Università di Trieste
LAUREA MAGISTRALE IN GEOSCIENZE
Curriculum Geofisico
Curriculum Geologico Ambientale

Anno accademico 2017 – 2018

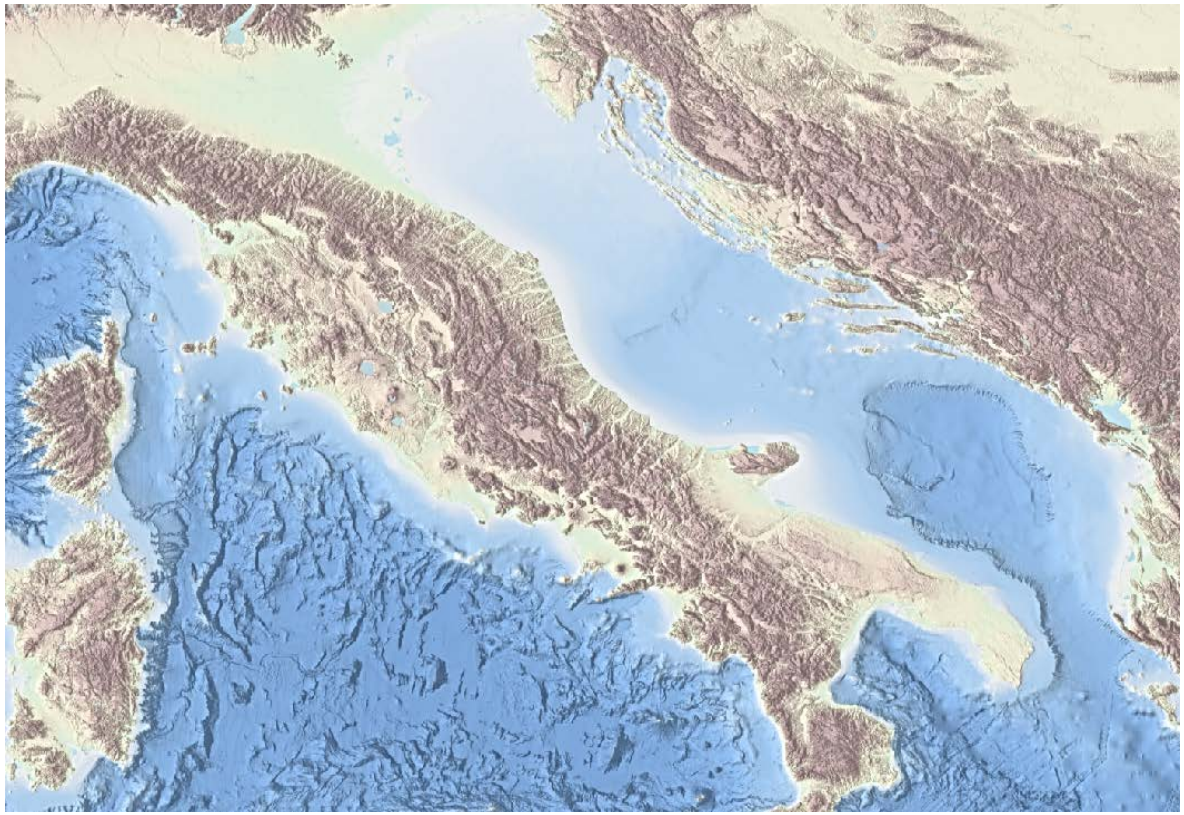
Geologia Marina

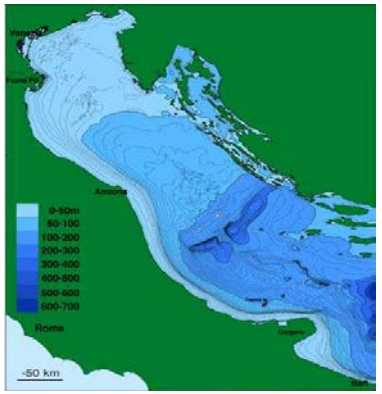
Parte I

Modulo 5.3 Mari Italiani – Adriatico

Docente
Valentina Volpi

General features and Morphology





Surface ~ 140 km^2

Length > 150 m

Depth
north: up to 75 m
centre: over 200 m (Fossa del Pomo)
south: max 1223 m

Coast

The coasts have a rocky character, with marly-arenaceous formations and prevailing limestones at the promontories of Conero, Gargano and Salento. The northwestern and Albanian coasts are generally low with the presence of lagoon; these are areas where the river contribution in high (e.g. Po Delta)., while it is not so for karstic areas. The eastern coasts are particularly complex with a lot of islands (i.e. Croatia, Dalmatia).

ADRIATIC REGION and ADRIA PLATE

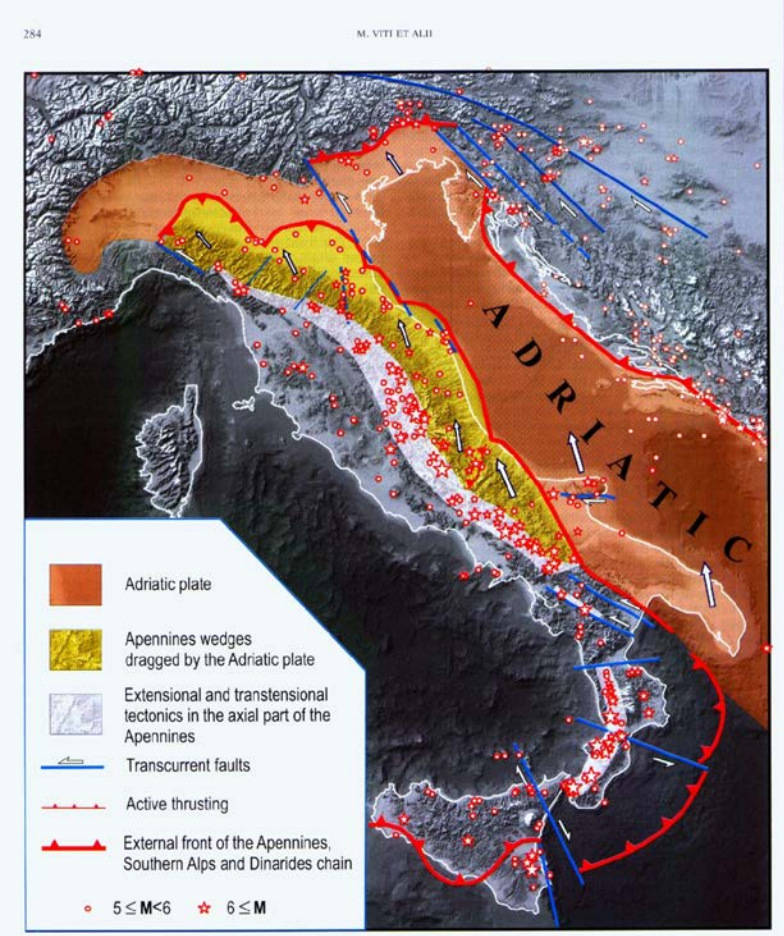


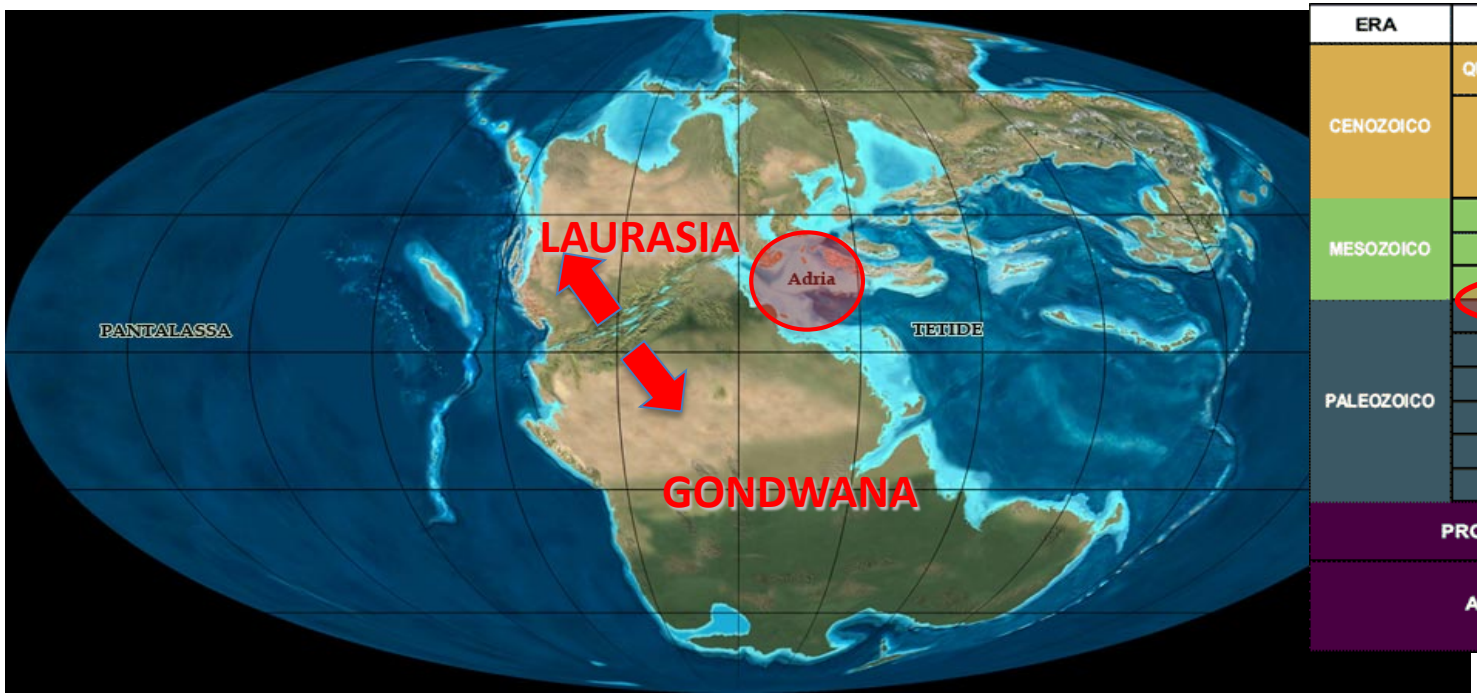
Fig. 5 - Middle Pleistocene to Present tectonic activity and major earthquakes (stars and dots) are explained as an effect of the relative motion between the Tyrrhenian-Western Apennines system (grey area) and the Adriatic-Eastern Apennines system (brown and yellow domains). Empty arrows indicate the motion, with respect to Eurasia, of the Adriatic plate and of the Apenninic wedges dragged by it. Seismicity information is taken from GRUPPO DI LAVORO CPTI (2004). See text for explanations.
– L'attività tettonica post-Pleistocene medio e i maggiori terremoti (stelle e punti) sono interpretati come effetti del movimento relativo tra il dominio Tirreno-Appennino occidentale (zona scura) e il dominio Adriatico-Appennino orientale (zone nocciola e gialla). Le frecce vuote indicano il movimento (rispetto all'Eurasia) della placca Adriatica e della parte esterna di catena Appenninica trascinata da questa placca. La cinematica proposta implica trascorrenze sinistra nell'Appennino Lucano e tettonica distensiva/transtensiva nella rimanente parte della catena (dalla zona Irpina all'Appennino settentrionale), in accordo con i campi di deformazione dedotti dalle deformazioni recenti e dalla sismicità. Vedi testo per spiegazioni. Gli epicentri sono presi da: Gruppo di Lavoro CPTI (2004).

Boll. SGI 125 (2006) fasc. 3, 273-291, 6 ff.

(Viti et al., 2006)

Evolution of the Adriatic area

Late Paleozoic – early Mesozoic (330-250 Ma)



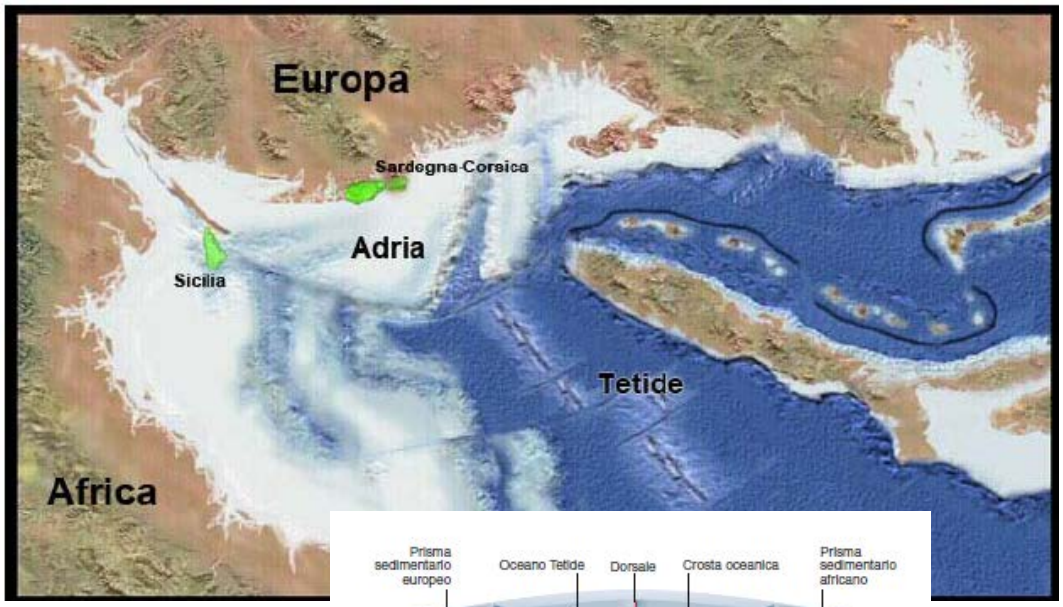
ERA	PERIODO	EPOCA	MILIONI di anni fa
CENOZOICO	QUATERNARIO	OLOCENE	0,01
		PLEISTOCENE	1,8
	TERZIARIO	PLIOCENE	5
		MIOCENE	26
		OLIGOCENE	37
		EOCENE	53
		PALEOCENE	65
MESOZOICO	CRETACEO		144
	GIURASSICO		213
	TRIASSICO		260
PALEOZOICO	PERMIANO		286
	CARBONIFERO		360
	DEVONIANO		408
	SILURIANO		438
	ORDOVICIANO		505
	CAMBRIANO		540
PROTEROZOICO			2500
ARCHEANO			

A single super continent will be the prologue of the geological history of the planet. Right along the line of separation of Pangea, began the story of future Italy. It is here where Adria, a promontory of North Africa, occupied entirely by Tetide, will be the origin of the Mediterranean and the Italian peninsula.

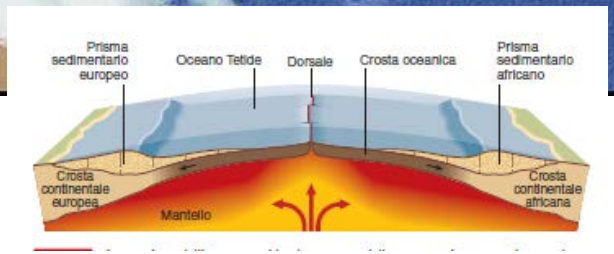
Evolution of the Adriatic area

Late Paleozoic – Early Mesozoic (330-250 Ma)

Isola di Andros nelle Bahama (dal satellite).
Le piane di marea, caratterizzate da ampie aree paludose dove l'acqua salmastra permane quando la marea si ritira, sono probabilmente molto simili a quelle dove, nel Triassico italiano, si formò la *Dolomia Principale*.



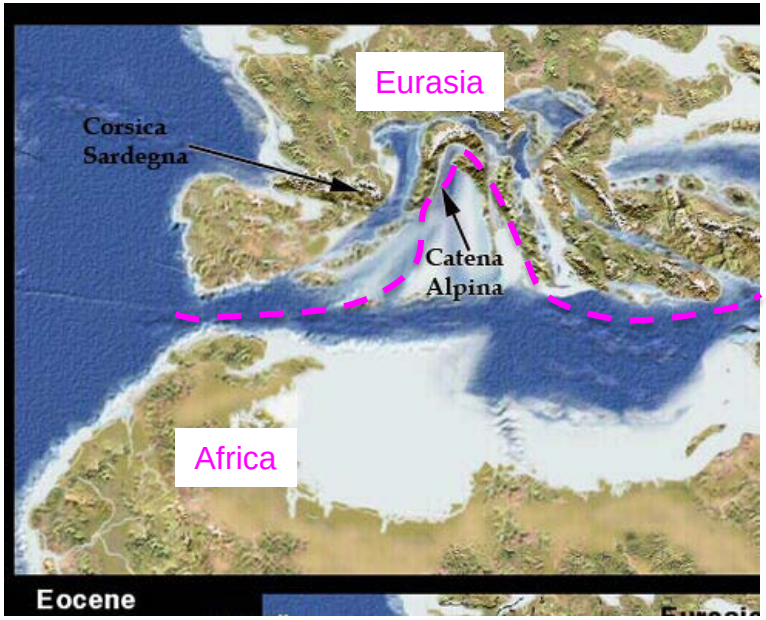
Gran Lago Salato, Utah.
Questo **lago salato,** nel quale l'intensa evaporazione fa depositare grandi quantità di sali, è probabilmente molto simile all'ambiente nel quale nel Triassico si formarono le *Anidriti di Burano*.



Italy, or rather what will become our territory, was on Adria plate and on its margins, in contact with the African and European plates. It was covered by an epicontinental shallow sea, surrounded by low coastal plains periodically invaded by tides. You can see the profiles of Sicily, and of Sardo-Corso block highlighted in green. The only areas emerged, with arid plains and dryed reliefs, were a small part of Tuscany and Sardinia that was on the coast of the European continent; the rest of the area were occupied by reefs and coral atolls, tidal plains, brackish swamps.

Evolution of the Adriatic area

Late Mesozoico – Early Cenozoic (65 Ma)

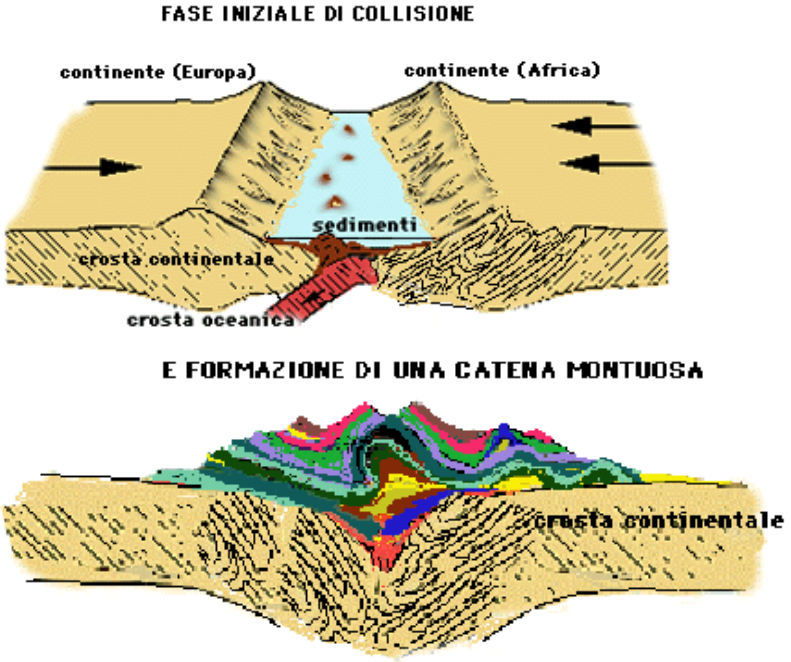


Origin of Alps

The rocks that formed the basement of the Tethys underwent a slow but continuous compression that emerged from the wtare od the ocean and gave rise to the system of thrust sheets and folds of the Alpine chain and the other mountains ranging from the north African Atlas, through the Pyrennes and Alps.

ERA	PERIODO	EPOCA	MILIONI di anni fa
CENOZOICO	QUATERNARIO	OLOCENE	0,01
		PLEISTOCENE	1,8
	TERZIARIO	PLIOCENE	5
		MIOCENE	26
		OLIGOCENE	37
		EOCENE	53
		PALEOCENE	65
MESOZOICO	CRETACEO		144
	GIURASSICO		213
	TRIASSICO		260
PALEOZOICO	PERMIANO		286
	CARBONIFERO		360
	DEVONIANO		408
	SILURIANO		438
	ORDOVICIANO		505
	CAMBRIANO		540
PROTEROZOICO			2500
ARCHEANO			

Starting from Cretaceous (140-66 m.a.) Europe and Africa changed direction and started to collide. The sediments deposited in the ocean between them were split and overlapped, part went deep and part was lifted on the continetal platforms.



Evolution of the Adriatic area

Upper Oligocene – Lower Miocene (25 - 18 Ma)

Rotation of the Blocco Sardo-Corso

ERA	PERIODO	EPOCA	MILIONI di anni fa
CENOZOICO	QUATERNARIO	OLOCENE	0,01
		PLEISTOCENE	1,8
	TERZIARIO	PLIOCENE	5
		MIOCENE	26
		OLIGOCENE	37
		EOCENE	53
		PALEOCENE	65
MESOZOICO	CRETACEO		144
	GIURASSICO		213
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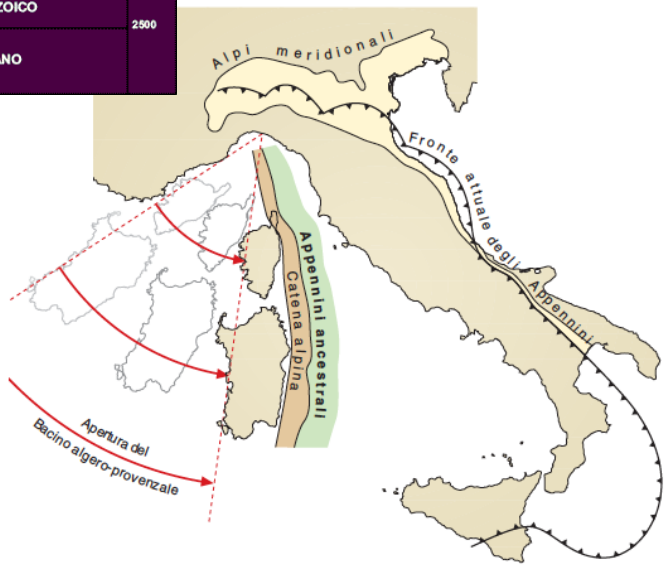
	CARBONIFERO		360
	DEVONIANO		408
	SILURIANO		438
	ORDOVICIANO		505
	CAMBRIANO		540
PROTEROZOICO			2500
ARCHEANO			

From about 25 Ma, an ocean basin formed (Algerian-Provence basin) with the rotation of the Sardo-Corso block (which today includes Corsica and Sardinia).



Apennines origin

The rotation toward south-east of the Sardo-Corso block, gave origin to the Apennine chain.

Evolution of the Adriatic area

Messinian salinity crisis – Upper Miocene (~7 Ma)

ERA	PERIODO	EPOCA	MILIONI di anni fa
CENOZOICO	QUATERNARIO	OLOCENE	0,01
		PLEISTOCENE	1,8
	TERZIARIO	PLIOCENE	5
		MIOCENE	24
		OLIGOCENE	37
		EOCENE	53
		PALEOCENE	65
MESOZOICO	CRETACEO		144
	GIURASSICO		213
	TRIASSICO		260
PALEOZOICO	PERMIANO		286
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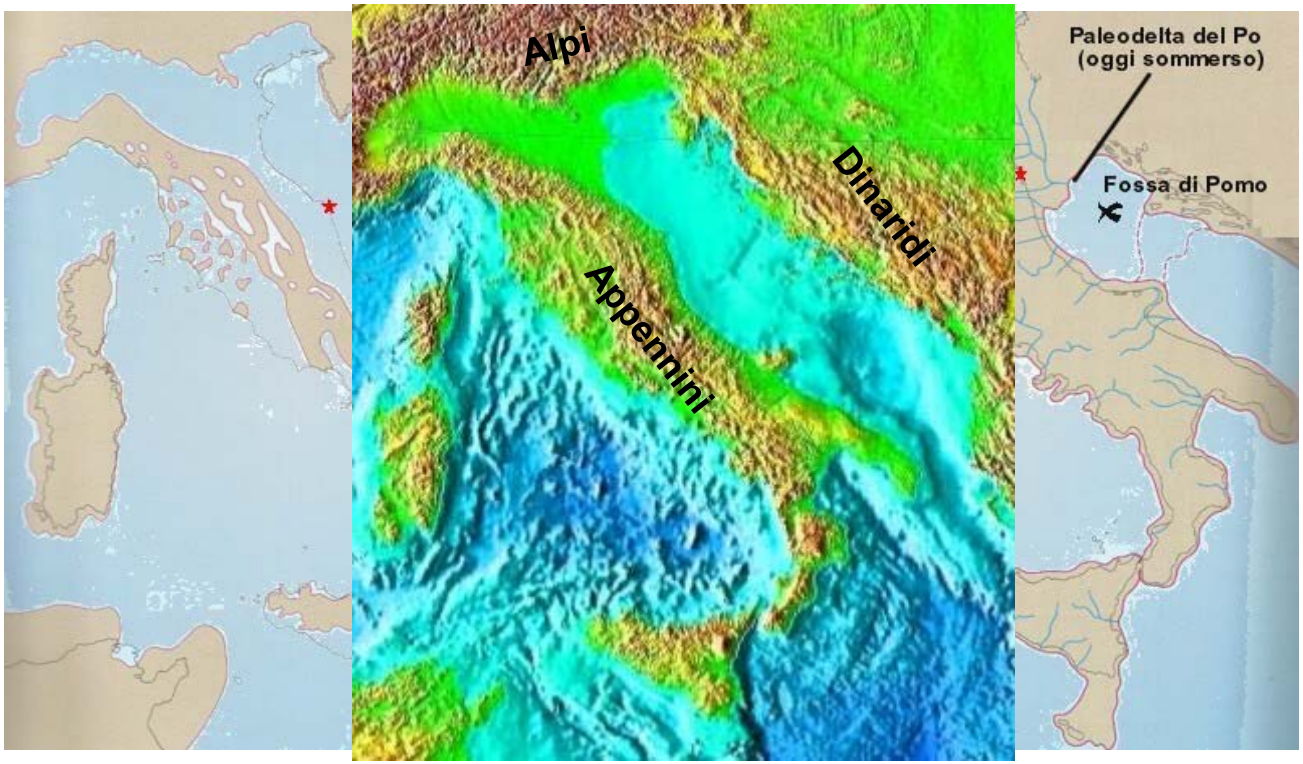
	DEVONIANO		408
	SILURIANO		438
	ORDOVICIANO		505
	CAMBRIANO		540
PROTEROZOICO			2500
ARCHEANO			

Approximately 6.9 million years ago, the slow approach and consequent collision between European and African plates led to the closure of the Strait of Gibraltar (other causes should be sought in lowering the sea level due to a glaciation and tectonic rise of the Mediterranean area). The Mediterranean became a closed sea, subject to intense evaporation, which resulted in a lowering of the water level with the consequent emergence of large areas.
About 3.5 million years ago water began to enter the Gibraltar Strait again: 3000 meters high waterfall began filling the Mediterranean basin. Of all this, there are still enormous evaporitic sequences, especially Messianic chalk, emerging from Sicily to Monferrato.

Evolution of the Adriatic area

Pliocene – Pleistocene (5 – 1.8 Ma)



ERA	PERIODO	EPOCA	MILIONI di anni fa
CENOZOICO	QUATERNARIO	OLOCENE	0.01
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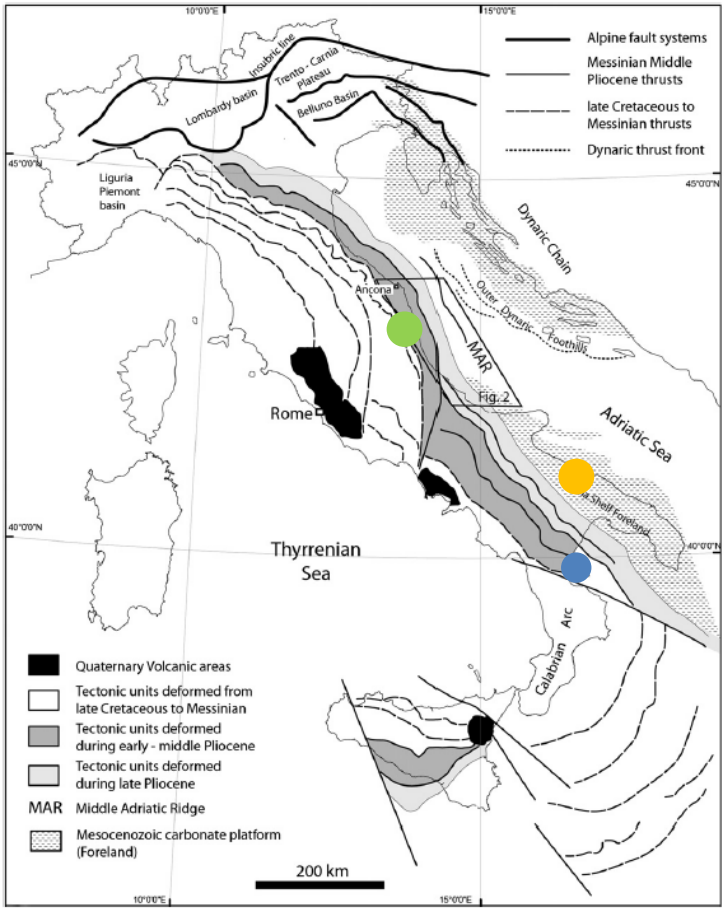
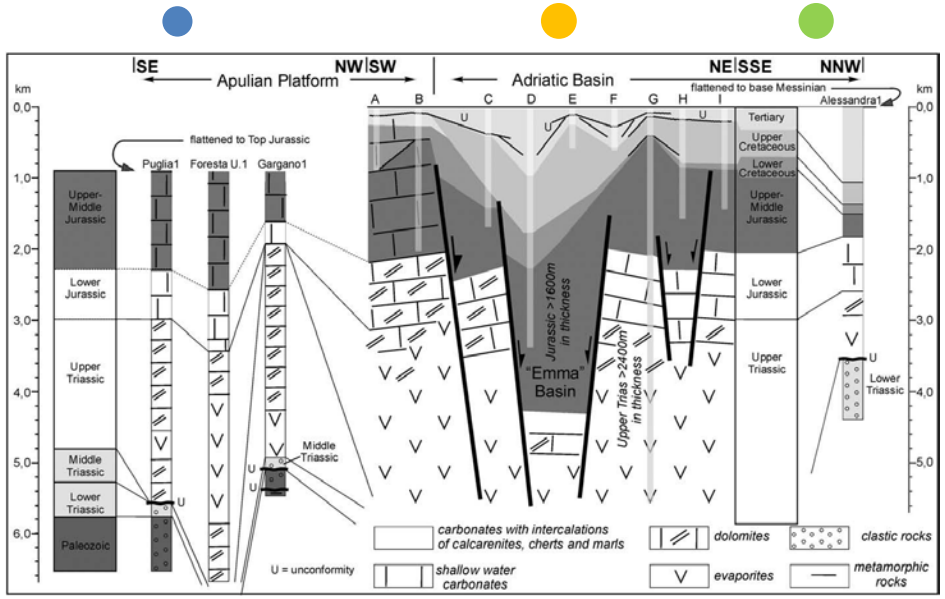
PROTEROZOICO			2500
ARCHEANO			

Above, on the left, the Adriatic area in Pliocene time. Sea level was about 100 meters higher than the present level, Italy was similar to a large archipelago. To the right, Italy in the Pleistocene age; the sea level was 90-100 meters lower than the current one. The Padano plain extended to the south of Ancona (indicated in red) and the river Po flowed into the current Fossa del Pomo, now filled with sediments.

STRATIGRAPHY OF THE APULIAN PLATFORM AND ADRIATIC BASIN
(calibrated from wellbore data)

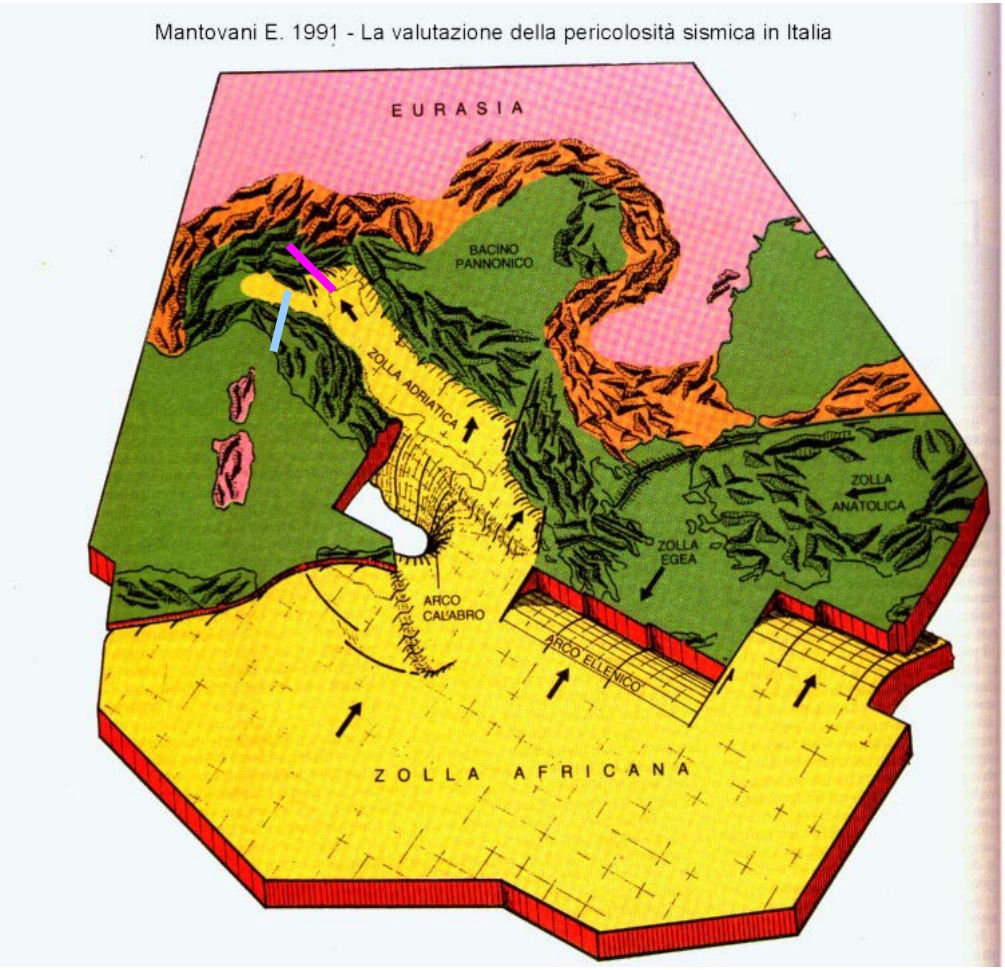


(Casero e Bigi, 2013)

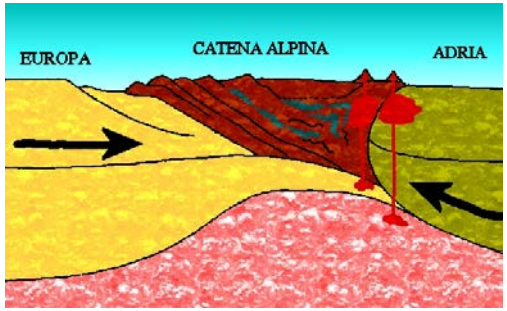


(Scisciani & Calamita, 2009)

PLATE MARGINS CONFIGURATION IN THE WESTERN MEDITERRANEAN



1)



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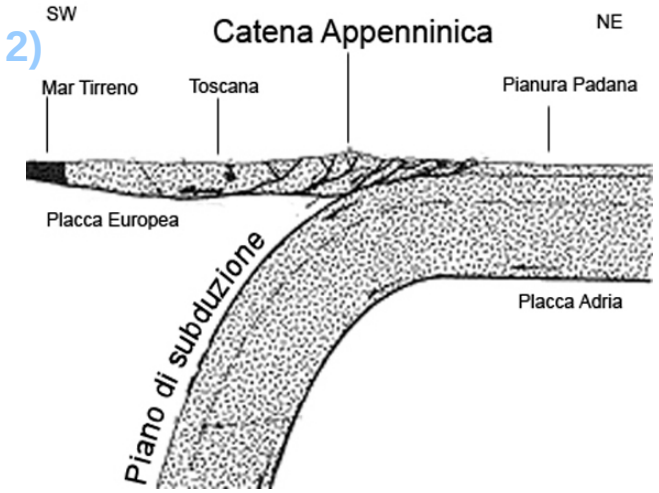
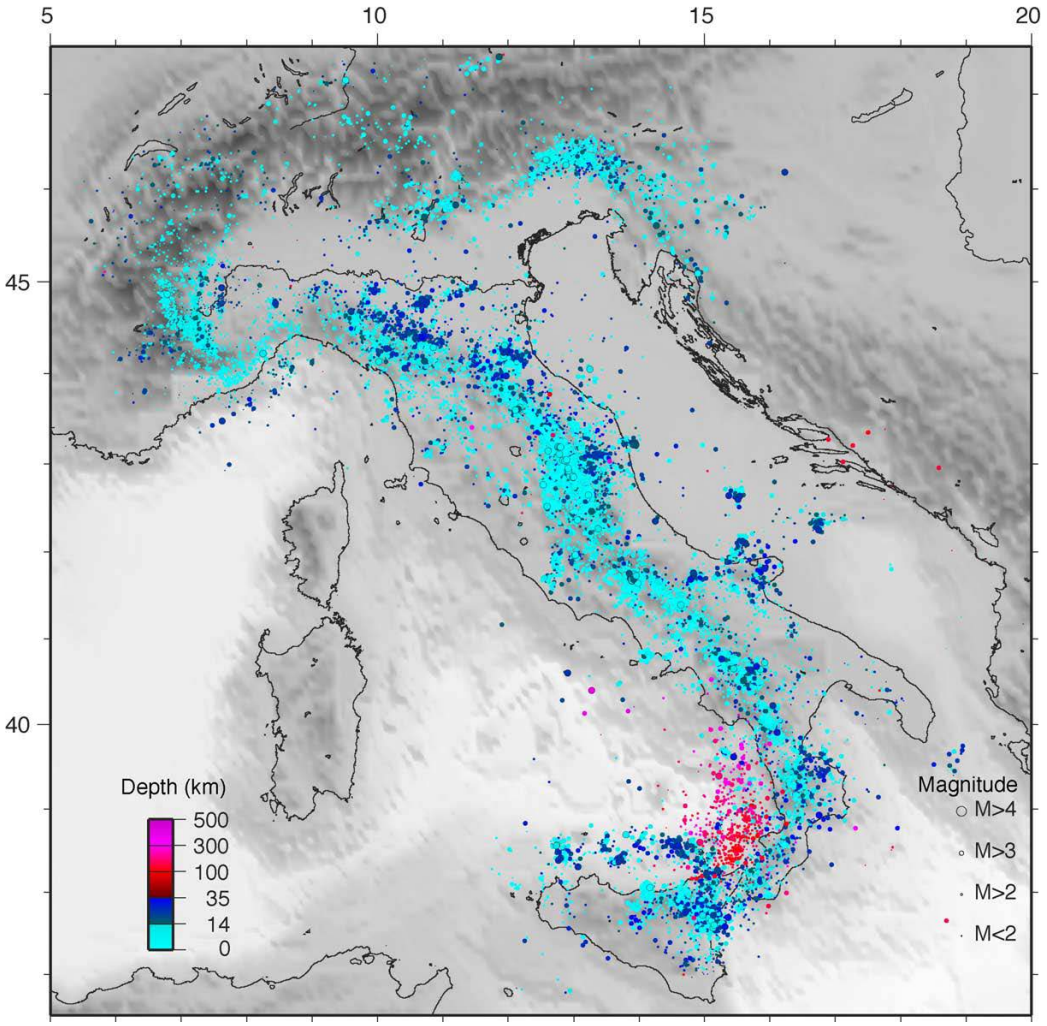


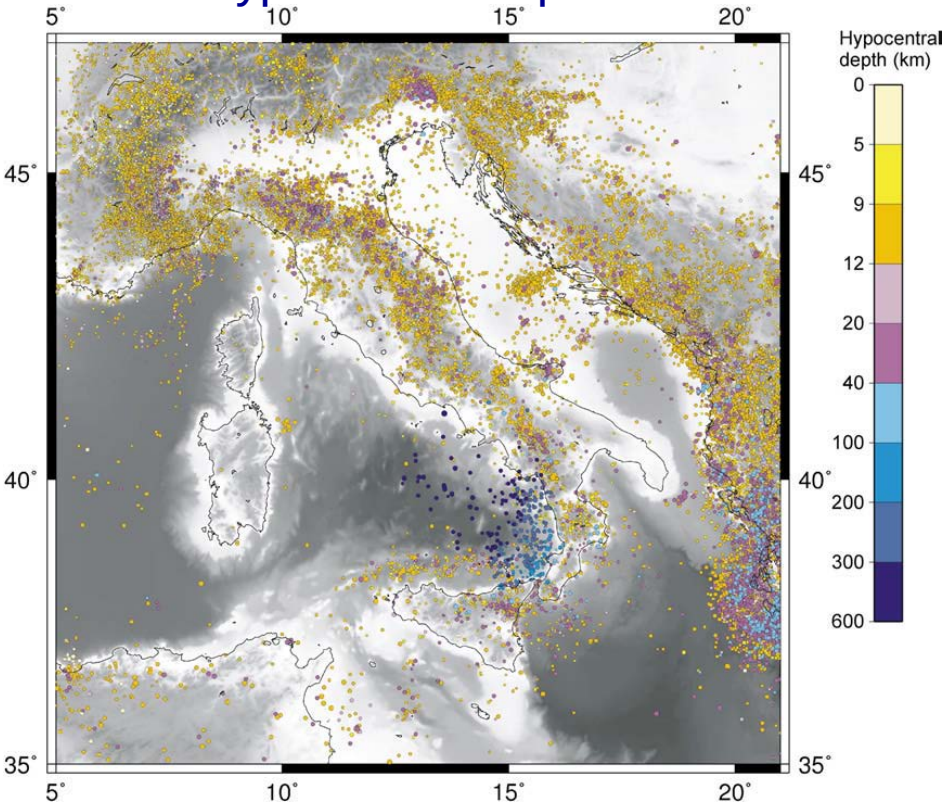
EARTHQUAKES LOCATIONS LIMIT THE BORDER OF THE ADRIA PLATE



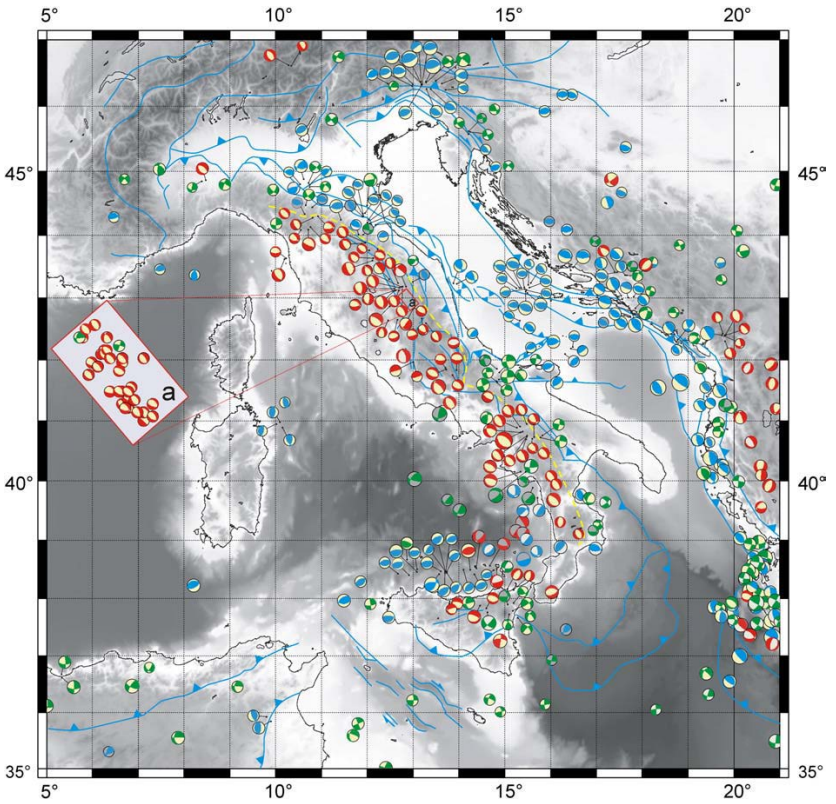
(Chiarabba et al., 2005)

SEISMICITY OF THE ADRIATIC REGION

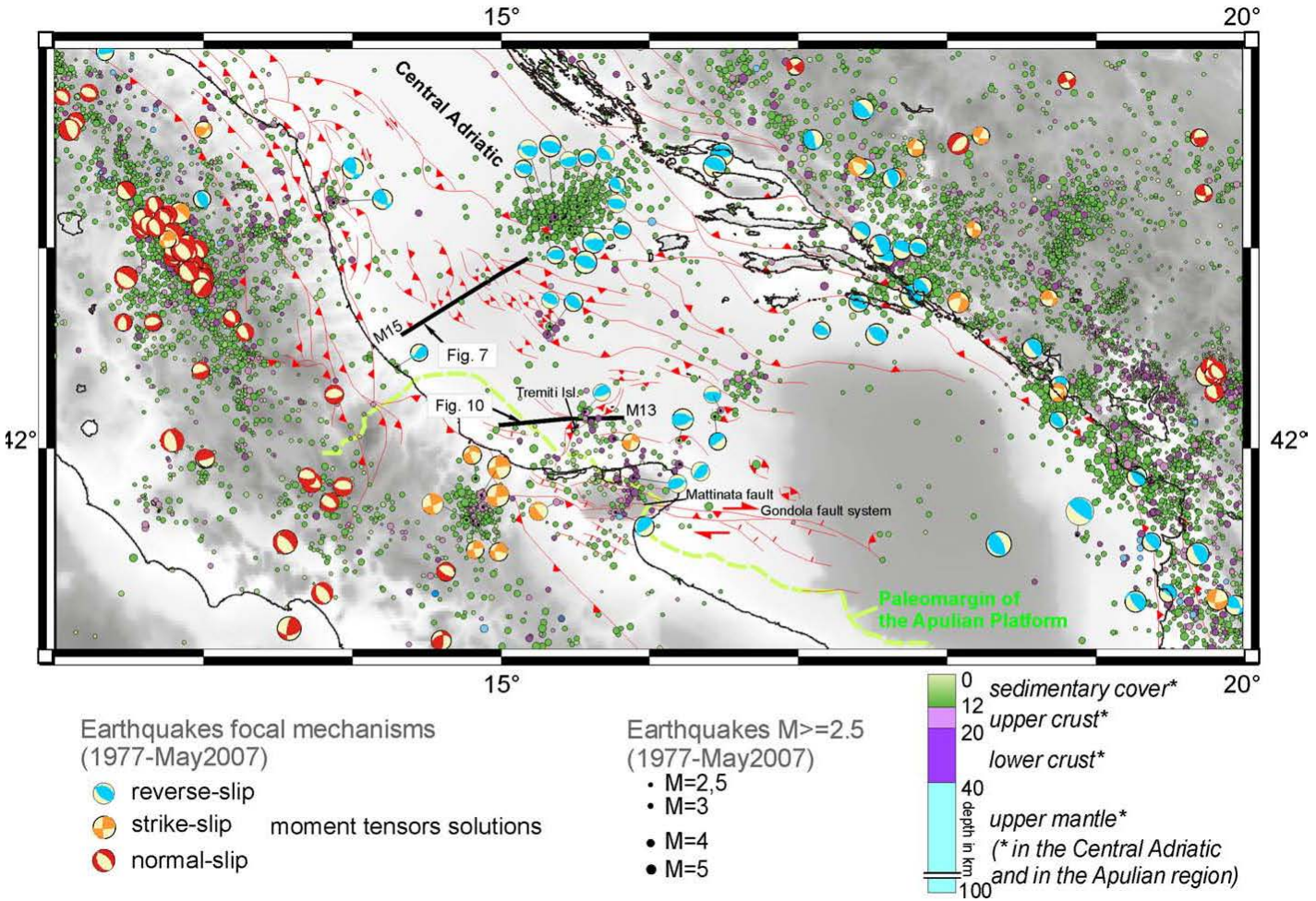
Hypocentral depth



Focal mechanisms

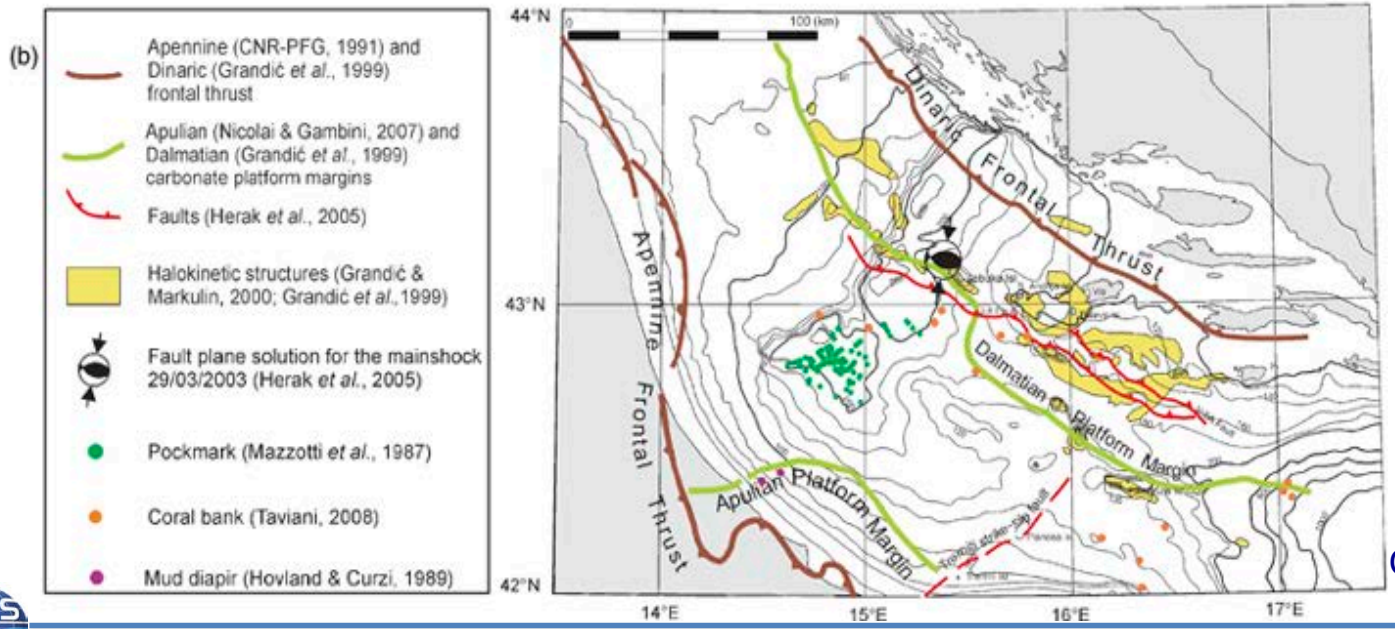


SEISMICITY OF THE ADRIATIC REGION



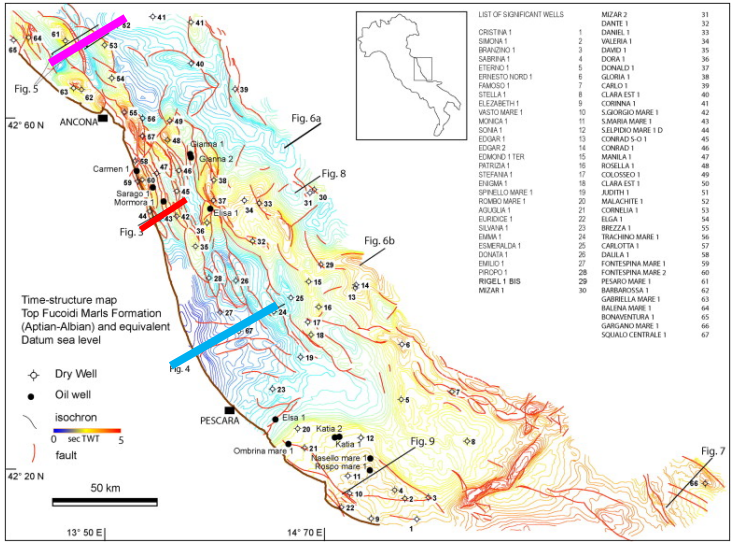
CENTRAL ADRIATIC
Structural setting

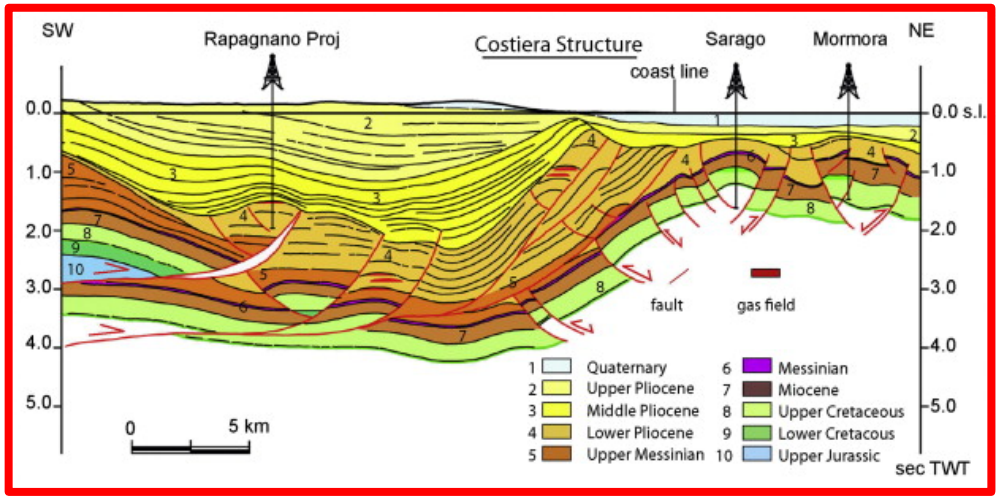
3 main deformation phases:
- extensional in the late Jurassic
- contractional/transtensional in the late Cretaceous
- compressional in the middle-late Pliocene and re-activation of pre-existing tectonic features

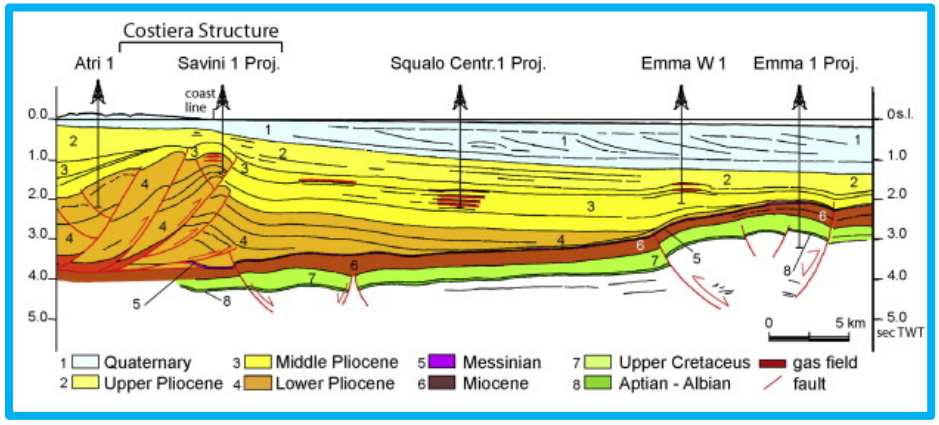


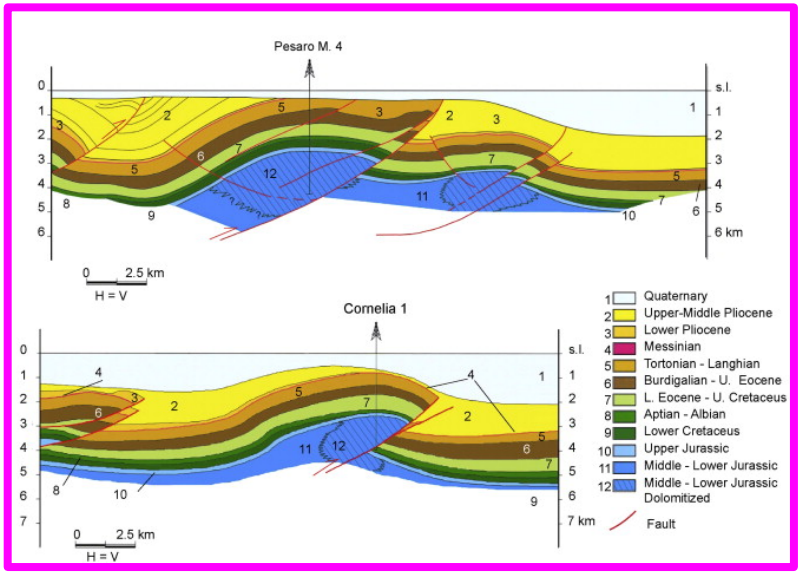
Geletti et al., 2008

CENTRAL ADRIATIC – Tectonic style



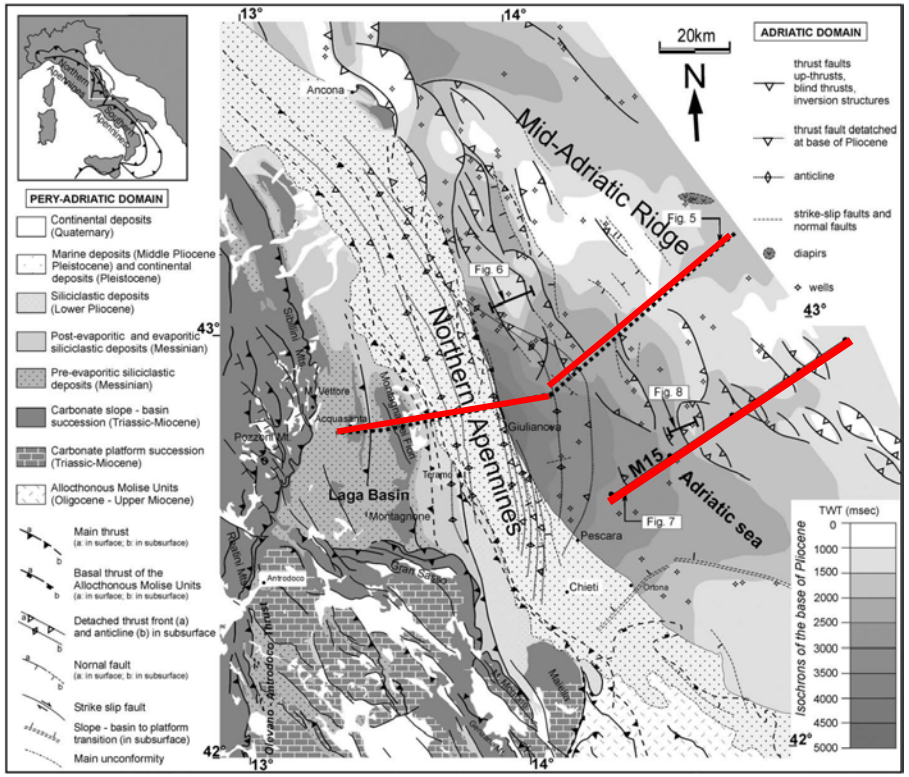


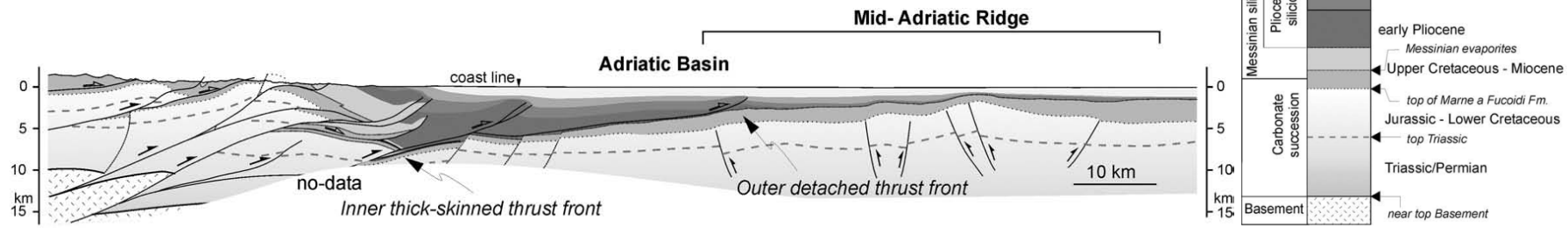




(Casero e Bigi, 2013)

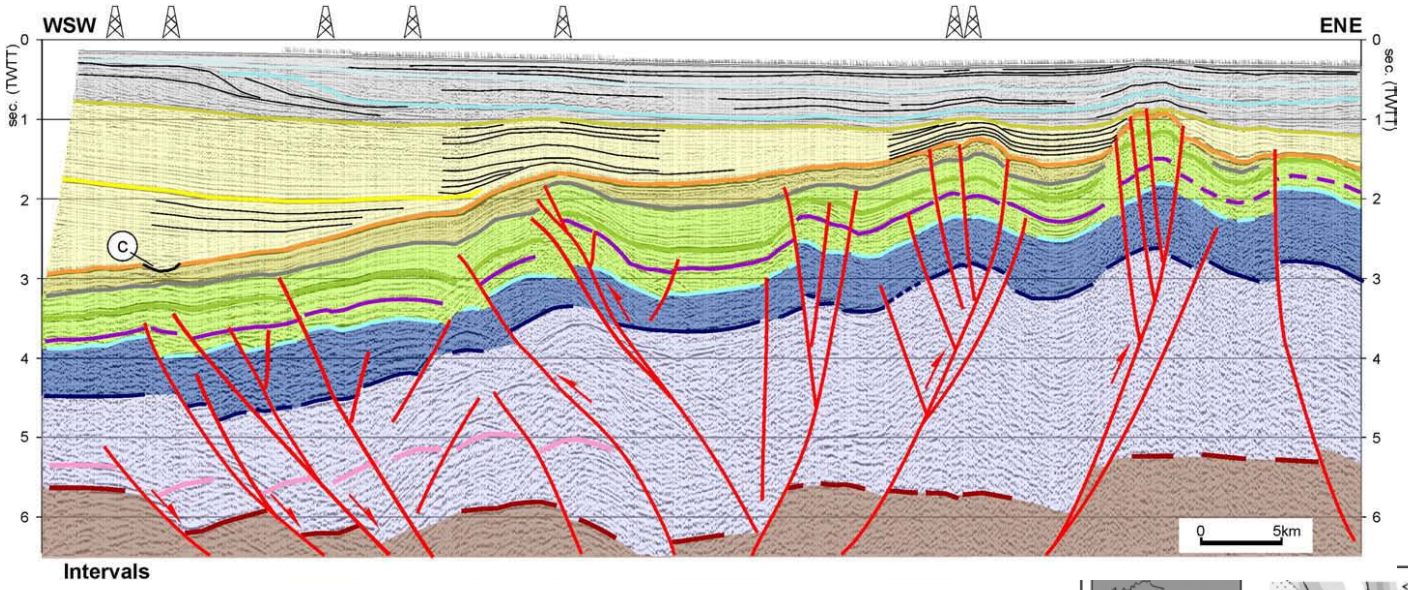
CENTRAL ADRIATIC
Mid-Adriatic Ridge





CENTRAL ADRIATIC

Mid-Adriatic Ridge



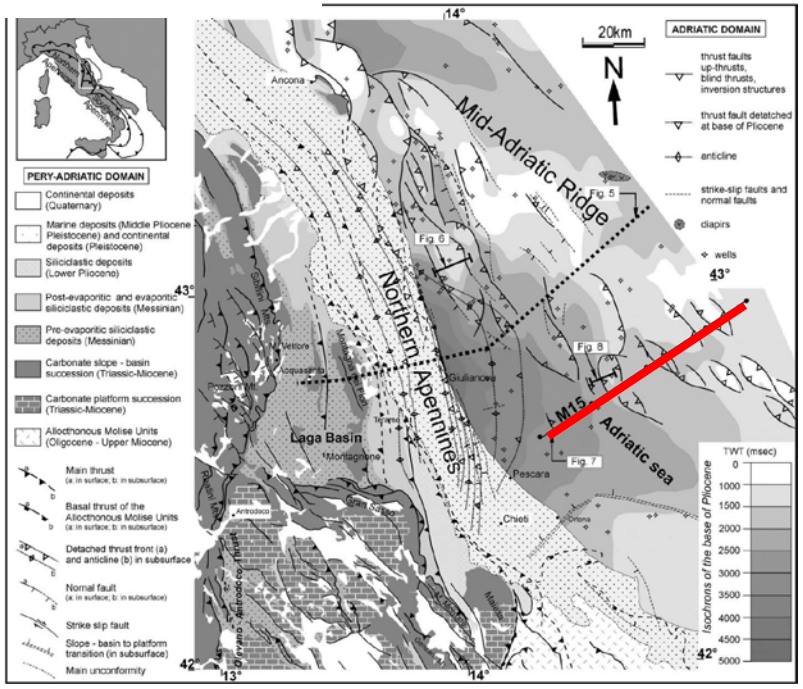
Intervals

Quaternary
Pliocene
Oligocene-Miocene
Middle Liassic-Eocene
Lower Liassic
Permian-Triassic
Basement

Key Reflectors

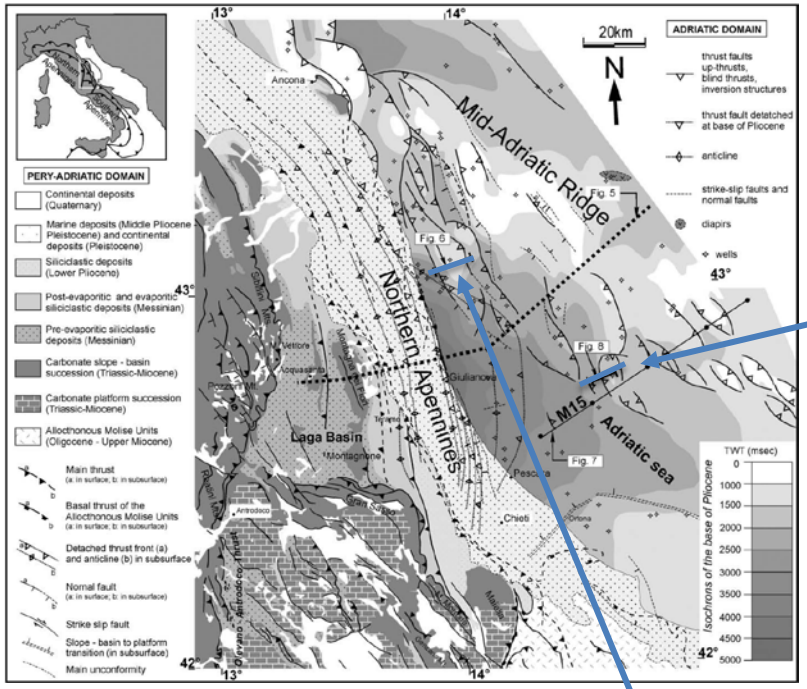
- Q1 Top Lower Pleistocene
- Q2 Within Lower Pleistocene
- P1 Top Pliocene
- P2 near Top middle Pliocene (volcanoclastic level)
- M Messinian
- E near Top Eocene (Scaglia Cinerea Fm.)
- LK Albian-Aptian (Marne a Fucoidi Fm.)
- MJ middle Jurassic (Rosso Ammonitico Fm.)
- LJ Top Lower Liassic (Top Calcare Massiccio Fm.)
- Tr1 near Top Triassic (Top Burano Fm.)
- Tr2 within Triassic
- P near Top Basement (Paleozoic)

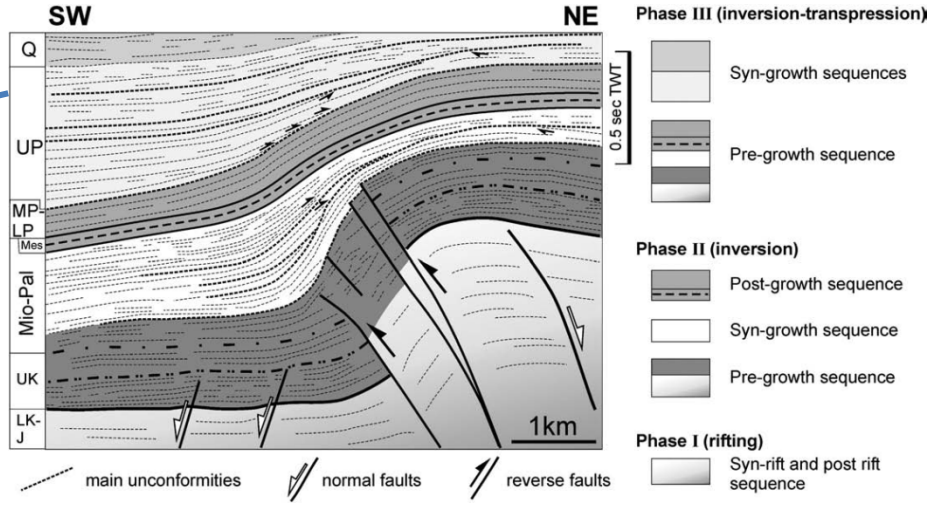
reflectors and unconformities within Pliocene and Quaternary
c incision

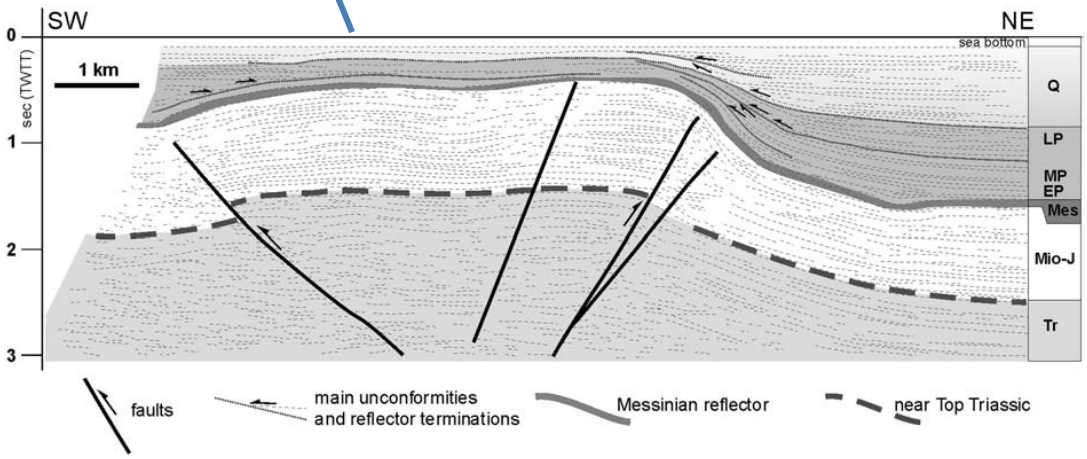


CENTRAL ADRIATIC

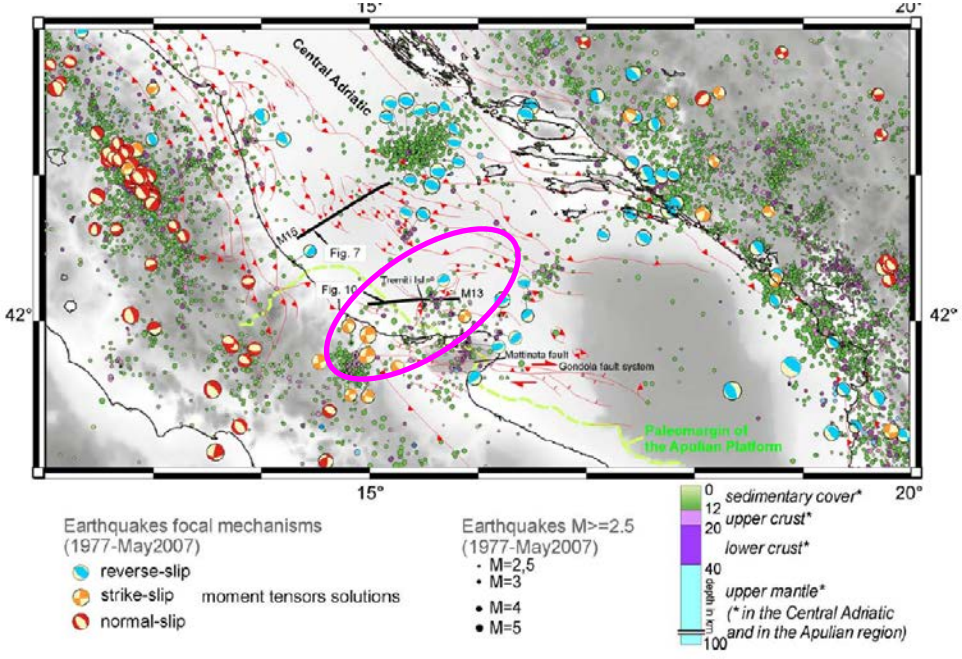
Mid-Adriatic Ridge

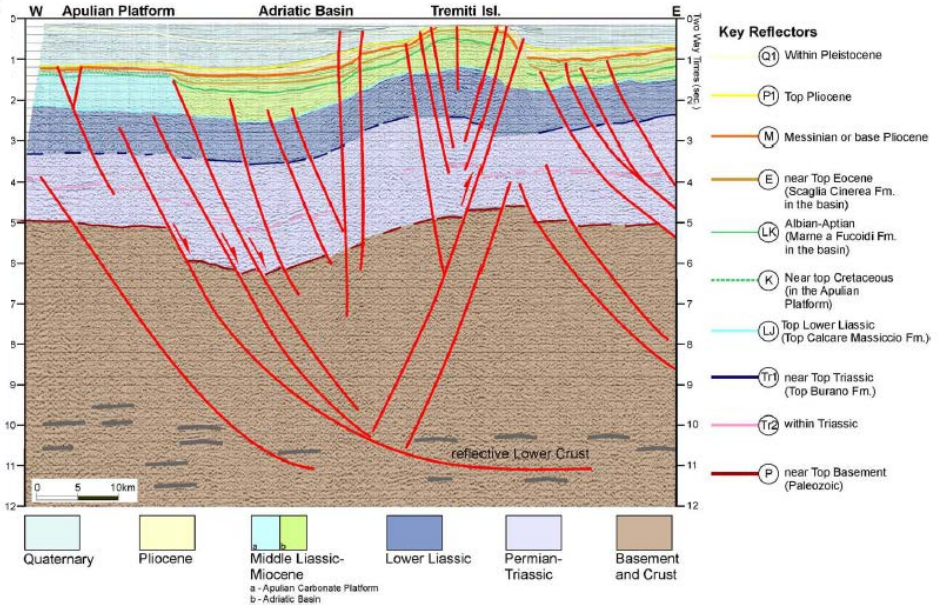






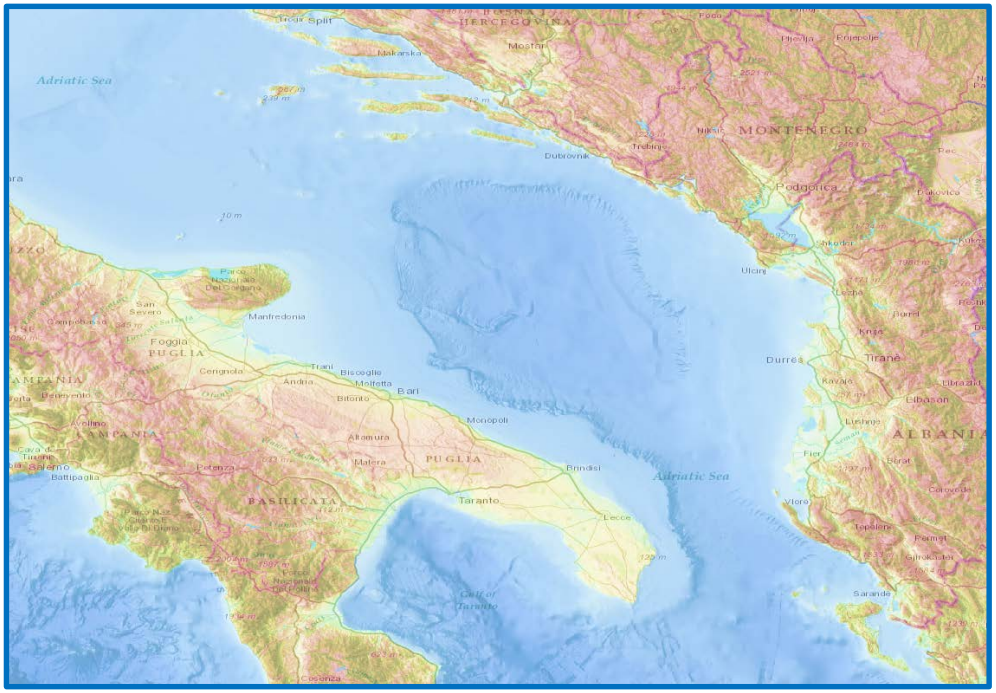
CENTRAL ADRIATIC
Tremiti Ridge





SOUTHERN ADRIATIC

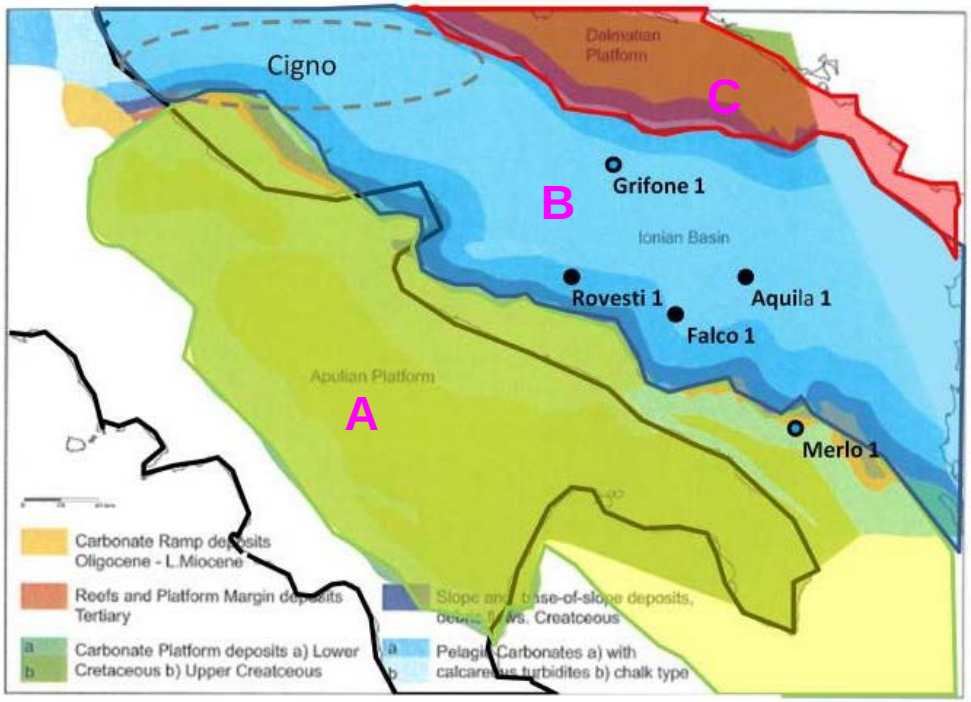
Bathymetry



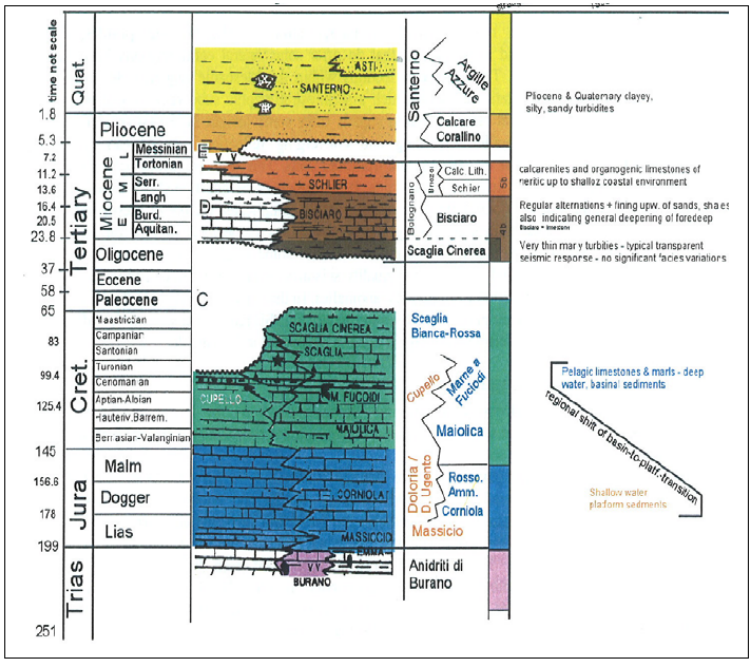
Structural sketch

SOUTHERN ADRIATIC

Stratigraphy



Modified after Nicolai & Gambini 2007



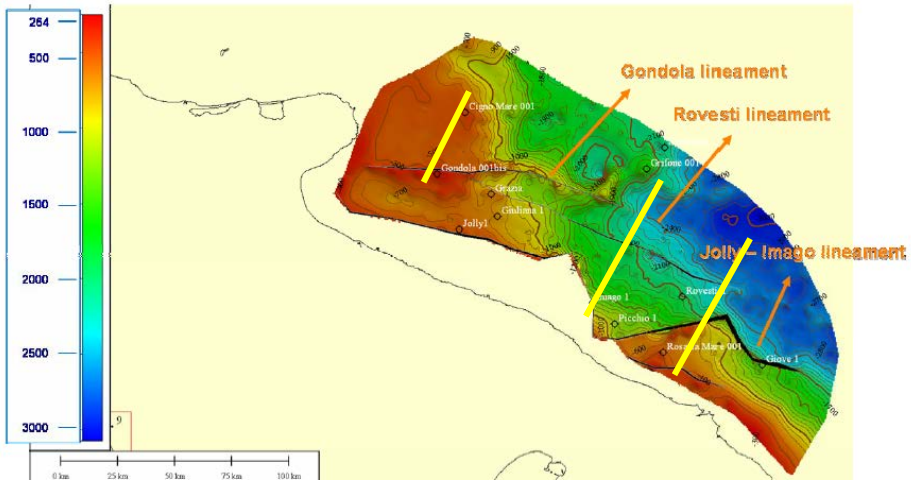
The Apulian zone (A), extending from Puglia region to the external sector of the Ionian islands (pre Apulian area), and characterized by thick carbonate Triassic to Miocene neritic sequences (> 6000 m).

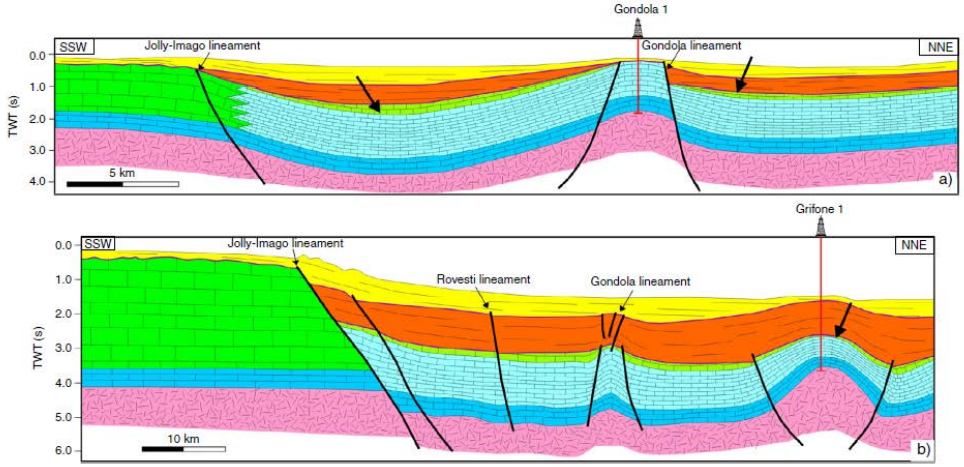
The Ionian zone, (B) It occupies the Southern Adriatic Sea area. Going further north it joins the Umbria-Marche Apennines, whereas to the west it outcrops in the eastern sector of the Gargano. It features neritic sediments up to the Early Jurassic (Early-Middle Lias), becoming pelagic up to the Middle-Late Eocene and finally terrigeneous (flysch) up to the Early Miocene.

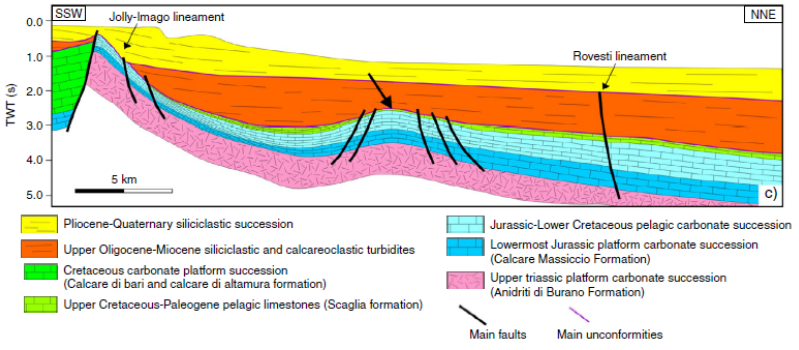
The Dalmatian zone, (C) outcrops along the Montenegro coastline, with neritic facies from the Triassic to the Middle Eocene and becoming flyshoidal from the Oligocene to the Early Miocene (Aquitanian).

SOUTHERN ADRIATIC

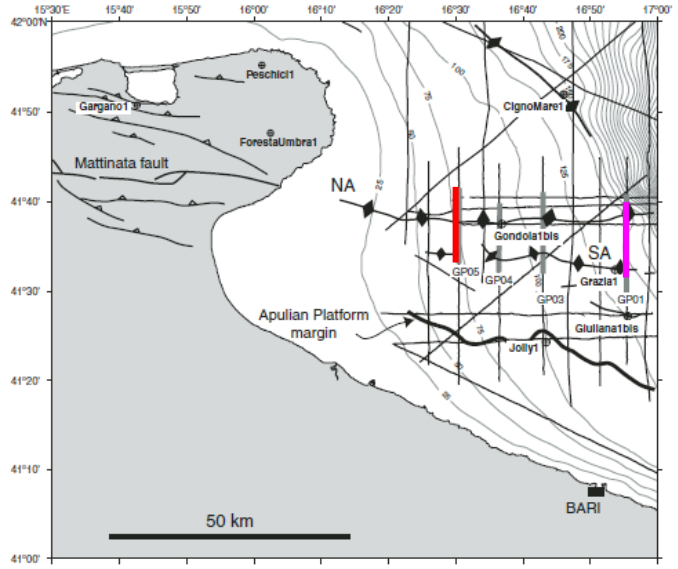
Structural setting

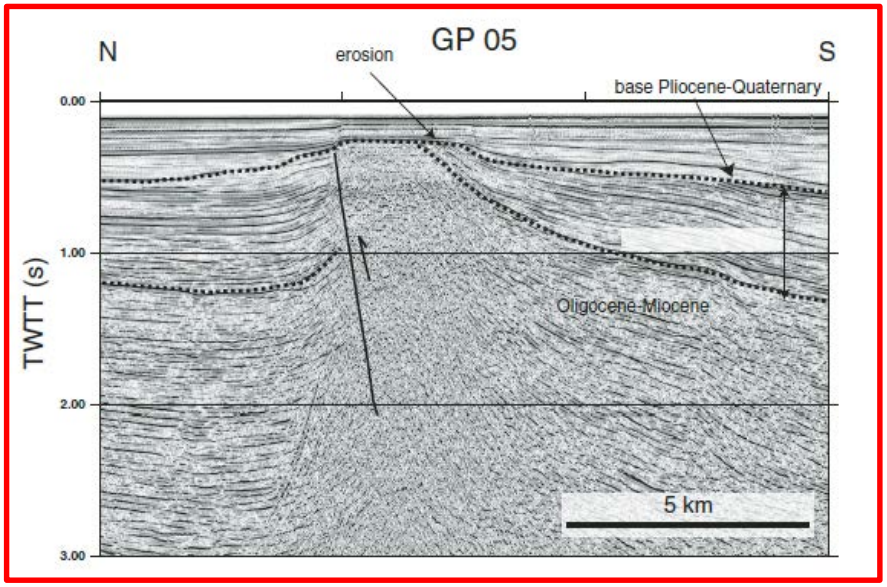


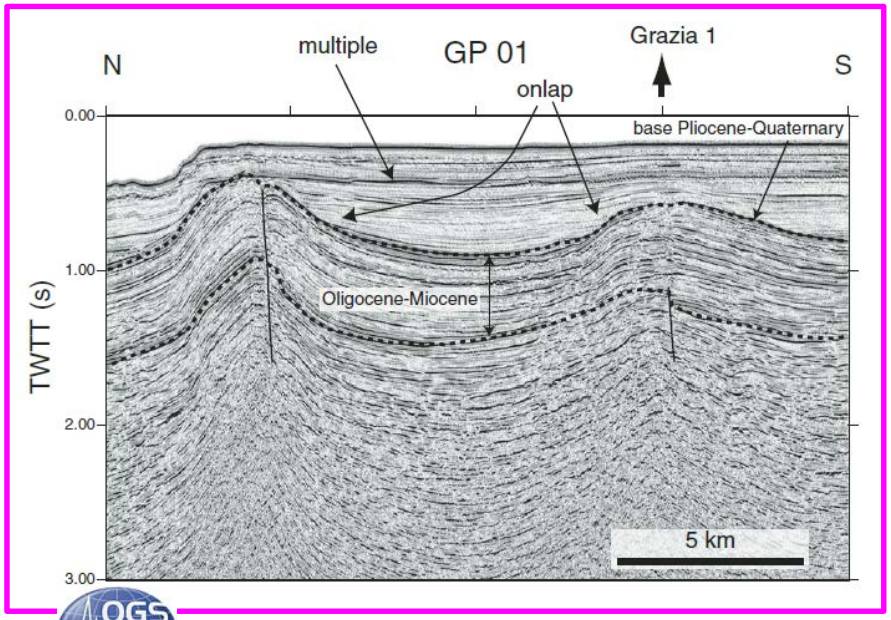


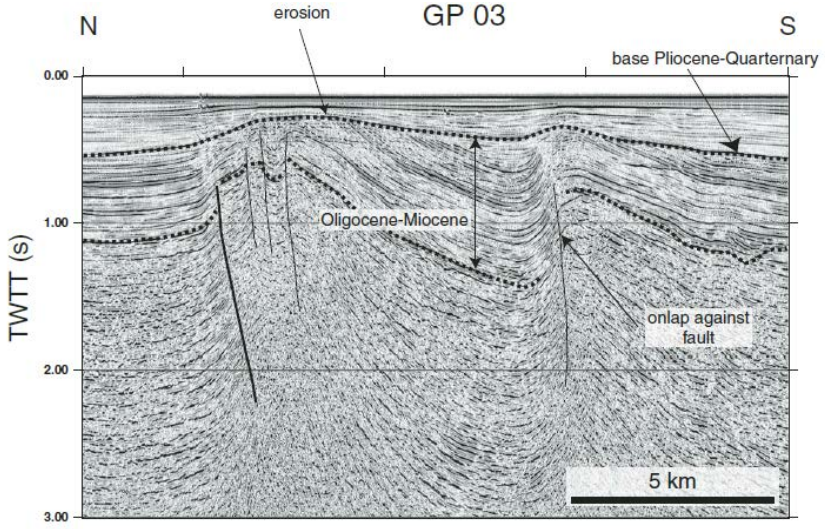


Volpi et al., 2014







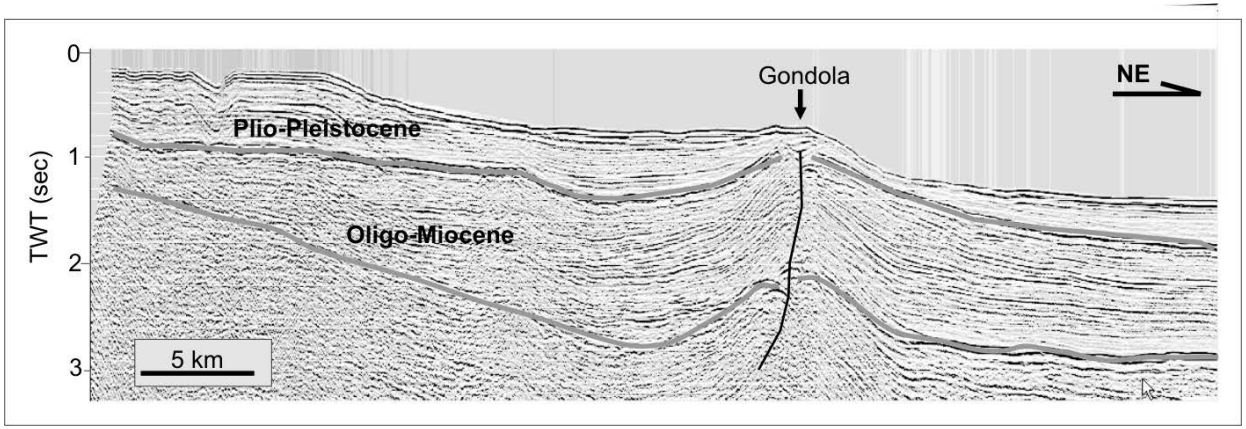


(Argnani et al., 2012)

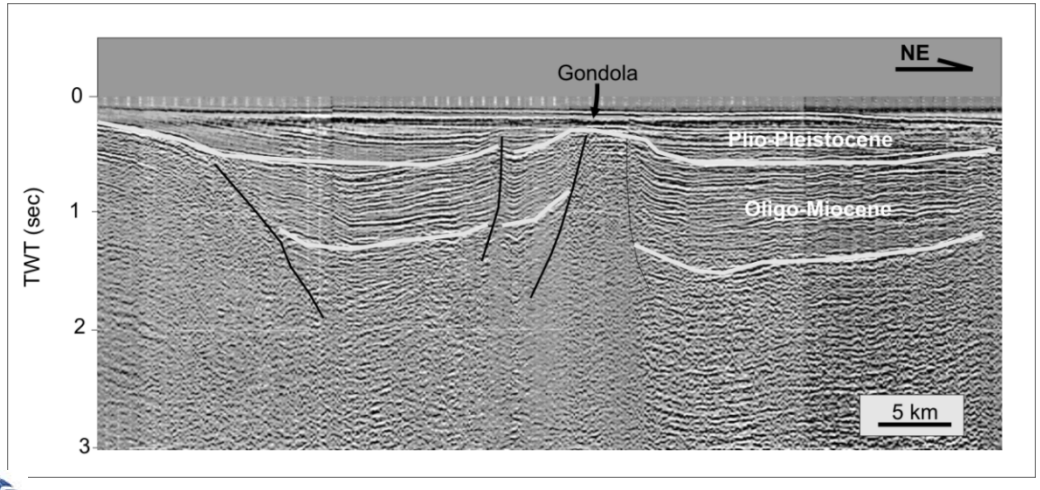
SOUTHERN ADRIATIC

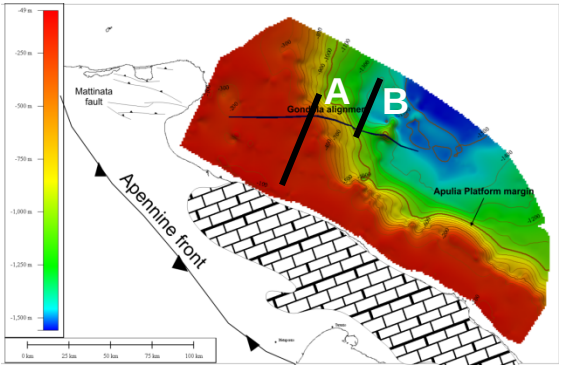
Gondola fault system

A



B

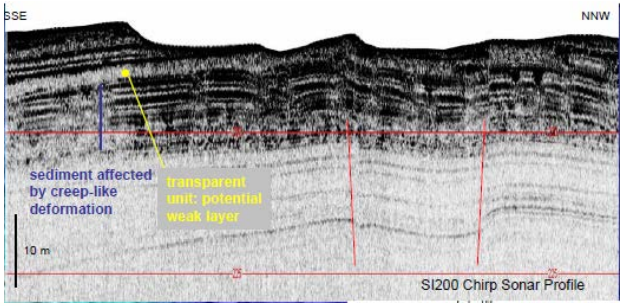


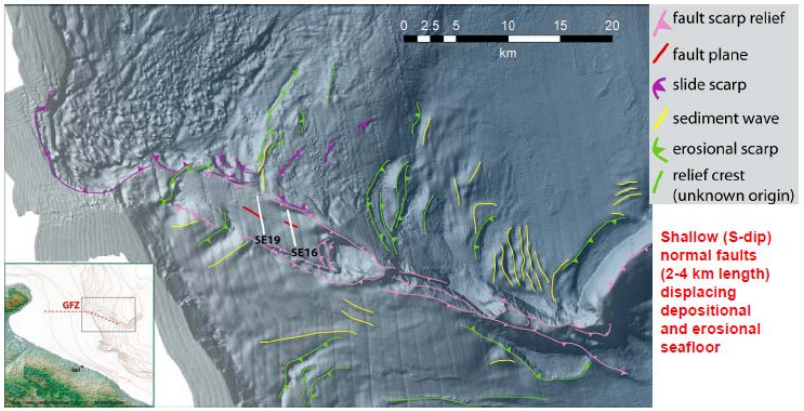


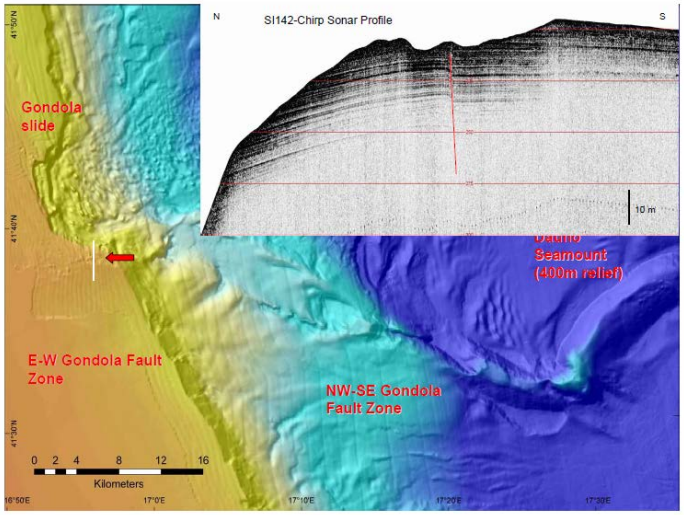
SOUTHERN ADRIATIC

Gondola fault system

Seafloor evidence and shallow deformation

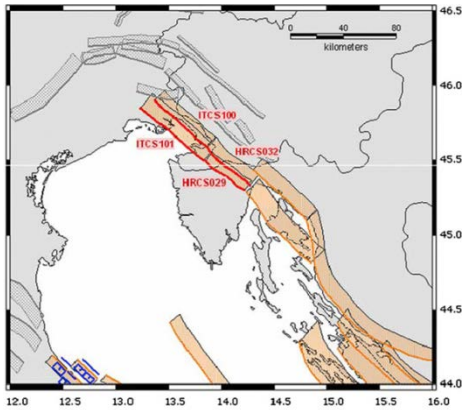




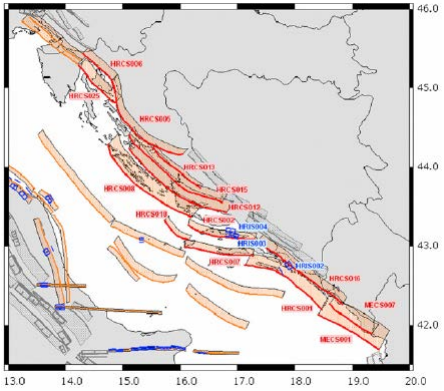


Ridente et al., 2010

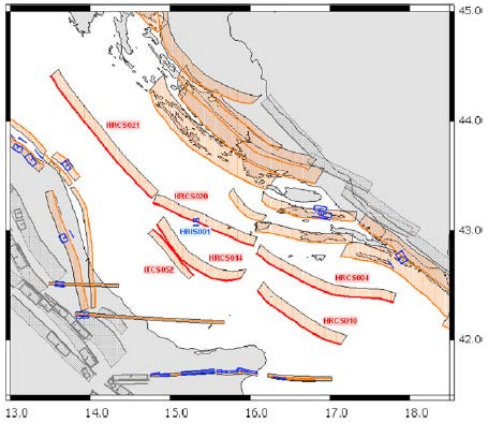
DISS INGV – Italian seismicity catalogue



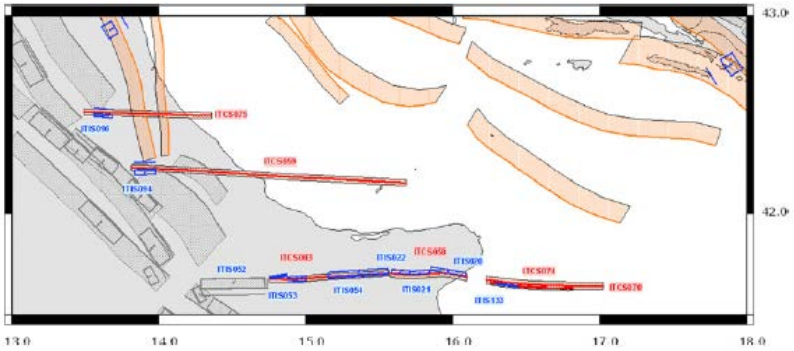
Region name	North-Eastern Adriatic
Region code	AD1
Structural setting	External Dinarides thrust belt
Principal faulting style	reverse to reverse-dextral strike slip
Largest Earthquake	14.08.1574 M_w 5.6 Lupoglav earthquake
Largest Tsunami	26.03.1511 I 2 Venice/Trieste tsunami



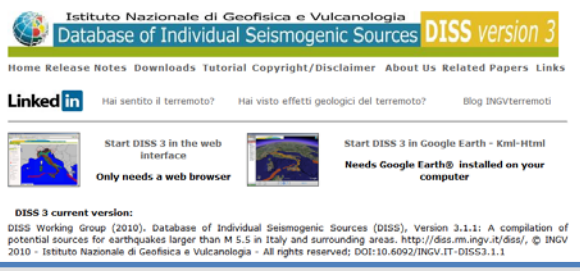
Region name	Eastern Adriatic
Region code	AD2
Structural setting	Internal and central part of External Dinarides thrust belt
Principal faulting style	thrusting, reverse to reverse-dextral strike slip
Largest Earthquake	06.04.1667 M_w 7.2 Dubrovnik earthquake
Largest Tsunami	06.04.1667 I 4 Dubrovnik tsunami



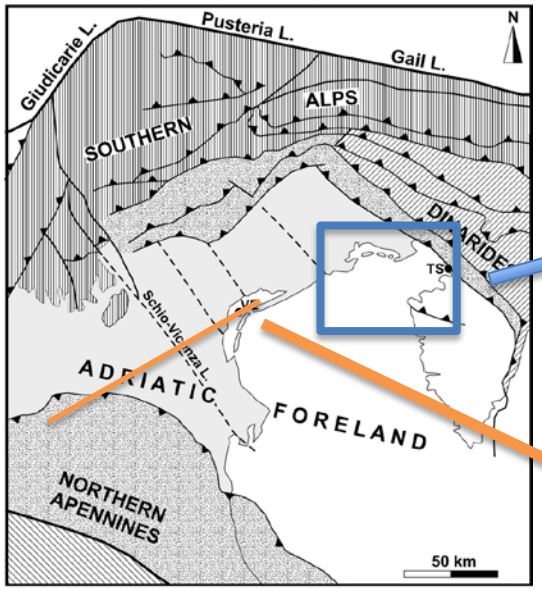
Region name	Central Adriatic
Region code	AD3
Structural setting	External parts of the External Dinarides and Apennines, Middle Adriatic
Principal faulting style	thrusting
Largest Earthquake	02.07.1844 M_w 5.6 Adriatic earthquake
Largest Tsunami	unknown

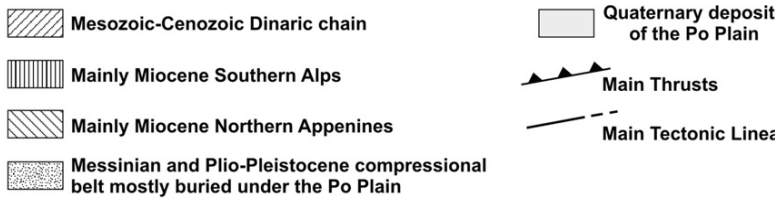


Region name	Southern Western Adriatic
Region code	AD4
Structural setting	Apulian foreland shear zone
Principal faulting style	dextral strike-slip
Largest Earthquake	30.07.1627 M_w 6.7 Gargano earthquake
Largest Tsunami	30.07.1627 I 5 Gargano tsunami

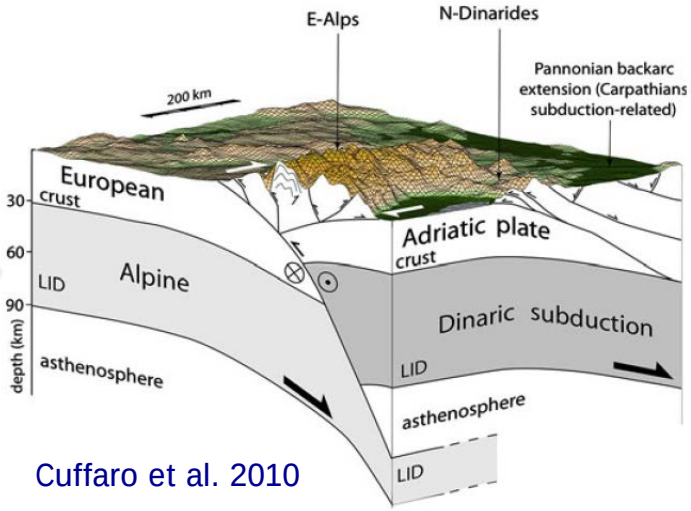


NORTHEF

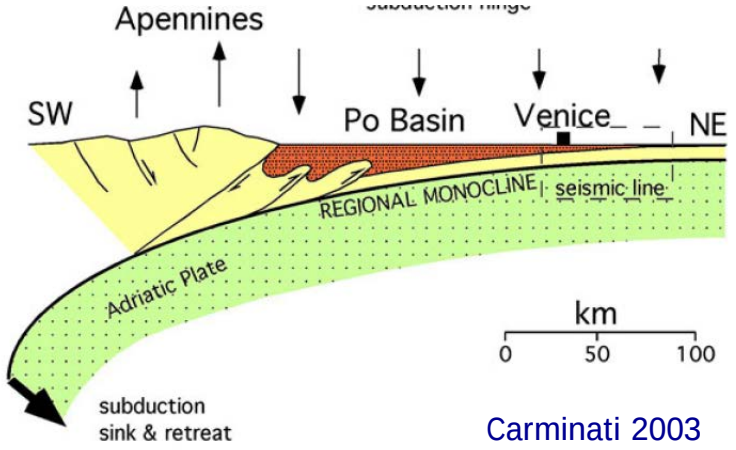




Structural map of the Northern Adriatic Sea region (modified from Castellarin et al., 2006).

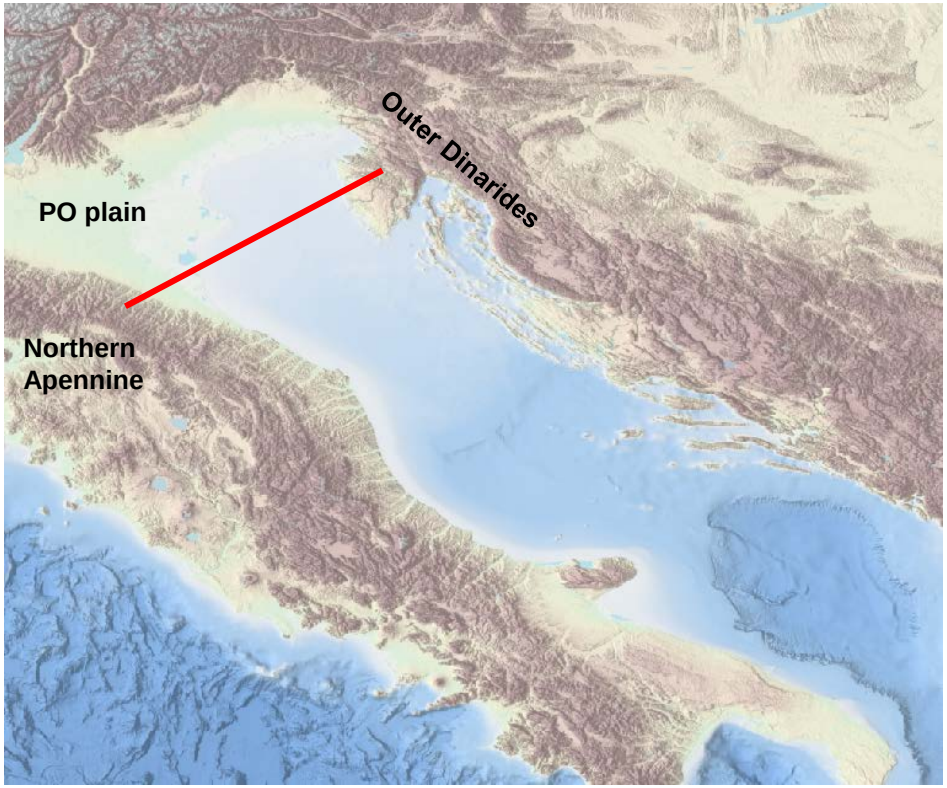


Cuffaro et al. 2010

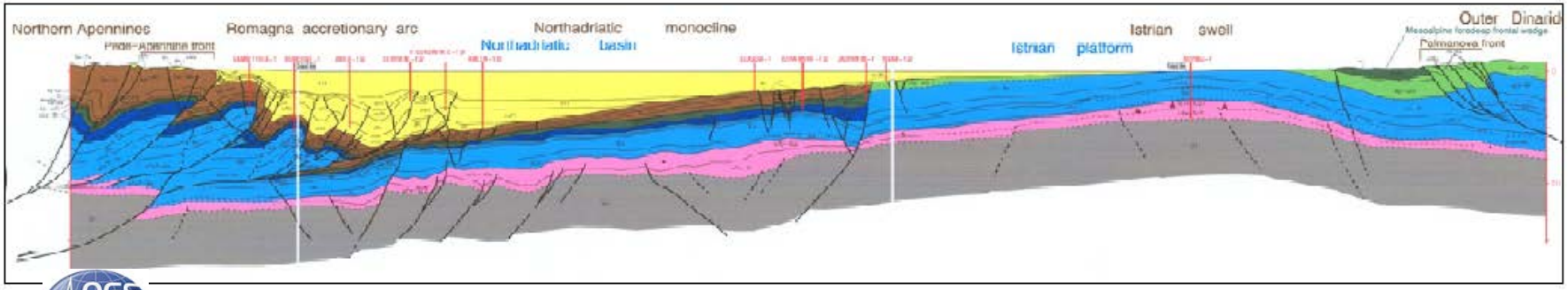


Carminati 2003

MORPHOLOGY AND PRESENT STRUCTURAL SETTING – NORTHERN ADRIATIC

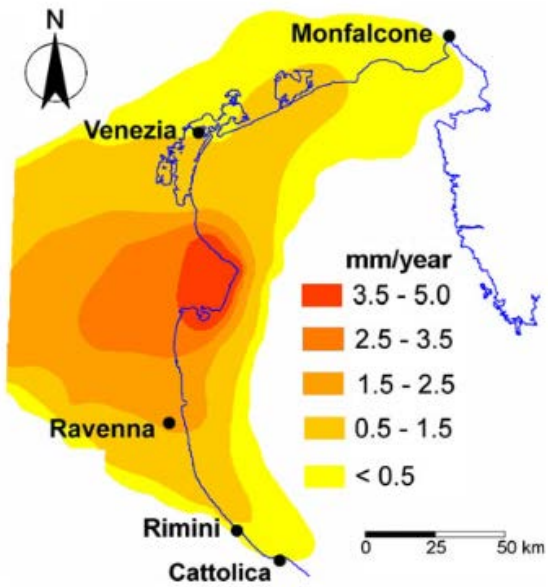


(Fantoni & Franciosi, 2010)

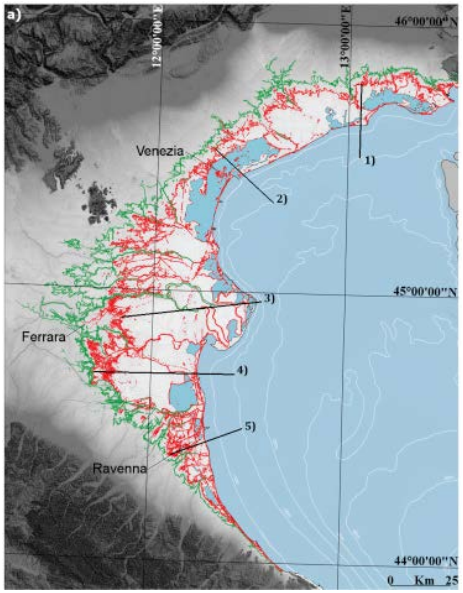


SUBSIDENCE IN THE NORTHERN ADRIATIC

As a consequence of climate change and human-induced land subsidence, coastal zones are directly impacted by sea-level rise. Natural component of land subsidence is tectonic activity, glacial isostatic adjustment and sediment compaction. The anthropogenic component is a consequence of the land use and soil exploitation (i.e. pumping and gas extraction). During next decades, the combined effects of land subsidence and of the sea-level rise in consequence of climate change are expected to enhance the shoreline instability, leading to a further retreat.



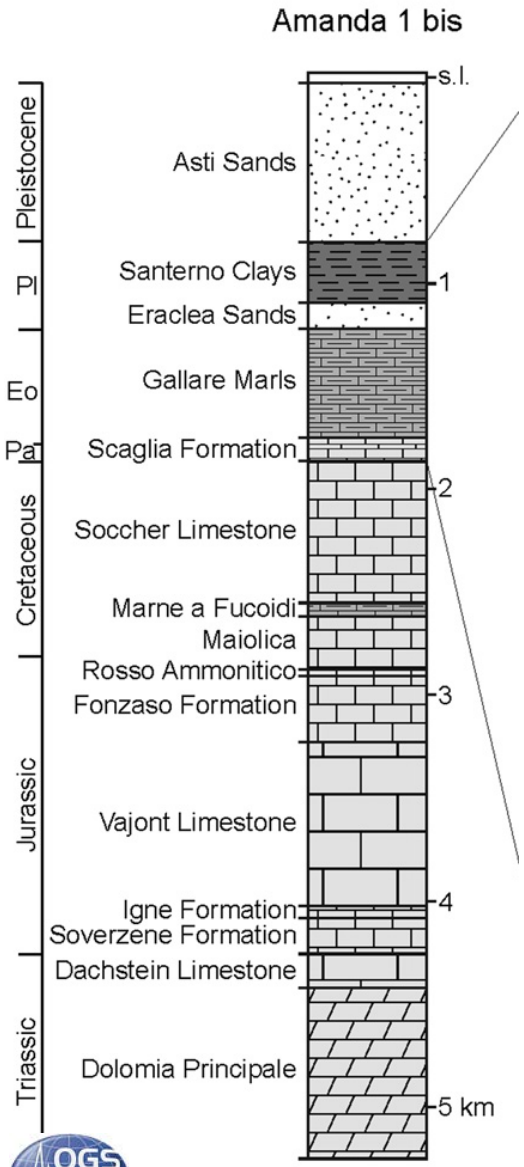
Recent natural land subsidence in the northern Adriatic coastal area (after Gambolati and Teatini 1998)

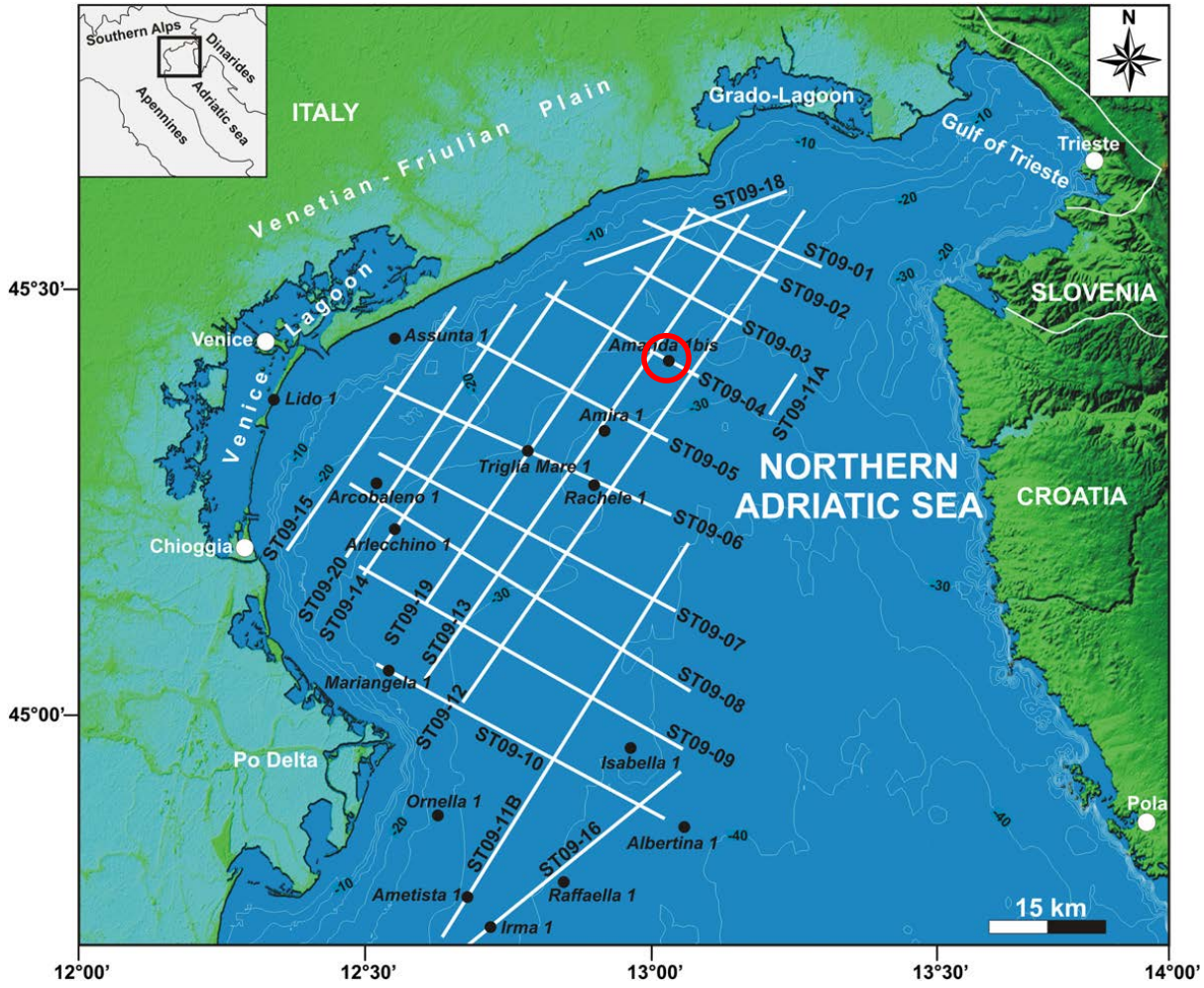


In the map, the limits of marine ingression expected for 2100 for the Rahmstorf scenarios (2007, red line) and the 5 m contour line (in green)

Area	IPCC 2013 AR5-8.5 min			IPCC 2013 AR5-8.5 max			Rahmstorf 2007 max scenario					
	km²	α (°)	distance (m)	km²	α (°)	distance (m)	km²	distance (m)	α (°)	slope max		slop
										marine	terrestrial	mar
North Adriatic	4616.7	0.51	59,132.0	4957.6	0.50	60,733.3	5451.7	61,280.4	0.49	0.79	0.01	0.24

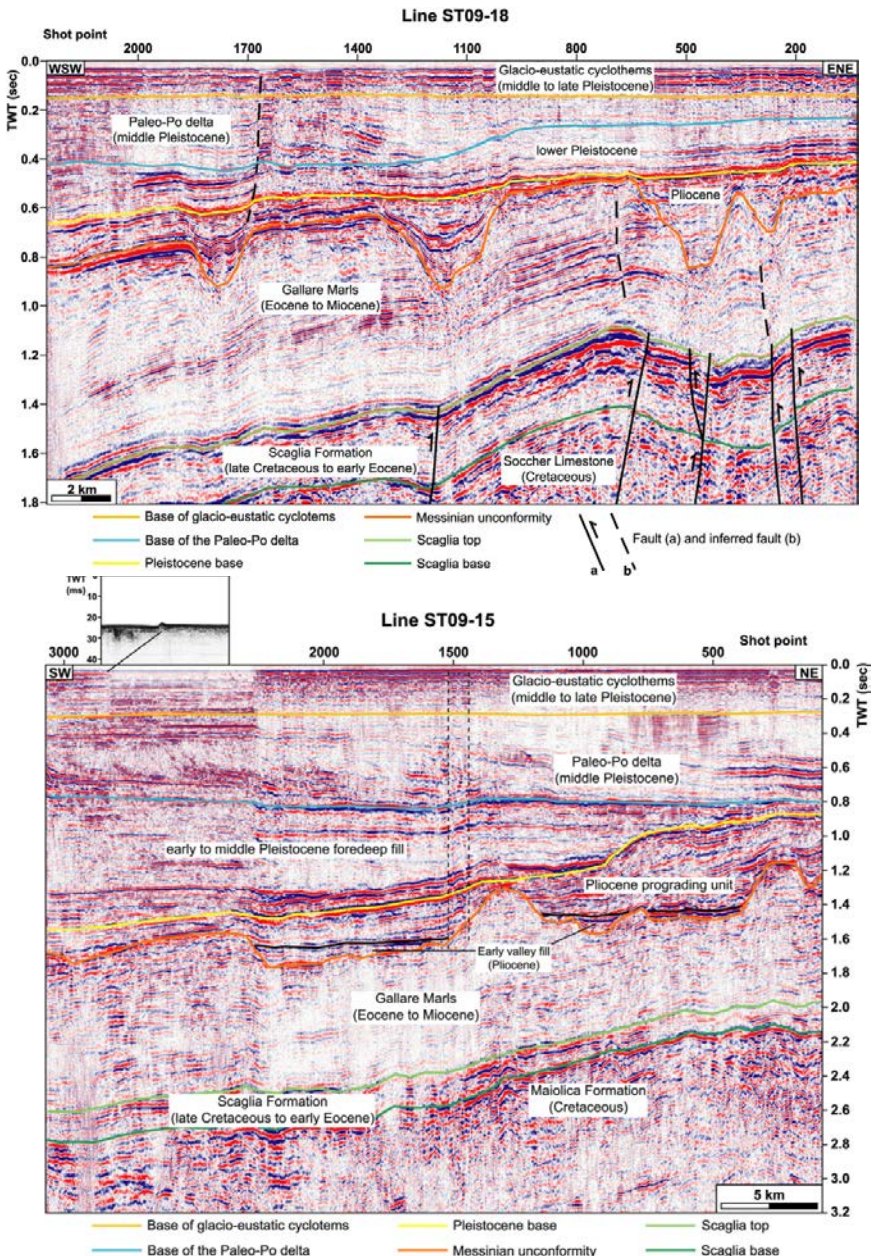
SCHEMATIC STRATIGRAPHY from AMANDA well data

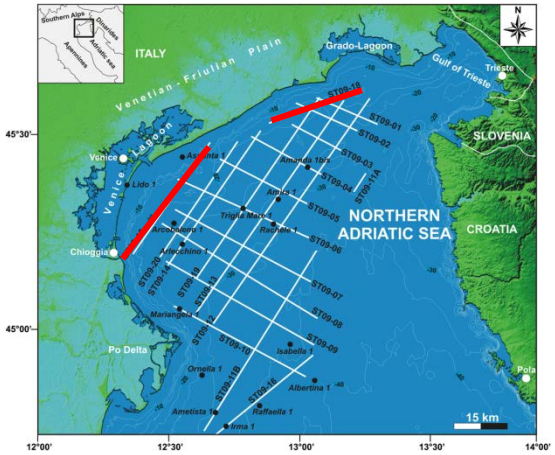




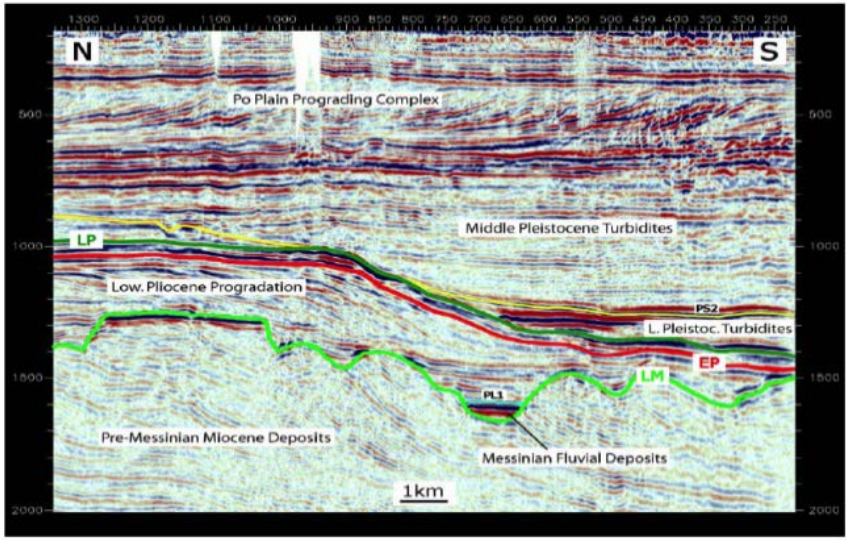
Donda et al., 2014. Deep-sourced gas seepage and methane-derived carbonates in the Northern Adriatic Sea. Basin Research (2014) 1–15, doi: 10.1111/bre.12087

SEISMOSTRATIGRAPHY – NORTHERN ADRIATIC



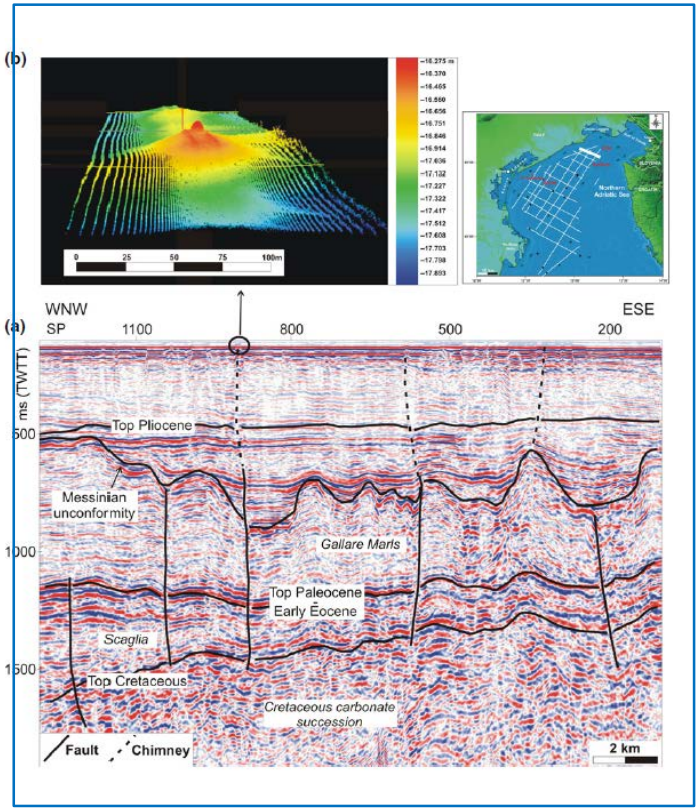


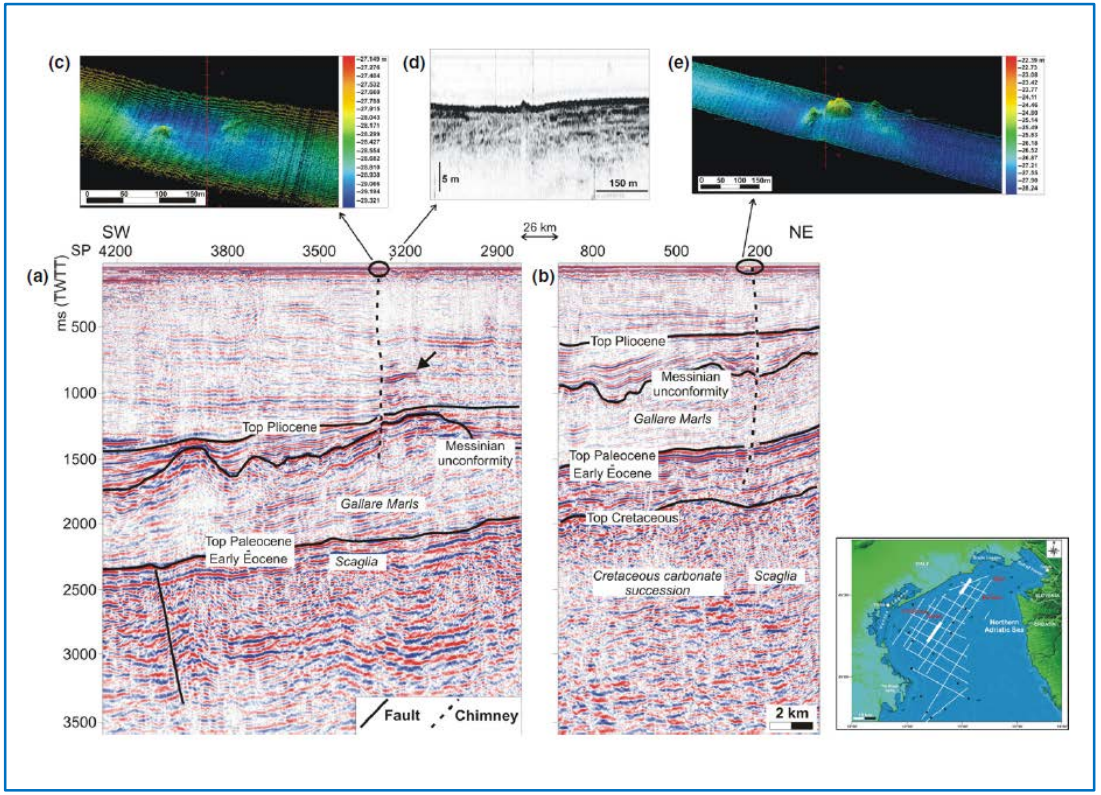
Donda et al., 2014. Deep-sourced gas seepage and methane-derived carbonates in the Northern Adriatic Sea. Basin Research (2014) 1–15, doi: 10.1111/bre.12087



Ghielmi, M., Minervini, M., Nini, C., Rogledi, S., Rossi, M., Vignolo, A., 2010. Sedimentary and tectonic evolution in the eastern Po-Plain and northern Adriatic Sea area from the Messinian to Middle Pleistocene (Italy). Rendiconti Scienze Fisiche e Naturali Accademia Lincei 21, 131e166

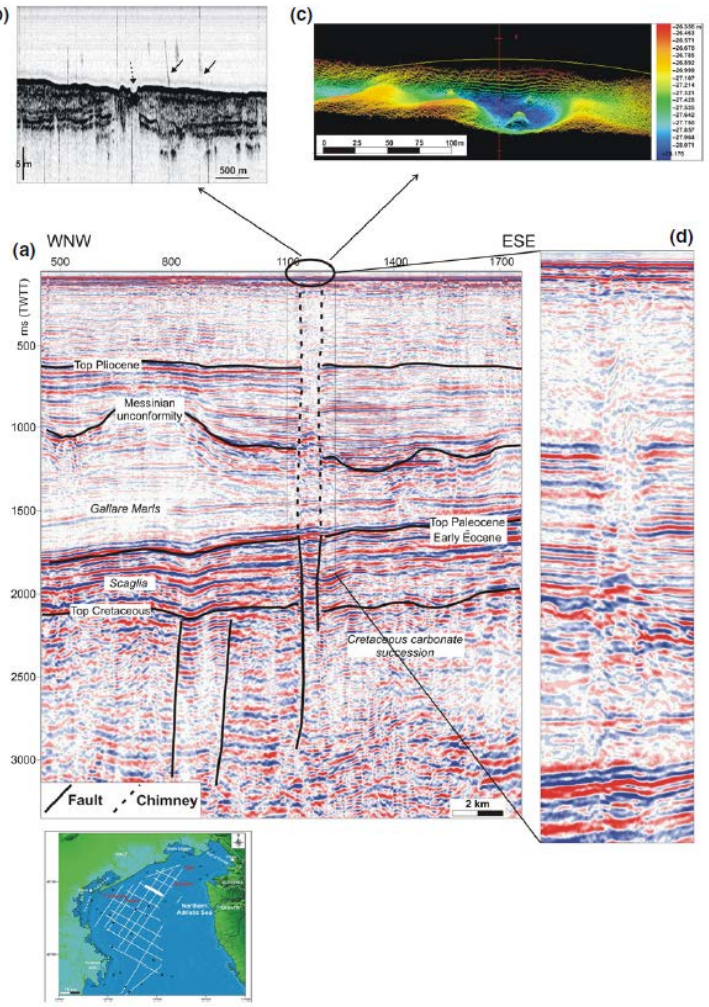
GAS SEEPS IN THE NORTHERN ADRIATIC

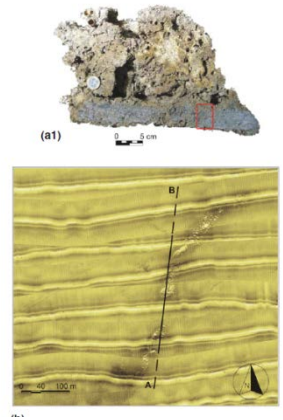


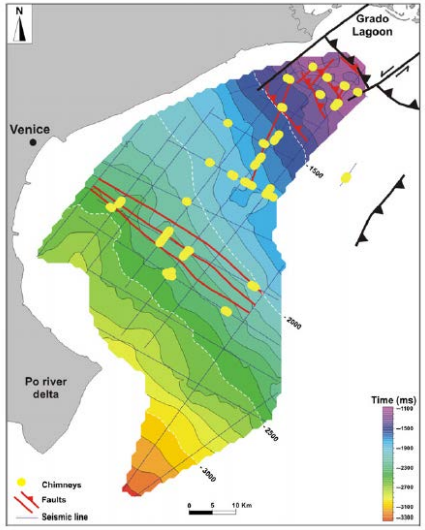


(Donda et al., 2014)

GAS SEEPS IN THE NORTHERN ADRIATIC

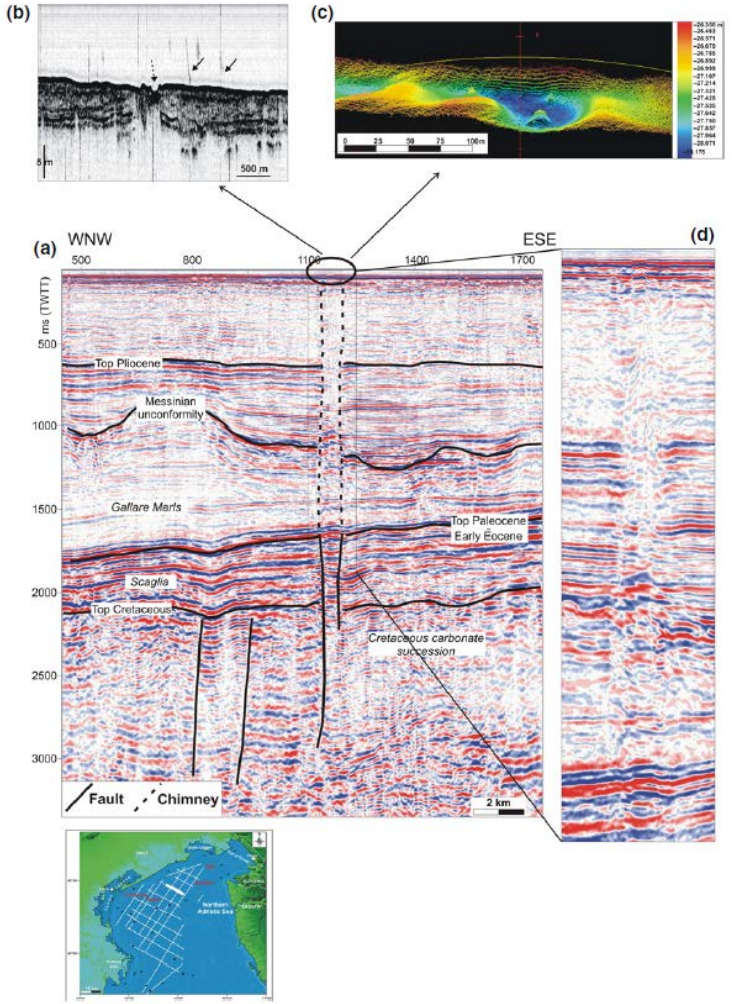


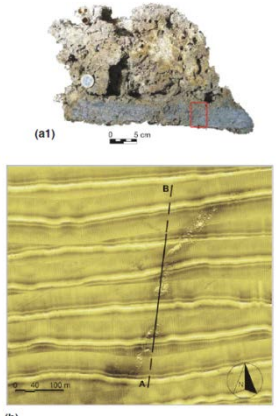


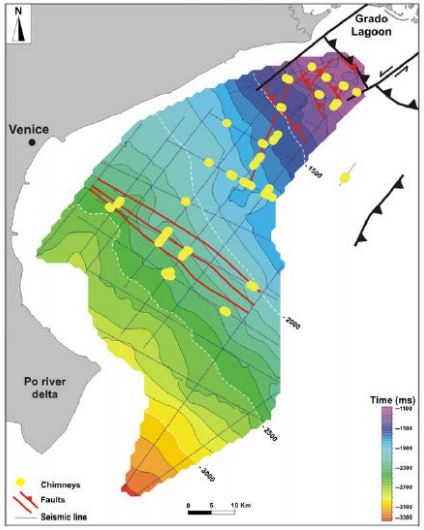


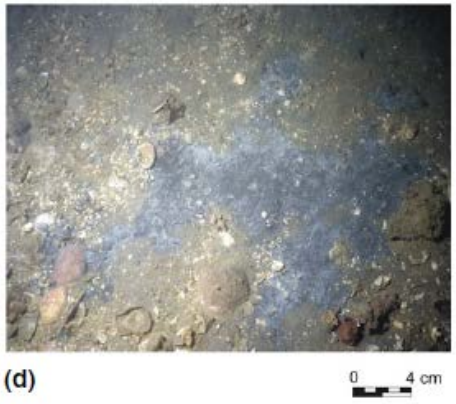
(Donda et al., 2014)

GAS SEEPS IN THE NORTHERN ADRIATIC





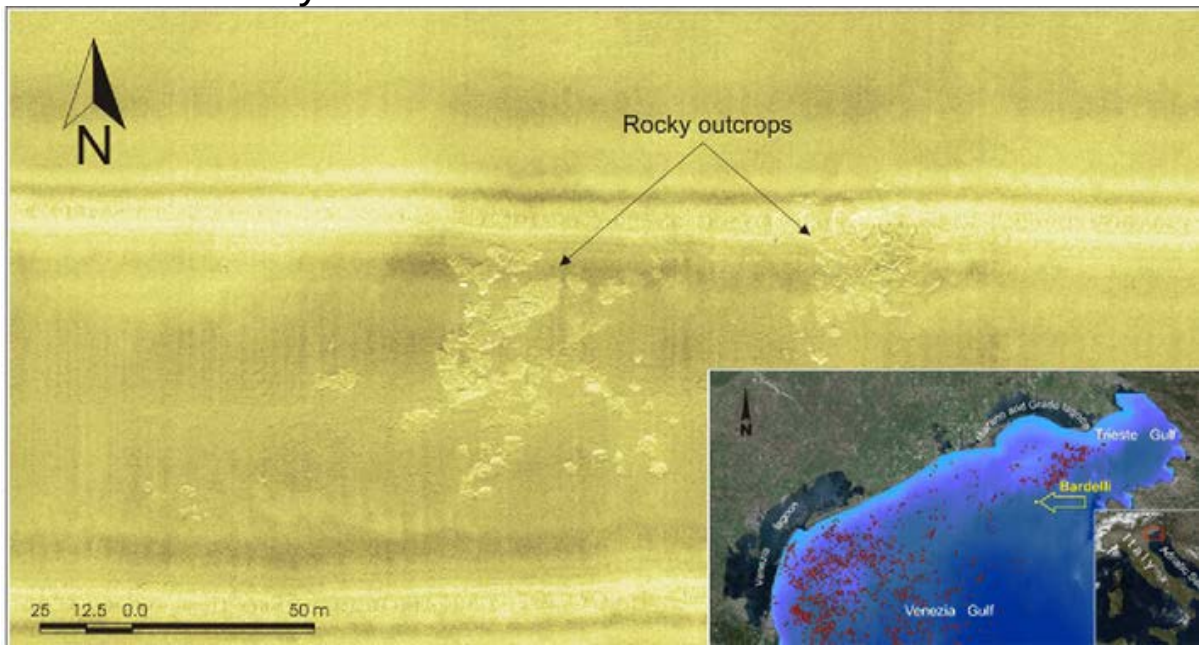




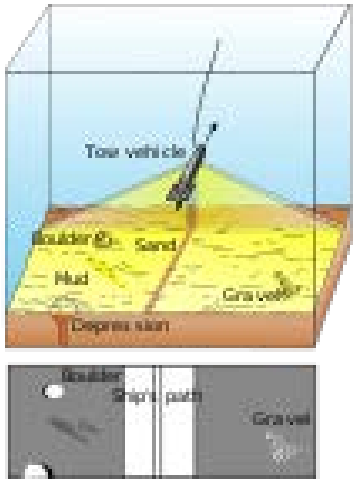
(Donda et al., 2014)

Trezze in the Northern Adriatic

Trezze, *grebeni* o *tegnue* are the names that locally, from Grado to Venice, are given to rock formations that rise from the sandy Adriatic seabed. They have a modest extension and constitute a "geological curiosity" which is not found in other parts of the Mediterranean. These "islands" of rock on sandy-muddy seabed are the ideal substrate for the establishment of sessile organisms (which must be anchored to the substrate) and thanks to the cavities and interstices present, provide shelter to the juvenile stages of many fish species. They represent a true oasis of biological wealth and biodiversity.

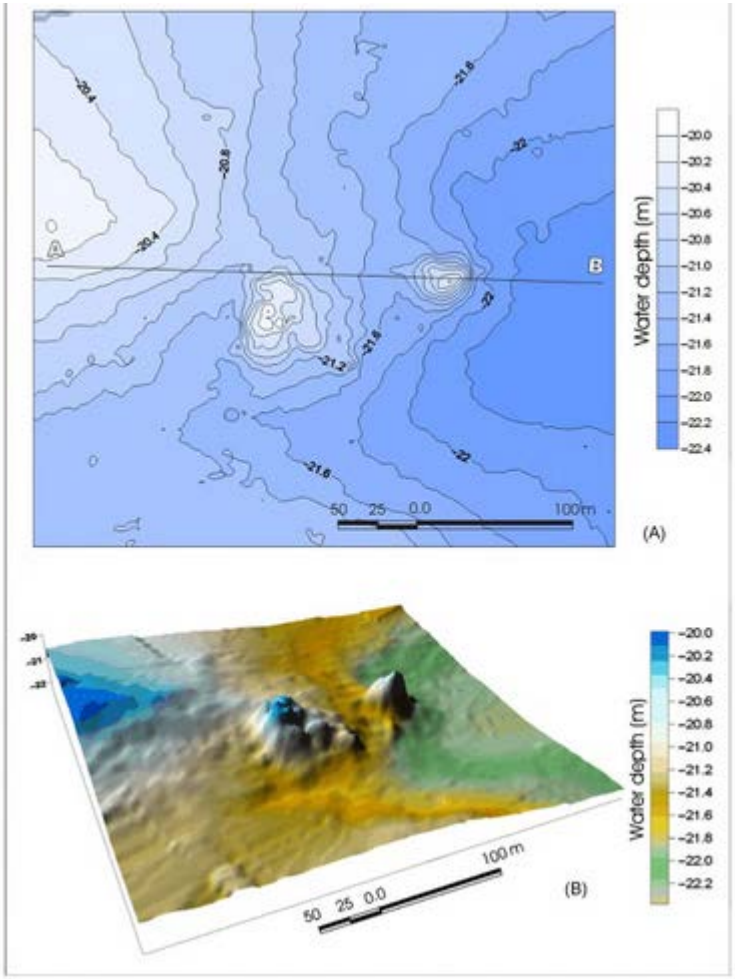


Side-scan sonar image of the seabed on a «trezza» (PhD thesis, Emiliano Gordini 2009)

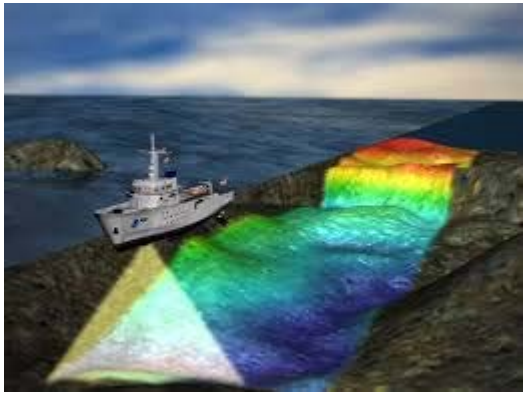


Side-scan sonar

Trezze in the Northern Adriatic



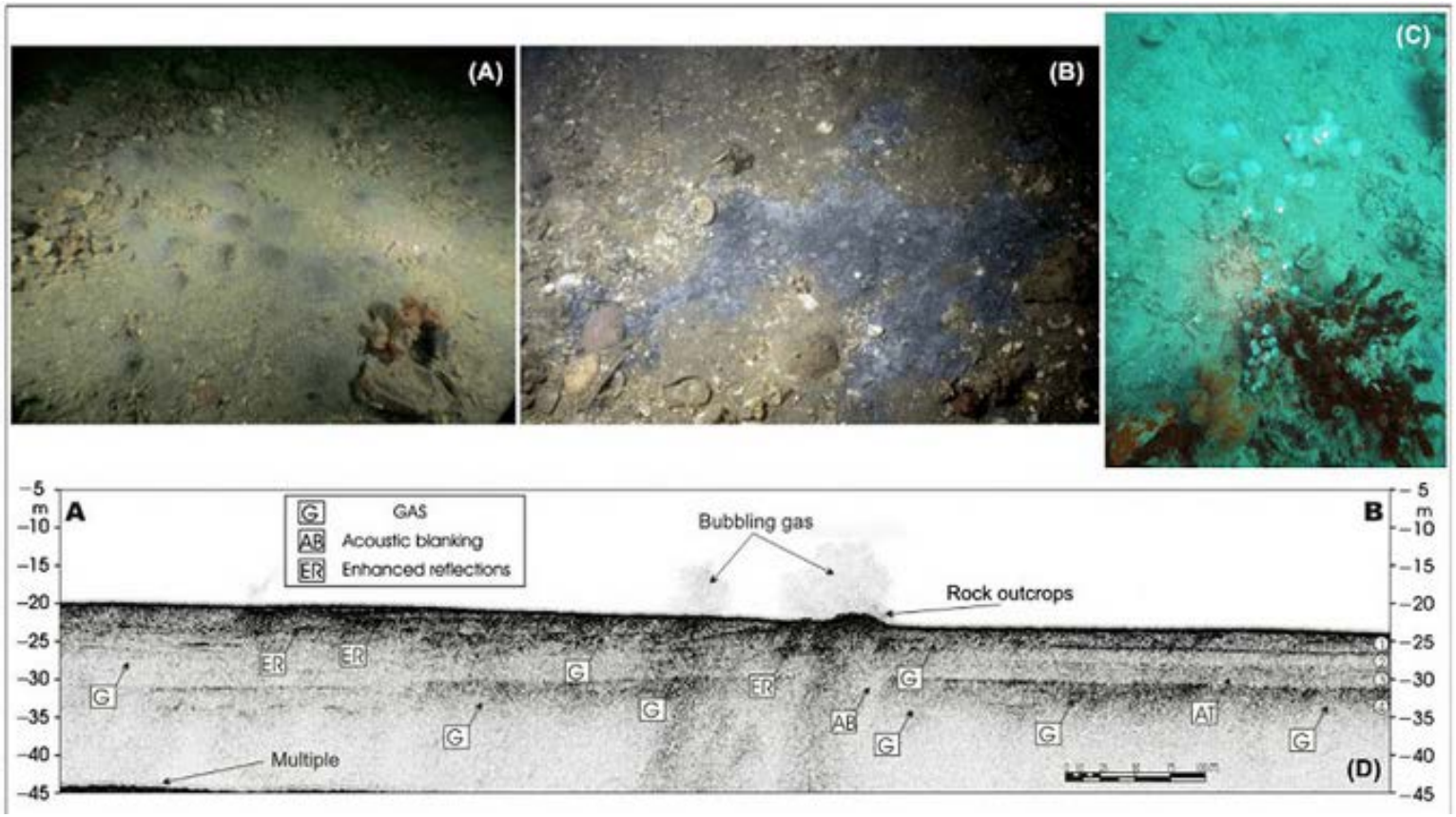
Their origin is related to processed linked to methane spills from the seabed. These rock formation have grown up as real tropical reefs by bioconstructing organisms such as calcareous alghae, madrepores, briozoas.. The calcareous skeletons of these organisms, stratifying one over the other, gave birth to the current outcrops that represent the coral reefs of the northern Adriatic.



Mutlibeam echosounder

Multibeam bathymety on a «trezza» (PhD Thesis, Emiliano Gordini, 2009)

Trezze in the Northern Adriatic



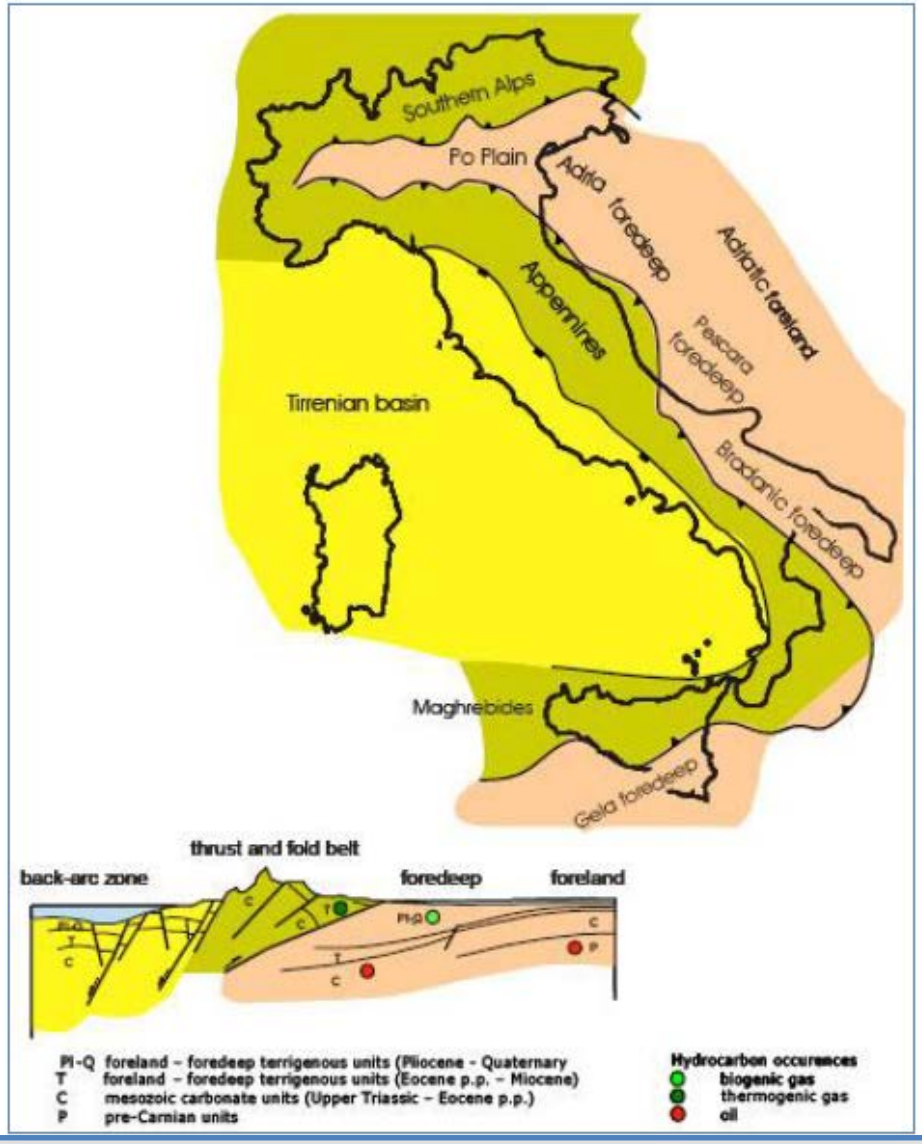
Affioramento sul fondo del mare dovuto ad una trezza, visualizzato con sismica ad altissima risoluzione dal sub-bottom chirp (Tesi Dottorato, Emiliano Gordini 2009)

HYDROCARBON EXLORATION

Zone marine originariamente aperte alle attività minerarie (Flaborazione dell'Ufficio cartografia della DGRME)

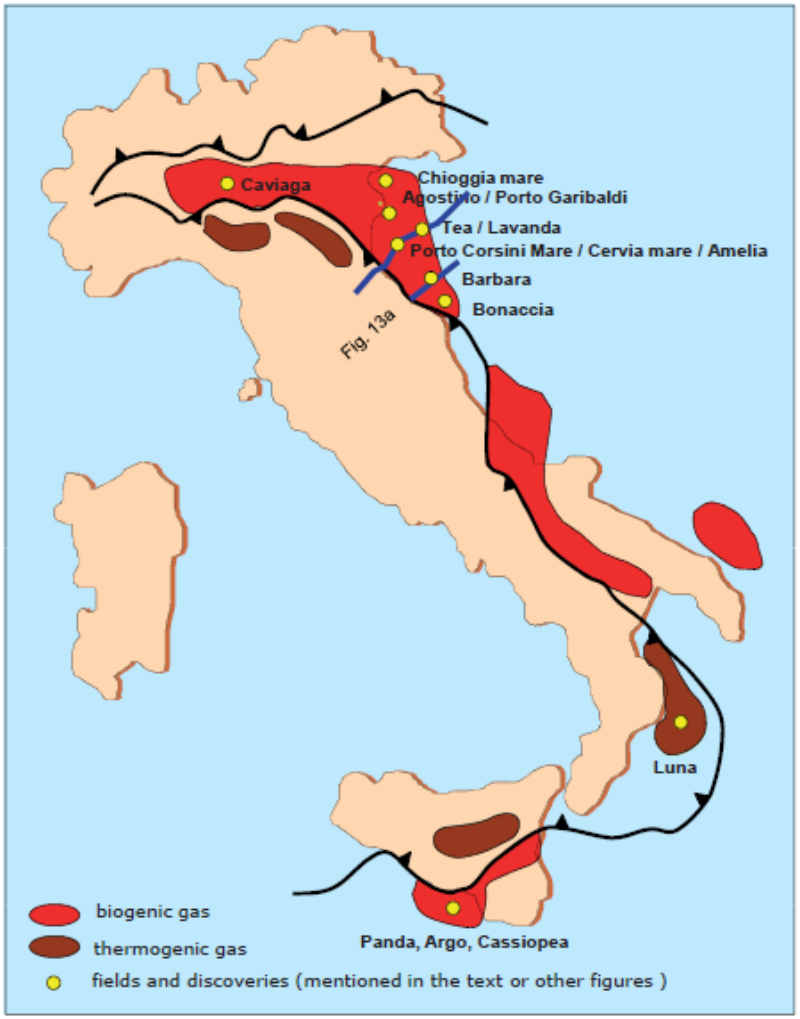
Zone marine aperte alle attività minerarie e rimodulate con D.M. 8/08/2013 (Elaborazione dell'Ufficio cartografia della DGRME)

LOCATION OF THE MAIN HYDROCARBON FIELDS AND STRUCTURAL SETTING



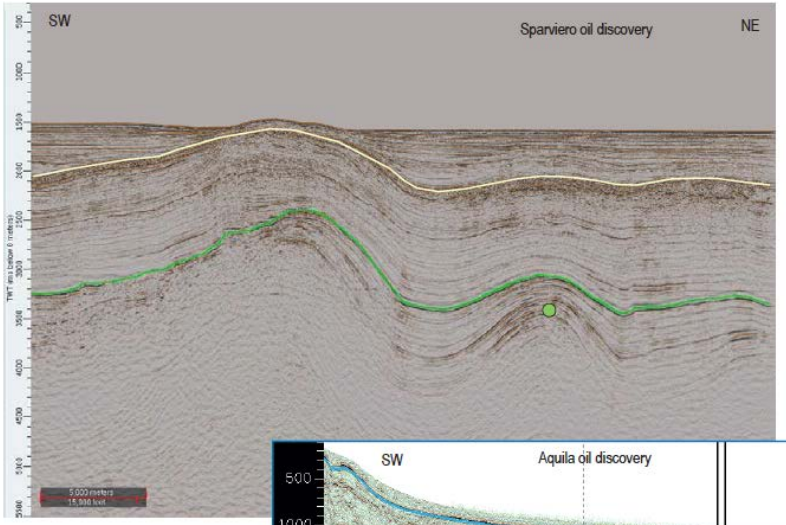
Hydrocarbon reservoirs

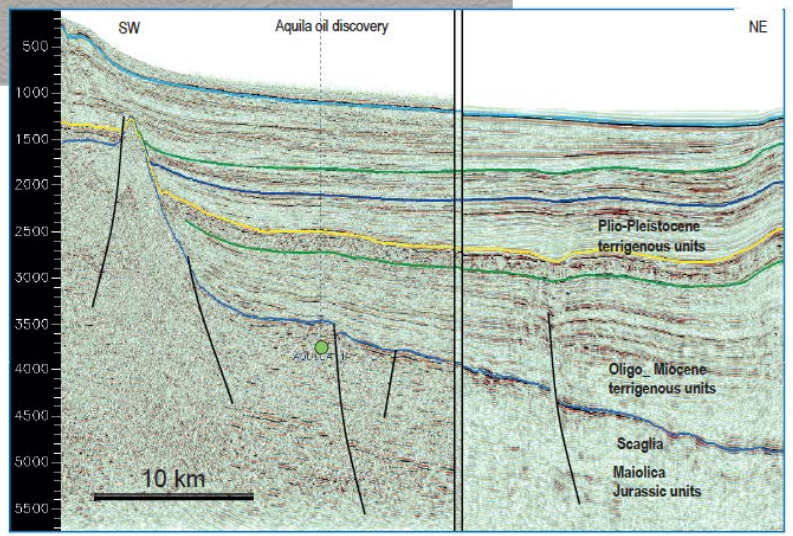
Oil



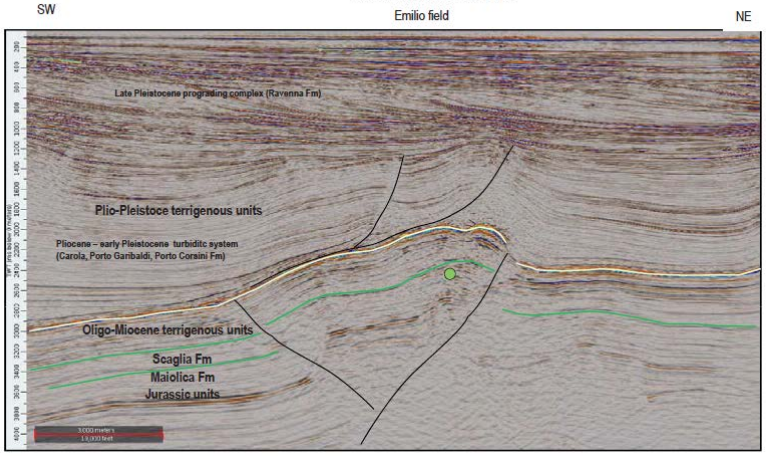
Gas

HYDROCARBON EXLORATION





Structural (compressiona) trap



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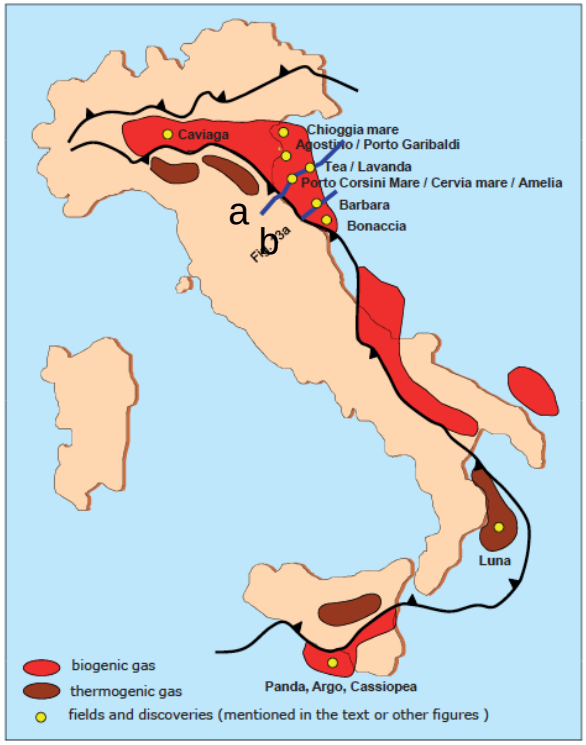
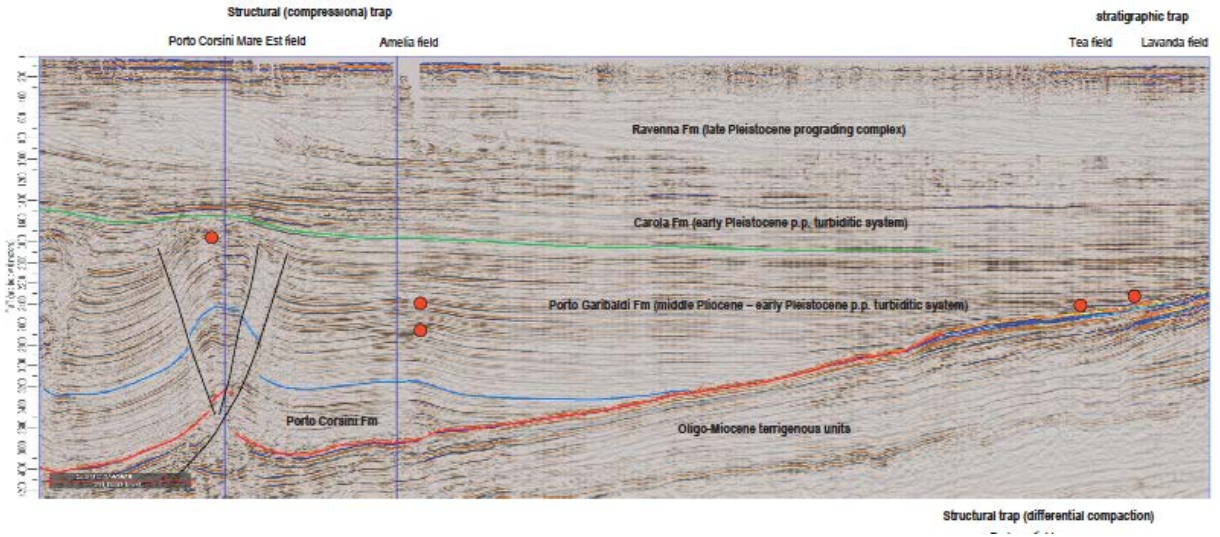
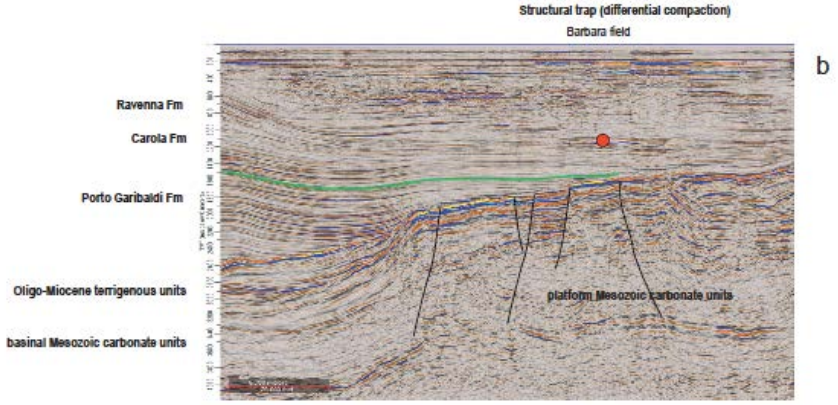
HYDROCARBON EXLORATION







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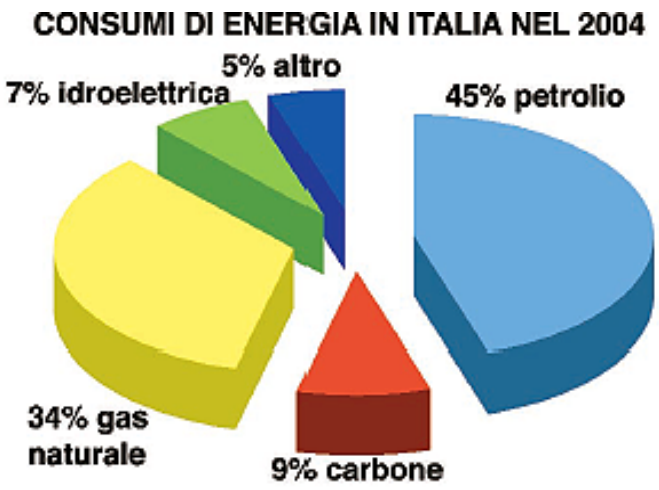
Marine strategy

In recent years there has emerged the awareness that the marine environment is a heritage valuable and must be protected and safeguarded.

The European Parliament and the Council of the European Union have issued a directive (transposed in Italy on October 13, 2010), which aims to reach the 'Good State of Marine Waters'. This is a phase of preparation and study of all the most critical aspects and a program of measures to be taken This program also includes the Mediterranean and consequently the Adriatic.

To know the marine environment (subsoil, water-bottom sea interface, water column and water-atmosphere interface) research plays a fundamental role.

Sistema energetico in Italia



Energia elettrica prodotta in Italia (per fonte primaria, nel 2005)	
da prodotti petroliferi	10,2%
da gas	42,5%
da carbone	12,4%
da altro termoelettrico	6,7%
da rinnovabili (idroelettrica, geotermia ecc.)	14,3%
da importazione	13,9%

Il sistema energetico in Italia si basa sul petrolio e sul gas naturale:
- *petrolio* (45%);
- *gas naturale* (34%).

Petrolio e gas naturale sono anche le fonti più costose e soggette a sbalzi di prezzo.
Seguono a grande distanza:
- *carbone* (9%);
- *energia idroelettrica* (7%).

L'Italia importa dall'estero buona parte della fonte di energia.

L' Adriatico ospita più del 50% delle riserve italiane di gas ed un volume significativo
di olio