Università di Trieste
Corso di Laurea in Geologia

Anno accademico 2021 - 2022

Geologia Marina

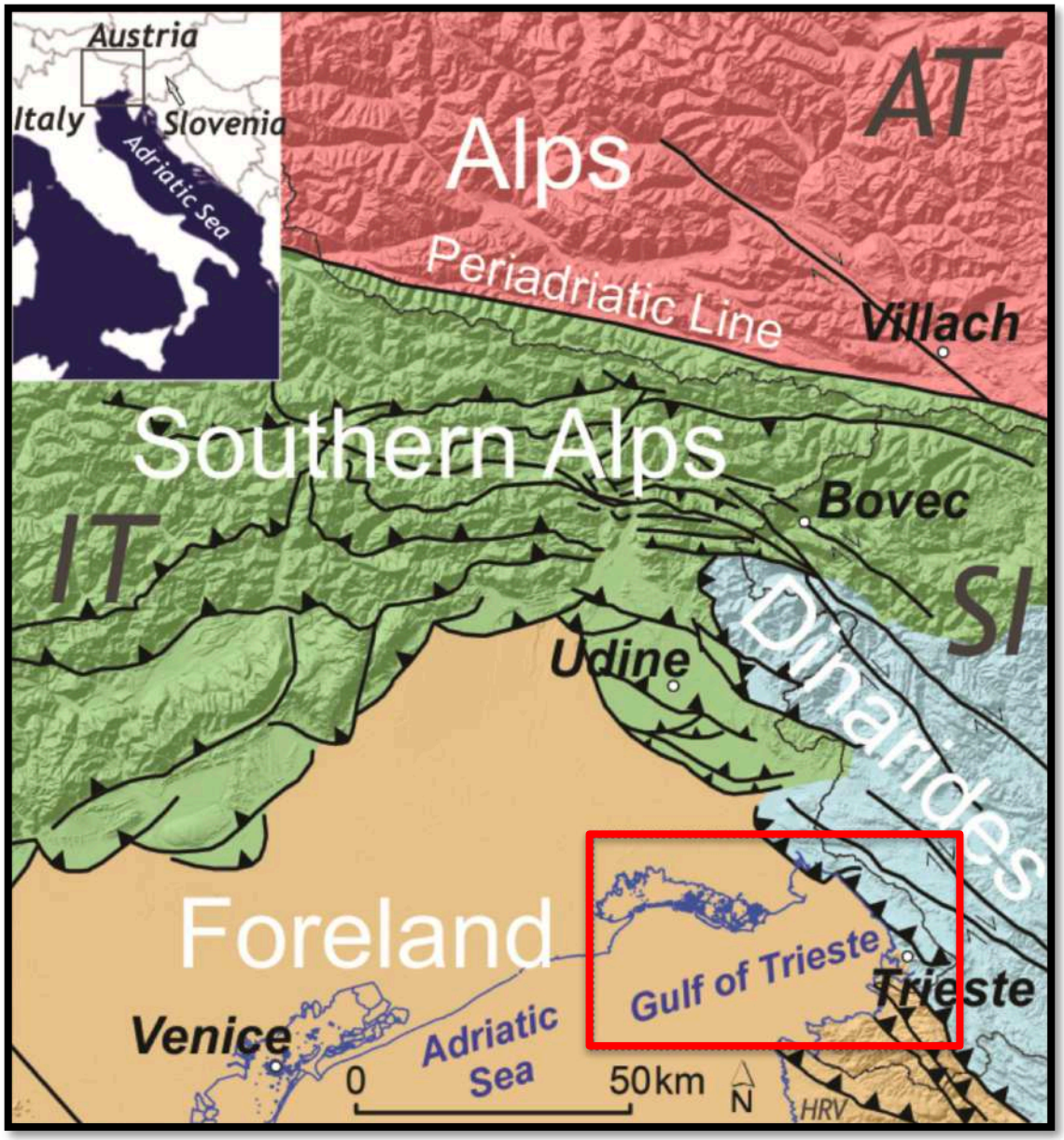
Parte V

Modulo 5.3 Golfo di Trieste

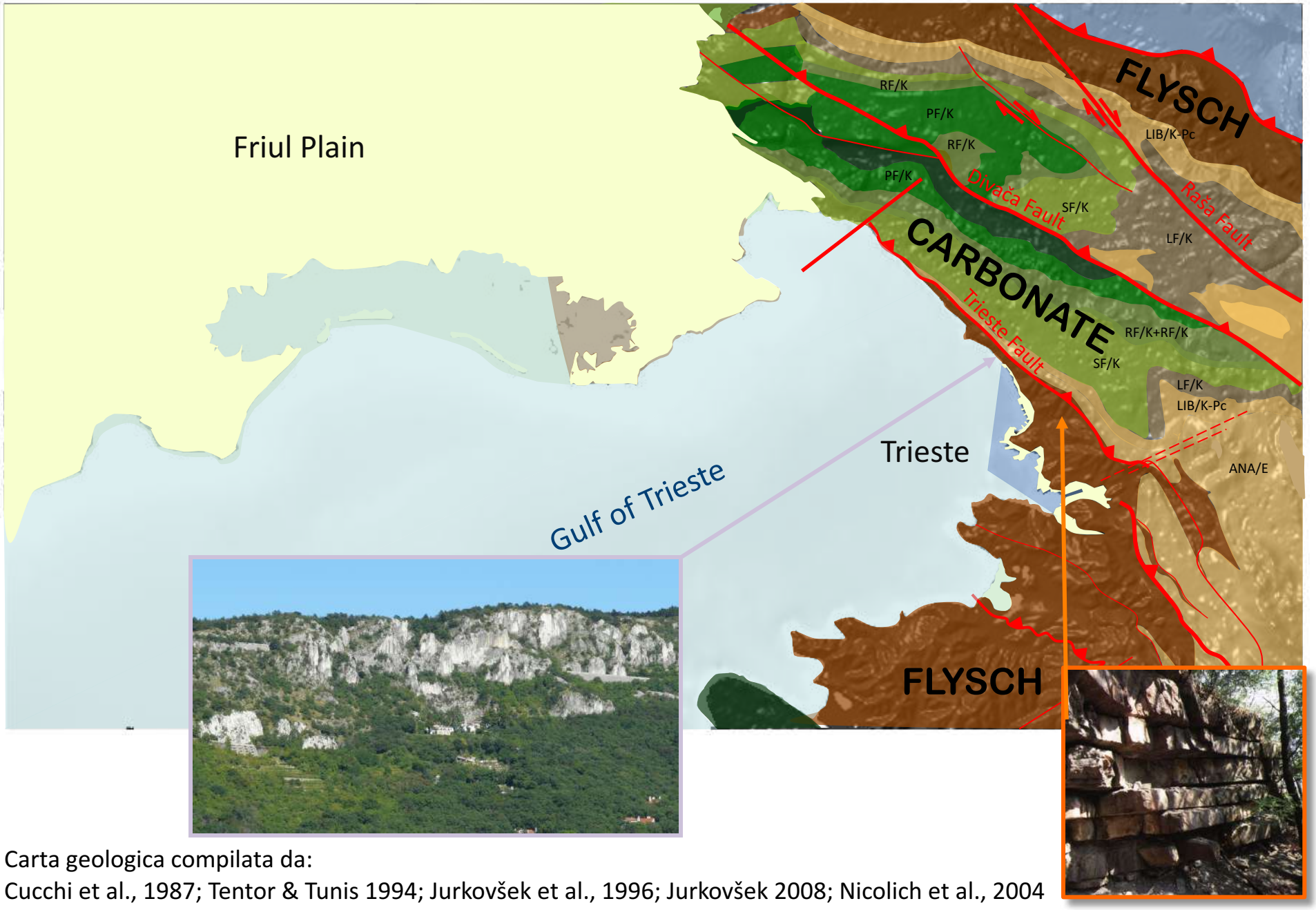
Docente
Martina Busetti

Il Golfo di Trieste

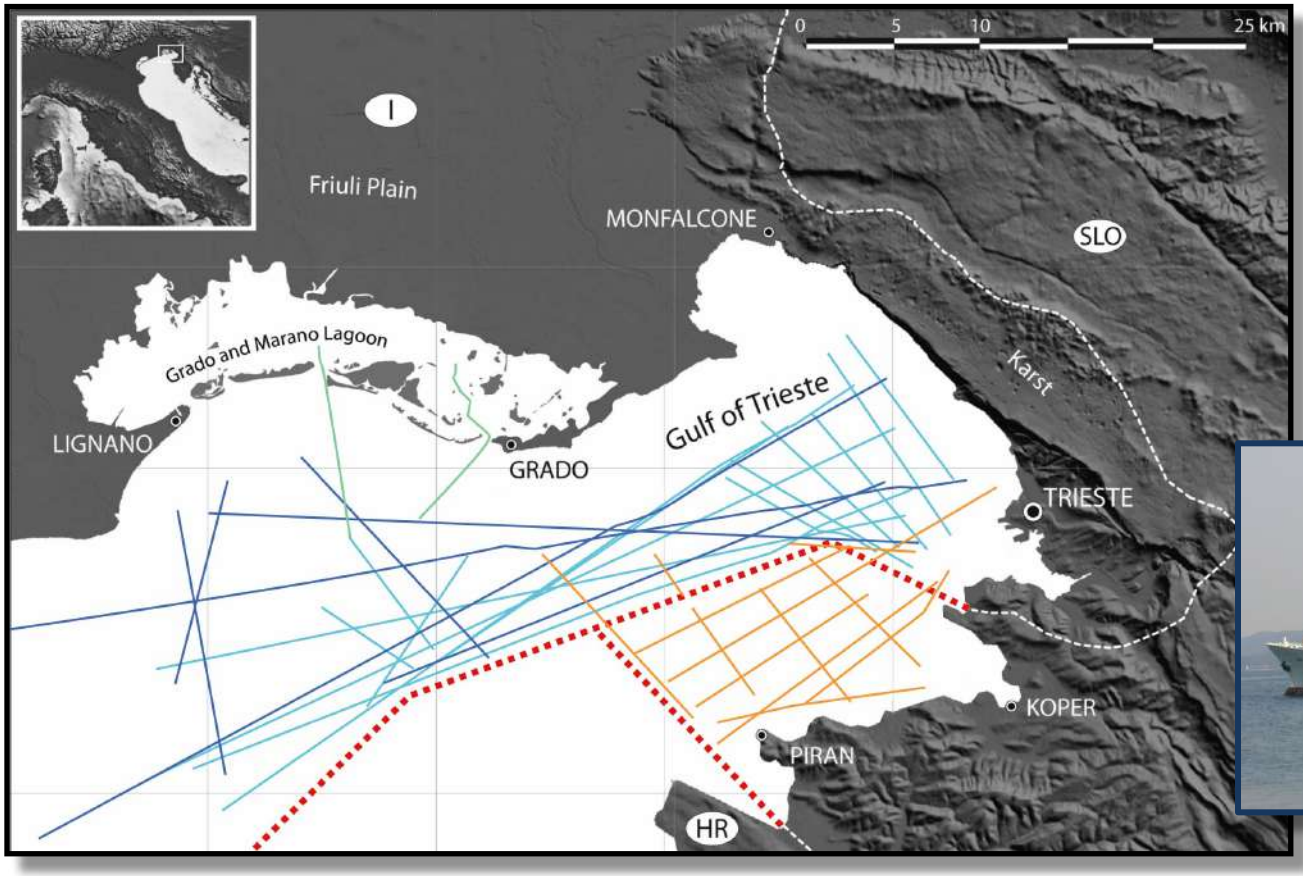
Estensione del Golfo di Trieste secondo Valussi (1973)



da Dal Cin, 2018 PhD Thesis



Carta geologica compilata da:
Cucchi et al., 1987; Tentor & Tunis 1994; Jurkovšek et al., 1996; Jurkovšek 2008; Nicolich et al., 2004



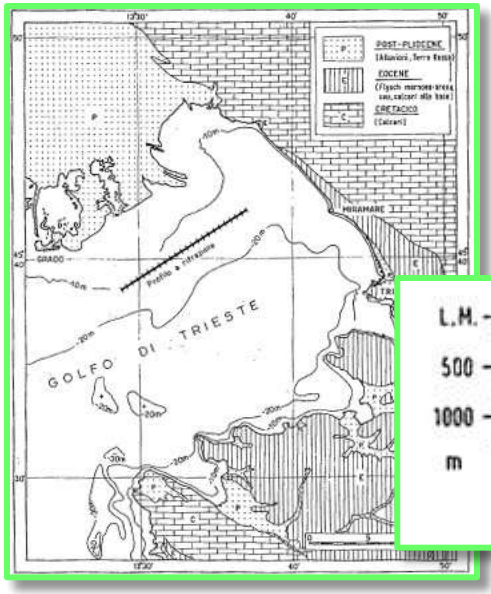
632 km di profili di sismica multicanale e Chirp

220 km nel 2005 - progetto Geotermia
Università di Trieste, OGS, convenzione per la Regione Autonoma Friuli Venezia Giulia

280 km nel 2009 - progetto Golfo Trieste
OGS

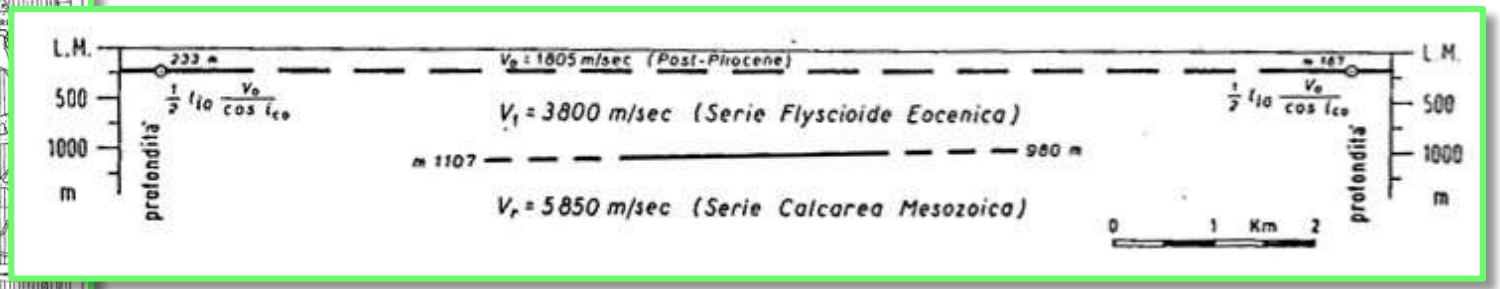
132 km nel 2013 - progetto SLOMARTEC
collaborazione OGS, Università di Lubiana e Harpha Sea d.o.o Koper (Slovenia)

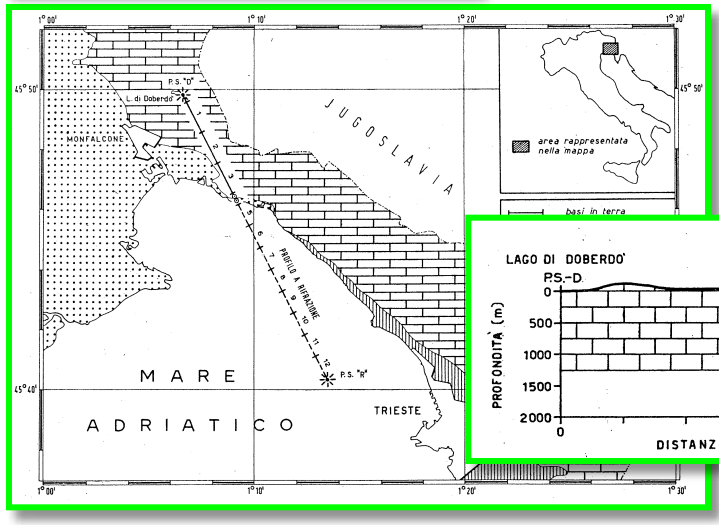
I pionieri della geofisica marina in Italia: le prime indagini nel Golfo di Trieste



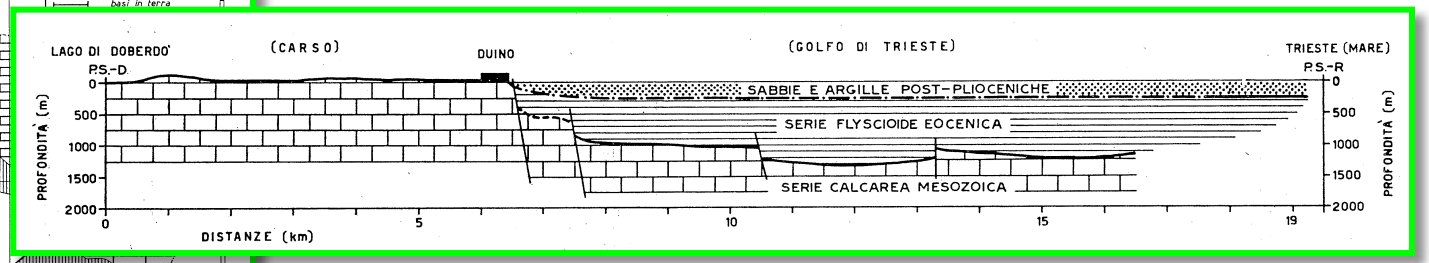
Le prime esplorazioni geofisiche dagli anni '50

Finetti, 1965
profilo sismico a rifrazione



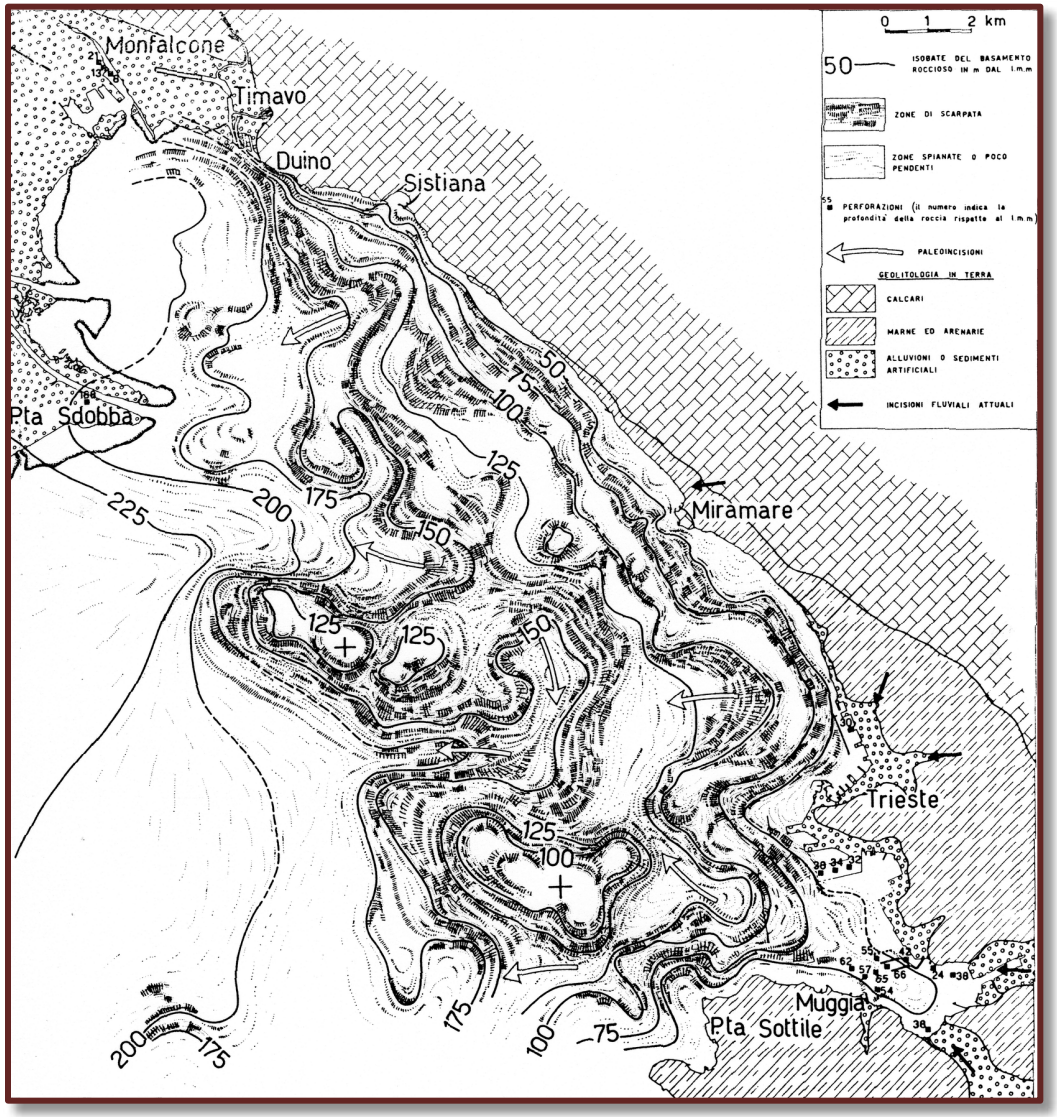


Finetti, 1967
profilo sismico a rifrazione

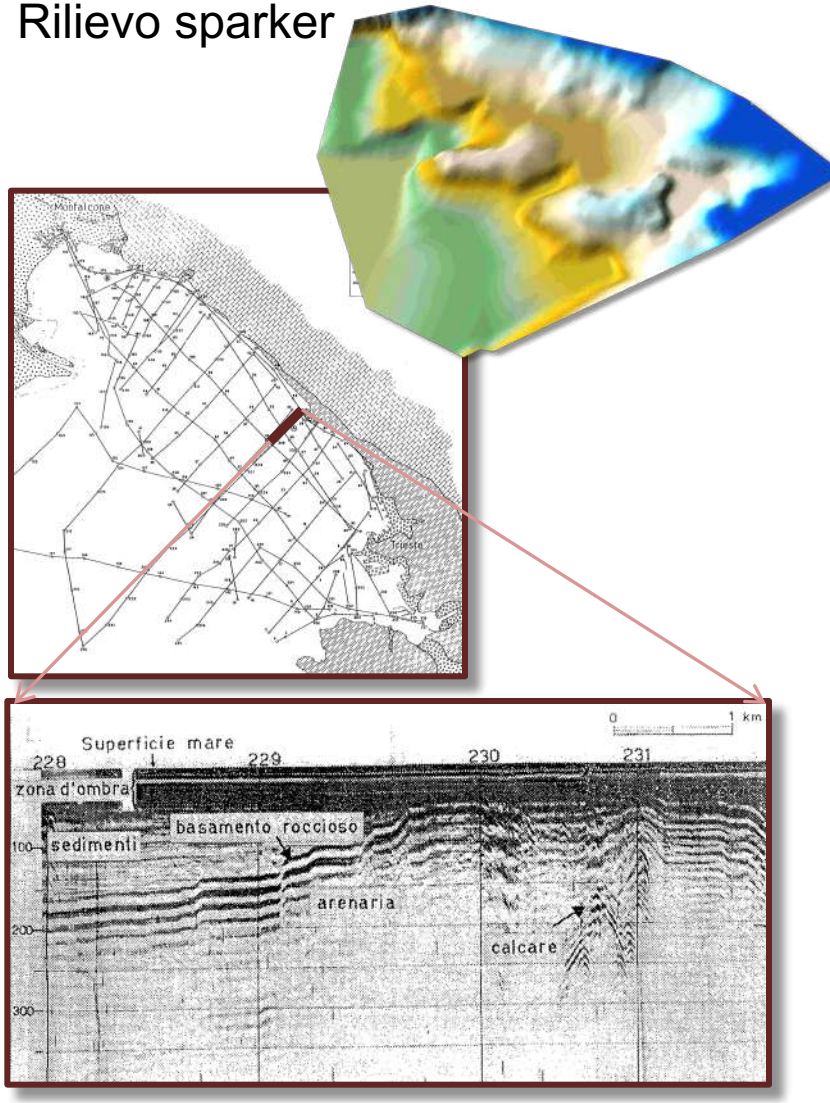


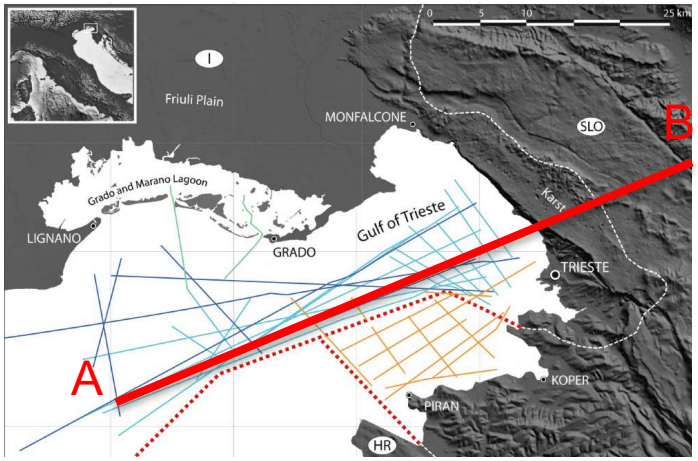
Il tetto del Flysch

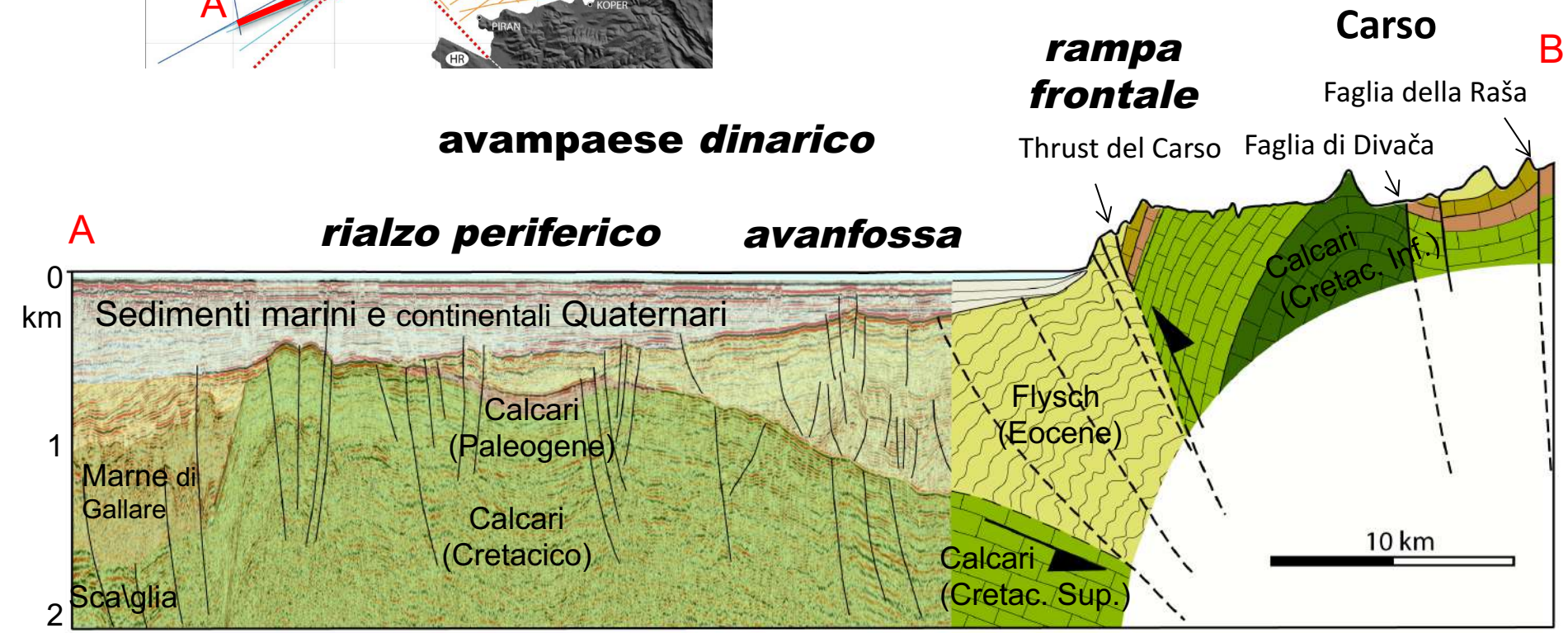
Morelli e Mosetti, 1968



Rilievo sparker

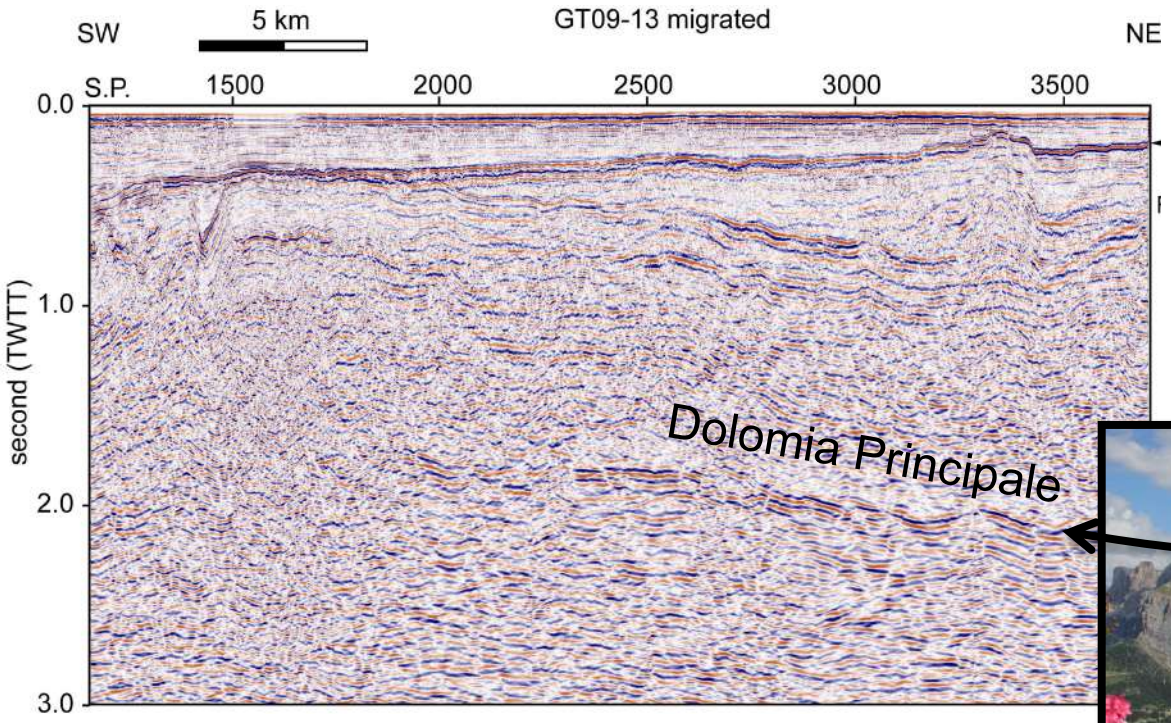


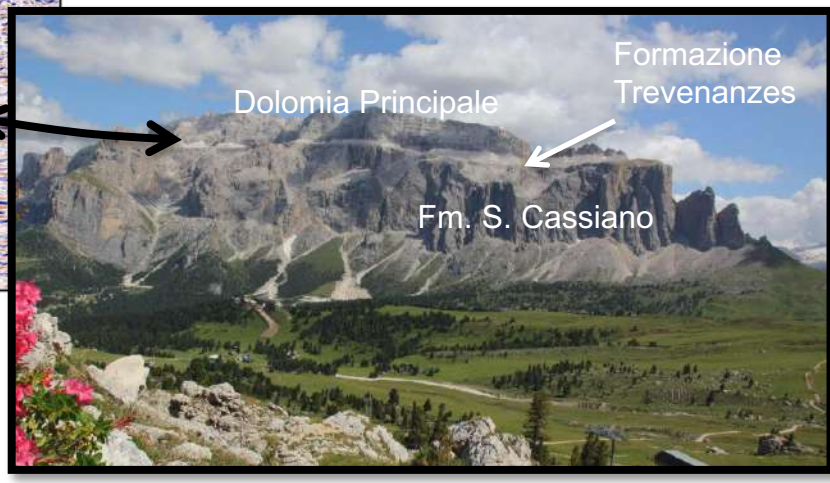


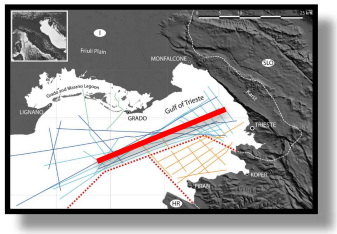


Sezione geologica a terra da GeoCGT FVG 2011

Modificata da Busetti et al., 2013







Nel Golfo di Trieste la base della Dolomia Principale è a 5 – 6 km di profondità

Isola di Andros (Bahamas)

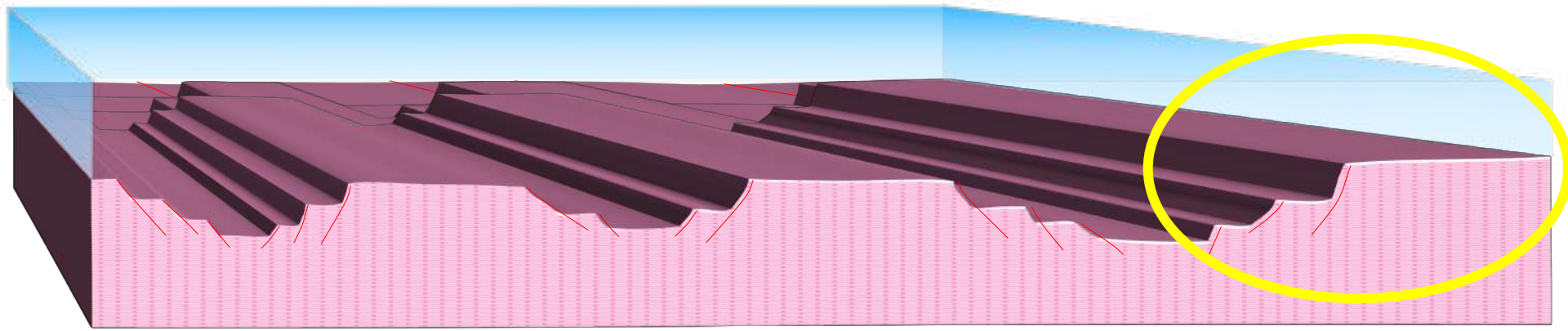
piana tidale: sedimentazione attuale dei carbonati

Piattaforma carbonatica della

Dolomia Principale

del Norico (Triassico Superiore – Mesozoico)

circa 228-204 Ma

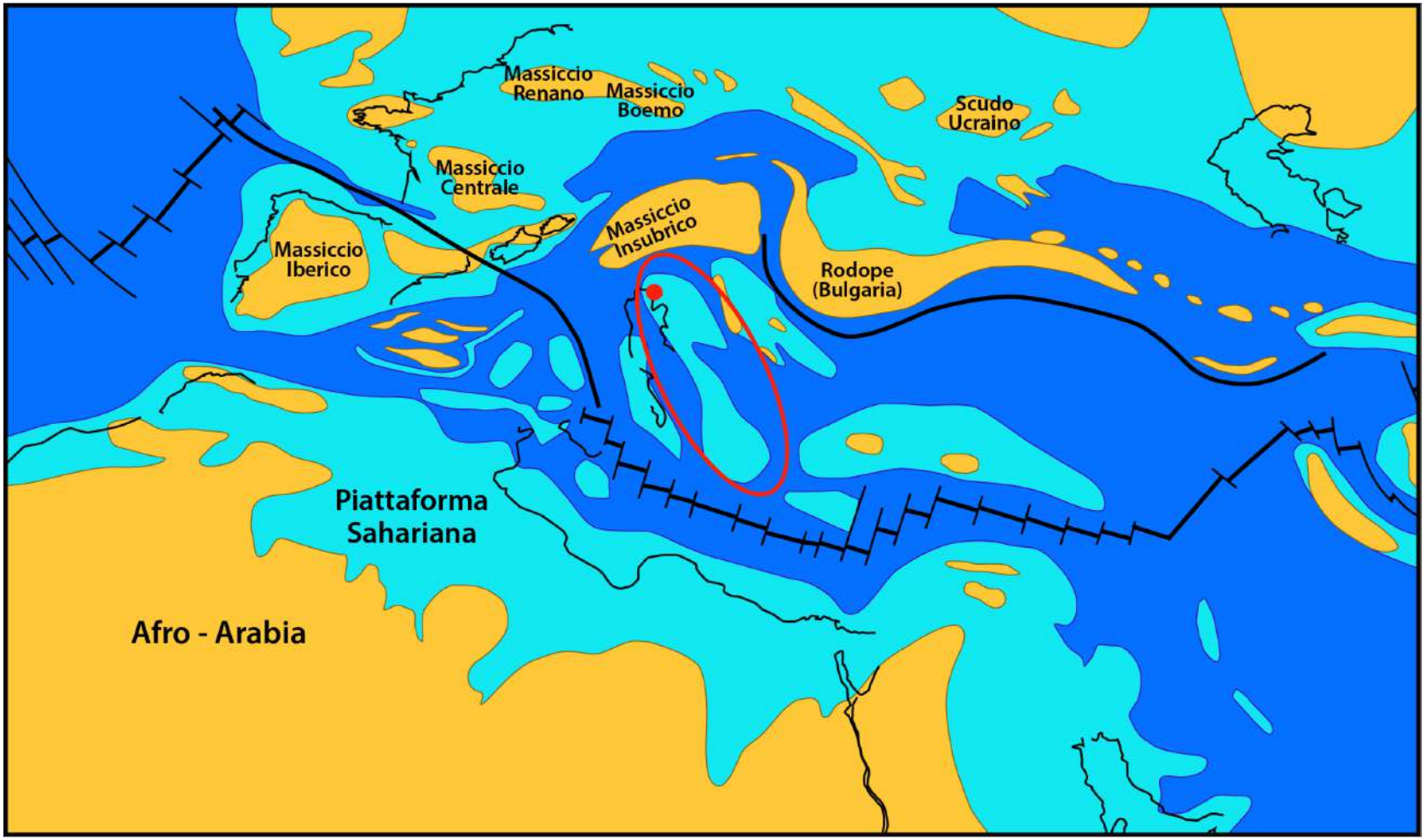


animazione di F. Zgur (OGS)

Mesozoico: margine passivo o divergente

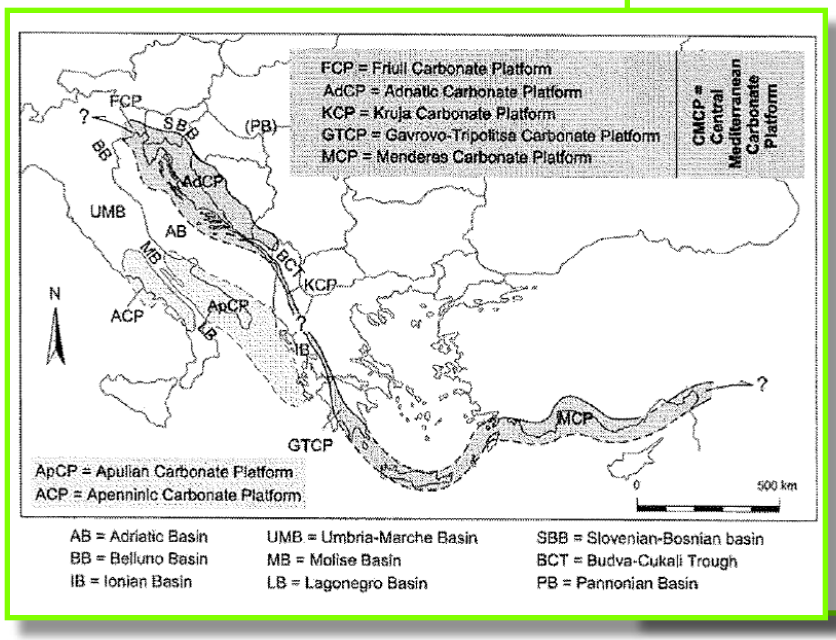
Il Carso e il Golfo di Trieste

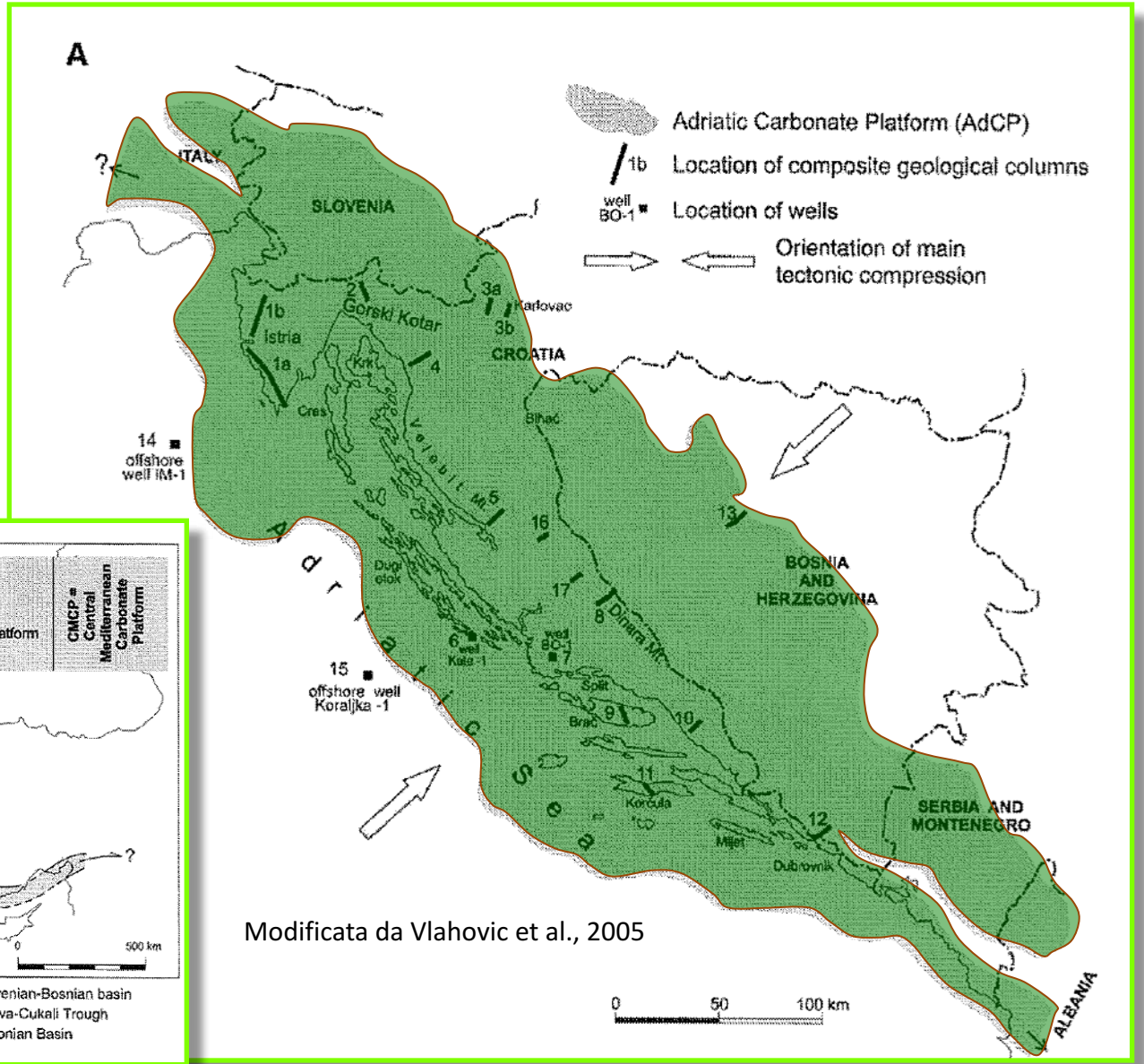
Mappa paleogeografica della parte centrale dell'Oceano della Tetide 95 milioni di anni fa



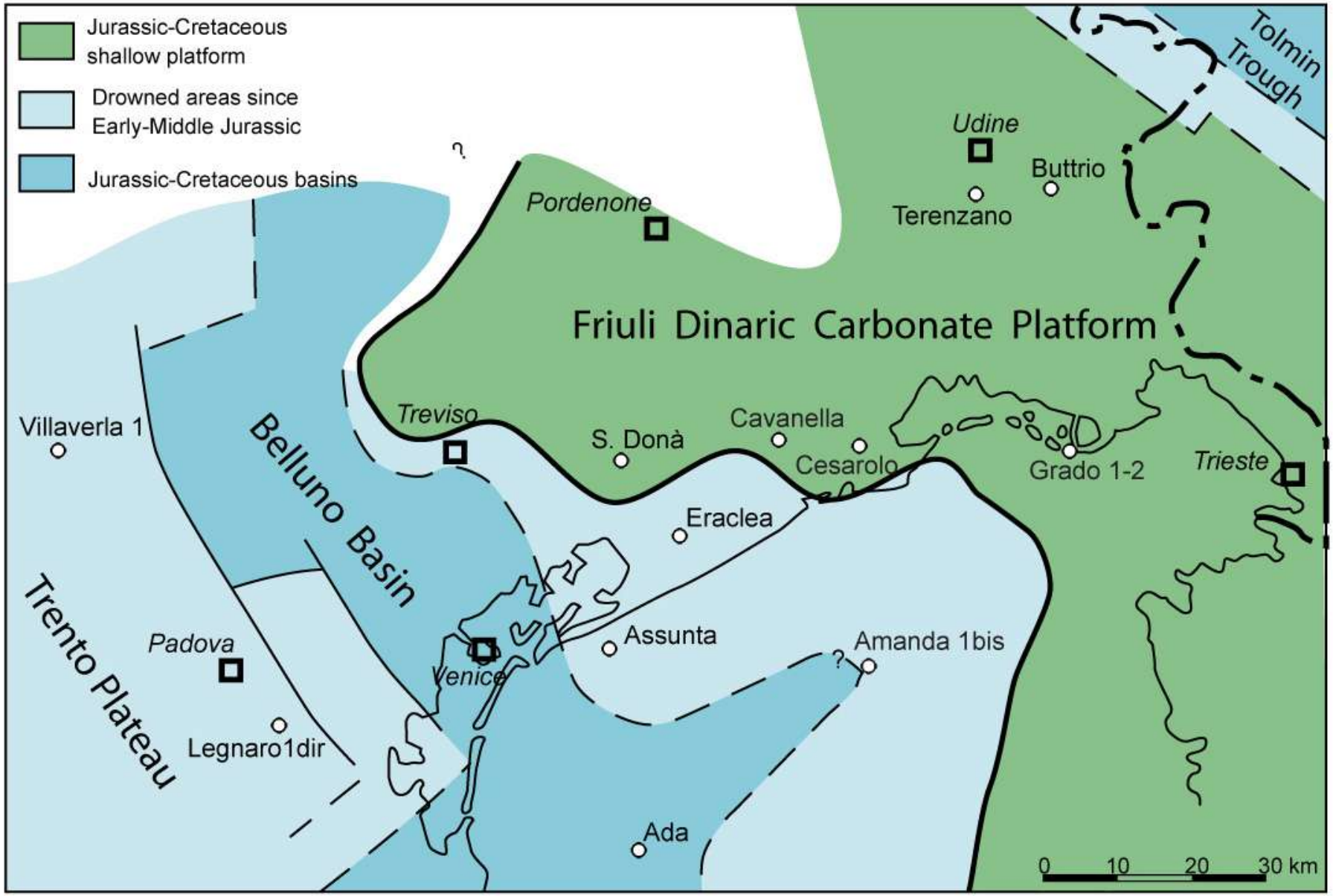
Mappa paleogeografica semplificata **della Tetide centrale di 95 milioni di anni fa**, basata su PHILIP et al (2000), modificata e ridisegnata. L'asterisco indica la posizione del Carso. Blu = mare profondo, oceano; azzurro = mare basso; giallo ocra = terre emerse. Abbreviazioni: A = Piattaforma Carbonatica Apula (Puglia e Maiella), ACP = Piattaforma Carbonatica Appenninica, AD = Piattaforma Carbonatica Adriatico-Dinarica, AM = Massiccio Armoricano, AnA = Anti Atlante, Bih = Massiccio di Bihor (Romania), BM = Massiccio Boemo (Repubblica Ceca), Ebr = Massiccio dell'Ebro (Spagna), G = Gavrovo (Bulgaria), IM = Massiccio Iberico (Spagna), InsM = Massiccio Insubrico (Lombardia settentrionale), MC = Massiccio Centrale (Francia), Me = Menderes (Turchia), Mu = Muzurdan (Turchia), Pl = zona Pelagoniana, Pn = Panormide (Sicilia), Pr = Provenza (Francia), Rh = Rodope (Bulgaria), RM = Massiccio Renano, SaP = Piattaforma Sahariana, US = Scudo Ucraino.

La piattaforma carbonatica Dinarico Friulana Meso-Cenozoica





Modificata da Vlahovic et al., 2005



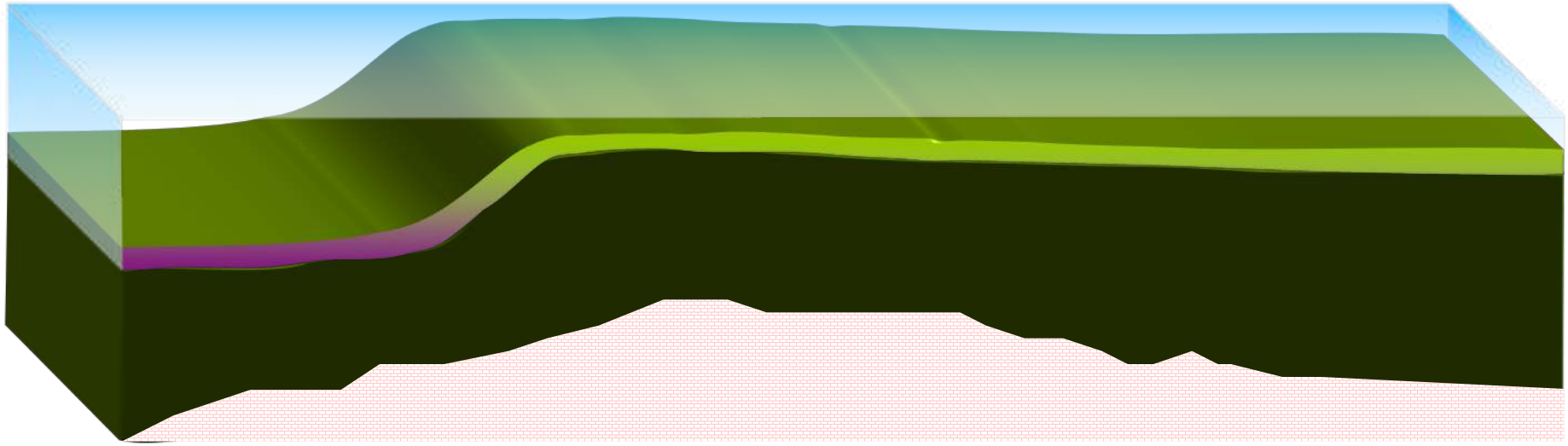
Modificata da Cati et al., 1987

Formazione della piattaforma carbonatica

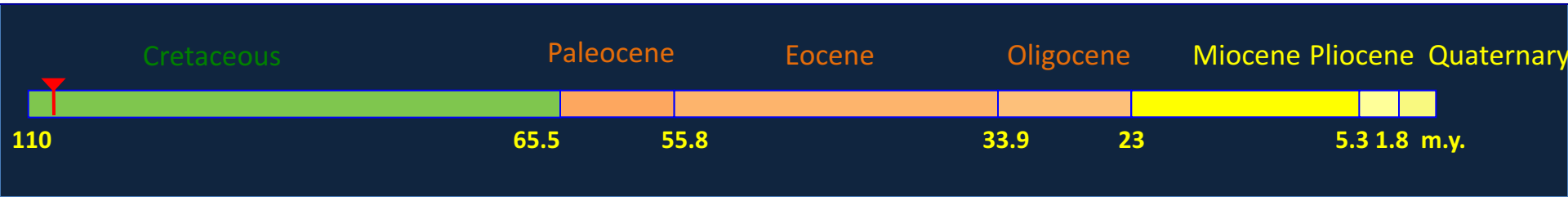
Subsidenza lenta e costante + mare poco profondo

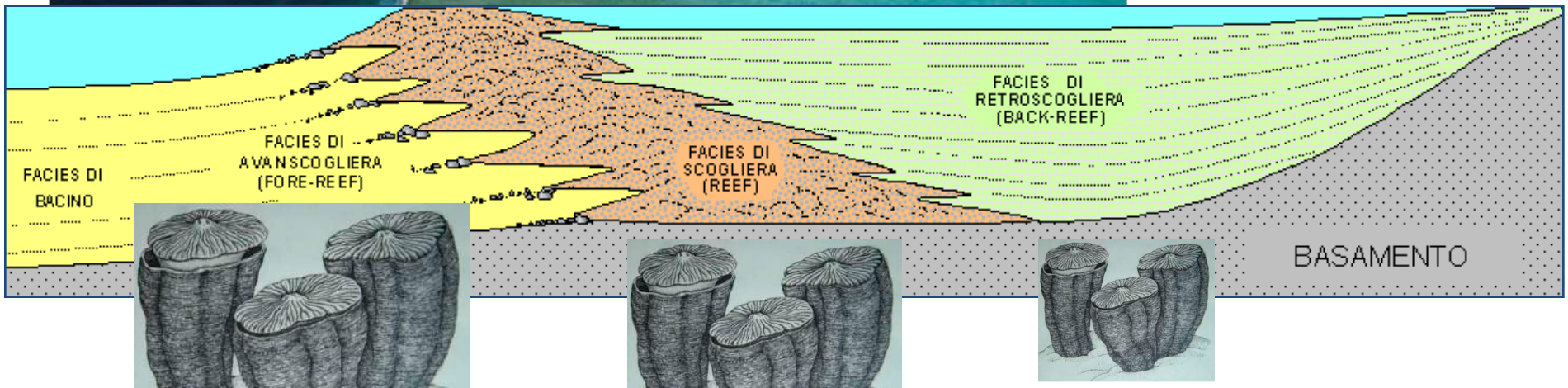
↓

accumulo di sedimenti carbonatici



animazione di F. Zgur (OGS)





Ippuriti grandi + caprine

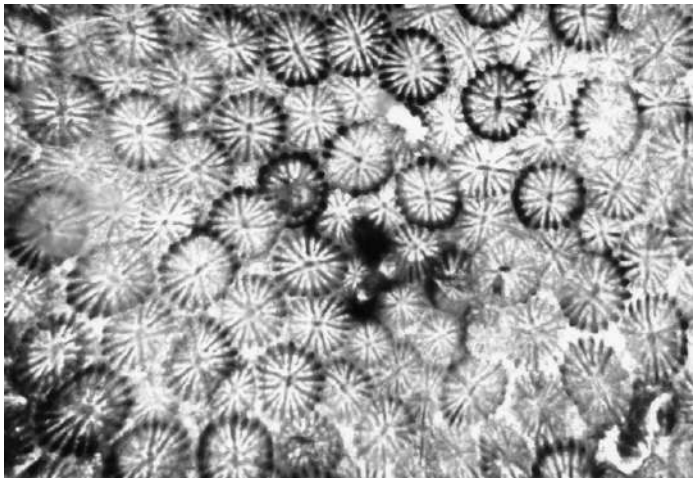
Ippuriti grandi

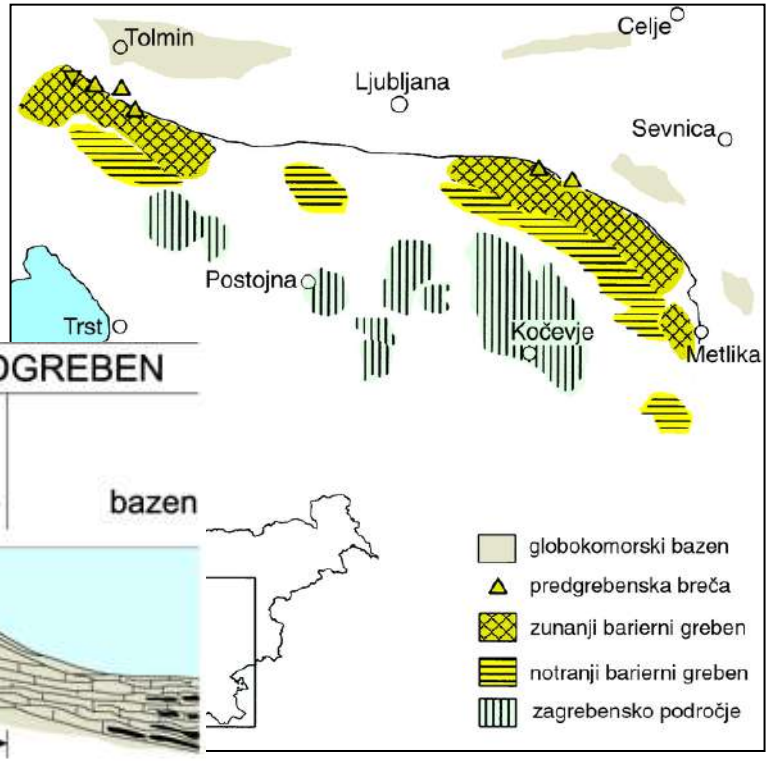
Ippuriti piccole e isolate e radioliti

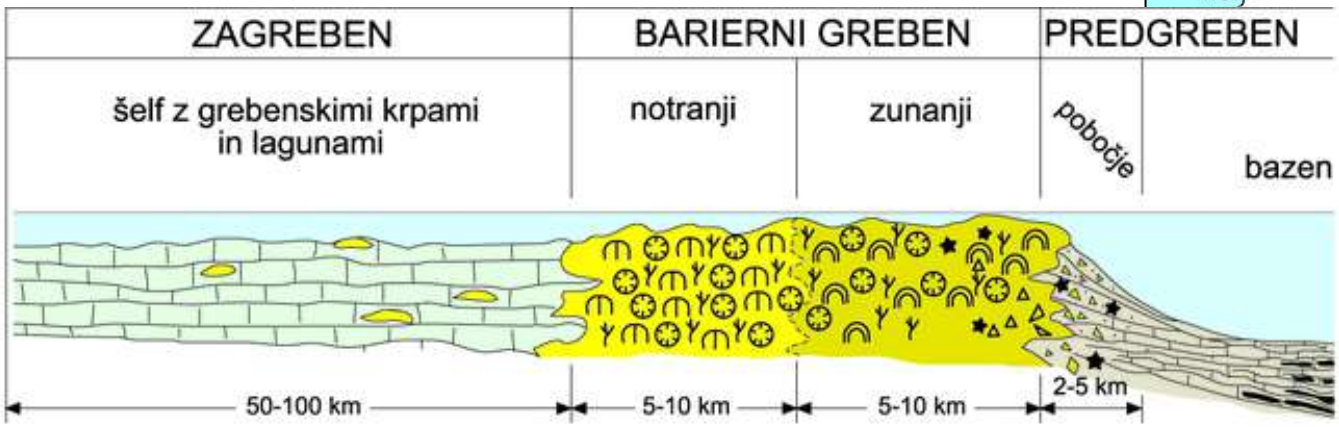
I coralli giurassici

151-157 milioni di anni fa

accumulo di 200 metri di carbonati in 6 milioni di anni



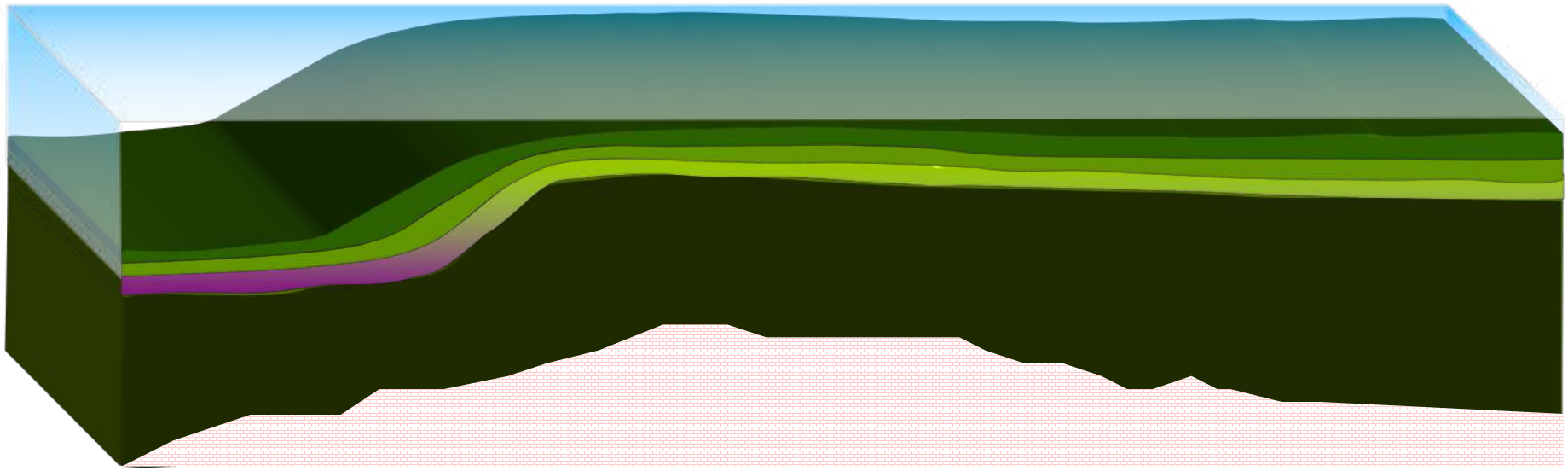




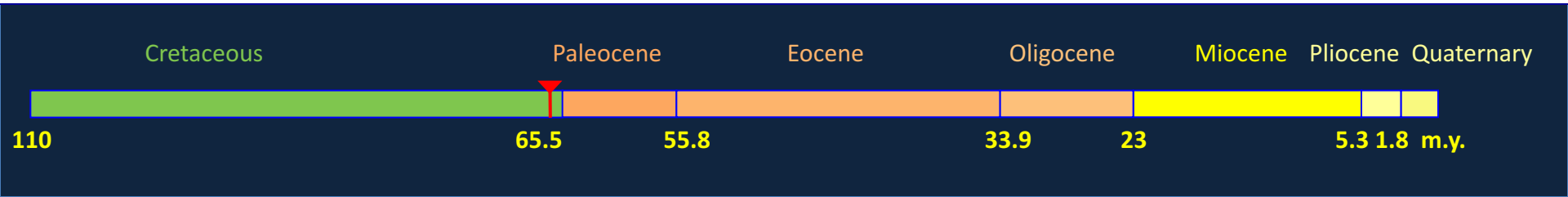
Continua la crescita della piattaforma carbonatica

Subsidenza lenta e costante + mare poco profondo

accumulo di sedimenti carbonatici



animazione di F. Zgur (OGS)

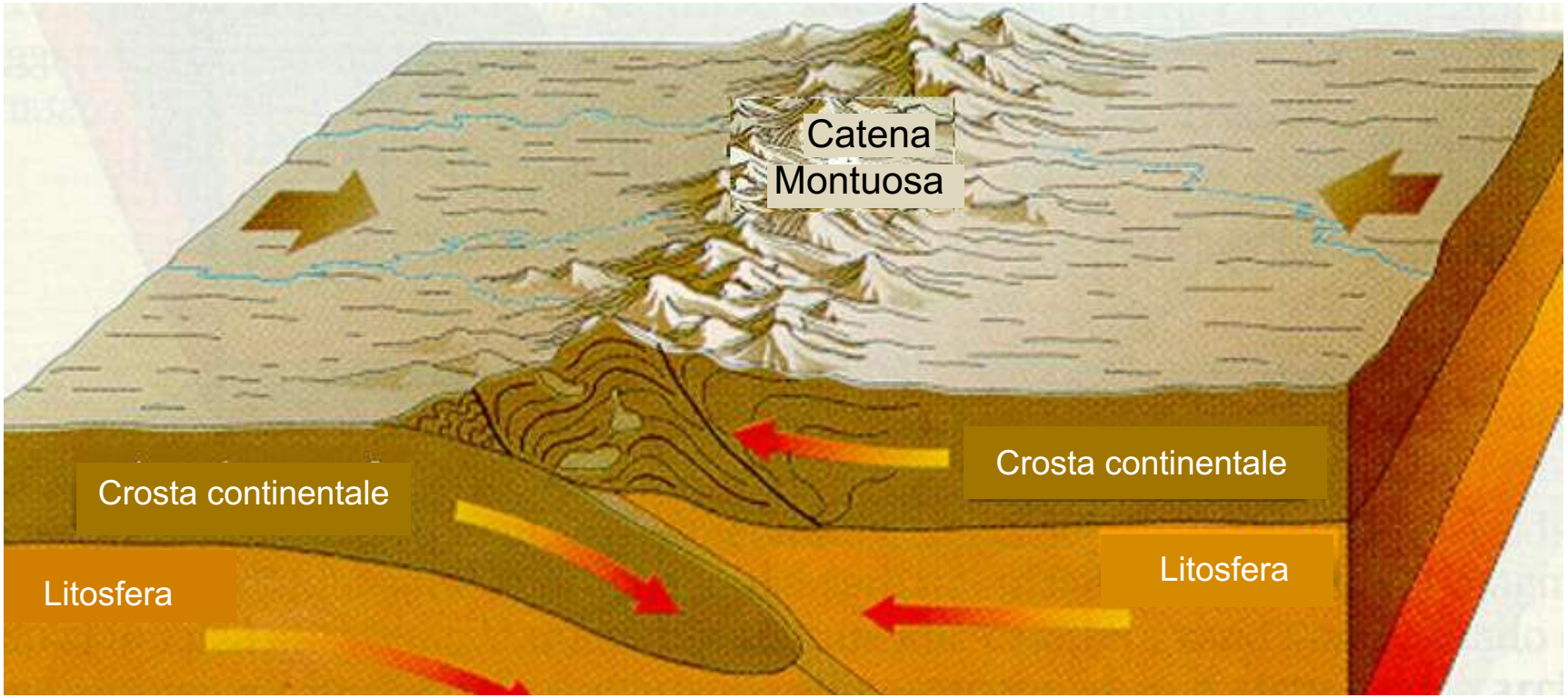


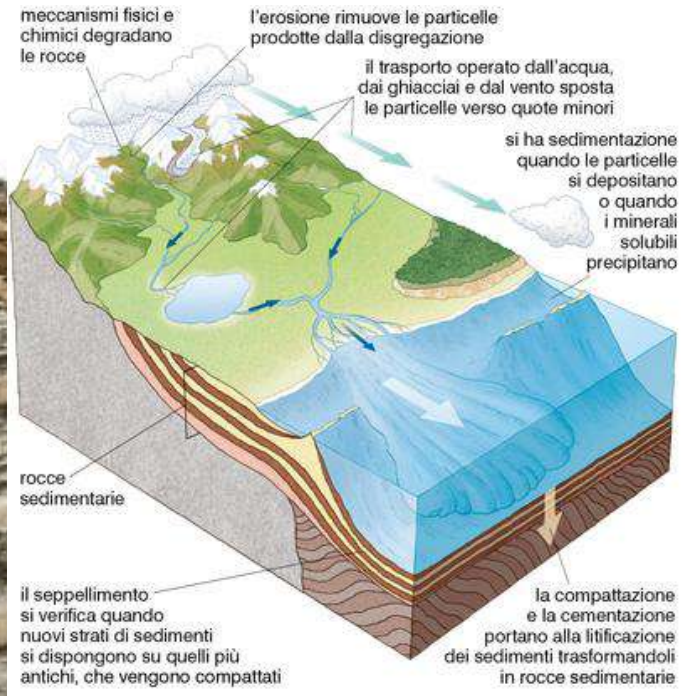
Antonio - adrosauro del Cretacico Superiore (70-80 milioni d'anni)

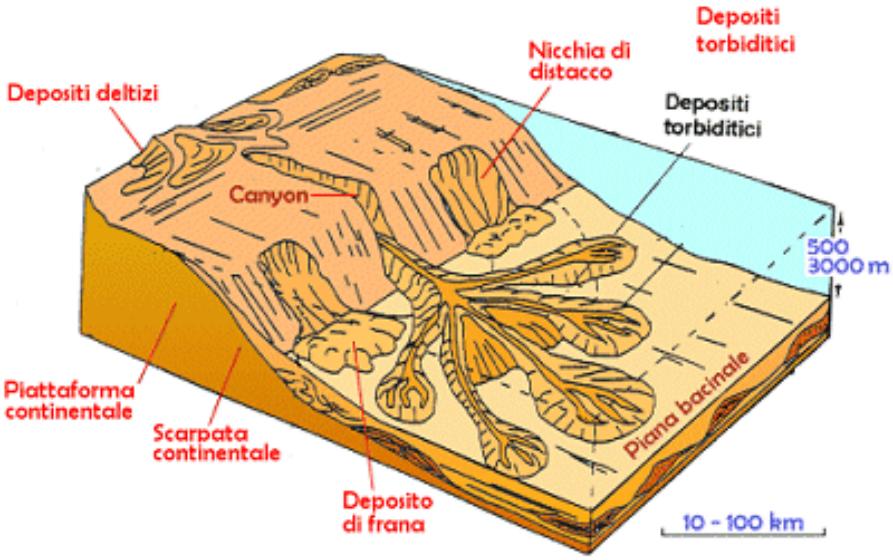
Sito paleontologico del Villaggio del Pescatore

Cenozoico: margine attivo o convergente

Formazione delle Dinaridi

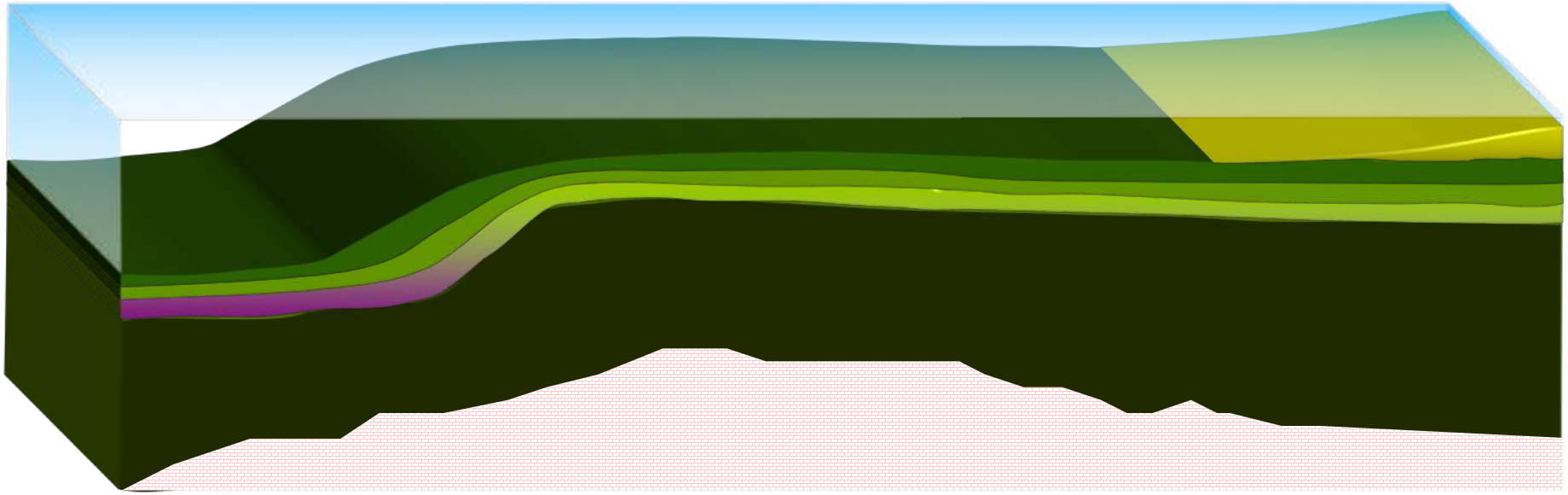




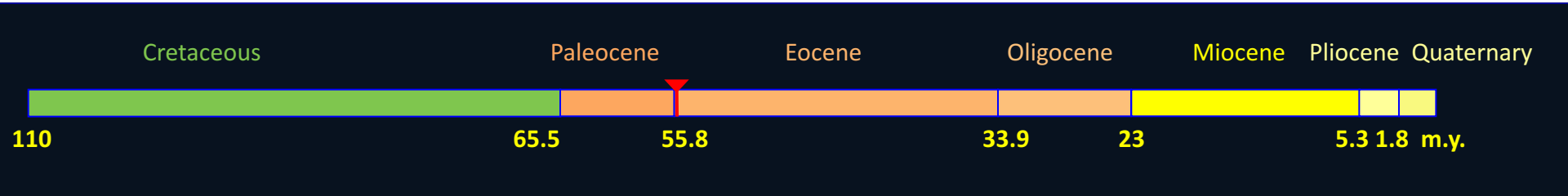


Flysch di Trieste (Eocene inf.– medio)

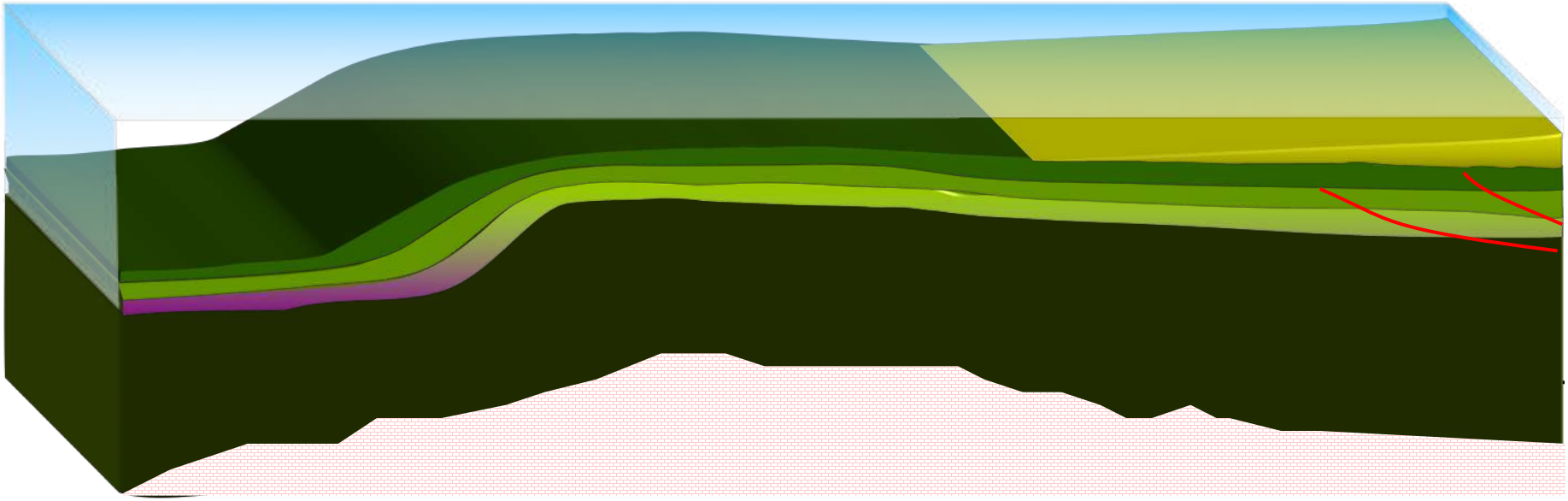
EOCENE: inizio deposizione del Flysch proveniente dall'erosione della Catena Dinarica Interna (orientale) più antica



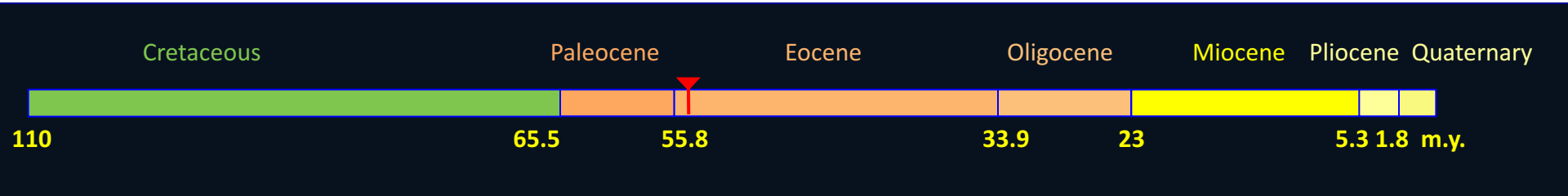
animazione di F. Zgur (OGS)

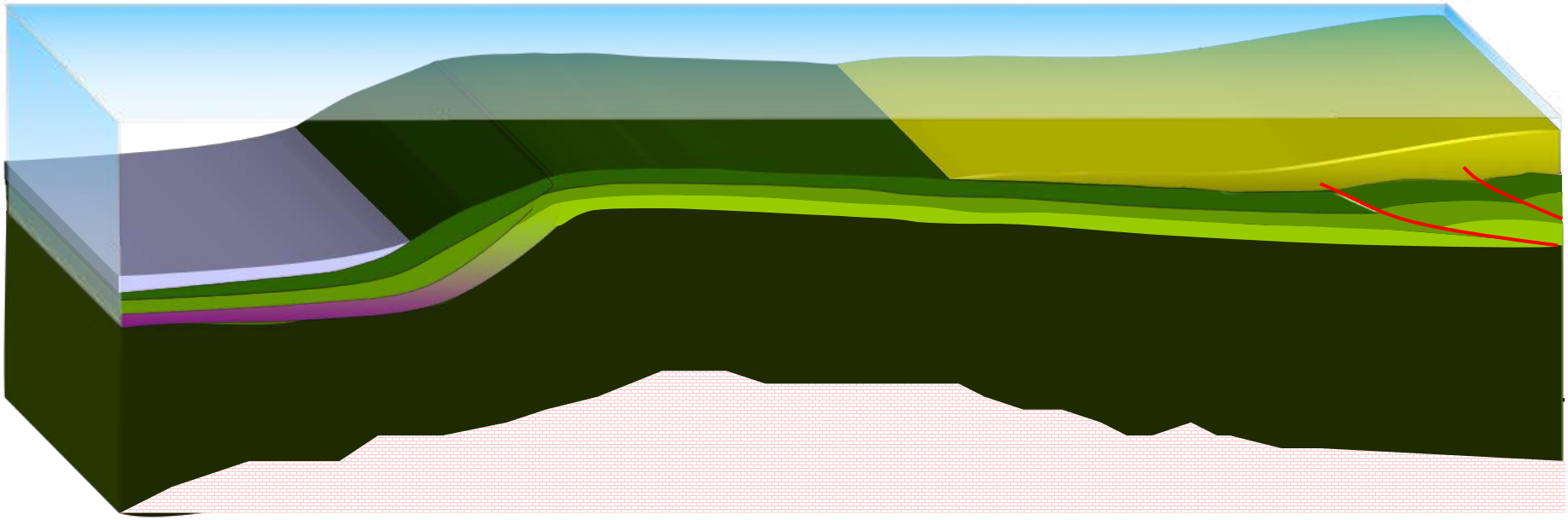


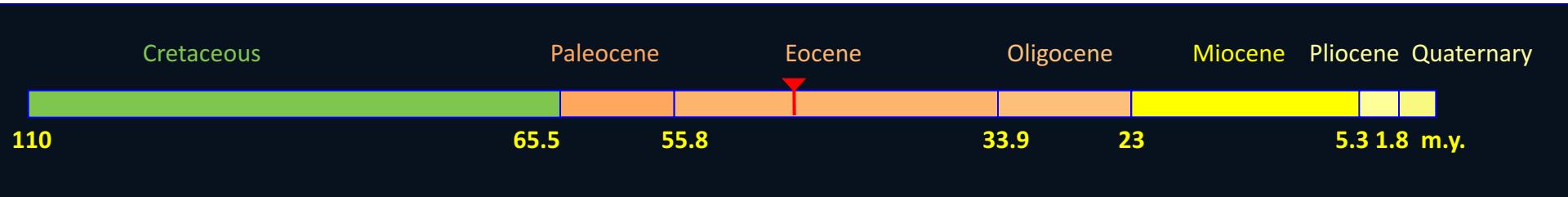
Progressiva migrazione della deformazione dinarica verso ovest

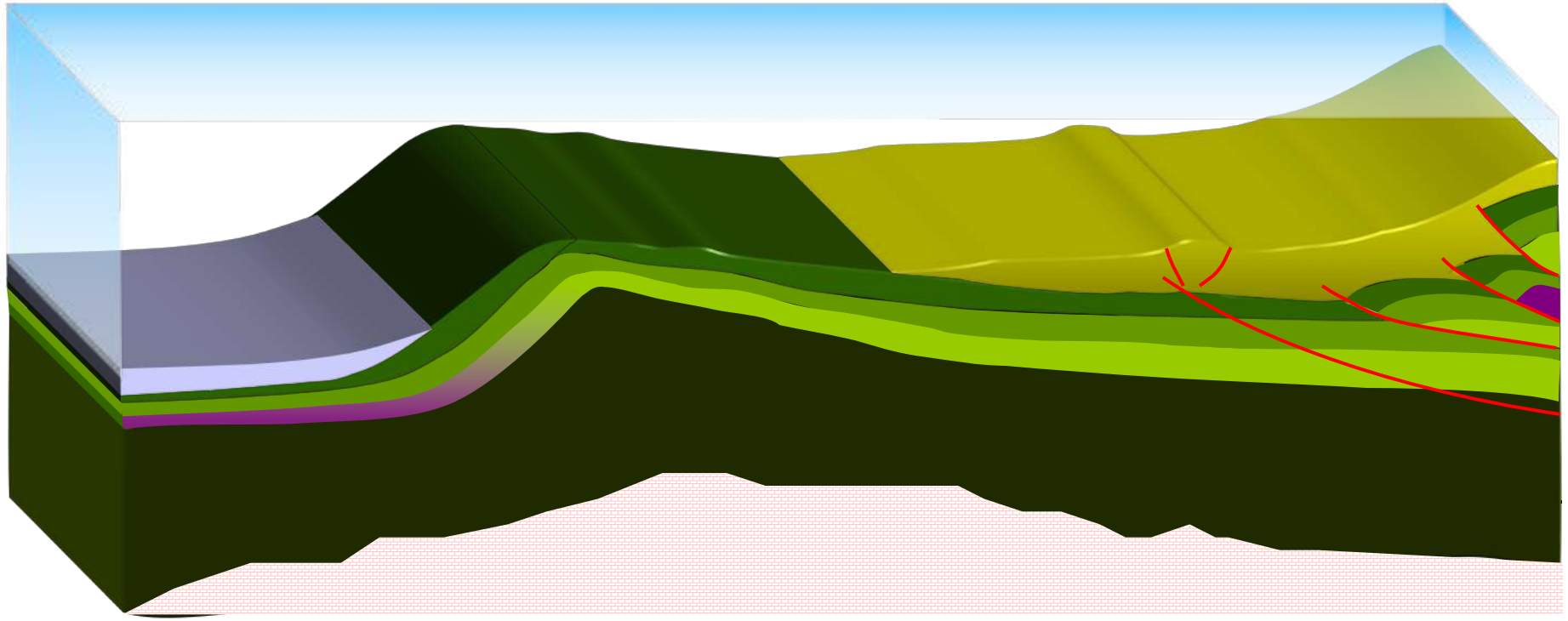


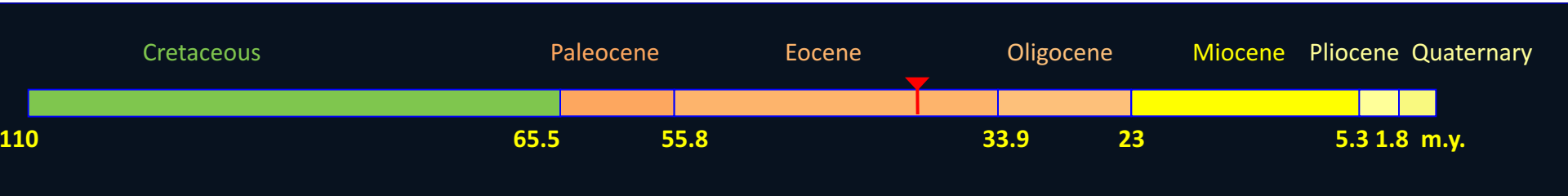
animazione di F. Zgur (OGS)



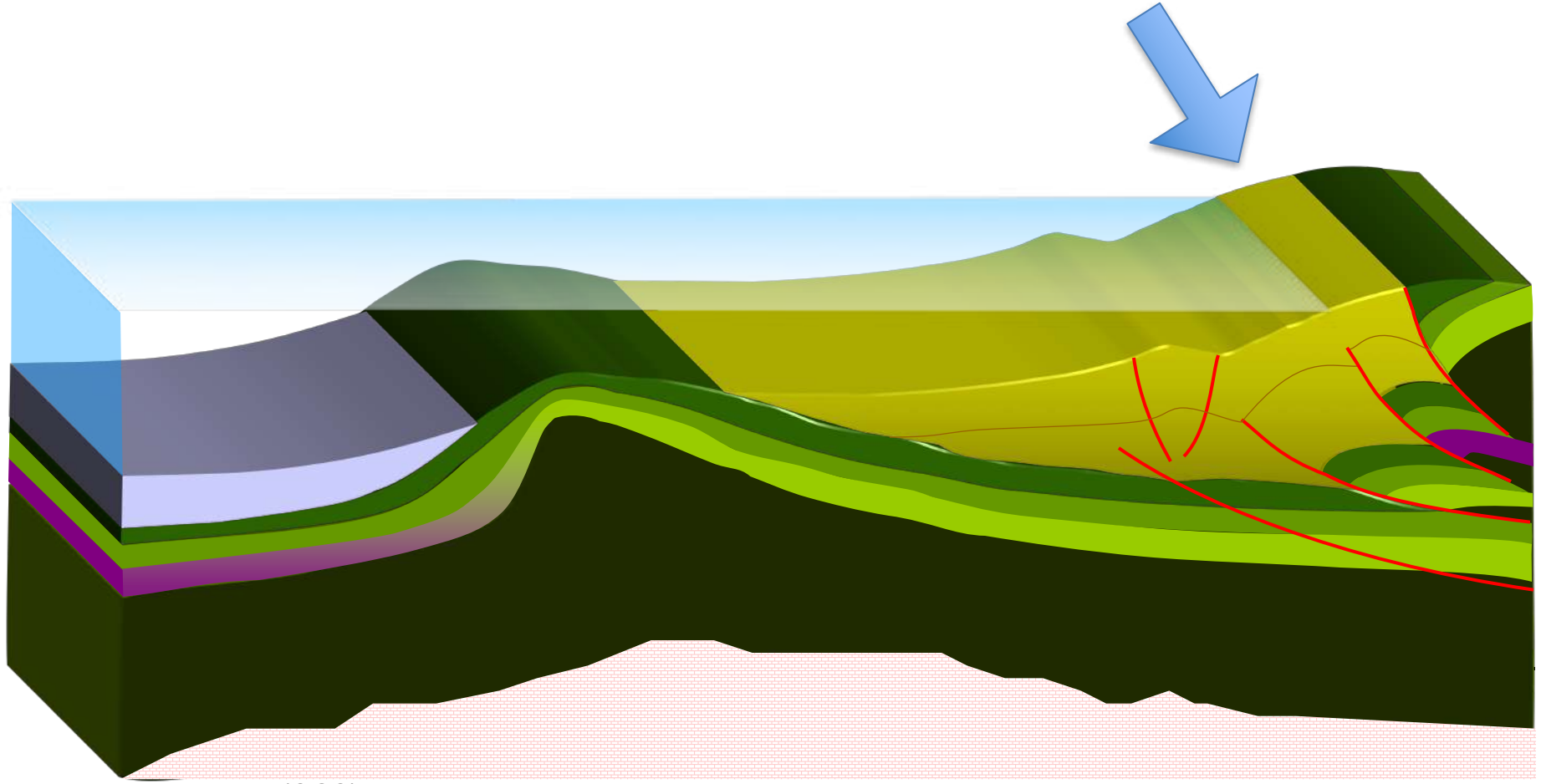



Cretaceous
Paleocene
Eocene
Oligocene
Miocene
Pliocene
Quaternary
110
65.5
55.8
33.9
23
5.3
1.8
m.y.

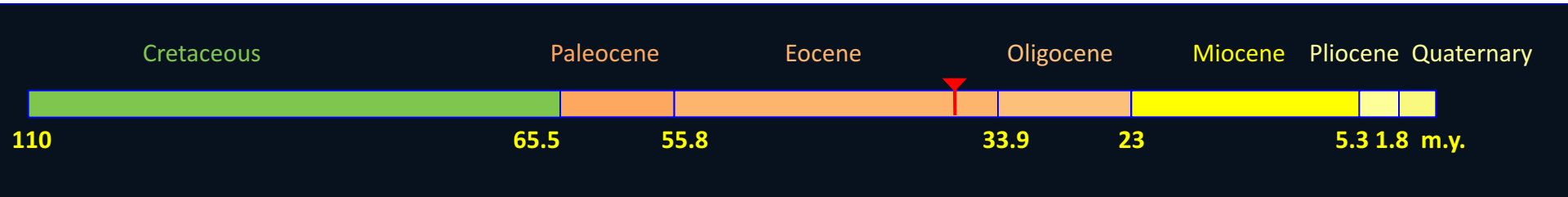



Cretaceous
Paleocene
Eocene
Oligocene
Miocene
Pliocene
Quaternary
110
65.5
55.8
33.9
23
5.3
1.8
m.y.

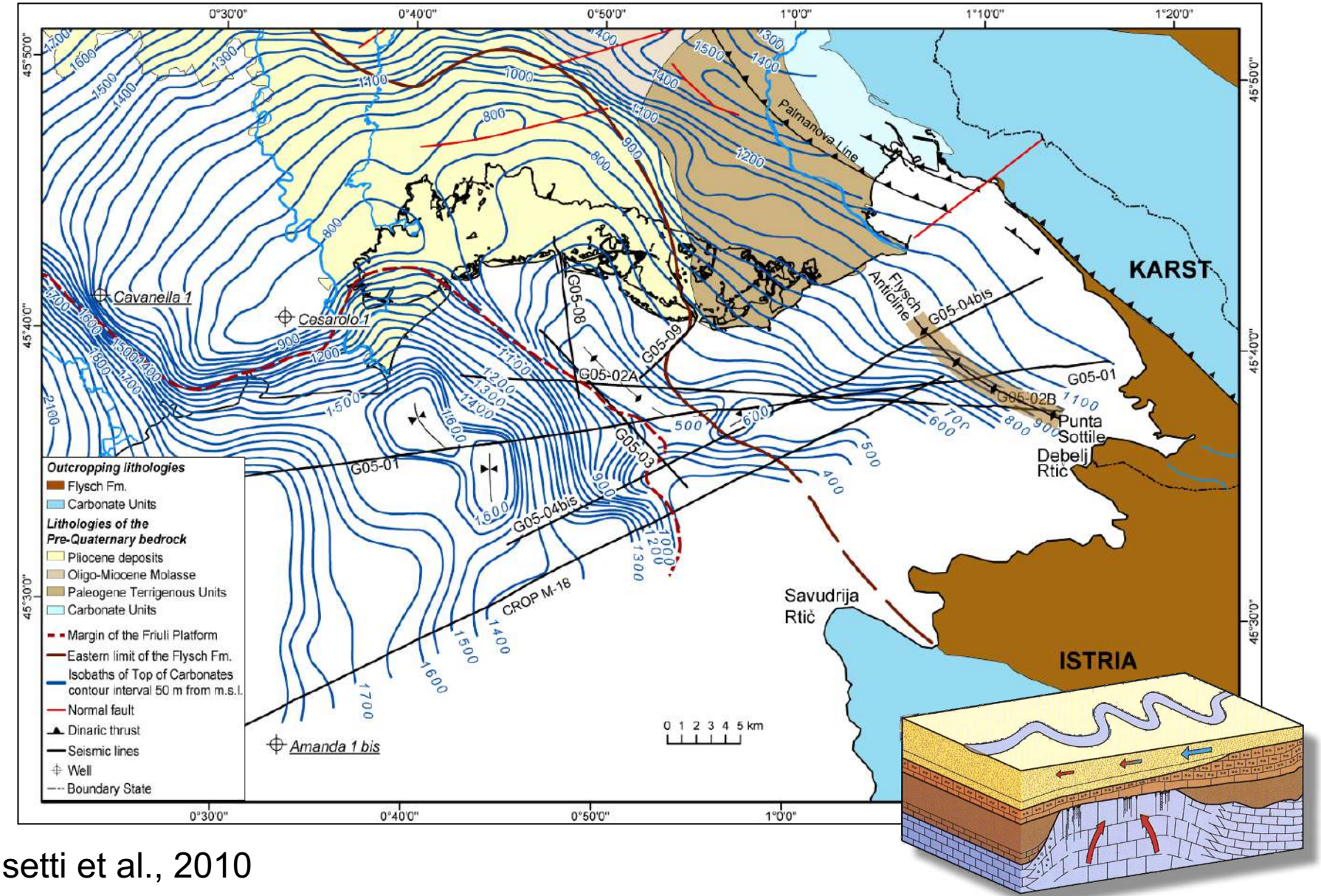
EOCENE: formazione del Thrust del Carso



animazione di F. Zgur (OGS)



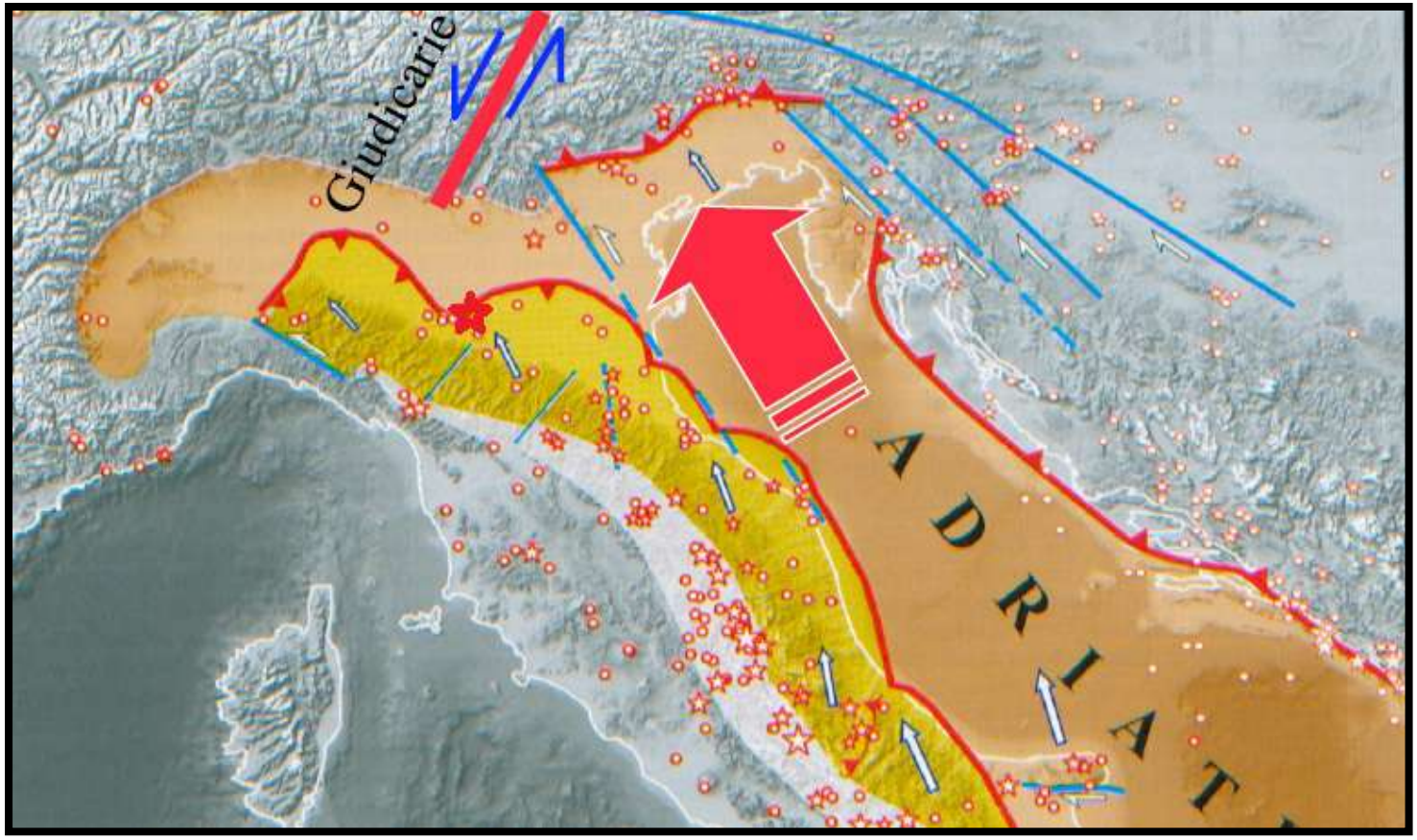
Mappa del tettodi carbonati (metri)

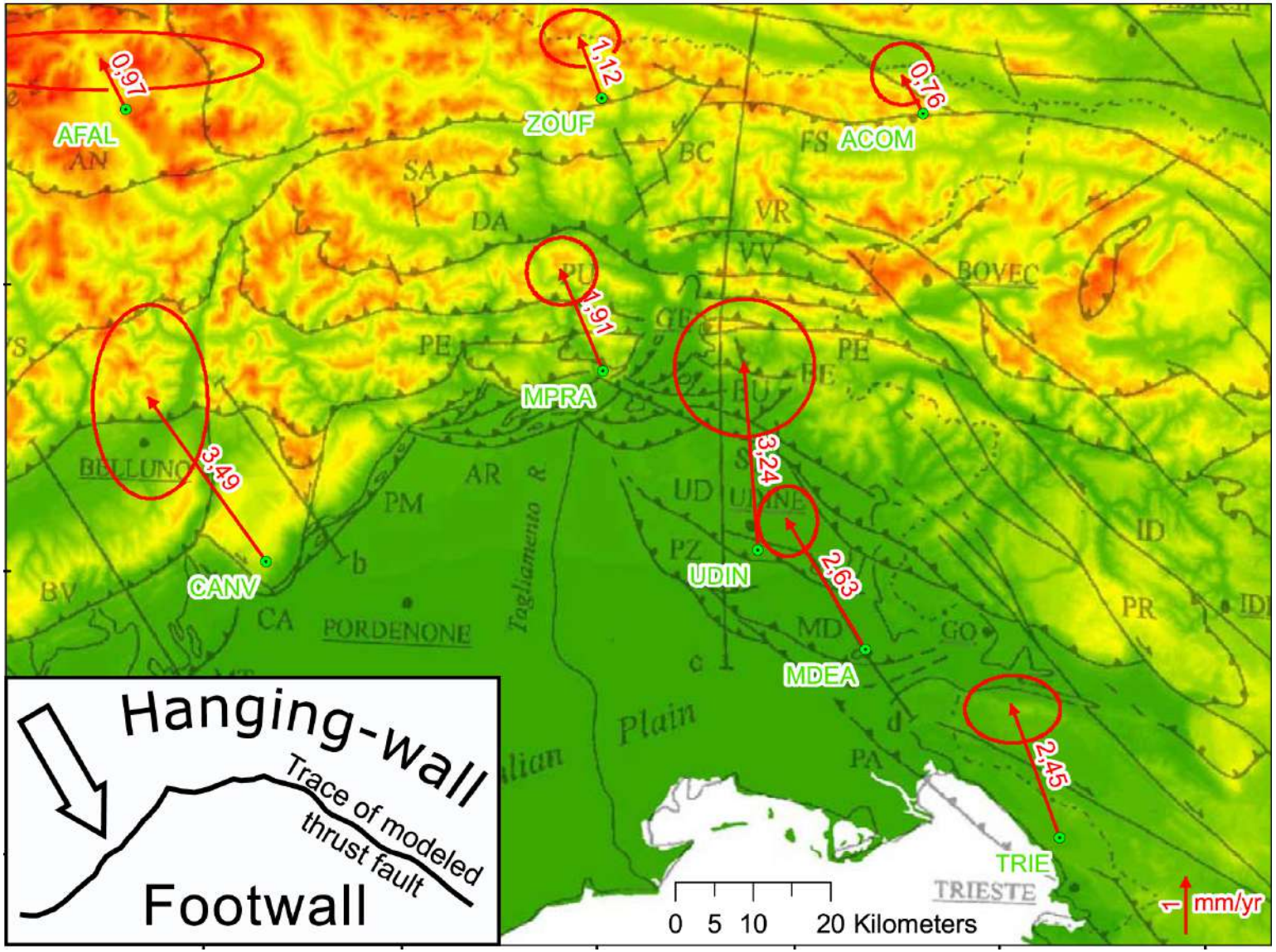


Busetti et al., 2010

La fase Alpina

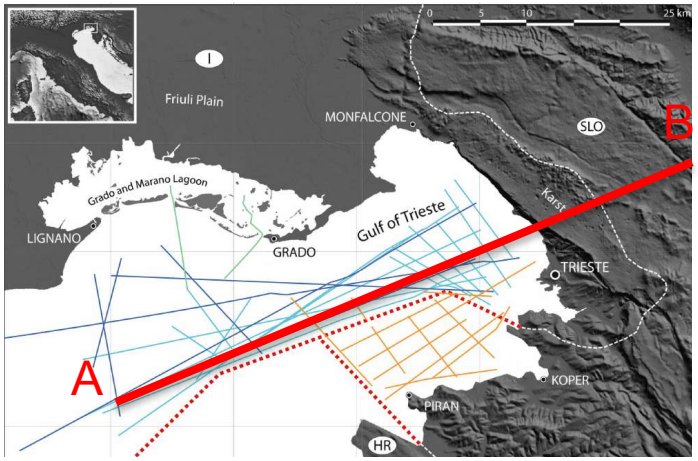
Collisone verso nord della placca Adria e trascorrenza ad est

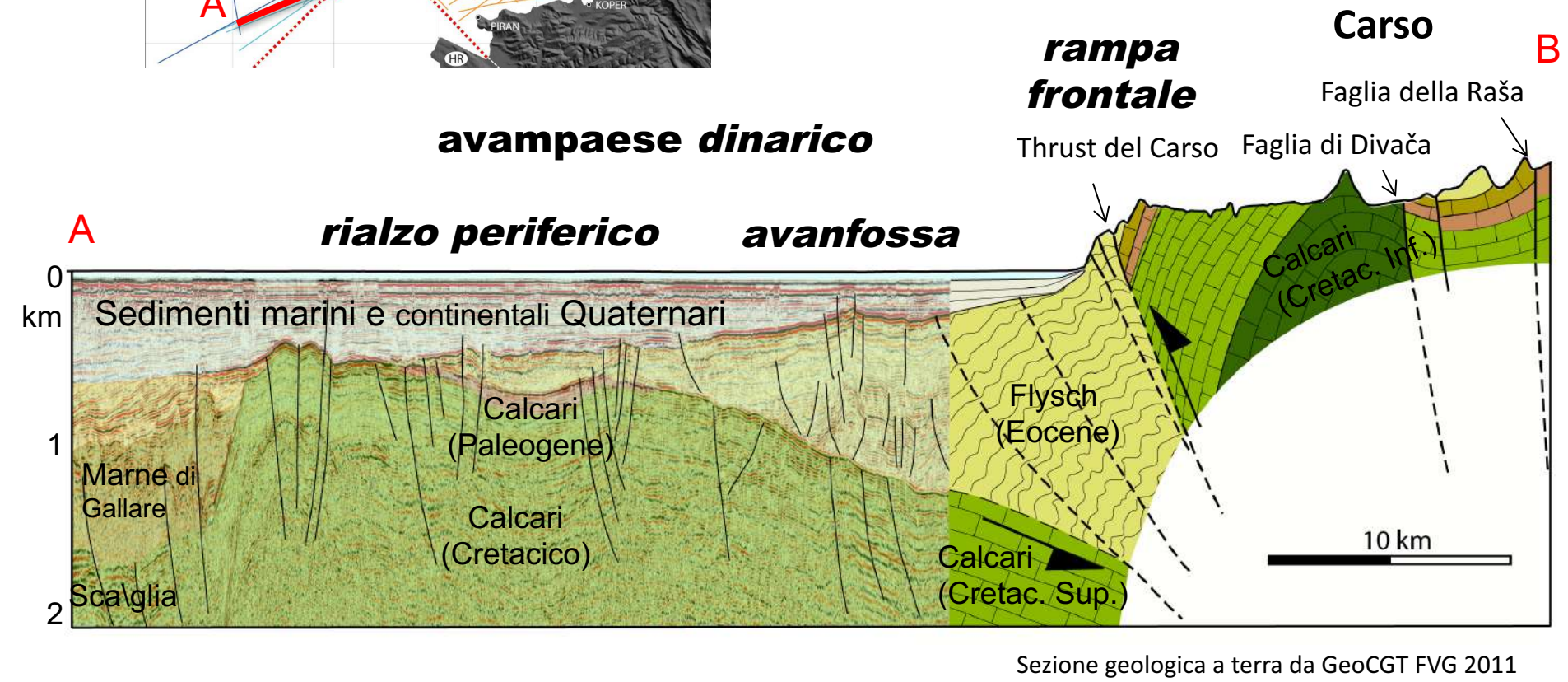




Bechtold et al., JGR, 2009

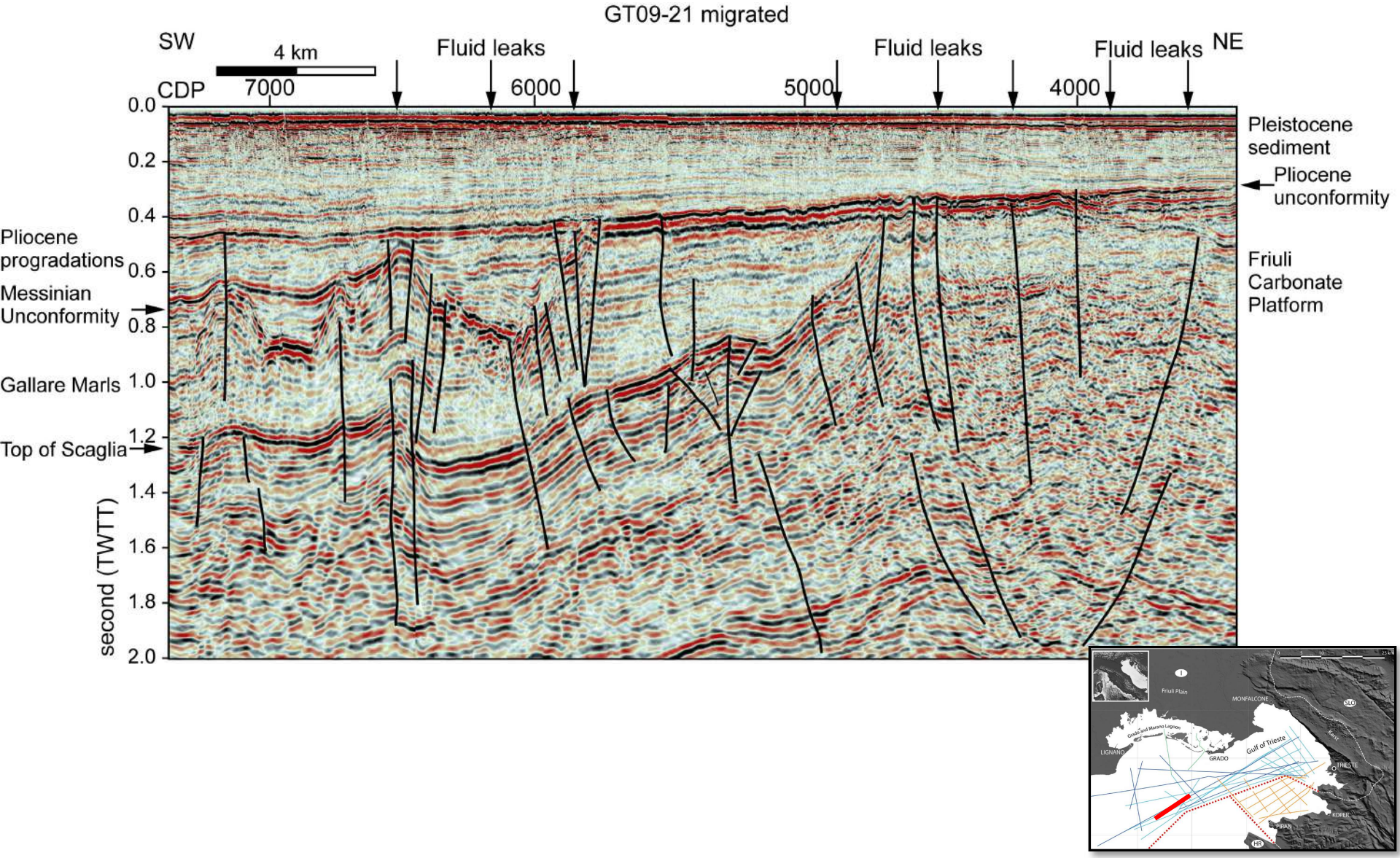
movimenti in millimetri all'anno





Sezione geologica a terra da GeoCGT FVG 2011

Modificata da Busetti et al., 2013

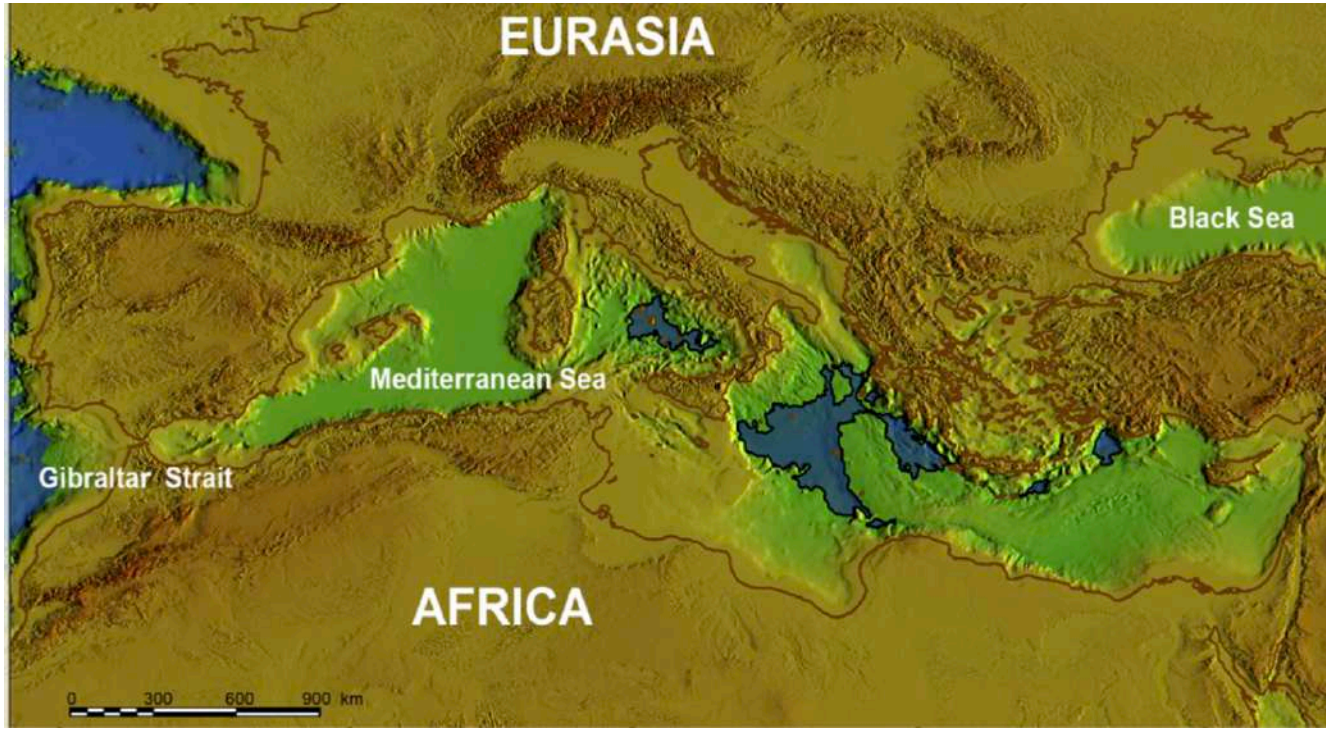

GT09-21 migrated
SW
4 km
Fluid leaks
Fluid leaks
Fluid leaks
NE
CDP
7000
6000
5000
4000
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
second (TWTT)
Pleistocene sediment
Pliocene unconformity
Friuli Carbonate Platform
Pliocene progradations
Messinian Unconformity
Gallare Marls
Top of Scaglia
Friuli Plain
MONFALCONE
Grado and Marano Lagoon
LIGNANO
GRADO
Gulf of Trieste
TRIESTE
KOPER
PIRAN
SLO
HR

Paleogeografia durante la crisi di salinità del Mediterraneo nel Messiniano (ca 6 Ma)

• interruzione comunicazione con l'Atlantic drammatica diminuzione del livello del mare > il Mediterraneo diventa un lago-mare

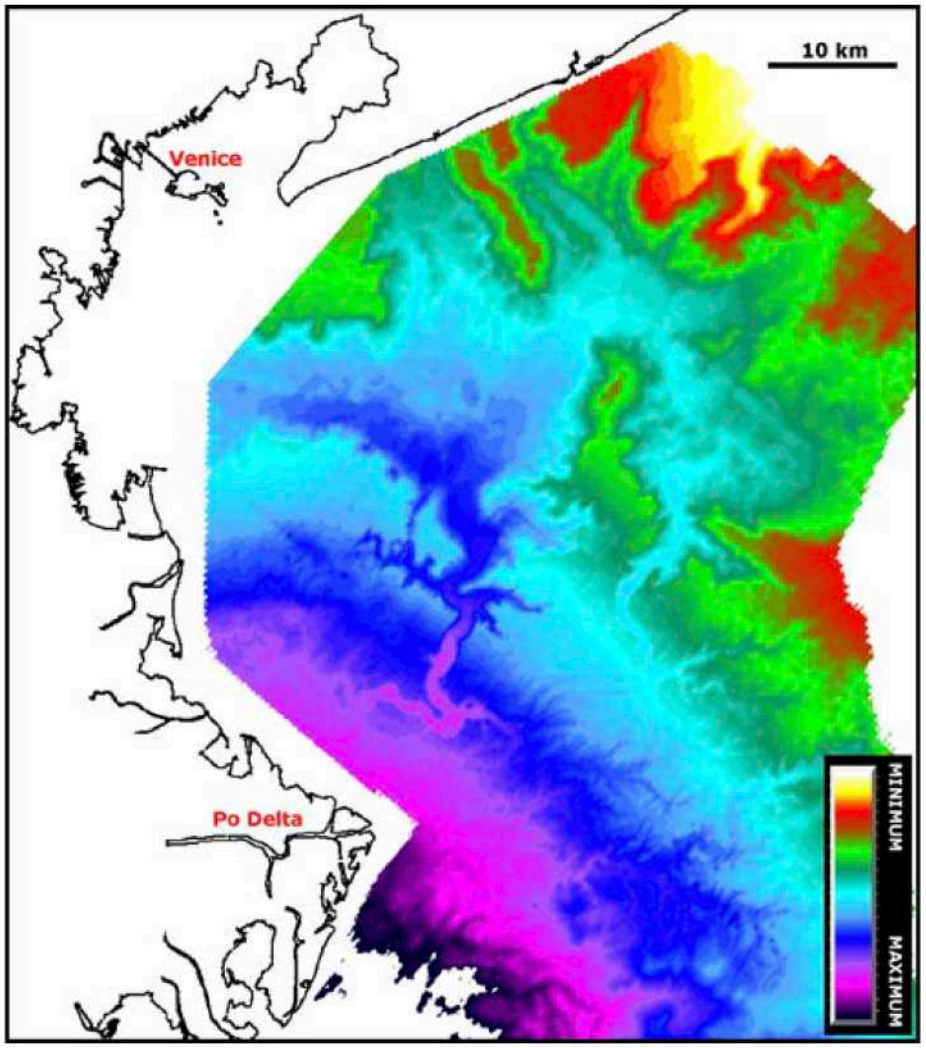
• *crisi salina del Messiniano* > nel bacino si depositano spesse sequenze evaporitiche (principalmente sale e gessi)

• nelle zone periferiche si verificano profonde erosioni fluviali.

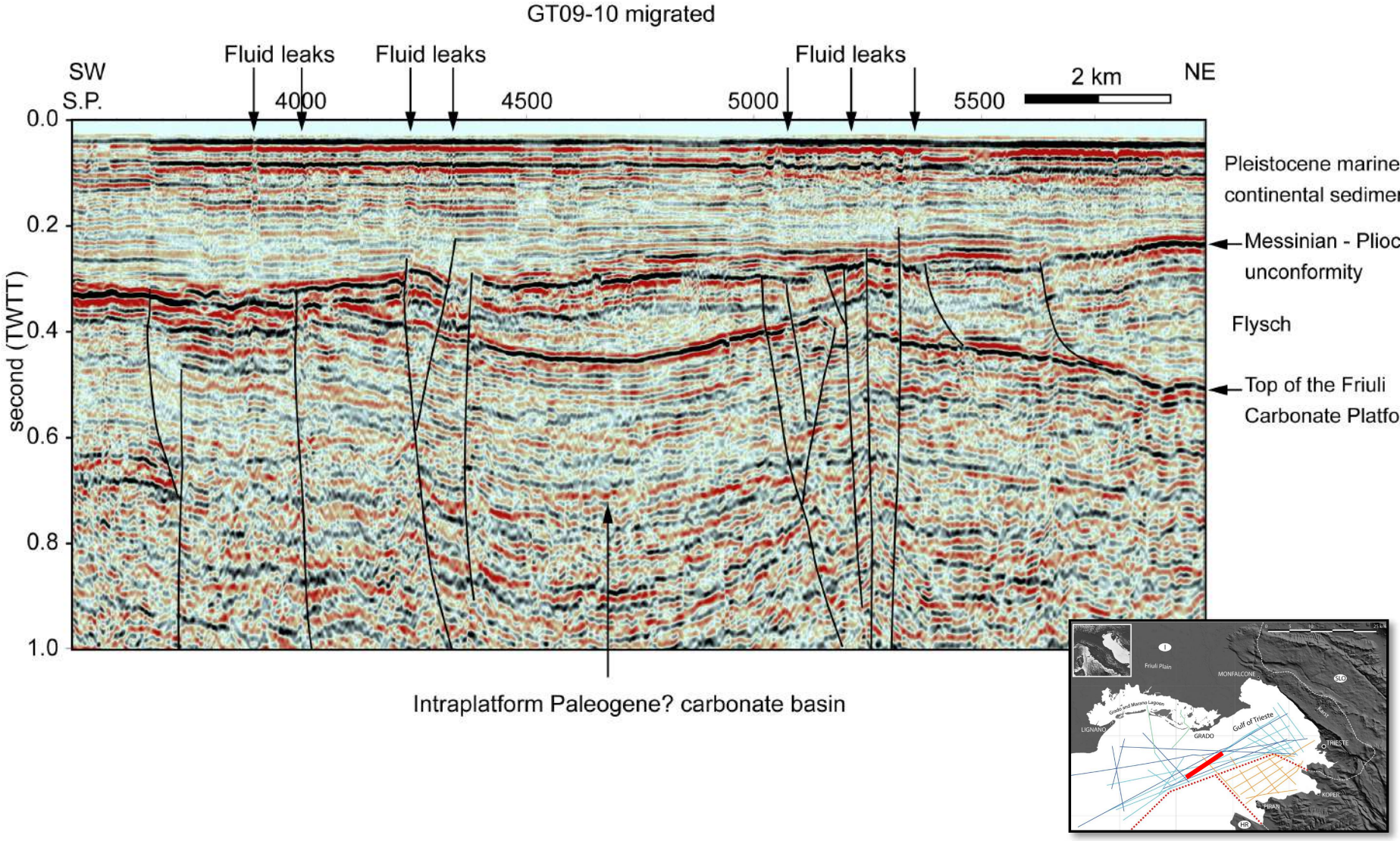


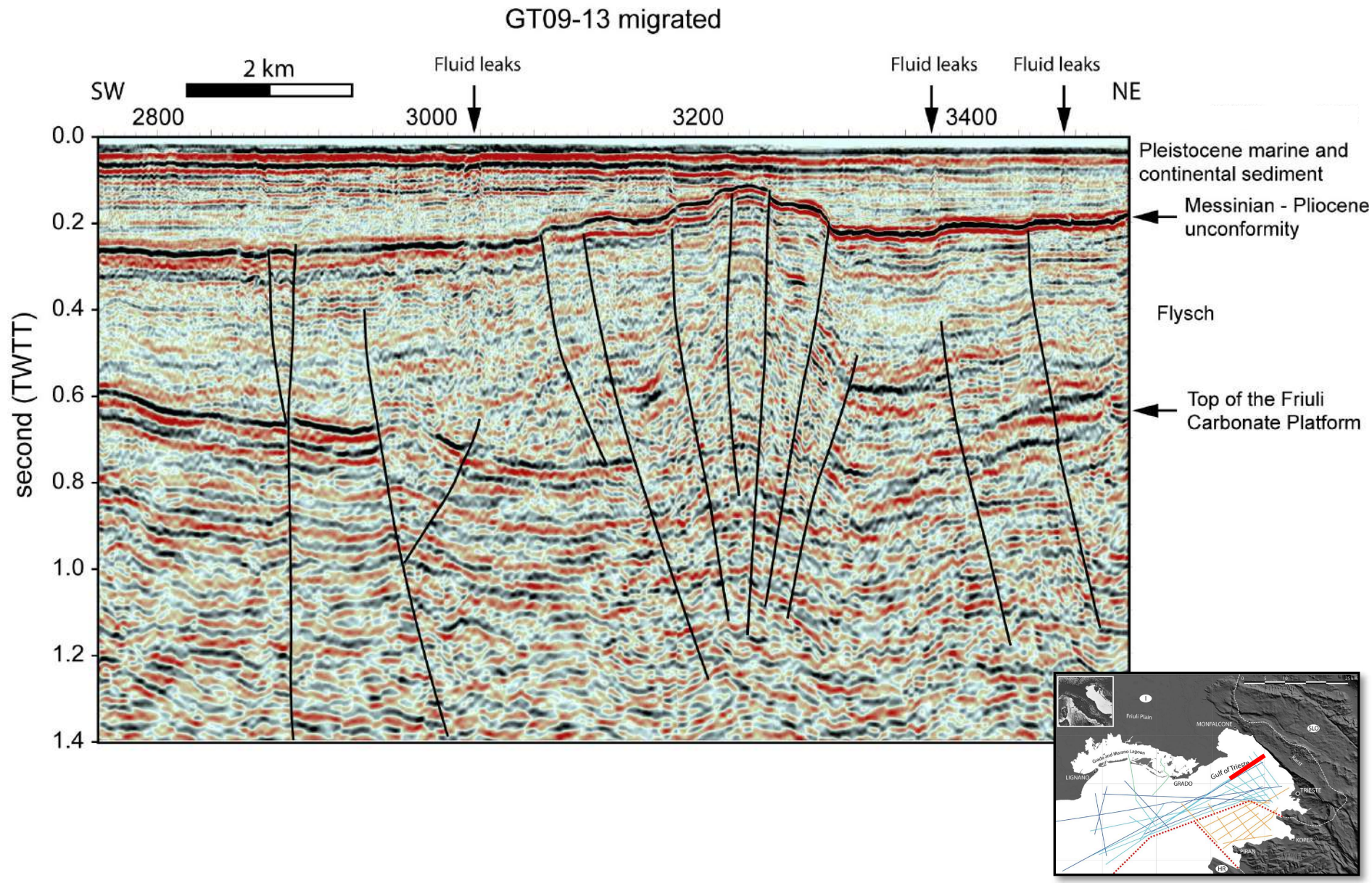
Anzidei et al., 2014

Mappa della superficie di erosione Messiniana nell'Alto Adriatico da sismica ENI 3D



Ghielmi et al., 2013

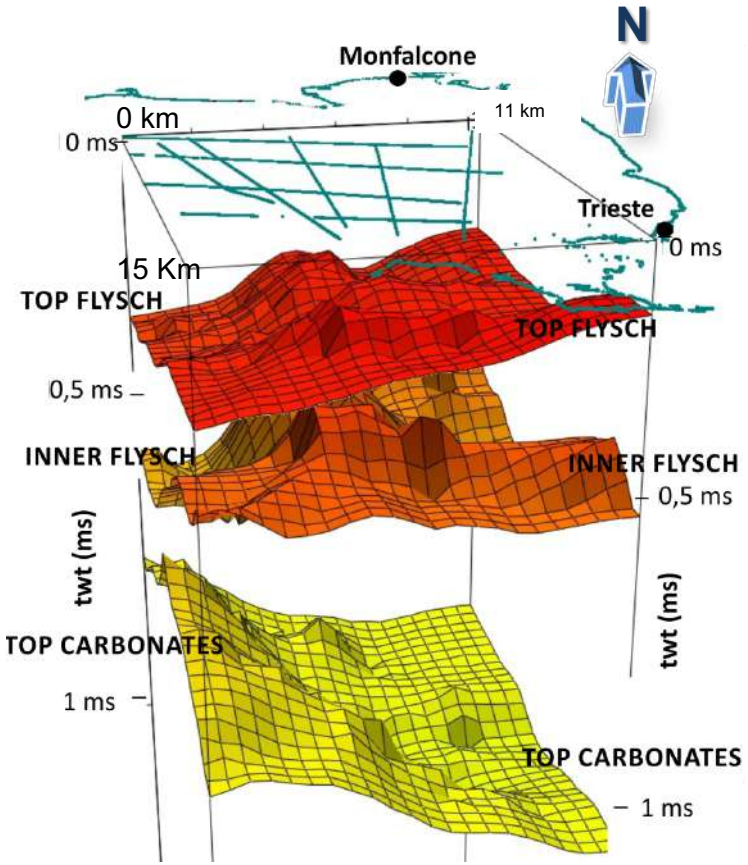

GT09-10 migrated
SW
S.P.
Fluid leaks
Fluid leaks
Fluid leaks
4000
4500
5000
5500
2 km
NE
0.0
0.2
0.4
0.6
0.8
1.0
second (TWTT)
Pleistocene marine and continental sediment
Messinian - Pliocene unconformity
Flysch
Top of the Friuli Carbonate Platform
Intraplatform Paleogene? carbonate basin
Friuli Plain
MONFALCONE
LIGNANO
GRADO
Gulf of Trieste
TRIESTE
KOPER
PIRAN
SLO
HR

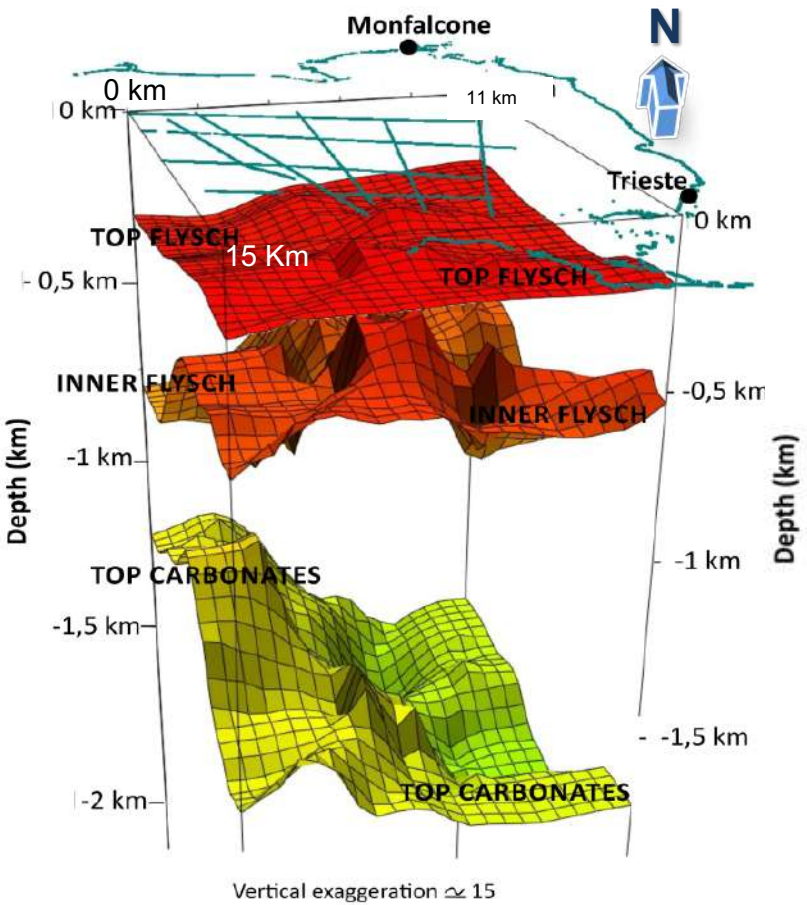

GT09-13 migrated
SW
2 km
NE
2800
3000
3200
3400
Fluid leaks
Fluid leaks
Fluid leaks
second (TWTT)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Pleistocene marine and continental sediment
Messinian - Pliocene unconformity
Flysch
Top of the Friuli Carbonate Platform
Friuli Plain
MONFALCONE
Grado and Marano Lagoon
LIGNANO
GRADO
Gulf of Trieste
TRIESTE
KOPER
PIRAN
SLO
HR

3D Time and Depth Surfaces

- 3D time surfaces
from interpretation of
the post-stack time migrated profiles

- 3D depth surfaces
Time to depth conversion by using interval velocities
obtained from MCS data processing in time domain

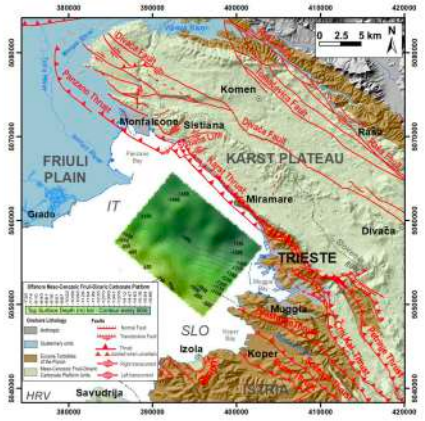




Gridding perfomed by using Cat3D, 2014, OGS Software

Dal Cin M., PhD 2018;
Dal Cin M. et al., submitted

Michela DAL CIN - ESFM –



Gulf of Trieste

Prestack Depth Migrated Profile GT13-27

SW — A — B — NE

Karst Highland

Trieste (Porto | Karst Thrust | Mt. Belvedere | Italy - Slovenia | Sežana | Divača Fault | Štorje | Tomačevica Fault | Raša Fault | Vipava Fault

Legend:
- Quaternary sediments - Q
- Eocene Flysch - F
- Meso-Cenozoic Friuli-Dinaric Carbonate Platform - C

Dinaric Foredeep

km

AUR, MRP, CCS, ALN, F, C, Q

10 km

vertical exaggeration x4

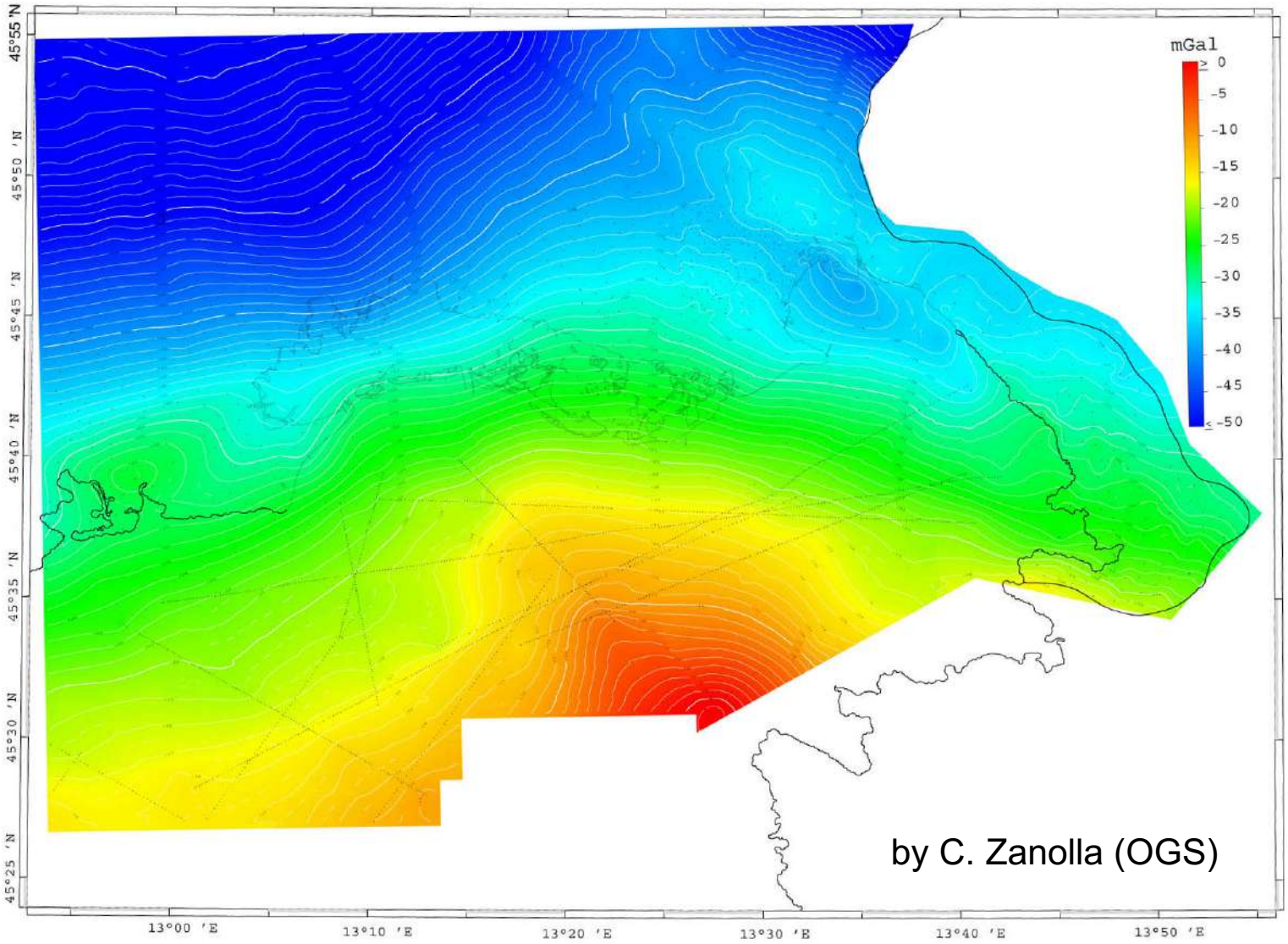
Distance (km)

Geological Section reconstructed from GEOCGT-FVG (2013) and Jurkovšek et al. (2016)

Legend:
- Quaternary sediments
- Terrigenous units: Flysch Unit - F (Ypresian - Lutetian)
- Faults
- Meso-Cenozoic Friuli-Dinaric Carbonate Platform units:
  - Alveolinid and Nummulitid Limestone - ALN (Upper Thanetian - Middle Ypresian)
  - Liburnia Formation - LIB (Upper Campanian - Thanetian)
  - Aurisina Limestone - AUR (Upper Cenomanian - Turonian - Lower Senonian)
  - Monrupino Formation - MRP (Middle-upper Cenomanian)
  - Monte Coste Limestone - CCS (Lower Aptian - Upper Albian)
  - Brje Formation - BF (Valanghian - Aptian)

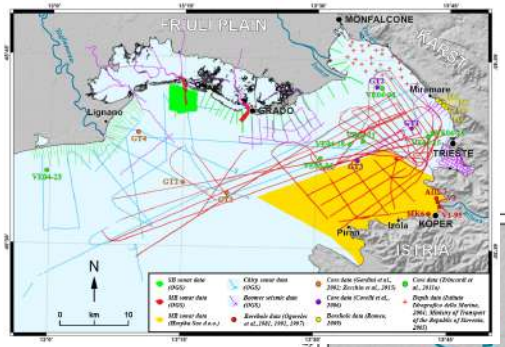
Dal Cin M., PhD 2018;
Dal Cin M. et al., submitted

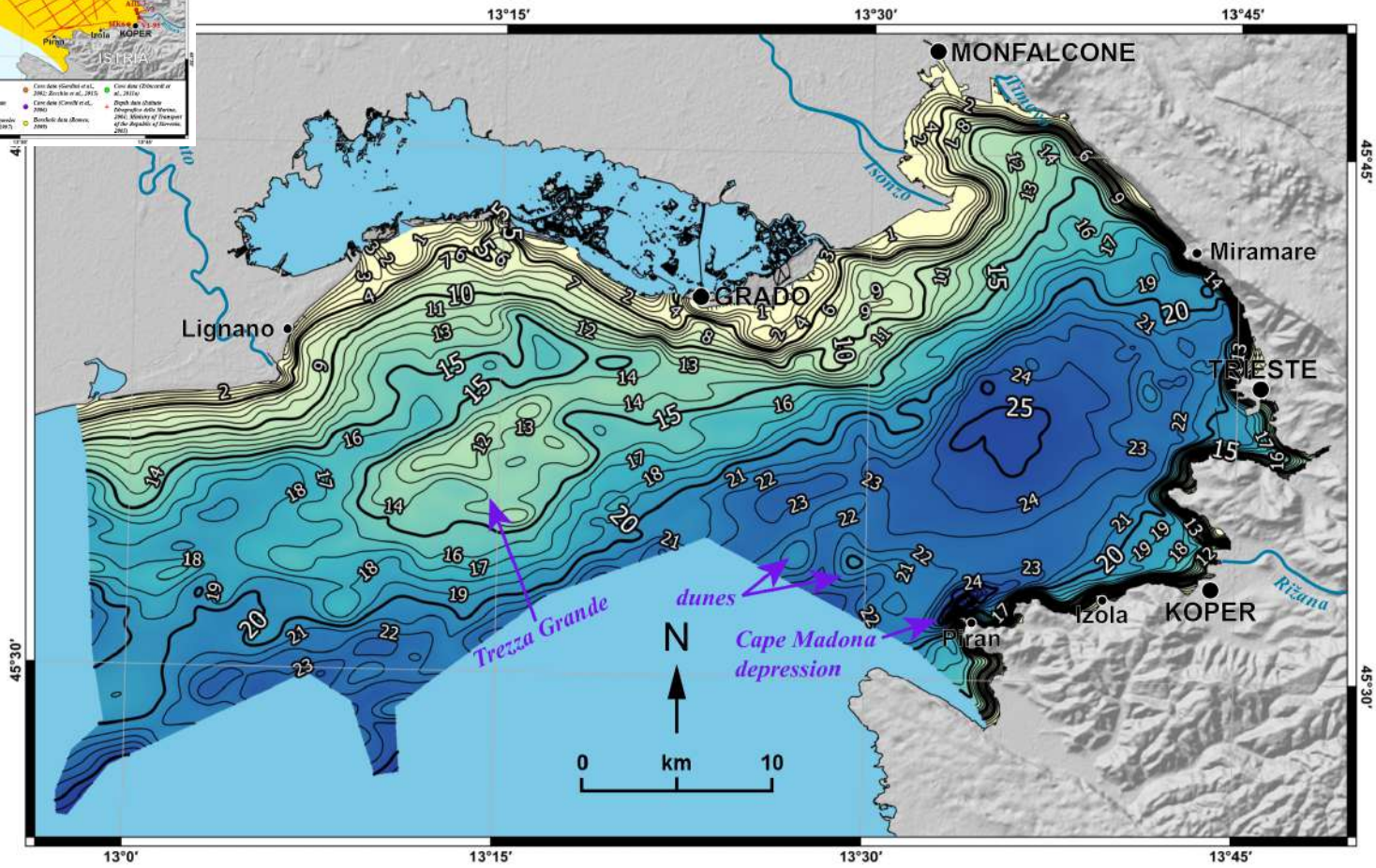
Anomalie di gravità secondo Bouguer



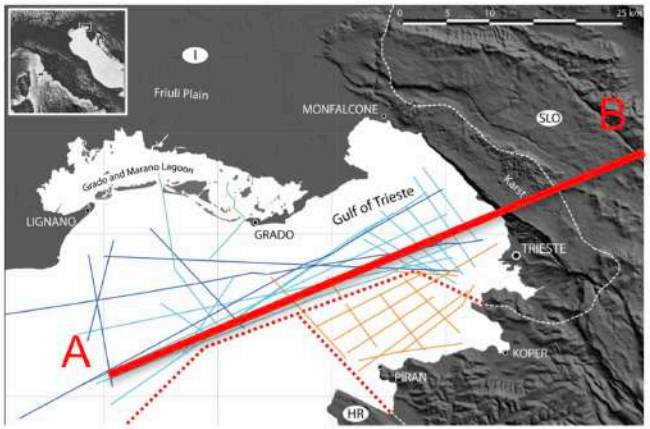
Busetti et al., 2010

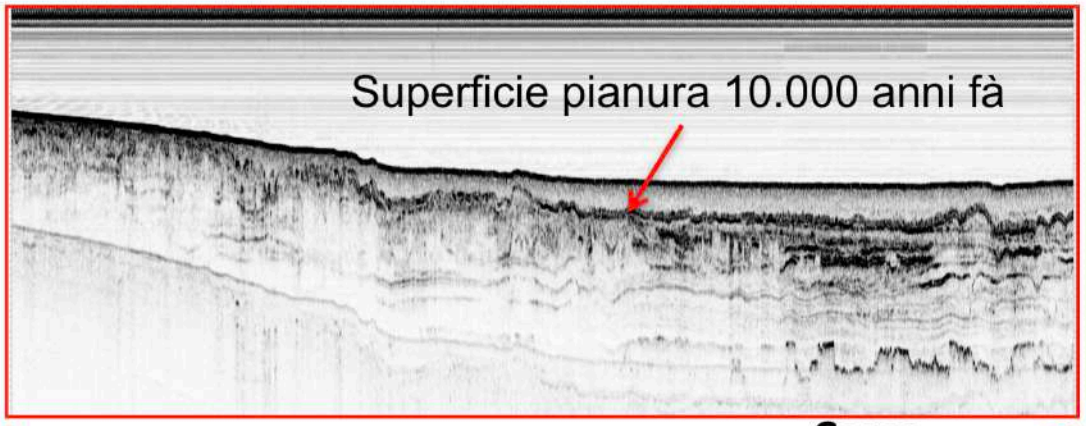
Carta Batimetrica (metri)

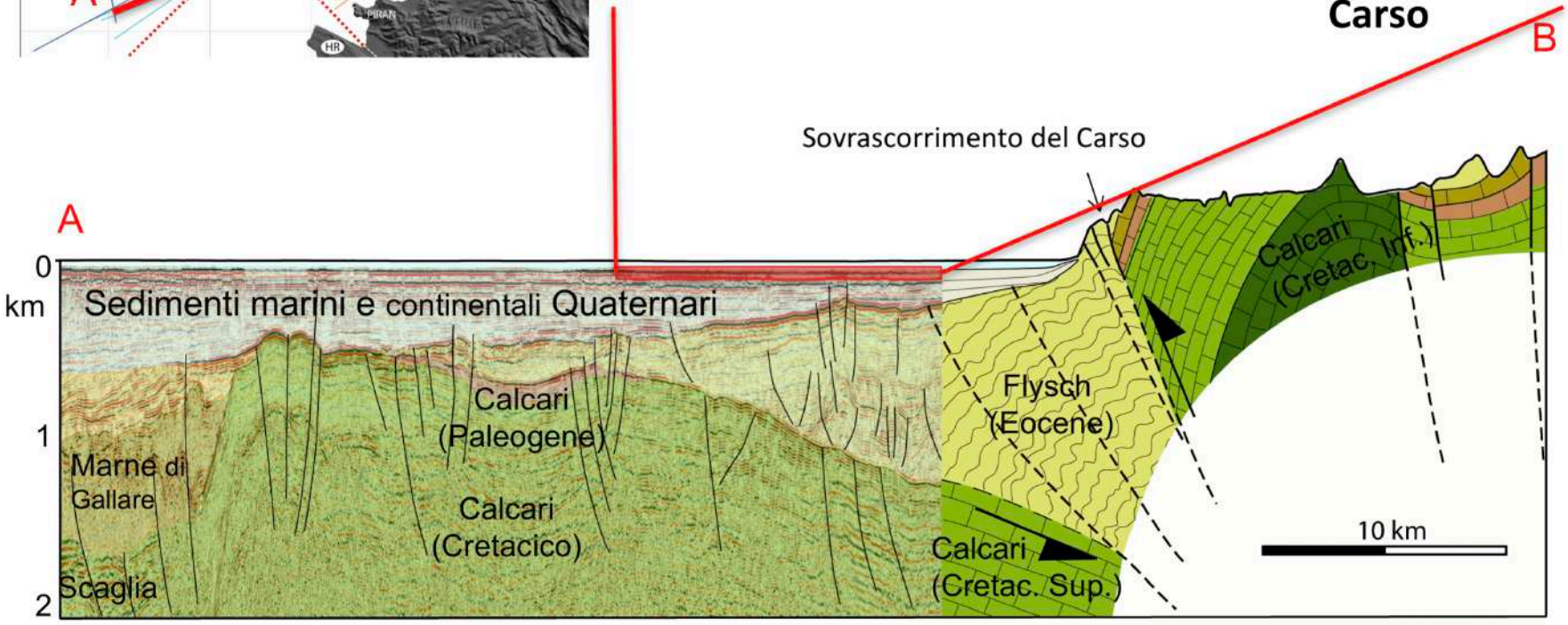




Trobec et al., 2018

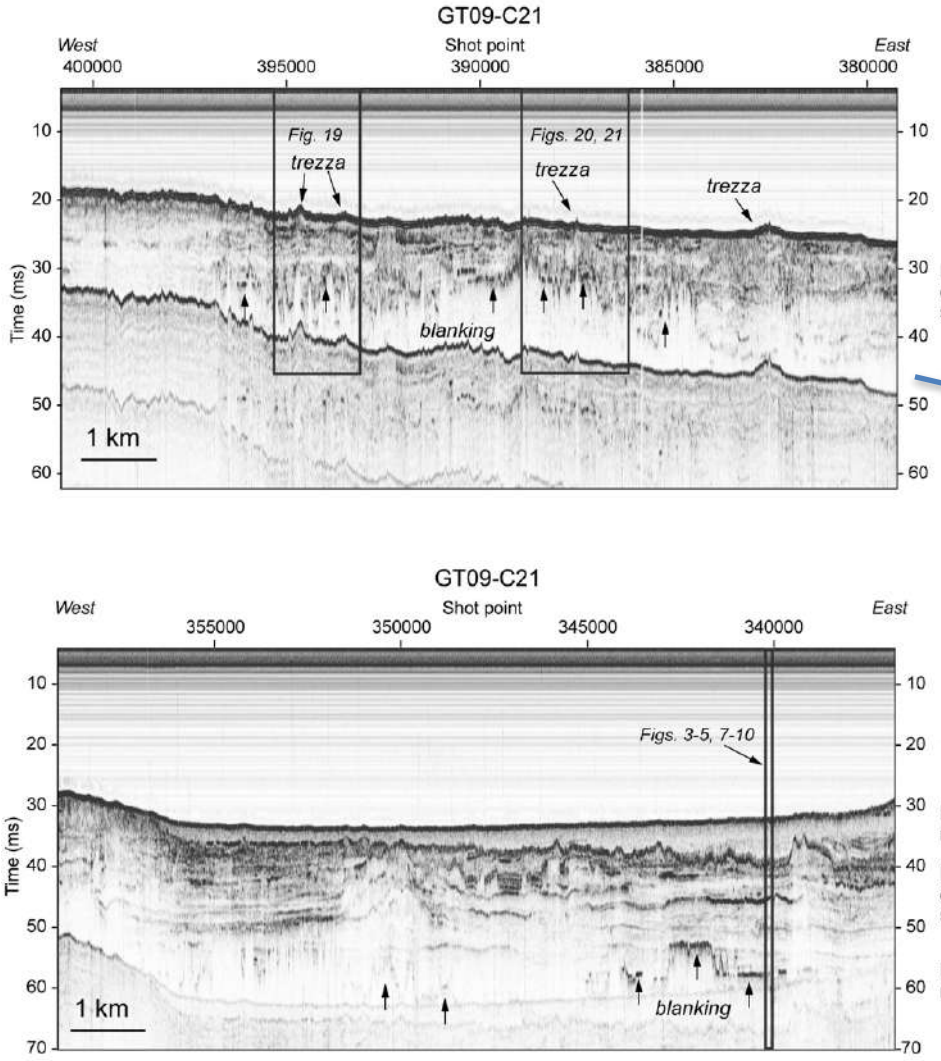


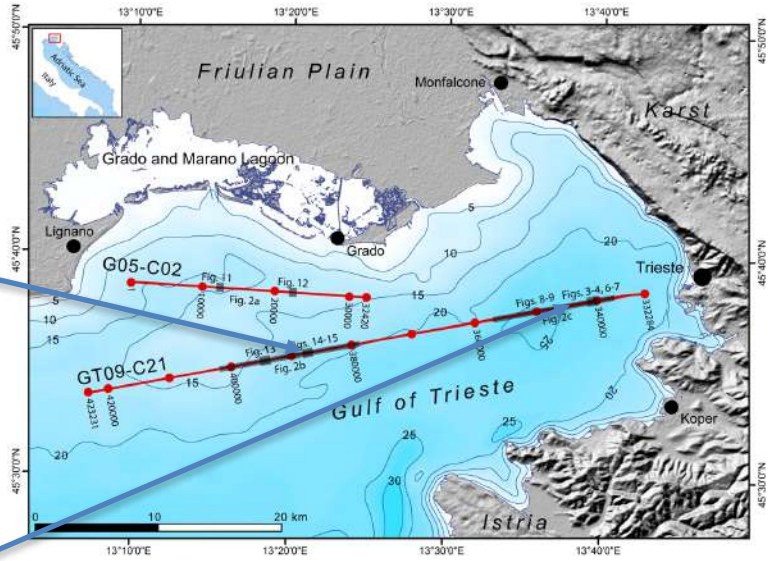




Modificata da Busetti et al., 2013

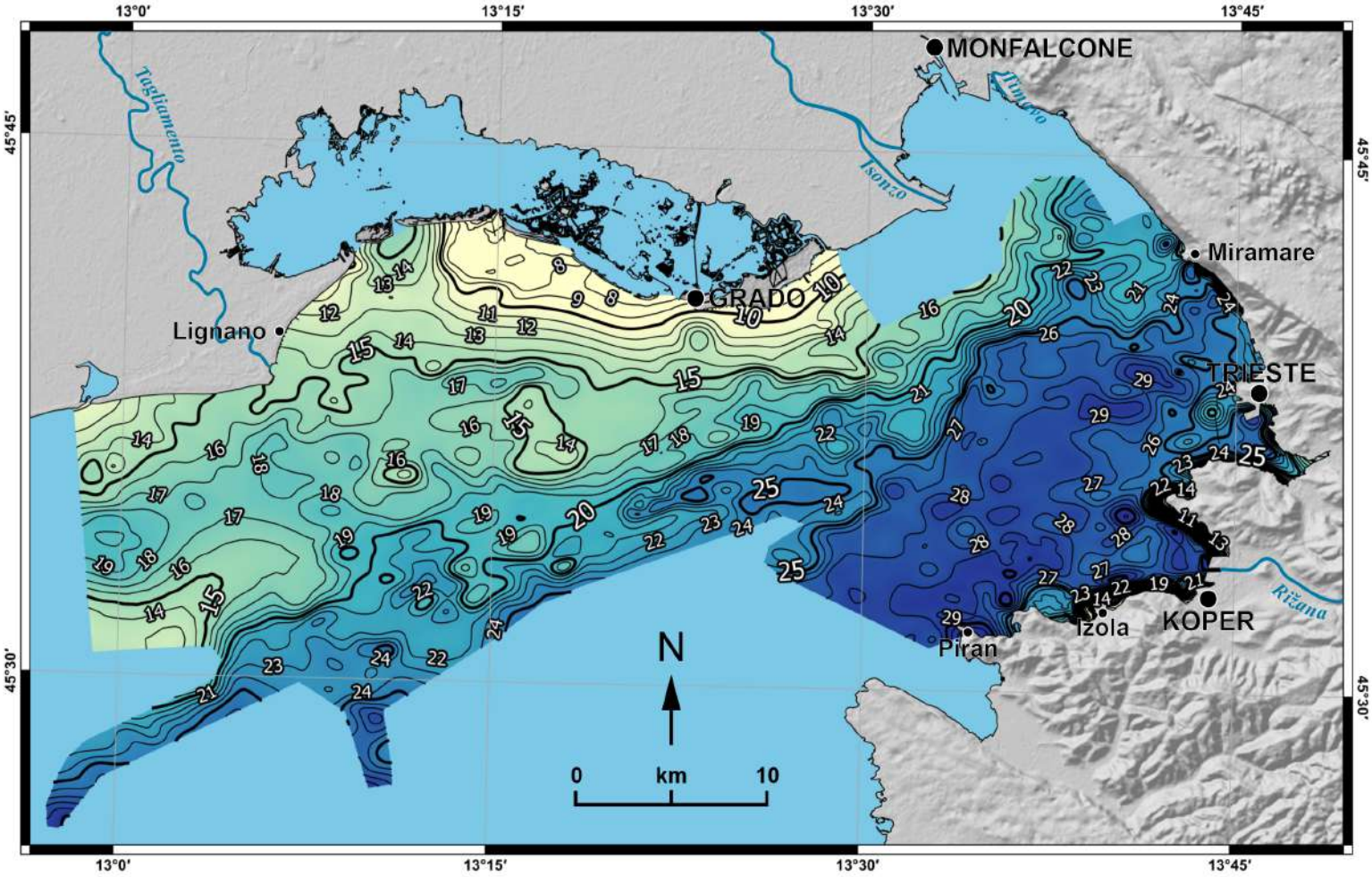
Sezione geologica a terra da GeoCGT FVG 2011





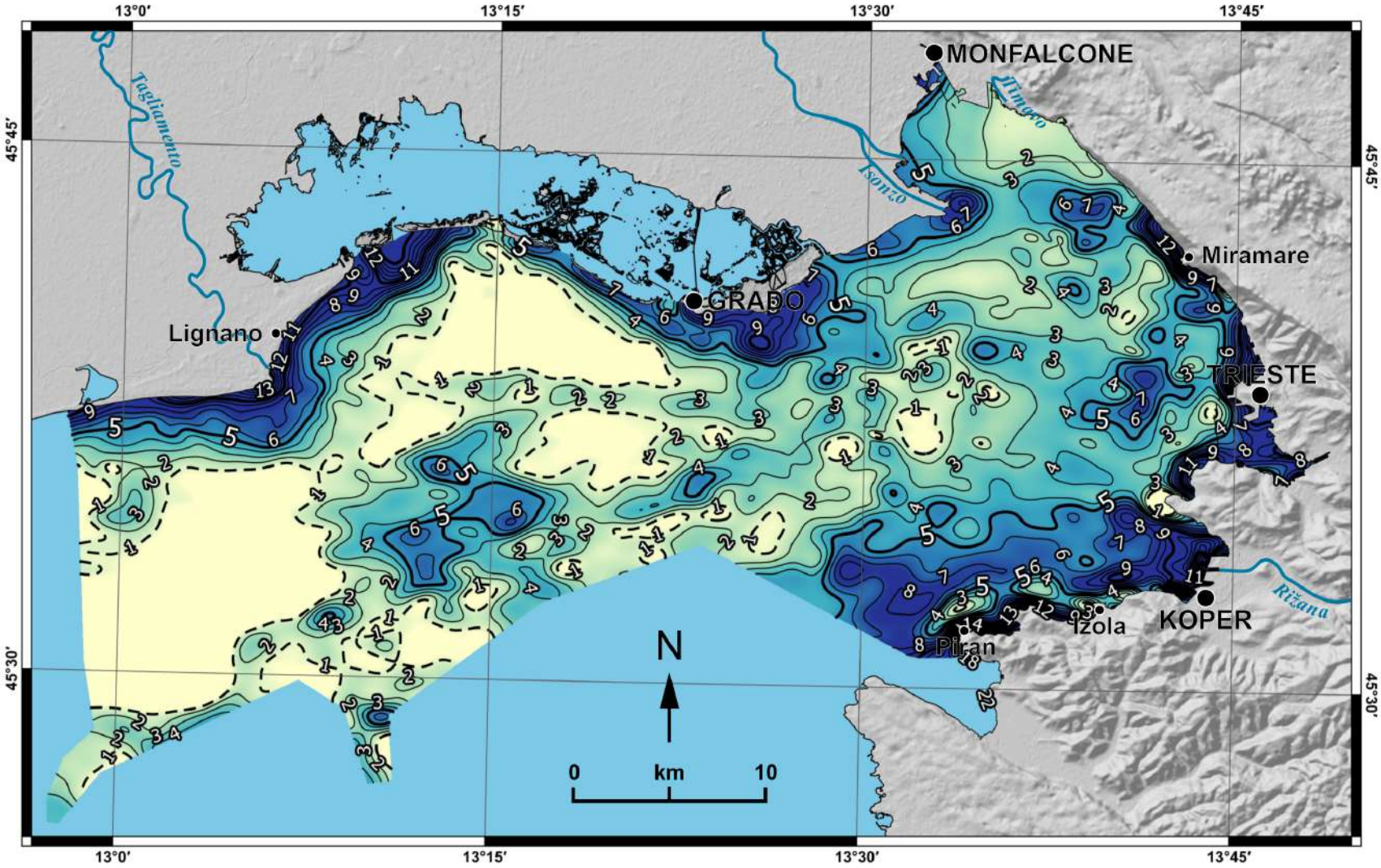
Vesnaver et al., 2021

Base dei sedimenti olocenici marini (metri) paleopianura del tardo Pleistocene



Trobec et al., 2018

Mappa dello spessore dei sedimenti olocenici marini (metri)



Trobec et al., 2018

La risorsa geotermica

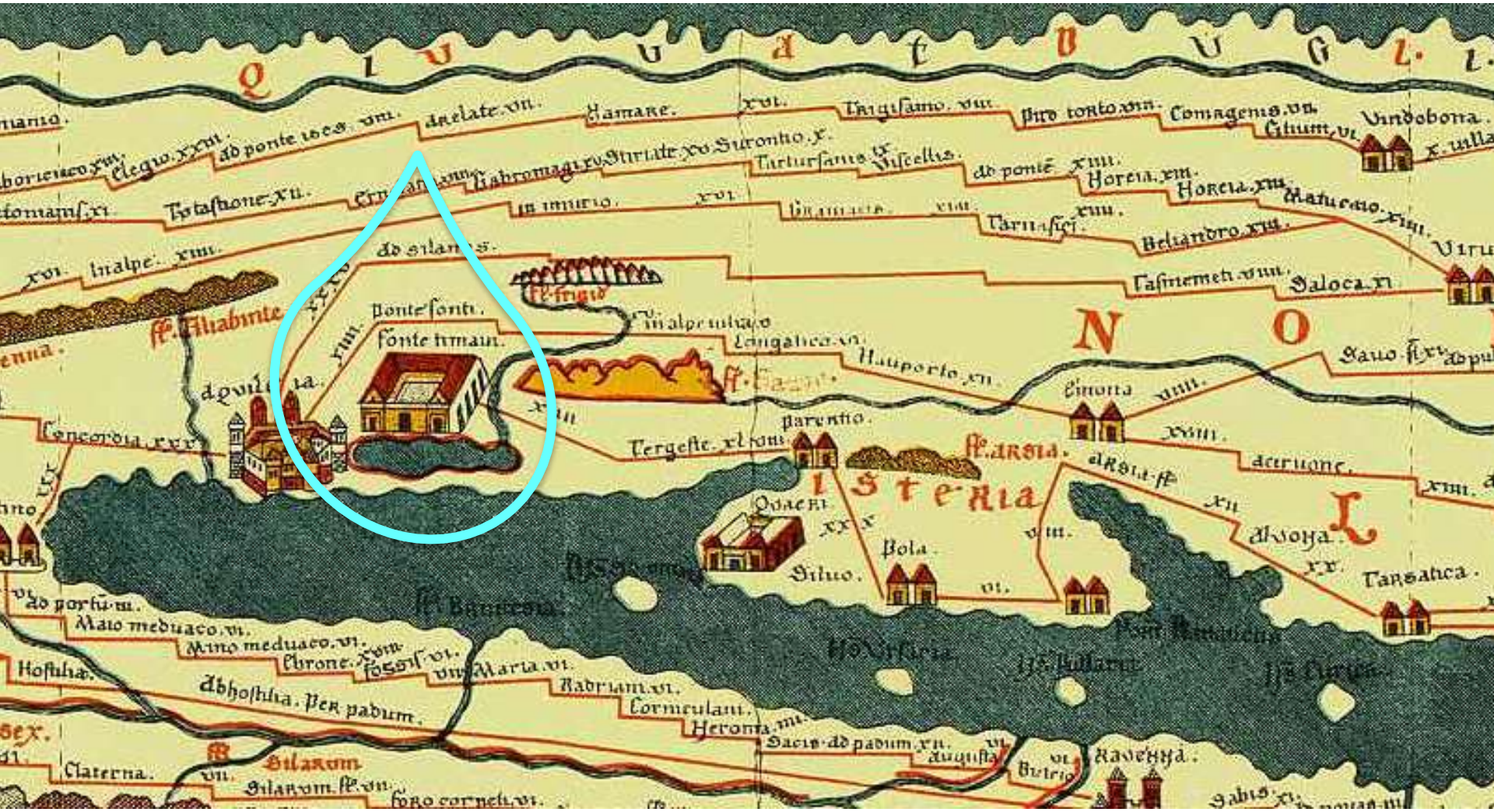
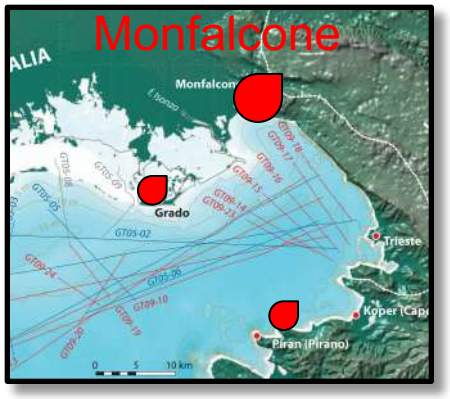


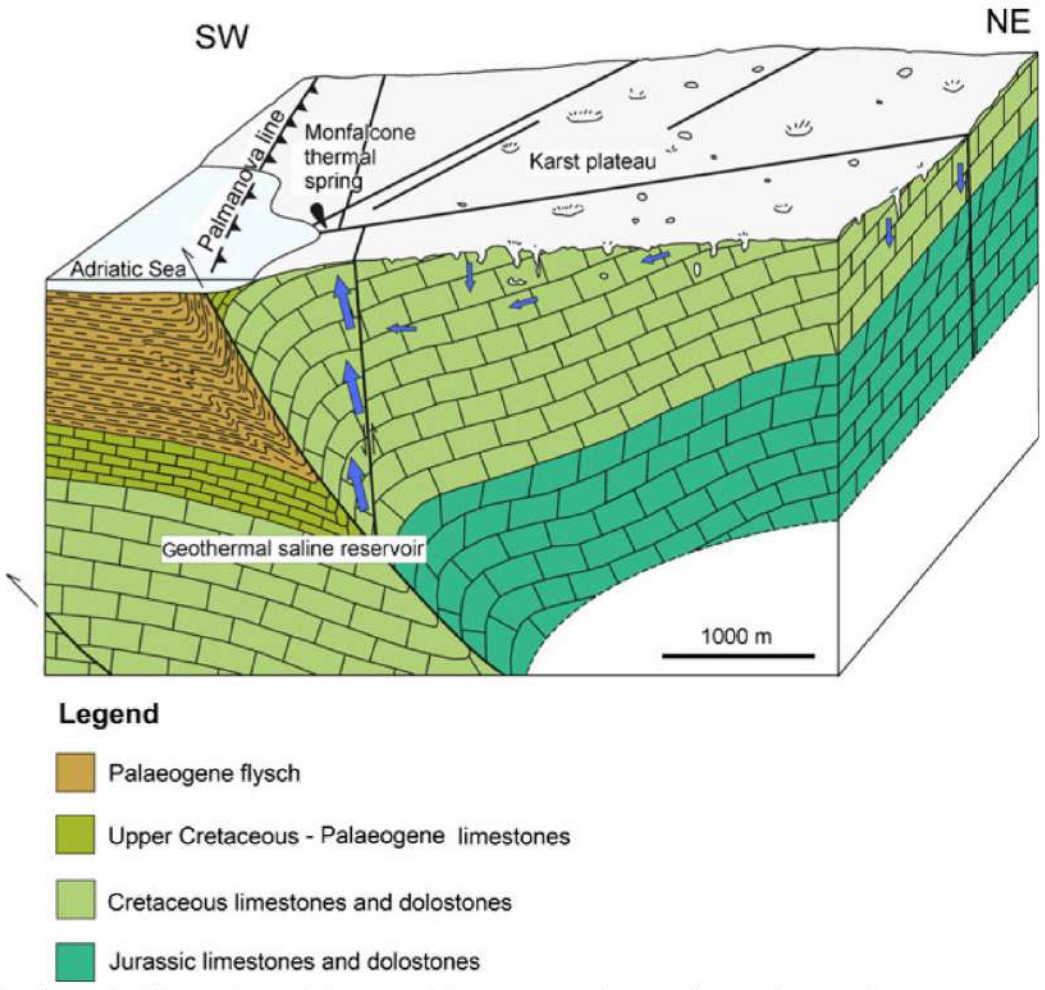
Tavola Peutingeriana (Biblioteca Nazionale di Vienna)
Copia del XII-XIII secolo di un'antica carta romana del IV secolo

Acque termali: *le terme Romane di Monfalcone*



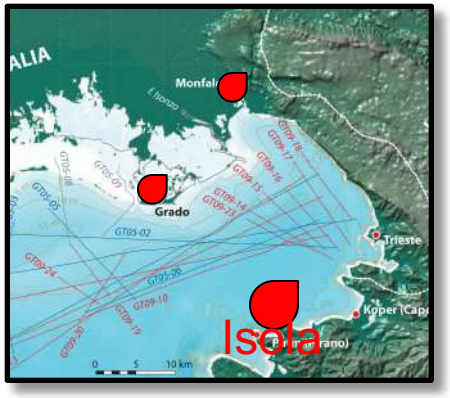
Temperatura acqua:
32.6° – 39.8° C

Acque saline mioceniche



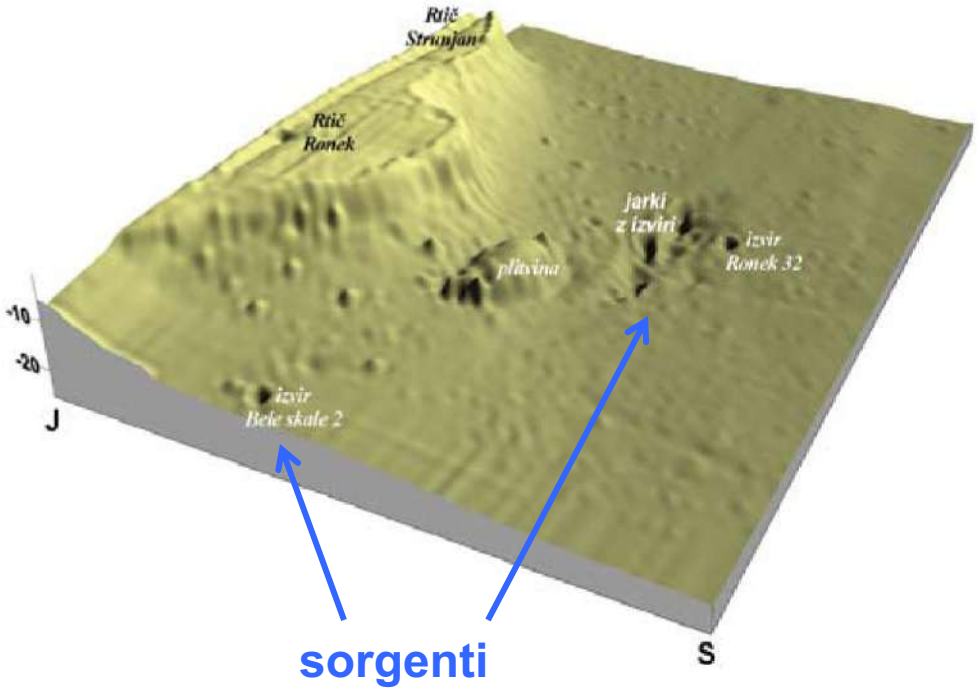
Petrini et al., 2013

Acque termali: *le sorgenti marine di Isola*



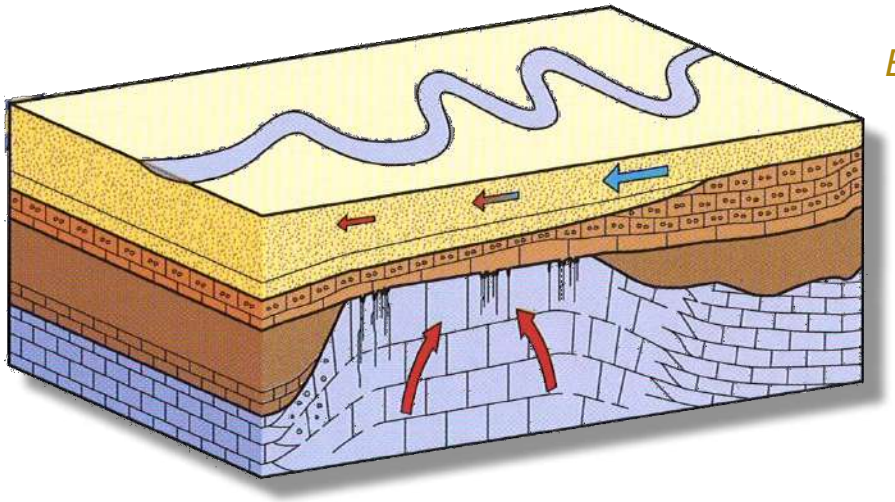
8 sorgenti marine

temperatura acqua 22° -30° C

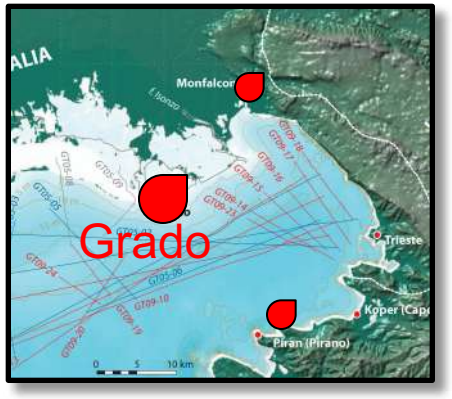


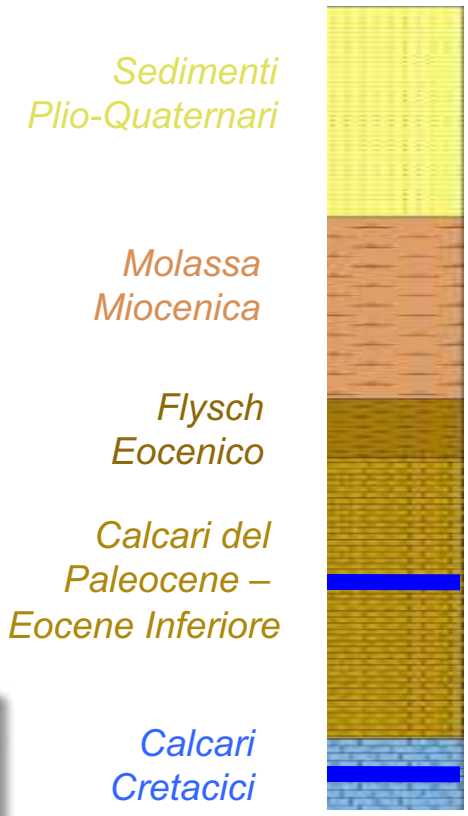
Žumer, 2004

Acque termali: *il pozzo Grado-1*



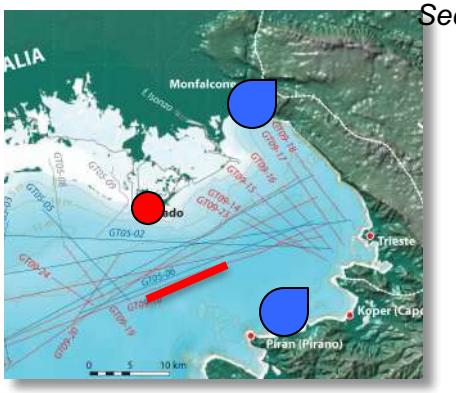
GRADO-1





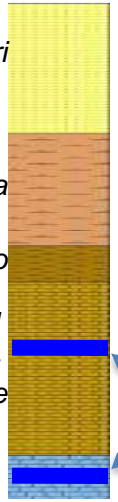
sistemi di fratture con acqua salmastra a 44° C

Della Vedova et al., 2008
Cimolino et al., 2010

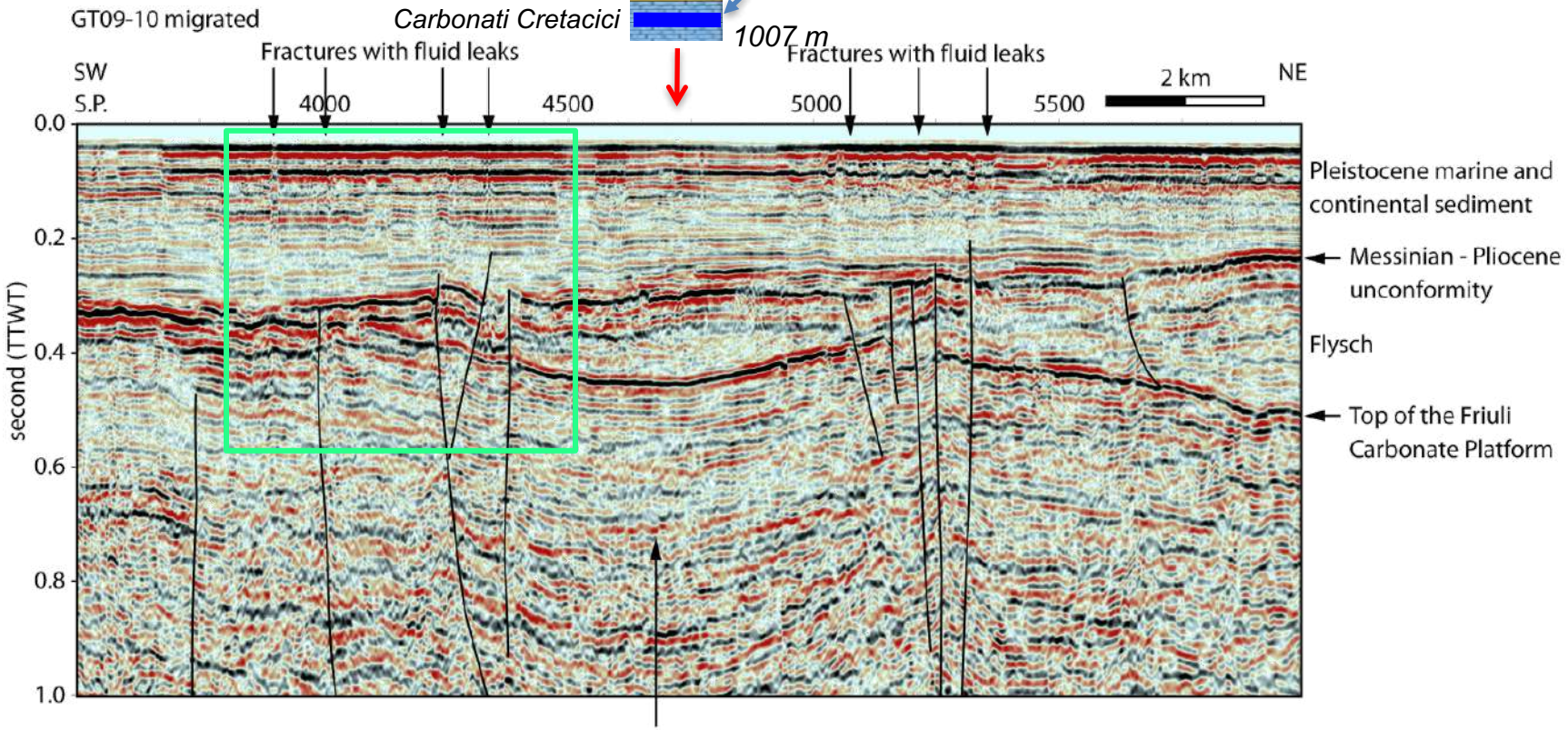


Cimolino et al., 2010

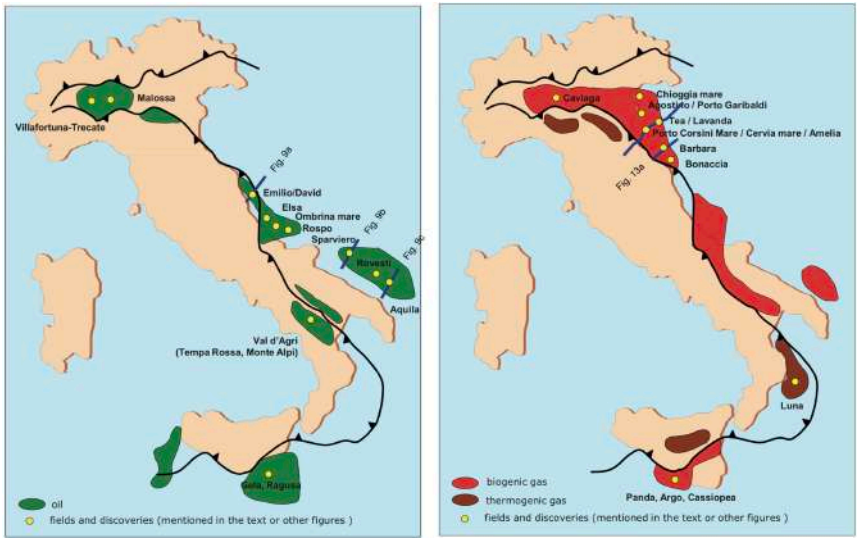
GRADO-1



sistemi di fratture con acqua salmastra a 44° C

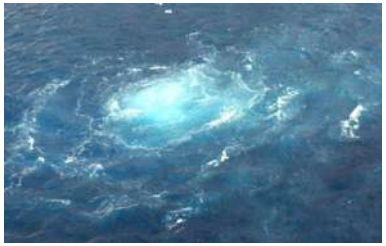


Gas biogenico nei sedimenti Plio-Quaternari



Cazzini et al., 2015

Emissioni di gas nel Golfo di Trieste



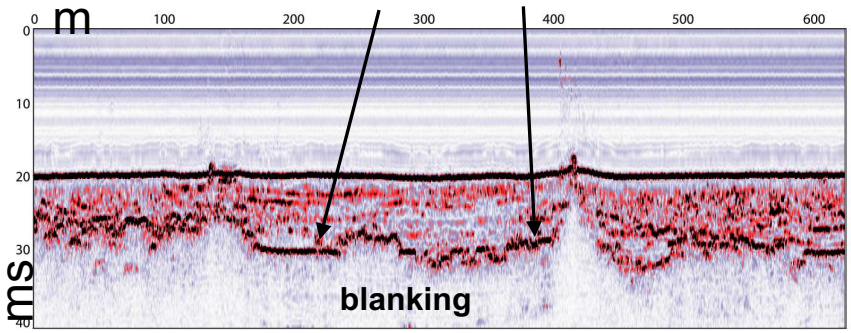
- Note dalle popolazioni locali e denominate *bromboli*
- Documentate da Morgante nel 1947

Dati chirp: imaging della presenza di gas nei sedimenti

***Blanking**:* zone in cui il segnale sismico è pressoché assente.
Causa: forte attenuazione delle alte frequenze contenute nel segnale acustico dovuto **all'assorbimento e allo *scattering* delle bolle di gas presenti nei sedimenti** (Judd e Hovland, 1992).

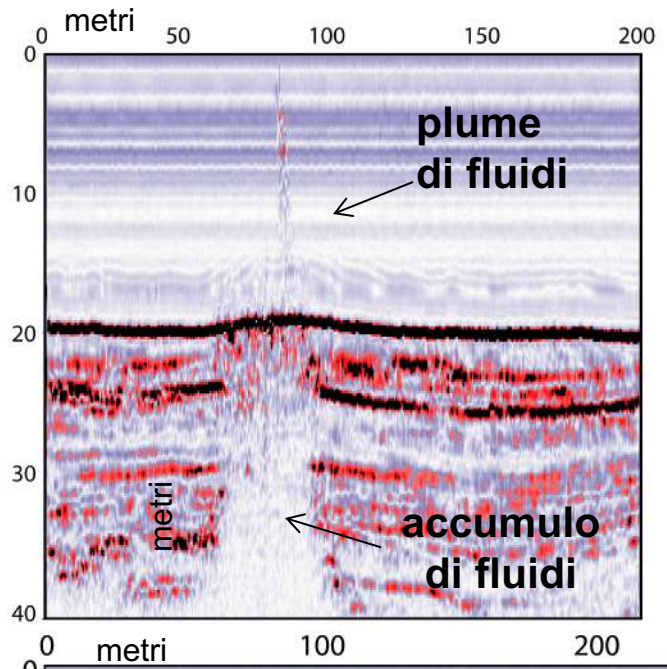
Nei profili chirp il tetto dei settori caratterizzati da *blanking* è marcato da un riflettore ad elevata ampiezza (***enhanced reflections***): la sua discontinuità laterale conferma che non è originato da una discontinuità stratigrafica, ma da una disomogeneità dovuta alla distribuzione dei gas nella porosità dei sedimenti.

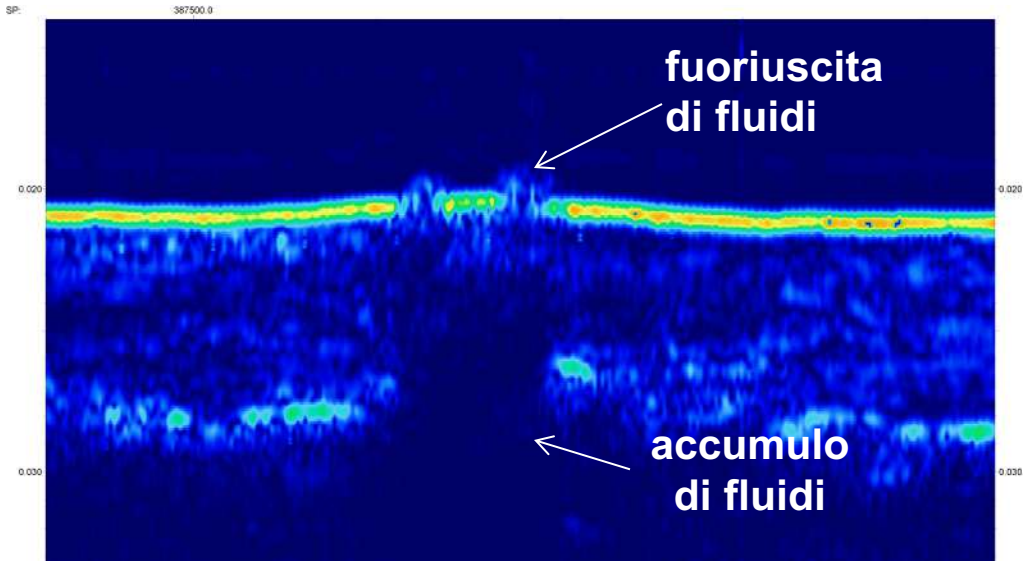
Riflettori ad elevata ampiezza (enhanced reflector)

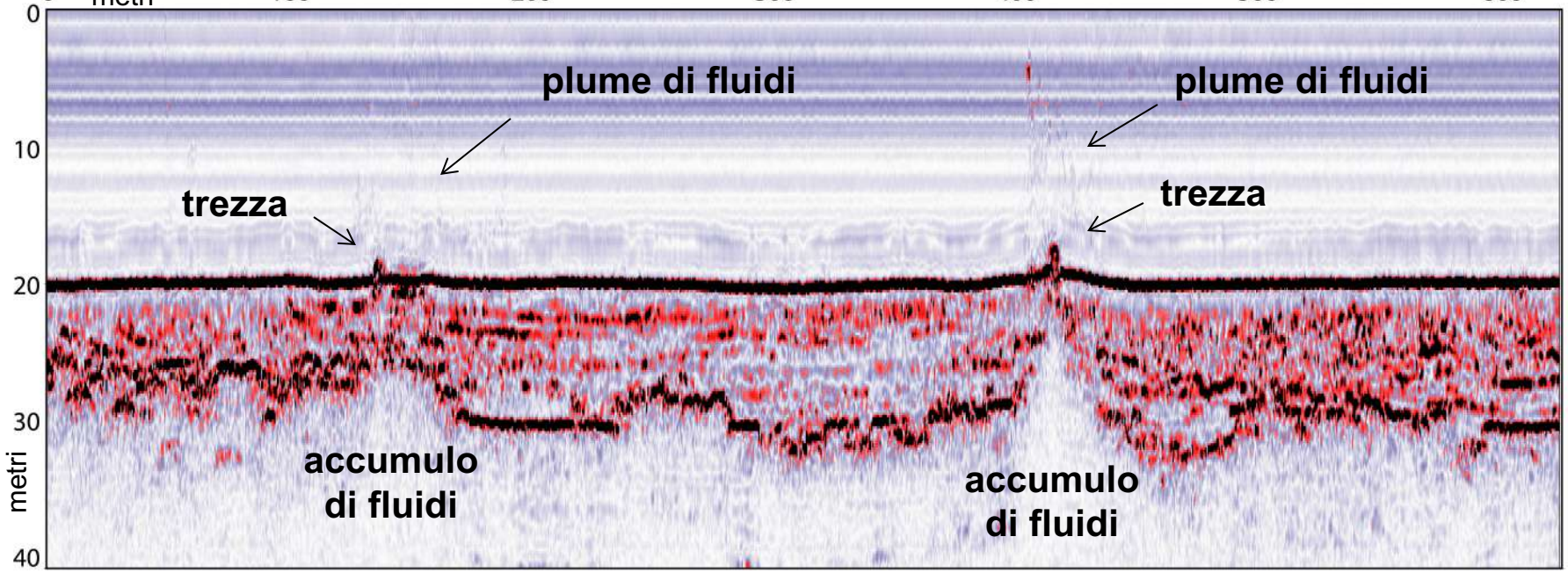


I profili chirp, con frequenze dell'ordine di qualche kHz, evidenziano la presenza di gas nei sedimenti e nella colonna d'acqua.

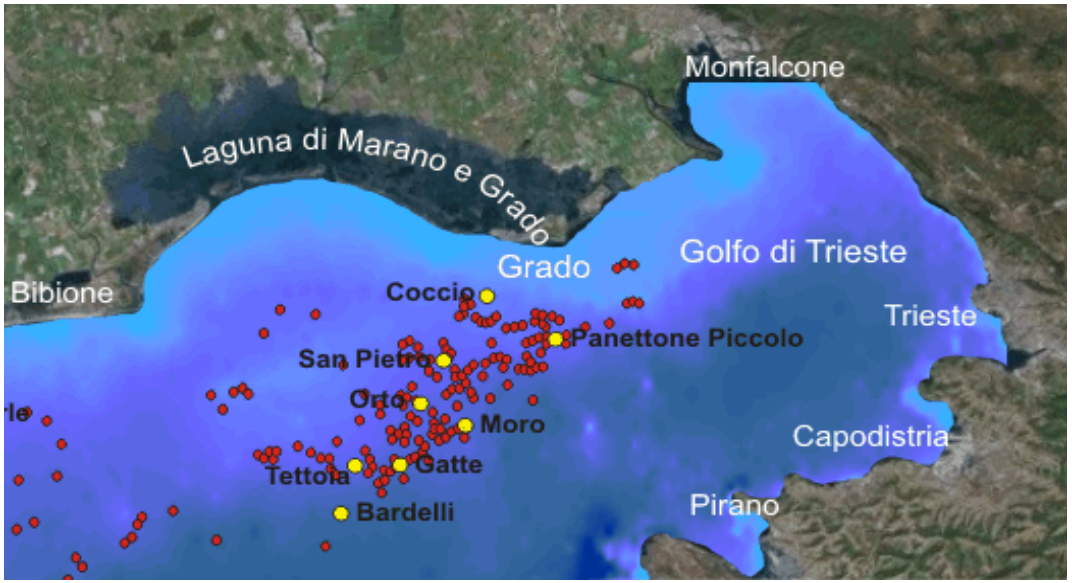
Fuoriuscite di fluidi





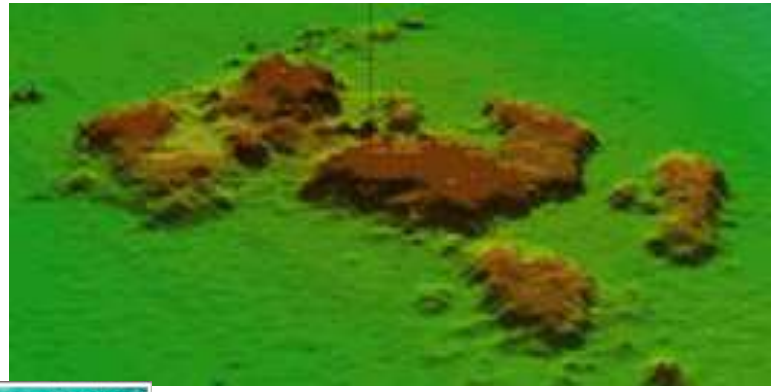


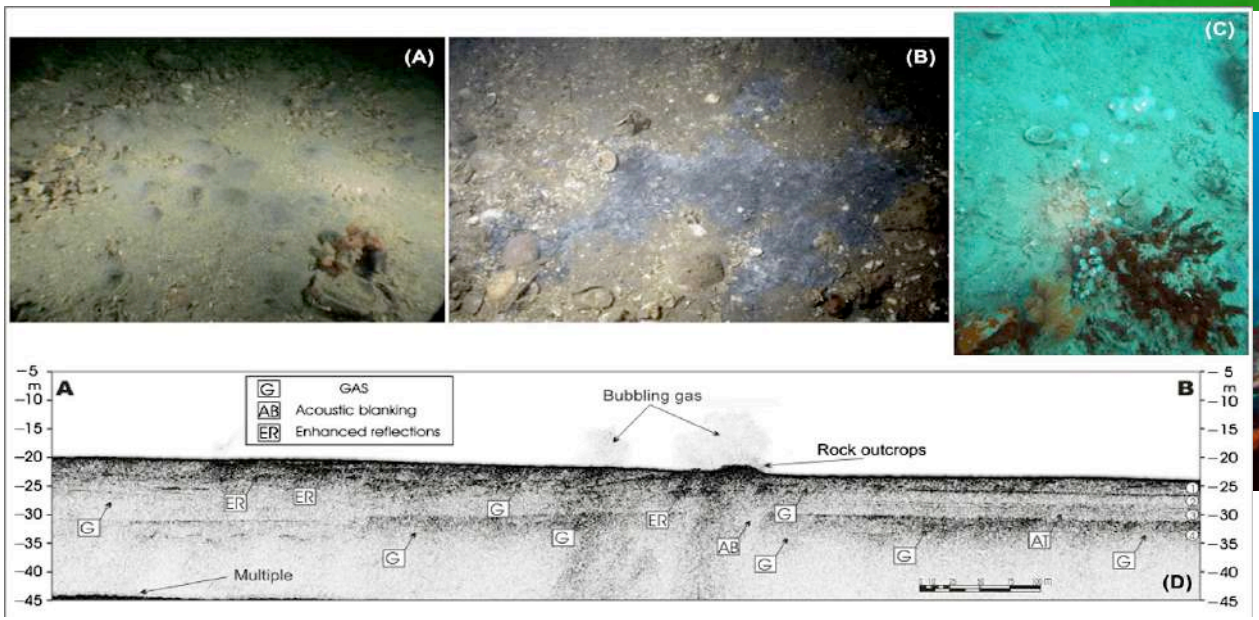
Le trezze



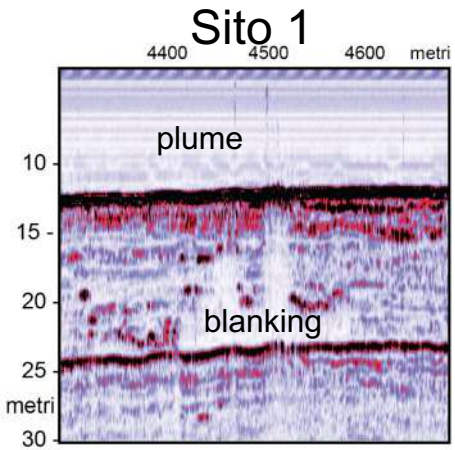
affioramenti carbonatici metano-derivati

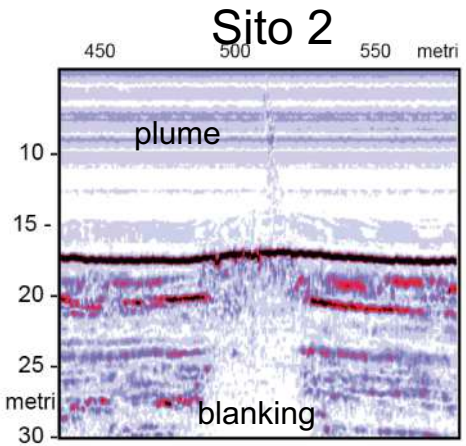
emissioni di fluidi
di cui 80-85 % metano

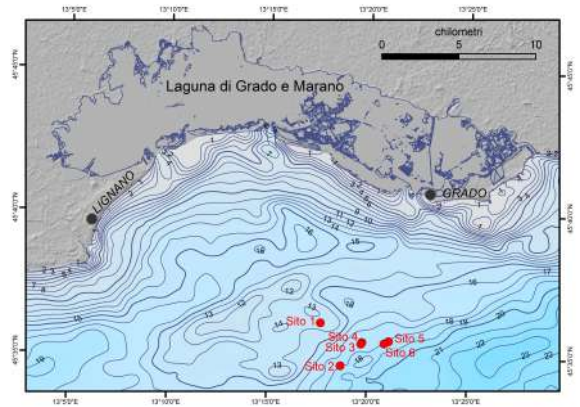


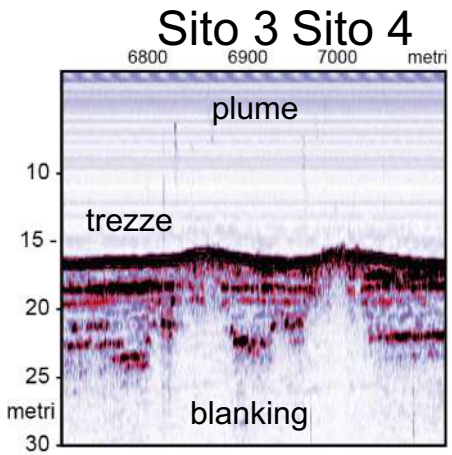


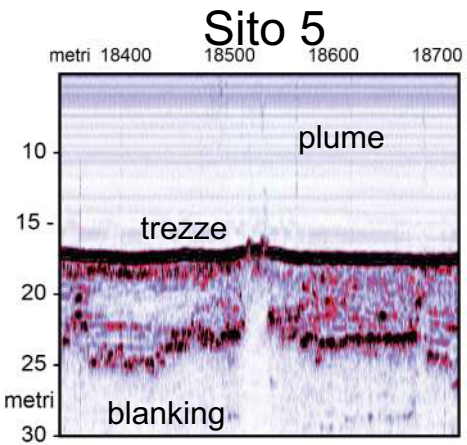
Gordini et al., 2012

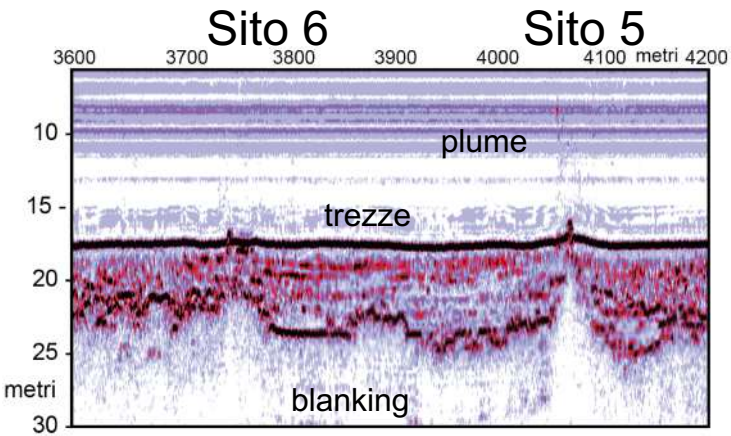




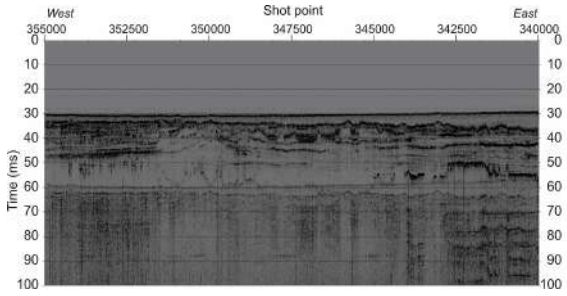




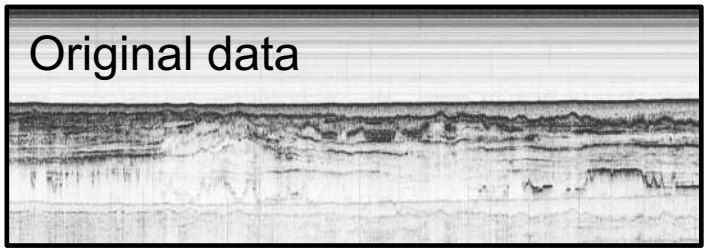


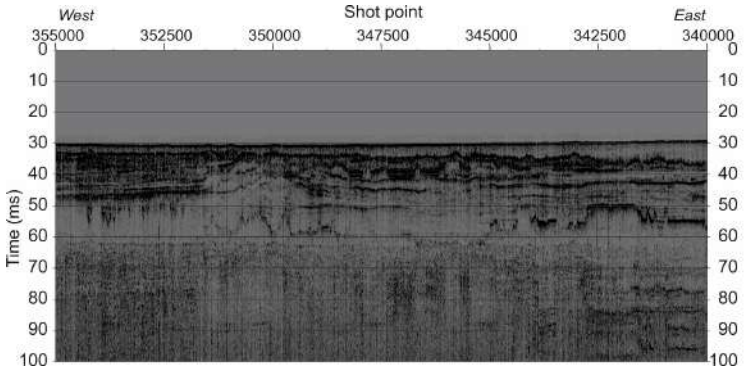


Busetti, Babich e Del Ben, 2020

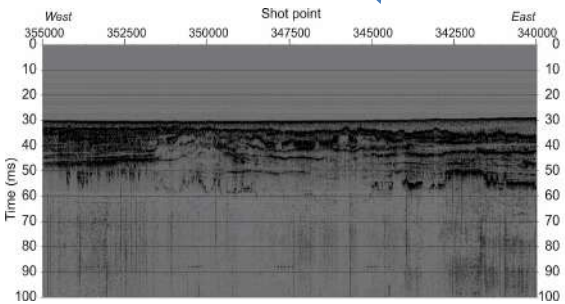


Normalization by a t^2 gain

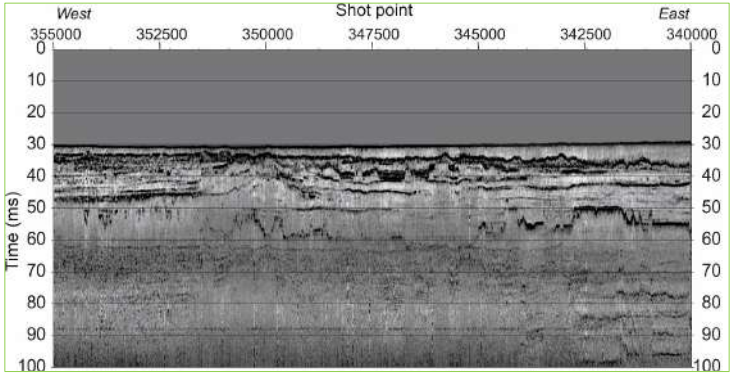




Multiple subtraction

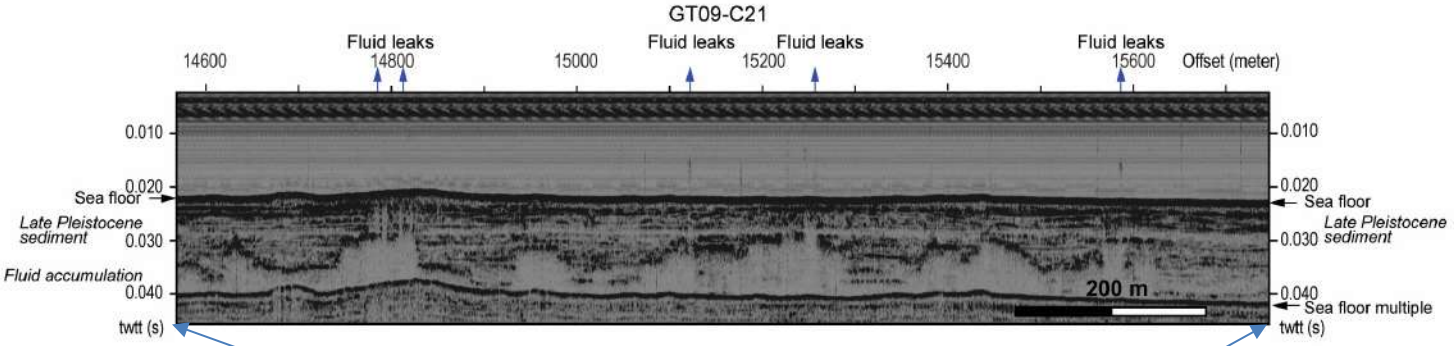


Gapped deconvolution



t^2 gain + gapped deconvolution + FX deconvolution

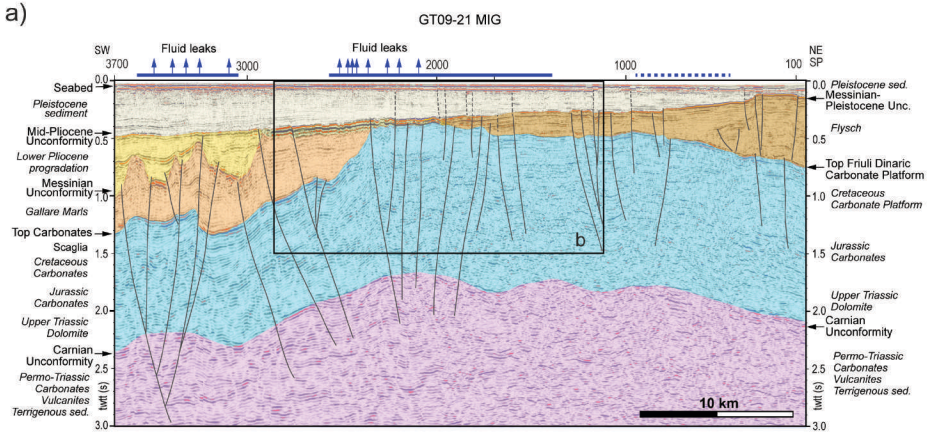
Vesnaver et al., 2021



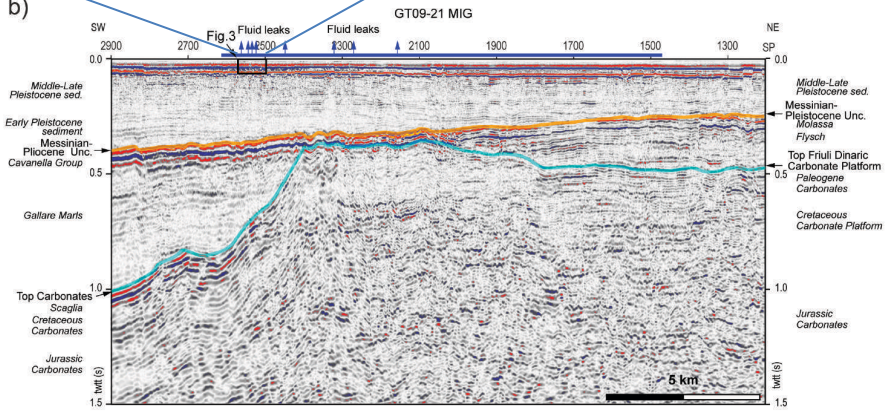
Gas nei sedimenti

Plume di gas nella colonna d'acqua

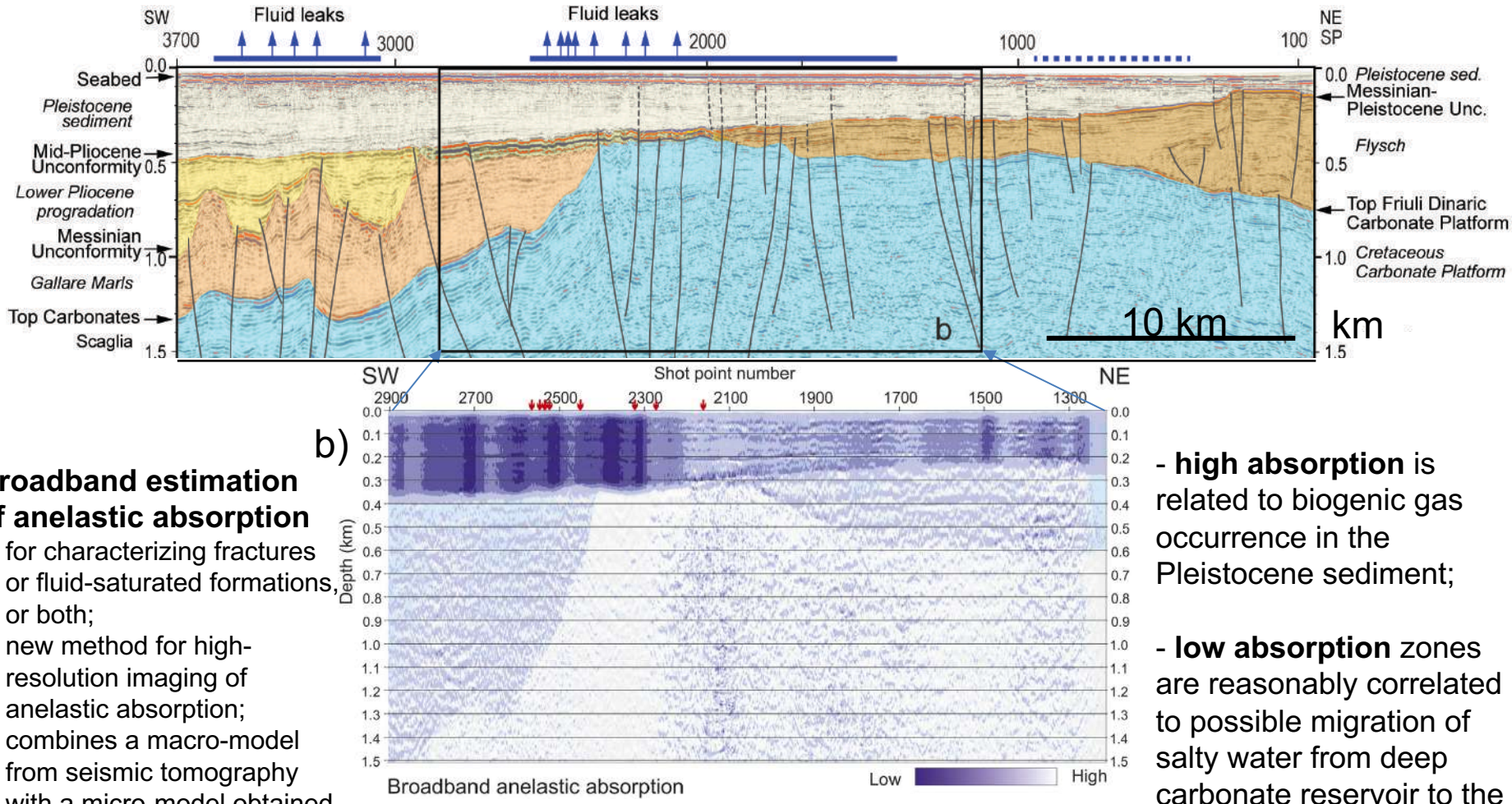
a)



b)



Vesnaver et al., 2021



b)

Broadband estimation of anelastic absorption

- for characterizing fractures or fluid-saturated formations, or both;
- new method for high-resolution imaging of anelastic absorption;
- combines a macro-model from seismic tomography with a micro-model obtained by the pre-stack depth migration of a seismic attribute (i.e., the instantaneous frequency).

- **high absorption** is related to biogenic gas occurrence in the Pleistocene sediment;

- **low absorption** zones are reasonably correlated to possible migration of salty water from deep carbonate reservoir to the Miocene- Pleistocene sediment.

Vesnaver et al., 2020; 2021

References

Bechtold, M., Battaglia M. , Tanner D. C., and Zuliani D. , 2009. Constraints on the active tectonics of the Friuli/NW Slovenia area from CGPS measurements and three-dimensional kinematic modelling. J. Geophys. Res., 114, B03408, doi:10.1029/2008JB005638.

Busetti M., Volpi V., Nicolich R., Barison E., Romeo R., Baradello L., Brancatelli G., Giustiniani M., Marchi M., Zanolla C., Nieto D., Ramella R., and Wardell N., 2010. Dinaric tectonic features in the Gulf of Trieste (Northern Adriatic). Bollettino di Geofisica Teorica e Applicata, 51(2-3), 117-128.

Busetti M., Volpi V., Barison E., Giustiniani M., Marchi M., Ramella R., Wardell N., and Zanolla C., 2010. Cenozoic seismic stratigraphy and tectonic evolution of the Gulf of Trieste (Northern Adriatic). GeoActa, SP, 3(2010), 1-14.

Busetti M., Zgur F., Vrabec M., Facchin L., Pelos C., Romeo R., Sormani L., Slavec P., Tomini I., Visnovich G., Zerial A., 2013. Neotectonic reactivation of Meso-Cenozoic structures in the Gulf of Trieste and its relationship with fluid seepings. Atti del 32° Convegno del Gruppo Nazionale di Geofisica della Terra Solida (GNGTS), Trieste, 19-21 novembre 2013, Tema3: Geofisica Applicata, 29-34.

Busetti M., Zgur F., Romeo R., Sormani L., Pettenati F., 2013. Caratteristiche geologico-strutturali del Golfo di Trieste. In: D'Angelo S. e Fiorentino A. (a cura di), Contributi al Meeting Marino, Roma 25-26 ottobre 2012, Atti Ispra, 65-70.

Busetti M., Babich A., Del Ben A., 2020. Evidenze geofisiche di emissioni di fluidi nel Golfo di Trieste (Nord Adriatico). Mem. Descr. Carta Geolg. d'It., 105, 11-16.

Cati A., Sartorio D. and Venturini S., 1987b: Carbonate Platforms in the Subsurface of the Northern Adriatic Area. Memorie della Società Geologica Italiana, 40, 295-308.

Cazzini F., Dal Zotto O., Fantoni R., Ghielmi M., Ronchi P., Scotti P., 2015. Oil and gas in the Adriatic foreland, Italy. Journal of Pretroleum Geology, 38(3), 255-279, https://doi.org/10.1111/jpg.12610

Cimolino A., Della Vedova B., Nicolich R., Barison E. and Brancatelli G.; 2010. New Evidence of the outer Dinaric deformation front in the Grado area (NE-Italy). Rend. Fis. Acc. Lincei 21-Suppl. 1: S167-S179. DOI 10.1007/s12210-010-0096-y.

Dal Cin M., 2018. 3D velocity depth model in the Gulf of Trieste by means of tomographic analysis from multichannel seismic reflection data. PhD Thesis, PhD course Earth Science and Fluid Mechanics. University of Trieste, OGS and ICTP, Trieste, March 2018, 212 pp. Supervisor A. Camerlenghi, cotutors M. Busetti, G. Böhm, S. Picotti and F. Zgur. http://hdl.handle.net/11368/2922569

Della Vedova B., Castelli E., Cimolino A., Vecellio C., Nicolich R. and Barison E.; 2008. La valutazione e lo sfruttamento delle acque geotermiche per il riscaldamento degli edifici pubblici. Rassegna Tecnica del Friuli Venezia Giulia, 6/2008, 16-19.

Gordini E., Falace A., Kaleb S., Donda F., Marocco R. and Tunis G.; 2012: Methane-Related Carbonate Cementation of Marine Sediments and Related Macroalgal Coralligenous Assemblages in the Northern Adriatic Sea. In: P. T. Harris and E. K. Baker (eds.), Seafloor Geomorphology as Benthic Habitats, Elsevier, 183-198.

Finetti I.R., 1965. Ricerche sismiche marine nel Golfo di Trieste (Profilo sismico a rifrazione "Grado-Miramare"). Bollettino di Geofisica Teorica ed Applicata 7(27), 201-217.

Finetti I.R., 1967. Ricerche sismiche a rifrazione sui rapporti strutturali fra il Carso e il Golfo di Trieste. Bollettino di Geofisica Teorica ed Applicata 9(35), 214-225.

Ghielmi M., Minervini M., Ninic C., Rogledi S., Rossi M., 2013. Late Miocene–Middle Pleistocene sequences in the Po Plain – Northern Adriatic Sea (Italy): The stratigraphic record of modification phases affecting a complex foreland basin. Marine and Petroleum Geology, 42, 50-81. https://doi.org/10.1016/j.marpetgeo.2012.11.007

Jurkovšek B., Toman M., Ogorelec B., Šribar L., Drobne K., Poljak M., Šribar L., 1996. Geological map of the northern part of the Trieste-Komen Plateau. Institut za geologijo, geotehniko in geofiziko, Ljubljana, 1 plate, 143 pp.

Mosetti F. and Morelli C.; 1968: Rilievo sismico continuo nel Golfo di Trieste. Andamento della formazione arenacea (Flysch) sotto il fondo marino nella zona tra Trieste, Monfalcone e Grado. Bollettino della Società Adriatica di Scienze, LVI(1), 42-57.

Nicolich R., Della Vedova B., Giustiniani M. and Fantoni R.; 2004. Carta del sottosuolo della Pianura Friulana (Map of subsurface of the Friuli Plain). Regione Autonoma Friuli Venezia Giulia, Direzione Centrale Ambiente e Lavori Pubblici, Servizio Geologico, 32 pp.

GEO-CGT;2013. Carta geologica del Carso Classico scala 1:50.000 (Progetto GEO-CGT - Carta di sintesi geologica alla scala 1:10.000 –) and "Brevi Note Illustrative della Carta Geologica del Carso Classico Italiano" with the contribution of Cucchi, F., Piano, C., Fanucci, C. F., Pugliese, N., Tunis, G., Zini. Regione Autonoma Friuli Venezia Giulia. Retrieved April 4, 2016, from http://www.regione.fvg.it/rafvg/cms/RAFVG/ambiente-territorio/tutela-ambiente-gestione-risorse-naturali/FOGLIA201/FOGLIA9/

Petrini et al., 2013 Petrini, R., Italiano, F., Ponton, M. et al. Geochemistry and isotope geochemistry of the Monfalcone thermal waters (northern Italy): inference on the deep geothermal reservoir. Hydrogeol J 21, 1275–1287 (2013). https://doi.org/10.1007/s10040-013-1007-y

Tentor M., Tunis G., and Venturini S., 1994. Schema stratigrafico e tettonico del Carso Isontino. Natura Nascosta, 9, 1-32.

Trobec A., Busetti M., Zgur F., Baradello L., Babich A., Cova A., Gordini E., Romeo R., Tomini I., Poglajen S., Diviacco P., and Vrabec M., 2018. Thickness of marine Holocene sediment in the Gulf of Trieste (Northern Adriatic Sea). Earth Science Data System 10, 1077-1092, https://doi.org/10.5194/essd-10-1077-2018

Vesnaver A., Busetti M., e Baradello L., 2021. Chirp data processing for fluid detection at the Gulf of Trieste (northern Adriatic Sea). Bollettino di Geofisica Teorica e Applicata, 62(3), 365-386.

Vesnaver A., Böhm G., Busetti M., Dal Cin M. and Zgur F., 2021. Broadband Q-Factor Imaging for Geofluid Detection in the Gulf of Trieste (Northern Adriatic Sea). Front. Earth Sci. 9:640194. doi: 10.3389/feart.2021.640194

Vlahović I., Tišljar J., Velić I. and Matičec D.; 2005. Evolution of the Adriatic Carbonate Platform: Paleogeography, main events and depositional dynamics. Paleogeography, Paleoclimatology, Paleoecology, 220, 333-360.

Žumer J., 2004. Odkritje podmorskih termalnih izvirov. Geografski Obzornik, 51(2), 11-17.