Petroleum source rock evaluation of an Upper Miocene to Lower Pliocene clastic sedimentary succession in the Hellenic Fold and Thrust Belt: Ionian Foreland Basin, northwest Greece

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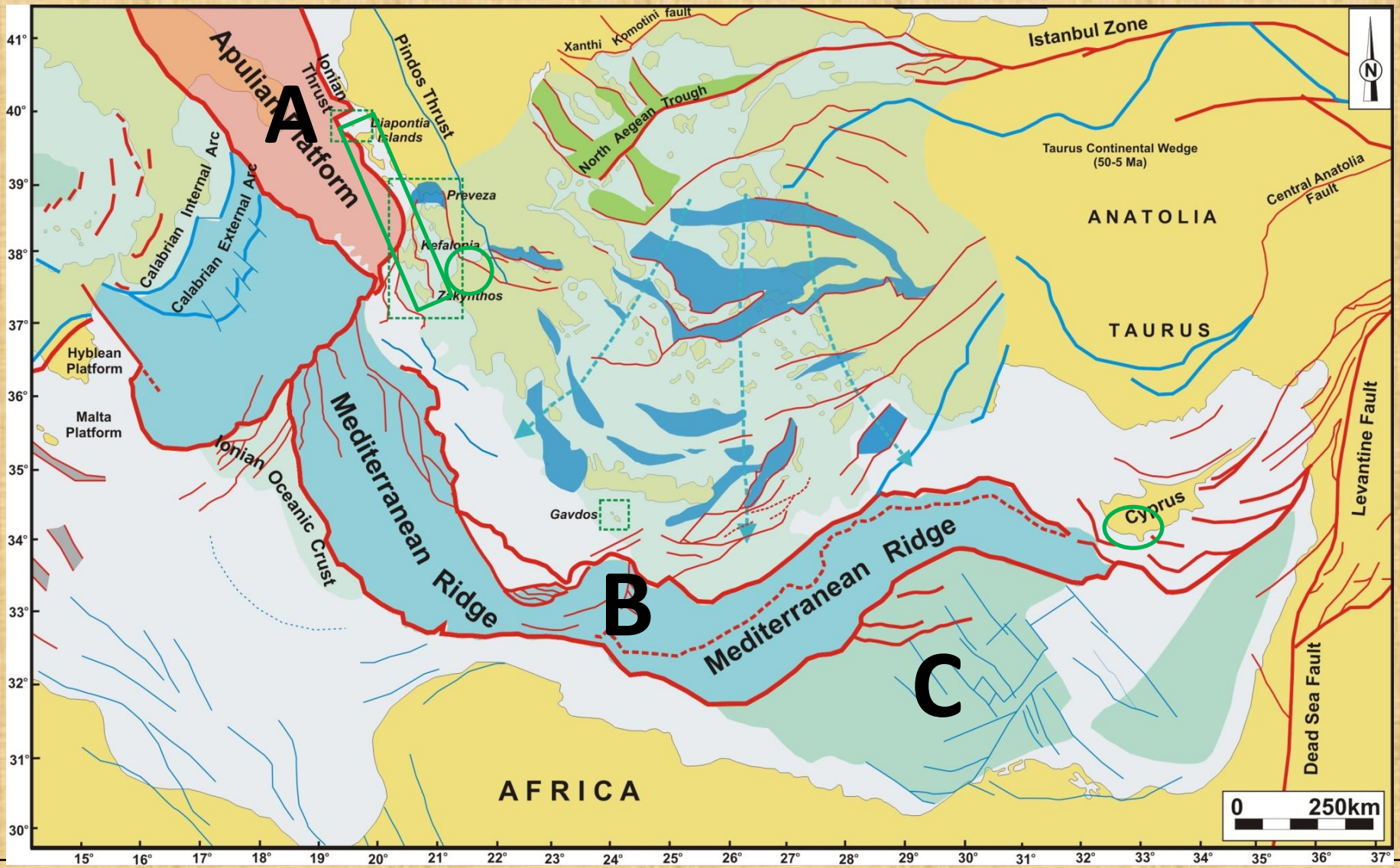
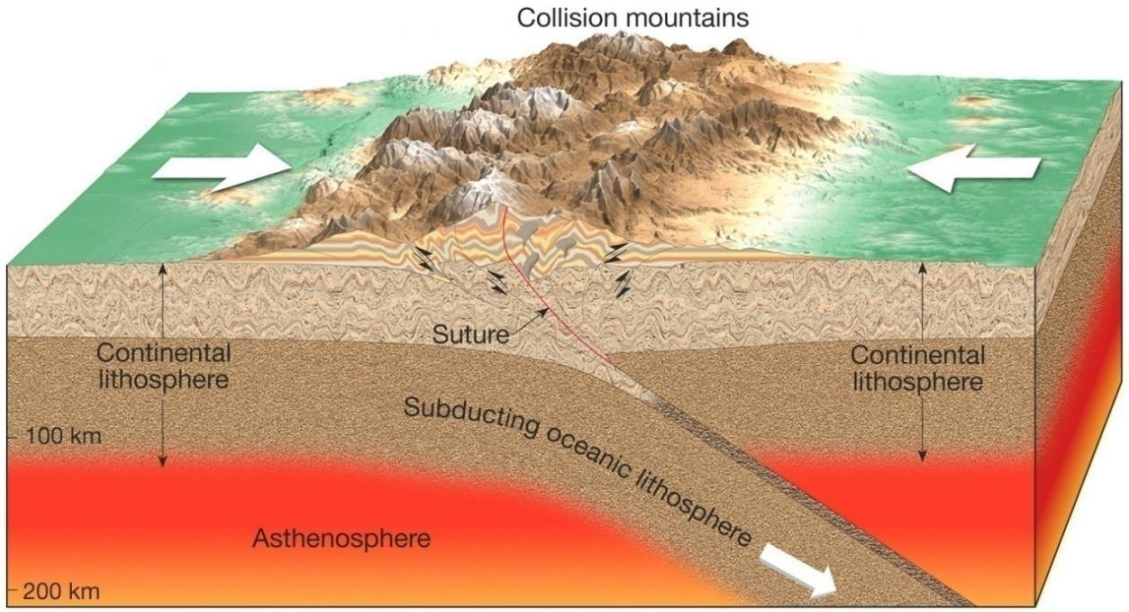


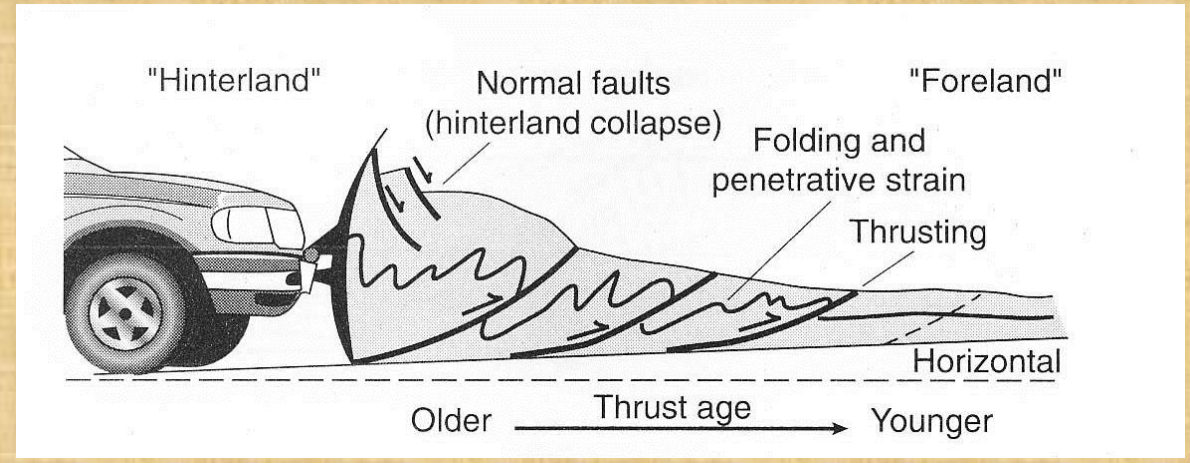
The Northwestern part (A), with the red, shows the Apulian platform, the Southern part (B), with the deep blue, show the Mediterranean Ridge, the North Aegean sea (C) with green, show the troughs with Prinos and Epanomi hydrocarbon fields, and (D) Levantine basin with huge oil and gas fields of Cyprus and Israel(modified from Chamot-Rooke et al., 2005).

PRINCIPLES

A Fold and Thrust Belt (FTB) is a series of mountainous foothills, adjacent to an orogenic belt, which form due to contractional tectonics.



C. Continental-continental



FTB commonly form in the forelands adjacent to major orogens as deformation propagates outwards.

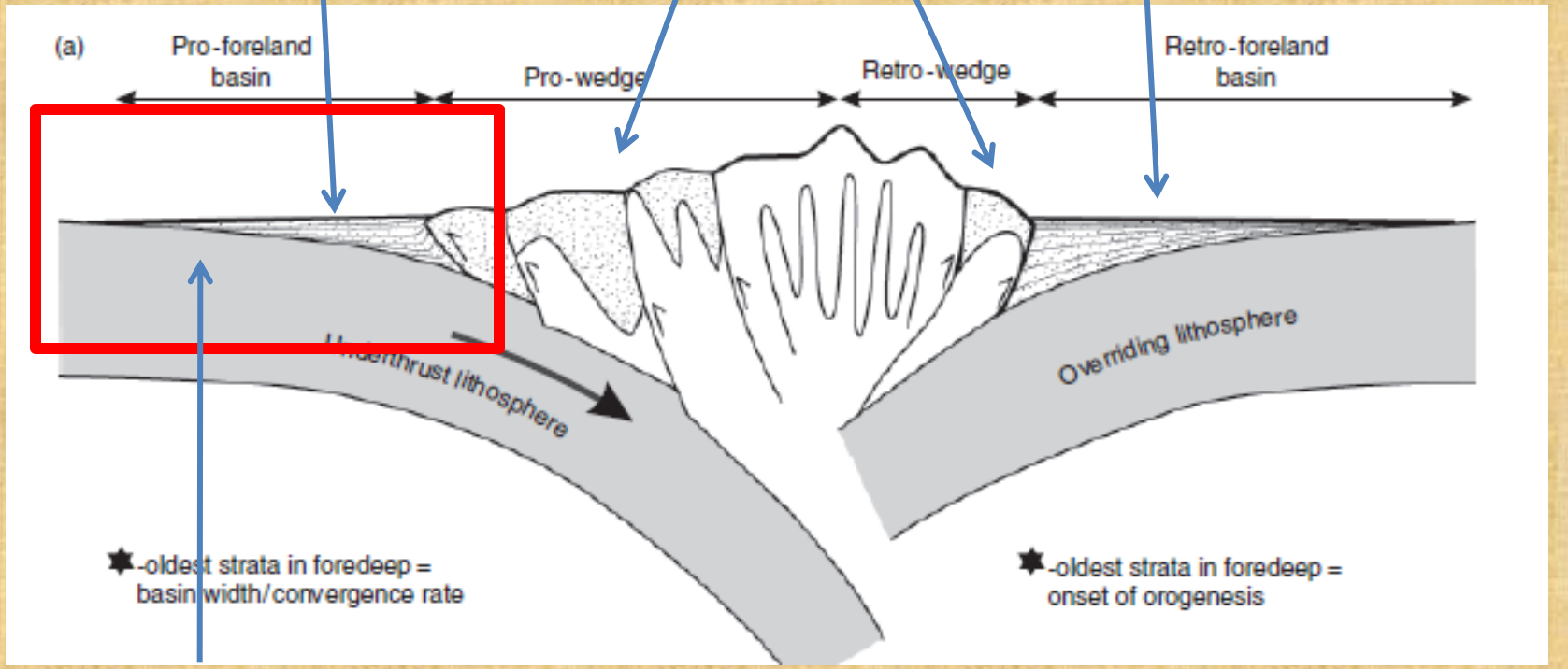
WEST-
IONIAN SEA

PINDOS OROGEN

EAST-
MAINLAND

PINDOS
PRO-FORELAND

PINDOS
RETRO-FORELAND



NEXT SLIDE

EAST-
MAINLAND

1. Foredeep (the "basin" itself).
2. Forebulge.
3. Back-bulge basin.
4. Wedge top/piggy-back basin.

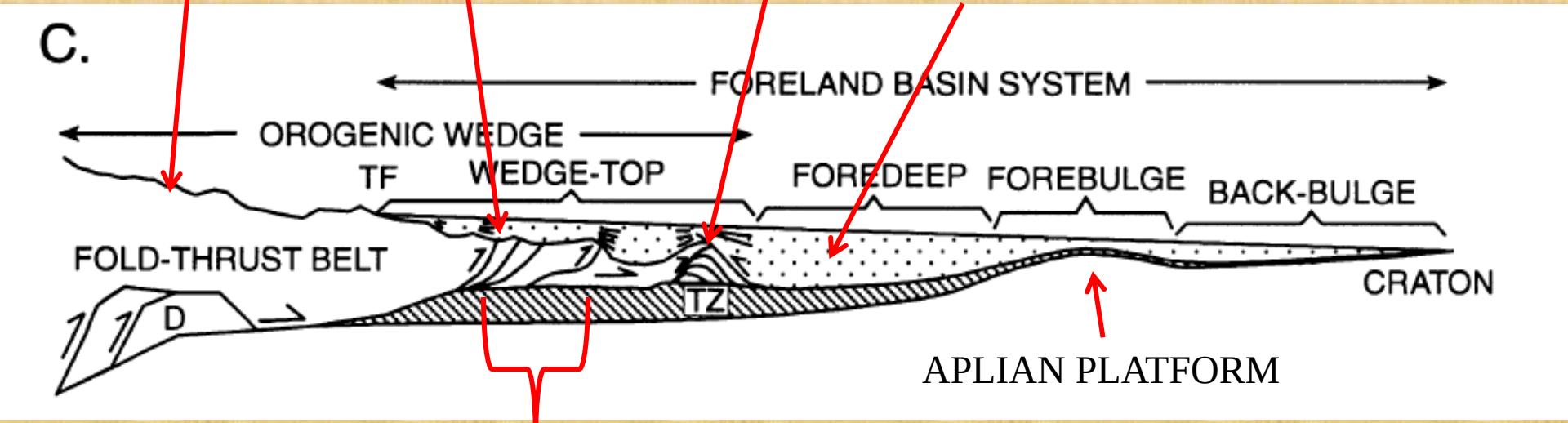
WEST-
IONIAN SEA

PINDOS OROGEN

PINDOS THRUST

IONIAN THRUST

IONIAN FORELAND BASIN



APLIAN PLATFORM

INTERNAL-MID-EXTERNAL
IONIAN THRUST

Soft-sediment deformation as reflected in the Miocene deposits in Cyprus: Evidence of syndepositional tectonics

by

E. Karoulla, P. Stylianou, Ch. Elia, G. Iliopoulos, A.G. Maravelis, A. Zelilidis

Characterizing the submarine fan deposits fans of Pindos foreland, western Greece: Constraints based on statistical treatment of bed thickness distribution, ichnofauna research and conglomerate clast composition analysis

by

N. Bourli, V. Savva, A. Noti, G. Pantopoulos, A.G. Maravelis, A. Zelilidis

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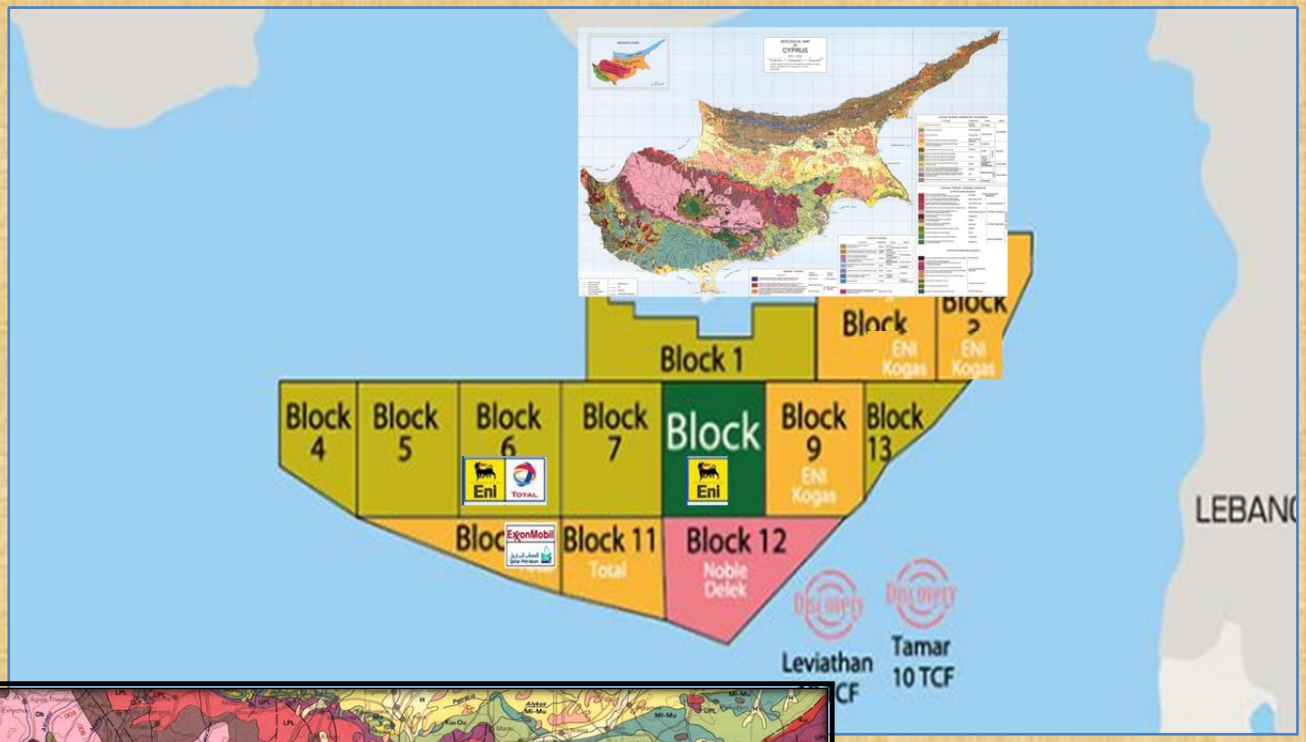
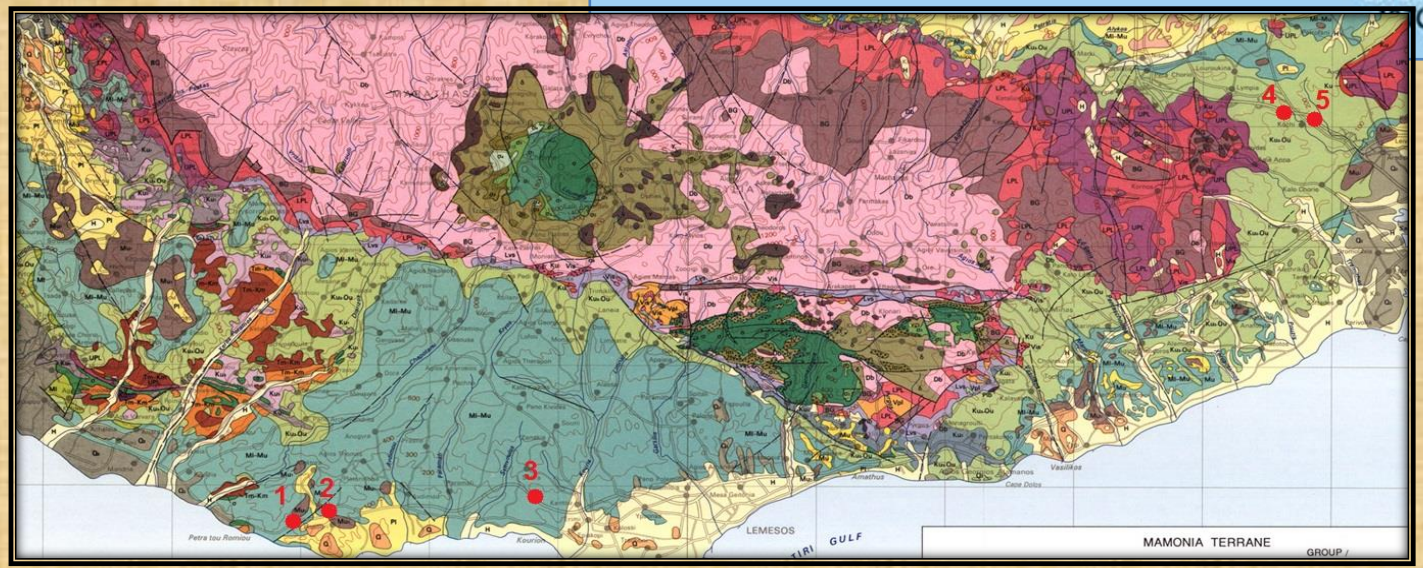
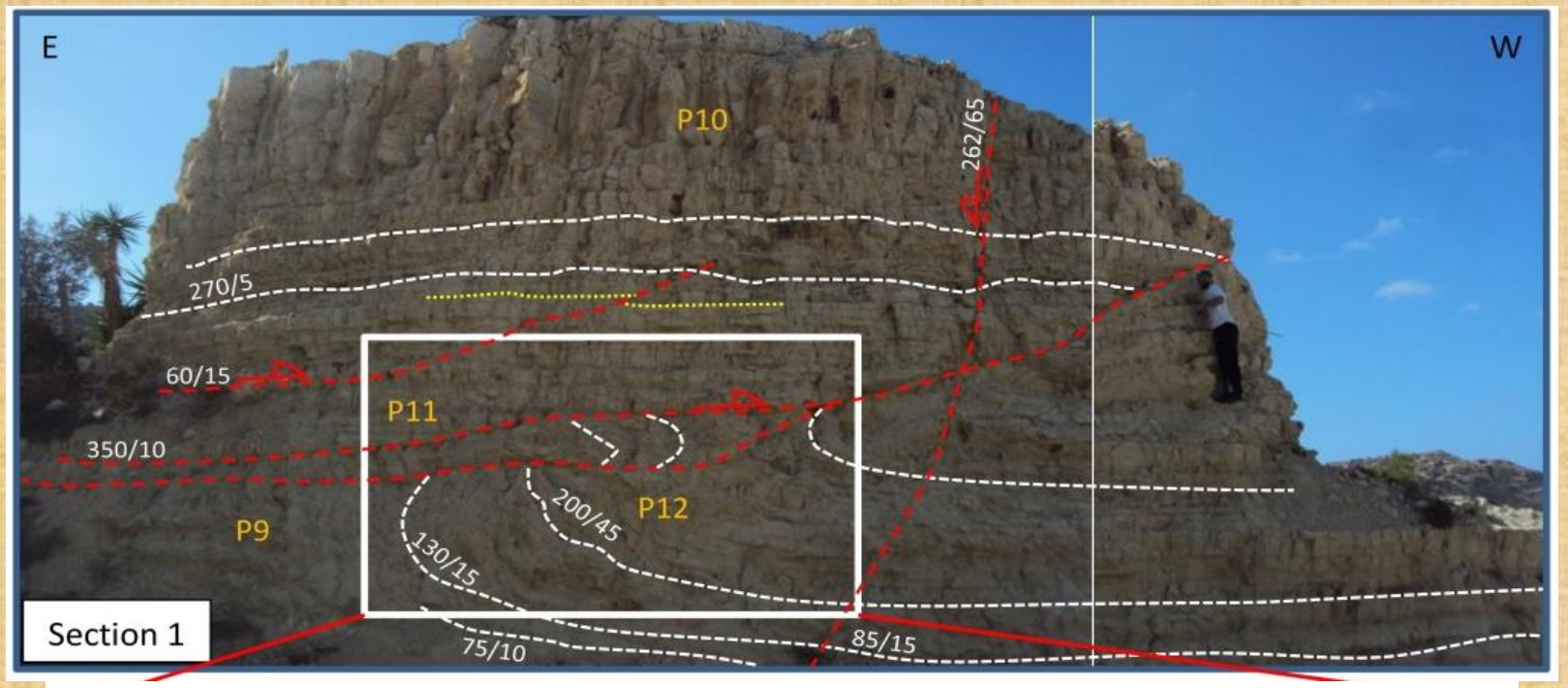
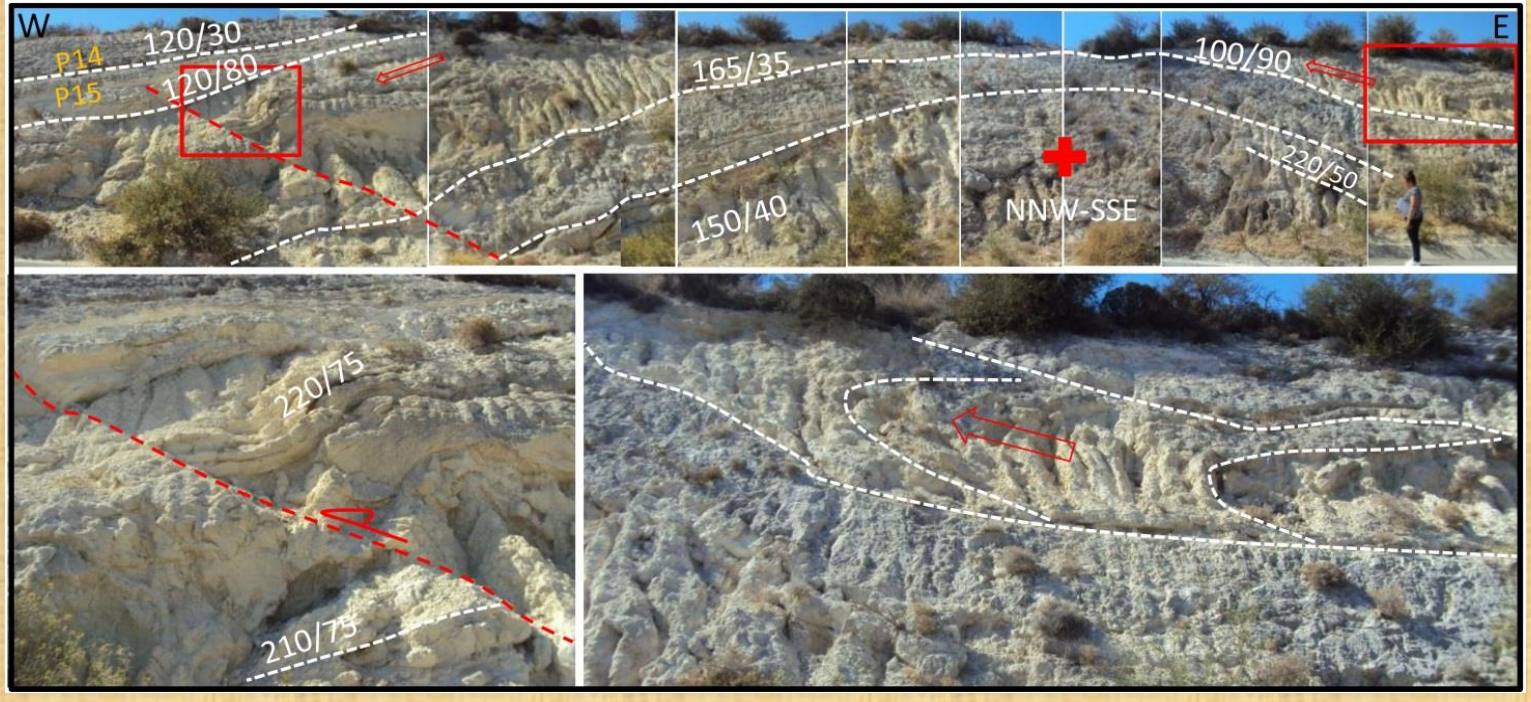
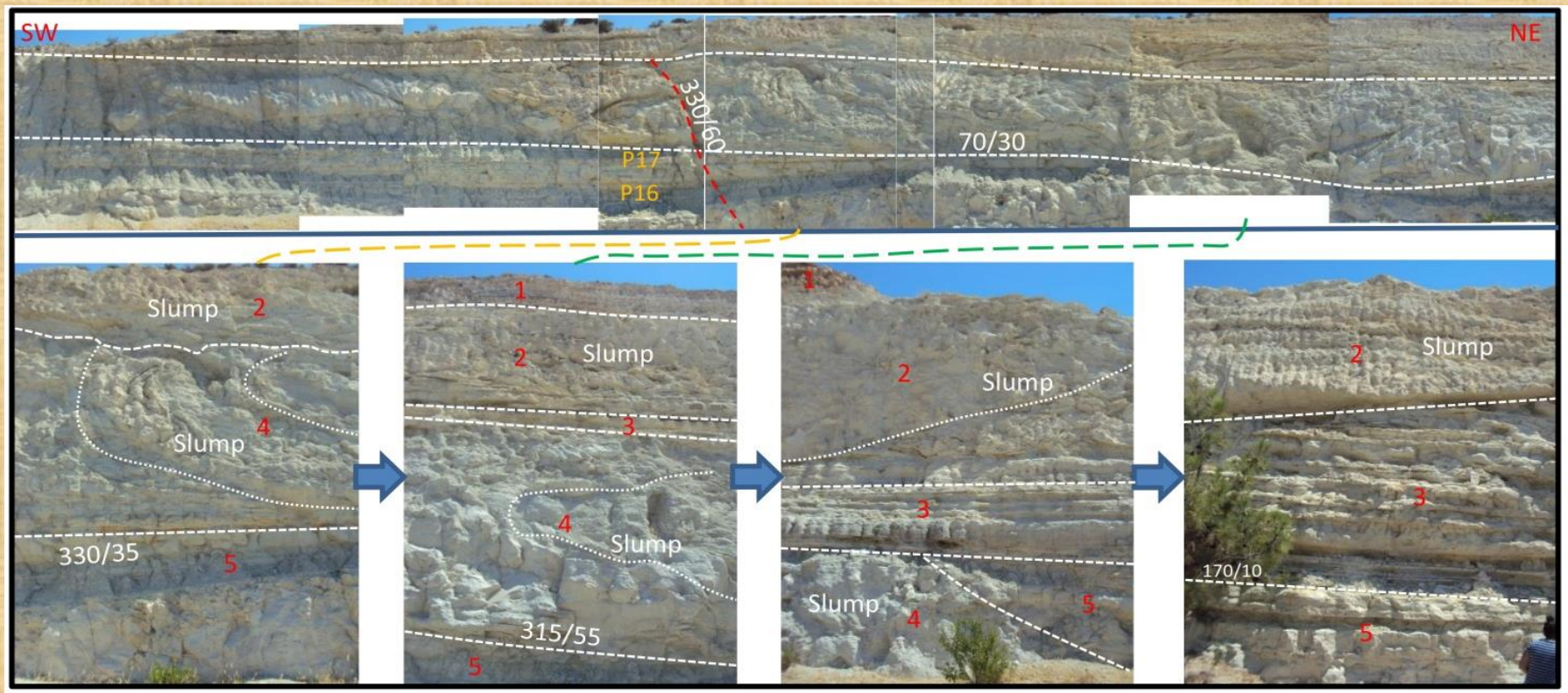
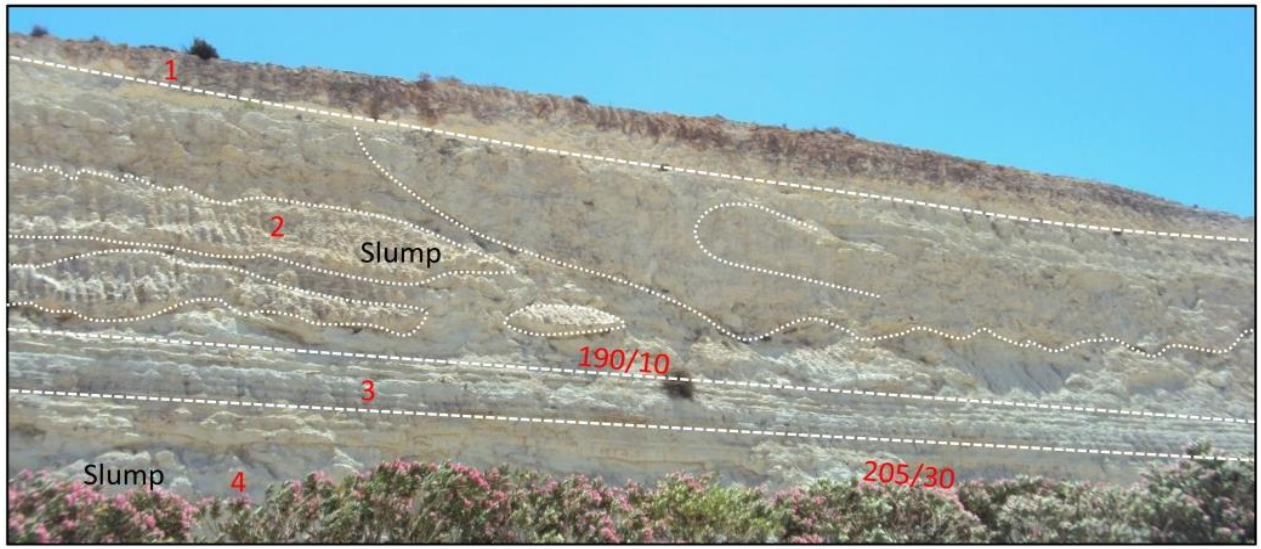


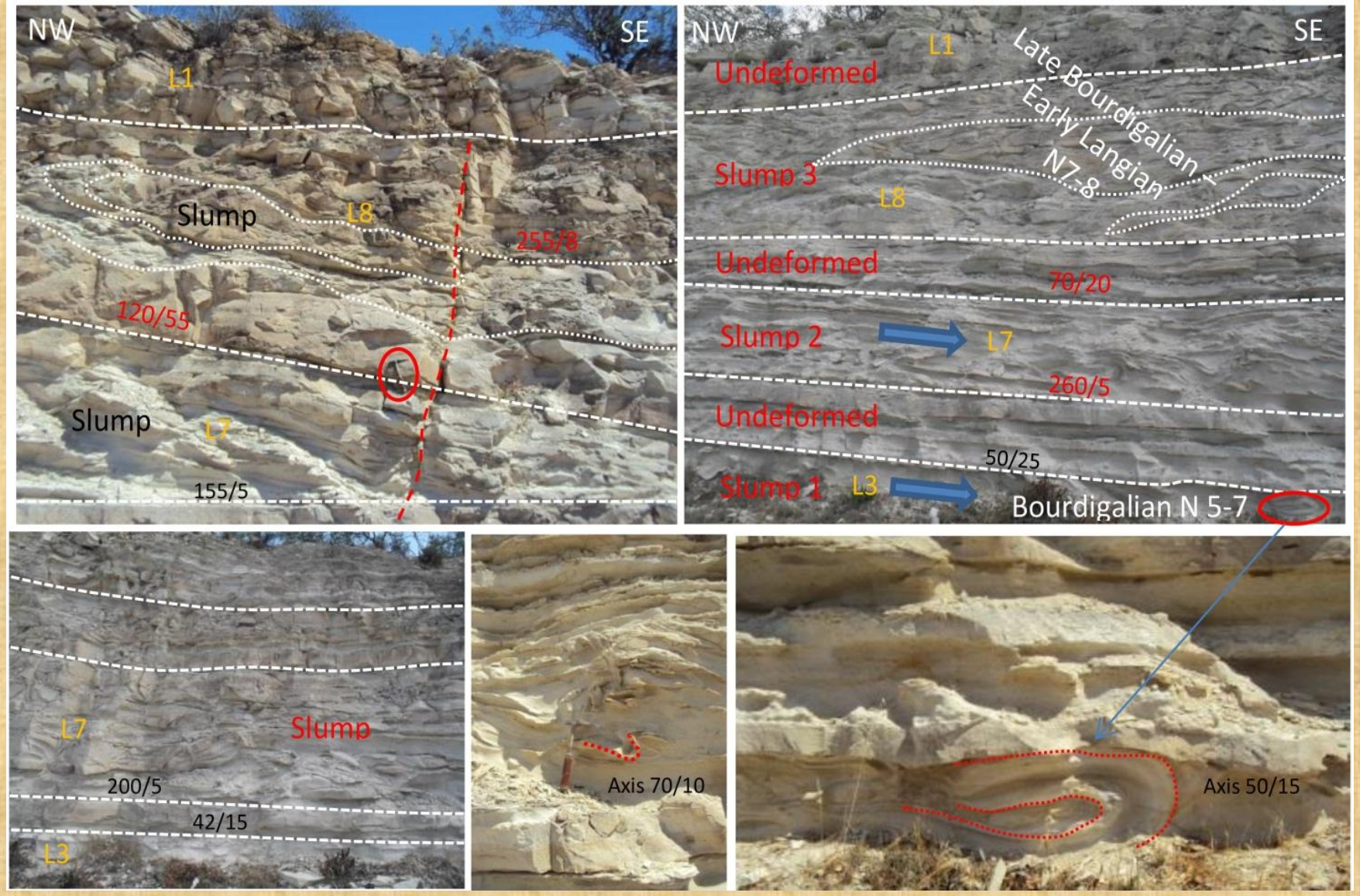


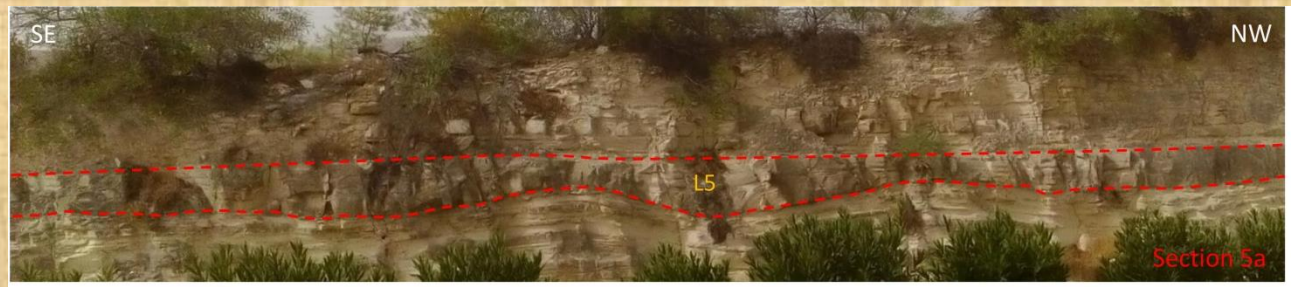

E
W
P10
262/65
270/5
60/15
P11
350/10
P12
200/45
P9
130/15
Section 1
75/10
85/15


W
E
P14
P15
120/30
120/80
165/35
150/40
NNW-SSE
100/90
220/50
220/75
210/75

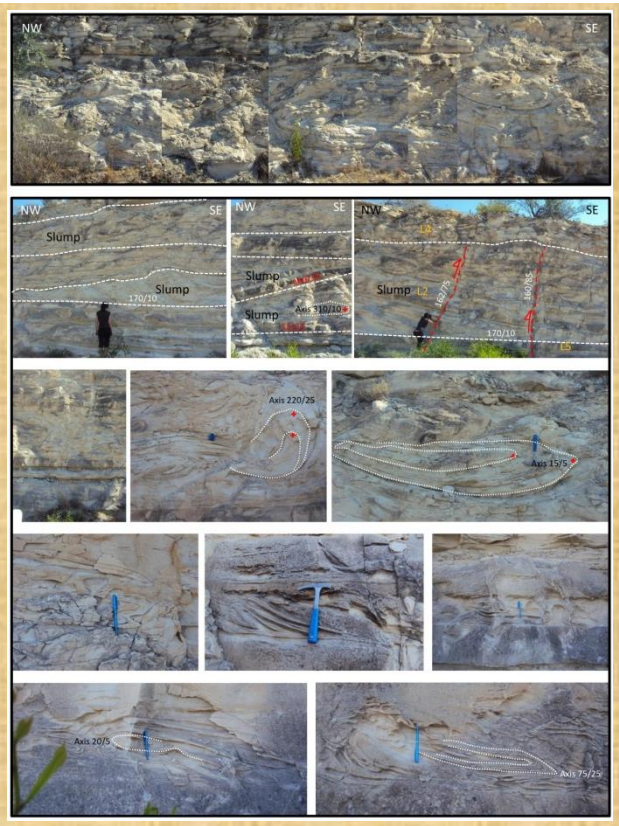

SW
NE
330/60
P17
P16
70/30
Slump
2
Slump
4
330/35
5
1
2
Slump
3
4
Slump
315/55
5
1
2
Slump
3
Slump
4
5
2
Slump
3
170/10
5


1
2
Slump
190/10
3
Slump
4
205/30

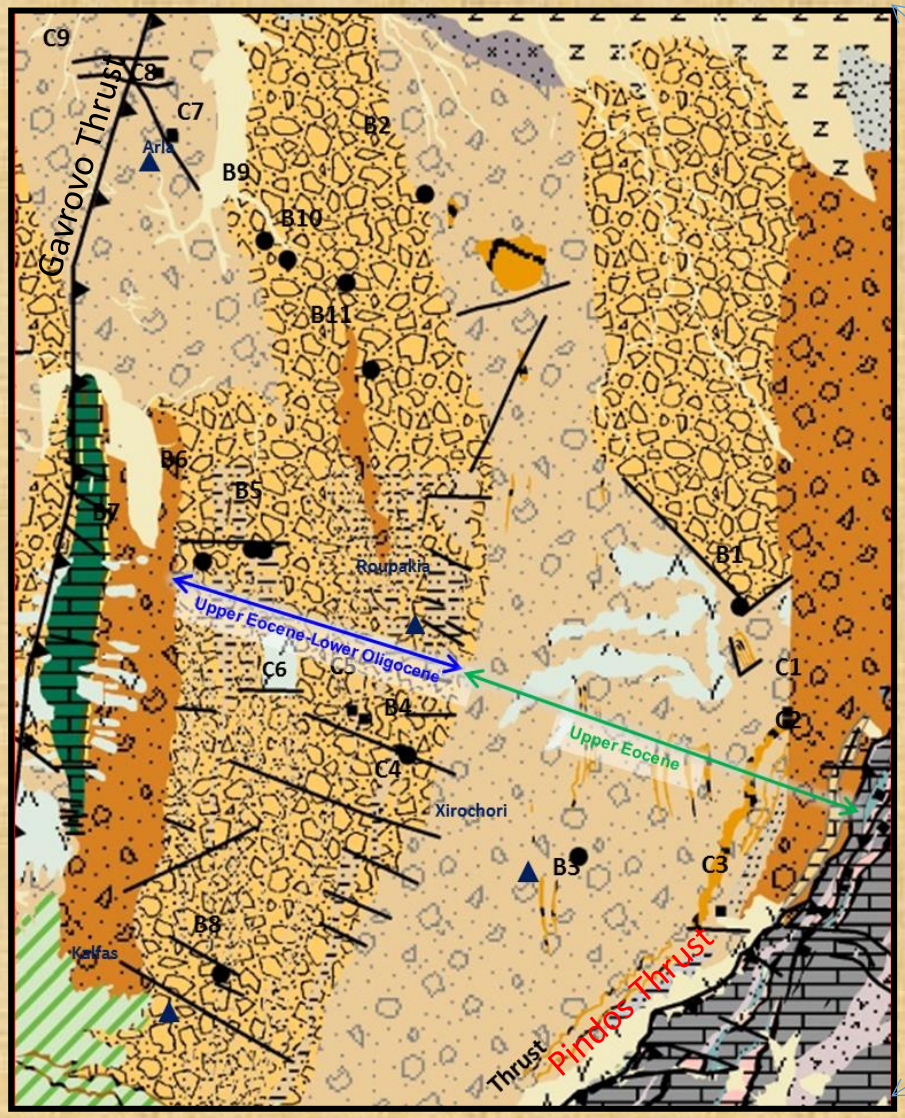

NW
SE
L1
Slump
L8
255/8
120/55
Slump
L7
155/5
NW
SE
L1
Undeformed
Late Bourdigalian
Early Langian
N7-8
Slump 3
L8
Undeformed
70/20
Slump 2
L7
260/5
Undeformed
50/25
Slump 1
L3
Bourdigalian N 5-7
L7
Slump
200/5
42/15
L3
Axis 70/10
Axis 50/15

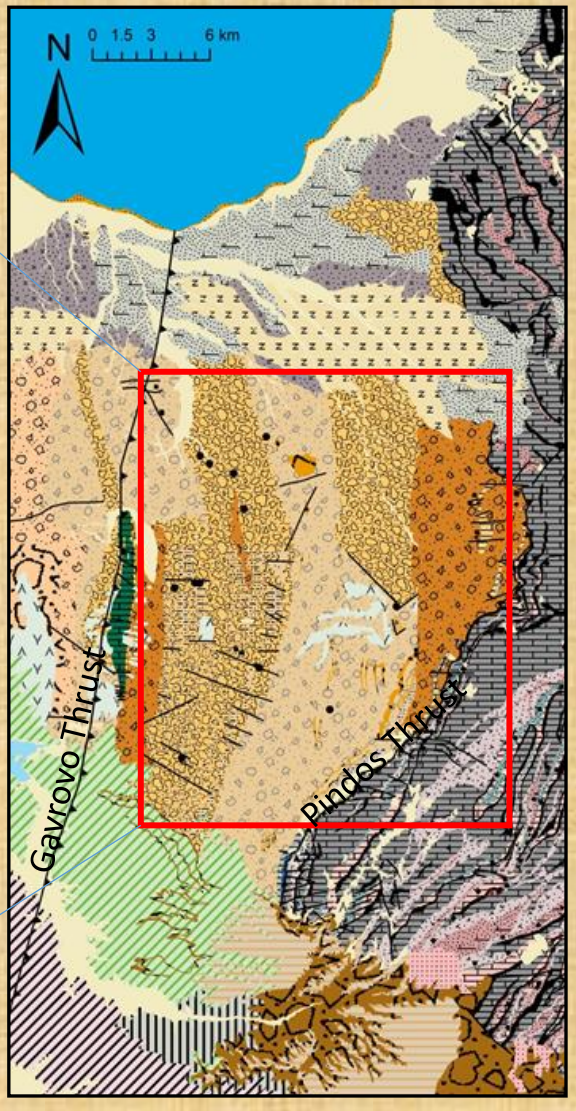

SE
NW
L5
Section 5a

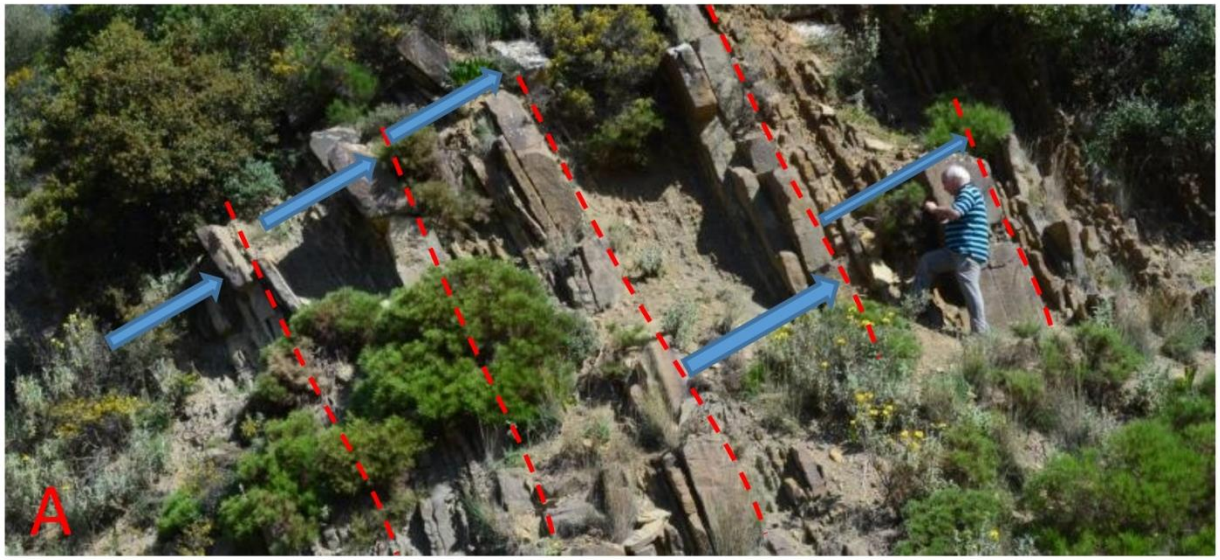

L4
164/85
slump
236/5
slump
L2
52/5
255/5
L6
L5
Section 5b

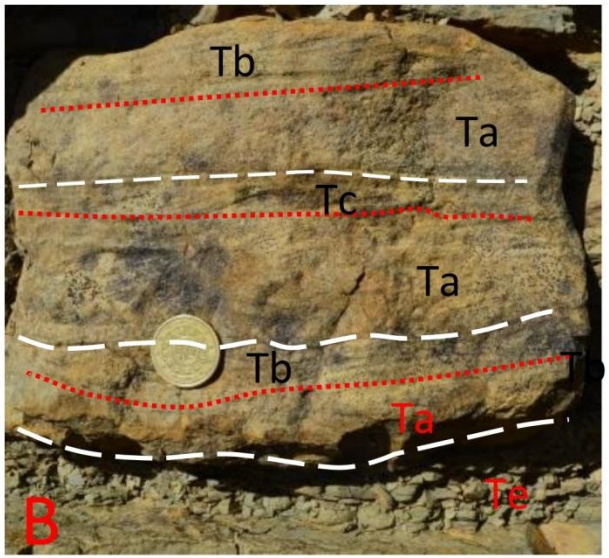

NW
SE
Slump
Slump
170/10
Slump
Axis 310/10
Slump L2
170/10
Axis 220/25
Axis 15/5
Axis 20/5
Axis 75/25

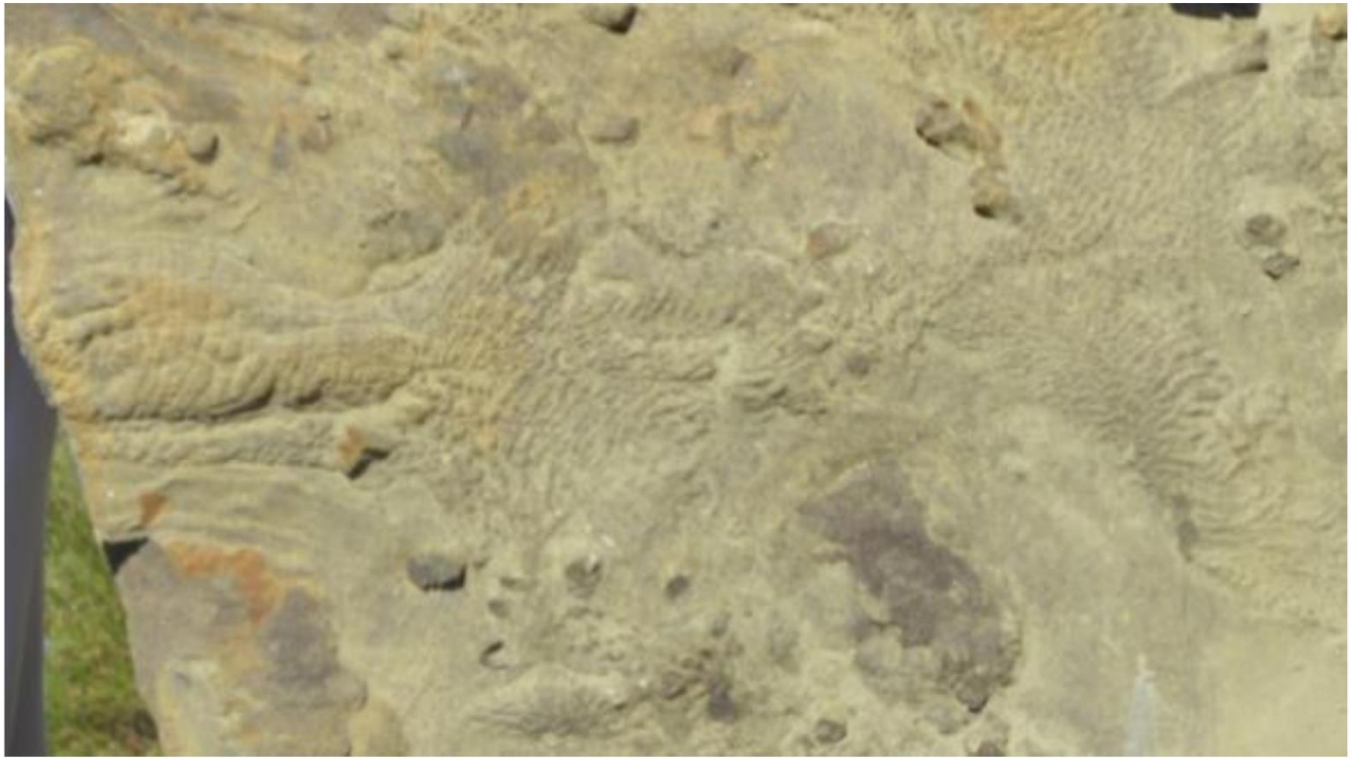
Characterizing the submarine fan deposits fans of Pindos foreland, western Greece: Constraints based on statistical treatment of bed thickness distribution, ichnofauna research and conglomerate clast composition analysis

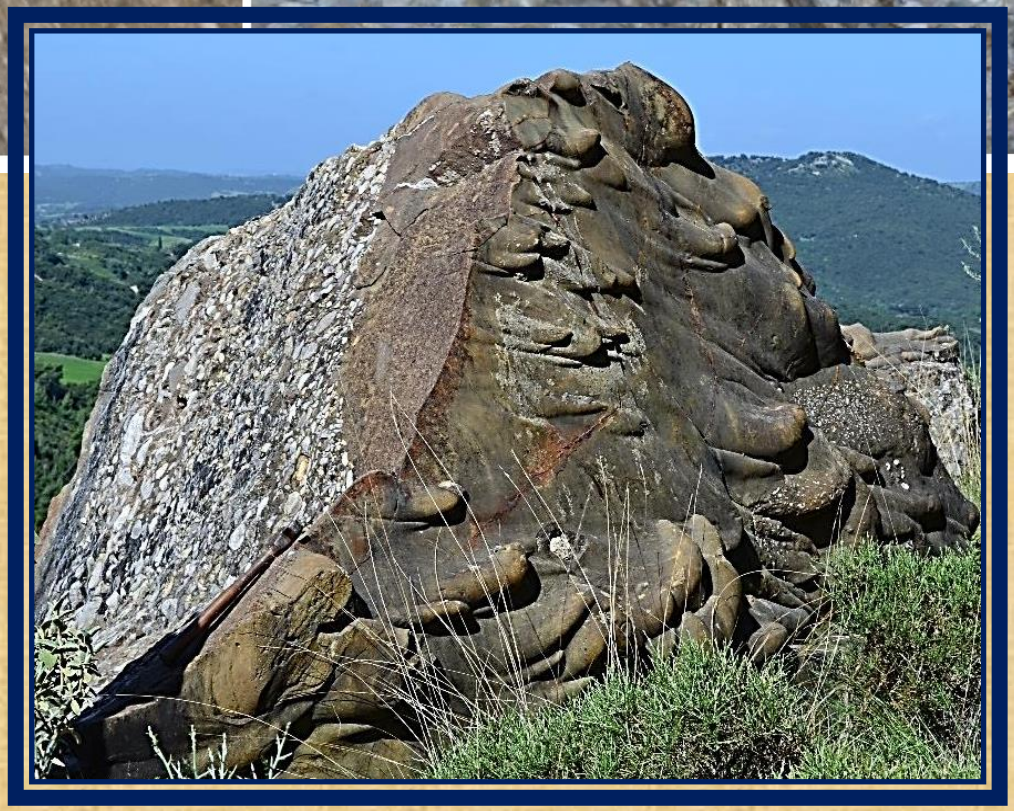


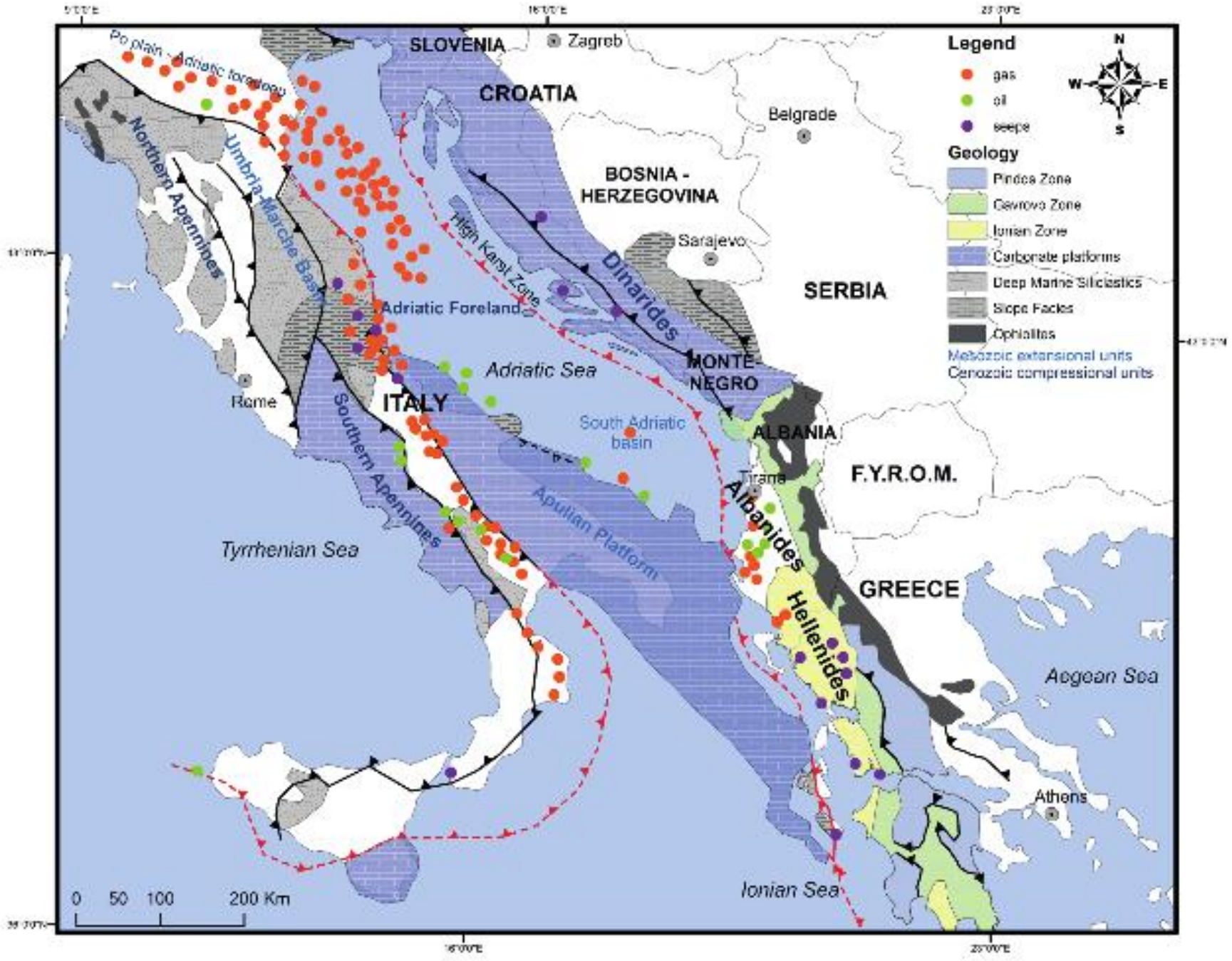



A


Tb
Ta
Tc
Ta
Tb
Ta
Te
B






SLOVENIA
Zagreb
CROATIA
Belgrade
BOSNIA - HERZEGOVINA
Sarajevo
SERBIA
MONTE-NEGRO
ALBANIA
F.Y.R.O.M.
Tirana
GREECE
ITALY
Rome
Adriatic Sea
Tyrrhenian Sea
Ionian Sea
Aegean Sea
Athens
Po plain - Adriatic foredeep
Northern Apennines
Umbria-Marche Basin
High Karst Zone
Adriatic Foreland
Dinarides
Southern Apennines
South Adriatic basin
Apulian Platform
Albanides
Hellenides
0 50 100 200 Km
Legend
gas
oil
seepe
Geology
Pindos Zone
Gavrovo Zone
Ionian Zone
Carbonate platforms
Deep Marine Siliciastics
Slope Facies
Ophiolites
Mesozoic extensional units
Cenozoic compressional units
N
S
W
E

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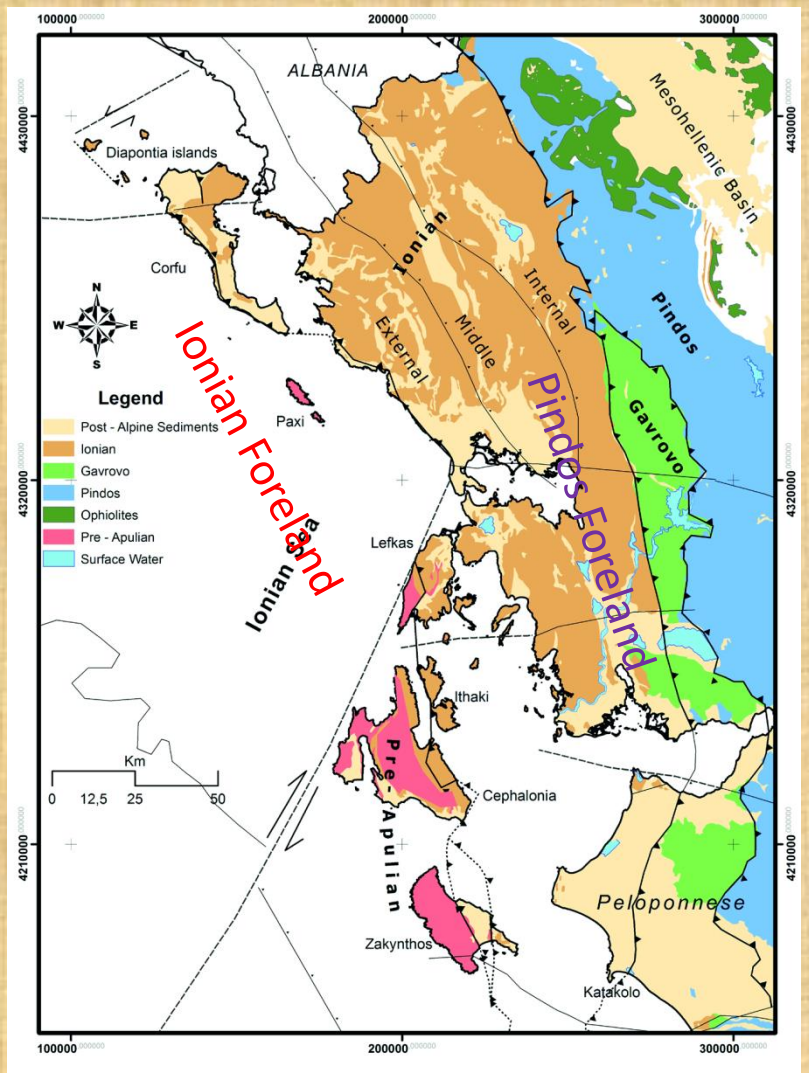
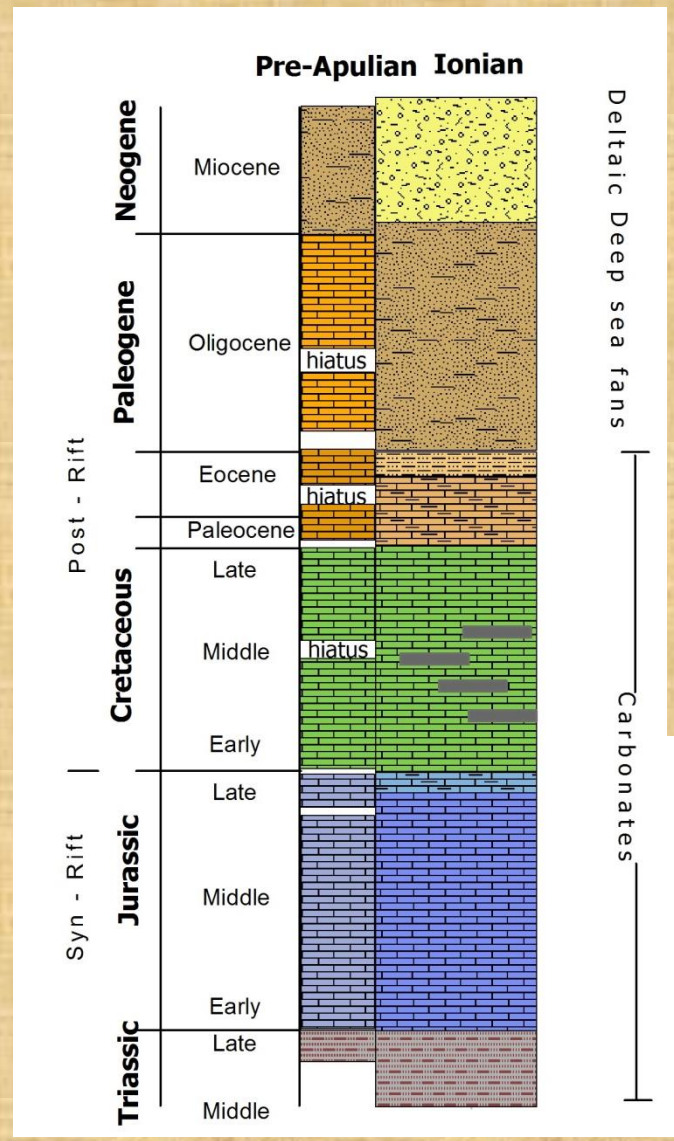
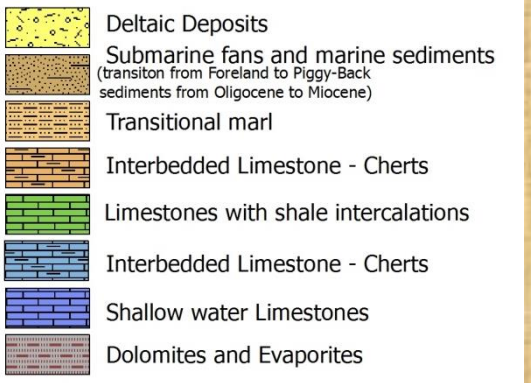


Introduction – Geological setting

Geological map of the external Hellenides in NW Greece showing the Ionian foreland with the major structural elements within Pindos foreland.

PRE-APULIAN ZONE

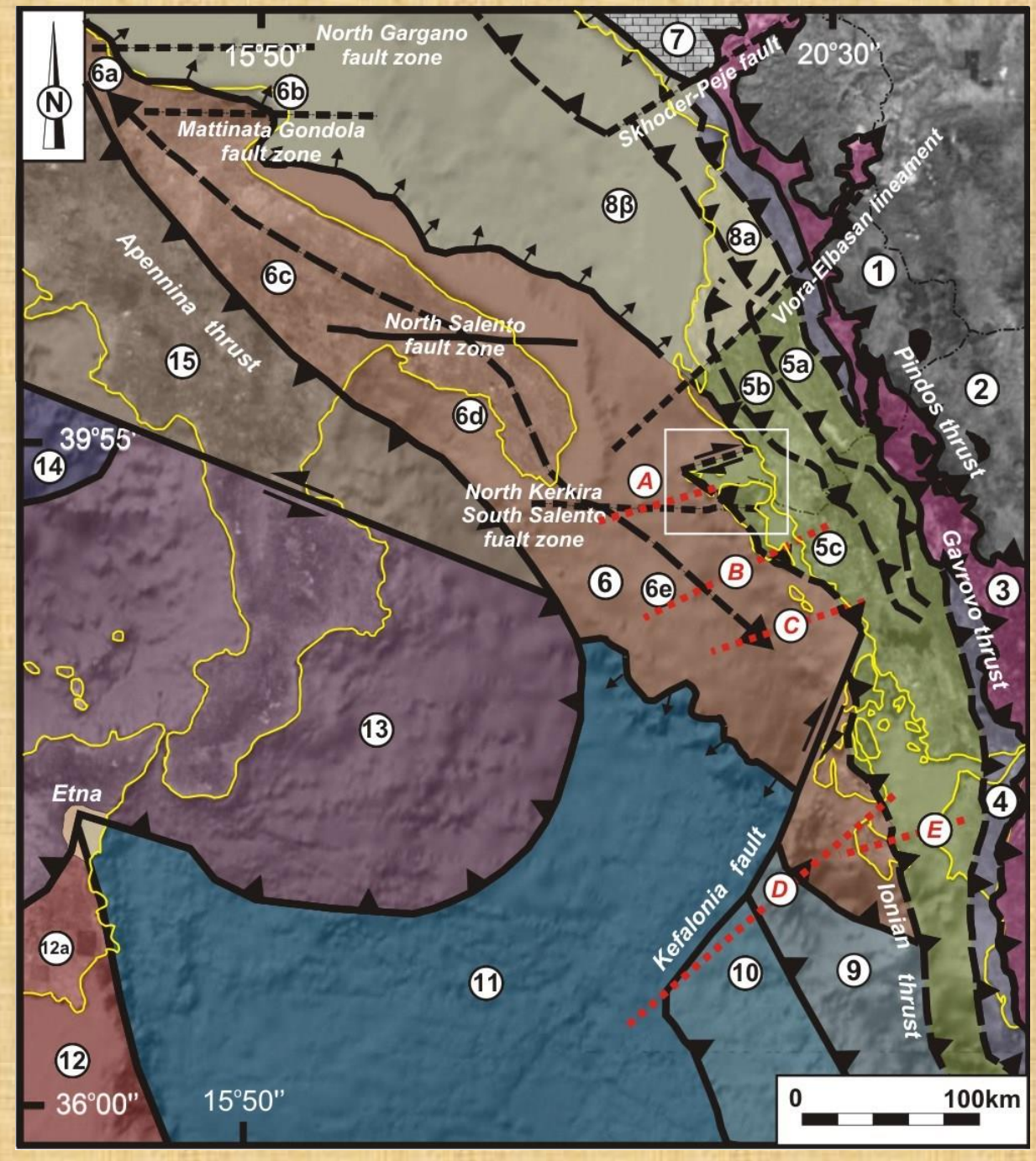


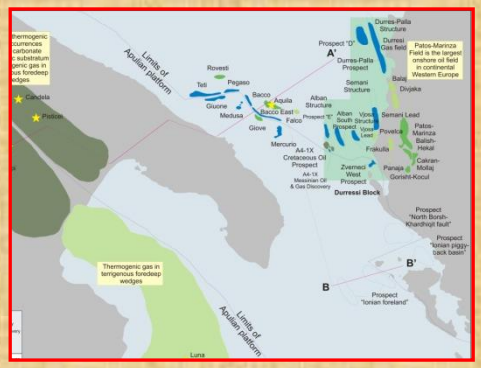


AGE			LITHOLOGY
QUATERNARY	PLEISTOCENE	CALABRIAN	marine marls
TERTIARY NEOGENE	PLIOCENE	PIACENZIAN	marine marls and sands
		ZANCLEAN	
	MIOCENE	MESSINIAN	marls
		TORTONIAN	
		SERRAVALIAN	
		LANGHIAN	marly limestones, marls
		BURDIGALIAN	
		AQUITANIAN	
PALEOGENE	OLIGOCENE	CHATTIAN	often marly pelagic limestones with breccias, extensive hiatuses
		RUPELIAN	
	EOCENE	PRIABONIAN	pelagic limestones, breccias limestones
		BARTONIAN	
		LUTETIAN	
		YPRESIAN	
	PALEOCENE	THANETIAN	
		SELANDIAN	
		DANIAN	
CRETACEOUS	LATE	MAASTRICHTIAN	undifferentiated, brecciated upwards limestones which cherts, hiatuses
		CAMPANIAN	
		SANTONIAN	
		CONIACIAN	
		TURONIAN	
		CENOMANIAN	
	EARLY	ALBIAN	
		APTIAN	
		BARREMIAN	
		HAUTERIVIAN	
		VALANGINIAN	
		BERRIASIAN	

PRE APULIAN (OR PAXOI) ZONE

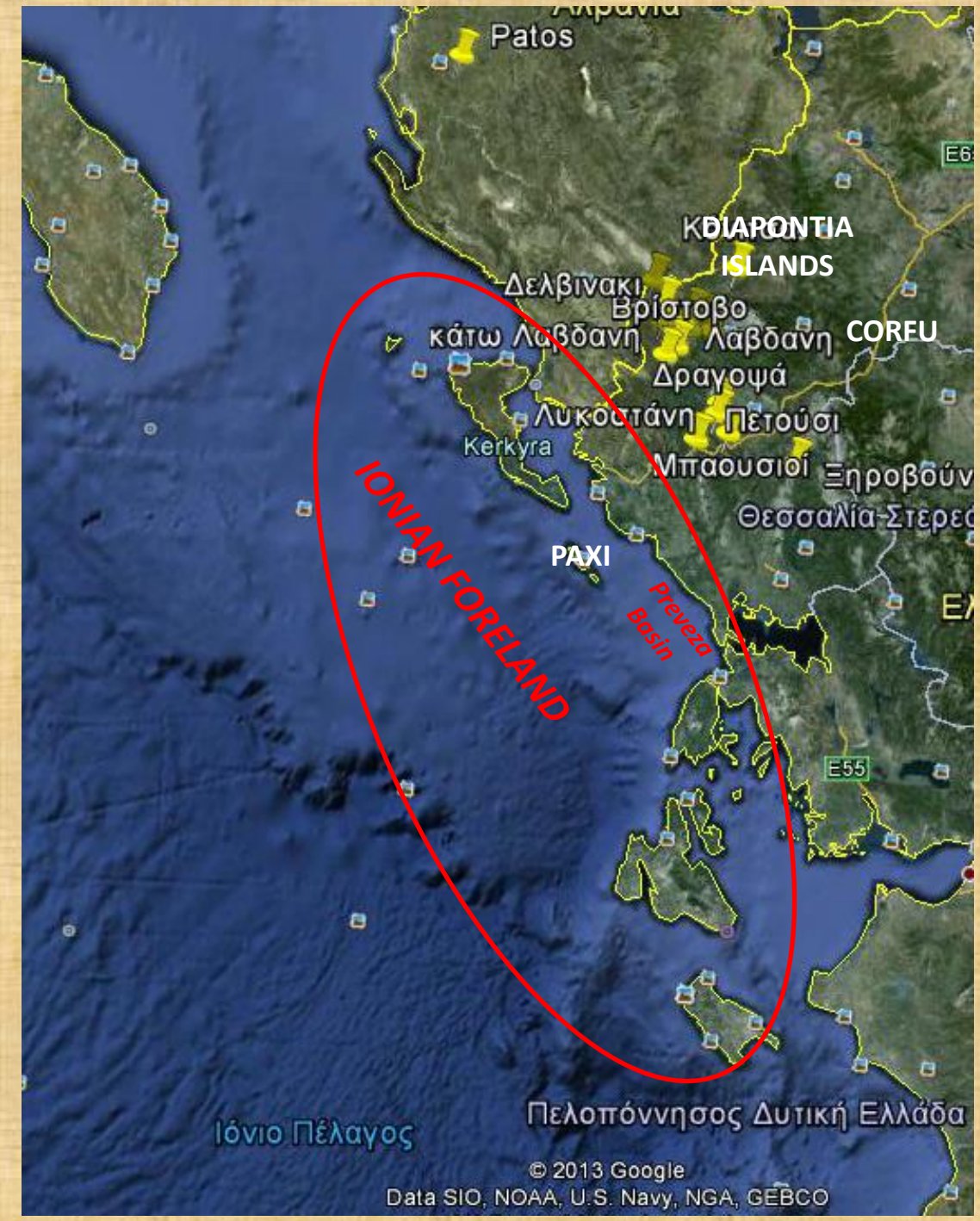
AGE			LITHOLOGY
JURASSIC	LATE	TITHONIAN	limestones, marly limestones, marls, occasionally hiatuses
		KIMMERIDGIAN	
		OXFORDIAN	
	MIDDLE	CALLOVIAN	thin-bedded limestones with cherts,marly limestones and marls,anhydrites
		BATHONIAN	
		BAJOCIAN	
		AALENIAN	
	EARLY	TOARCIAN	limestones, dolomitic limestones, anhydrites, shale intercalations
		PLIENSBACHIAN	
		SINEMURIAN	
		HETTANGIAN	
TRIASSIC	LATE	RHAETIAN	evaporites, dolomites, shale intercalations
		NORIAN	
		CARNIAN	
	MIDDLE	LADINIAN	
		ANISIAN	??????
	EARLY	SCYTHIAN	

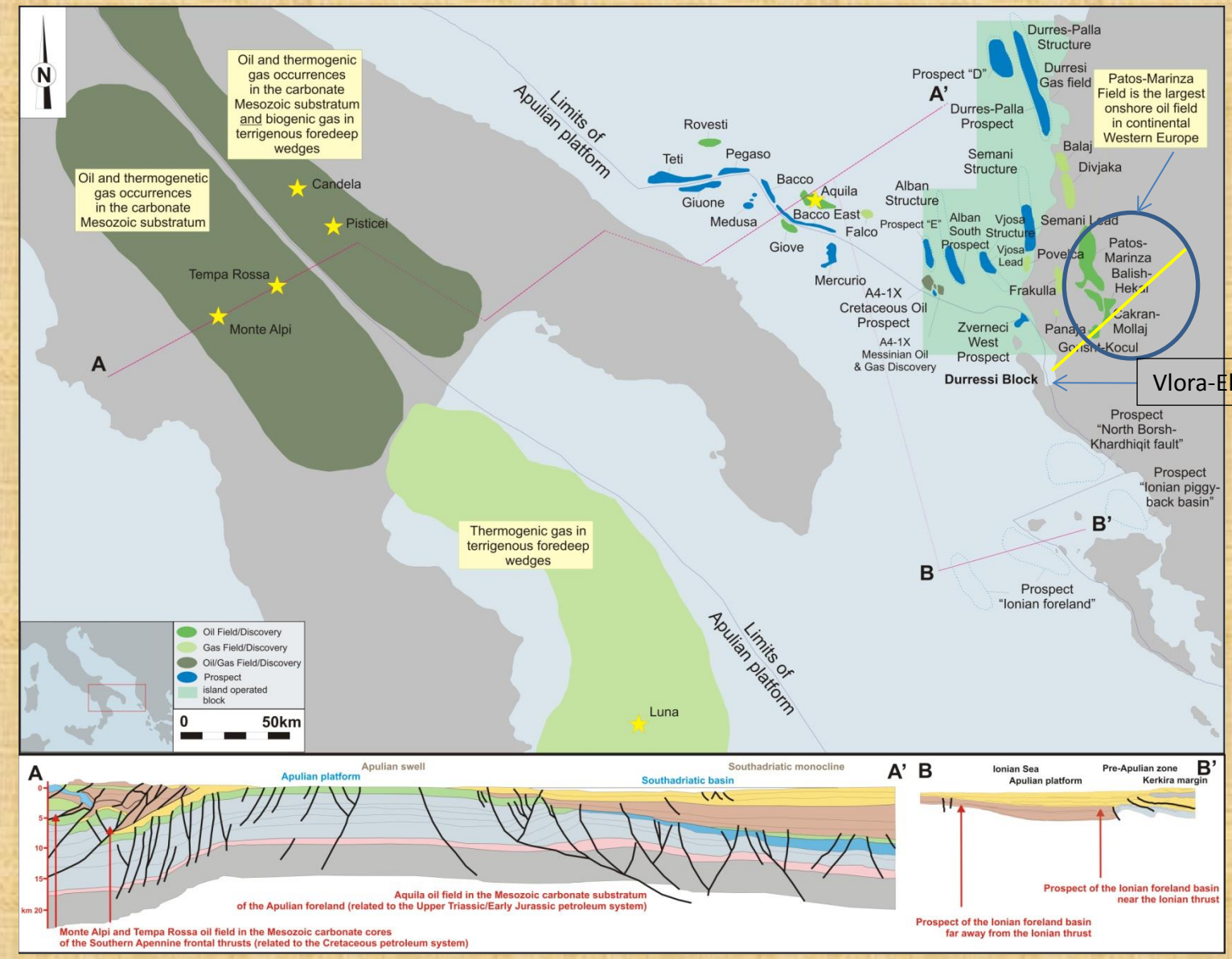




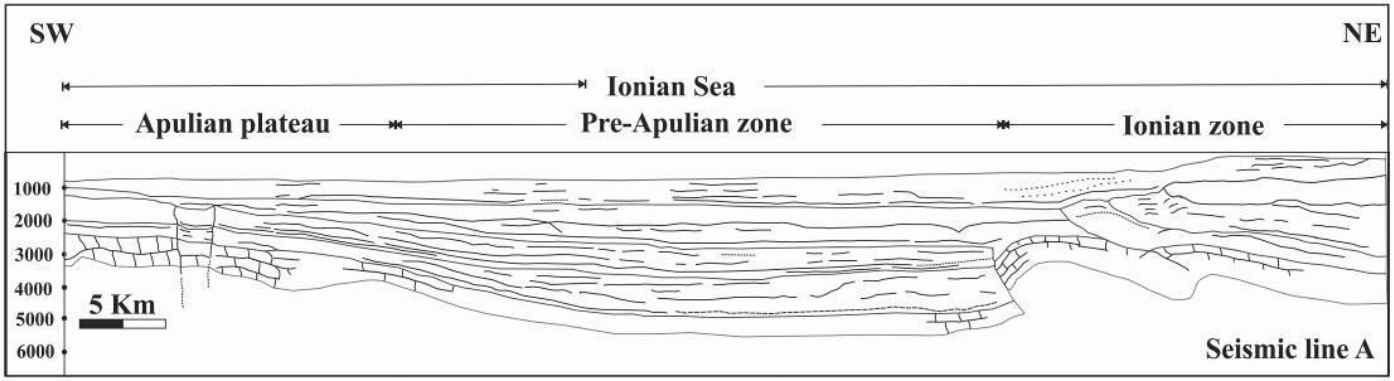
The red dashed lines are seismic lines.
The yellow line is the coastline.

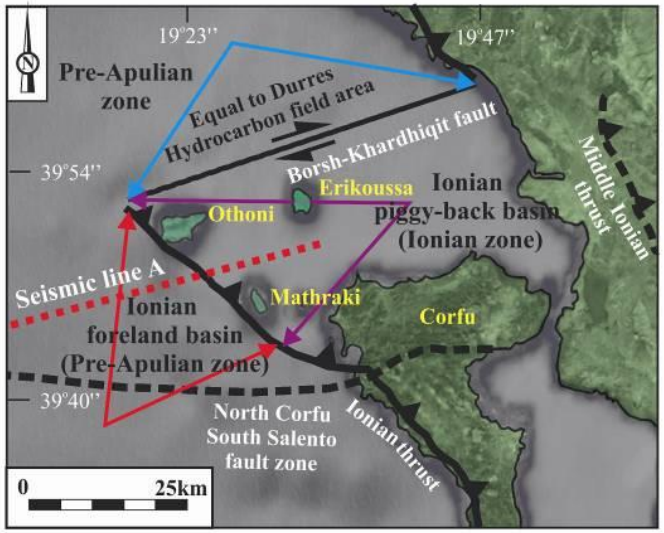
1. Internal Albanides,
2. Internal Helenides,
3. Pindos zone (Krasta),
4. Gavrovo zone (Kruja),
5a. Internal Ionian zone,
5b. Middle Ionian zone,
5c. External Ionian zone,
6. Apulian platform:
   6a. Plateau Rospo,
   6b. Gargano promontory,
   6c. Murge ridge,
   6d. Salento peninsula,
   6e. Apulia plateau,
7. Albanian Alps,
8a. Dures basin, 8b. Ionian-Albania basin,
9. Hellenic trench,
10. Mediterranean ridge,
11. Ionian abyssal plain,
12. Africa, 12a. Hyblean plateau,
13. Calabrian arc,
14. South Tyrrhenian sea,
15. South Apennine.


Patos
DIAPONTIA ISLANDS
Δελβινακι
Βρίστοβο
κάτω Λαβδανη
Λαβδανη
CORFU
Δραγοψά
Λυκόστάνη
Πετούσι
Kerkyra
Μπαουσιοί
Ξηροβούν
Θεσσαλία-Στερε
IONIAN FORELAND
PAXI
Preveza Basin
E55
Ιόνιο Πέλαγος
Πελοπόννησος Δυτική Ελλάδα
© 2013 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

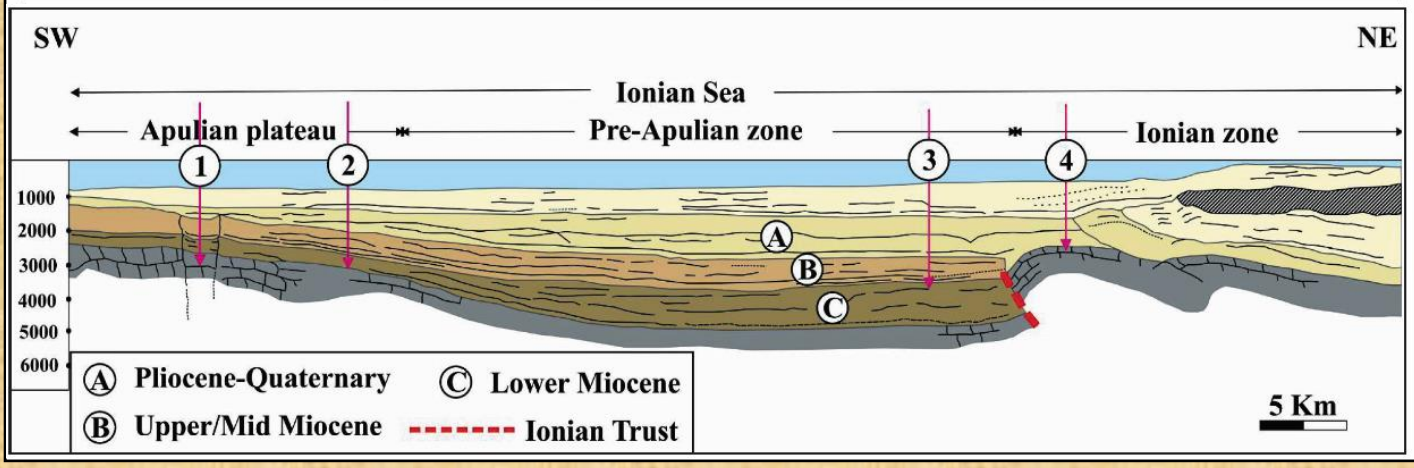


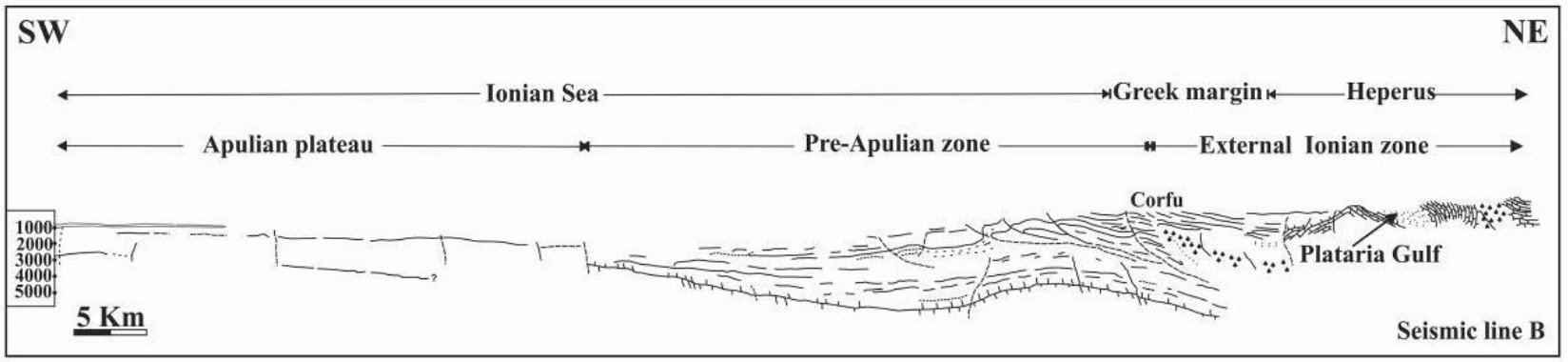
Synthetic sketch map showing Italian and Albanian hydrocarbon plays with an attempt for correlation with the northwestern part of Greece (Diapontia islands). Cross-sections AA' and BB' based on seismic data.

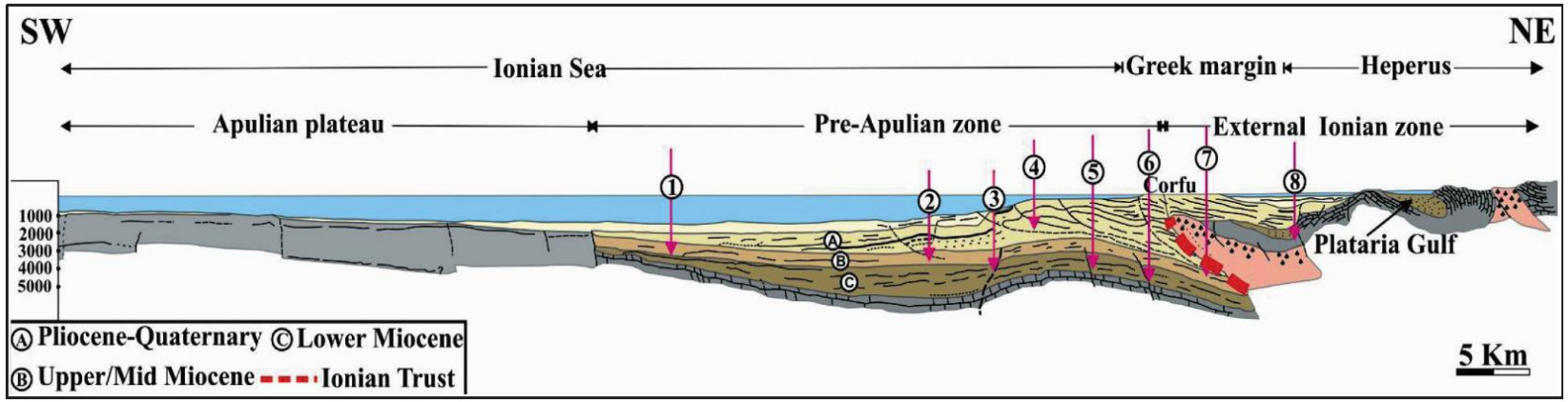


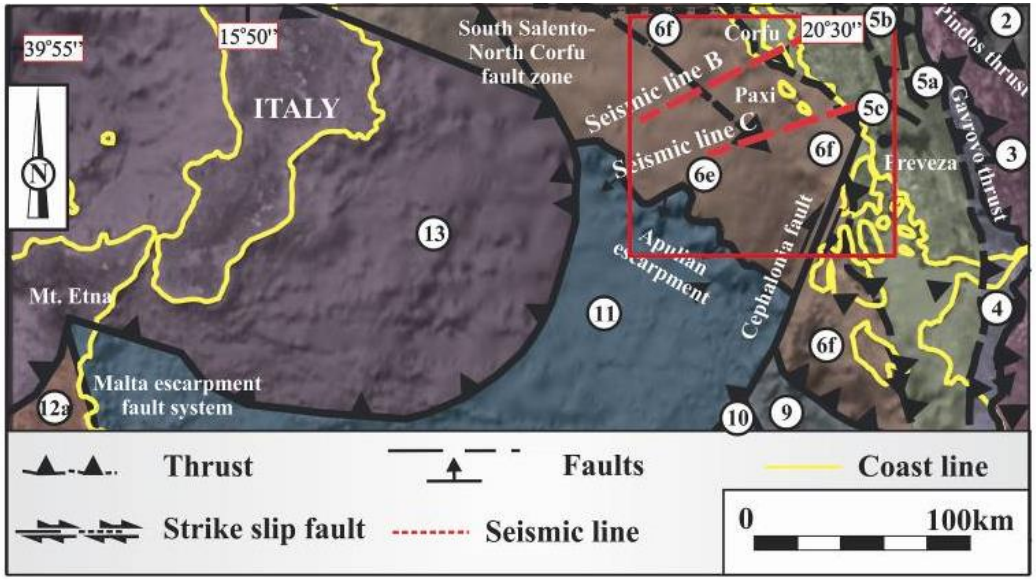


Maravelis et. al., 2012

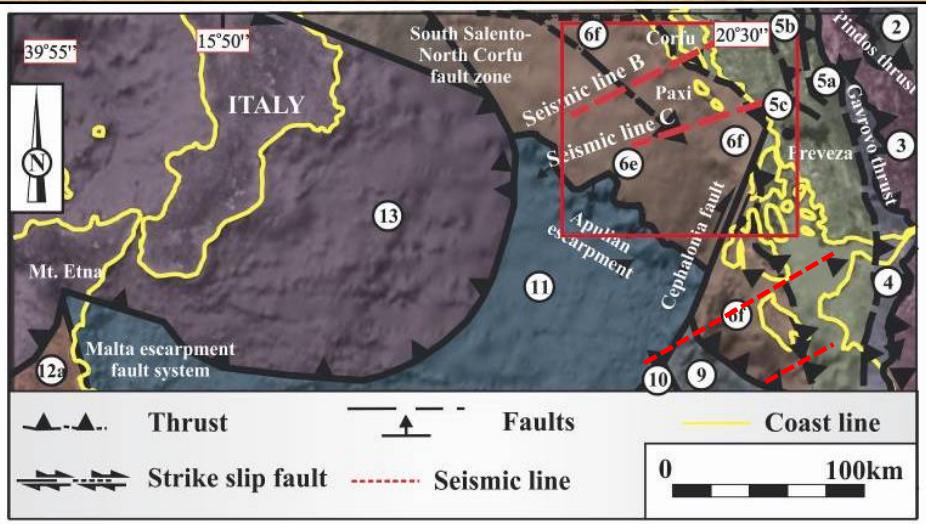


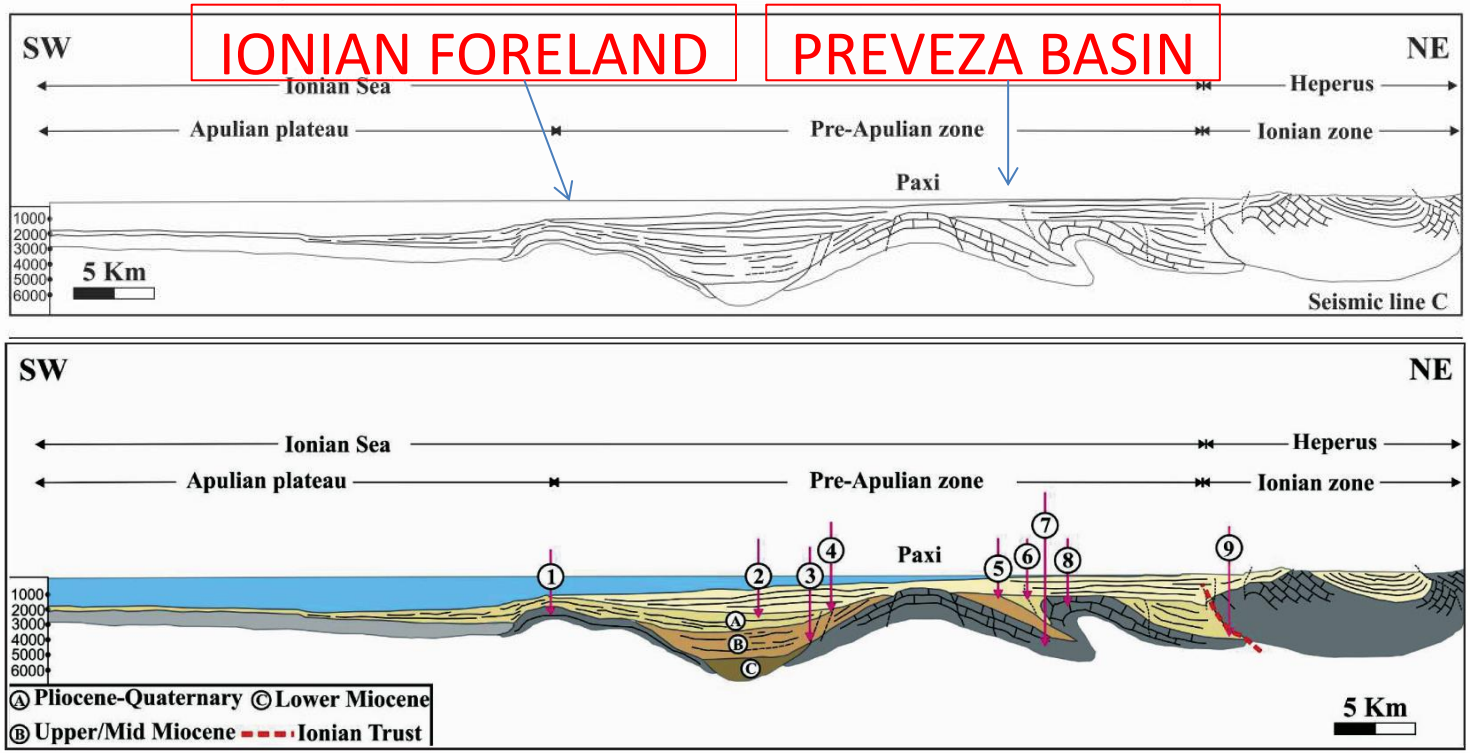




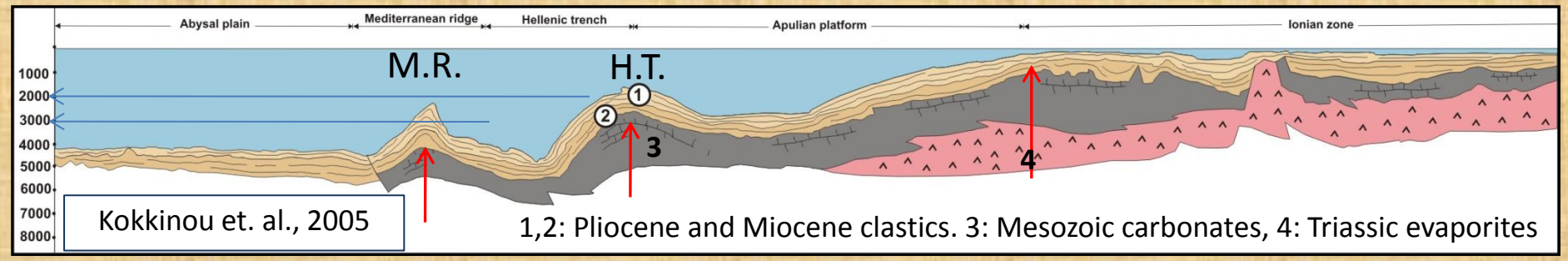


Maravelis et. al., 2012



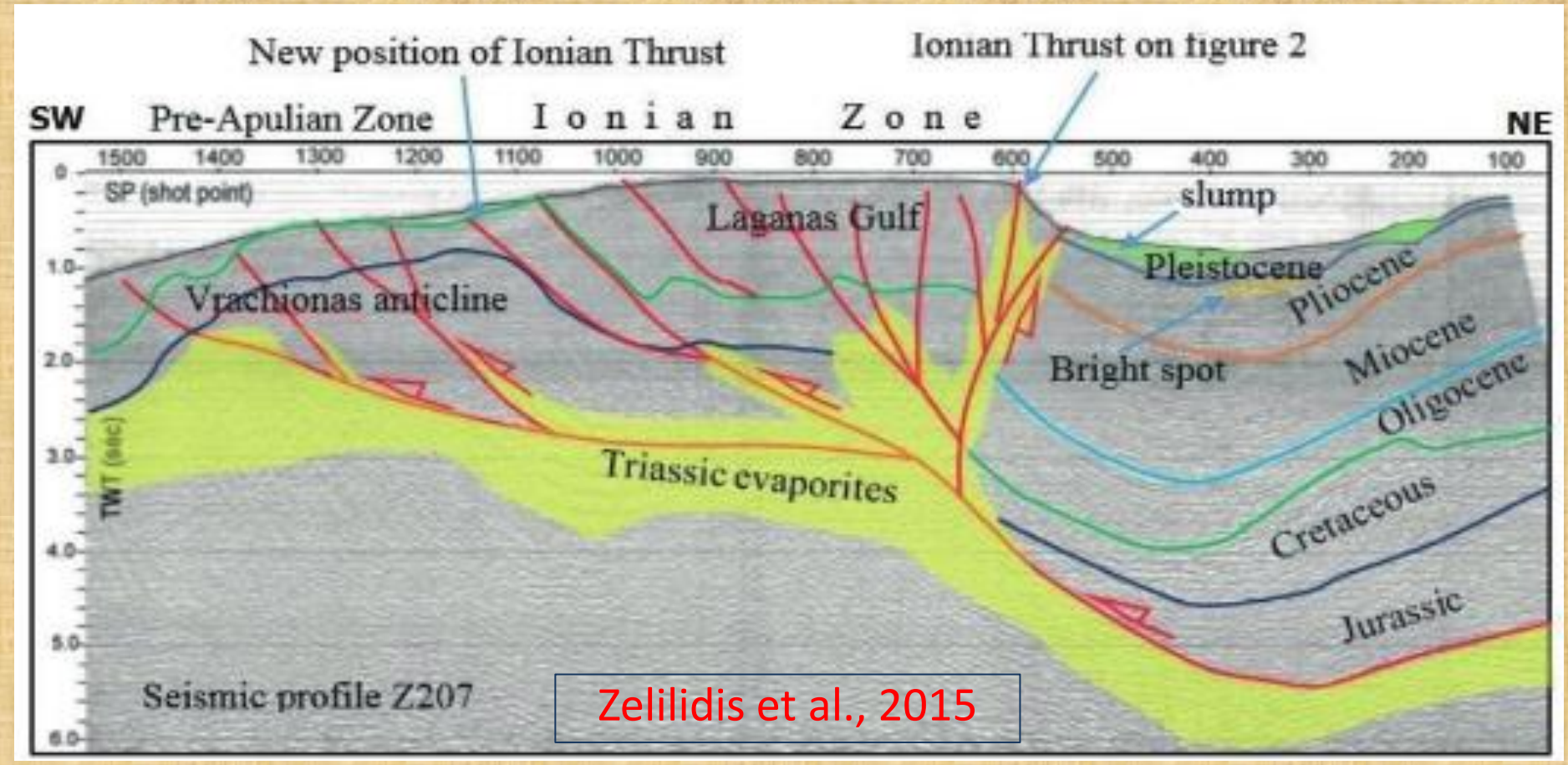


Maravelis et. al., 2012



Kokkinou et. al., 2005

1,2: Pliocene and Miocene clastics. 3: Mesozoic carbonates, 4: Triassic evaporites



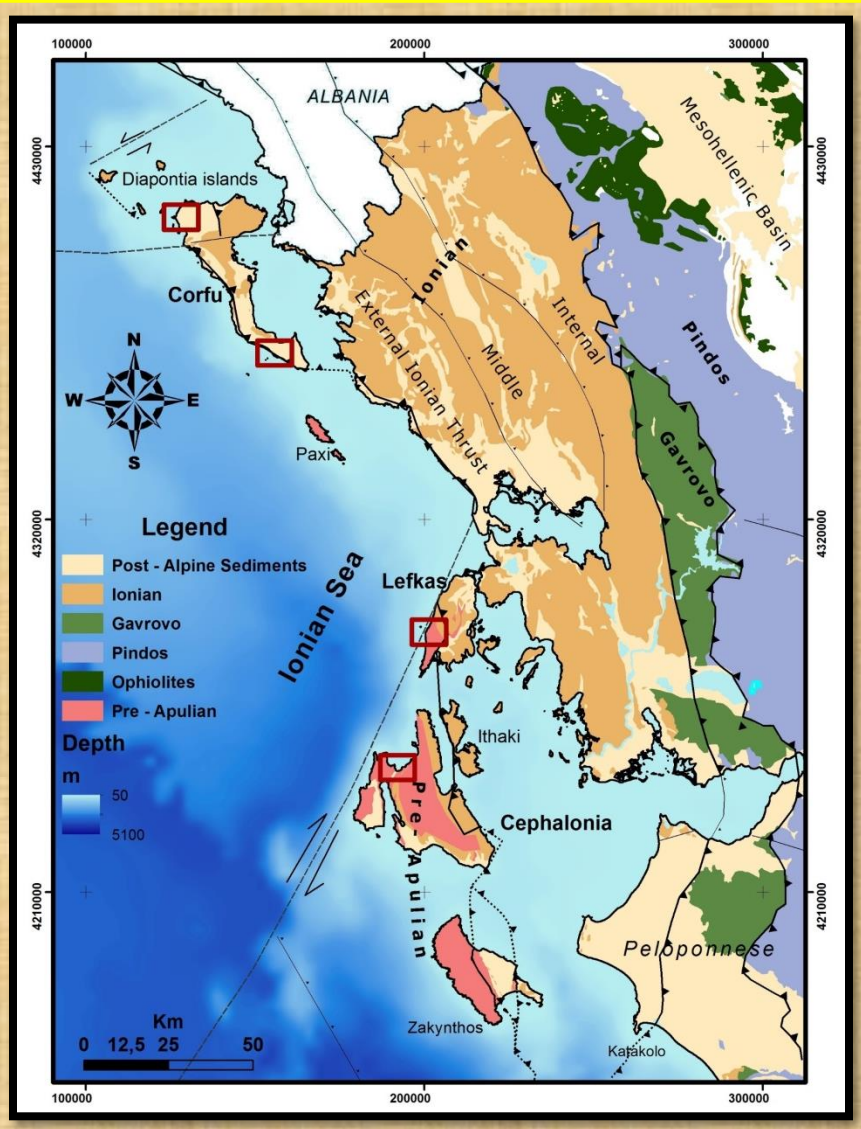
The Ionian foreland basin situated in the Western margin of the Hellenic Fold and Thrust Belt (the eastern margins of this foreland outcropped in Corfu, Lefkas and Kefallinia islands).

This investigation presents an outcrop based organic geochemical analysis applied to the Upper Miocene to Lower Pliocene clastic sedimentary succession at this part of the Hellenic Fold and Thrust Belt.

One hundred mudstone samples were collected from the northern and southern part of the study region and were analysed using Rock-Eval 6 pyrolysis method.

The analytical data indicate that the sedimentary succession contains units that can be considered as potential source rocks and are worthy of further consideration.

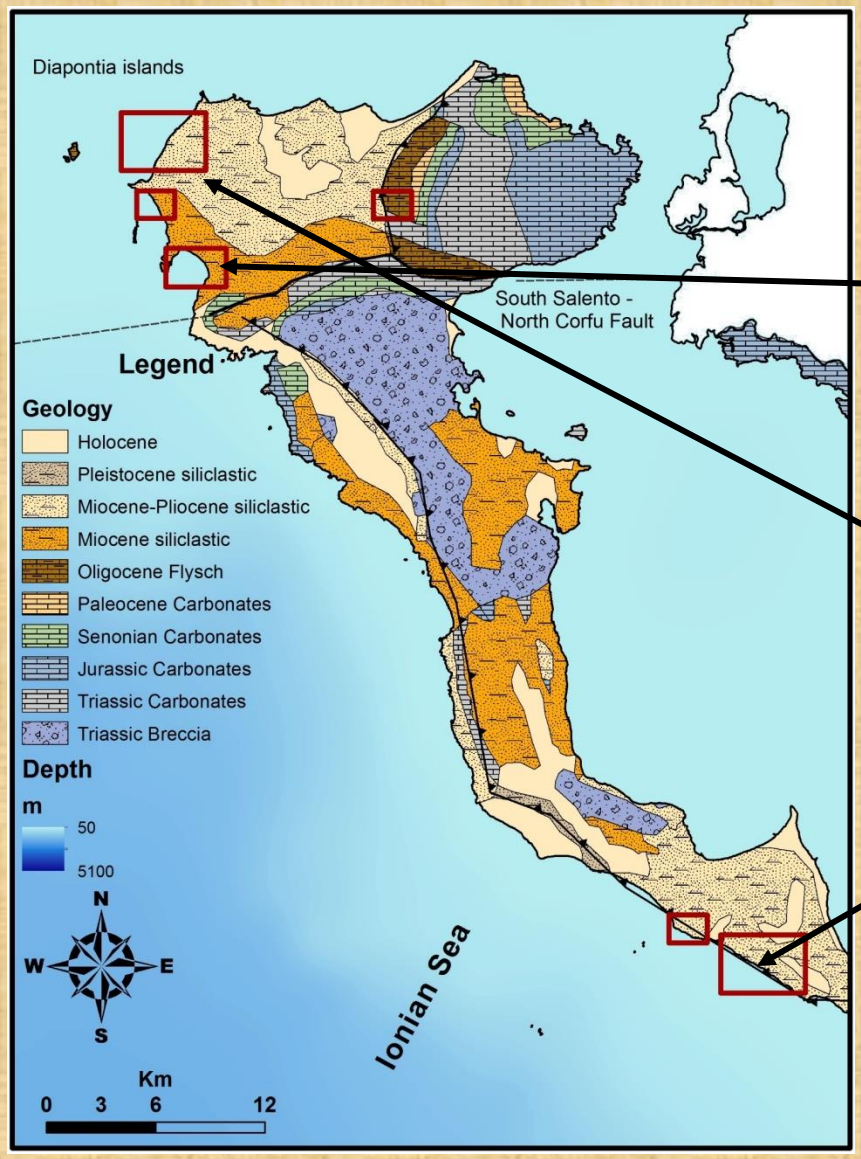
GEOLOGICAL SETTING

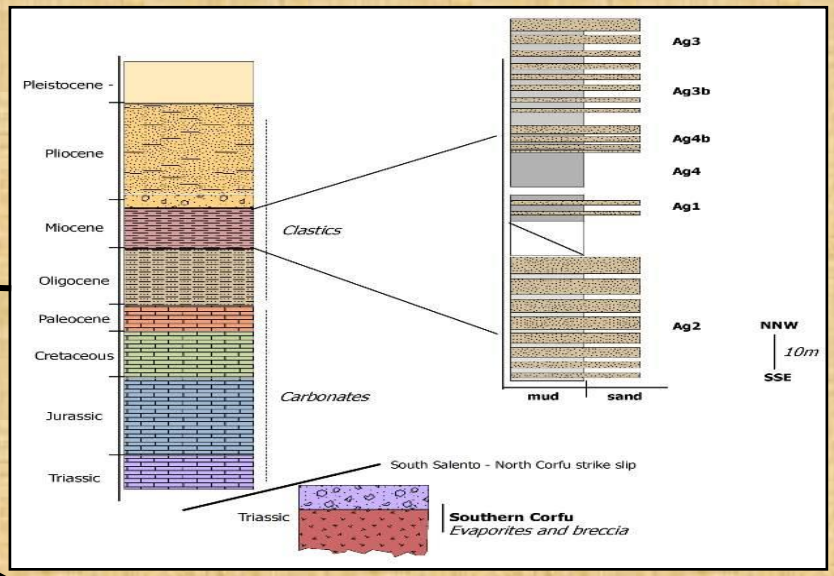


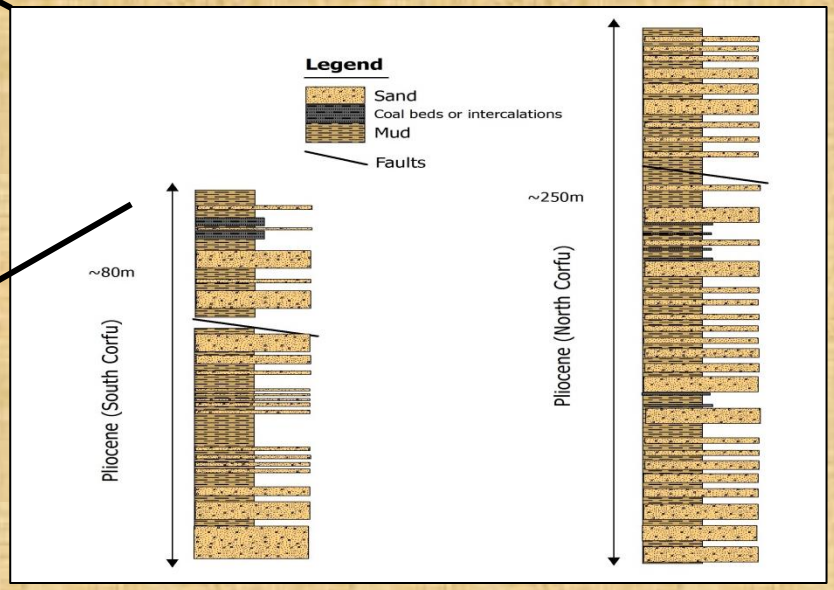
- Current study examined upper Miocene-Lower Pliocene outcrops in three islands (Corfu, Lefkas and Cephalonia) and numerous sections. Older investigations have took place in Zakynthos and Diapontia Islands.

- The main geotectonic features of the broad study area are: The Ionian Thrust, the Cephalonia Transfer Fault and the North Corfu - South Salento fault. Those features control the evolution and the diversity of the examined sub-basins.

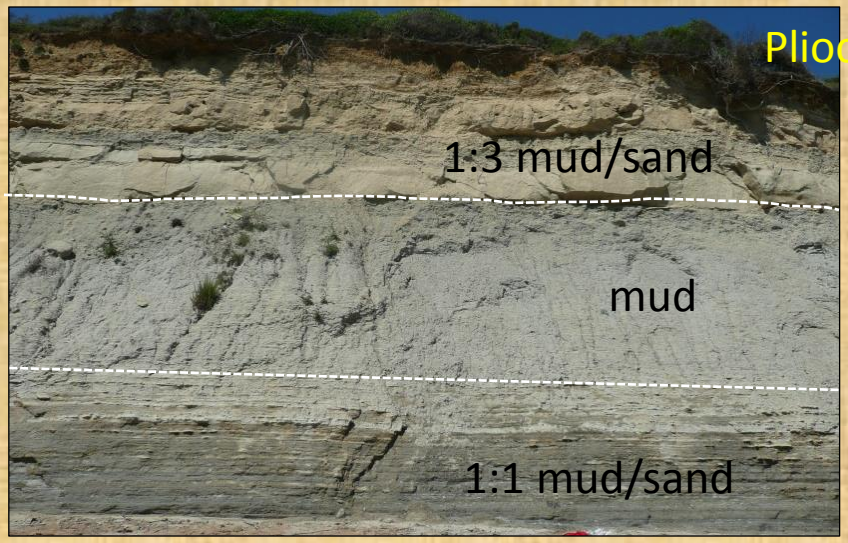
GEOLOGICAL SETTING

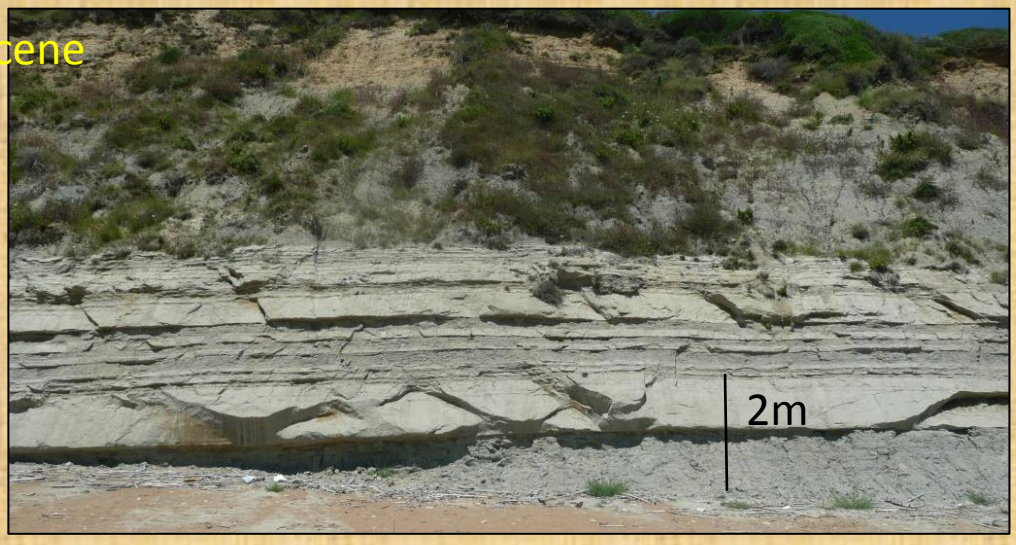




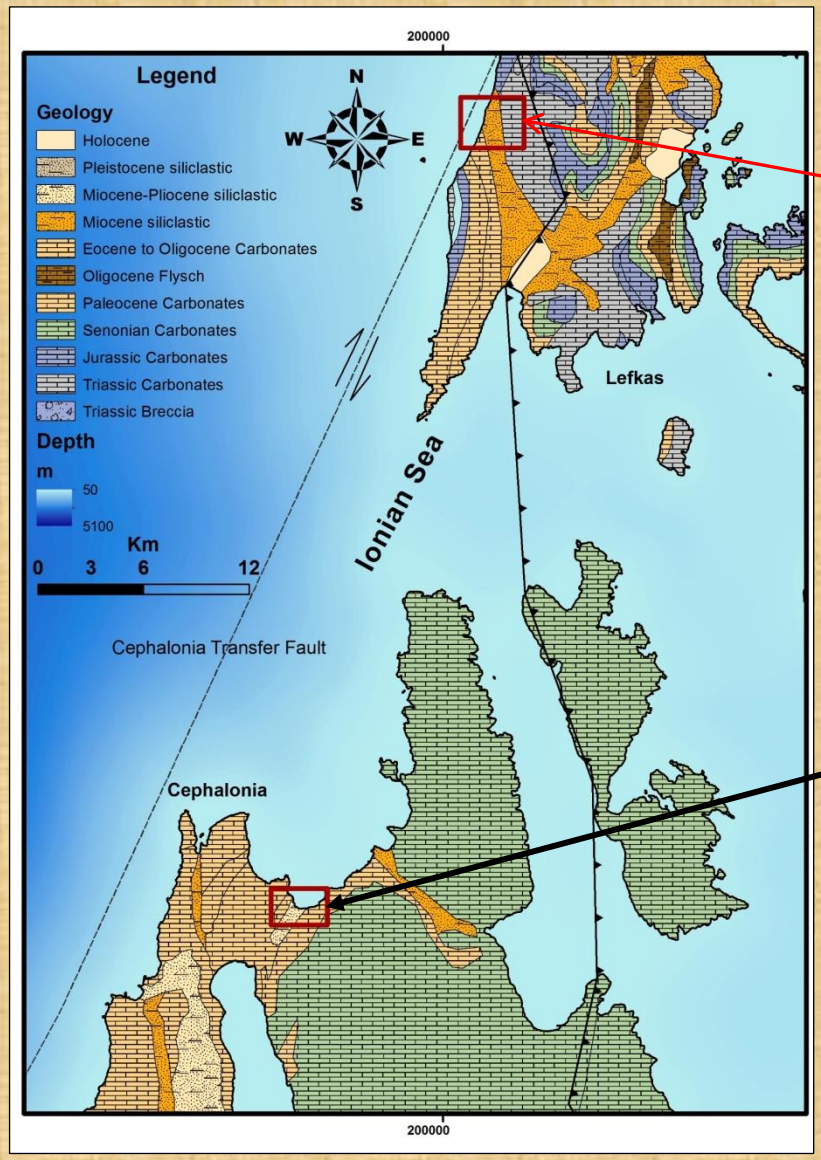


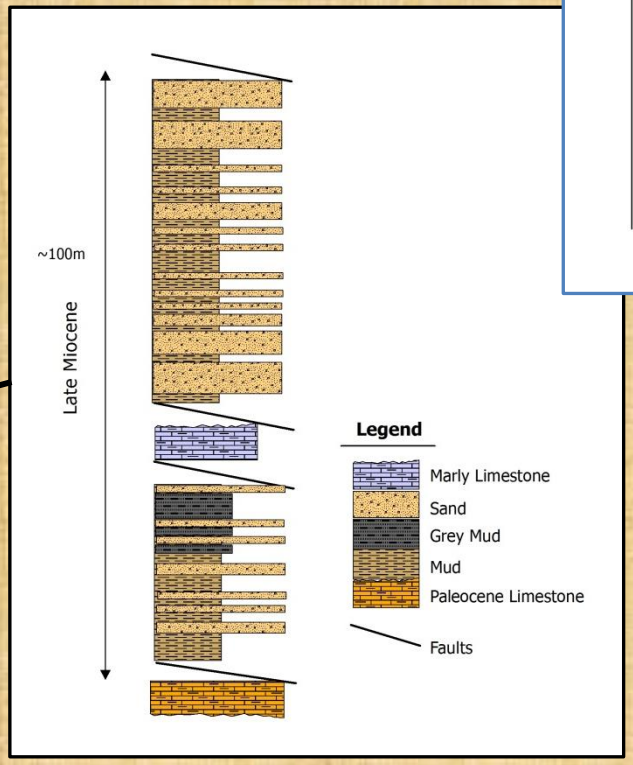
GEOLOGICAL SETTING –CORFU

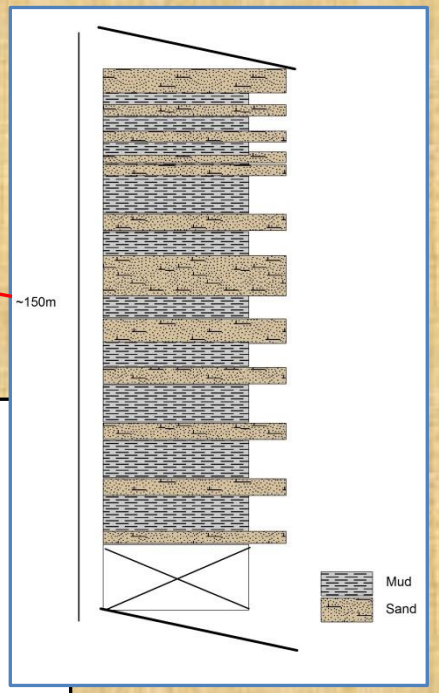




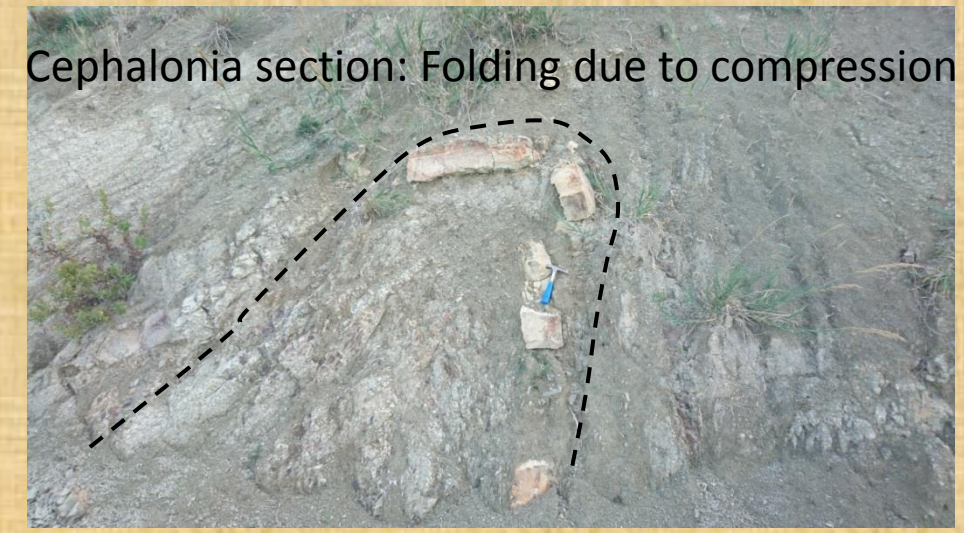
GEOLOGICAL SETTING







GEOLOGICAL SETTING – CEPHALONIA & LEFKAS



GEOCHEMICAL INVESTIGATION

- More than 100 hundred mudstone samples where collected and their organic content and geochemical characteristics were examined with Rock-Eval 6 pyrolysis.

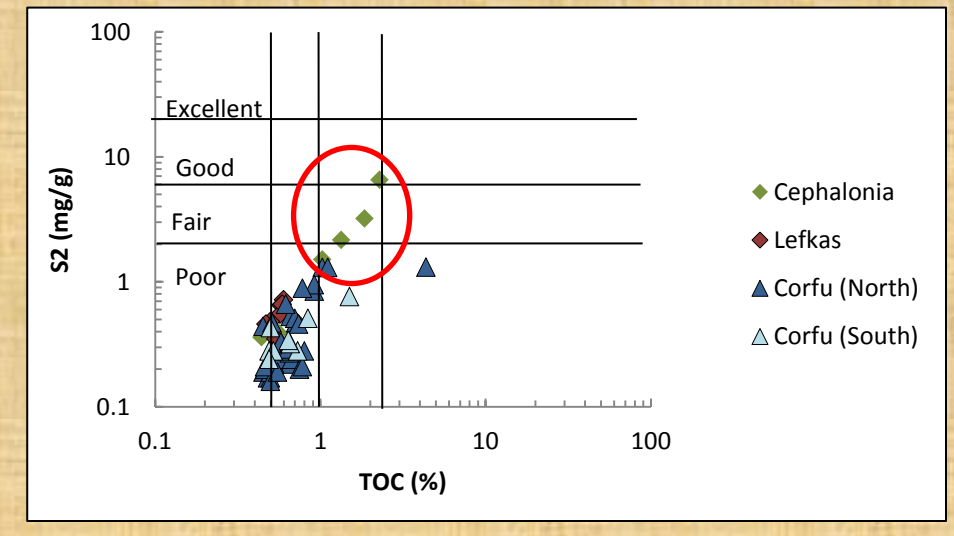
- Sampling took place in various locations: Three sections of upper Miocene age in Cephalonia island, in Agia Kiriaki Bay (NW). Four sections of Upper Miocene age in Lefkas island, in Kalamitsi area (SW).

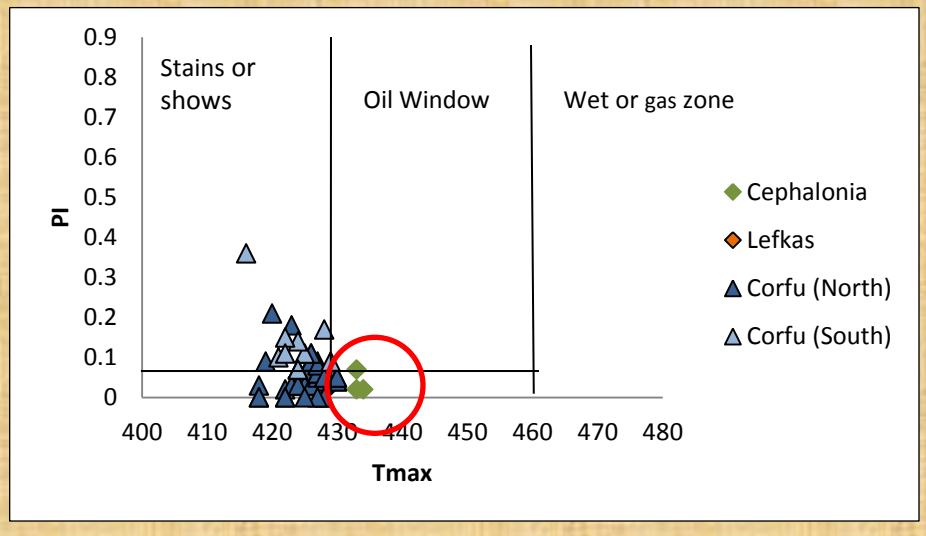
- Three sections in South Corfu Pliocene accumulations in Lefkimmi area. The Miocene sections in central to northern Corfu, in Agios Georgios Pagon and Arillas. The Pliocene accumulations in Agios Stefanos bay and Cape d' Amour (NW).

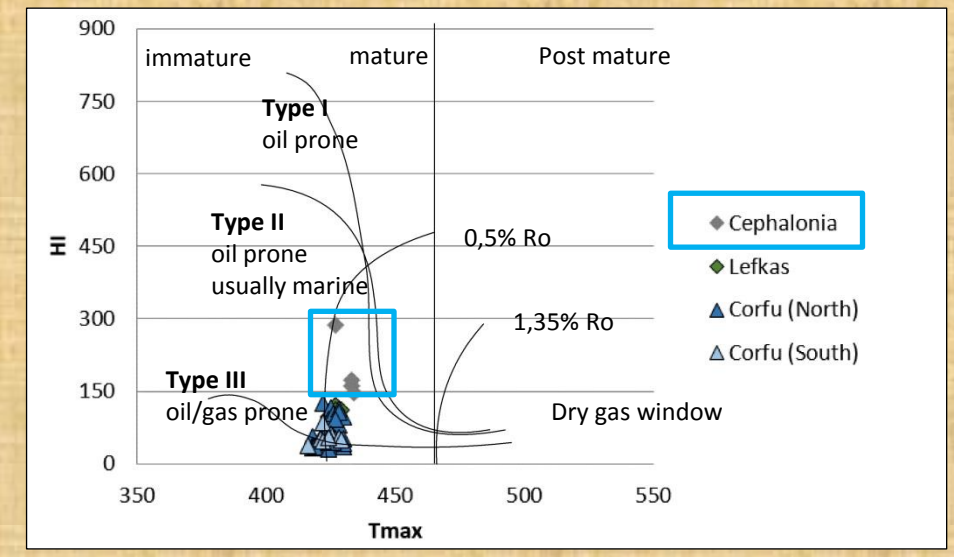
- Caution was taken to avoid contamination during sampling. The samples were dried and later crushed and sieved using a 250μm sieve in order to perform Rock Eval 6 pyrolysis. Selection within the original number of samples to perform the analysis was done through laboratory investigations of TOC content (Gaudette titration method) and their color assessment.

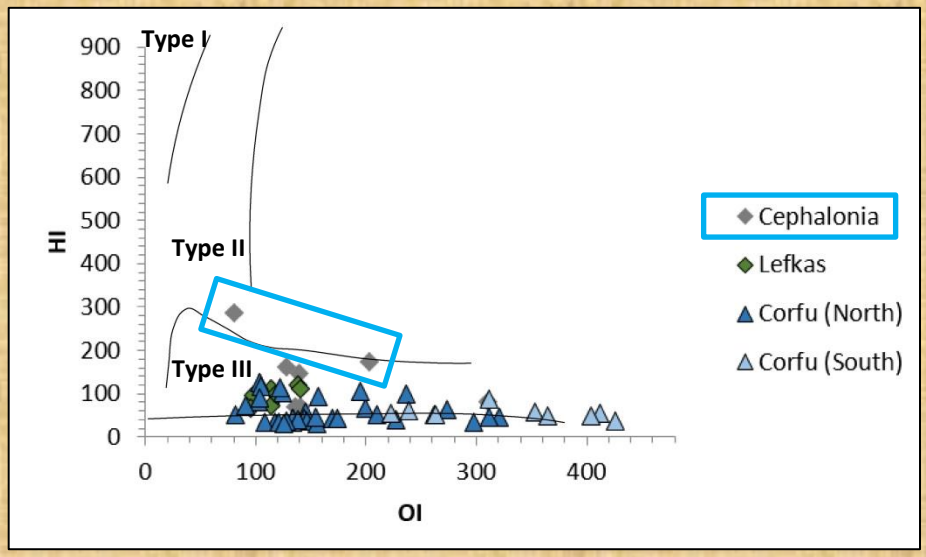
- The following plots present the first results

GEOCHEMICAL INVESTIGATION









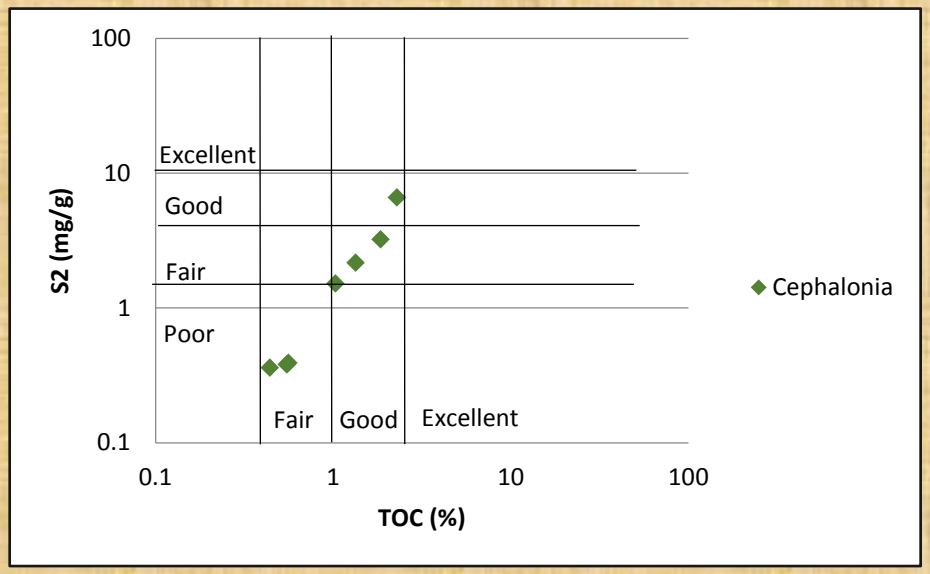
GEOCHEMICAL INVESTIGATION

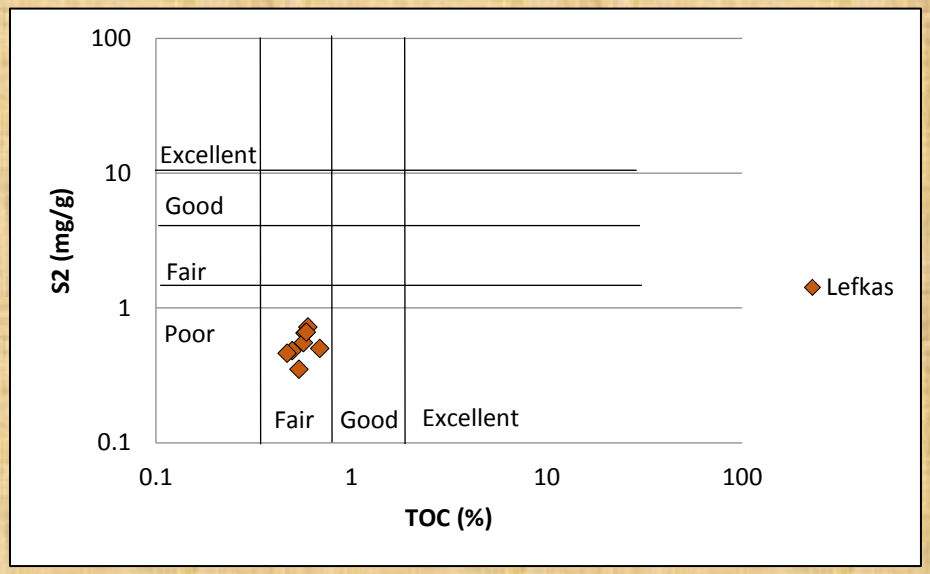
- Southern Corfu sections (Pliocene) present an average of 0,7% TOC and >0,35 S2 values. The upper section has lower TOC values but with the occurrence of thin (~1cm) lignite beds with measured TOC reaching ~40%.

- Northern Corfu sections can be divided in Upper Miocene (Agios Georgios Pagon and Arillas) and lower to middle Pliocene (Agios Stefanos, Cape d' Amour) sections. Samples from the Oligocene Pindos foreland sediments were also examined (NE Corfu). Upper Miocene sediments present more promising results, reaching to 1,5% TOC content and an average above 0,5%, while Pliocene sediments with TOC >0,5% are approx. 40%. However, samples within the Pliocene sequence may present TOC up to 4,36%.

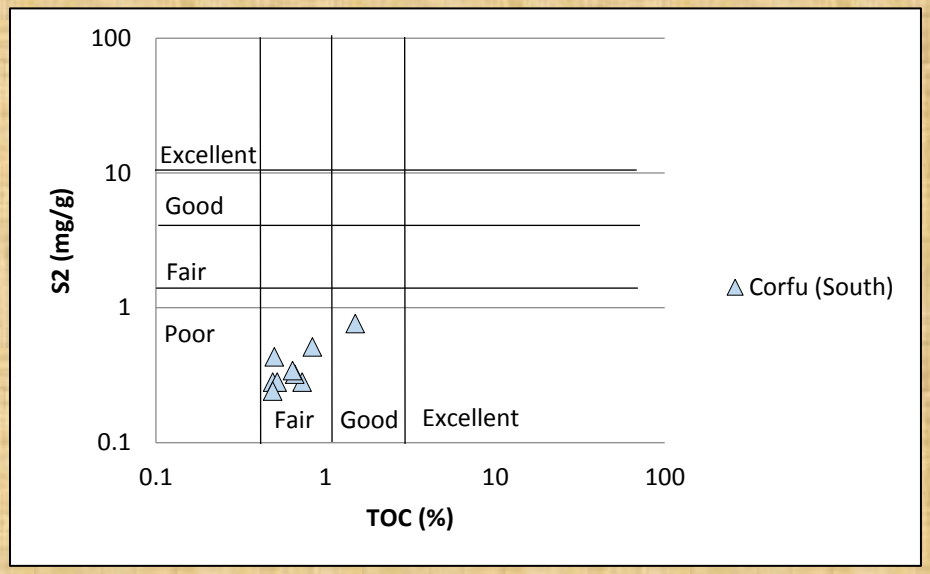
- The lower parts of the Lefkas section present average TOC >0,5% and S2 values ~0,56 mg/g. A general decrease in TOC content is present upwards, with fewer samples over the 0,5% threshold.

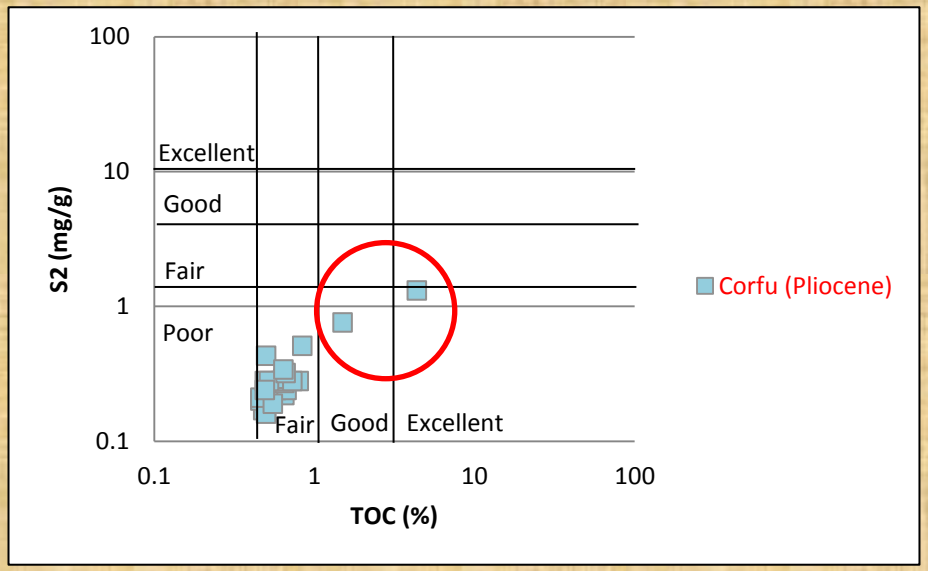
- Accordingly, the lower parts of the Cephalonia sections present a very promising >1% average and >2 mg/g S2 values (reaching up to 2,21% and 6,57 mg/g respectively). A similar to Lefkas decrease trend is observed upwards.

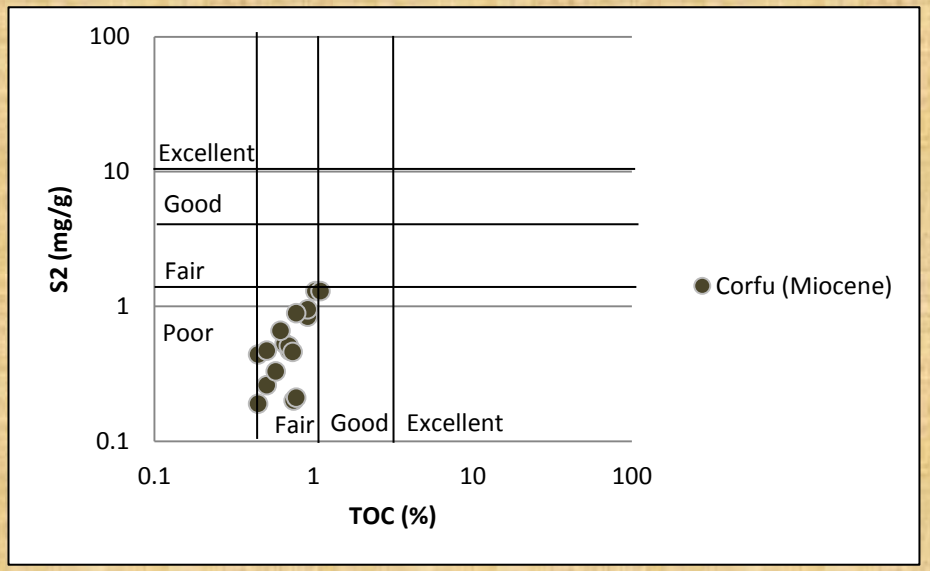

100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Cephalonia

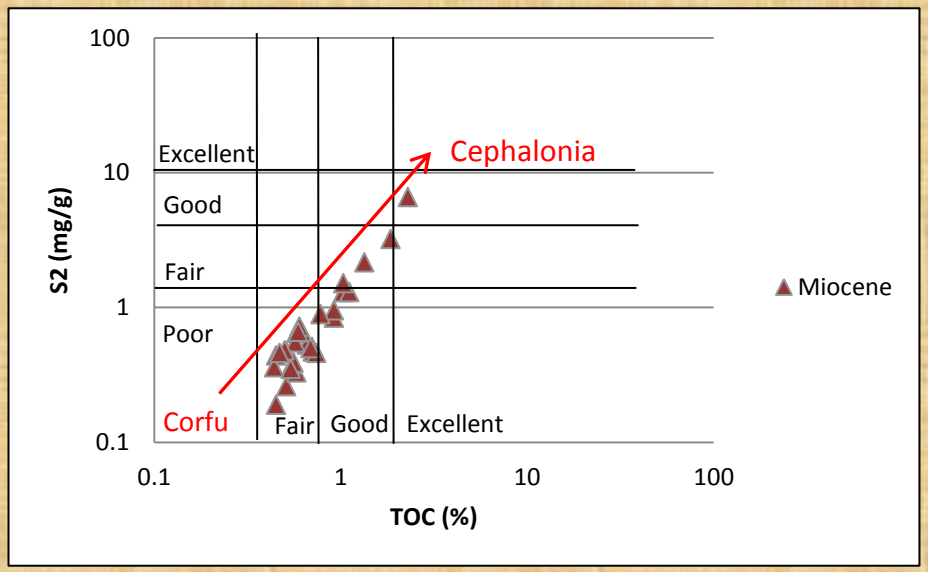

100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Lefkas

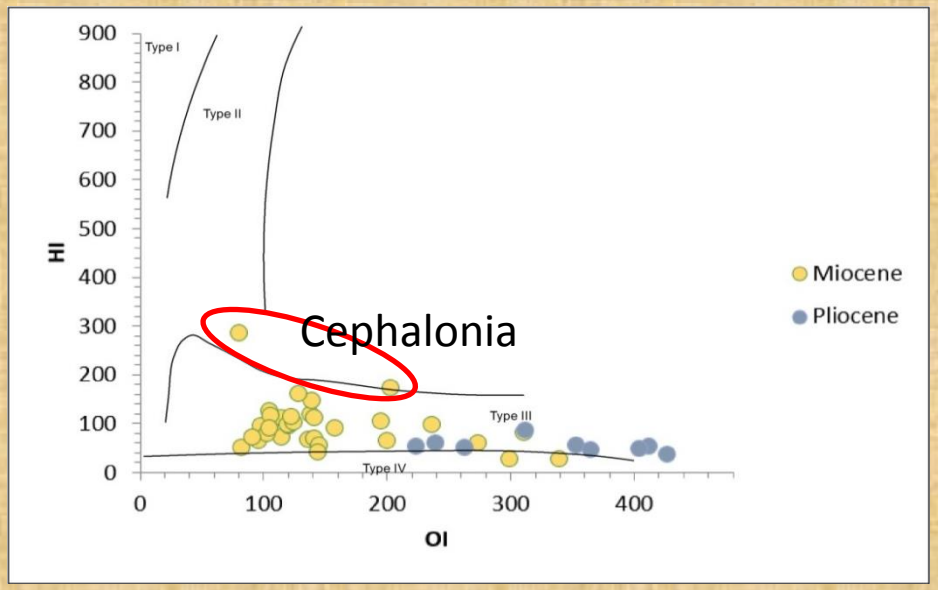

100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Corfu (North)


100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Corfu (South)


100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Corfu (Pliocene)


100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Corfu (Miocene)


100
10
1
0.1
S2 (mg/g)
Excellent
Good
Fair
Poor
Cephalonia
Corfu
Fair
Good
Excellent
0.1
1
10
100
TOC (%)
Miocene


900
800
700
600
500
400
300
200
100
0
HI
Type I
Type II
Type III
Type IV
Cephalonia
0
100
200
300
400
OI
Miocene
Pliocene

GEOCHEMICAL INVESTIGATION

- As shown in the presented plots, sampling throughout the outcrop sites present a mostly fair to good source rock potential, while the majority of the samples correspond to Type III kerogen, with some samples to Type II.

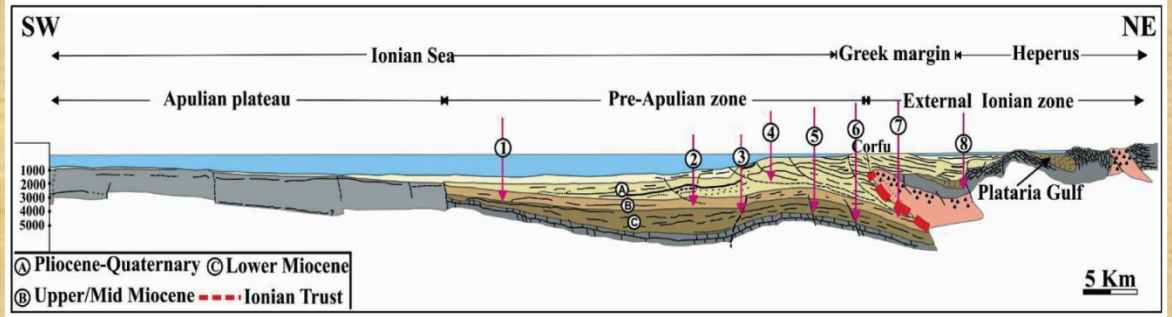
- T_{max} measurements present an average 425^{o} and a range between 416 to 434^{o}. These results indicate that the samples are immature with respect to oil generation. The PI vs Tmax plot proves this general maturity trend. Tmax fluctuations present a similar trend between sections and islands, with slightly higher values for the lower sections in Cephalonia island.

- Immaturity of the kerogen indicates lack of high temperatures during burial. However, deeper and thicker accumulations of those sediments (down slope and offshore equivalents) may present higher thermal evolution.

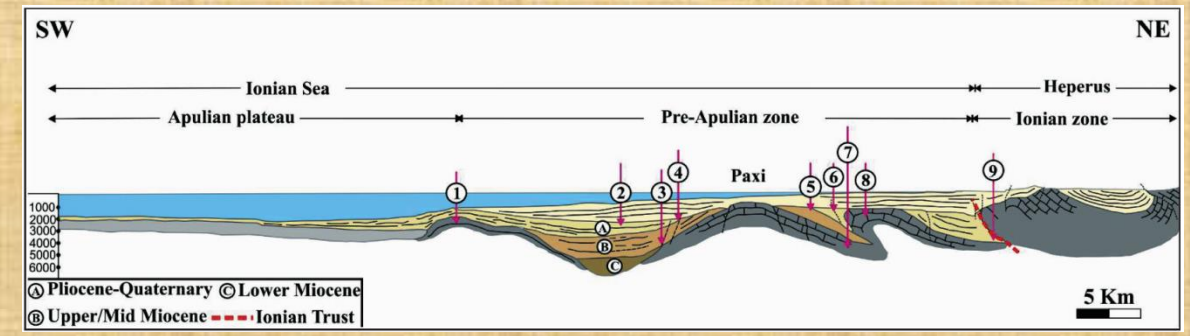
- Combining these results with older published investigations in Zakynthos and Diapontia islands it is shown that certain parts of the Upper Miocene-Lower Pliocene accumulations in the Ionian sea may prove significant gas-prone source rocks. Thicker accumulations of those sediments have been investigated in the Ionian Sea and our ongoing research will focus in a further understanding of the geochemical patterns in the broad area.

DISCUSSION

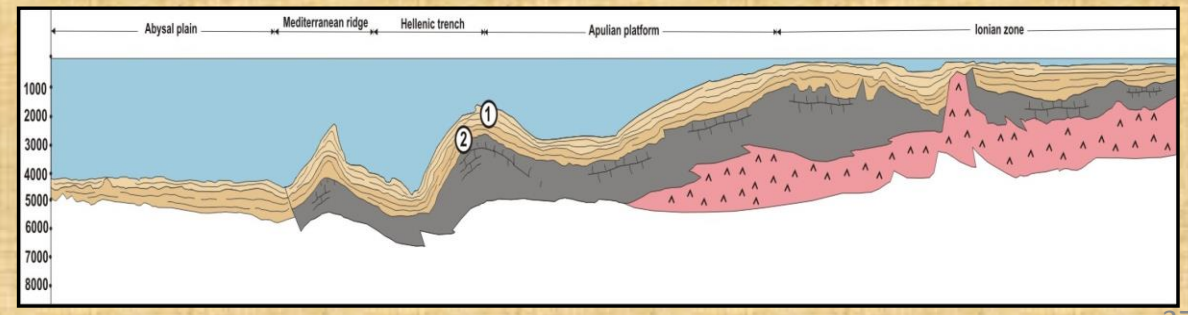
- The tectonic setting of Western Greece is mixed. The Cephalonia fault divides the area in two different regimes: Ocean-continent subduction to the North (Corfu, Diapontia) and continent-continent collision to the South (Lefkas, Cephalonia, Zakynthos)



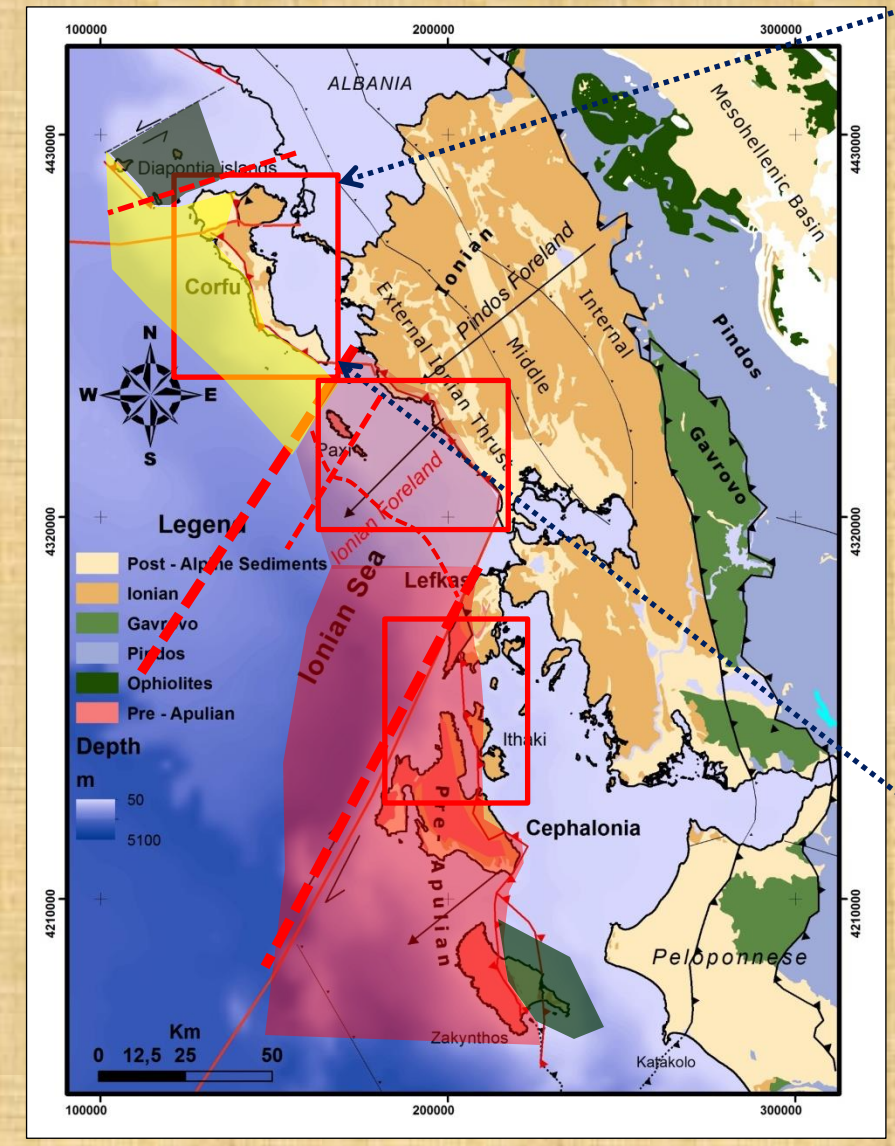
- In combination with the importance of salt diapirs throughout the Ionian Thrust, different characteristics and setting may be present between sub-basins.

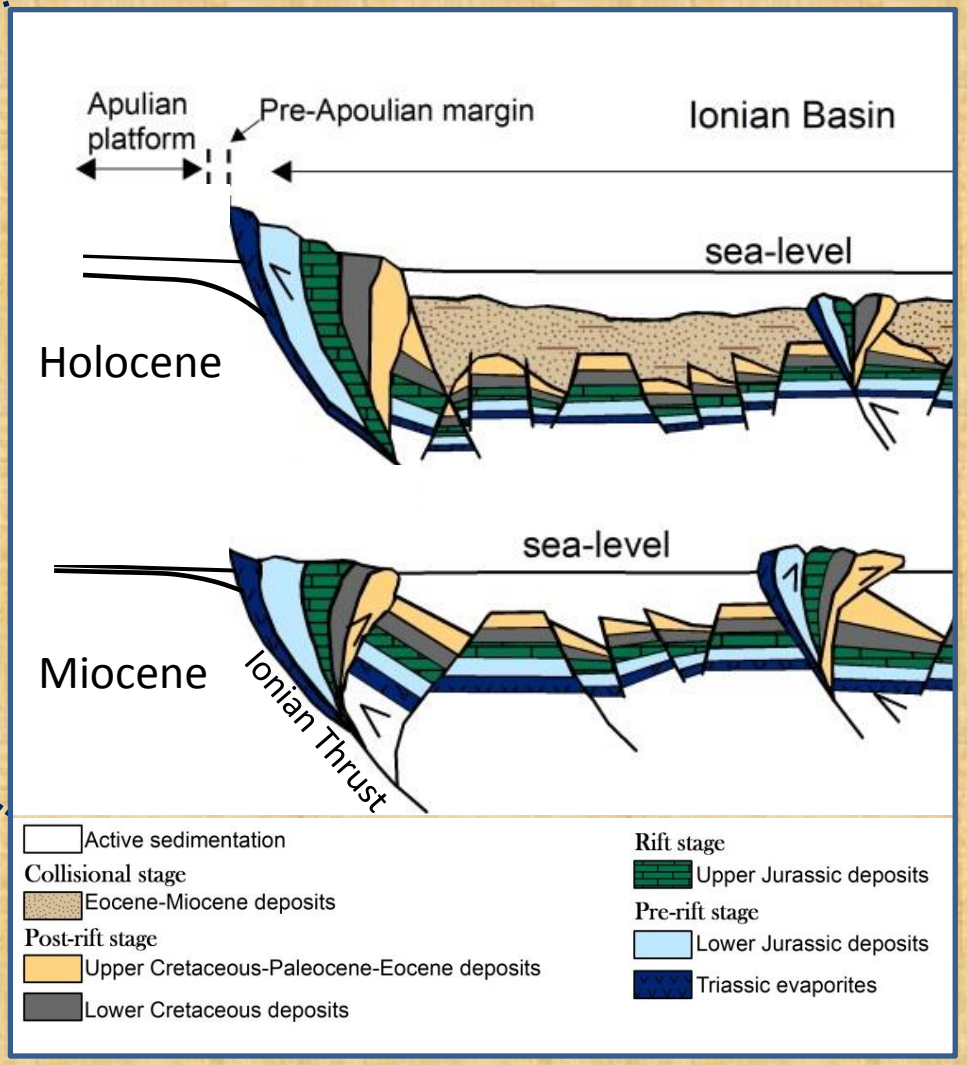


- Research has presented a variety of basin settings: piggy – back basins (Zakynthos, Diapontia), foreland basins proximate to Ionian Thrust (Lefkas, Corfu) and others with significant distance (Cephalonia).



CONCLUSION


100000
200000
300000
4430000
4320000
4210000
ALBANIA
Diapontia islands
Corfu
Paxi
Lefkas
Ithaki
Cephalonia
Zakynthos
Kapakolo
Peloponnese
Mesohellenic Basin
Ionian
External Ionian Thrust
Pindos Foreland
Middle
Internal
Pindos
Gavrovo
Ionian Foreland
Ionian Sea
Pre-Apulian
N
W
E
S
Legend
Post - Alpine Sediments
Ionian
Gavrovo
Pindos
Ophiolites
Pre - Apulian
Depth
m
50
5100
Km
0 12,5 25 50


Apulian platform
Pre-Apoulian margin
Ionian Basin
sea-level
Holocene
sea-level
Miocene
Ionian Thrust
Active sedimentation
Collisional stage
Eocene-Miocene deposits
Post-rift stage
Upper Cretaceous-Paleocene-Eocene deposits
Lower Cretaceous deposits
Rift stage
Upper Jurassic deposits
Pre-rift stage
Lower Jurassic deposits
Triassic evaporites

Thank you for your attention