D R I F T

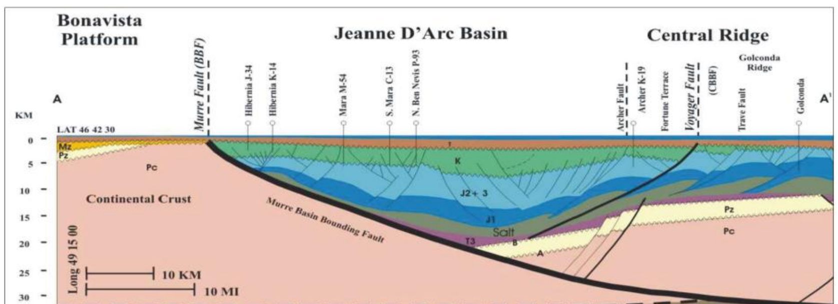
Central Atlantic spreading, and thermal subsidence

Central Atlantic Rifting

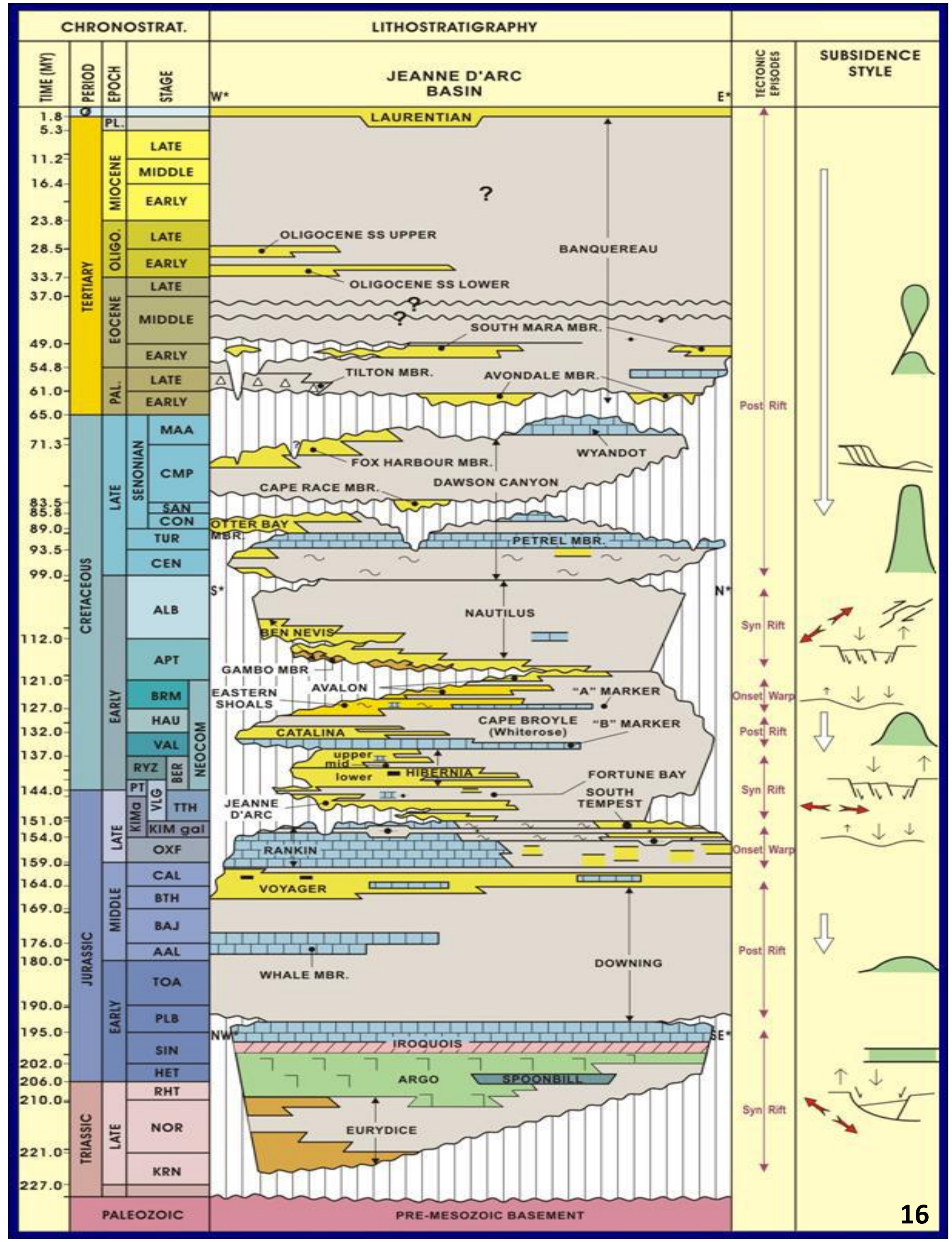


Jeanne d'Arc Basin
- Stratigraphic Chart





after Enachescu, 1987 & 1994



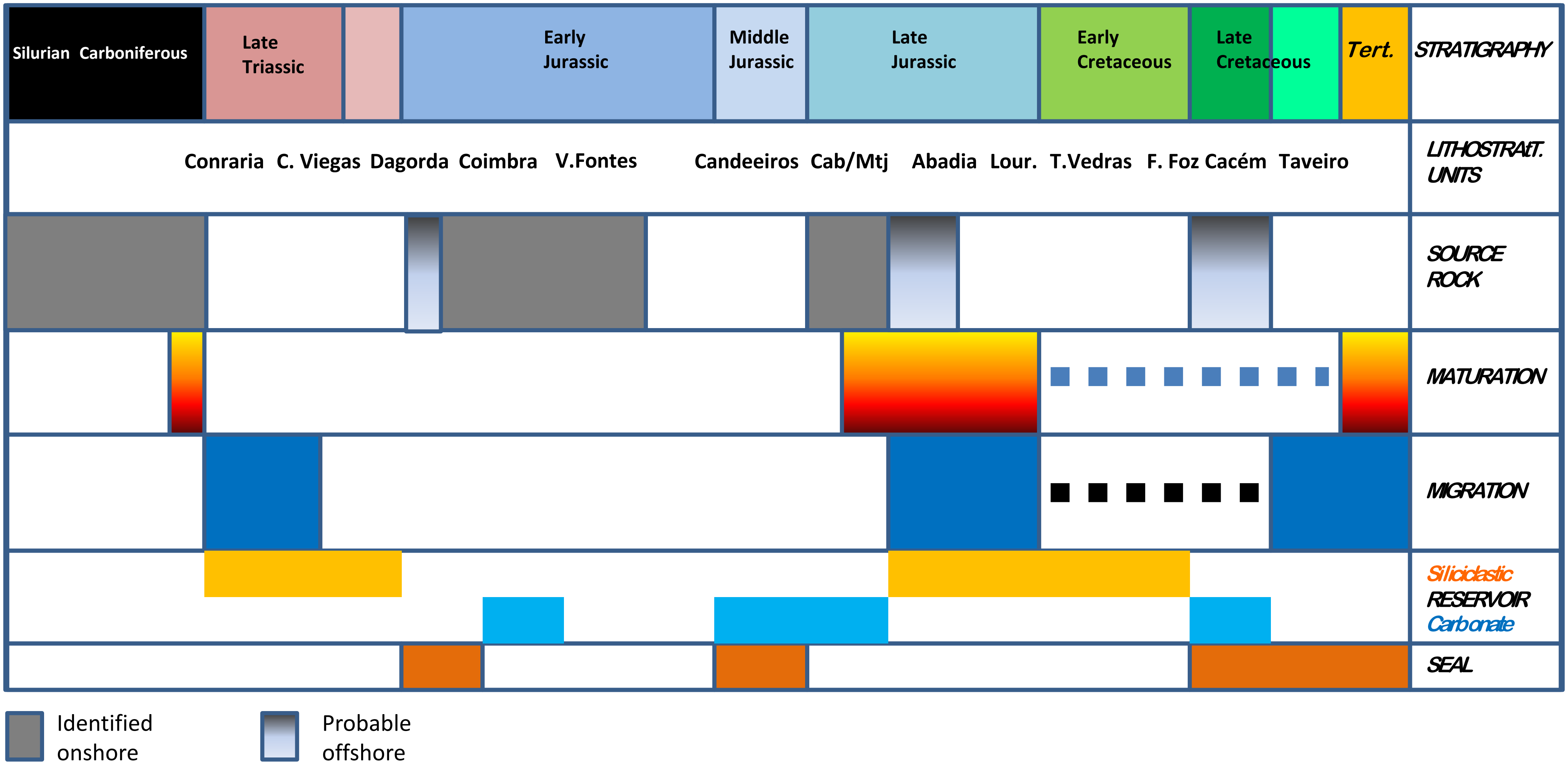
Michael E. Enachescu, *Euxinic Exploration*

Petroleum Exploration Opportunities in Jeanne d'Arc Basin, *Call for Bids NL 09 -1.* On Behalf of NL DNR, October 2009

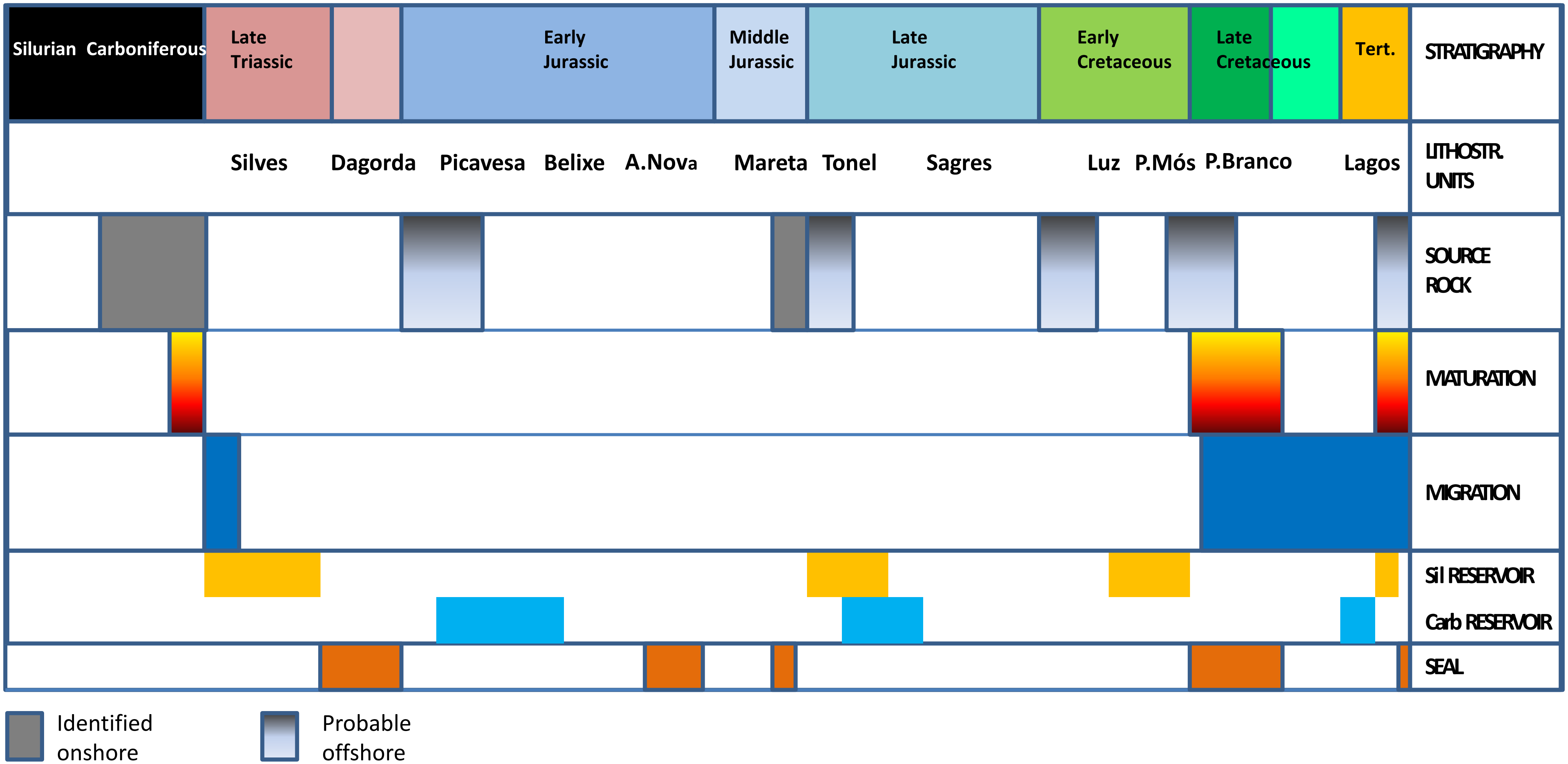
http://www.nr.gov.nl.ca/nr/invest/jeanne_d_arc_presentation.pdf

accessed 26/07/12

THE LUSITANIAN BASIN
simplified petroleum systems



THE ALGARVE BASIN simplified petroleum systems



DAILY CHRONOGRAM

DAY 1

Lagos Hotel – dep. 8.30 am
Lagos-Carrapateira = 35 km = 35 min.

STOP 1 (9.30h - 12.30h) – CARRAPATEIRA
1A - Bordeira beach
1B , 1C - Pontal
1D - Três Angras
1E – Amado beach

LUNCH (12.30h - 13.30h)

Carrapateira-Telheiro = 30 km = 30 min.

STOP 2 (14.00h – 15.30h) – TELHEIRO

Telheiro–S.Vicente Cape = 10 km = 15 min
(+ 30 min. landscape stop)

STOP 3 (16.30h - 17.30h) – TONEL

STOP 4 (17.30h - 18.30h) – MARETA

Mareta – Lagos = 35 km = 35 min.

Lagos Hotel – 19.30h
Dinner – 20.30h

DAY 2

Lagos Hotel – dep. 8.30 am
Lagos-Zavial = 25 km = 30 min.

STOP 5 (9.30 – 10.30) – ZAVIAL

Zavial – Luz = 15 km = 30 min
(+30 min. landscape stop)

STOP 6 – LUZ BEACH (11.30 - 12.30)

LUNCH (12.30 - 13.30)

Luz – Lagos = 10 km = 15 min.

STOP 7 (14.00 – 15.00) – PIEDADE

Lagos – Santiago do Cacém = 200 km
= 2h15min (mostly highway)

STOP 8 (17.30 - 19.00) – SANTIAGO

Santiago Hotel – 19.30h
Dinner – 20.30h

DAY 3

Santiago Hotel – dep. 8.30 am
Santiago – Palmela = 110 km = 1h15min.

STOP 9 (10.00h – 10.45h) – PALMELA

Palmela – São Luís = 10km = 15 min.

STOP 10 – SÃO LUÍS (11.00 – 11.30)

São Luís – Setúbal – Arrábida = 30 km
= 30 min (+30 min landscape stops)

LUNCH (12.30 - 13.30)

Arrábida – Sesimbra = 20 km = 25 min

STOP 11 (14.00 – 15.30) – SESIMBRA

Sesimbra – Espichel = 20 km = 25 min

STOP 12 (16.00 - 17.30) – ESPICHEL

Espichel – Lisboa = 60 km = 1h
Lisbon Hotel area – 19.00h

STOP'S OVERVIEW

	1 CRP	2 TEL	3 TON	4 MAR	5 ZAV	6 LUZ	7 PD	8 SC	9 PAL	10 SL	11 SES	12 ESP
Tertiary/ U. CRET.	-	Up-lifted littoral platform	-	-	Miocene Fossiliferous marls	-	Miocene Fossiliferous marls	-	Miocene Fossiliferous marls (cuesta)	-	-	Up-lifted littoral platform
Lower CRET.	-	-	-	-	Coastal Dolomitic silts and marls	Coastal sands and transitional marls	-	-	Eroded fluvial sands	-	-	Fluvial sands and transitional marls
Upper JURASSIC	Marly Limestones (SR)	-	Marly Limestones	Marly Limestones (SR)	-	-	-	-	Limestones	Orogenic intraform. Conglomer.	-	Shallow marine marls
M. JUR.	Marine Marls		Marine Marls	Marine marls	-	-	-	-	-	-	-	-
Lower JURASSIC	Dolomites	Dolomites	-	-	-	-	-	Volcanics and Dolomites	-	-	Volcanics and Dolomites	-
Upper TRIASSIC	Aeolian and sabkha Red-beds	Aeolian and sabkha Red-beds	-	-	-	-	-	Alluvial Red-beds	-	-	Sabkha Evaporitic clays	-
Etc.	Border outcrop of the Alentejo Basin	Erosional Unconform. on Carbonif. shales	U. Jurassic unconform. sealing M.J. faulting	Exposed Reef	Miocene Erosional Unconform.	Igneous intrusion	Coastal Karstic landscape	CAMP volcanics (Alentejo Basin)	Alpine deformation Duplex structure	U. Jurassic up-lift of basement	Diapiric and CAMP volcanics (Lusitanian)	Alpine up-lift

STOP 1
CARRAPATEIRA

Along the Carrapateira promontory a Late Triassic to Late Jurassic sequence can be seen.

Late Triassic redbeds comprise fluvio-aeolian sands with trough cross-bedding. The Hettangian comprises alternating red clays and marly reduced dolomites, deposited in a sabkha-like environment.

Early and Middle Jurassic carbonates are mainly shallow-water deposits with intense dolomitisation.

Upper Jurassic deposits are the result of renewed orogenic instability and subsidence, with signs of uplift, emersion, karsification and erosion. Some restricted lagoonal facies contain significant organic matter.

Magmatic intrusions may be observed, mainly related to the Late Jurassic doleritic Alentejo-dyke.

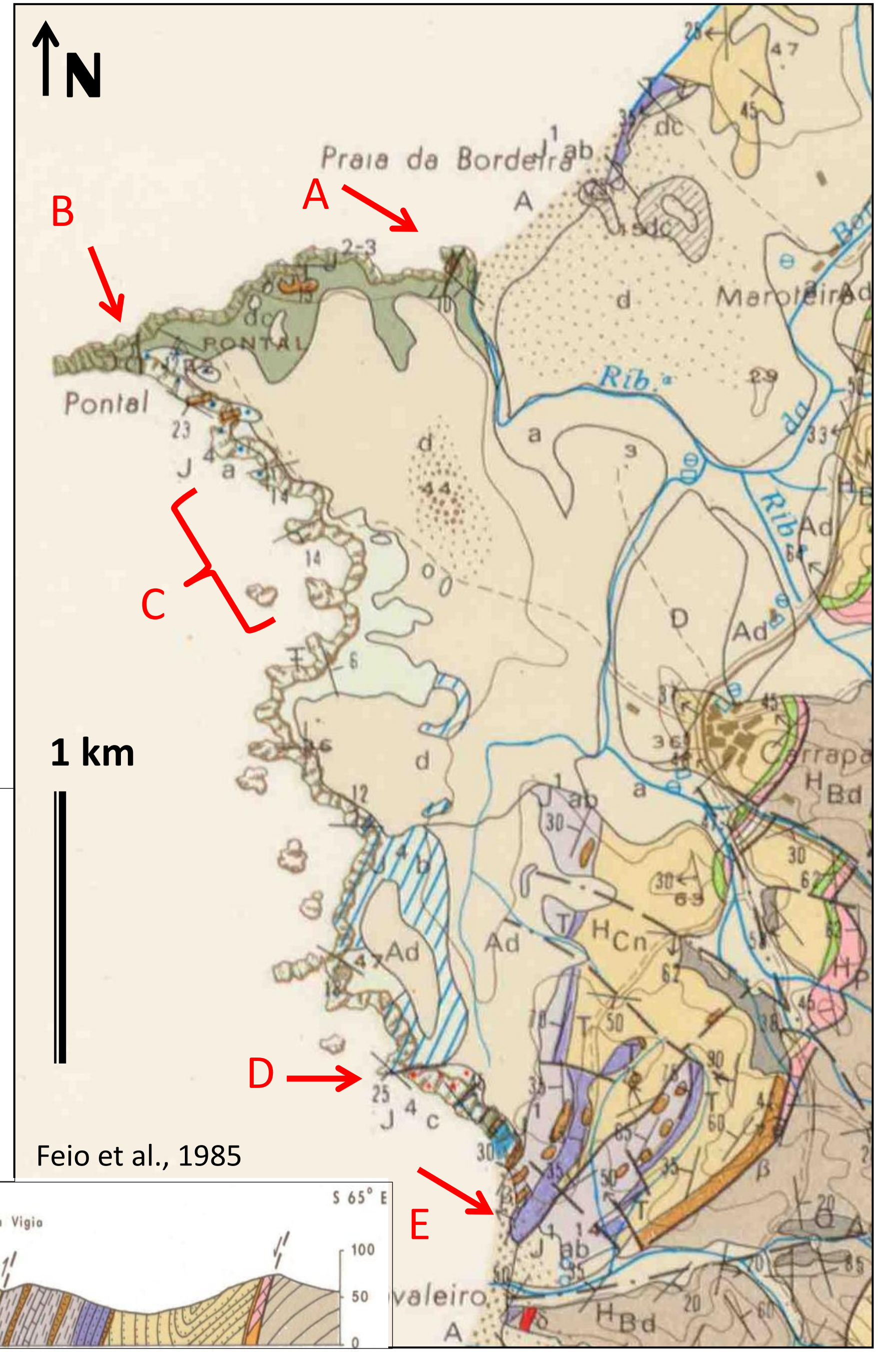
UPPER JURASSIC
- Volcanic tuffs and breccias — D
- Marly limestones (*dolom) — C
- Limestones and Dolomites — B

MIDDLE JURASSIC Dolomites — A

L. JURASSIC Marls & dolomites

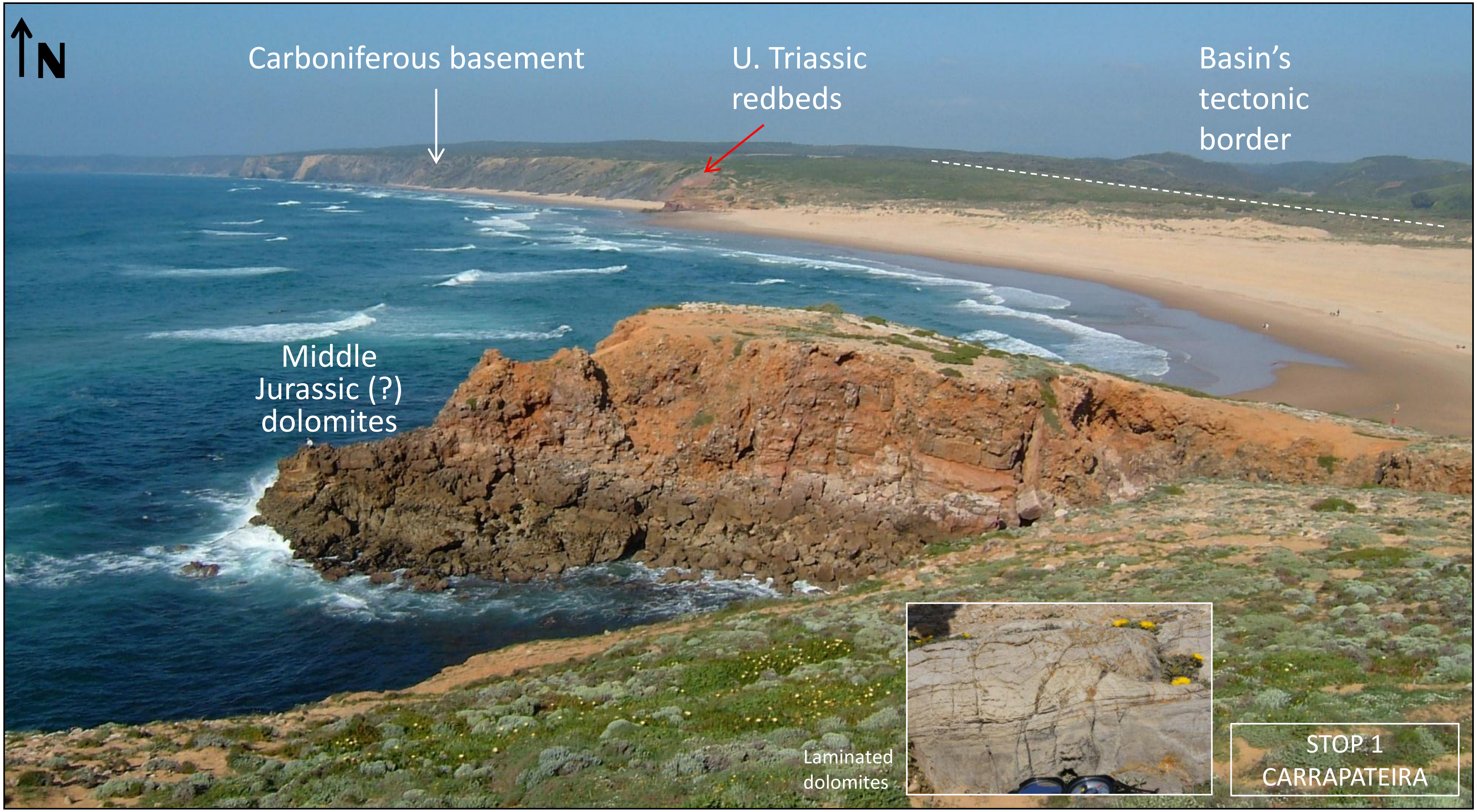
HETTANGIAN Red clays & marls — E

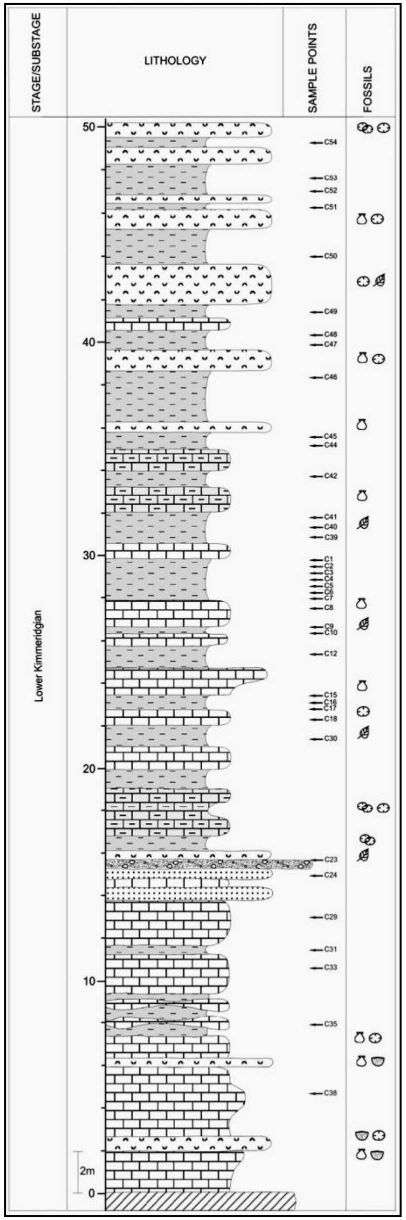
UPPER TRIASSIC Redbeds



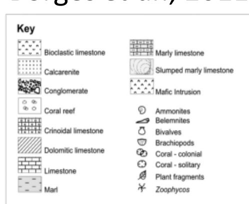
Feio et al., 1985

The Carrapateira promontory shows most of the Jurassic sequence of the western Algarve Basin.
The Mesozoic basin is controlled and affected by NNE-SSW bordering faults and defines a broad faulted syncline.
Upper Triassic redbeds and Hettangian red clays and marls overlie Carboniferous metasedimentary basement.
The Lower and Middle Jurassic units show intense dolomitization and dating is very uncertain.





Borges *et al.*, 2011



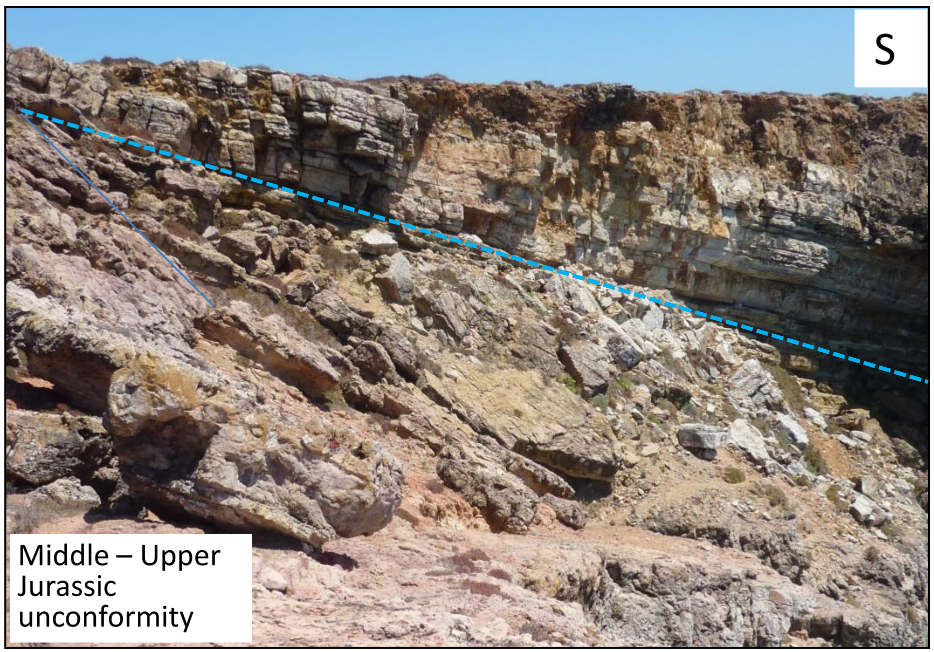
Upper Jurassic interbedded limestones and marls at Três Angras.

Calciclastic marls and bioclastic limestones pass into interbedded grey marls and limestones. The uppermost limestone beds are rich in macrofossils including well preserved corals in life position.

Corals and foraminifera, as well as dinoflagellates indicate an Early Kimmeridgian age (Ribeiro *et al.*, 1987; Borges *et al.*, 2011).

Upper Triassic aeolian like redbeds

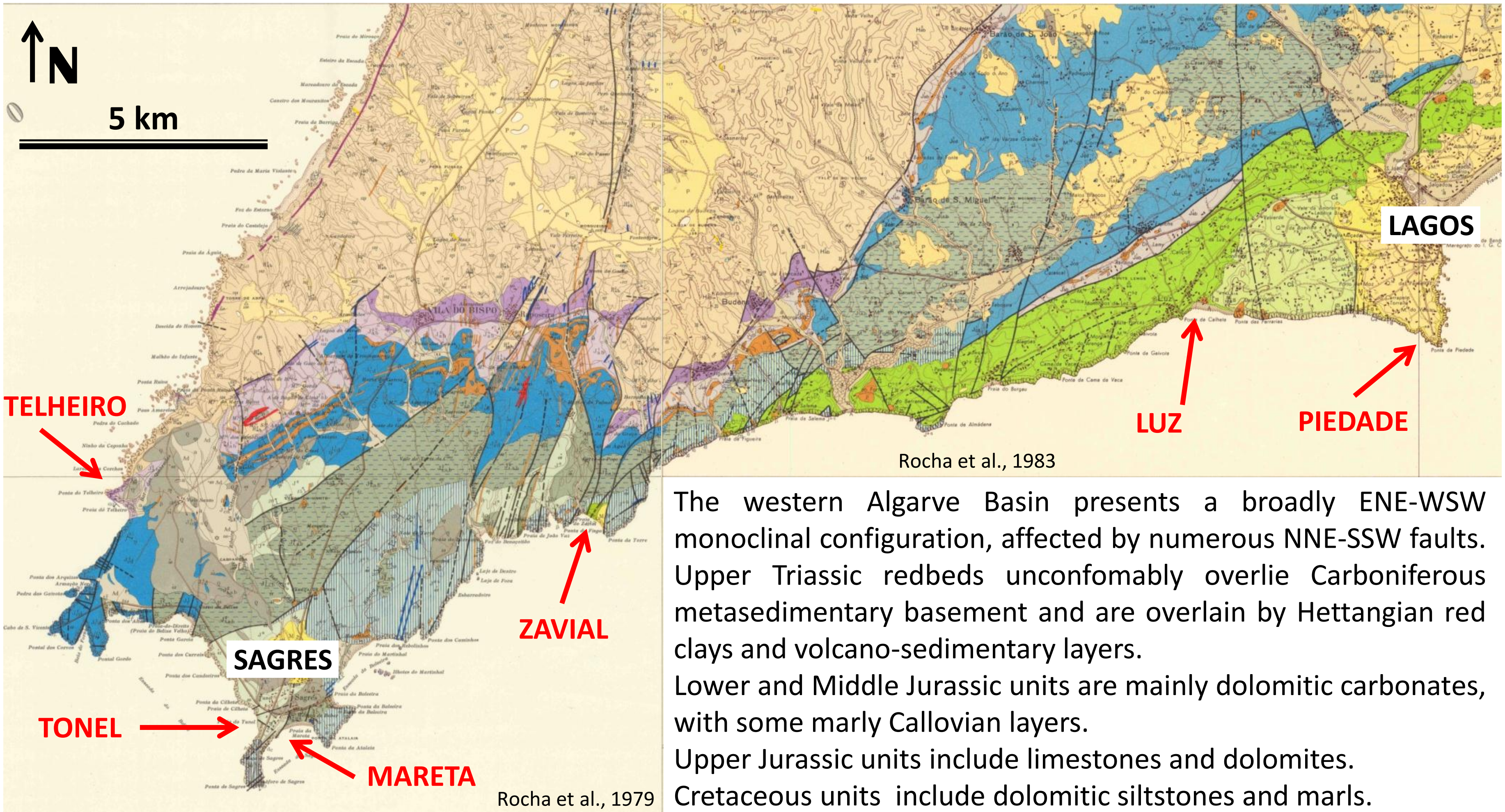
Hettangian red clays & dolomites



Middle – Upper Jurassic unconformity

Tithonian (?) calciclastic conglomerates

WESTERN ALGARVE BASIN
SAGRES – LAGOS AREA



The western Algarve Basin presents a broadly ENE-WSW monoclinal configuration, affected by numerous NNE-SSW faults. Upper Triassic redbeds unconfomably overlie Carboniferous metasedimentary basement and are overlain by Hettangian red clays and volcano-sedimentary layers.

Lower and Middle Jurassic units are mainly dolomitic carbonates, with some marly Callovian layers.

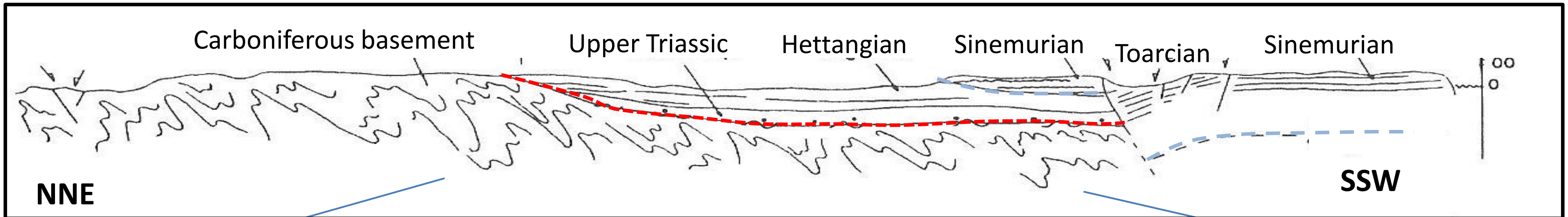
Upper Jurassic units include limestones and dolomites.

Cretaceous units include dolomitic siltstones and marls.

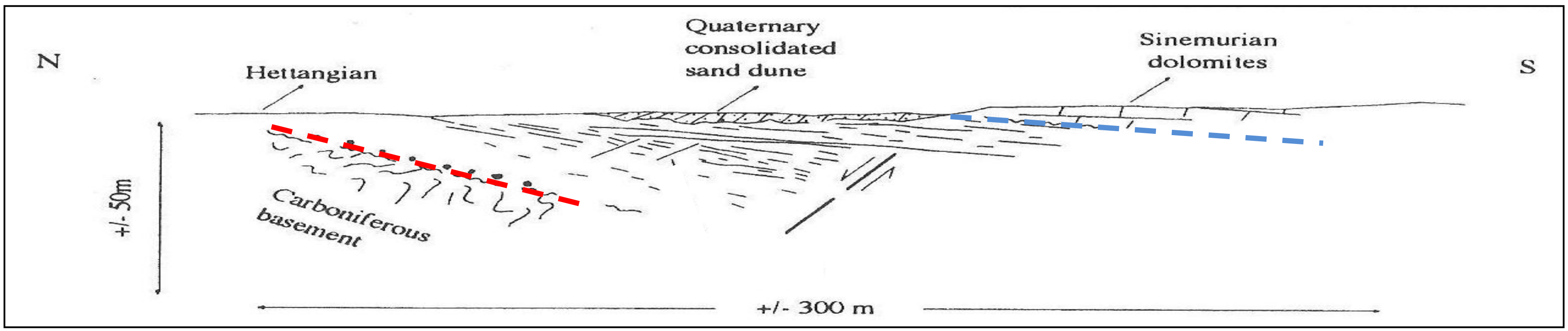
STOP 2
TELHEIRO

The Telheiro beach probably shows one of the best exposed outcrops of the Triassic unconformity in Europe, exposed along a 60 metre high coastal cliff.

Late Triassic sandstones , dipping around 20º SE, overlies upright chevron folds in black shales and greywackes of Carboniferous age, deformed during the Variscan orogeny.



(Terrinha, 1997)



The unconformity is overlain by red and yellow fluvio-aeolian sandstones with abundant large-scale trough bedding.

This 2-5 meters thick package is overlain by well bedded planar clays with marly intercalations, deposited in a sabkha-like environment.

The first dolomitic layers, of probable Sinemurian age, represent the marine invasion of the basin, which continued throughout most of the Jurassic.

The whole area comprises a well developed planation surface, associated with Cenozoic marine abrasion and neotectonic uplift.

Quaternary consolidated aeolian-sands, with cross-bedding and rhizoconcretions, overlie a palaeovalley, incised in Hettangian marls, between resistant sandstones hard dolomites.

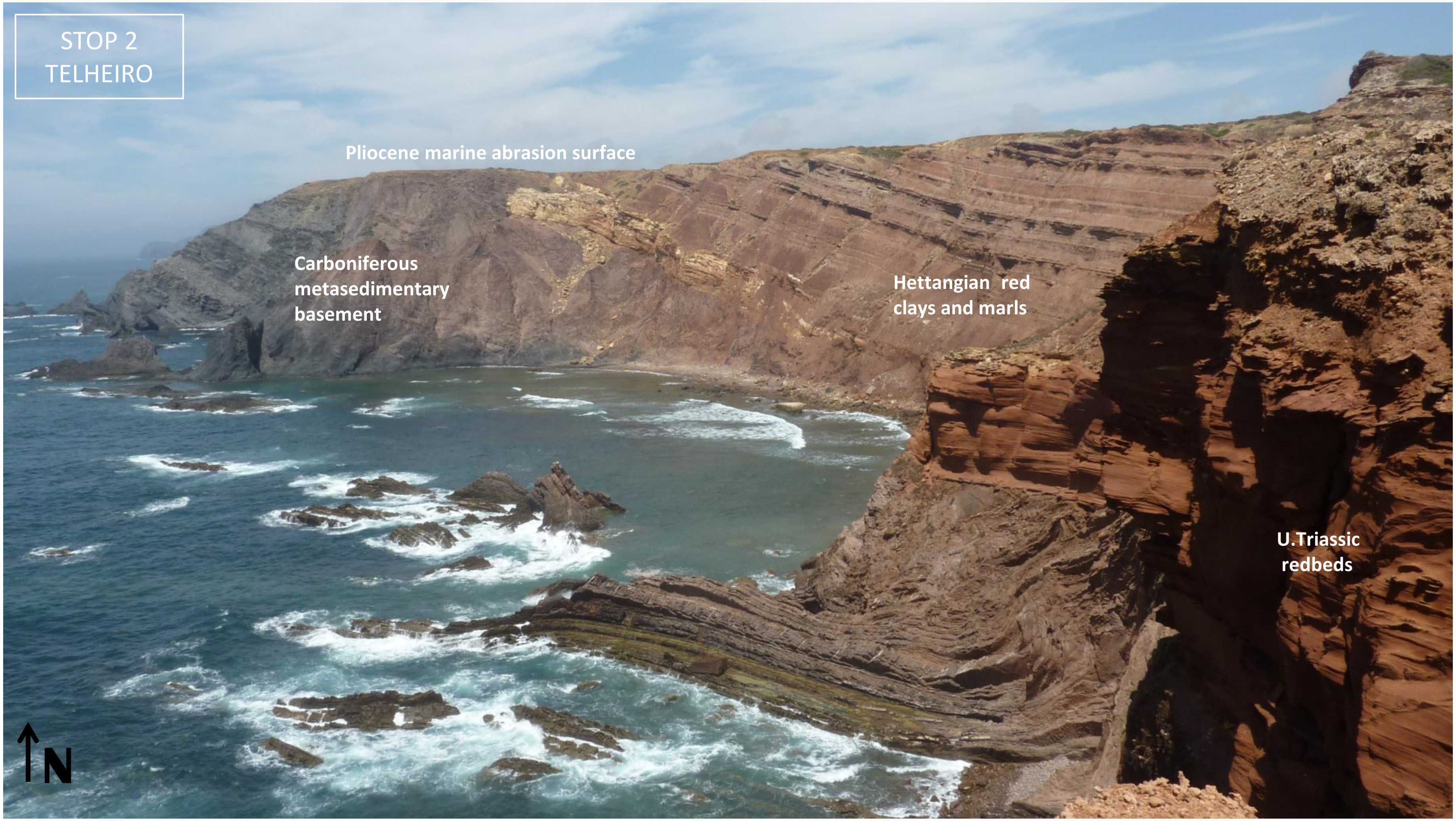
This major unconformity between Carboniferous shales and Triassic redbeds resulted from a long geological evolution:

i) deposition of deep marine clays and sands in a distal turbiditic environment, c. 360 My ago;

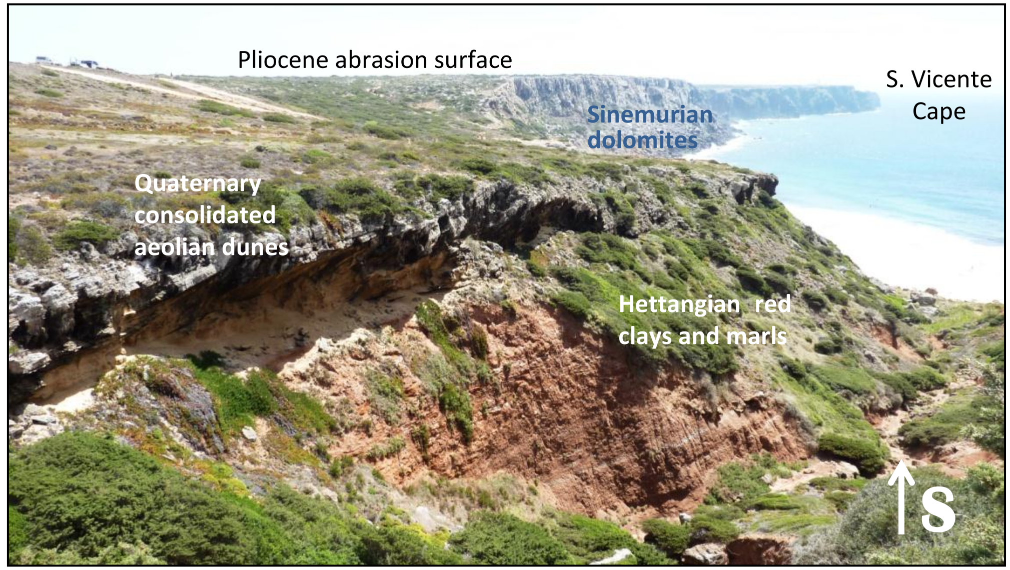
ii) intense orogenic subsidence, heating and ductile deformation at depths of around 5 km, c.310 My ago;

iii) post-orogenic gradual uplift and erosion of thousands of meters, until exposure and weathering, c.260 My ago;

iv) deposition of the first layers of fluvio-aeolian sands lying unconformably on top of the deformed Carboniferous shales.




STOP 2
TELHEIRO
Carboniferous
metasedimentary
basement
N


Pliocene abrasion surface
S. Vicente
Cape
Sinemurian
dolomites
Quaternary
consolidated
aeolian dunes
Hettangian red
clays and marls
S

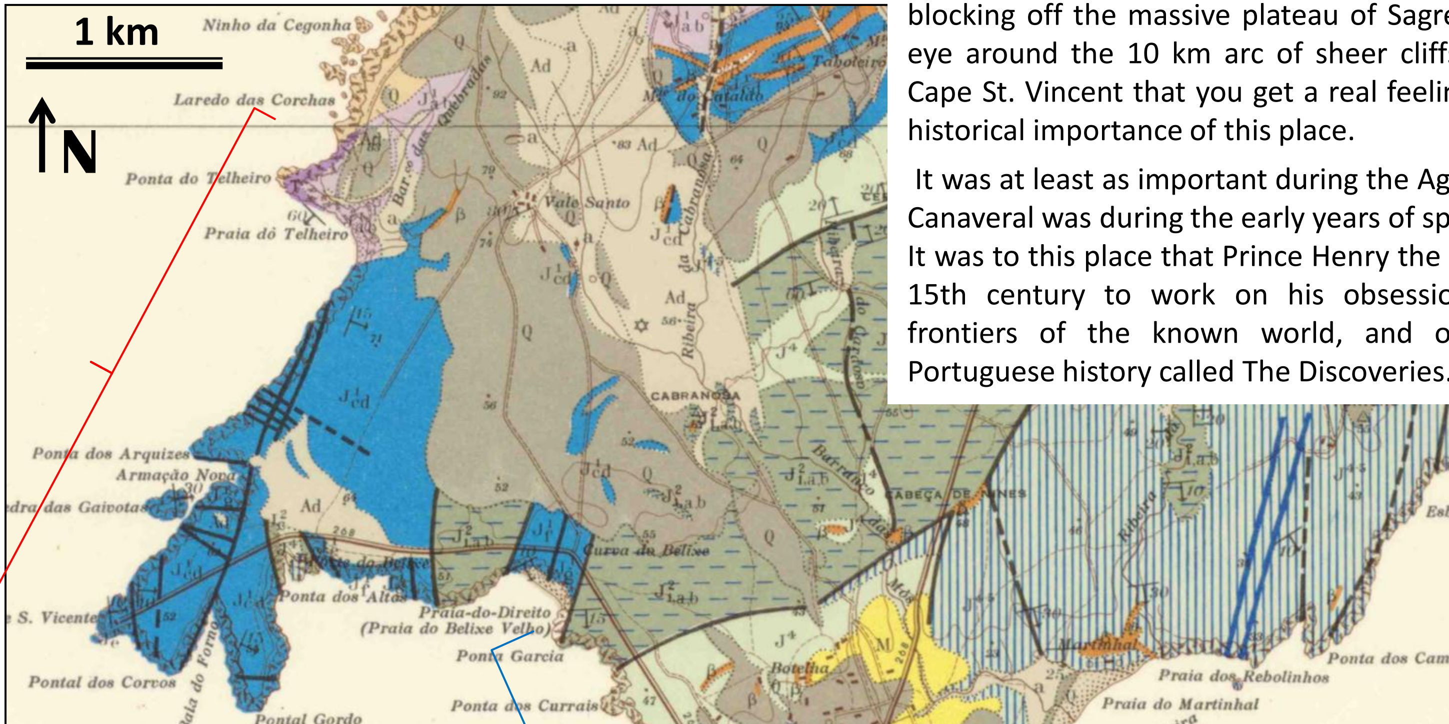

Carboniferous
metasedimentary
basement
U. Triassic
redbeds


Hettangian red
clays and marls
U. Triassic
redbeds

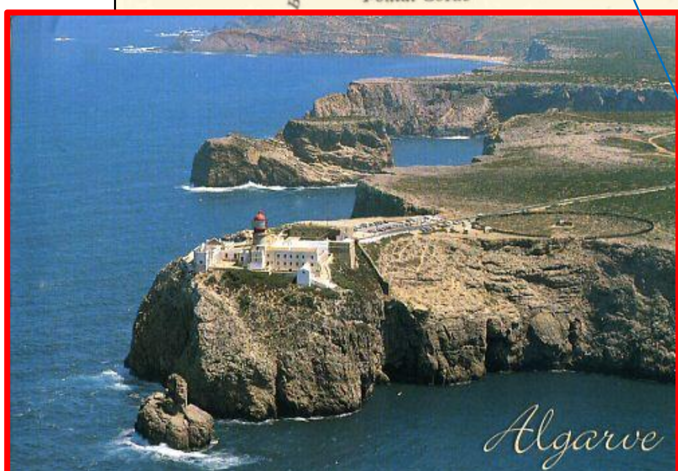
SAGRES AREA

Sagres is the "Promontorium Sacrum", considered by the Romans as "the western end of the inhabited world". It is only when you catch sight of the grey ramparts of the fortress blocking off the massive plateau of Sagres point and cast your eye around the 10 km arc of sheer cliffs to the lighthouse at Cape St. Vincent that you get a real feeling for the tremendous historical importance of this place.

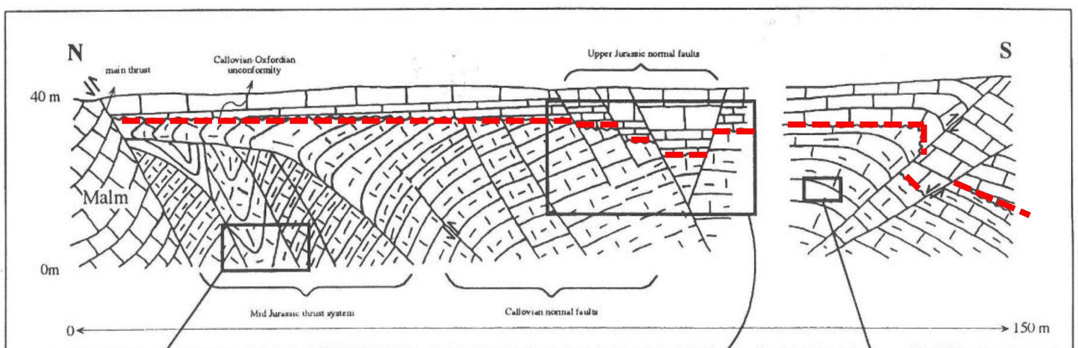
It was at least as important during the Age of Discovery as Cape Canaveral was during the early years of space exploration.
It was to this place that Prince Henry the Navigator, came in the 15th century to work on his obsession to push back the frontiers of the known world, and opened the phase in Portuguese history called The Discoveries.



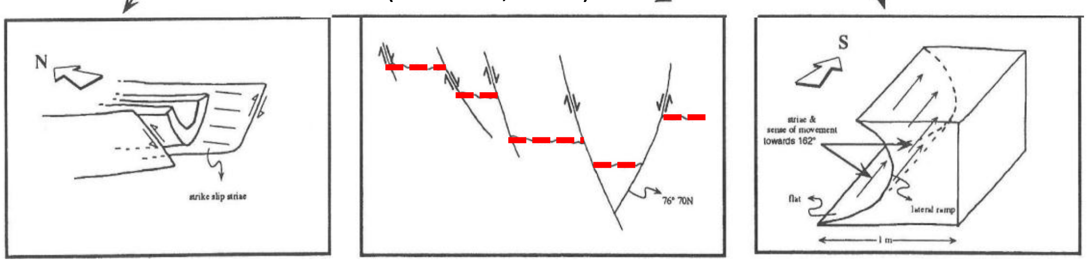
Rocha et al., 1979



STOP 3 TONEL



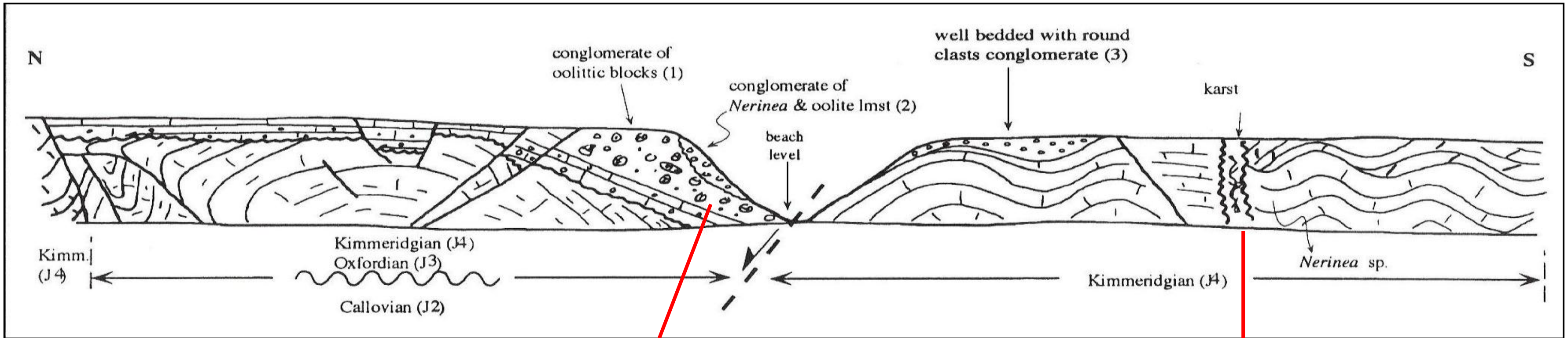
(Terrinha, 1997)

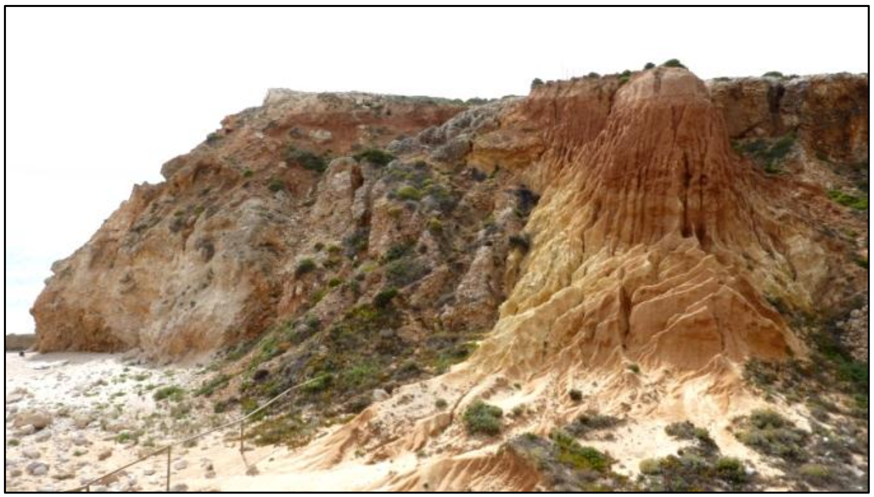


This beach is one of the best places to see the Callovian-Oxfordian unconformity in the Algarve Basin. The Callovian external platform marly limestones are overlain by a hard-ground with ferruginous concretions and a 1.5m thick limestone, with late Callovian to early Oxfordian reworked ammonites and phosphatic nodules.

This situation points to an important uplift, exposure and erosion, before the deposition of the middle Oxfordian oolitic limestones in shallow water conditions.

The marly Callovian strata show folds and thrusts with NE-SW oriented compressive evidences, cut by the Callovian unconformity; both the Callovian and Oxfordian units present extensional geometries with a NE-SW orientation (Terrinha, 1997).





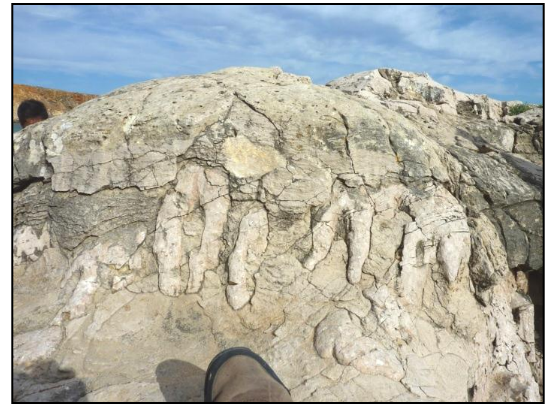
Karstic features are an important part of the Algarve's coastal geomorphology, related to the Tertiary inversion, uplift and exposure. Karstification is believed to have been a long lived process, with multiple dissolution, collapse and infill events. It affects not only the Mesozoic carbonate units, but also the Miocene fossiliferous marls, such as in Piedade (see Stop 7). In many places, the vertical collapse structure is filled by Pliocene and/or Quaternary sands, which once covered the whole littoral abrasion platform.

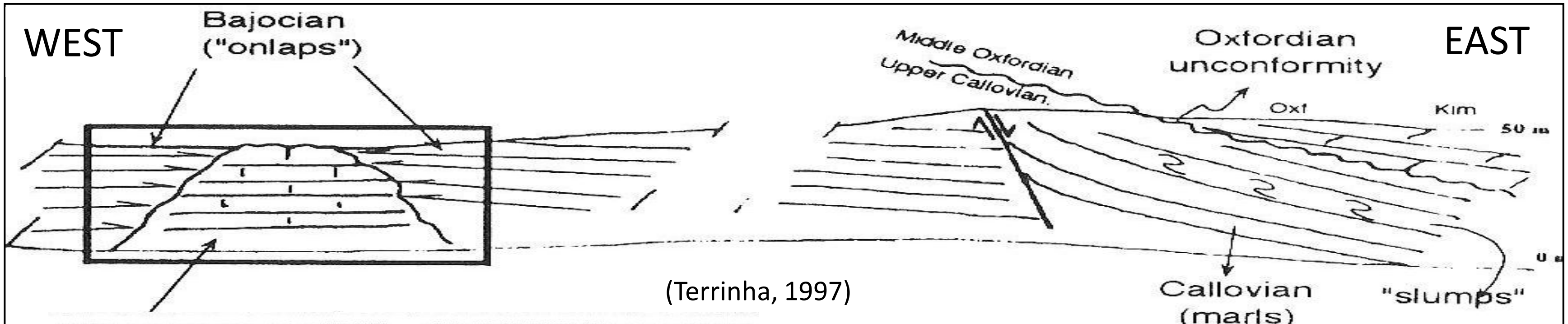
STOP 4 MARETA

This beach shows a thick sequence of Middle to Upper Jurassic marine carbonates.

The stratigraphic sequence starts with a Bathonian reefal dome with signs of exposure and karstification. The karst cavities are filled and covered by onlapping Upper Bajocian sandy limestones with abundant *Zoophycus*.

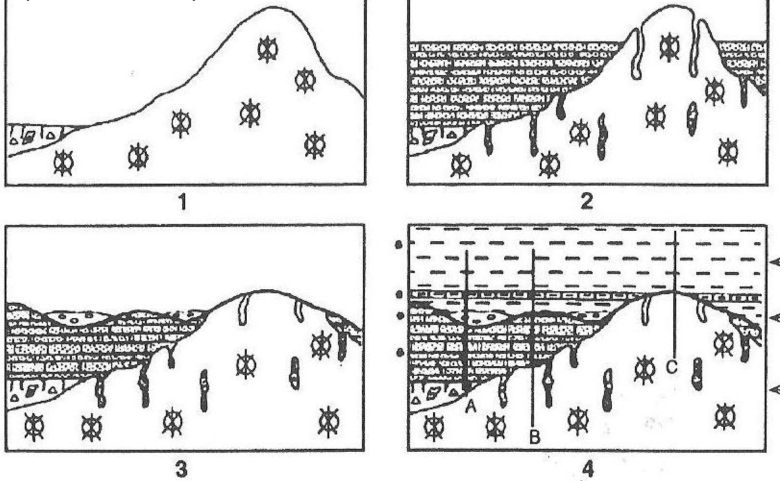
Early Bajocian reef, with karstic cavities filled-up by Late Bajocian onlapping sands.

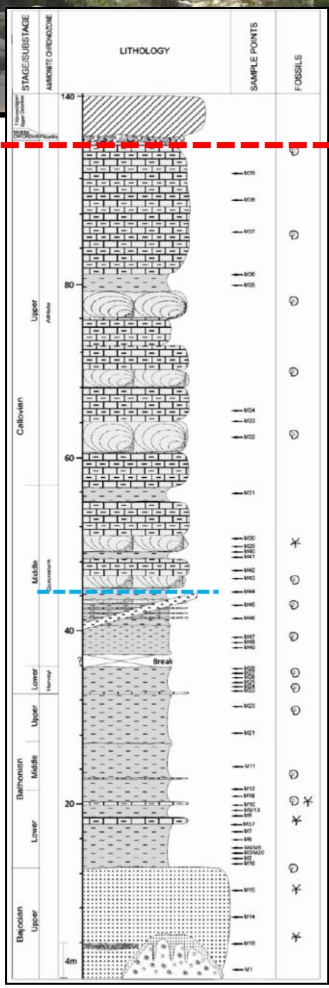




(Terrinha, 1997)

(Rocha, 1976)

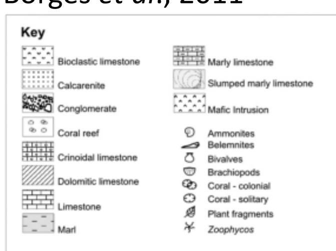




Towards East, the cliff exposes Middle Bathonian to mostly Callovian grey marls, containing belemnites and ammonites, as well as syn-sedimentary slump structures. These external platform facies have a good source rock potential.

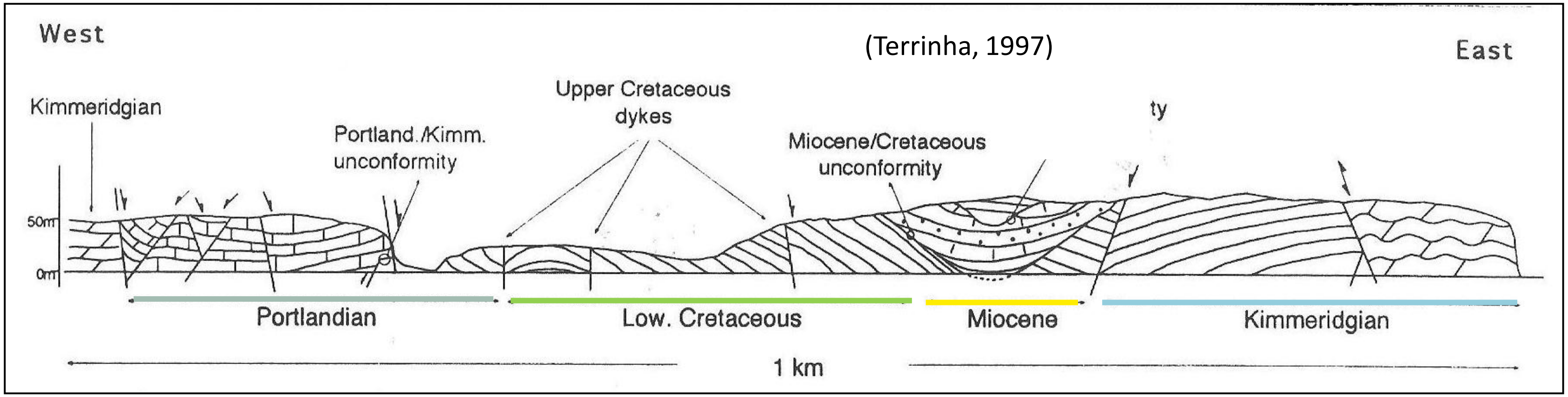
At the eastern end of the cliff, the Callovian unconformity gives way to more compact limestones and dolomites of Oxfordian to Kimmeridgian age.

Borges *et al.*, 2011



Dark grey Callovian marls with source rock potential (TOC and maturation).

STOP 5 ZAVIAL

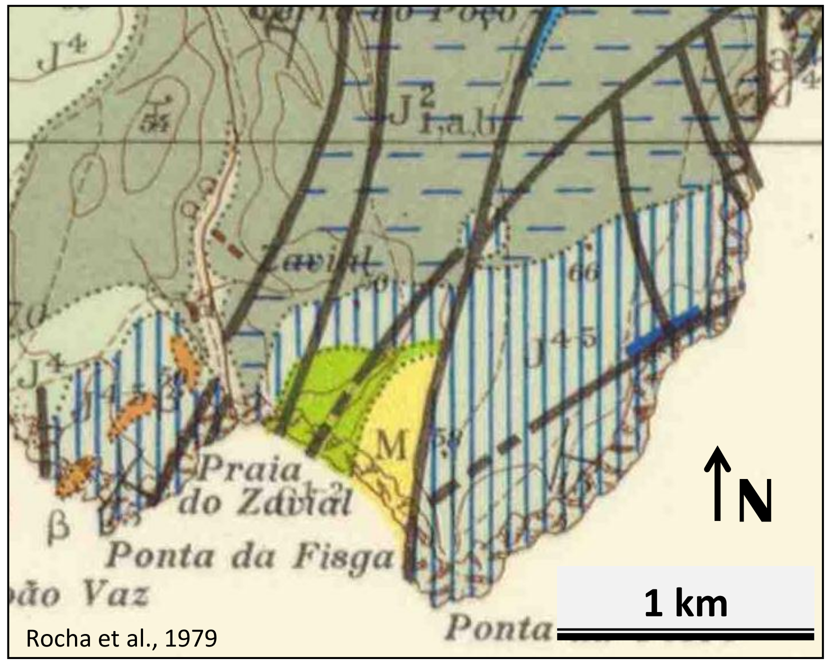


This beach shows a graben of Cretaceous yellowish dolomites, bounded on both sides by Late Jurassic pinkish limestones and dolomites.

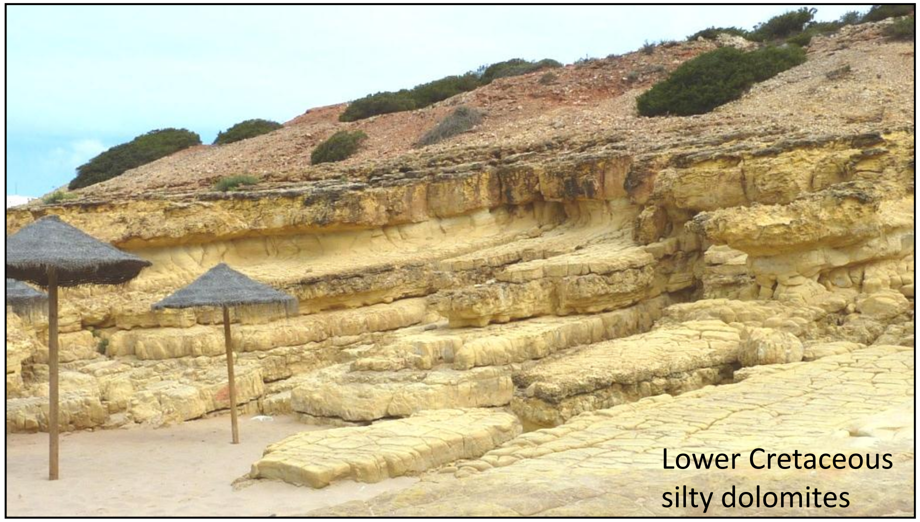
The Cretaceous succession is folded into an anticline, exposing along the beach most of its east dipping flank, crossed by late Cretaceous intrusive dykes with a NNE-SSW orientation.

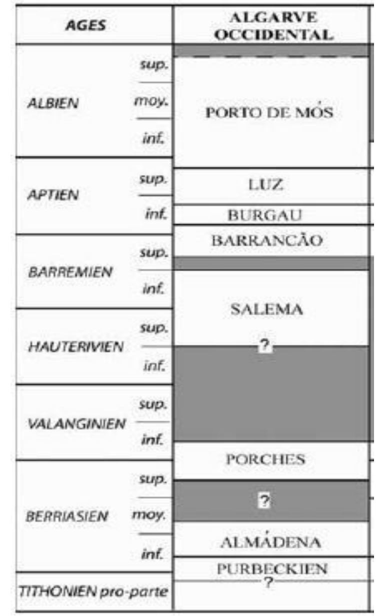
Inside this graben, we can see an unconformity separating the Cretaceous marly limestones from the Miocene fossiliferous sandy marls. This unconformity and the Miocene deposits are folded in a compressional syncline with a NE-SW axis.

This structure is related to the alpine orogenic inversion of the Algarve Basin, with middle Miocene NW-SE oriented compression.

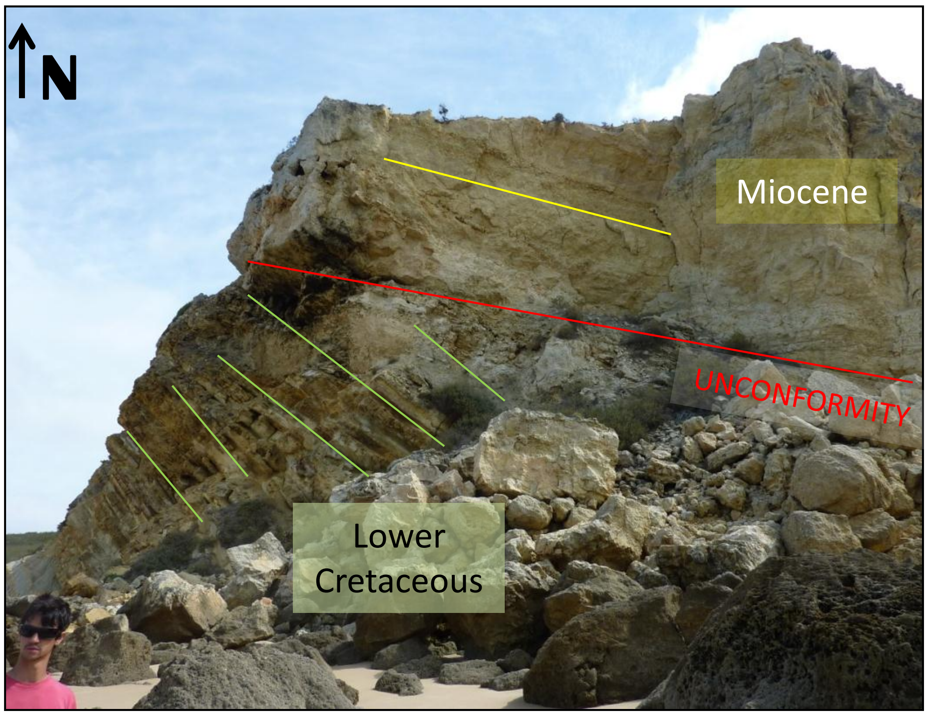


STOP 5
ZAVIAL





Rey, 2010



The Cretaceous succession is composed of decimetric layers of alternating silty dolomites and marly dolomites, deposited in a coastal environment. Towards east, these units give place to reddish clays representing lagoonal to transitional environments with sub-aerial exposure.

These are interrupted by a 3 metre thick package of quartzic sands, cemented by carbonates, with cross-bedding, pointing to some kind of coastal siliciclastic environment, such as a beach-barrier.

After this sandy intercalation, clays with different colourations appear and grade into marly limestones, within trangressive pattern.

This sequence may be assigned to the Upper Hauterivian to Lower Aptian, based on lithostratigraphic correlation of the sandy intercalation (Barrancão Formation).

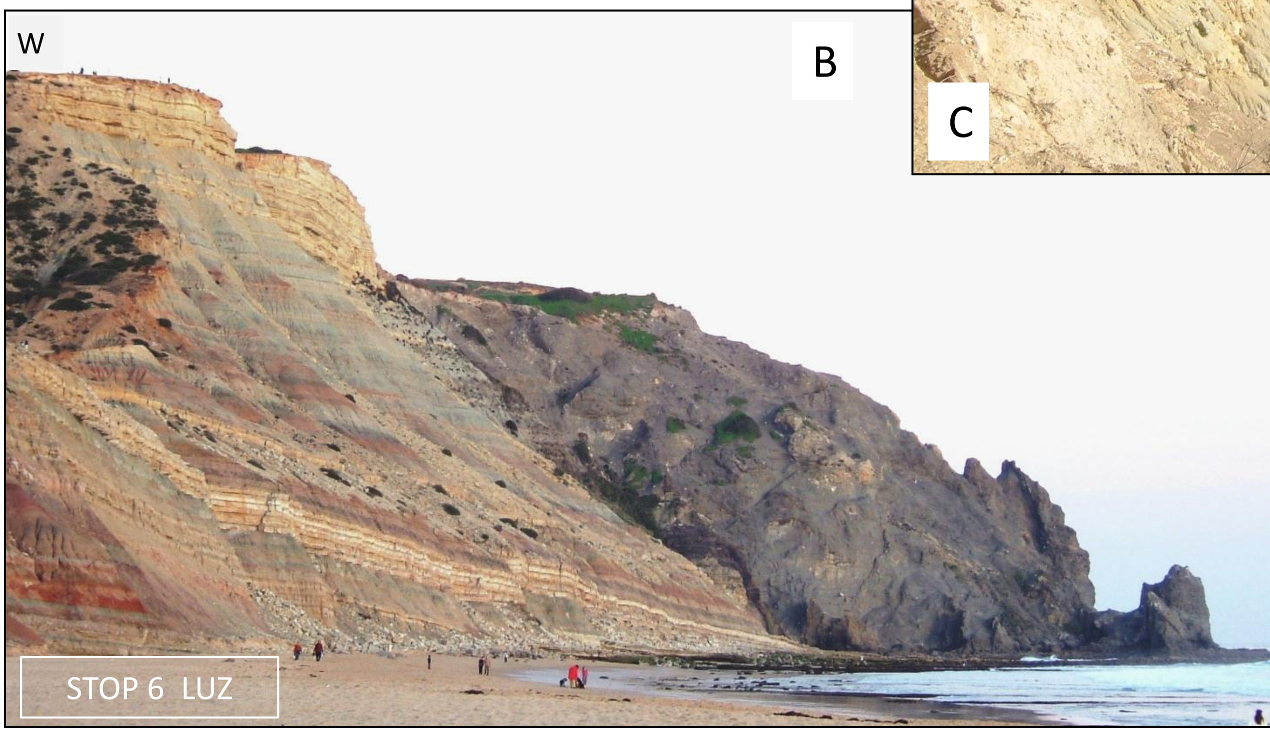
STOP 6 LUZ

The cliffs along this beach expose a thick Lower Cretaceous sequence, covering the whole Aptian interval.

West of the beach, a broad rocky platform is composed of yellowish fine sandstones with carbonate cementation, dipping gently to SE. These layers show undulated geometries and cross-bedding, suggesting hummocky structures and deposition in shallow coastal environments with intense wave action during storms.

Another striking feature is the concentration, in specific layers, of abundant fossils of *Nerinea algarbiensis.* These fossils are mostly oriented N-S, perpendicularly to the interpreted palaeocoastline.

The Albian sequence shows an overall transgressive pattern, with continental red and purple mottled clays with carbonate paleosoils. Towards the top, some bioclastic sands appear intercalated in reduced grey clays and carbonates, suggesting a coastal environment.
The top of the cliff shows a thick package of shallow marine limestones. Dark rocks appears on the eastern promontory, corresponding to a Late Cretaceous igneous intrusion.



A. Continental red and purple clays with paleosoils.

B. Continental to transitional clays with sandy bioclastic intercalations, affected by normal faulting, with large igneous intrusion to the right.

C. Cliff exposing the upper part of the transitional clay deposits ("Luz Marls") and the lower shallow-marine carbonates ("Marly limestones" of Porto de Mós).

STOP 7 PIEDADE

This tourist spot shows well developed karstic erosion in Miocene limestones.

After the Mesozoic infill of the Algarve Basin, intense inversion resulted in uplift and erosion during the Late Cretaceous and Paleocene in the present day onshore areas.

In Neogene times, a flexural basin developed along this region, in relation to secondary extension around the Gibratltar arc (Terrinha, 1997). Sedimentation resumed in Middle Miocene with deposition of rhythmic fossiliferous limestones and marls in coastal environments.

This coastal landscape is also a result of the the post-Miocene uplift of the Western Algarve during the Plio-Quaternary. Karstic features are partially filled up by Pliocene red sands, which after collapse of the karstic vertical wall give place to the present-day holes and arches.

STOP 8 SANTIAGO

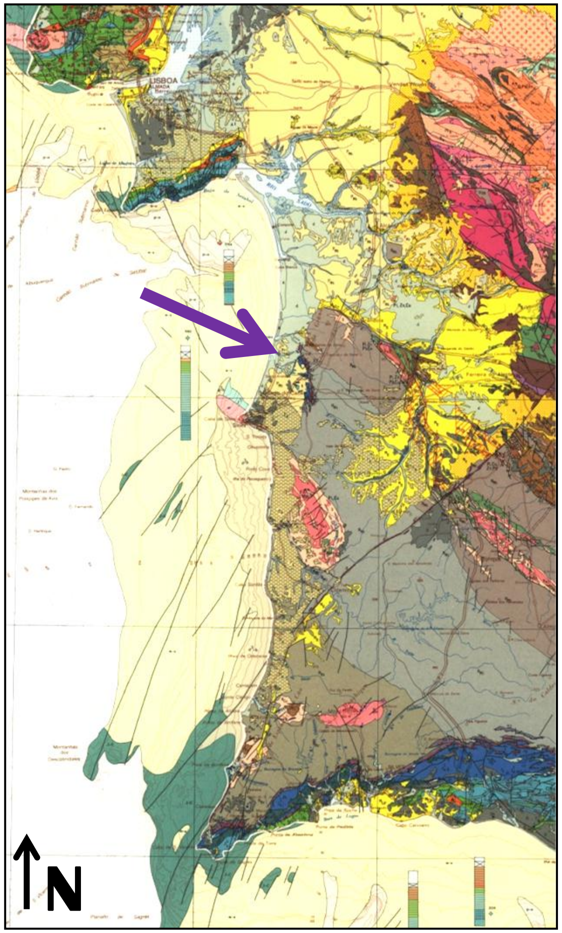
The Santiago do Cacém area is the only place where the Mesozoic Alentejo Basin outcrops onshore. It is therefore a crucial site to study this basin and its position between the Algarve and the Lusitanian basins. Uplifted basin bordering blocks expose most of the Upper Triassic and Lower Jurassic sequence, dipping to the West.

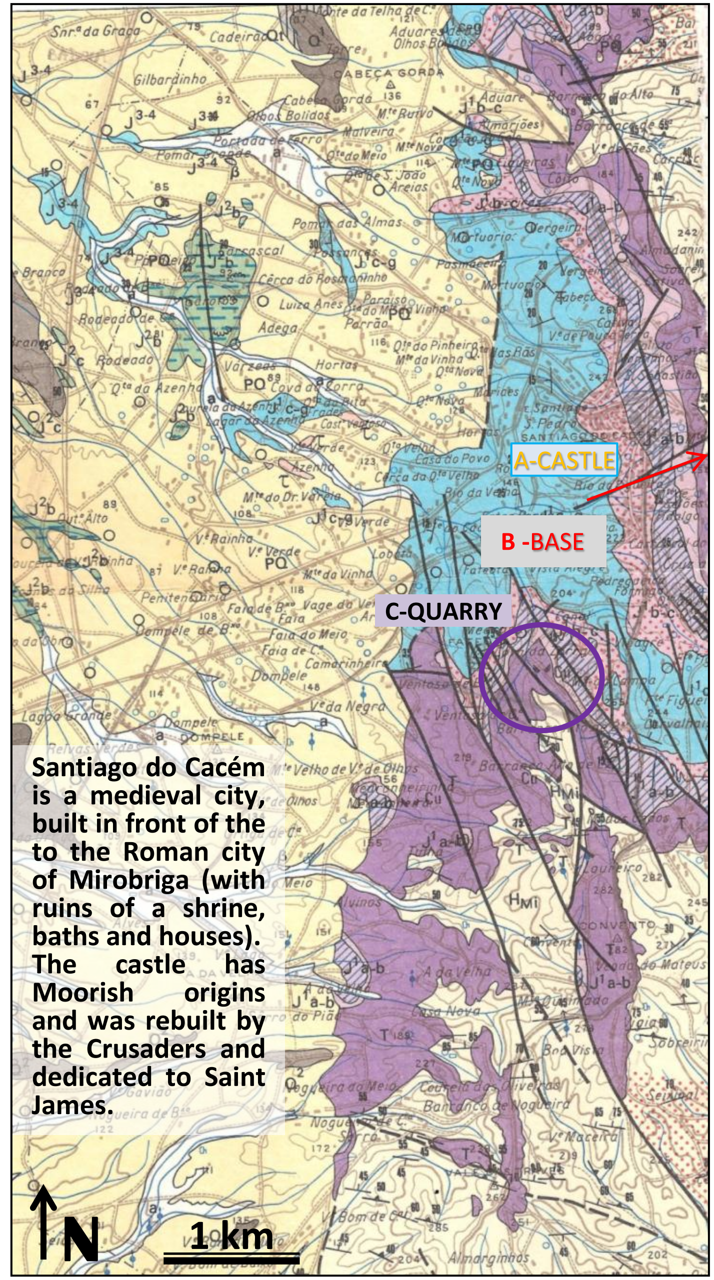
The Carboniferous Palaeozoic basement is overlain by coarse-grained continental redbeds, deposited in proximal to distal alluvial fans. Upwards, these deposits grade into red clays and platy dolomites, deposited in a sabkha-like environment.

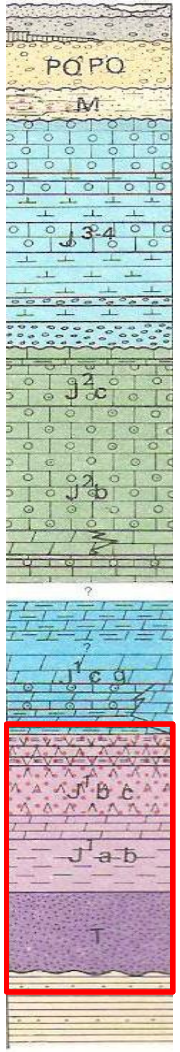
This sequence is overlain by a volcano-sedimentary complex with tholeitic basalts, related with the Central Atlantic Magmatic Province (CAMP), also recognised in Southern Portugal.

Sinemurian opening to shallow marine influences promoted the deposition of massive marly dolomites.

Middle Jurassic carbonates are separated from Upper Jurassic intraformational conglomerates by a regional unconformity.







100m

NEOGENE sands

UPPER JURASSIC

Calciclastic limestones

Marls

Conglomerates

MIDDLE JURASSIC

Oolithic limestones

Limestones

LOWER JURASSIC
marly dolomites

Hettangian volcanics

Hett. platy dolomites

T/J red clays

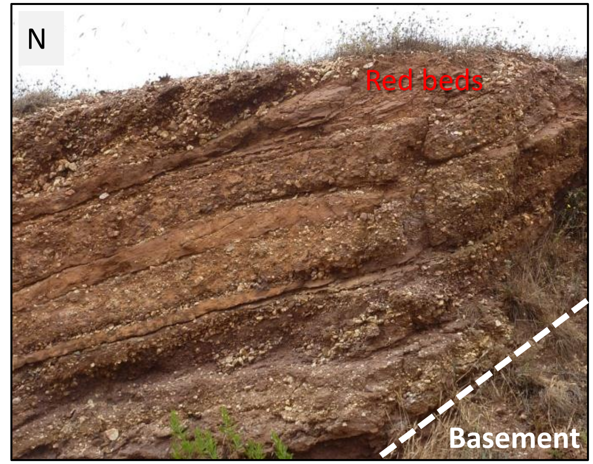
UPPER TRIASSIC
coarse redbeds

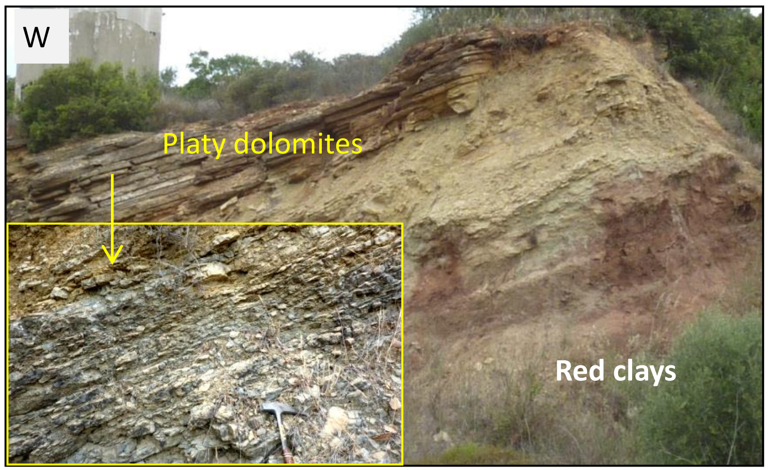
CARBONIFEROUS
basement (shales)

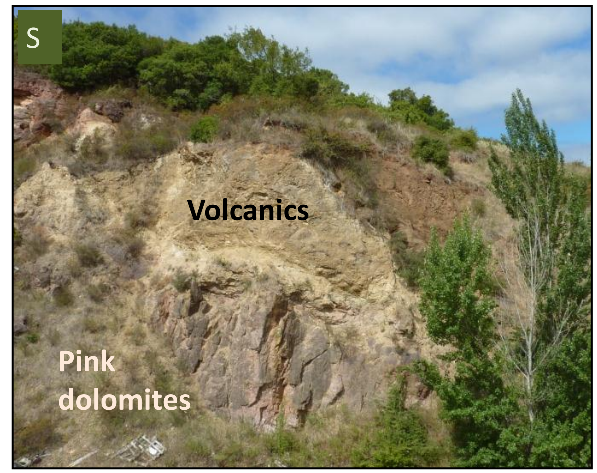
STOP 8A - Santiago Castle: the main monoclinal structure can be seen, with the Lower Jurassic dolomites marking the flattened hill tops dipping to West; to the North, the Arrabida Chain in the horizon.

STOP 8B – Close to the Hotel, a small outcrop shows the contact between the folded Carboniferous meta-ssedimentary basement and the overlying Upper Triassic conglomeratic redbeds.

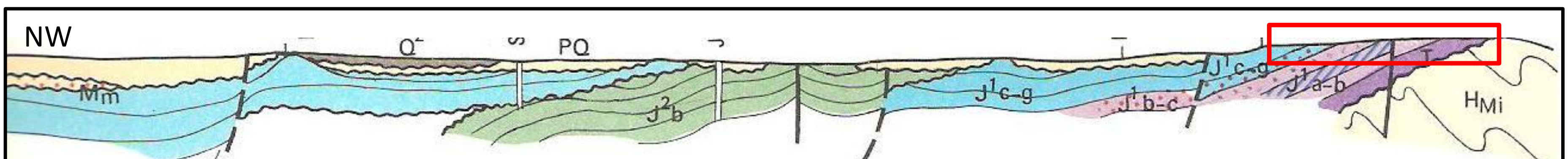
STOP 8C – South of the town, an extensive area occupied by numerous quarries shows the Upper Triassic to Lower Jurassic sequence including: conglomeratic redbeds, red clays, platy dolomites, pinkish dolomites and CAMP-related volcanics.





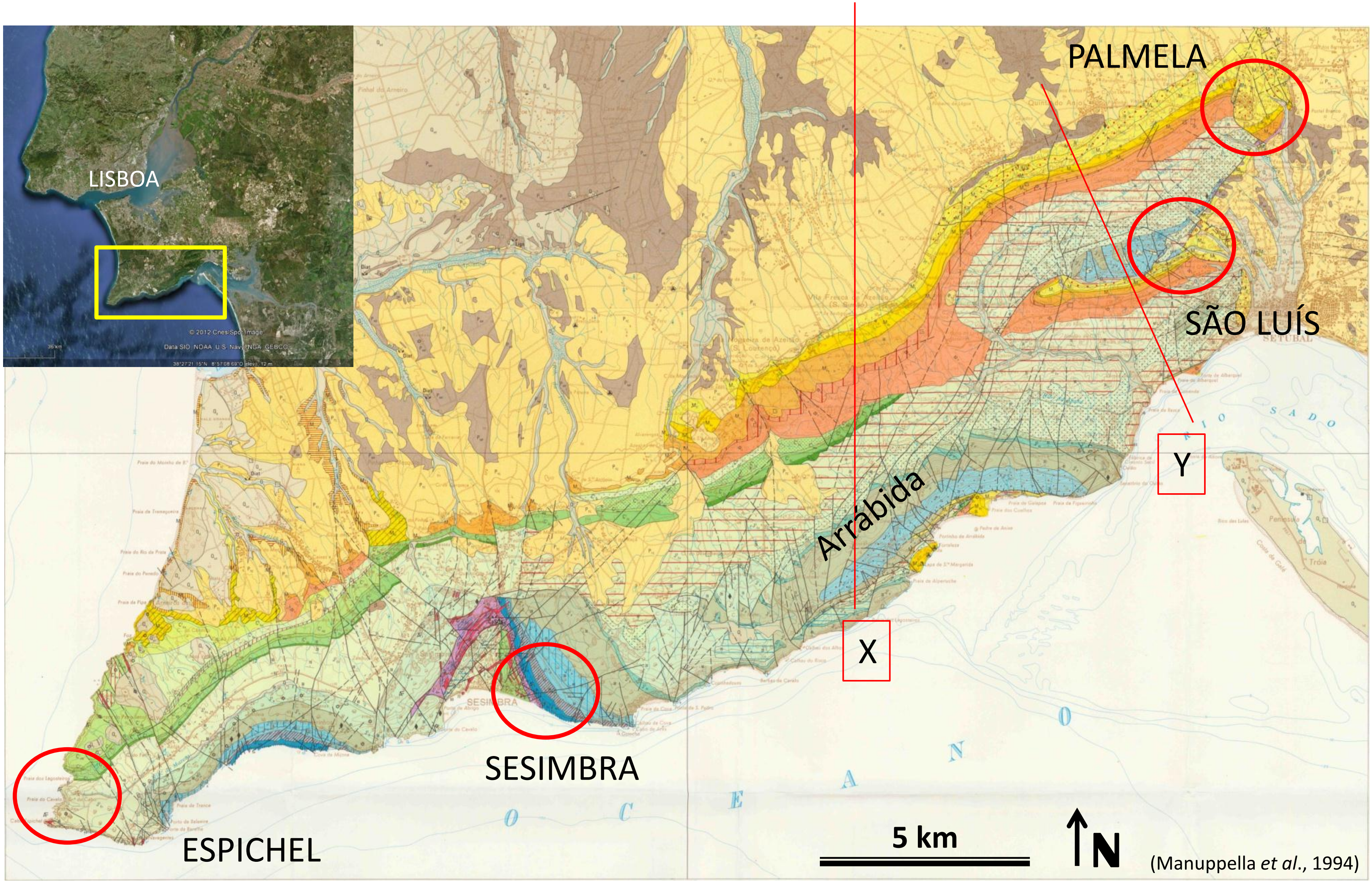


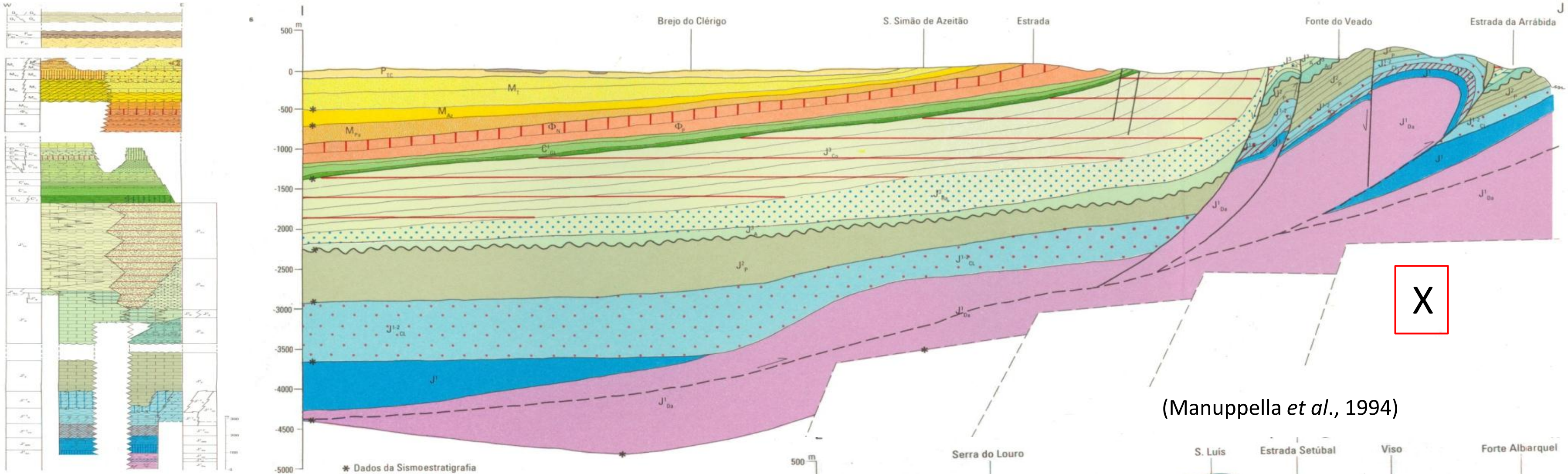
STOP 8 - SANTIAGO



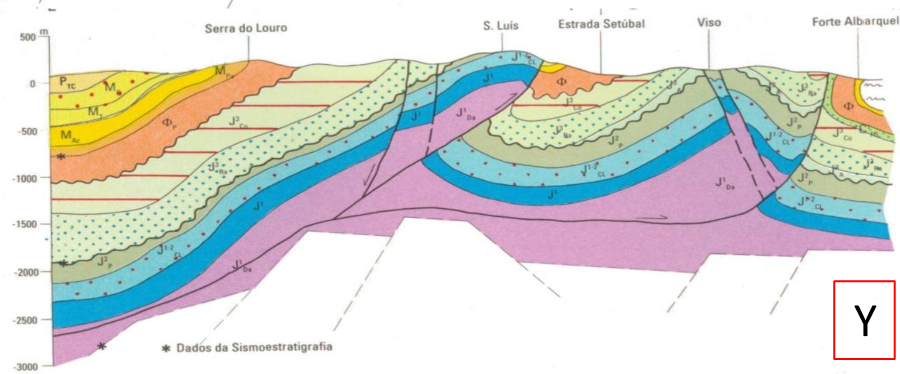
Geological cross section from Santiago towards NW

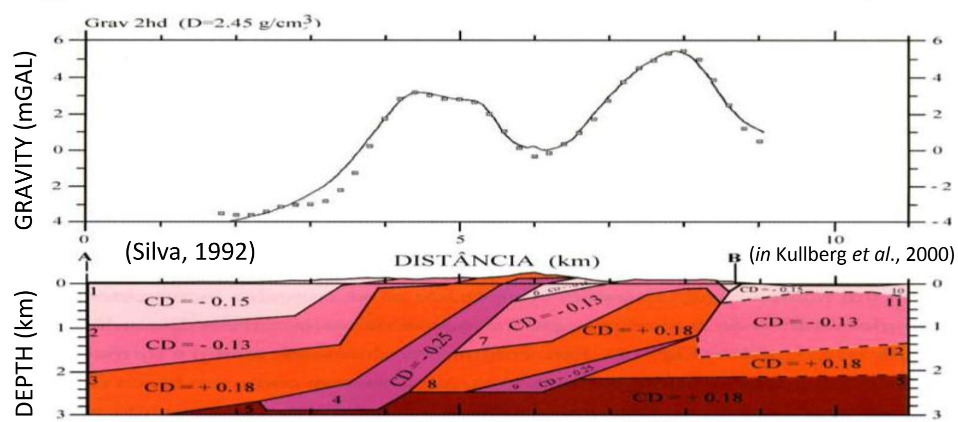
ARRÁBIDA AREA





(Manuppella *et al.*, 1994)





(Silva, 1992)

(*in* Kullberg *et al.*, 2000)

The Arrábida chain is an alpine structure, related to the Cenozoic inversion of the Lusitanian Basin. Several uplift related unconformities may be identified, namely in the Late Cretaceous and Upper Miocene.

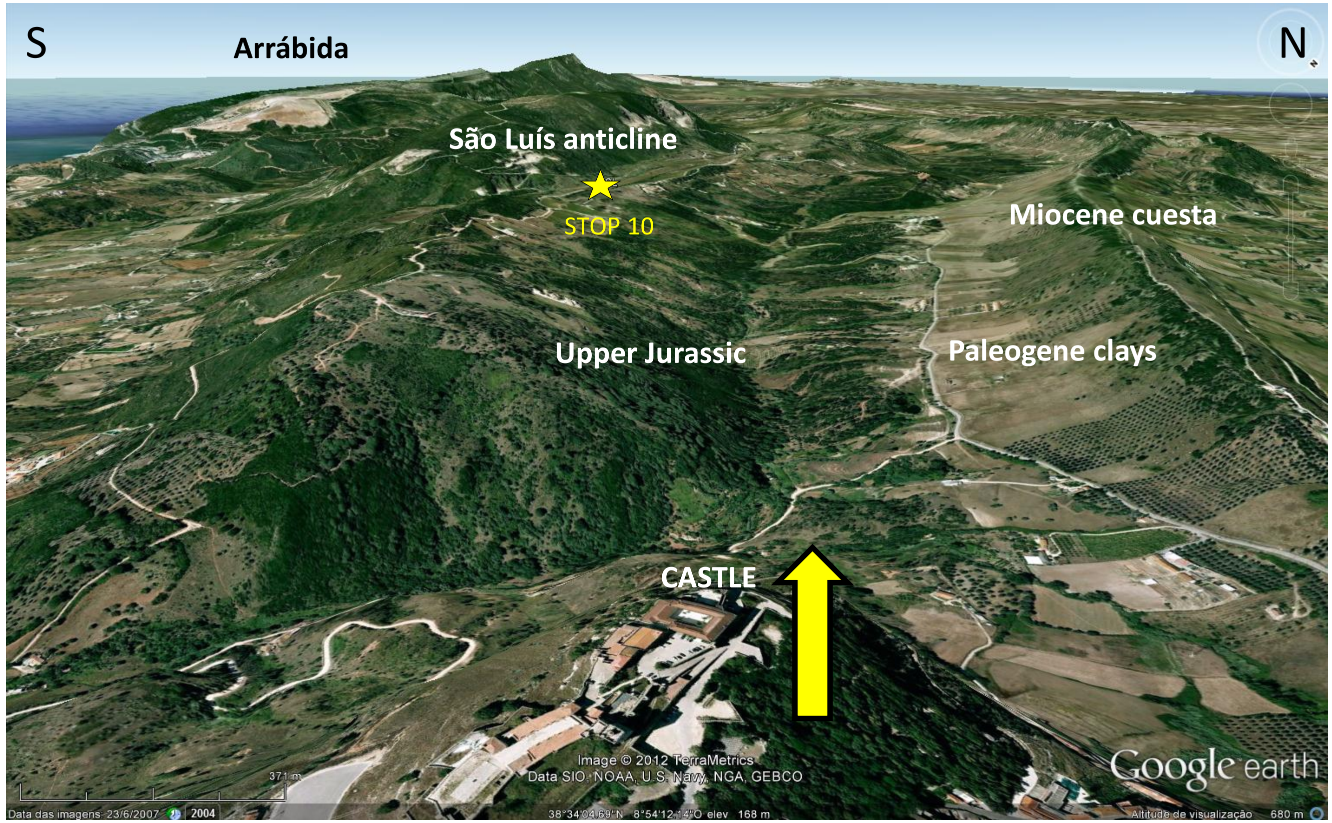
The overall structure is an assymetrical anticline, with an ENE-SSW oriented axis and thrusting towards South, as seen at Espichel Cape and Arrábida hill.

This simple structure becomes more complex towards East, with the duplication of the thrusting anticline in a duplex structure, with two parallel axis – the São Luís and the Viso hills.

This inversion structure is related to the alpine N-S compression, reactivating the Mesozoic lystric NNE-SSW faults as strike-slip transfer faults.

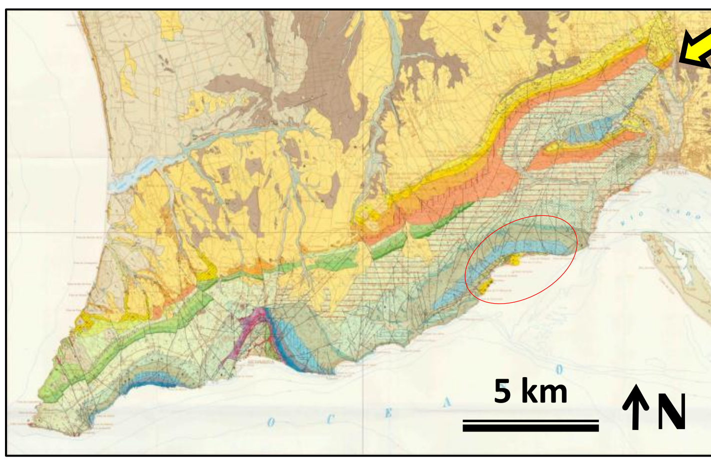
Gravimetric data and models suggest the role of uplifted basement blocks controlling the movements along a detachment layer of Hettangian evaporitic clays.

STOP 9
PALMELA

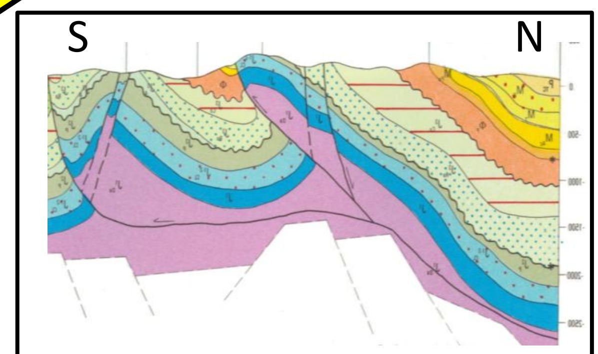


The view from Palmela Castle shows a landscape cross section of the alpine Arrabida chain.
From right to left we can see:
i) the elongated "cuesta" with Miocene fossiliferous limestones;
ii) the valley with Paleogene clays;
iii) the hill of Upper Jurassic conglomerates;
iv) the top of the hill with Lower and Middle Jurassic limestones defining the São Luís anticline.

Quick stop at the Arrabida chain: alpine inversion and Miocene deformation



View from the castle



(Manuppella et al., 1994)

STOP 10 SÃO LUÍS

Late Kimmeridgian Intraformnational conglomerates.

70% Qz + 30%C
[7 cm] [15 cm]

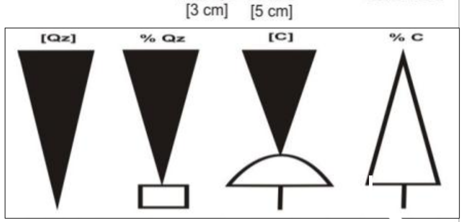
2% Qz + 80% C
[5 cm] [10 cm]

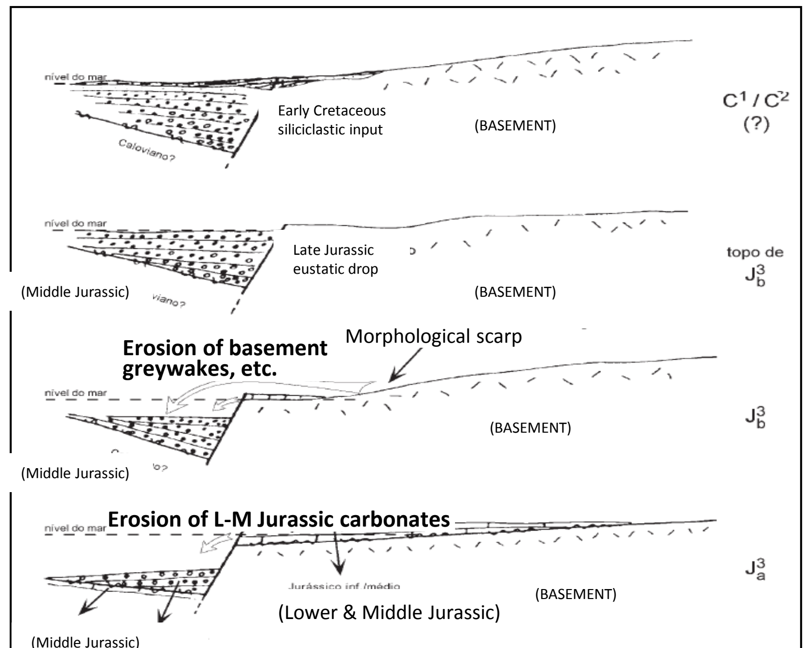
The Late Kimmeridgian to Tithonian Arrabida conglomerates show an interesting vertical evolutive pattern, with a calciclastic composition at the base and gradually increasing siliciclastic component (Palaeozoic clasts of quartz, chert, jasper, etc.) towards the top. This situation results from the exhumation of uplifted basement blocks, related to the Late Kimmeridgian basin reorganisation.

10% Qz + 90%C
[3 cm] [5 cm]

60% Finos

5% Qz + 90%C
[1 cm] [20 cm]





Kullberg et al., 2000

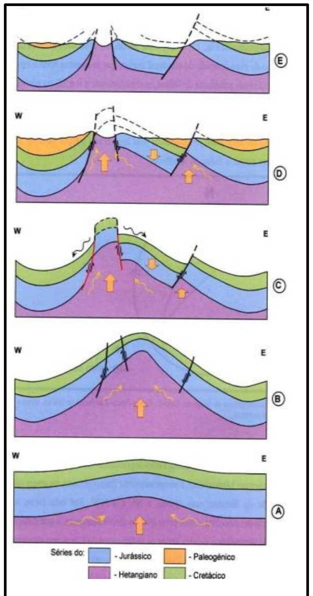
STOP 11
SESIMBRA

Sesimbra is an ancient fishing village, now surrounded by summer houses.

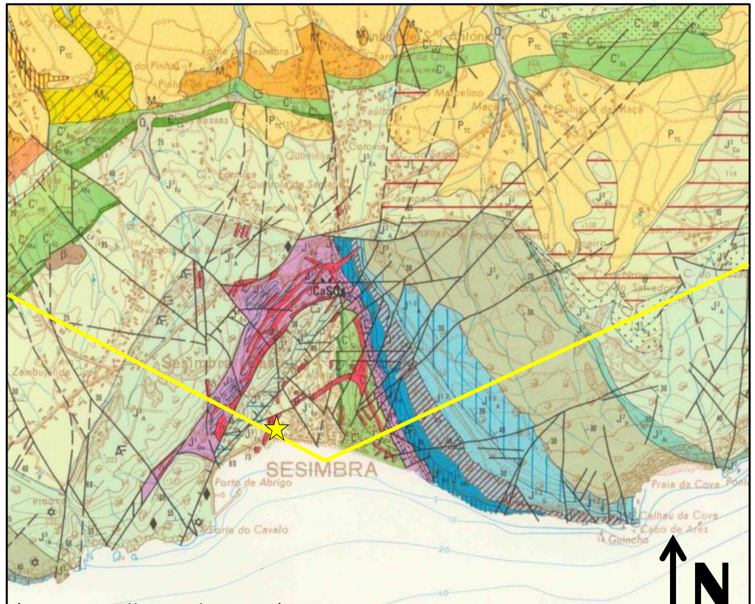
East of the village, the California Hills expose the Lower Jurassic sequence, begining with stratified volcanics. These basaltic rocks correspond to the CAMP event and represent its most northerly occurrence in Western Iberia.

They are overlain by Lower Jurassic dolomites with intense (hydraulic?) fracturation. Upwards in the sequence, some marly layers are time-equivalent of a important Lower Jurassic source rock of the Lusitanian Basin (Vale das Fontes Formation). However, due to its bordering paleogeographic position, its source potential is low.

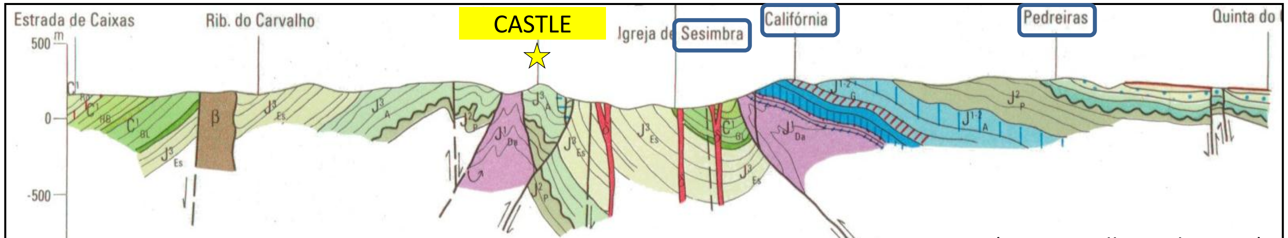
Looking eastwards from the castle, the houses occupy the valley with Upper Jurassic and Lower Cretaceous siliciclastics, whereas the facing California Hills correspond to a diapiric inversion structure, bringing up evaporites and Lower and Middle Jurassic units.



(Kullberg et al., 2000)



(Manuppella et al., 1994)



(Manuppella et al., 1994)

STOP 12 ESPICHEL

Cape Espichel is located 50 km S of Lisbon. Tourists are drawn there due to breathtaking views of its cliffs facing the Atlantic Ocean.

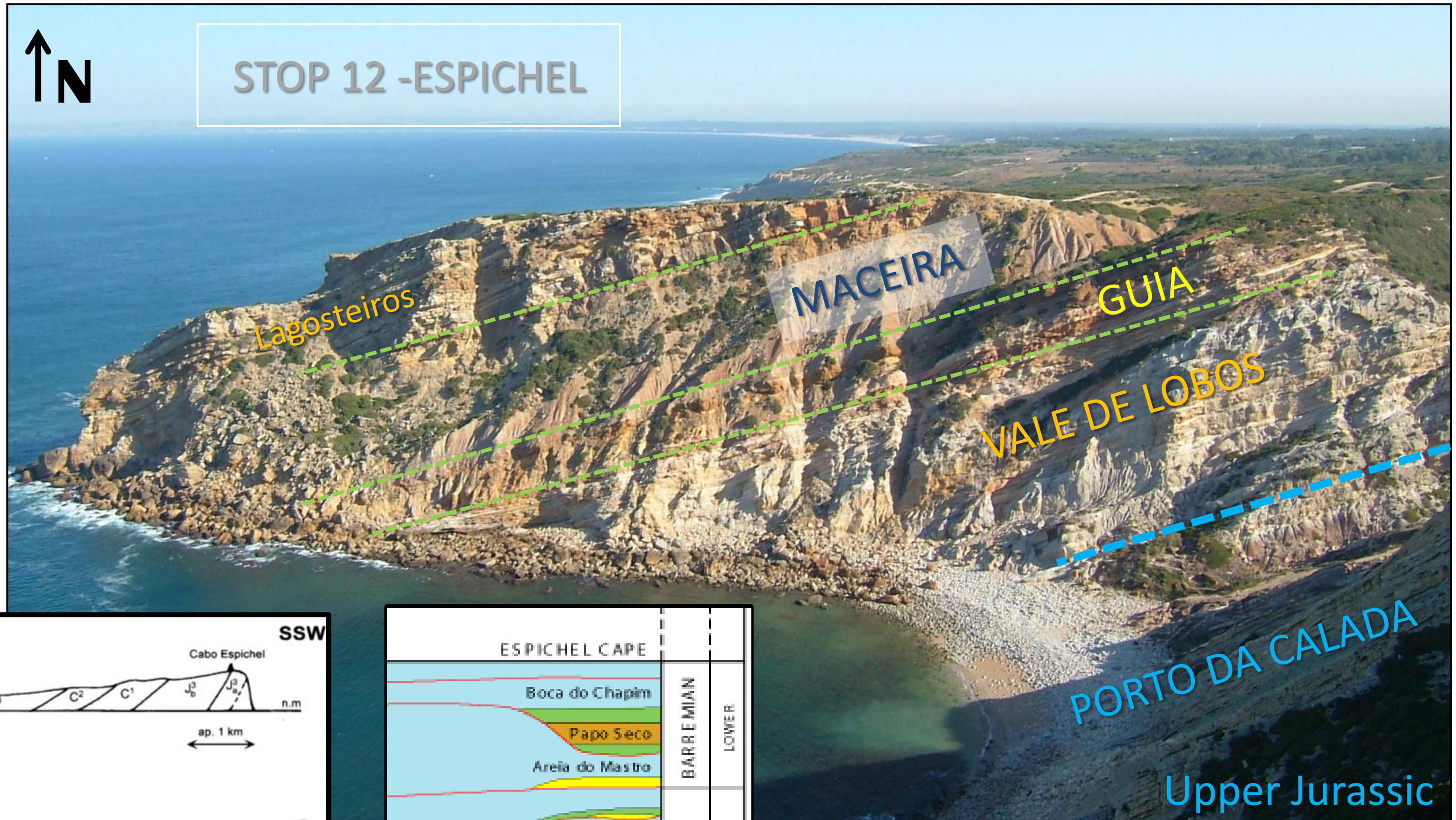
The location is famous for the sanctuary complex (l*Santuário de Nossa Senhora do Cabo Espichel*), built extremely close to the edge of the tall cliffs, which includes a church still in use today. Every year, a pilgrimage takes place with blessing of fishermen boats.

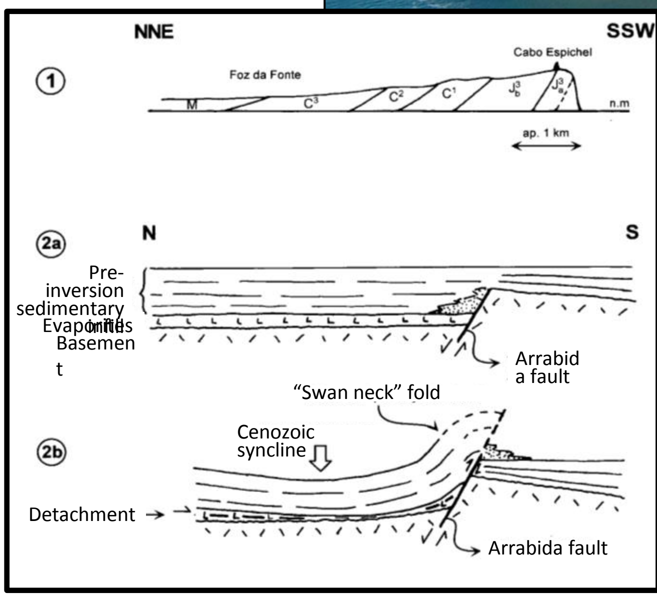
Several dinosaur fossil trackways are exposed in some of the now tilted Upper Jurassic strata which form the cape's cliffs. Local superstition interpreted the track ways as the path taken by the Holy Virgin ("Nossa Senhora") when riding a giant mule from the ocean and up the cliffs, which led to the eventual construction of the convent at that location.

To the North of the small chapel (a former medieval arab “morabit”), the cliff bordering the tiny beach exposes the transition to the first Lower Cretaceous continental deposits, related to the beginning of the opening of the North Atlantic. These siliciclastics , of Berriasian age, correspond to the first breakup surface of this basin.

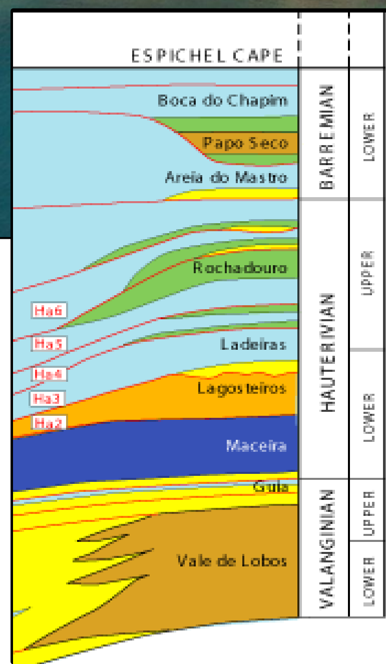
The Lower Jurassic sequence shows a succession of fluvial to shallow coastal marine deposits, resulting from an overall transgressive Berriasian - Hauterivian second-order eustatic cycle (Rey, 2010).

The tilting resulted from the Late Miocene uplift, prior to the Pliocene abrasion surface (also uplifted).





Espichel structure. **1** – Present day; **2a** - pre-inversion; **2b** – post-inversion (Kullberg et al., 2000).



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