Forme e processi del livello del mare

A cura di S. Furlani

Argomenti

- Il livello medio del mare
- Cause delle variazioni relative del livello del mare
- Misure delle variazioni relative del livello del mare
- Forme collegate alle variazioni relative del livello del mare

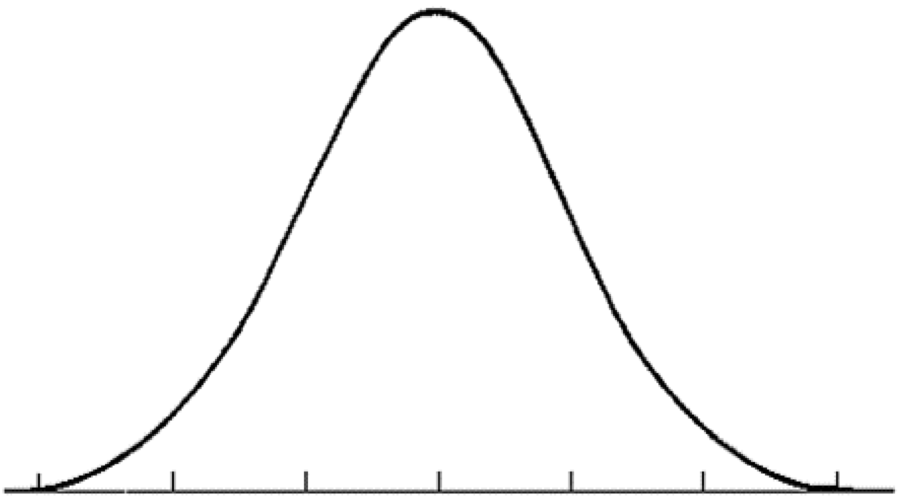
Sea level in the past

- Pitea di Massalia, nel III secolo a.C., osservò che in Britannia la marea varia di 80 cubiti (Plinio).
- Si pensava si trattasse degli effetti di una tempesta.
- Pitea fu il primo ad associare le maree all’azione delle fasi lunari.

Il livello del mare cambia?

- Il livello del mare era considerato stabile fino a buona parte del 19° secolo;

- Si pensava che un unico evento abbia modificato il livello del mare a scala globale: il Diluvio Universale, ma poi il livello tornò alle quote precedenti



ANSA

Ambiente&Energia

NEWS | SPECIALI ED EVENTI | DOSSIER | GALLERIA FOTOGRAFICA | VIDEO

Istituzioni e UE | Clima | Natura | Rifiuti & Inquinamento | Rinnovabili | Tradizionali | Nucleare | Mobilità | Consumo & Risparmio | Acqua | Expo 2015

Clima: innalzamento mari, 177 mln persone a rischio

Entro fine secolo con attuali livelli CO2, Italia al 20/mo posto

25 settembre, 18:13

SPECIALI ED EVENTI

Perugia protagonista a Ecomondo, Fiera della Green Economy

Capoluogo umbro presente con Comune e Gesenu

Rifiuti: a Ecomondo Waste trasforma il riciclo in arte

Stand con decine di animali in legno recuperato

water

MDPI

Article

Relat
Risk
Medi

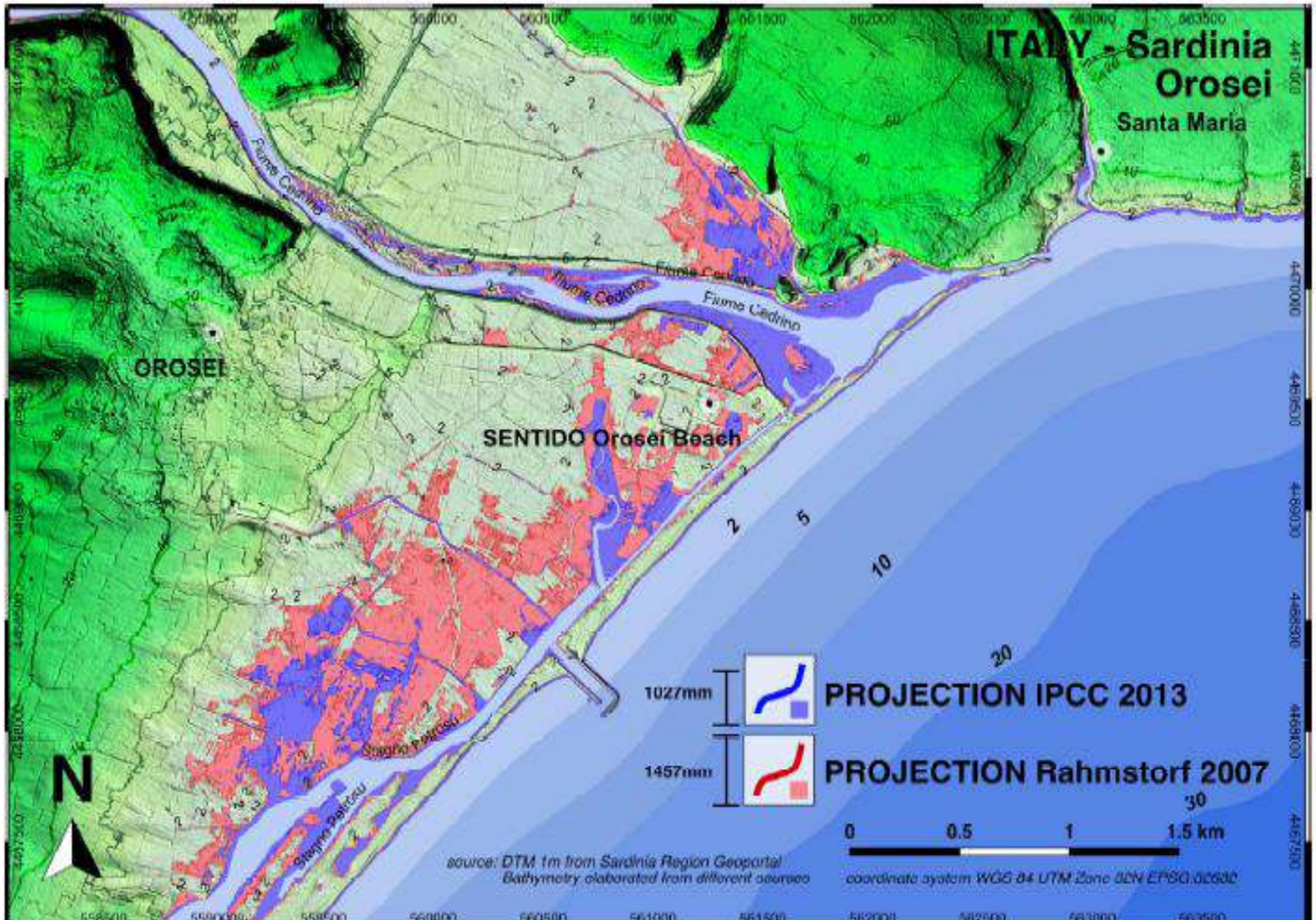


Figure 3. Map 3 Orosei (Sardinia Italy, see also Figure 1 for location). The potential submersion area, using Rahmstorf 2007 projections are 3.1 km^2.

Fabrizio
Giovanni ni [9],
Stefano F
Giovanni

Il livello del mare e le sue variazioni

Cos'è il livello medio del mare? È cambiato?

Cos’è il livello medio del mare

- **Indica la quota assoluta, cioè sulla superficie del geoide, approssimata con la superficie libera media degli oceani, pensata prolungata al di sotto delle terre emerse**

- Il **livello del mare relativo** (*relative sea level*, RSL) è una misura del livello del mare effettuata rispetto al fondale oceanico o rispetto a un punto di riferimento a terra.

- Il **livello del mare assoluto** (o altezza della superficie marina, *sea surface height*, SSH) è riferito al centro di massa della Terra.

- Il livello del mare, sia relativo che assoluto, subisce delle variazioni, sia sul breve che sul lungo periodo, che possono essere dovute a processi di tipo diverso.

Come misurarlo?

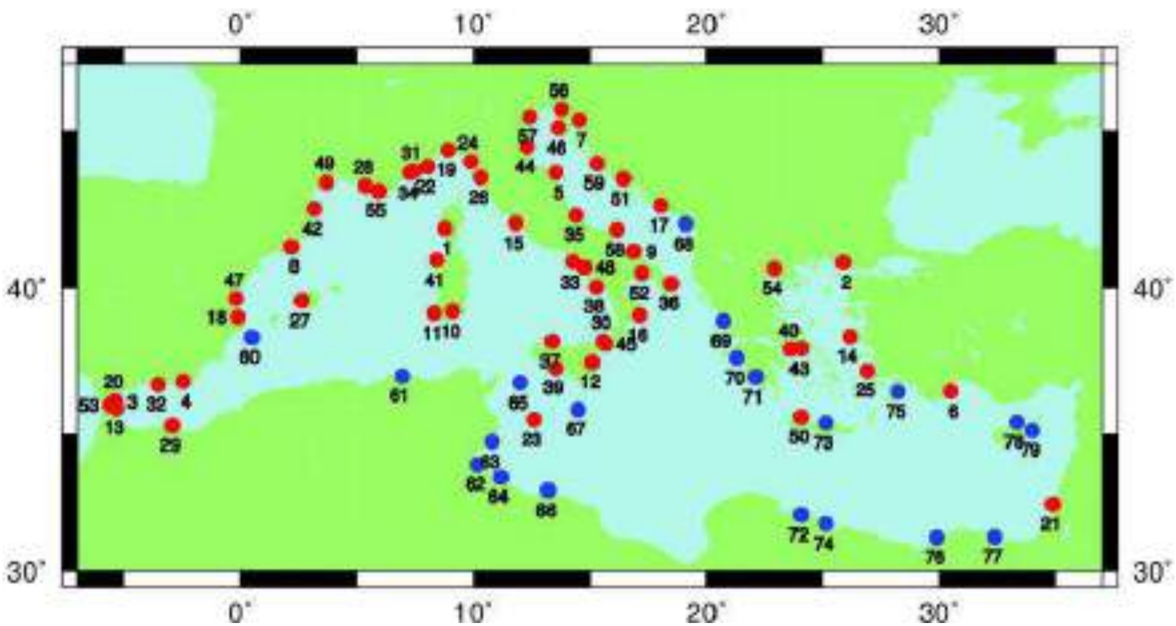
- Se osserviamo l'orizzonte, il livello del mare sembra abbastanza fisso, perché le maree sono generalmente trascurabili, anche se le variazioni possono essere molto ampie

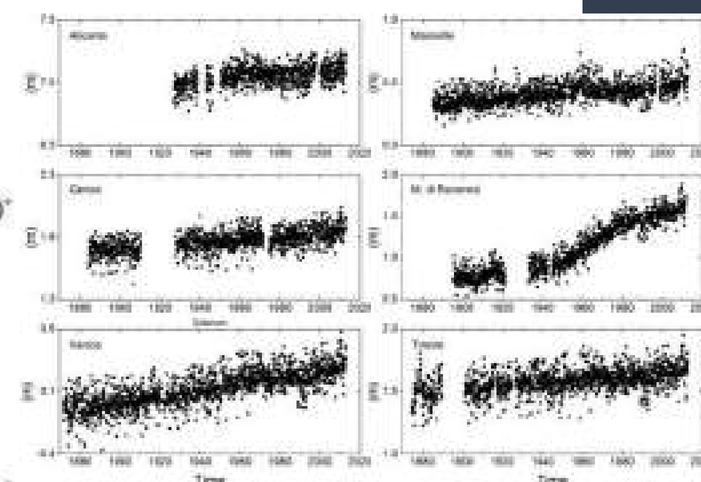
- Se misuriamo il livello del mare con i mareografi per lunghi periodi, possiamo trovare una posizione media, che nel tempo però può essere inficiata dai movimenti verticali della terraferma (es. Venezia si trova in una zona di subsidenza)

- Un secolo fa, un progetto ingegneristico ha dimostrato quanto difficile sia interpretare le differenze locali per stimare un valore medio nel tempo (es. ai bordi del canale di Panama, le differenze di marea sono enormi (6 m nel Pacifico e 1 m nell'Atlantico). Inoltre i valori medi sono diversi (20 cm + alto nel Pacifico)

Come misurare le variazioni?

- La topografia storica si è imbattuta in questo problema: come riferirsi al livello del mare?...ovvero la definzione del Datum (es. in Italia Genova 1942; nel Regno Unito, St. John's Church, Liverpool 1840, poi Victoria dock, poi Newlyn)
- Per le isole più lontane si usano spesso datum locali
- Problemi scomparsi con la tecnologia satellitare





Mappatura della superficie geoidica dei mari

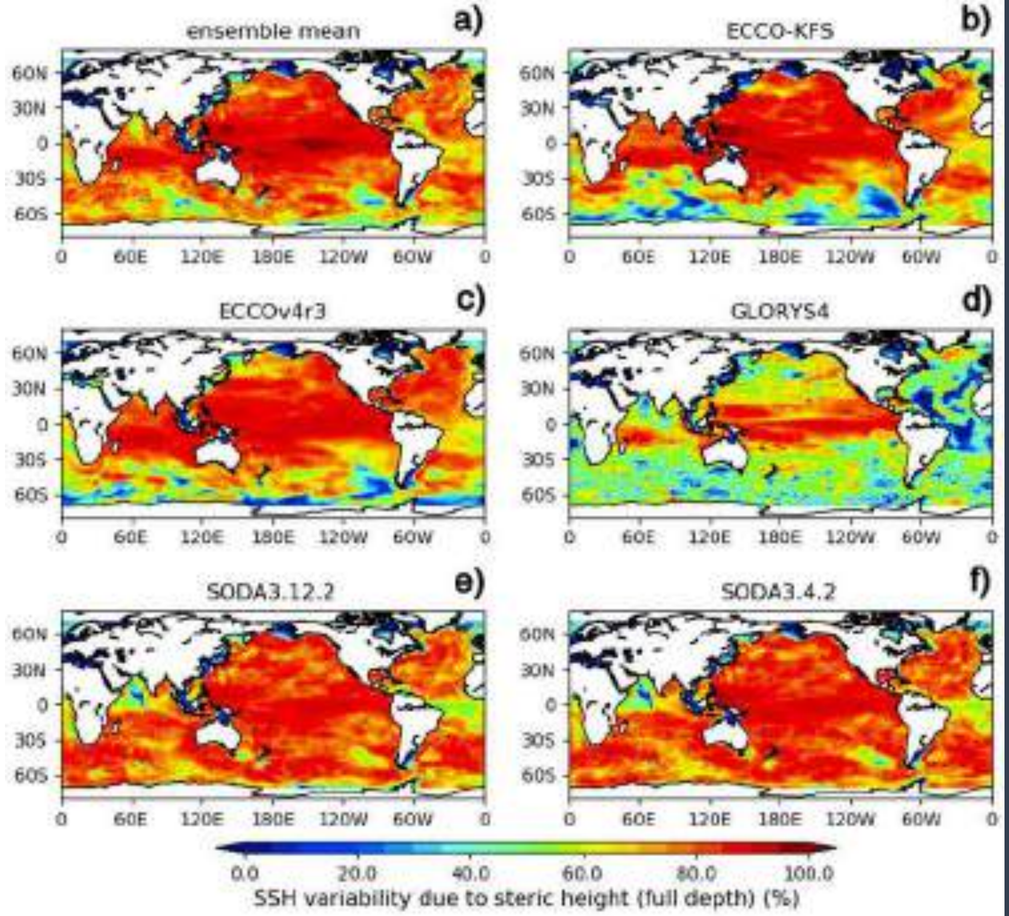
- I satelliti hanno dimostrato che la superficie della Terra non è piatta, ma ondulata (geoide) a causa della gravità
- Supponendo di poter rimuovere le maree, le correnti, le onde, rimarrebbe una superficie ondulata a seconda dei valori di gravità locali (differenze da +60 m nell'Atlantico settentrionale a -110 m nell'Oceano Indiano)
- Dal 1992 al 2006 il satellite TOPEX/Poseidon ha ruotato lungo 62000 orbite terrestri per raccogliere dati per mappare la topografia oceanica (altimetria radar), poi Seasta (ris. 3,3 cm), Jason-1, -2, -3 (2016)
- Due programmi (GRACE –satellite e GLOSS – mareografi, GOCE)
- Molto utile l'interferometria satellitare, con due o più immagini radar dallo stesso punto

Variazioni steriche

- Il livello eustatico del mare non è dovuto esclusivamente dalle variazioni nel volume dei ghiacci, ma anche dalle variazioni di temperatura e salinità degli oceani (variazioni di densità)

- Queste variazioni sono dette **variazioni steriche**, in quanto implicano variazioni nel volume e non nella massa

- I satelliti radar altimetrici ci forniscono dati che stimano la somma delle variazioni steriche e di massa, mentre GRACE fornisce informazioni delle variazioni di massa



Misurare le variazioni a lungo termine

- Il volume totale dell'acqua di mare è di circa 1322 x 10^6 km^3 su un'area di 361,9 x 10^6 km^2
- Per sollevare il livello del mare di 1 mm servono quindi 362 gigatonnellate di acqua. Attualmente dalla Groenlandia si ha una perdita netta di ghiacci di circa 285 Gt/anno.
- Attualmente l'Antartide contiene un corrispettivo di 73 m di acqua (se si sciogliesse tutto)
- I ghiacci continentali darebbero un totale di 3,9 m
- 228 m in totale durante LGM, considerando che la differenza di quota nell'LGM è stata al massimo di circa 145 m (livello minimo raggiunto durante l'LGM)

Cause delle variazioni del livello marino

Cause di cambiamento del l.m.m.

- Le variazioni del livello del mare sono considerate relative a causa della somma della componente eustatica, isostatica e tettonica

- L'altezza media di un punto sul livello del mare (msl) è dato dalla somma di:
  - Componente eustatica (globale)
  - Componente tettonica (locale)
  - Componente isostatica (locale)

$$\Delta\zeta_{obs} = \Delta\zeta_e + (\Delta\zeta_i + \Delta\zeta_w) + \Delta\zeta_{tect}$$

Global Glacial Coverage During the LGM

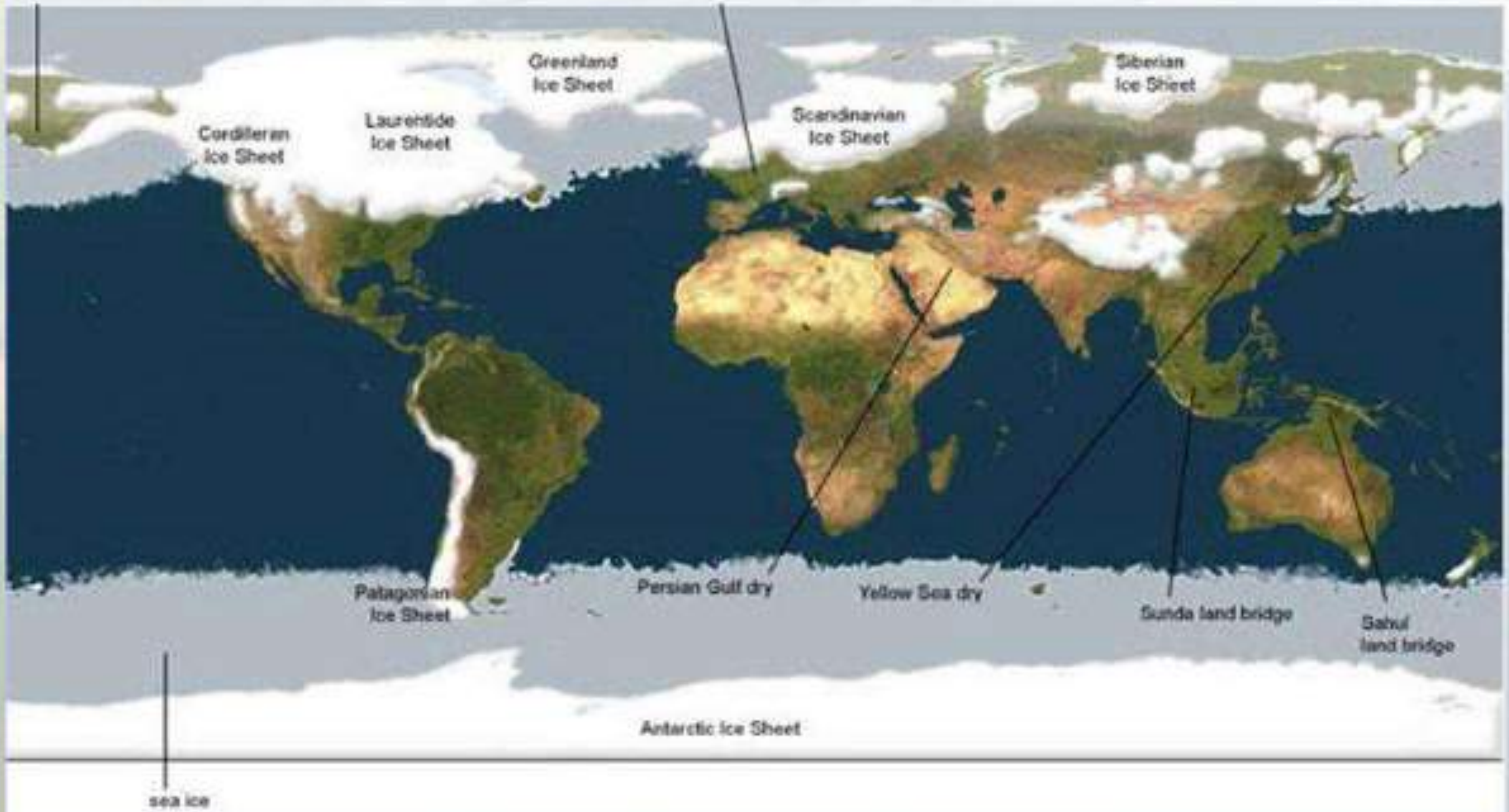
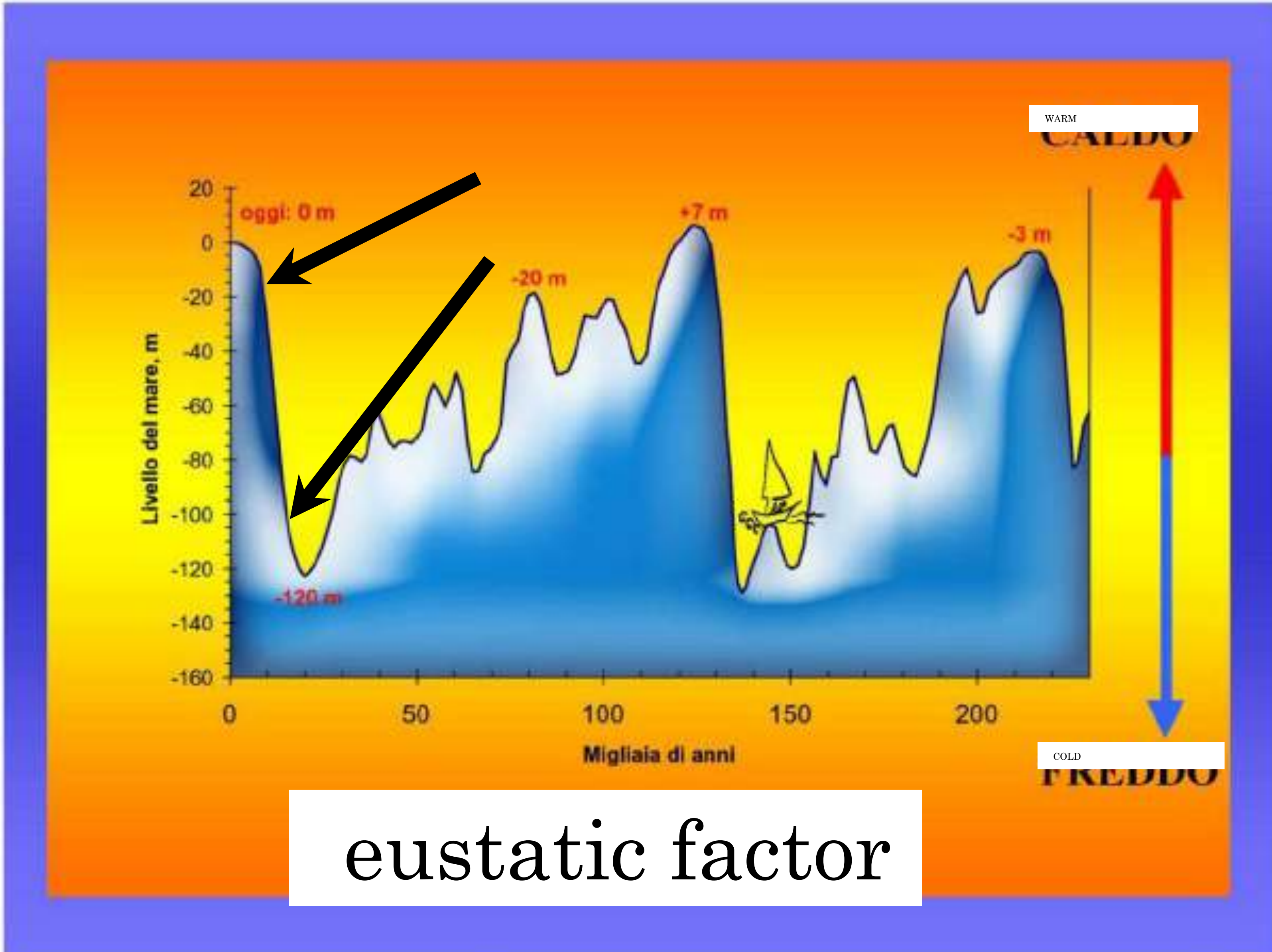


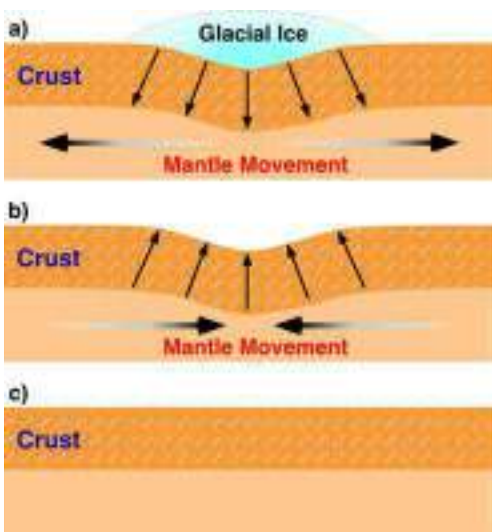
Image Source: http://www.humberriver.ca/globalice.html

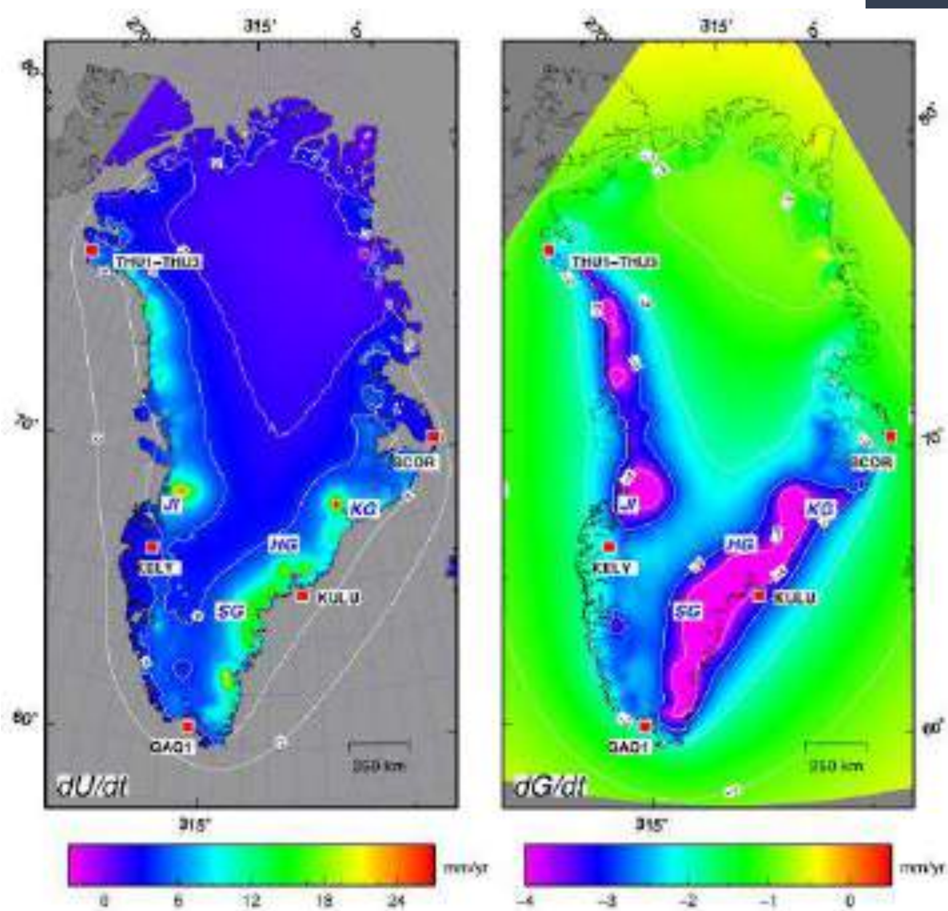

WARM
oggi: 0 m
+7 m
-20 m
-3 m
-120 m
20
0
-20
-40
-60
-80
-100
-120
-140
-160
Livello del mare, m
0
50
100
150
200
Migliaia di anni
COLD
eustatic factor

Glacio-isostasy adjustment (GIA)

- The increase in ice volume produces a subsidence process under the glacier

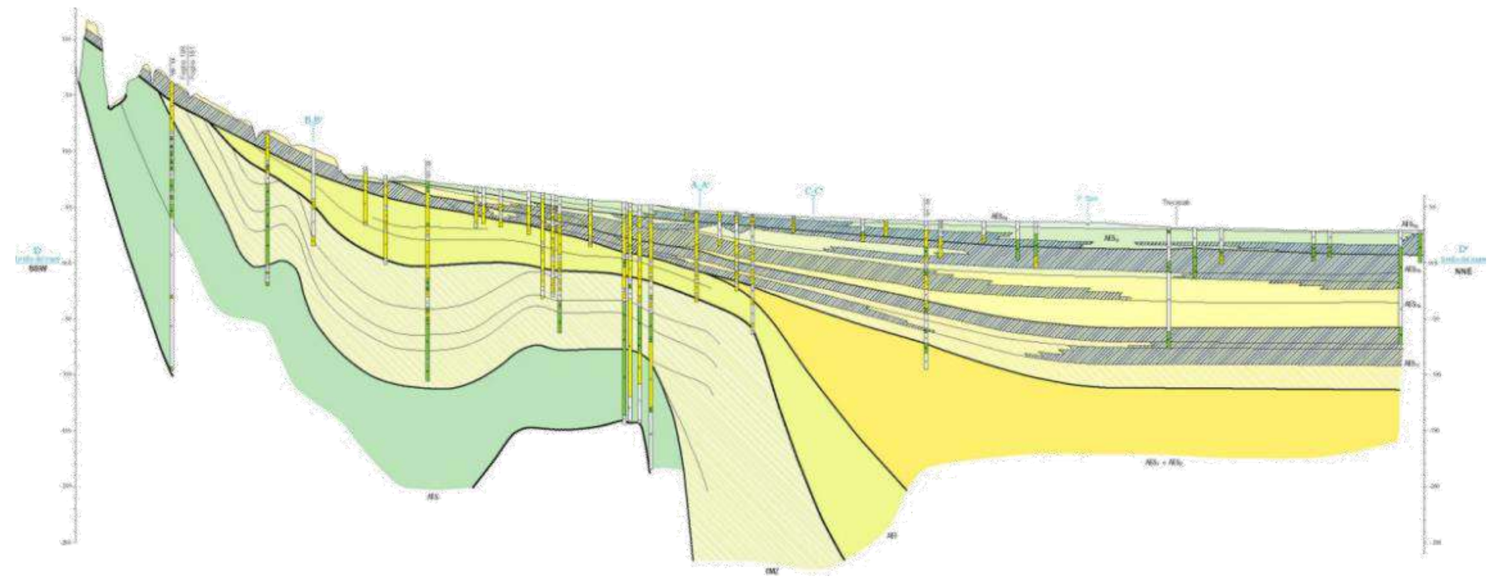
- During deglaciation, the crust uplifts up to 50/100 mm/year





Sediment isostasy (*sediment-isostasy*)

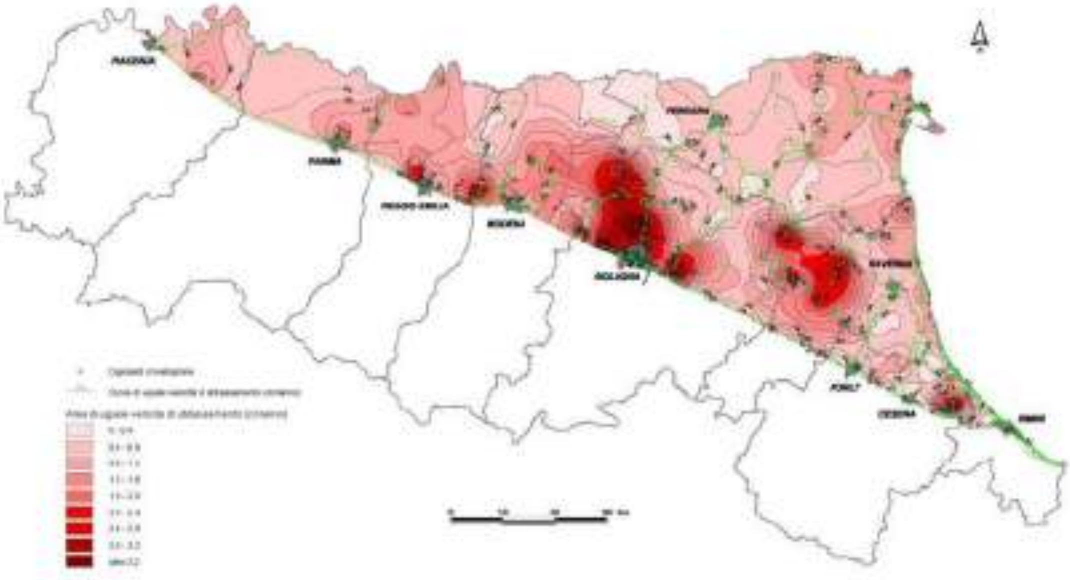
- Along the coasts, deltas can produce subsidence rates up to some millimetres/years;
- They can increase because of water, gas, or oil pumping.



Induced subsidence

- This type of subsidence is induced by human artifacts

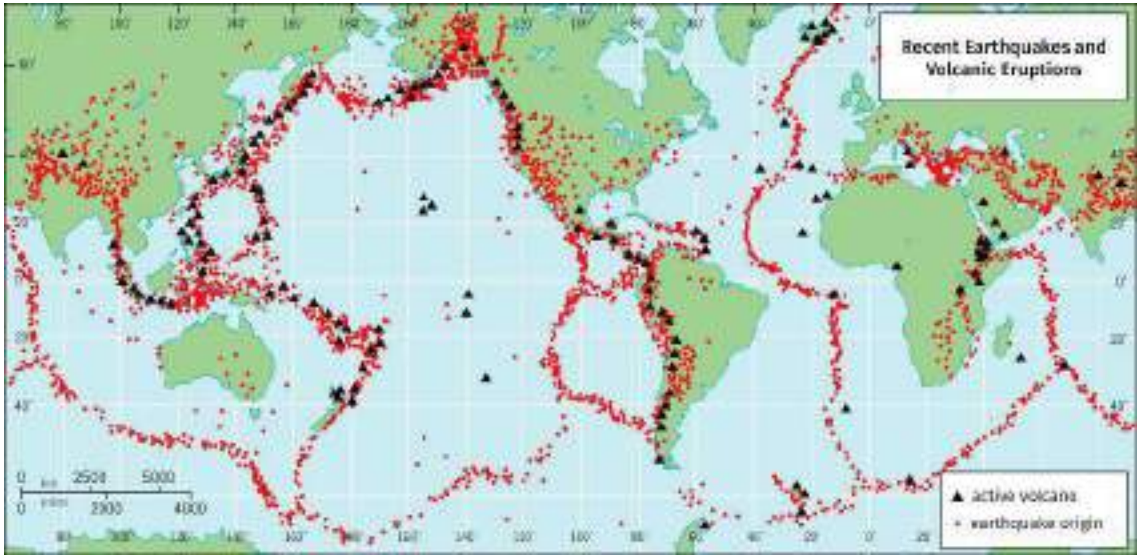
- In Tokyo, induced subsidence is up to 4.6 m, at the Po delta 2.7 m, as in Houston (Texas, Mississipi).



Tectonic factors

- Vertical movements of the ground can induce changes in the relative sea level. They can be long-lasting or continous and rapid;
- Continous and slow movements are called aseismic
- Rapid movements related to earthquakes are called co-seismic
- These movements produce several kind of geomorphological, sedimentological and arhcaeological markers of slc at different elevations on the present-day mean sea level.

Plate tectonics



http://the-dialogue.com/en/en66-how-plate-tectonics-is-connected-with-life-on-the-planet/

Steric variations

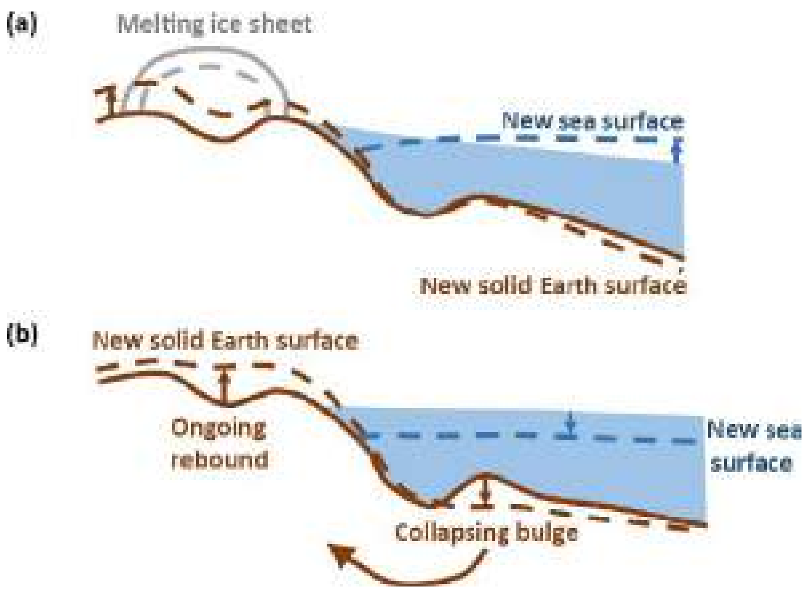
- Sea level can change because of the variations in density related to sea water density that depend from salinity, temperature and pressure.

- Density lower with temperature increasing and increases with incresing in salinity and pressure.

- Dense waters occupy a lower volume and the mean sea level lower, on the contrary, low dense waters cause an increase in sea level.

Hydro-isostasy

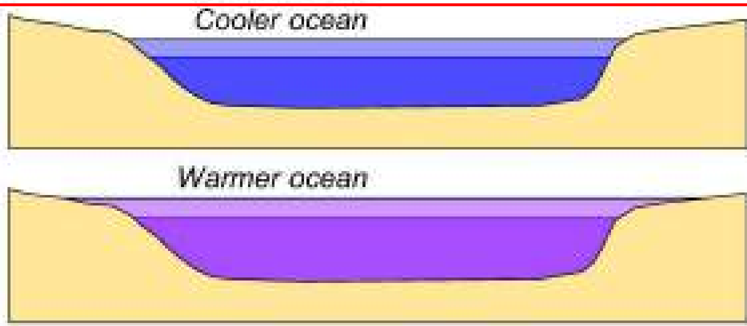
- During deglaciation, sea water from glaciers produces a load increase on sea-bottoms, so that the sea-bottom can lower
- It depends from the topographical features of the basin and increases off-shore;
- Hydro-isostasy can be very important on small islands in deep basins



Possible causes of sea-level change

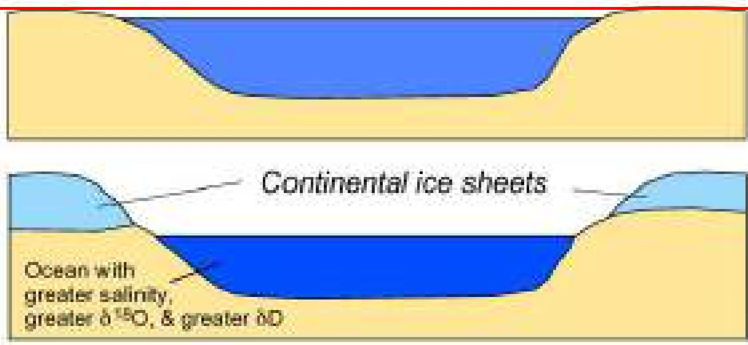
Sea level is known to have changed at geologic time scales. This page uses very schematic cartoons to present four possible causes, with emphasis on their different vertical and temporal scales.

1. **Warming** of ocean's water and thermal expansion



This causes SL change of **centimeters to meters.** Warming of water above the thermocline could be effected in a matter of years by mixing by waves and currents; warming of water below the thermocline requires circulation through the deep oceans and thus takes thousands of years.

2. Storage of ocean's water as ice in **ice sheets**



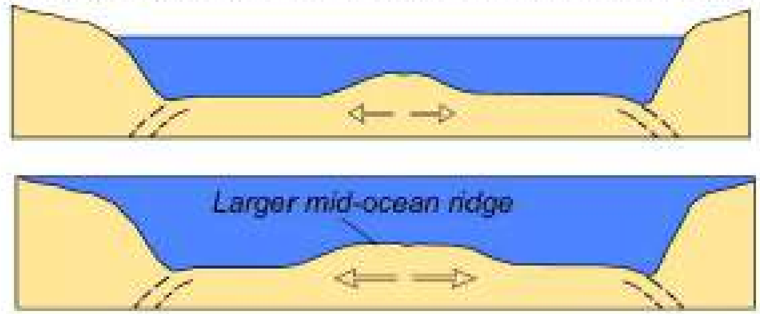
This causes SL change of **tens of meters to 200 meters.** Growth of ice sheets typically takes tens of thousands of years to lower sea level, whereas melt-out and sea-level rise can occur over thousands of years. Note that only this mechanism changes the *amount* of H_2O in the oceans.

Volume of water in the oceans changes

Volume of the ocean basins changes

3. Changes in rate of **sea-floor spreading**

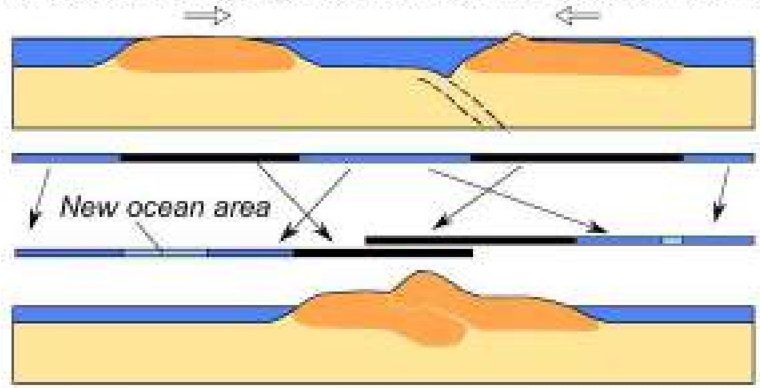
(More young, and thus hot, and thus expanded oceanic crust at MORs occupies more of the volume of the ocean basins)



This causes SL change of **hundreds of meters.** Correlation of lowering of sea level over the past tens of millions of years with slowing of seafloor spreading makes this model attractive.

4. **Continent-continent collision**

(Stacking of continental crust causes reduction of area of continents, leaving a greater oceanic area and thus volume)

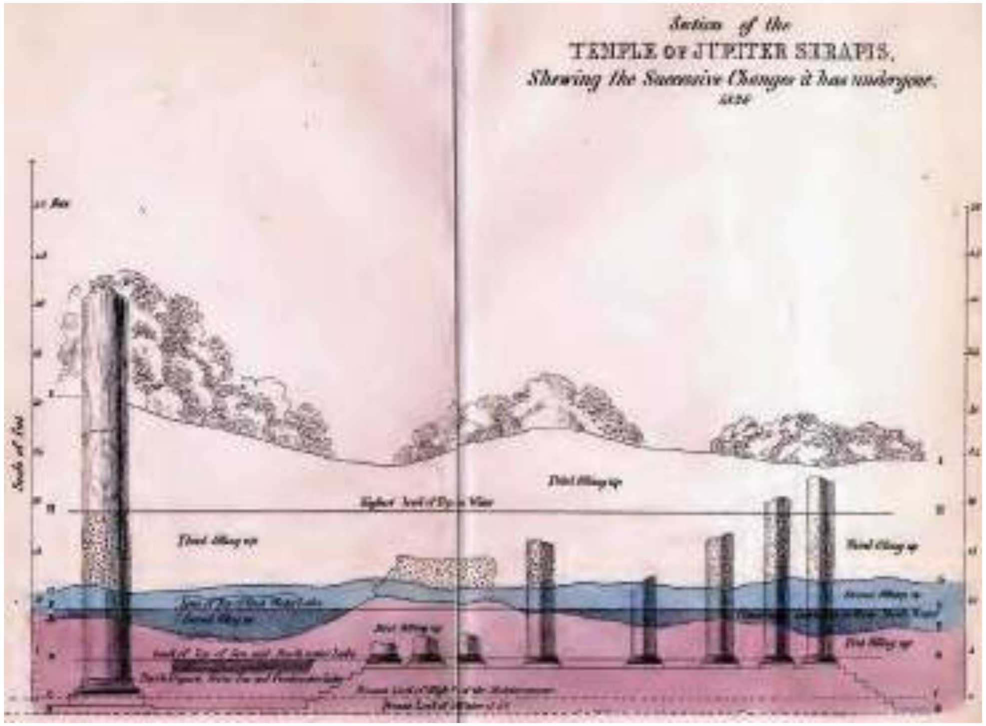


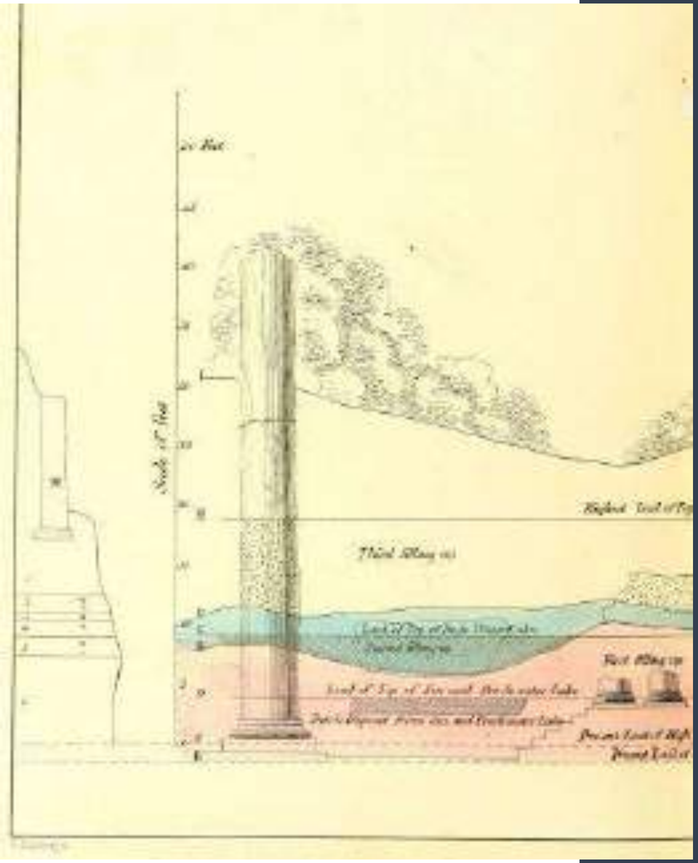
This causes SL change of **hundreds of meters.** Correlation of lowering of sea level over the past tens of millions of years with Himalayan collision, and correlation of lower Late Paleozoic sea level with the assembly of Pangaea, make this an attractive model. In addition, it is possible that continent-continent collision could lessen the global rate of sea-floor spreading, so that Causes 3 and 4 could coincide.

Indicatori collegati alle variazioni del livello marino

Evidenze di livelli marini del passato

- I primi studi sulle evidenze delle variazioni del livello del mare iniziarono nelle zone dove sono più accentuate: es. il tempio di Serapide a Pozzuoli ed il fenomeno dei bradisismi



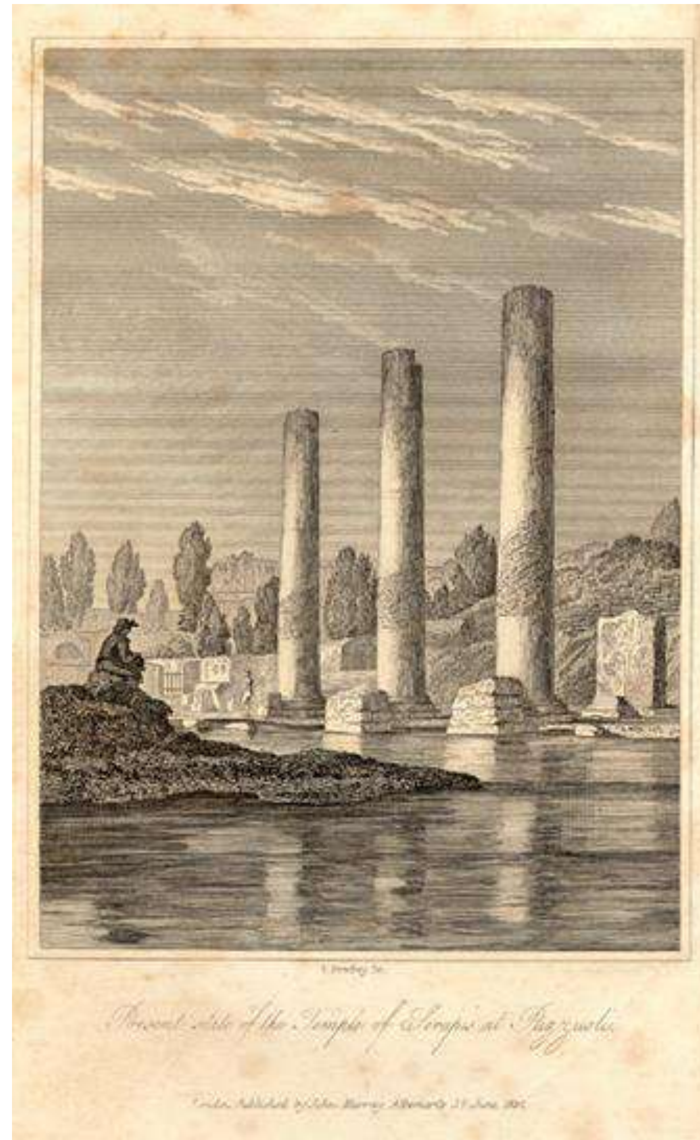


The sea level in the 19° century

- In 19° century the scientific debate regards the age of the Earth, and the first mobilist theories took hold;

- In 1830 Lyell devoted the cover of «*Principles of Geology*» to the Serapis temple

- He recognized that sea level was different in the historical times



Tipi di indicatori

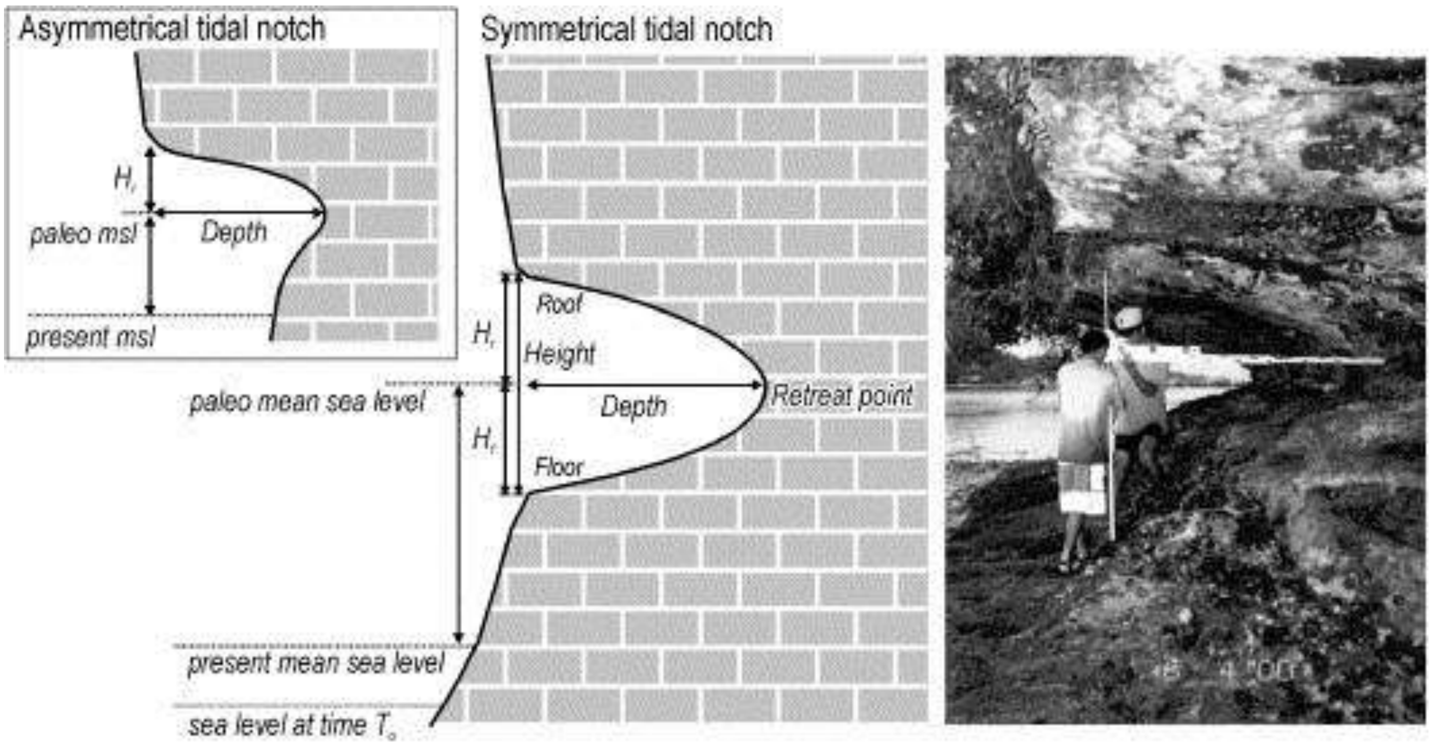
- Indicatori erosivi dei litorali (solchi marini, terrazzi marini, ecc)
- Indicatori deposizionali dei litorali (spiagge, paludi salmastre, speleotemi, beachrocks, ecc)
- Fossili e microfossili (*Lithophaga loithophaga*, reef a vermetidi, ecc)
- Indicatori archeologici (moli, peschiere, ecc)
- Altri indicatori (imbarcazioni spiaggiate, ecc)

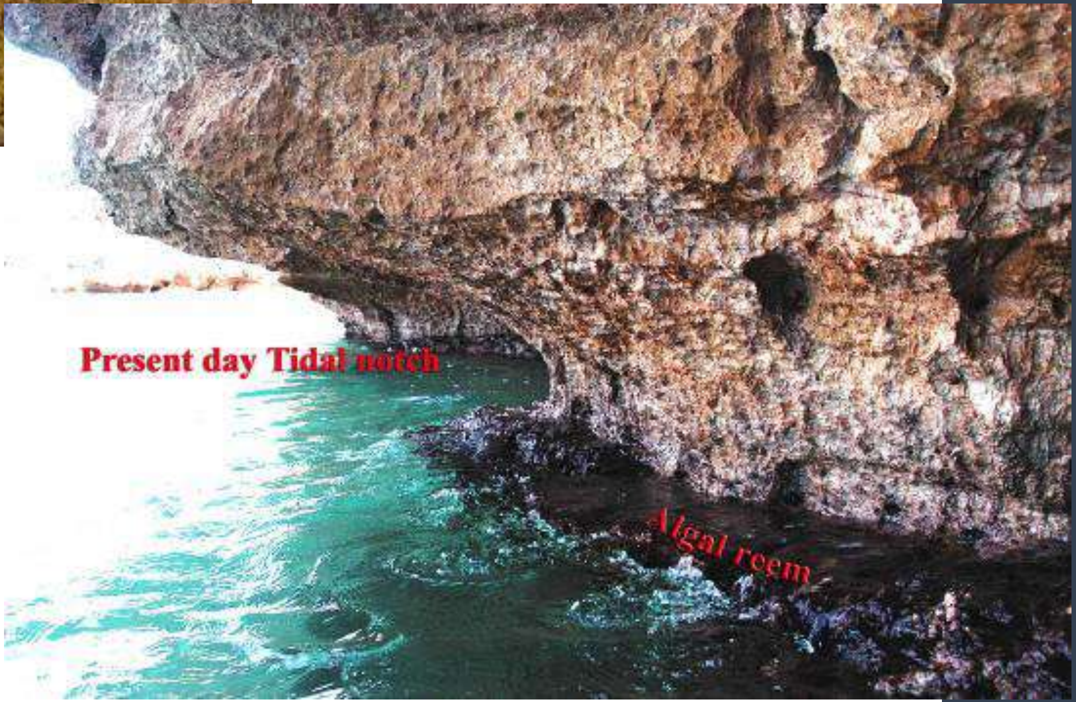
Indicatori erosivi dei litorali

Solchi marini (*Tidal notches*)

- I solchi sono forme tipiche dei litorali carbonatici che si formano nella zona di marea. La loro origine però può essere dovuta a cause diverse, come ad esempio differenze litologiche, ecc)
- Possono anche formarsi sotto il livello del mare per processi abrasivi
- Nel Mediterraneo, con ampiezze di marea ridotte, sono ottimi indicatori di livello del mare
- I solchi tidali *sensu strictu* sono di origine bio-chimica o chimica (dissoluzione) e sono strettamente collegati con il livello del mare

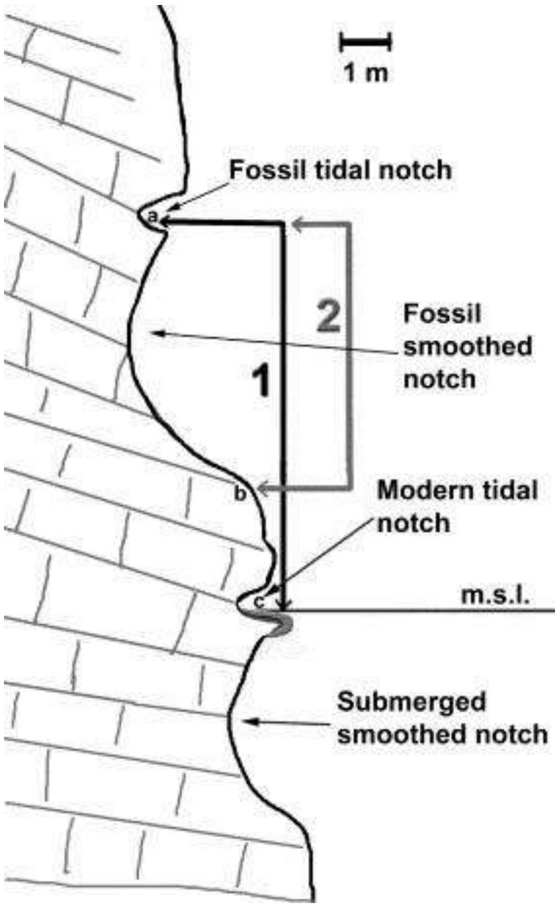
Shape of tidal notches



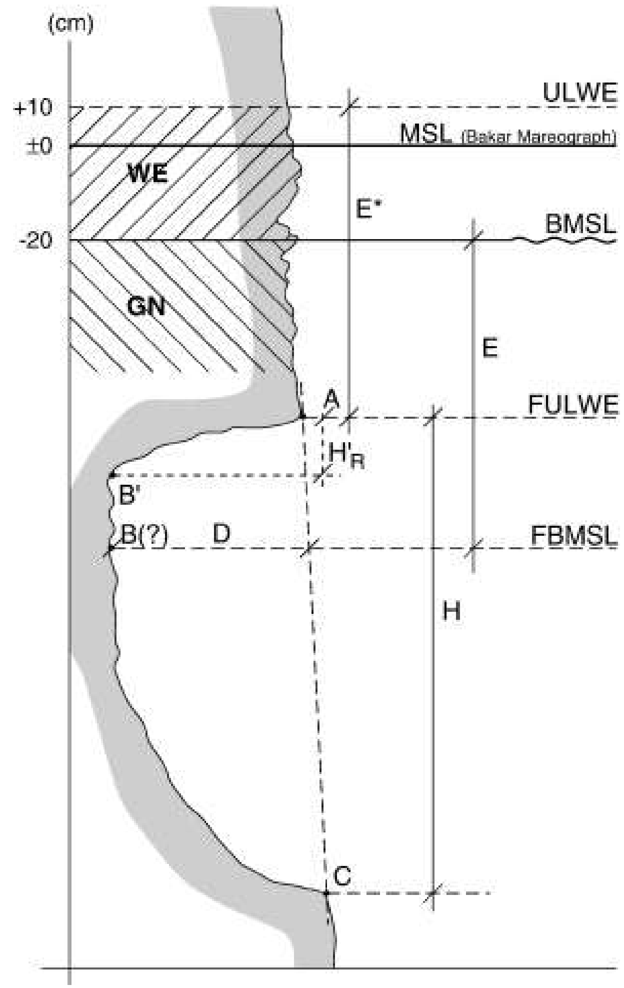

Present day Tidal notch
Algal reem

Present-day tidal notch

Fossil notches

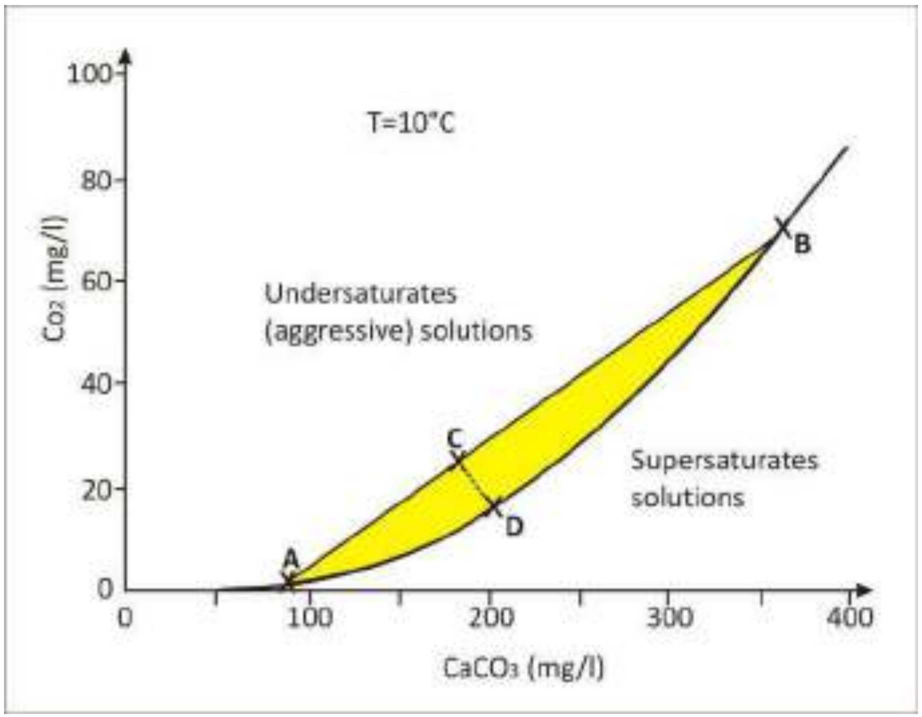


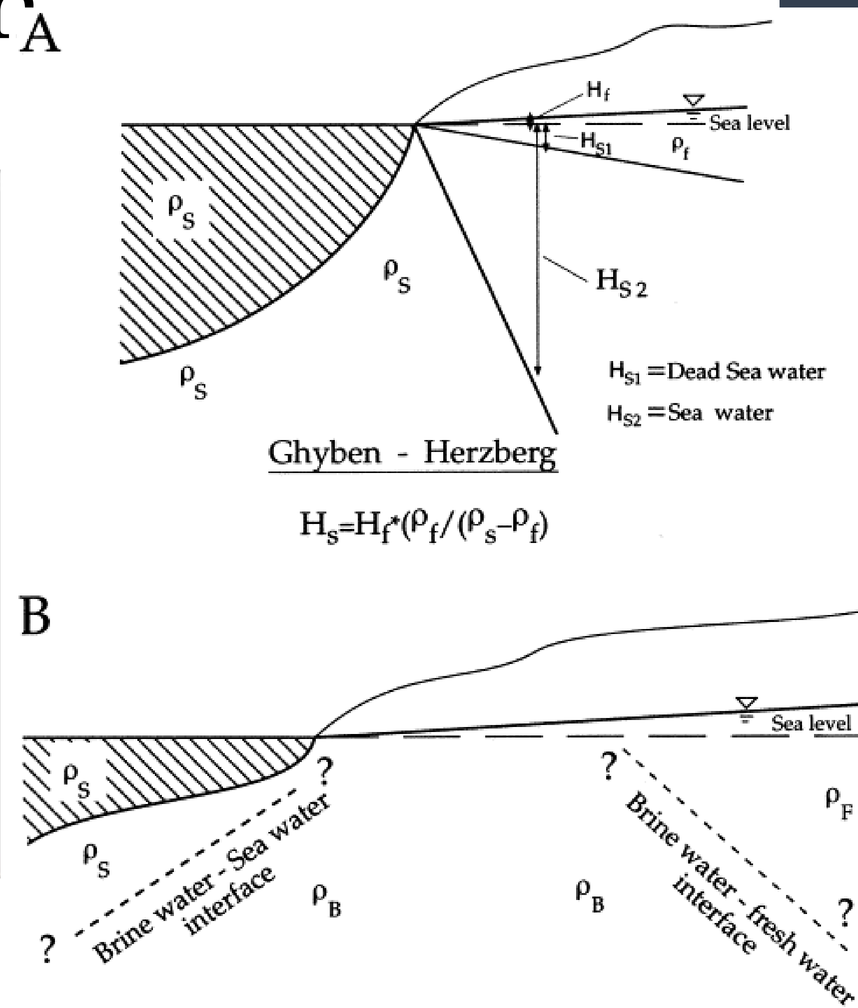
Antonioli et al. (2006),
Quateranry International

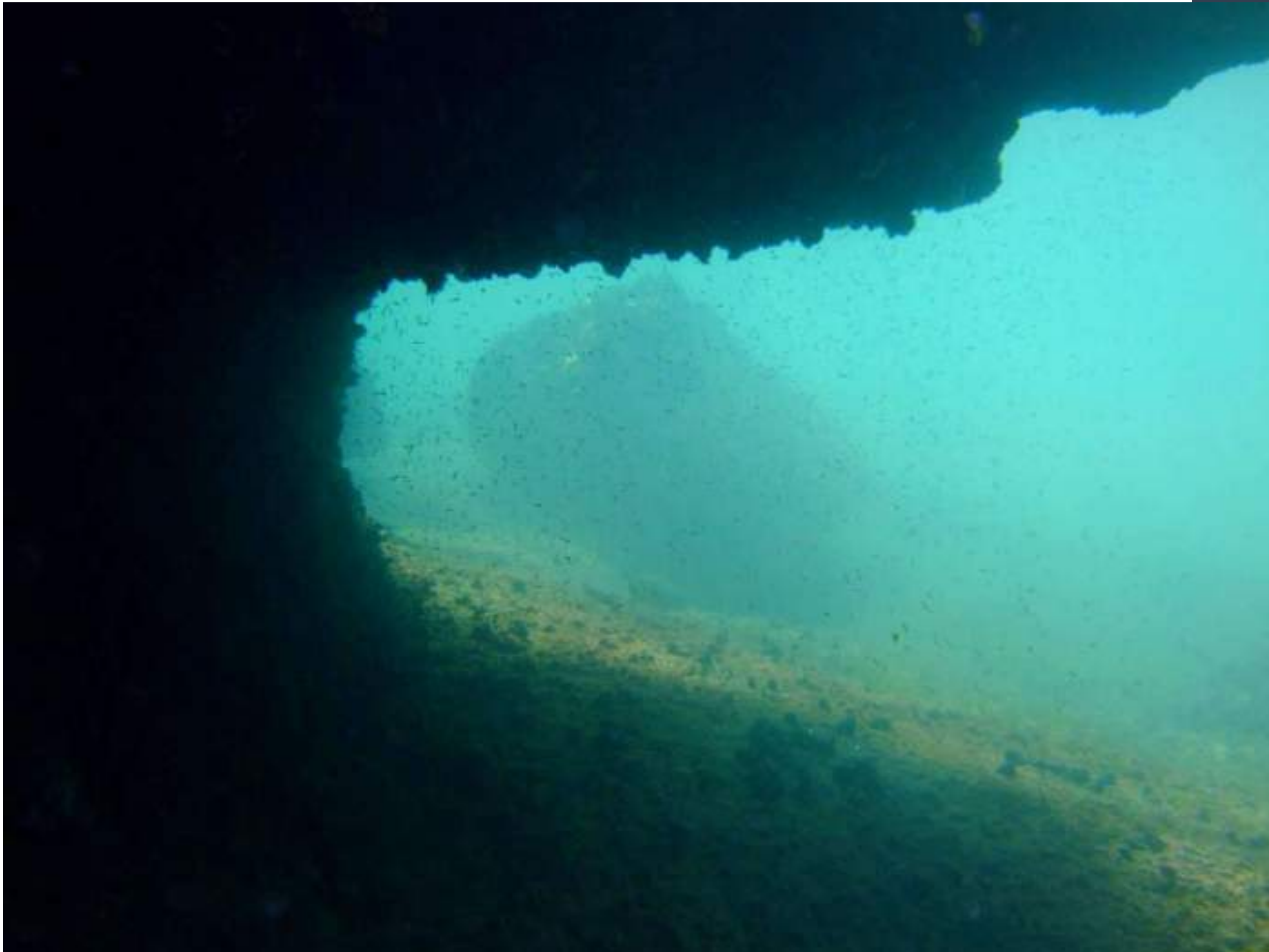


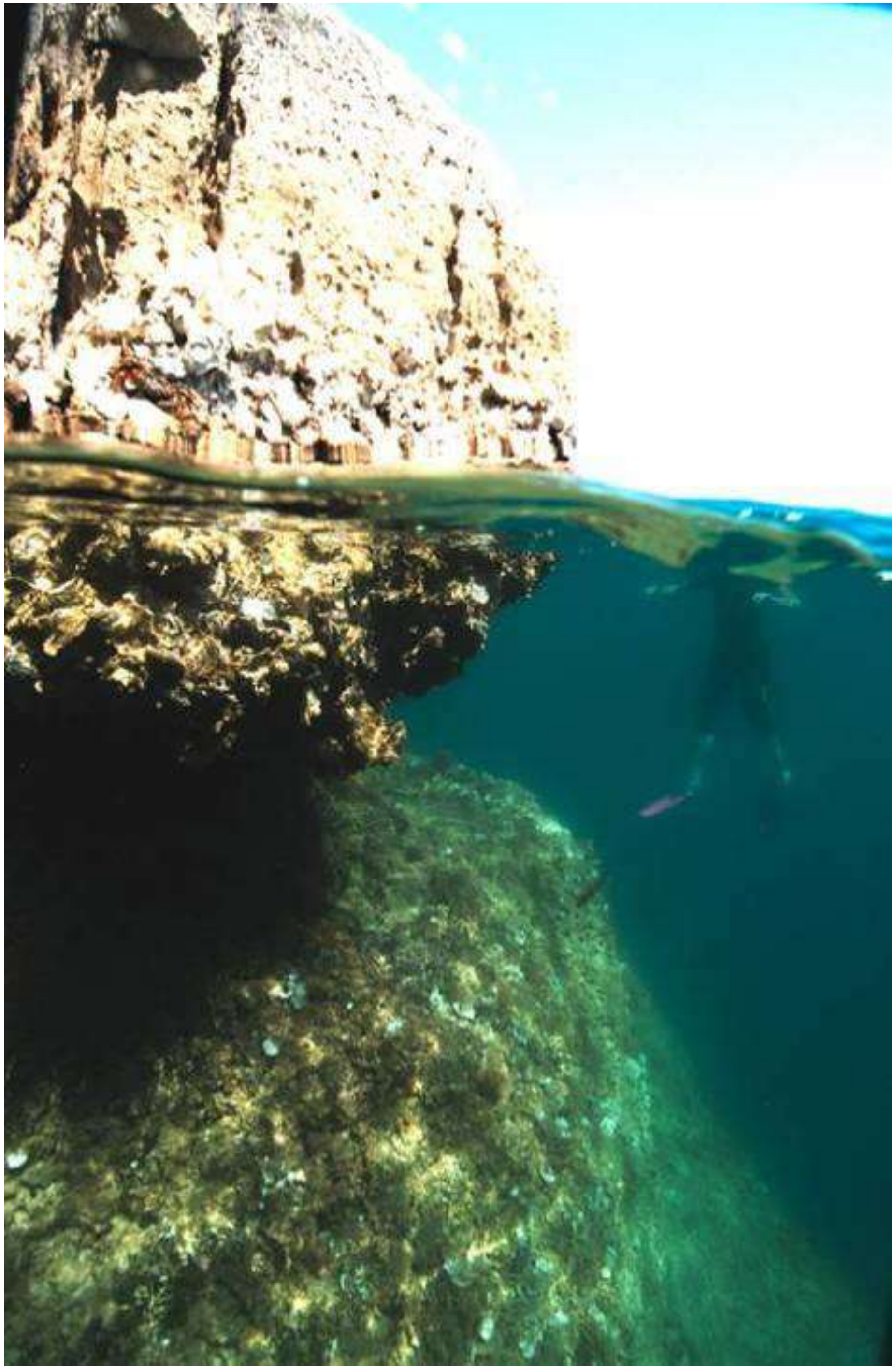
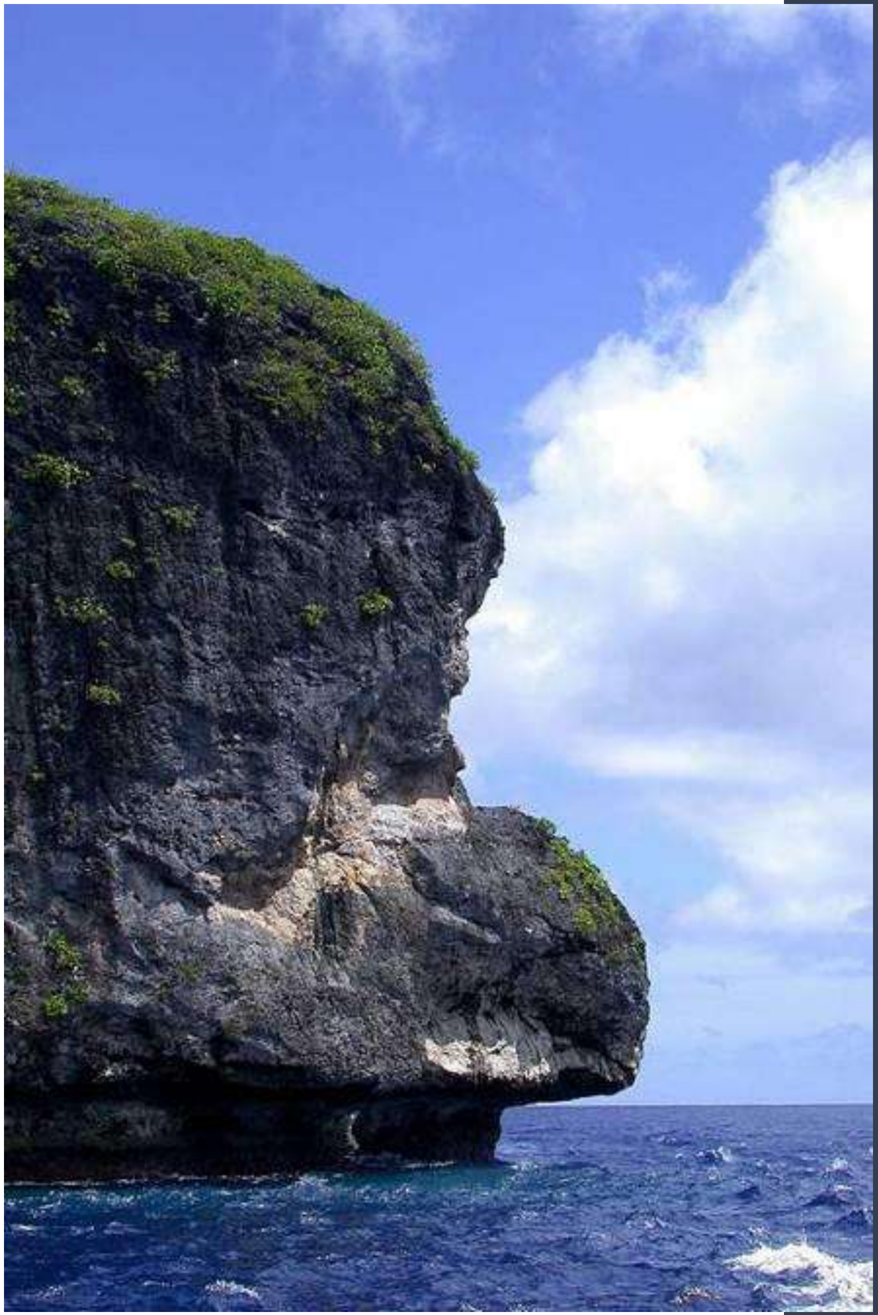
Benac et al. (2008), Marine geology

Mixing-corrosion







Trieste and Istria (Croatia), submerged tidal notches at -0.85 m and -2.5 m bsl


Uplifting coast

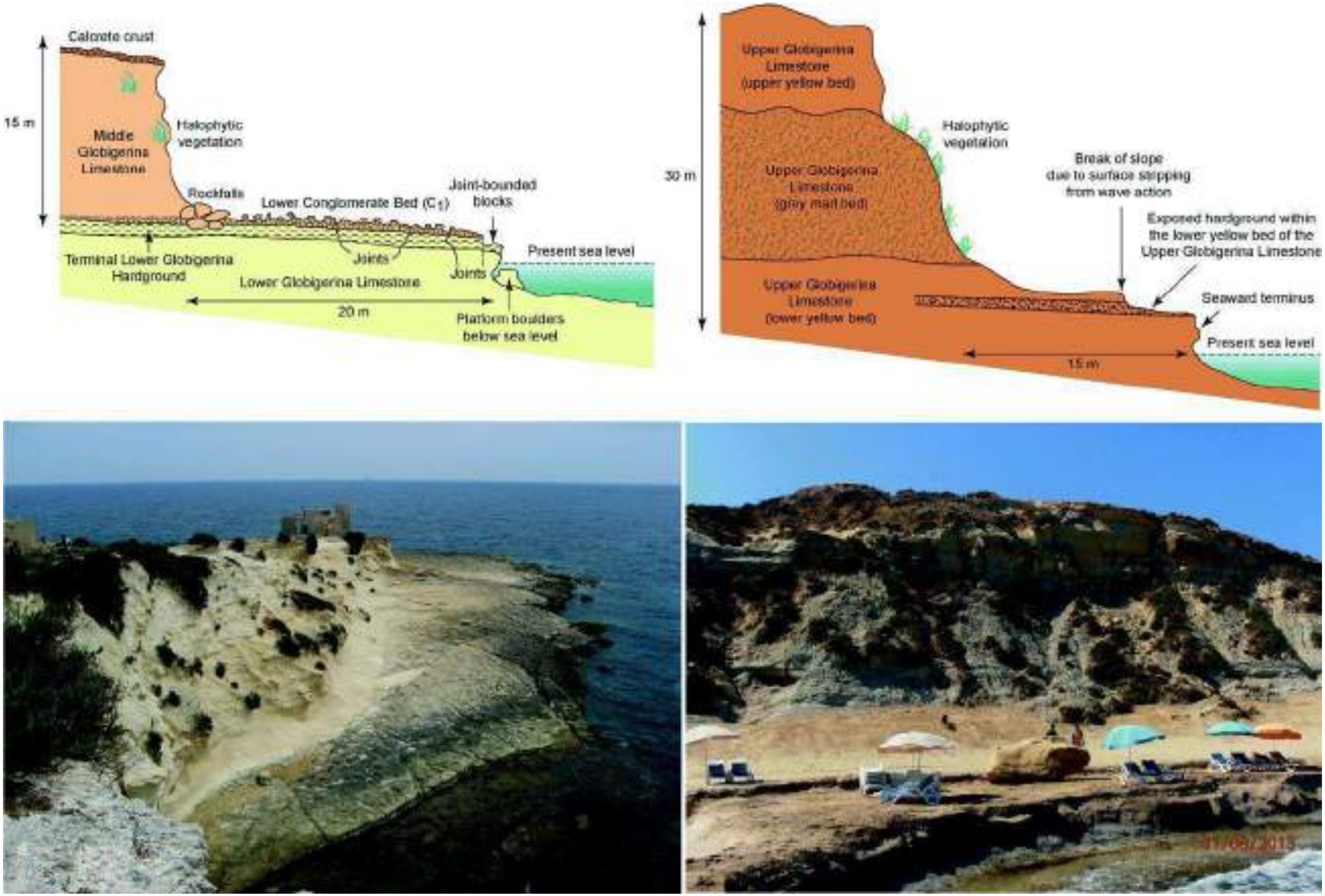

Stable coast

Downlifting coast

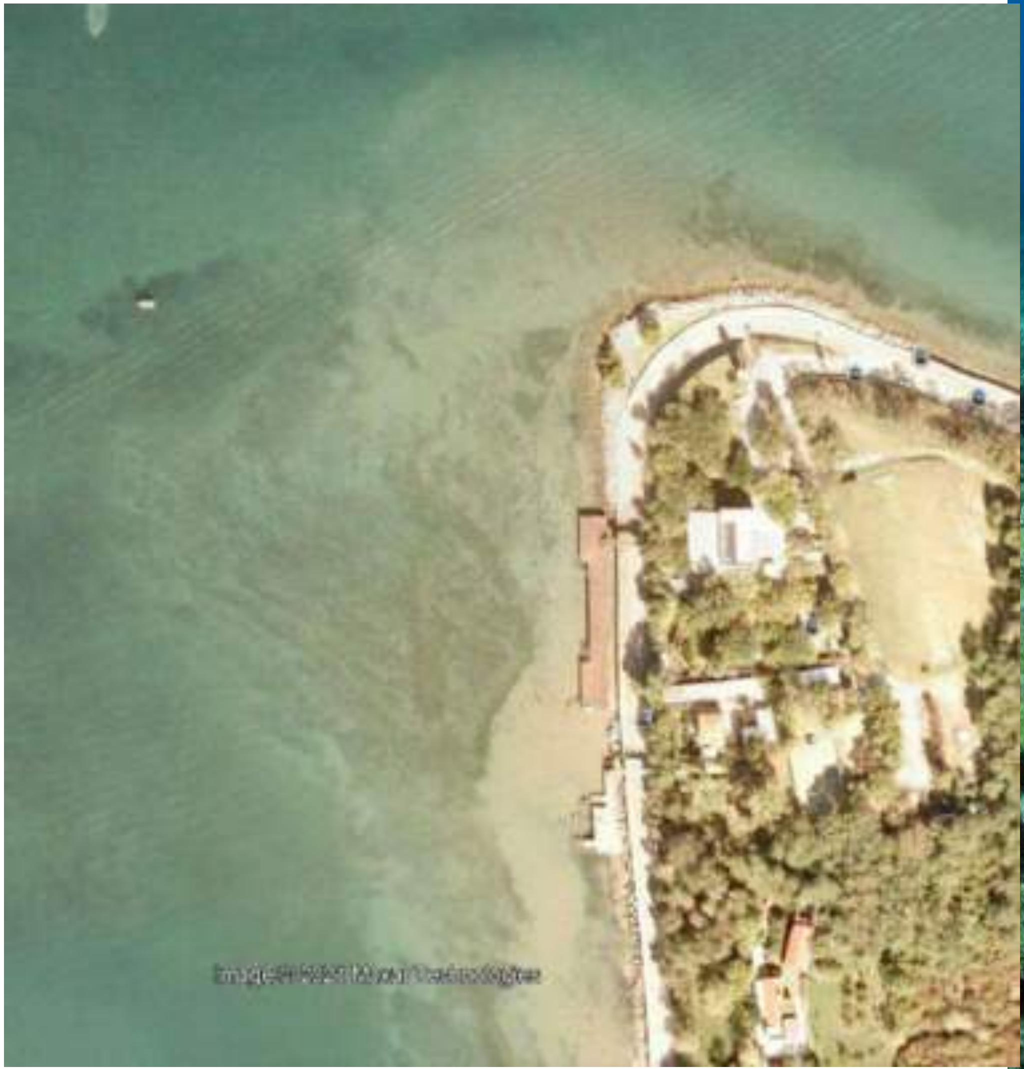
Bioerosive holes (*Lithophaga lithophaga*)

Piattaforme costiere e terrazzi marini (*Shore platforms and Marine terraces*)

- Si tratta di superfici rocciose sub-orizzontali dolcemente pendenti verso mare
- Sono forme ubiquitarie di solito tipicamente connesse a falese costiere retrostanti
- Piattaforme relitte si possono trovare sopra o sotto il livello del mare (da 1 a oltre 100 m di larghezza)



Gauci & Inkpen, 2019)



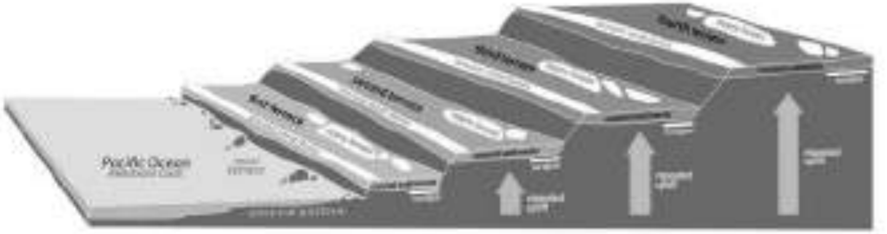


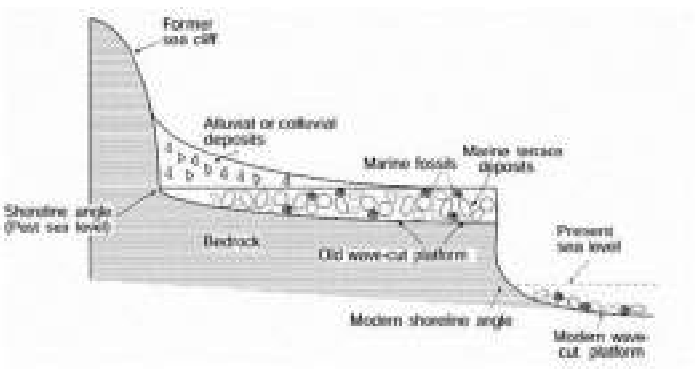
Figure 4. An oblique diagram of the surface and cross-sections of the Jug handle ecological Staircase showing the repeated substrate composition of each terrace: dunal ridge, coastal sediments and hardpan and podzols supporting the dwarf Cypress forests. Diagram by T.R. Paradise after Jenny (1973), Schulz et al. (2018).

Figure 3. Mendocino County's marine terraces: first, second, and third. The fourth terrace is somewhat visible with cleared ground above the third. Jenny's (1973) 'zero terrace is visible here as the wave-cut platform interspersed with pocket beaches and caves. Image: commons.wikimedia.org/wiki/File: Marine_terraces_California.jpg.

Indicatori deposizionali

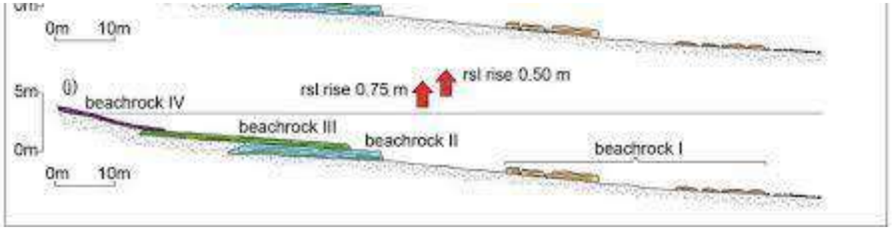
Indicatori deposizionali

- Indicatori deposizionali possono trovarsi sia sopra che sotto il livello del mare, però quelli sommersi sono più difficili da identificare
- Possono essersi depositati in condizioni diverse (alta o bassa energia)
- Quale parte della spiaggia era l'antico livello del mare? Domanda complessa a causa delle maree, coperture successive, modificazioni post-deposizionali
  - Spiagge, accumuli di tempesta
  - Depositi di ambienti salmastri, paludi
  - Terrazzi marini
  - Barriere coralline
  - Reef a vermetidi
  - Speleotemi
  - Beachrock



Beachrock

- Una beachrock è una struttura sedimentaria da friabile a ben cementata che consiste in una miscela di sedimenti di ghiaia, sabbia e limo cementati con minerali carbonati formatasi lungo la costa.
- A seconda della posizione, il sedimento che è cementato per formare la beachrock può consistere in una miscela variabile di conchiglie, frammenti di corallo, frammenti di roccia di diversi tipi, e altri materiali.
- Può contenere manufatti sparsi, pezzi di legno e noci di cocco. La beachrock si forma tipicamente nella zona intertidale nelle regioni tropicali o semitropicali.
- L'origine è discussa

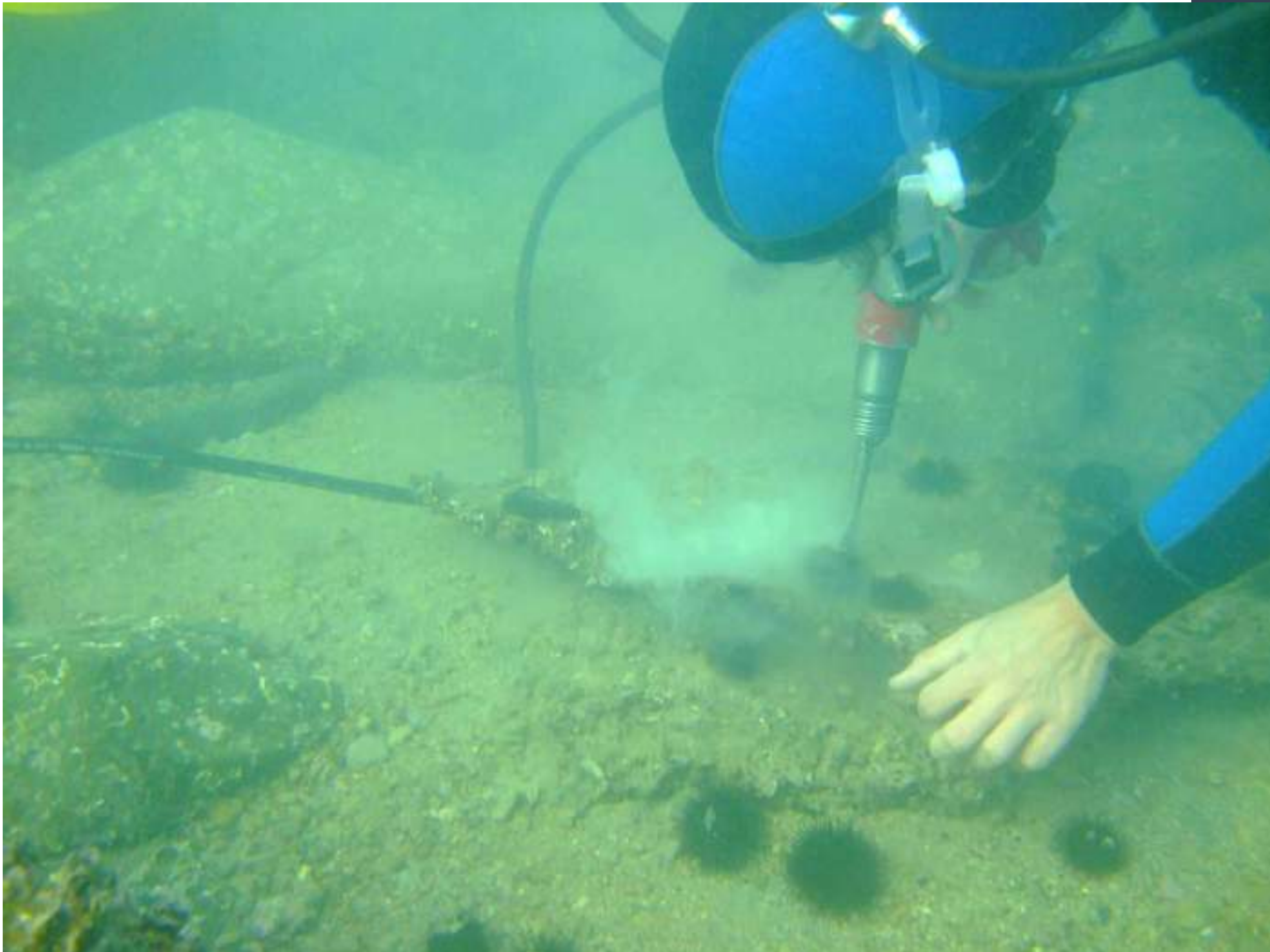


Mourtzas & Kolaiti (2020), AMQ

Beachrock (Greece)


Submerged beachrock (Croatia)


Submerged beachrock (Gulf of Trieste)



Speleotemi

- Lo studio degli speleotemi sommersi per gli studi sul livello del mare ha dato significativi contributi alla comprensione delle variazioni globali e regionali del livello del mare durante il medio e tardo Quaternario.
- In particolare nel Mar Mediterraneo, dove finora sono stati analizzati più di 300 speleotemi sommersi campionati in 32 grotte.

geosciences

MDPI

Review

The Use of Submerged Speleothems for Sea Level Studies in the Mediterranean Sea: A New Perspective Using Glacial Isostatic Adjustment (GIA)

Fabrizio Antonioli [1,*], Stefano Furlani [2], Paolo Montagna [3] and Paolo Stocchi [4]

Quota ed età radiometriche

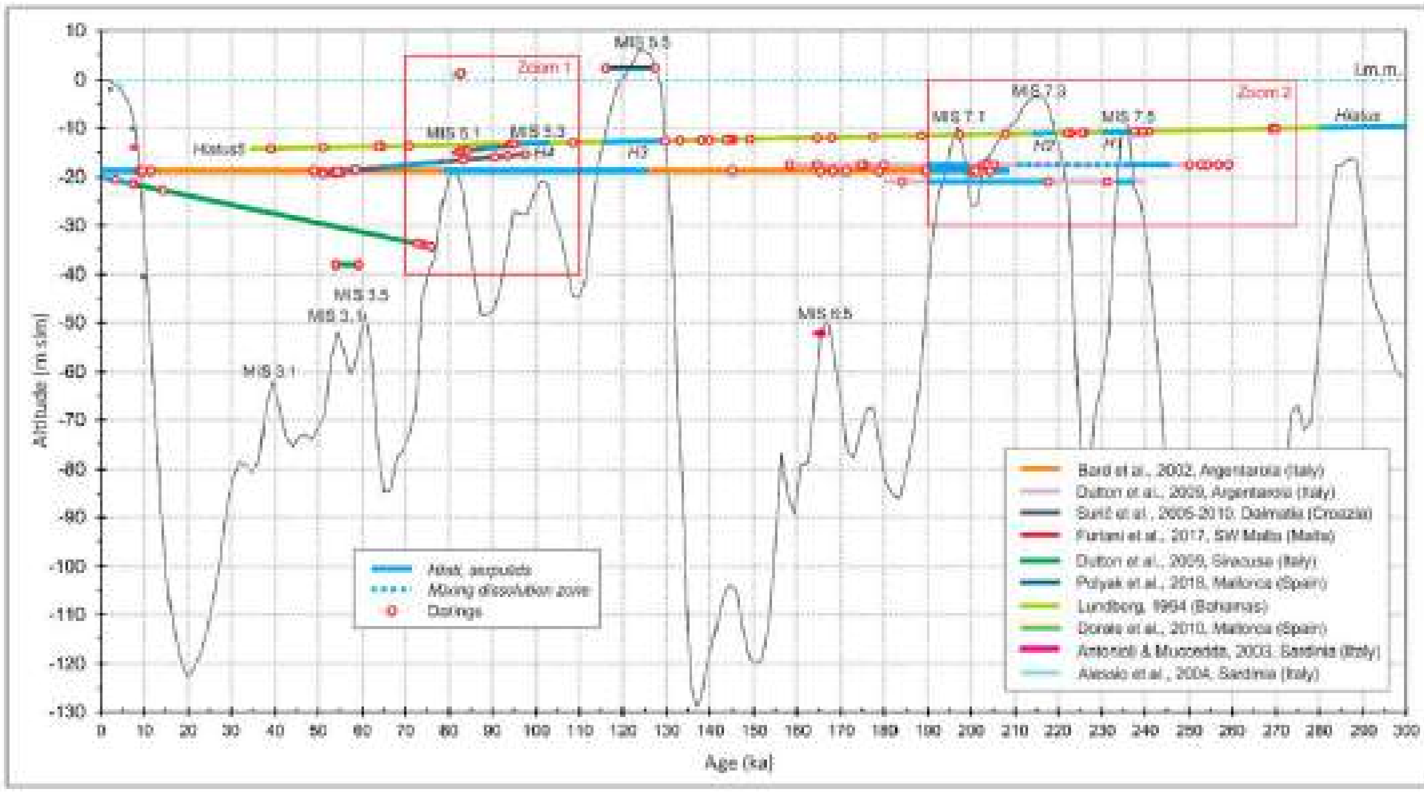


Figure 13. Elevations and radiometric ages (^{14}C and U-Th) of the Mediterranean speleothems and marine overgrowths discussed in the present study and a comparison with the DWBAH flowstone Table A1. Argentarola (Italy), −18.5 m [2] and −18 and −21.7 m [22]; Plemmirio (Italy), −23 m [64]; Grotta di Nettuno (Italy), −3 m [81]; U vode Pit (Krk Island, Croatia), Stalagmite K− 4 (−14.5 m) and K-18 (−18.8 m) [3]; POS from Mallorca (Spain), + 1.5 m [4,5]; Malta [65]; DWBAH Flowstone (Bahamas), −15 m [11]. Black line: global sea level curve reconstructed by [88].

Zoom MIS 5 e MIS 7

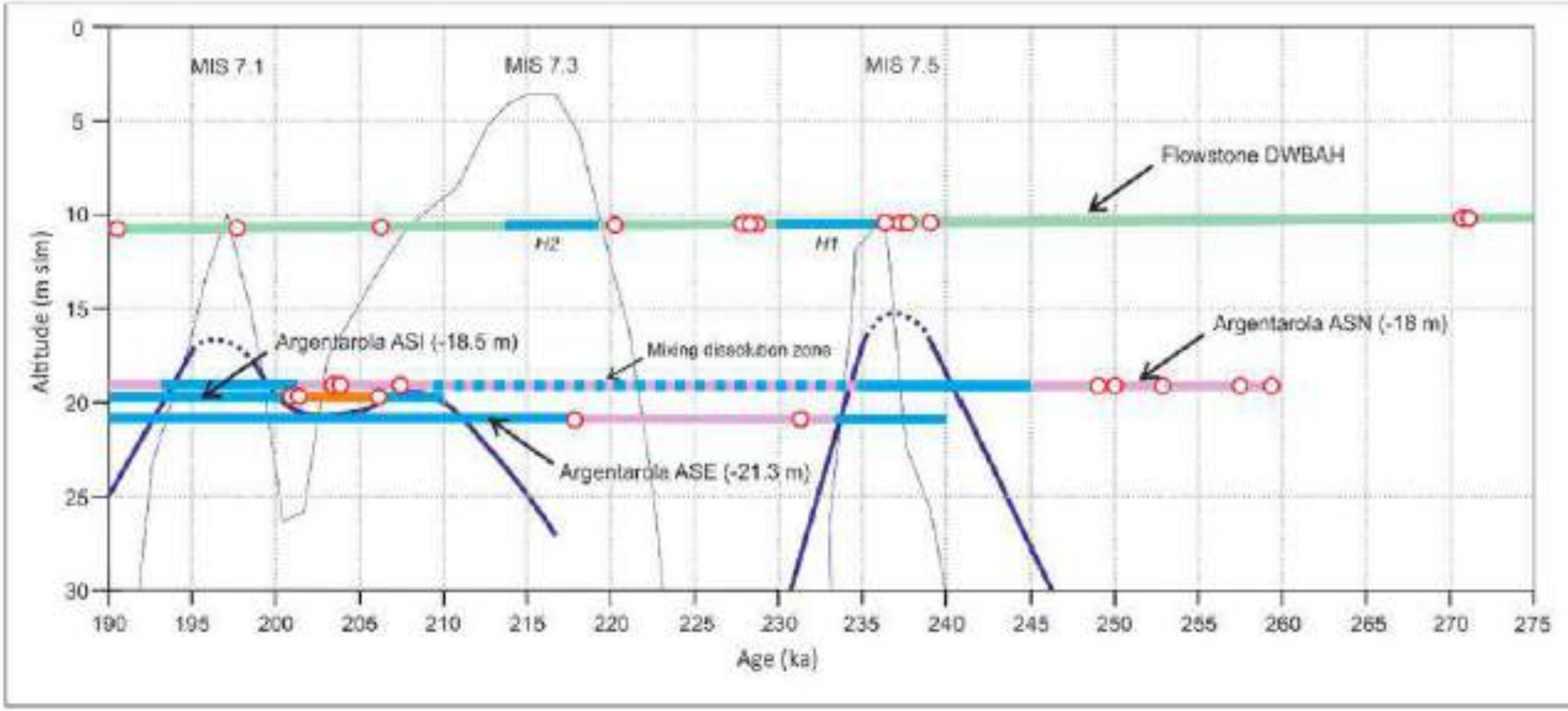


Figure 15. Zoom 2 of Figure 15. Green line: DWBAH flowstone [11]; orange line: Stalagmite ASN (−18 m) from Argentarola cave [22], and stalagmite ASI (−18.5) from Argentarola cave [2]; black line: global sea level curve reconstructed by [88]; dark blue line: sea level drown with observed data.

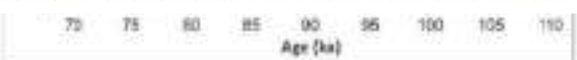
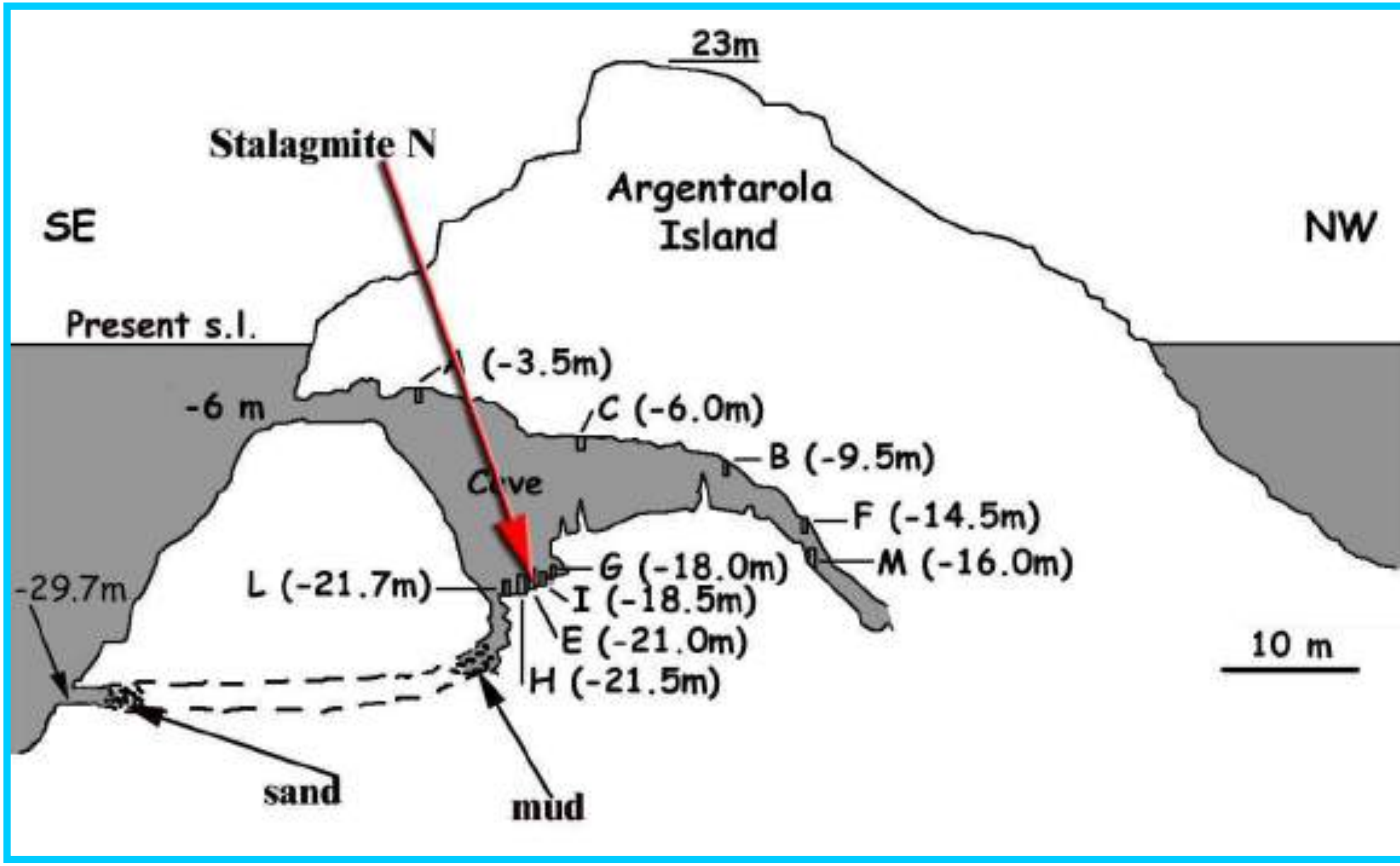
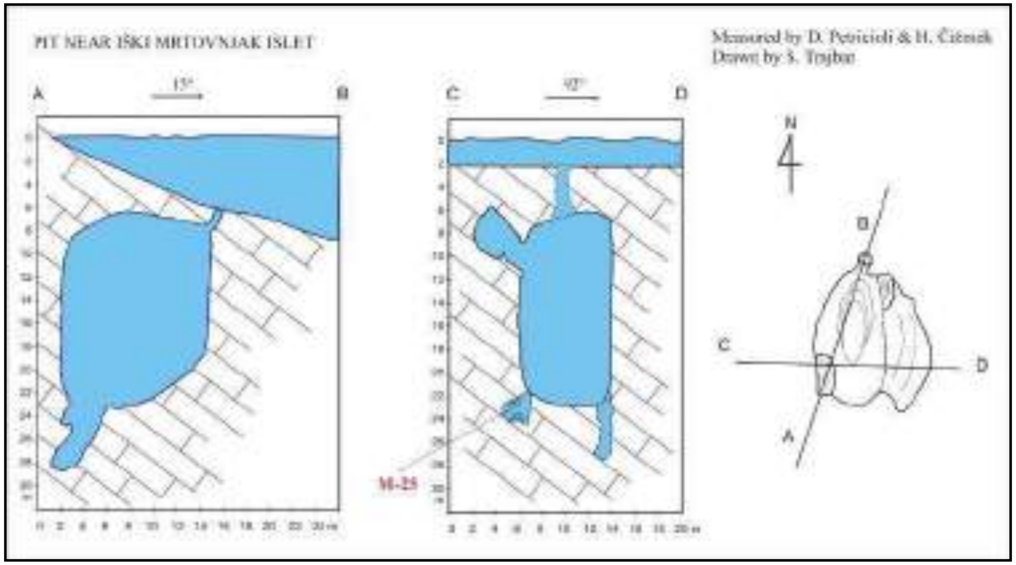


Figure 14. Zoom 1 of Figure 15. Light green line: DWBAH flowstone [11]; orange line: Stalagmite ASI (−18.5) from Argentarola cave, −18.5 m [2]; black line: Speleothems K14 and K18; yellow and blue line: Mallorca POS; green line: Plemmirio [64]; fine black line: global sea level curve reconstructed by [88].

Cross Section of Argentarola Cave

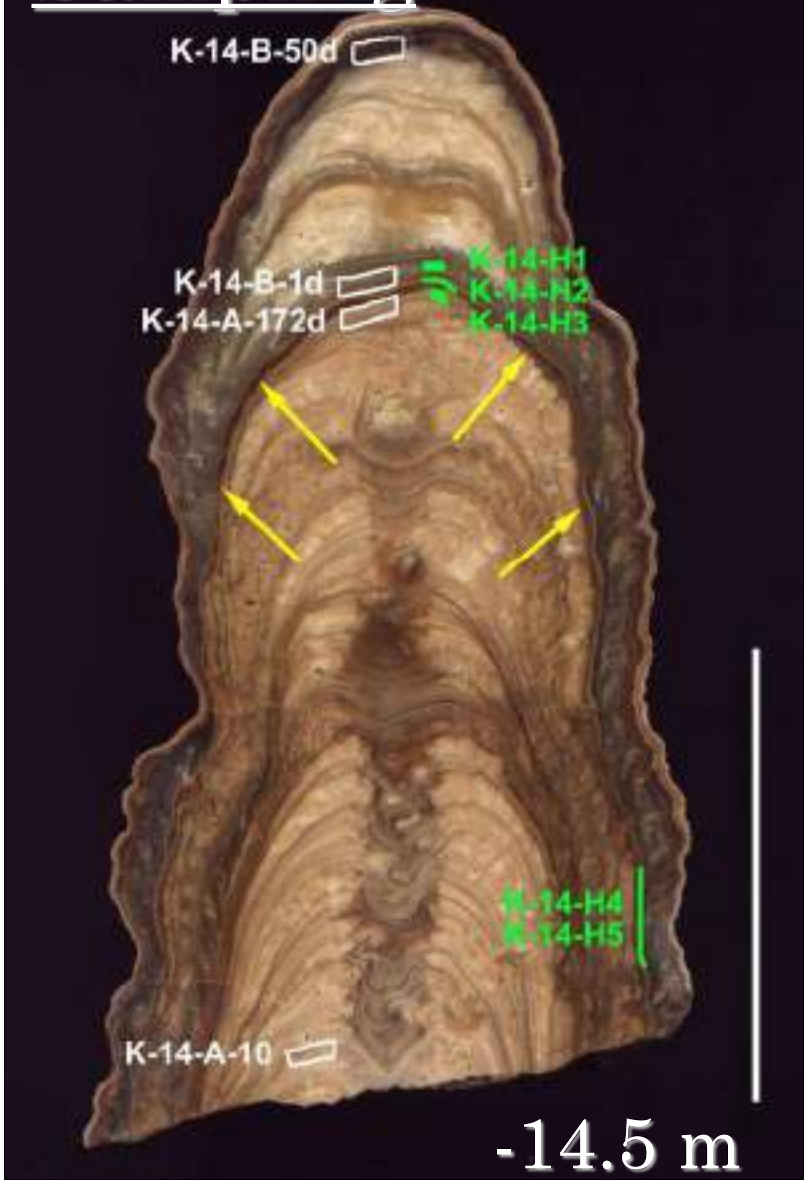



MIS 5
145.2±1.1
164.9±1.9
168.7±1.4
MIS 6
171.9±1.3
179.2±1.3
189.7±1.5
MIS 7.1
201.6±1.8
201.5±1.7
MIS 7.2
206.0±1.9
5 cm


PIT NEAR IŠKI MRTOVNJAK ISLET
Measured by D. Petricioli & H. Čižmek
Drawn by S. Trajbar
A
B
C
D
15°
92°
N
M-25

Sampling

K-14



K-18

Quaternary International 206 (2009) 134–146

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Archaeological remains as sea level change markers: A review

Rita Auriemma[a], Emanuela Solinas[b,*]

[a] Dipartimento Beni Culturali, Università degli Studi del Salento, Via D. Birago 64, 73100 Lecce, Italy
[b] Civico Museo Archeologico Su Domu Nosta, via Scaledda, 09040 Senorbì – CA, Italy

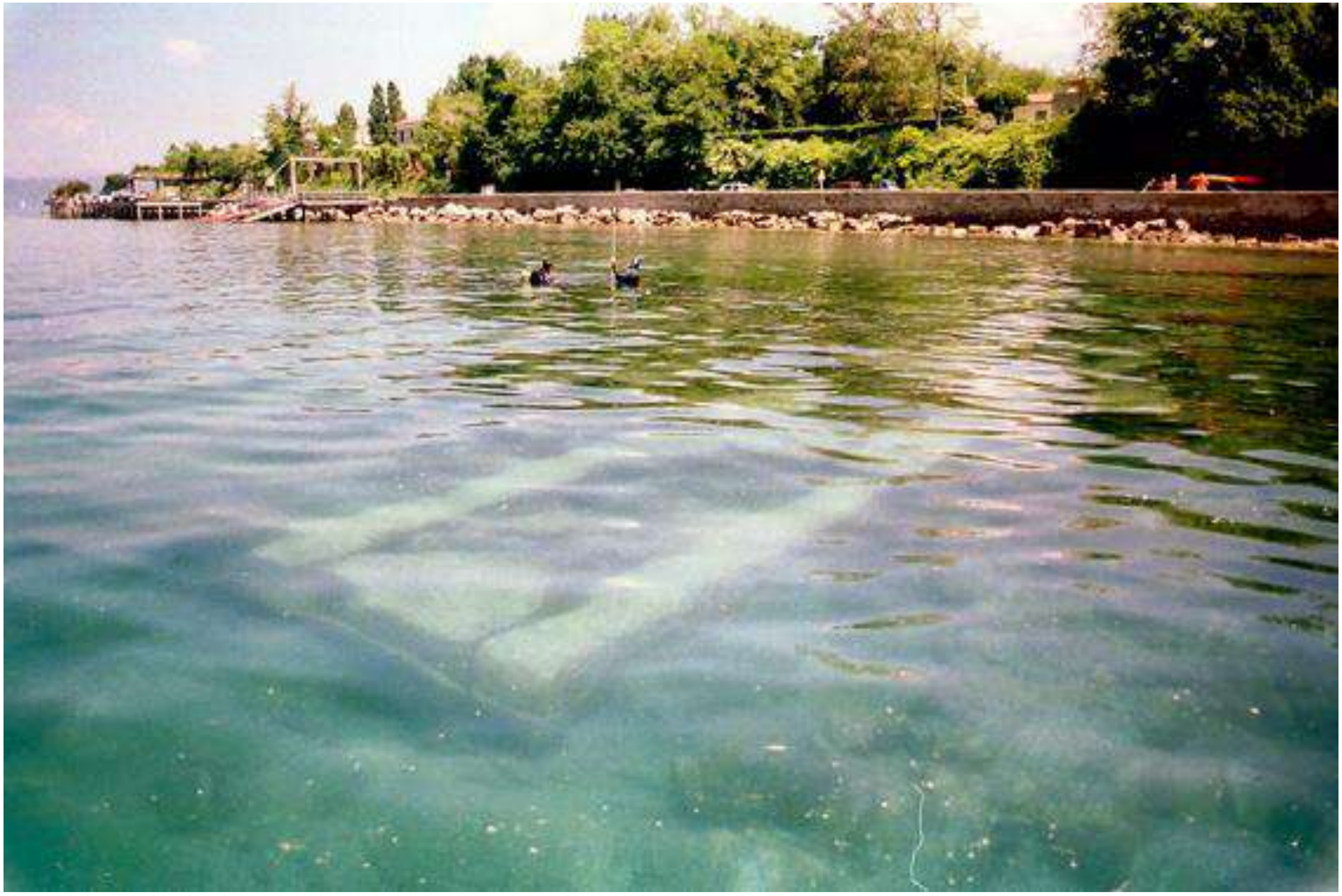
Strutture archeologiche

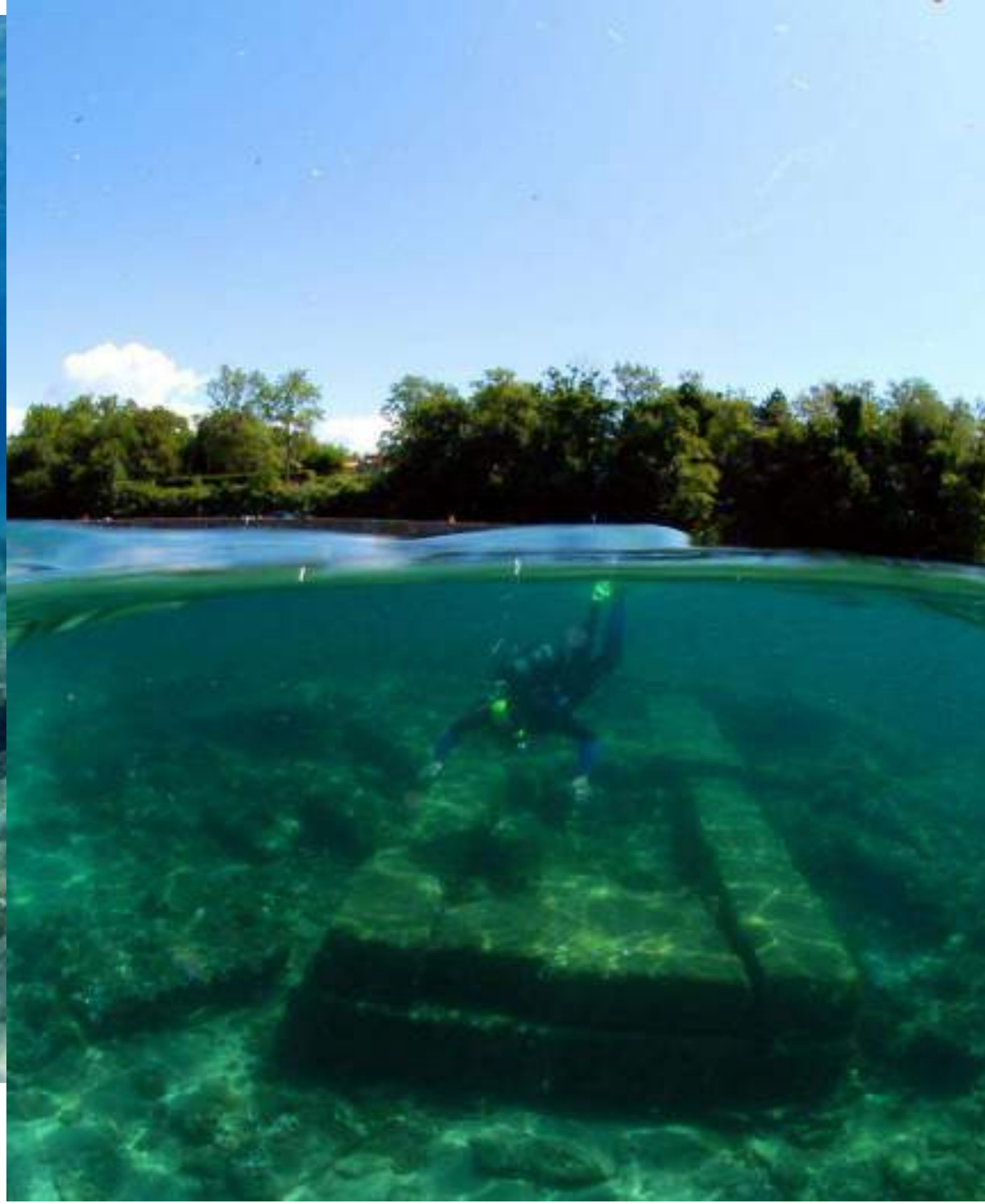
Table 1

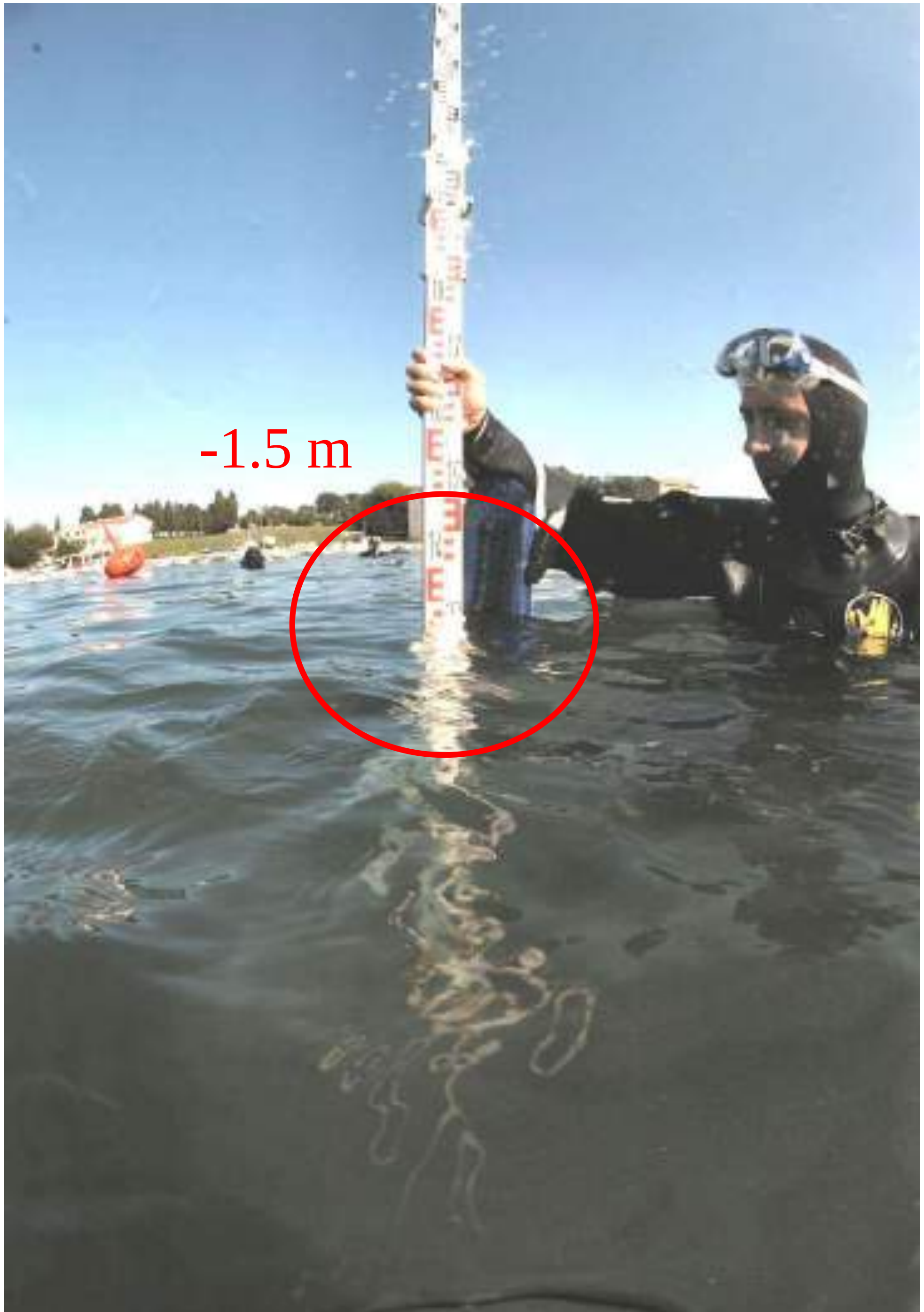
Type of evidences	Significant markers	Functional height (m)	Range of chronological error (years)	Reliability
1.1. Tyrrhenian Sea fishponds	(1) the closing shutters (2) the captation canals (3) the carvings for the trop-plein	0 a.m.s.l. (Anzidei et al., 2004)	≤100	High
1.1. Adriatic fishponds	Parts that can be recognized as: Piers Walking plane	0.60 a.m.s.l. (Antonioli et al., 2007)	≤100	Medium-low
2.1. Piers and quays	(1) Walkways (2) Missing carpentry (3) Bollards and the mooring rings (4) String-courses between building techniques or different coverings	0.60–1.00 a.m.s.l. (Antonioli et al., 2007)	≤100	High
2.2. Breakwaters	(1) Carved blocks, referable to an original breakwater dock (2) Other referential elements associated	0.60 a.m.s.l. (Antonioli et al., 2007) >0.70 a.m.s.l (Antonioli et al., 2007)	>100	Medium-low
3. Private and public buildings	(1) Pavements (2) Walking planes (3) Use surfaces	≥0.60 a.m.s.l. (Antonioli et al., 2007)	<100	Low
4. Coastal quarries	Mining plane Piano di distacco/cava/estrazione	0.30 (Lambeck et al., 2004b) 0.30 above high tide (Antonioli et al., 2007; Scicchitano et al., 2008)	>100	Medium
5. Hydraulic systems	(1) Cistern bottom (2) Canal basis	Above high tide (Auriemma et al., 2004)	>100	Medium-low
5a. Wells	Well bottom	0.30–0.40 under the water table (Sivan et al., 2004; Enei, 2008)	<100	Medium
6. Pre-protohistorical settlements	(1) Post holes (2) Hut floors (3) Stone-wall foundations	Above high tide (Scarano et al., 2003)	≤100	Low
7. Pre-protohistorical caves	(1) Cave floor (2) Sepulchral room/burials floor (3) Pits	0.30 above high tide (Antonioli et al., 2007)	<100	Medium-low
8. Paleo-beaches	Beach rock top level	Above high tide (Antonioli et al., 2007)	<100	Medium-low
9. Beached wrecks	Keel basis	−0.50/1.50 a.m.s.l.	≤100 (C14)	High

The reliability depends on the accuracy of the chronology and the degree of the functional height approximation. The error within the tide amplitudes should be considered (±0.23 m for the Tyrrhenian Sea and ±0.60 m for the Adriatic Sea).

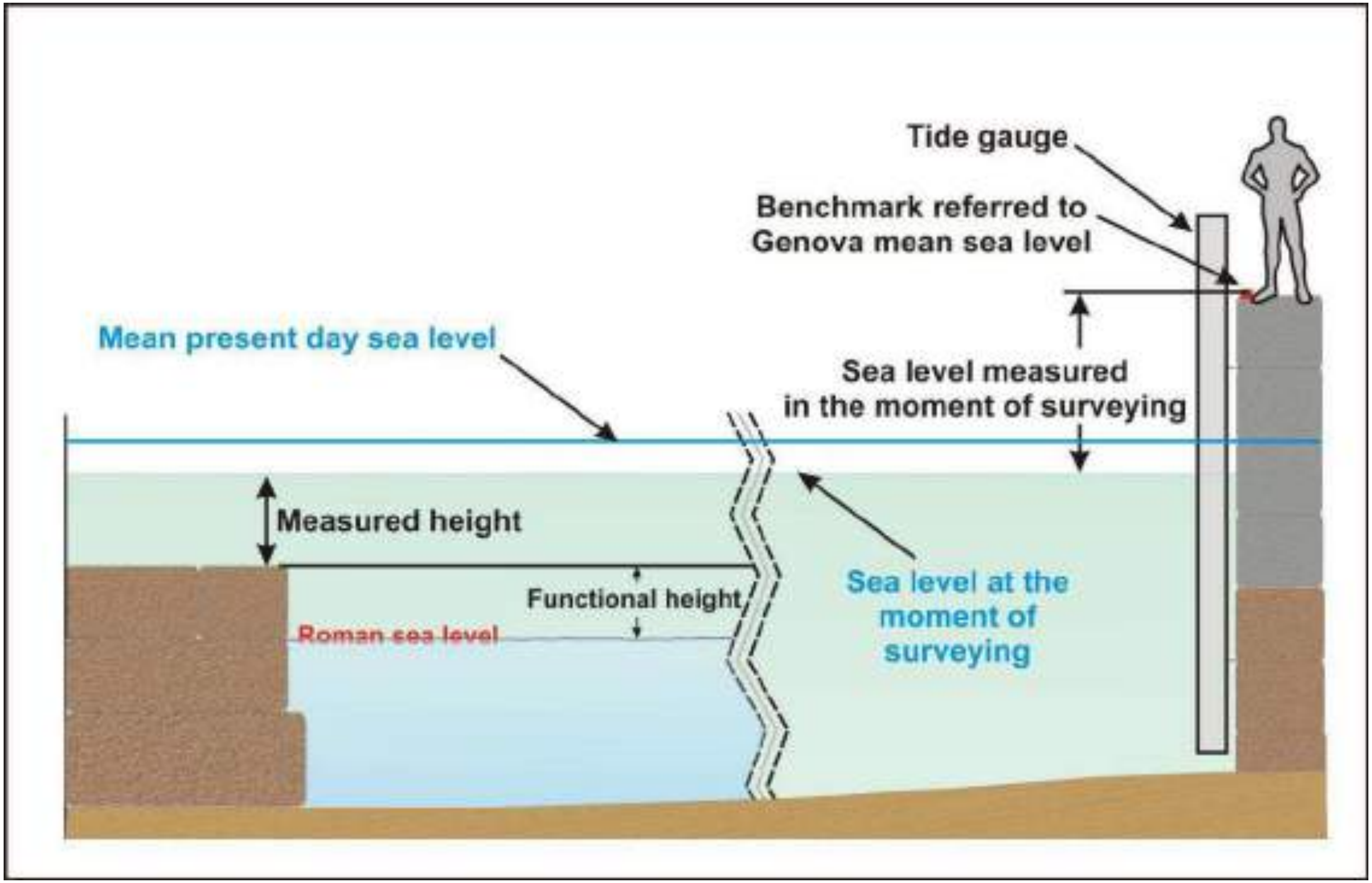
The Roman Age dock at Punta Sottile (Muggia, NE Adriatic Sea)



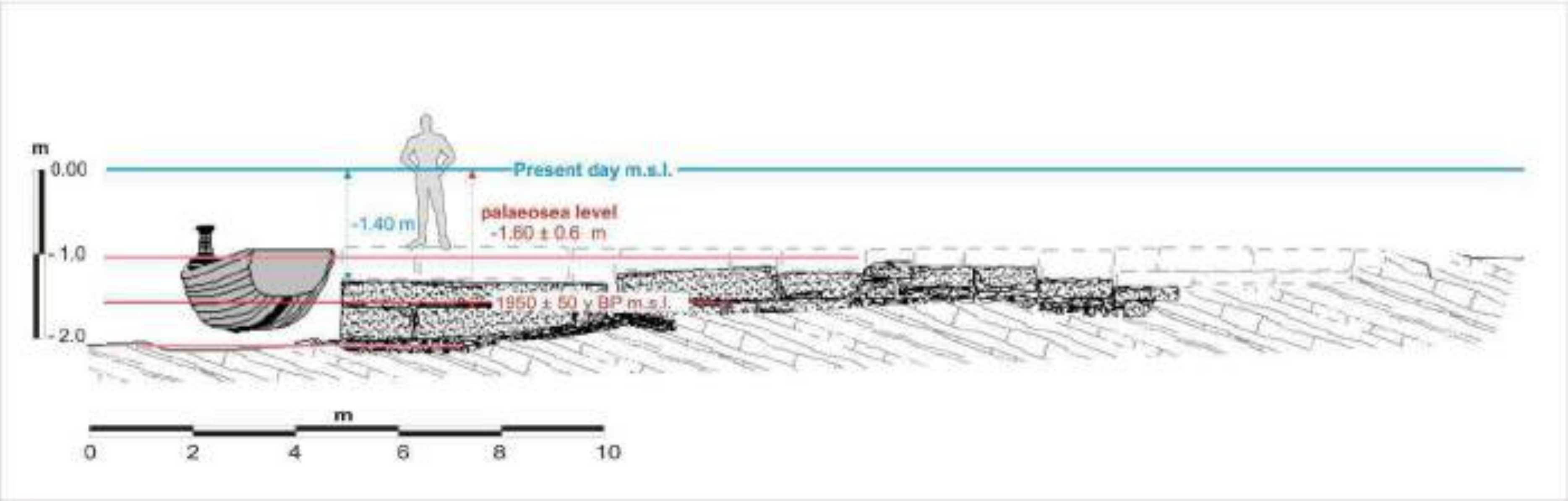


-1.5 m

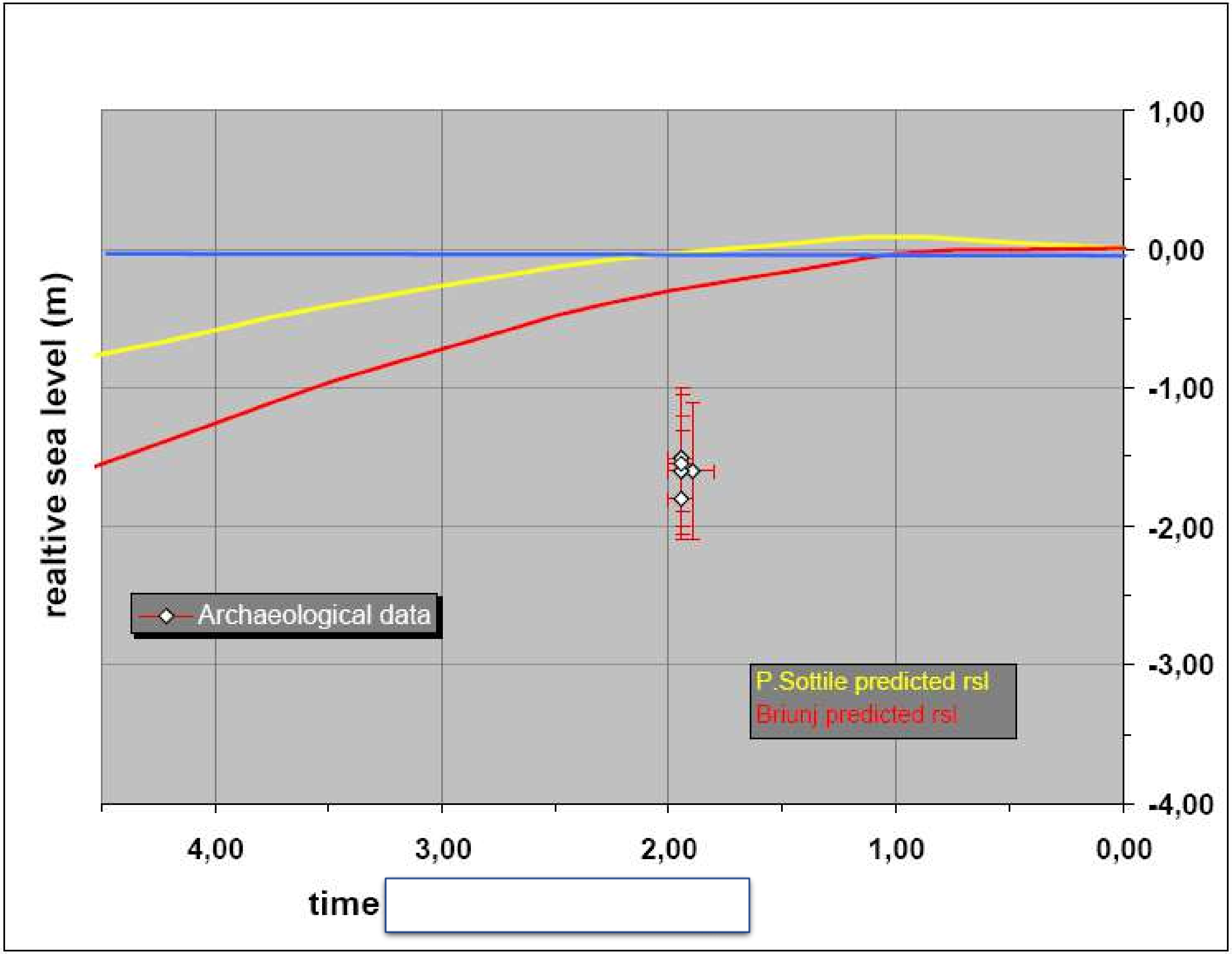
Measurements and corrections



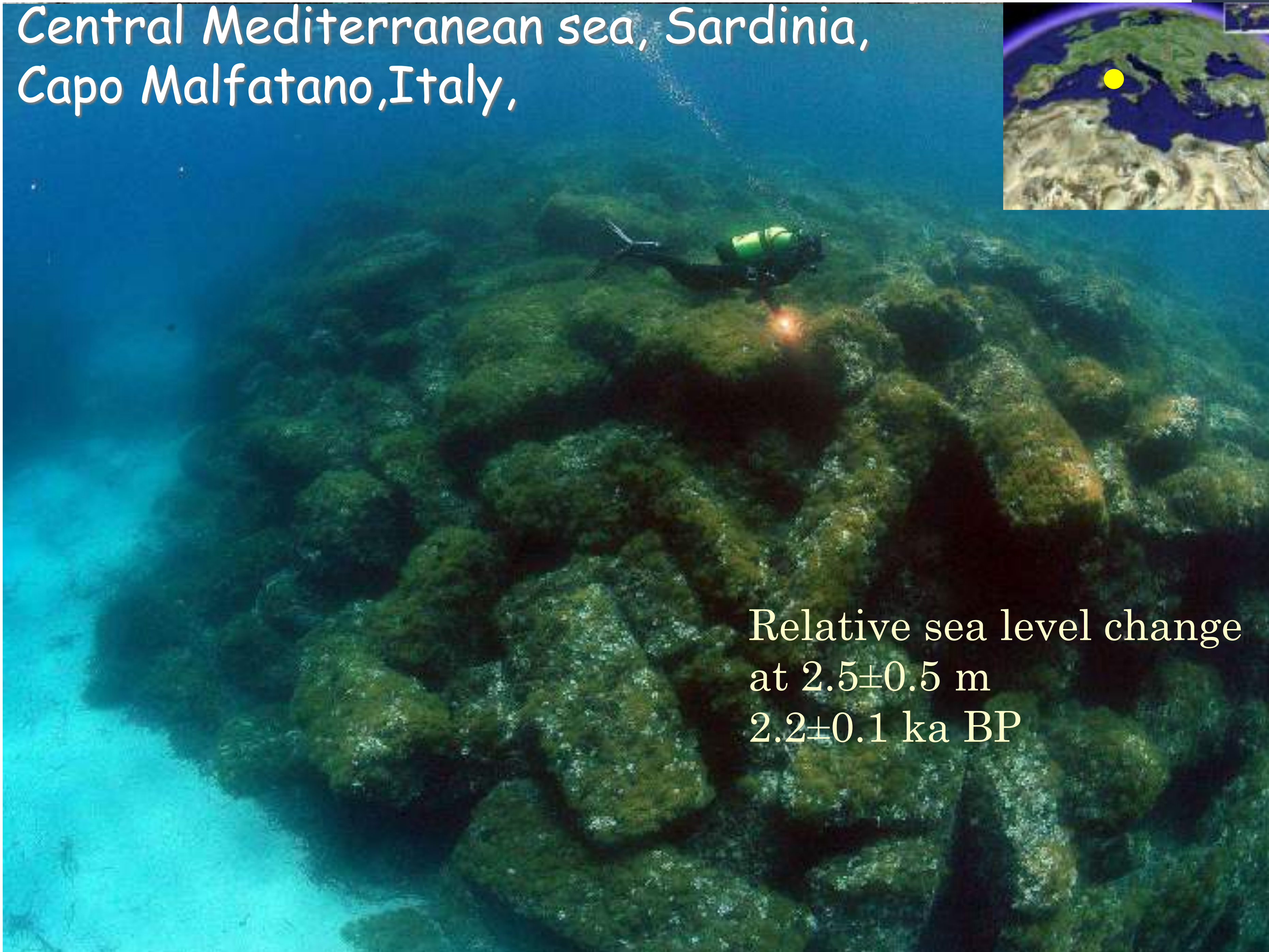
Moli attuali

Punta Sottile



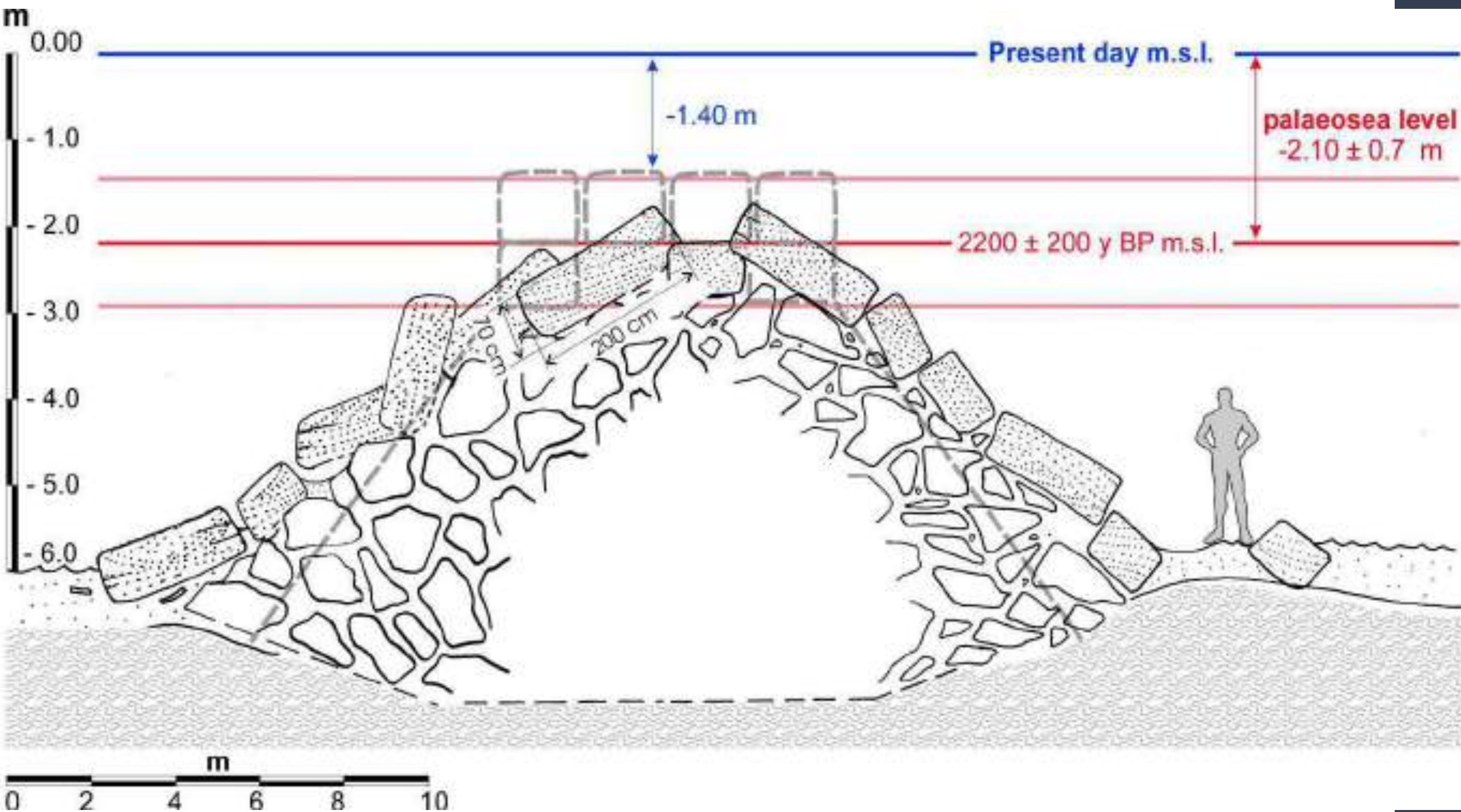

1,00
0,00
-1,00
-2,00
-3,00
-4,00
4,00
3,00
2,00
1,00
0,00
time
realtive sea level (m)
Archaeological data
P.Sottile predicted rsl
Briunj predicted rsl

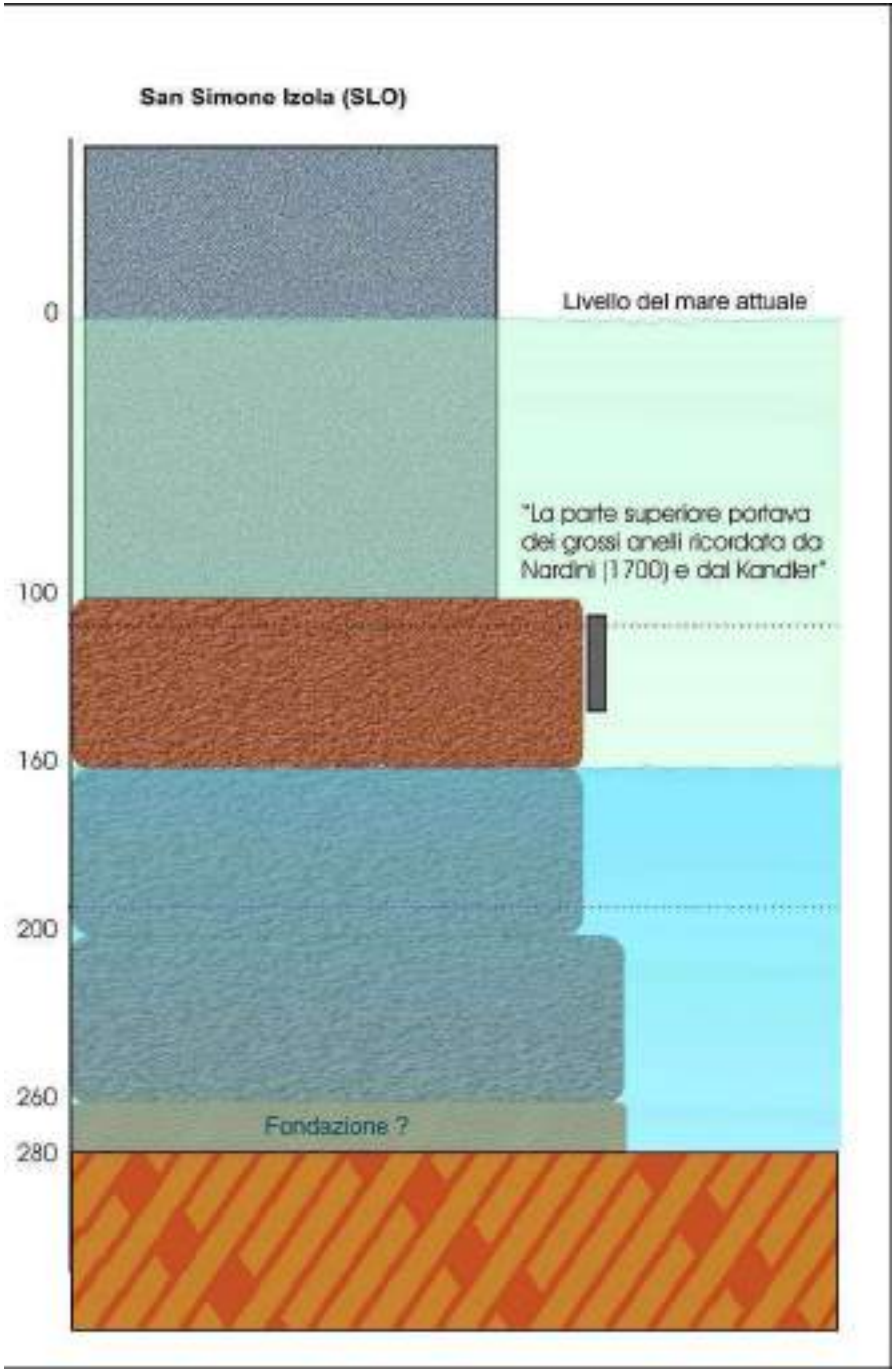
Central Mediterranean sea, Sardinia, Capo Malfatano,Italy,

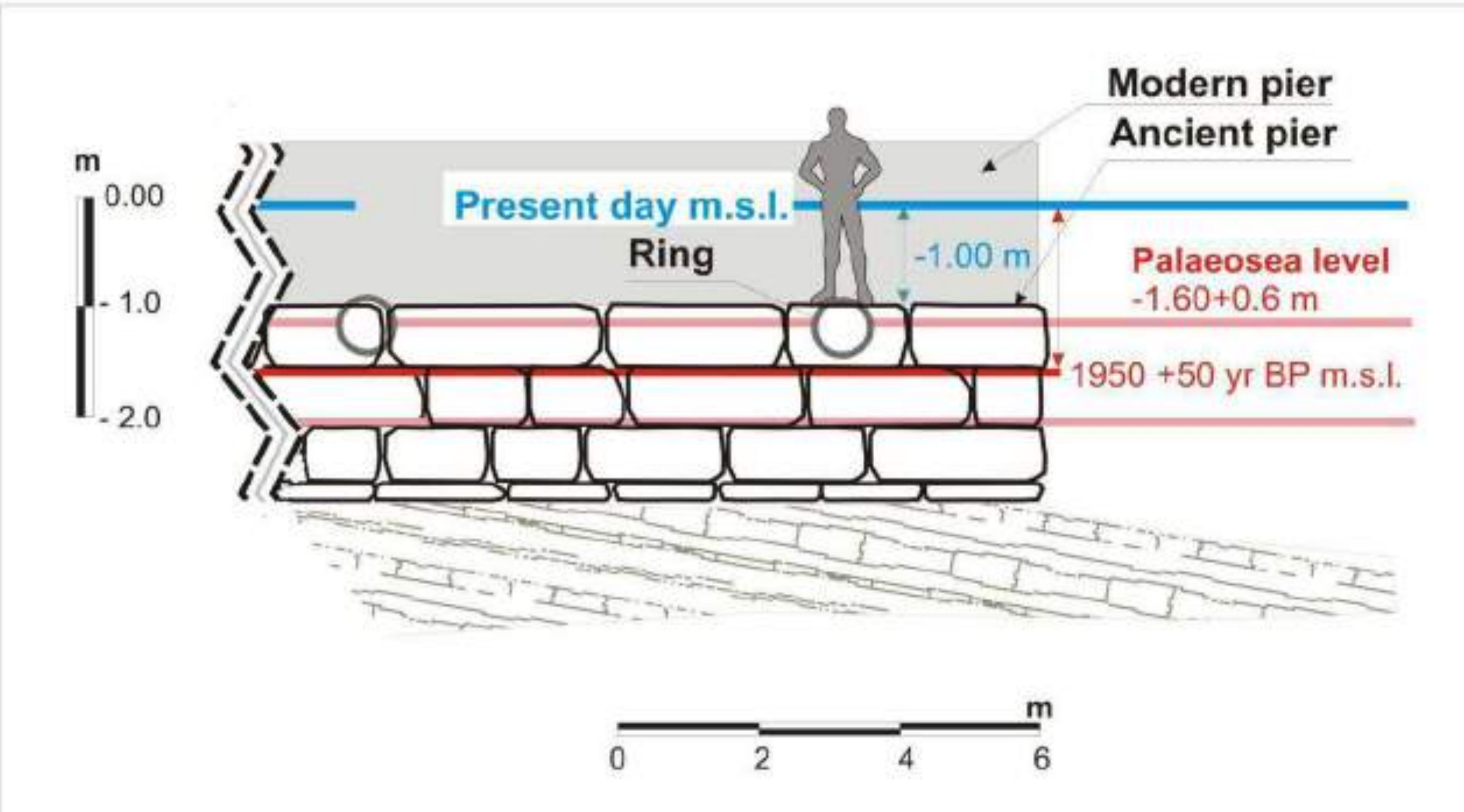


Relative sea level change
at 2.5±0.5 m
2.2±0.1 ka BP

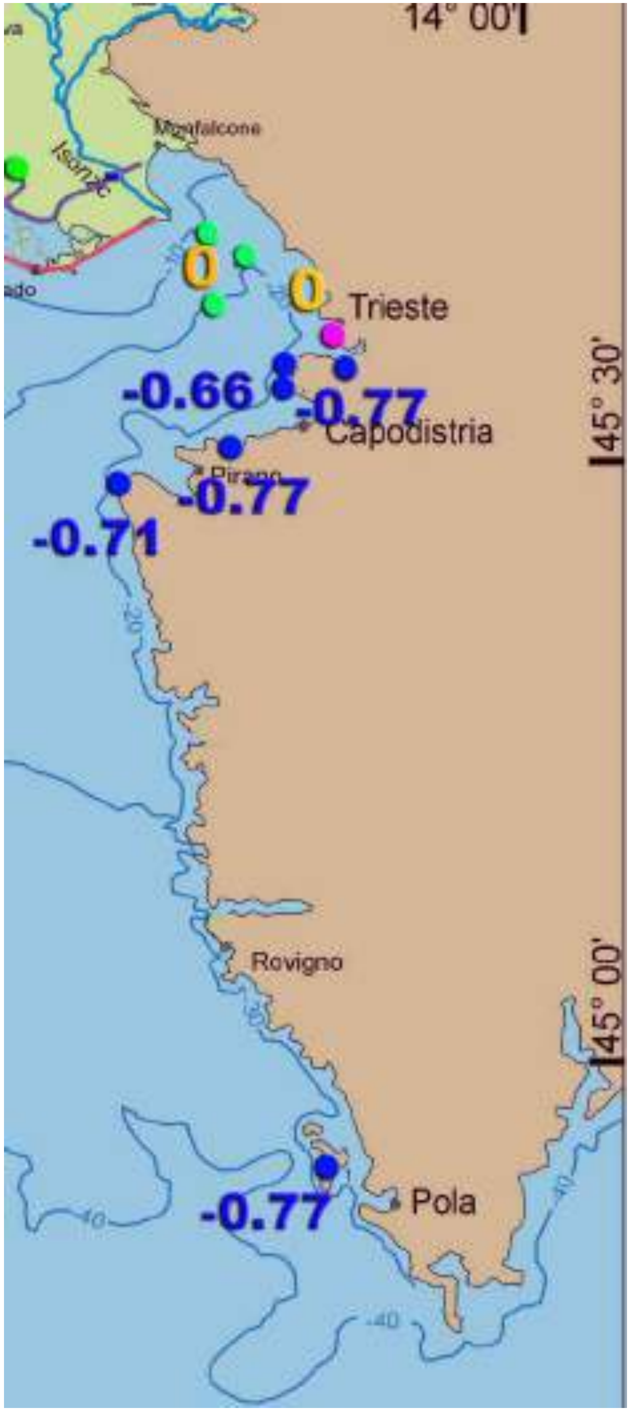
Italy, Central Mediterranean
(southern Sardinia, Capo Malfatano, Italy)



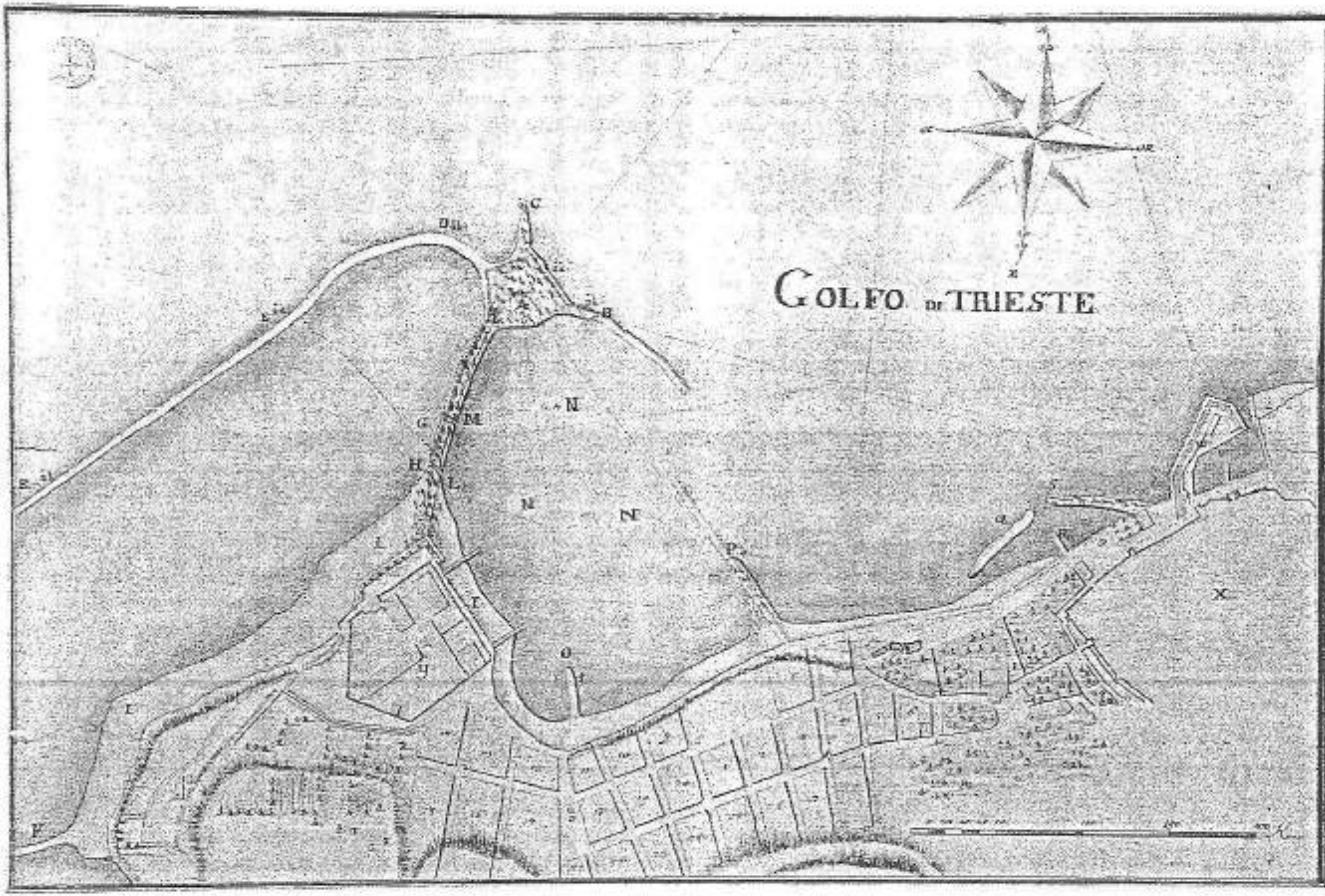

San Simone Izola (SLO)
Livello del mare attuale
0
"La parte superiore portava dei grossi anelli ricordata da Nardini (1700) e dal Kandler"
100
160
200
260
Fondazione ?
280



Modern pier
Ancient pier
m
0.00
- 1.0
- 2.0
Present day m.s.l.
Ring
-1.00 m
Palaeosea level
-1.60+0.6 m
1950 +50 yr BP m.s.l.
m
0
2
4
6



14° 00'
Monfalcone
Isonzo
Trieste
0
0
-0.66
-0.77
Capodistria
Pirano
-0.77
-0.71
45° 30'
Rovigno
45° 00'
-0.77
Pola


GOLFO DI TRIESTE


Marine deposit
Roman age pier


691
692
695
699

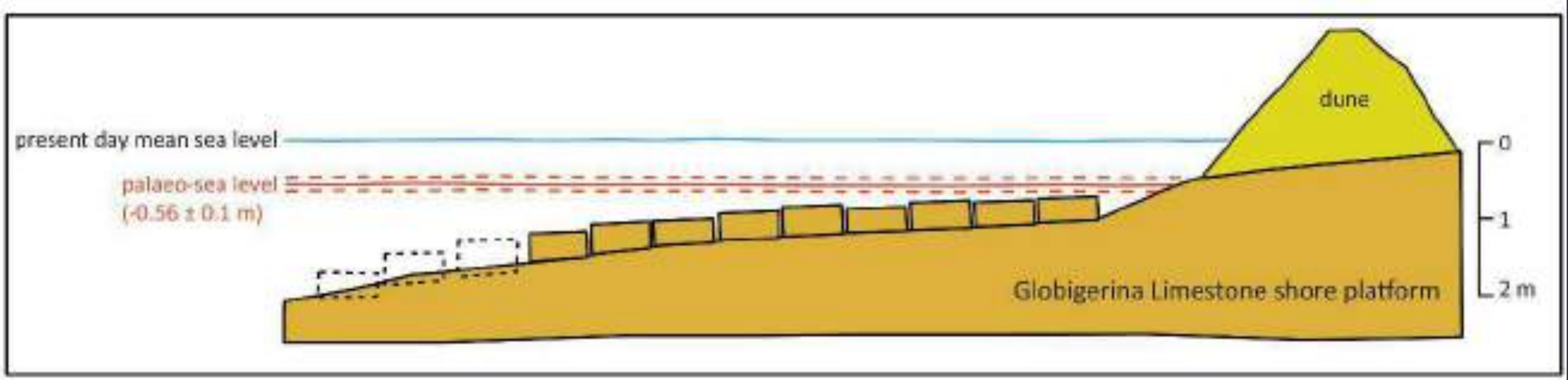
Marsaxlokk


technisub

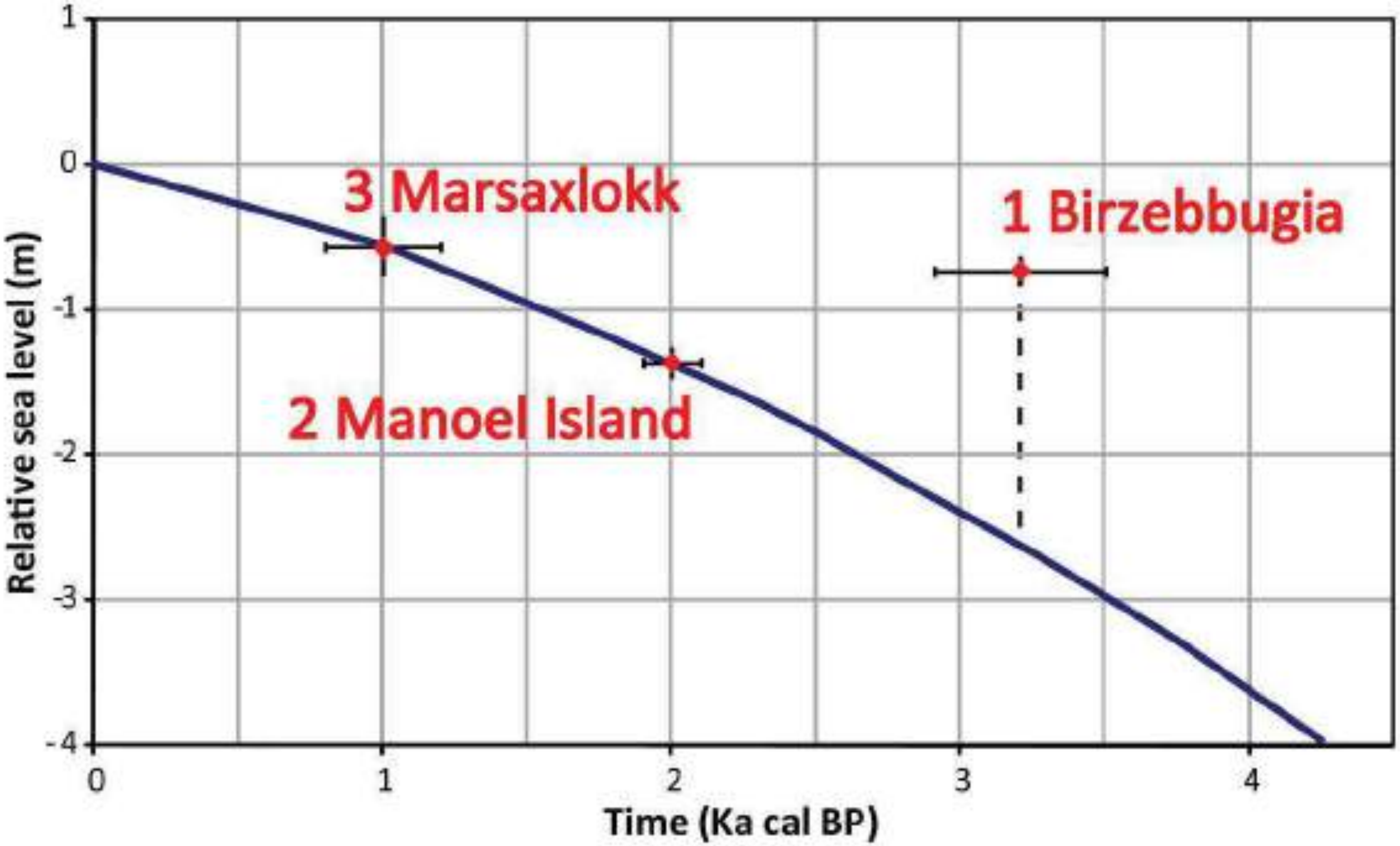
Marsaxlokk

- A complex underwater structure has been found out,

  almost completely ruined
- Middle-Age piers, 12 m long and 0.5 m wide
- Slightly inclined toward the sea
- Top between - 0.6 and - 0.9 m; at the end the depth is - 1.30 m



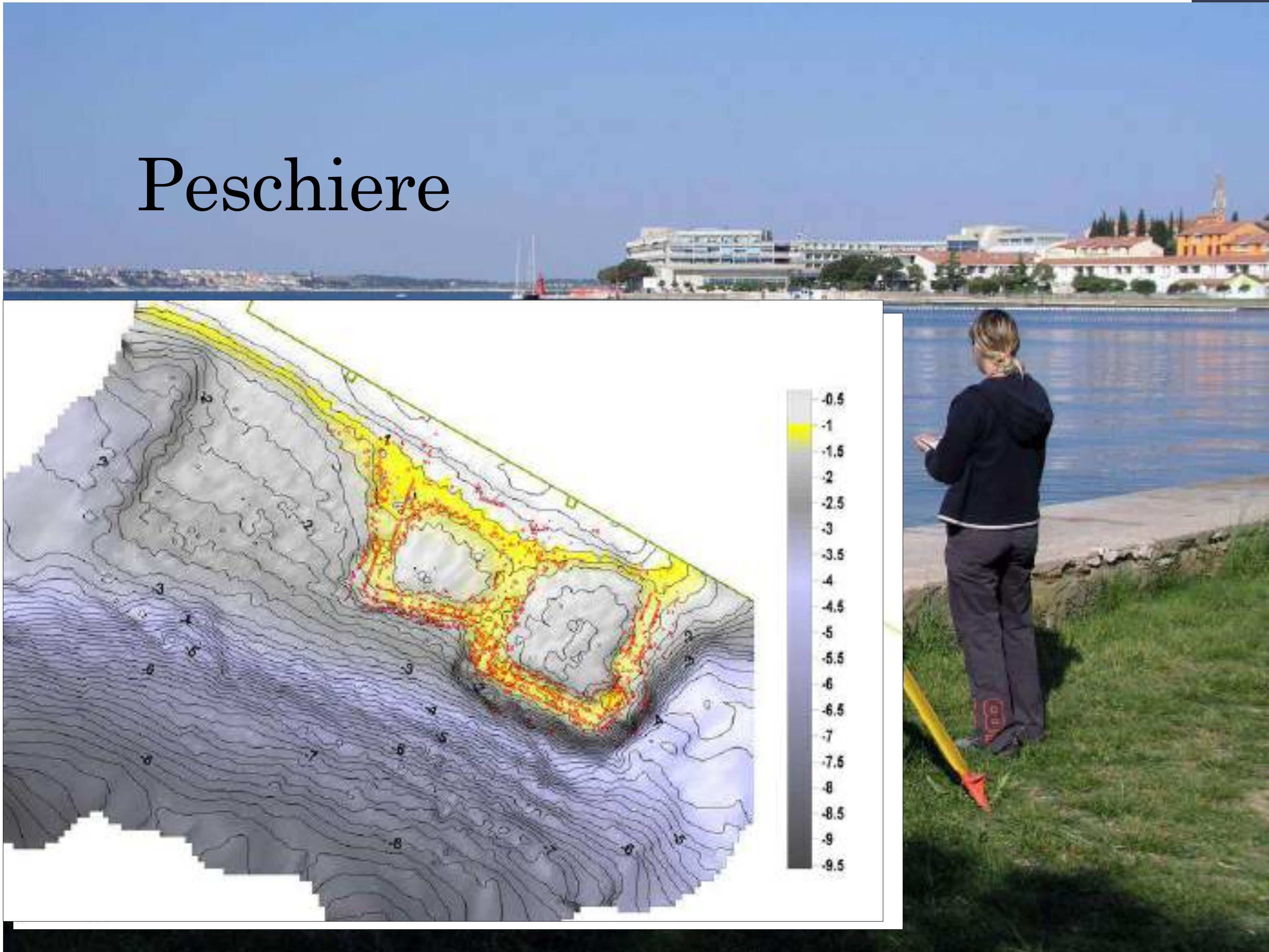
Comparison with the sea level curve



Lambeck et al., 2011

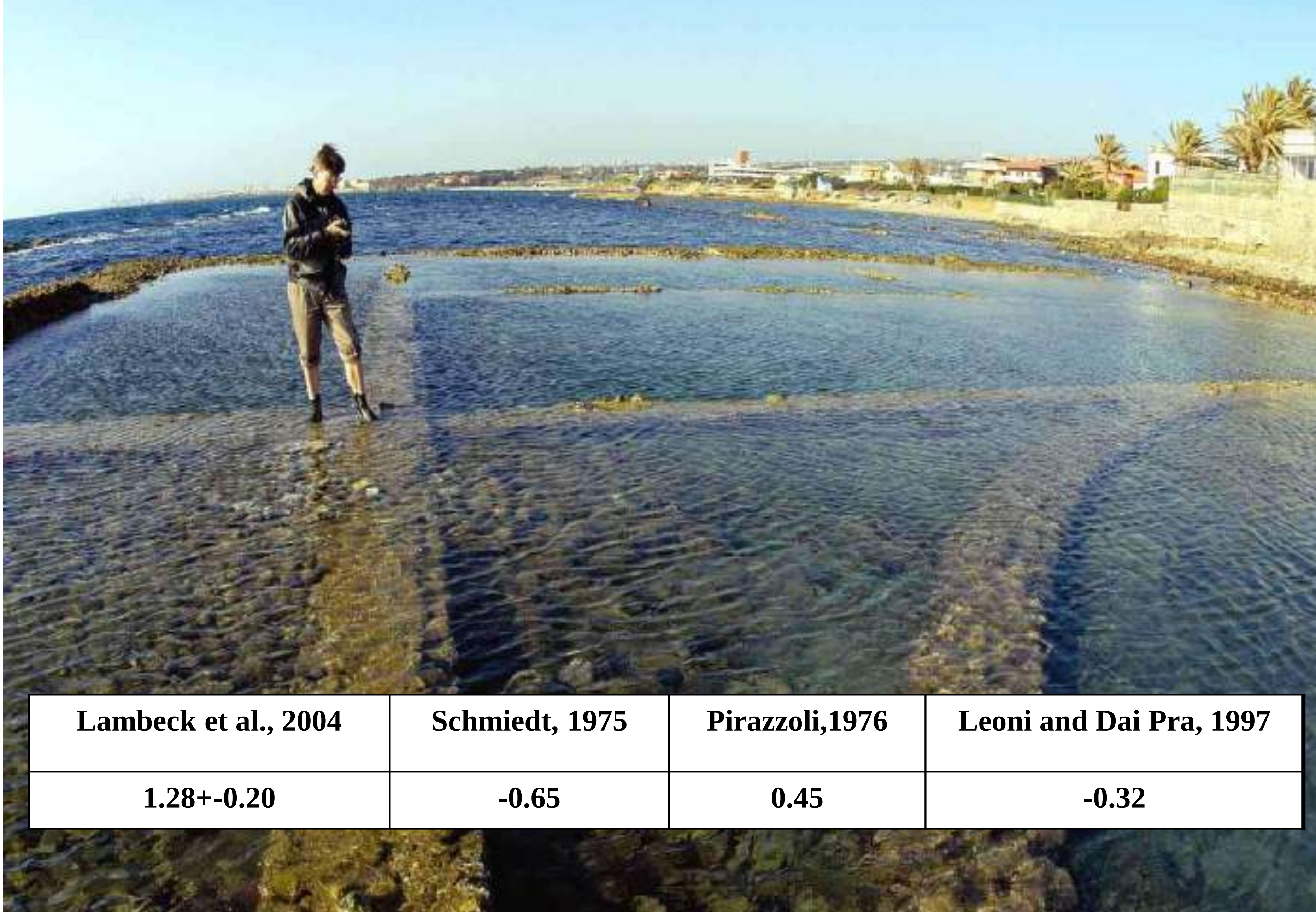

bollard

Peschiere



The tectonic subsidance calculation range betweent -0.5\0.6 mm\yrs in agreement with Istria and Kornati island archaeological remains measurements

Remains of Punta della Vipera: a Roman age fish tank



Lambeck et al., 2004	Schmiedt, 1975	Pirazzoli,1976	Leoni and Dai Pra, 1997
1.28+-0.20	-0.65	0.45	-0.32


Costa

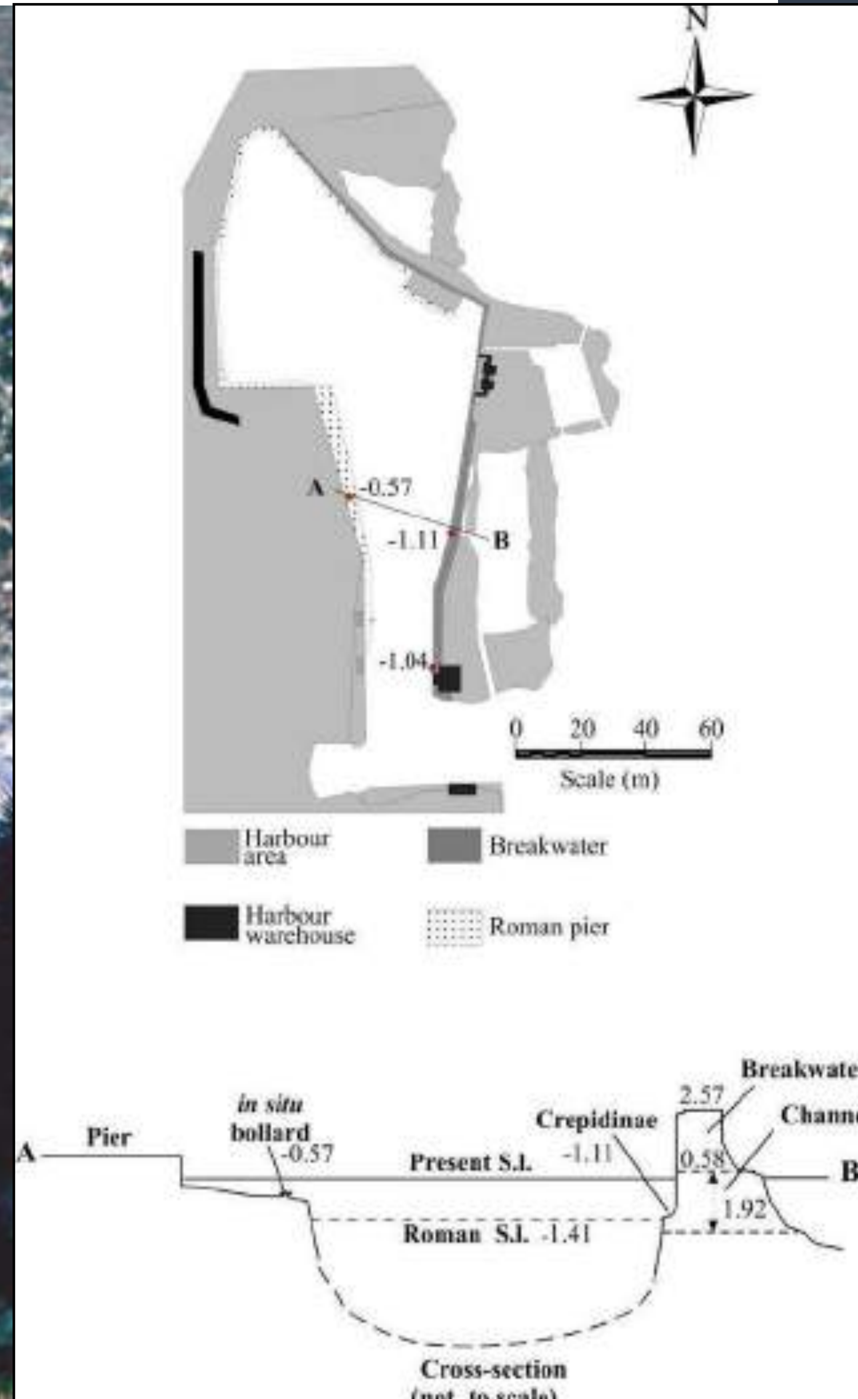

N
A
-0.57
-1.11
B
-1.04
0
20
40
60
Scale (m)
Harbour area
Breakwater
Harbour warehouse
Roman pier
A
Pier
in situ bollard
-0.57
Present S.l.
Crepidinae
-1.11
2.57
Breakwater
Channel
0.58
B
1.92
Roman S.l. -1.41
Cross-section (not to scale)


Image © 2007 DigitalGlobe
© 2007 Europa Technologies
©2005 Google

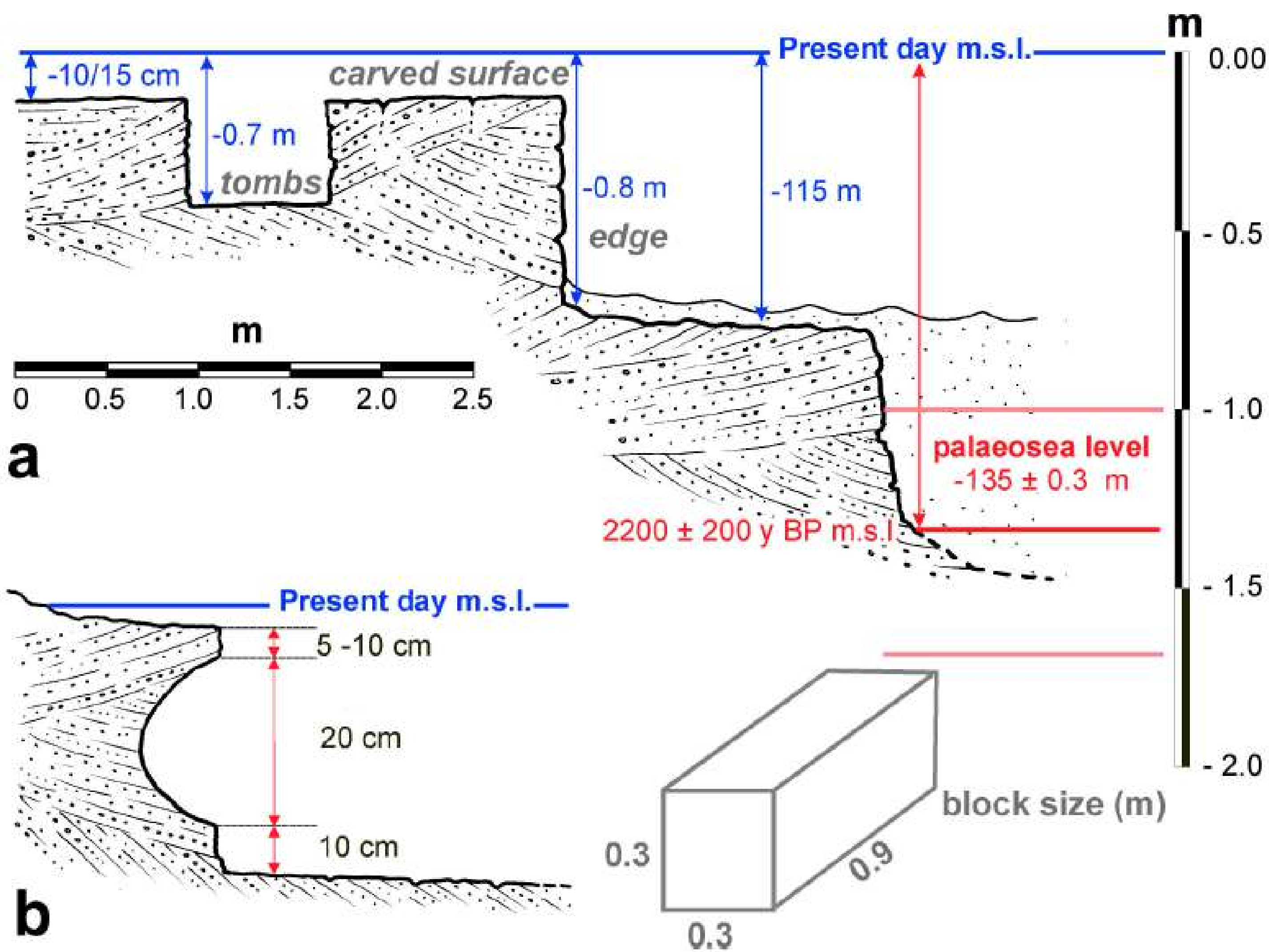
K


Tunisia Hammamet gulf
6

Saltpans

Relative sea level change at 1.3±0.3 m from the Tombs and the quarry

Italy, Central Mediterranean (northern Sardinia, Tharros)

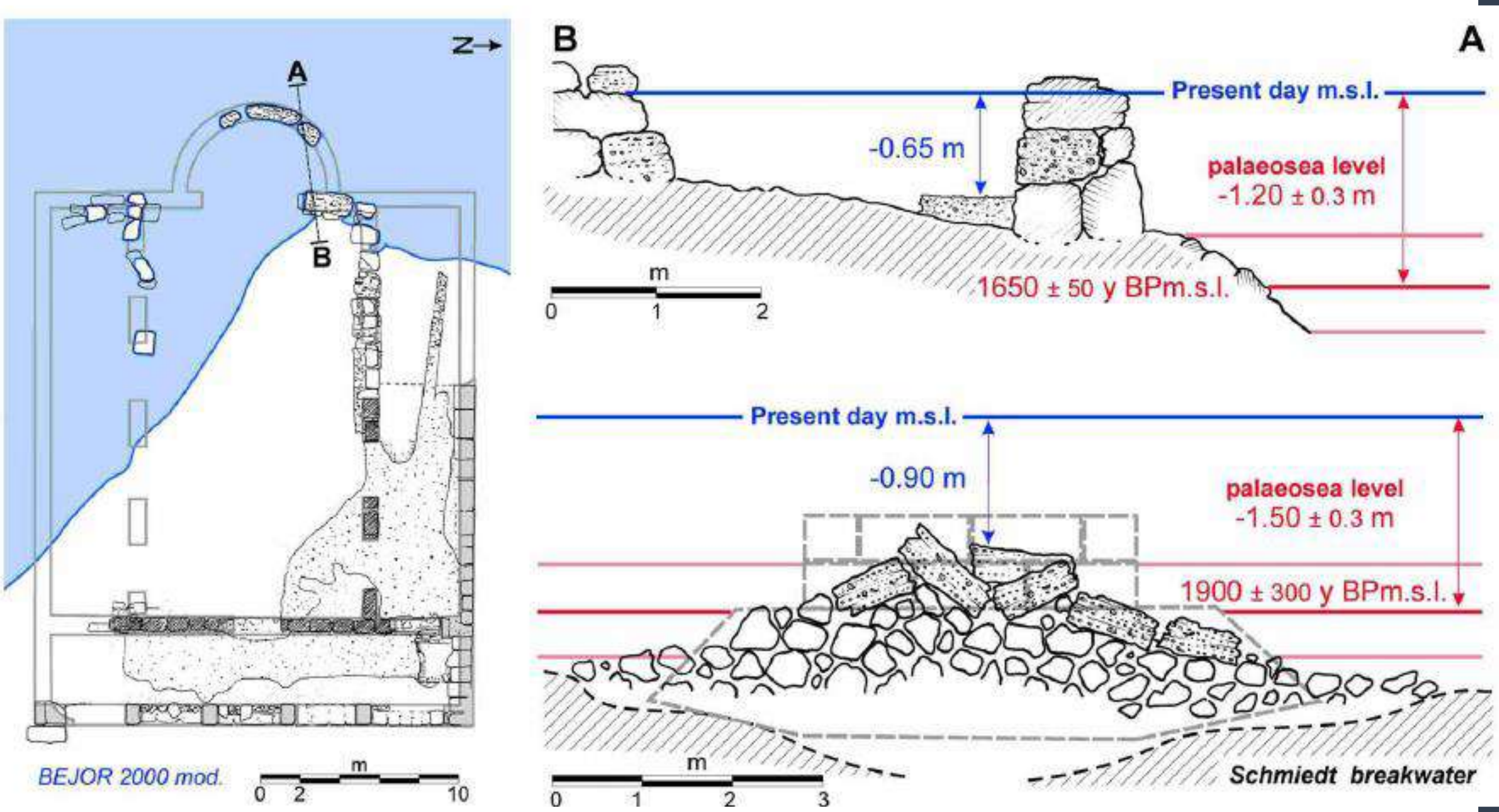


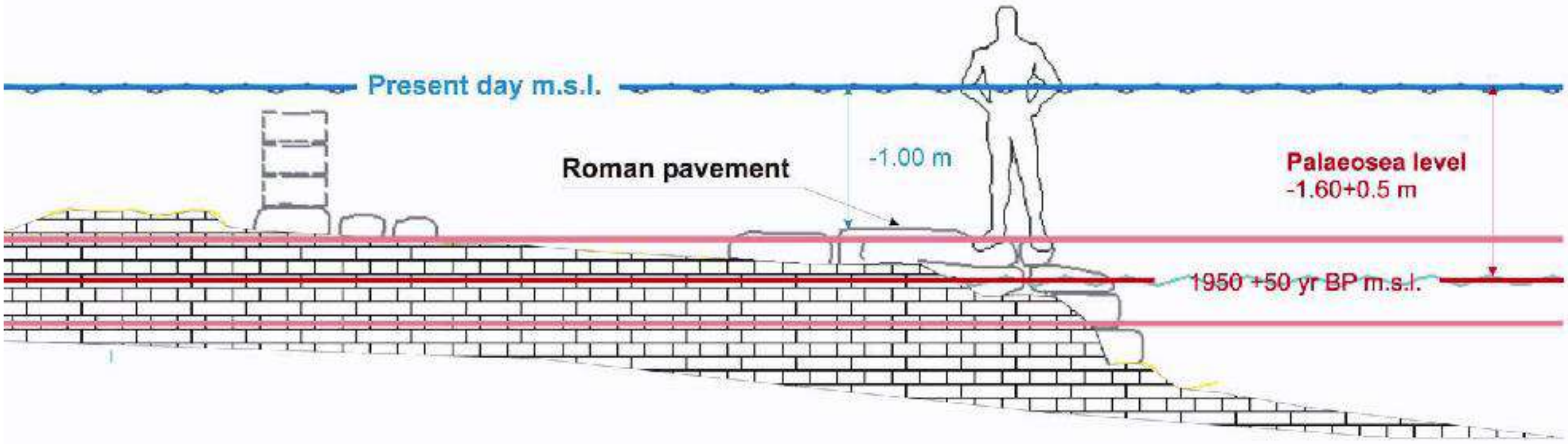

Cnidos
Fetye
Manisa
Izmir
Aydin
Denizli
Usak
Isparta
Nisyros
Yali
Santorini
© 2007 TeleAtlas
© 2007 Europa Technologies
Image © 2007 TerraMetrics
©2005 Google

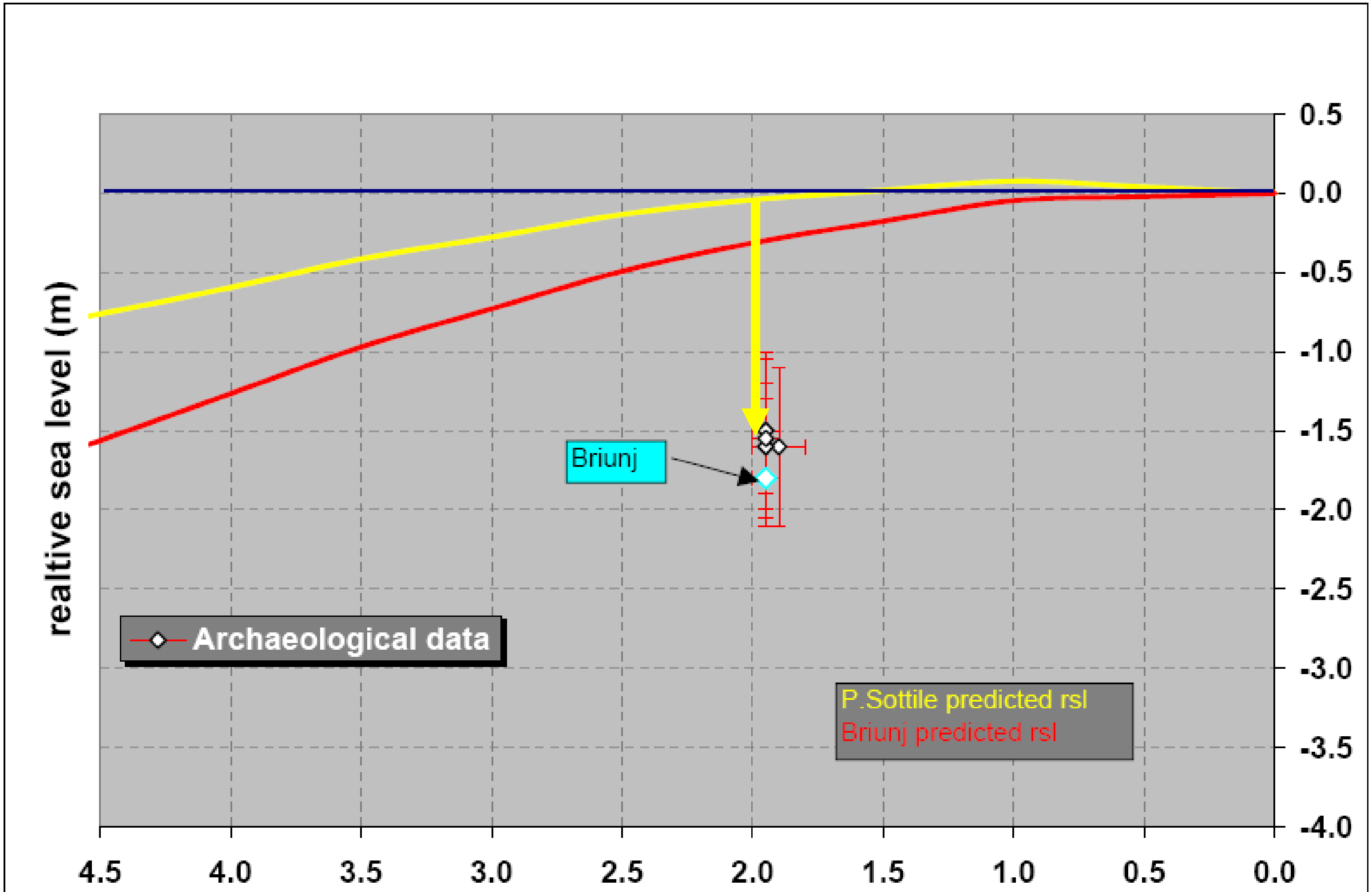

Mount Baba
Baba Dagi
Belceglz Korfezi
Image © 2007 DigitalGlobe
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Google

Turkey,

Italy, Central Mediterranean (southern Sardinia, Nora)




Present day m.s.l.
-1.00 m
Roman pavement
Palaeosea level
-1.60+0.5 m
1950 +50 yr BP m.s.l.

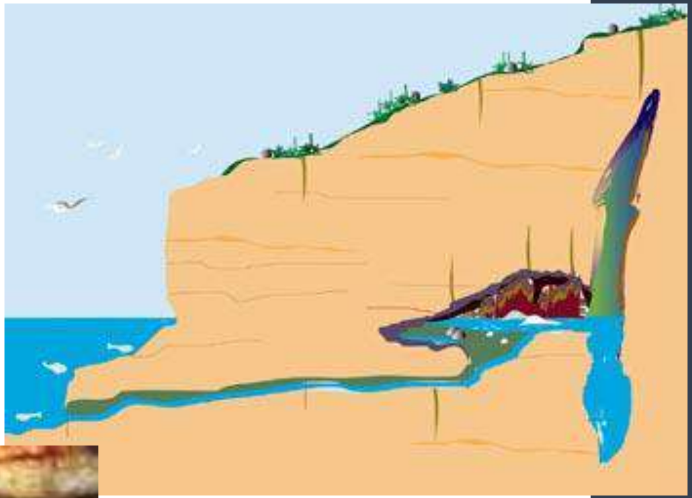


0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
realtive sea level (m)
time (×1000 cal years BP)
Briunj
Archaeological data
P.Sottile predicted rsl
Briunj predicted rsl

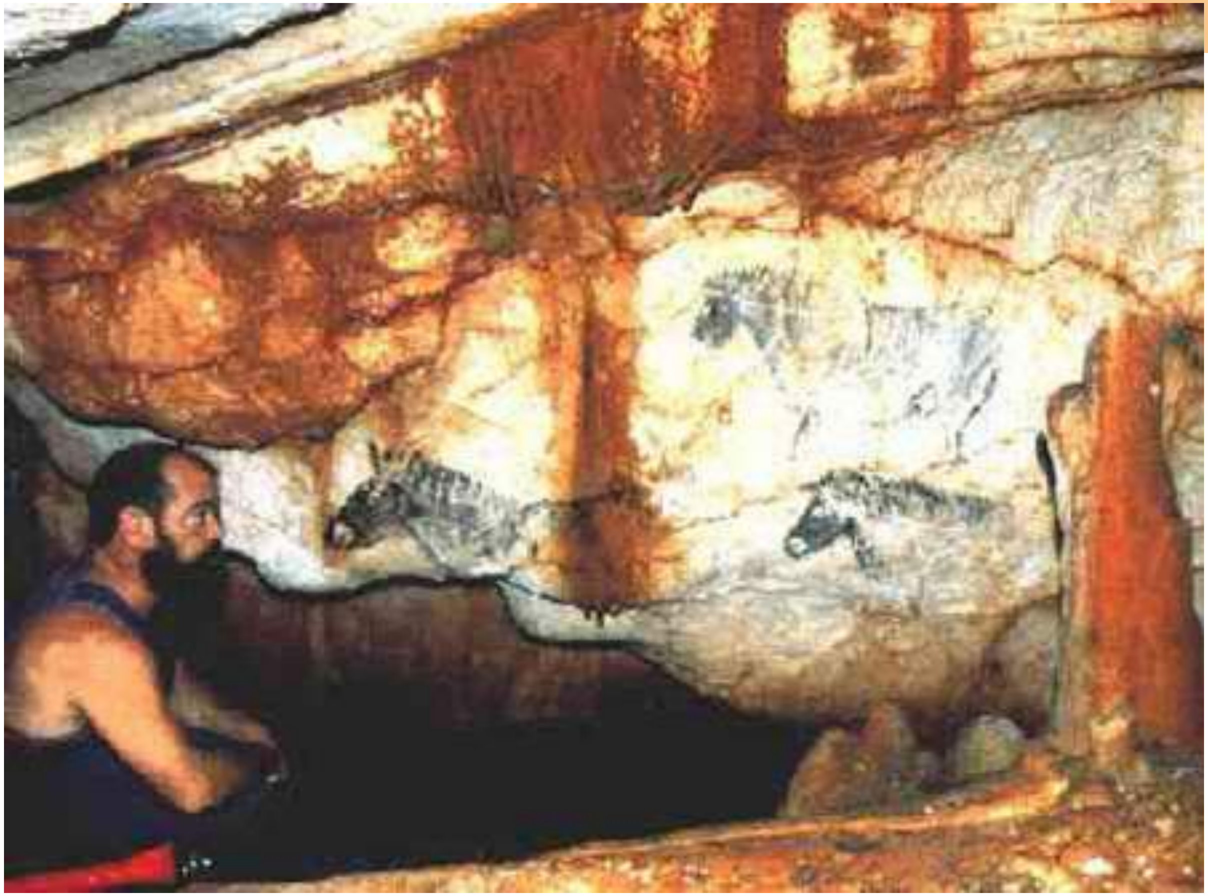
Fig 11

Submerged mo

Prehistoric GRAFFITI

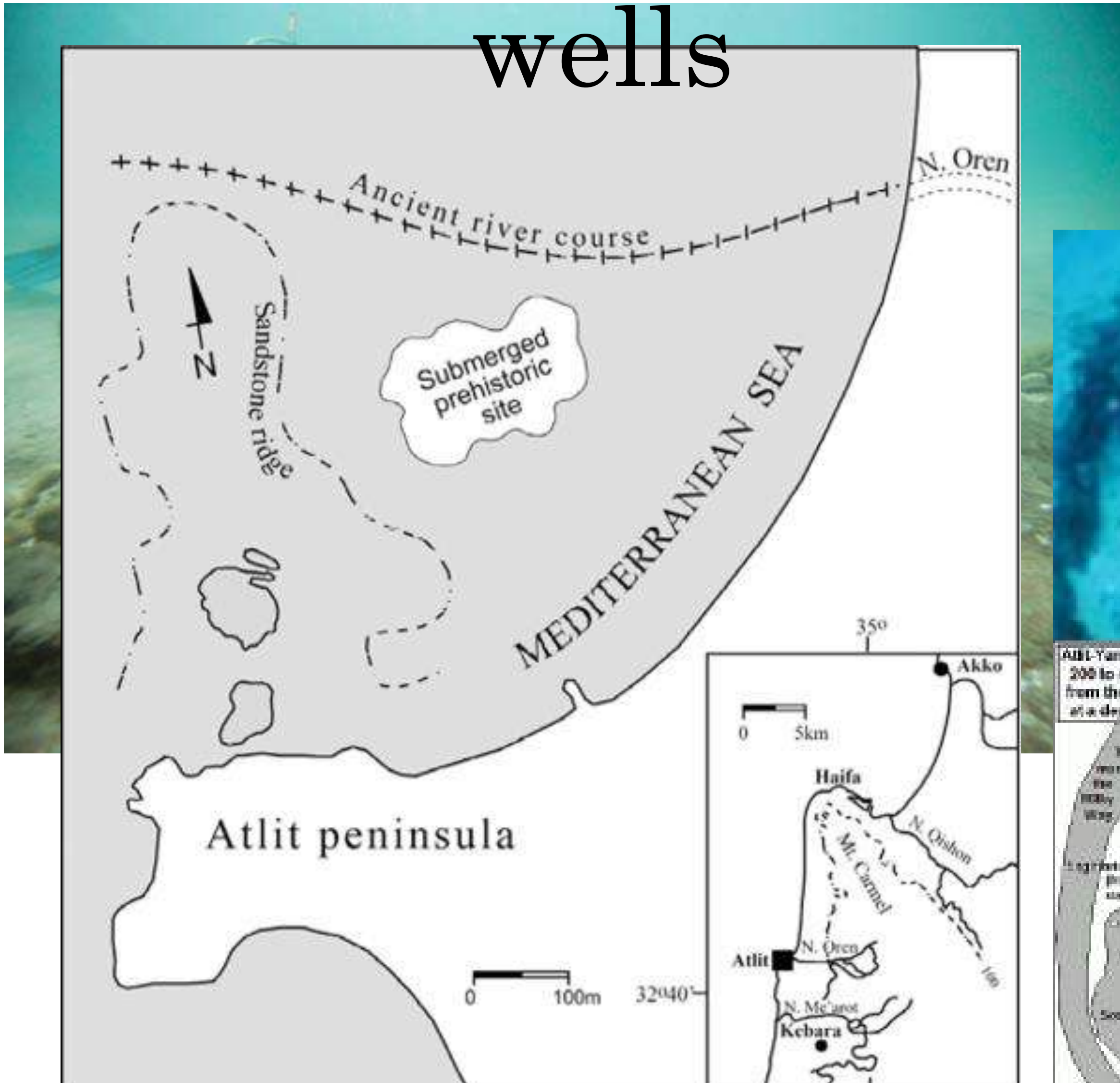


Cosquer Cave



Submerged water wells

Israel



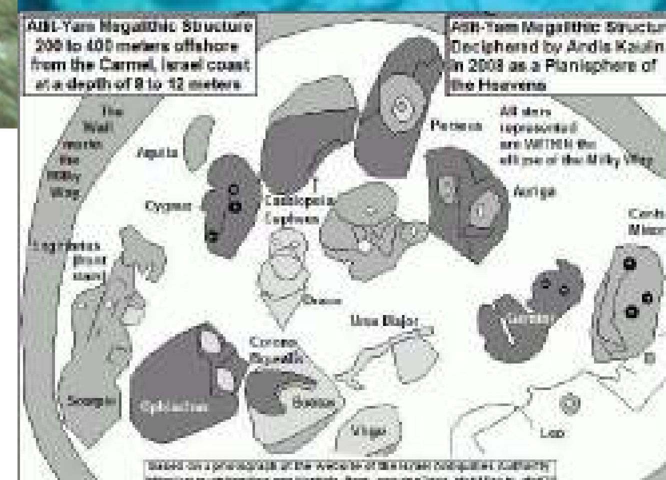
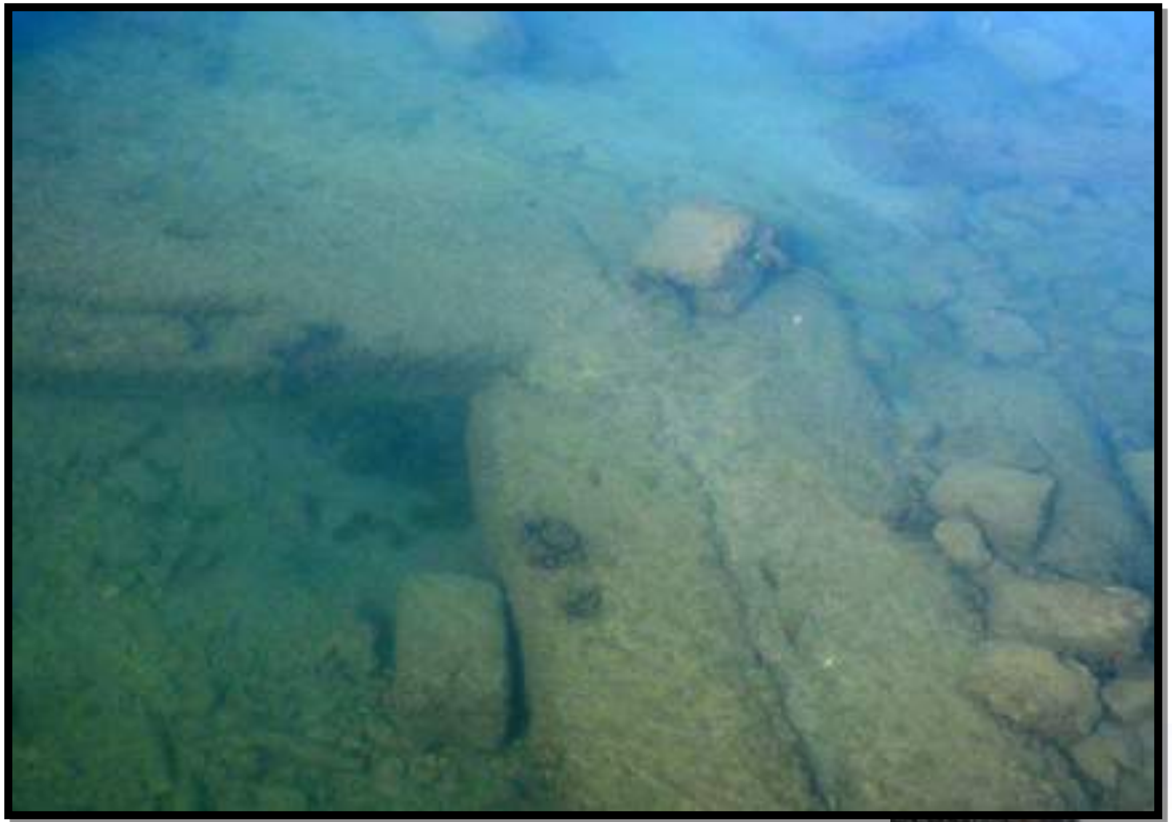


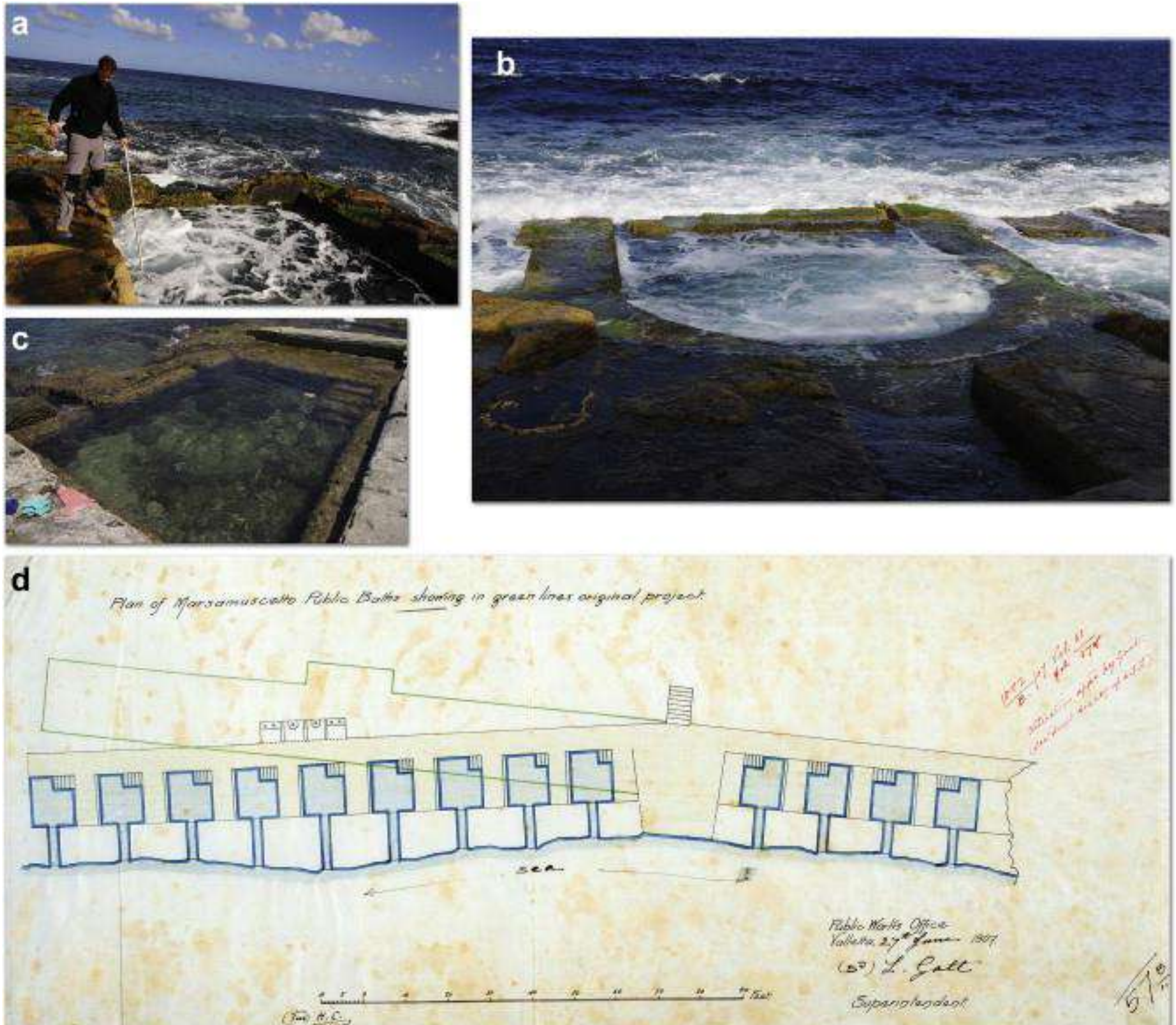
Photo J. Benjamin

Cart ruts Malta

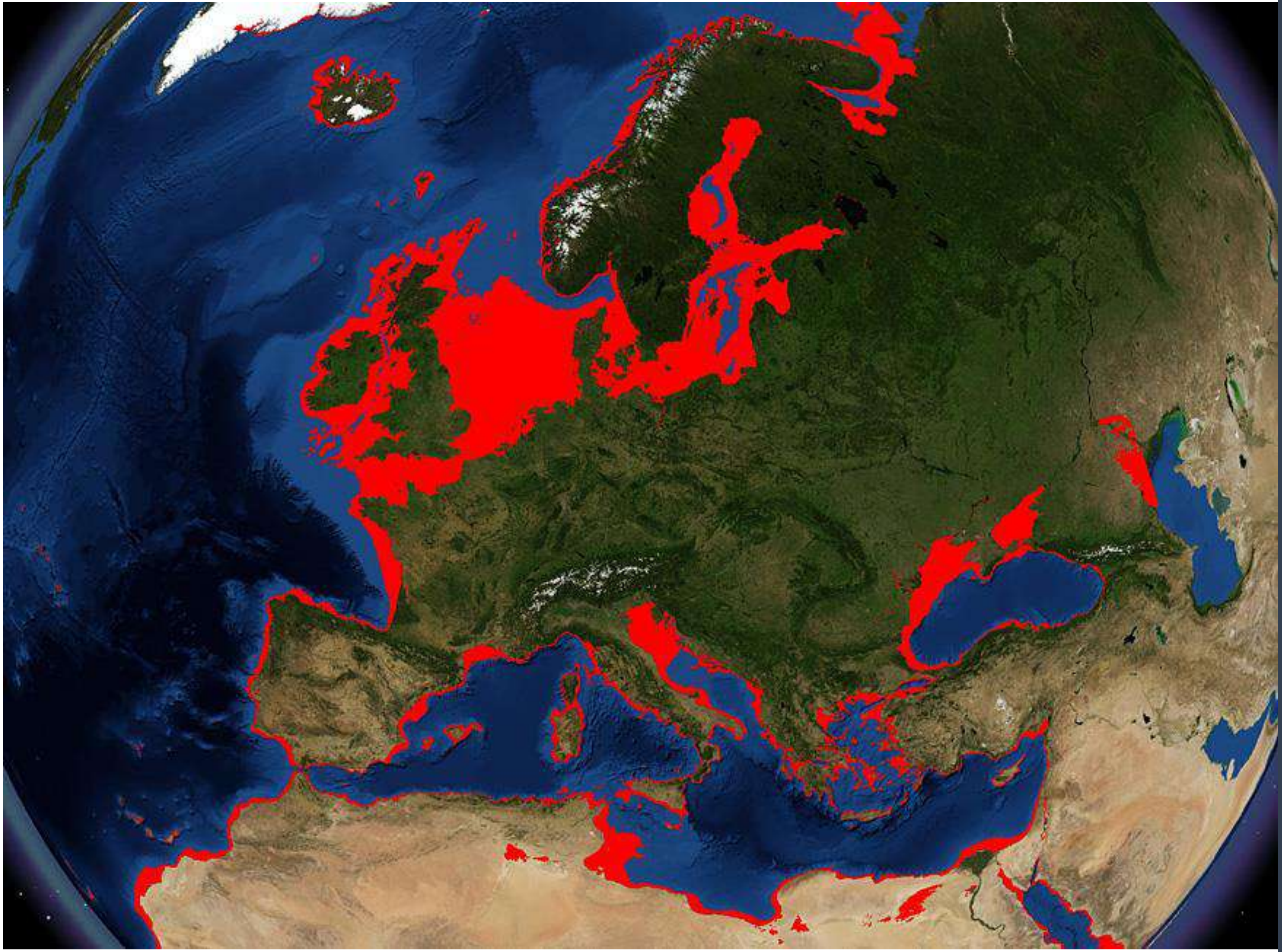


Victorian Age baths

- The submerged tanks are different from any swimming baths datable to the 19th century


a
b
c
d
Plan of Marsamuscetto Public Baths showing in green lines original project.
sea
Public Works Office
Valletta, 27th June 1907.
(Sd) L. Galt
Superintendent
Feet

Alcune considerazioni finali



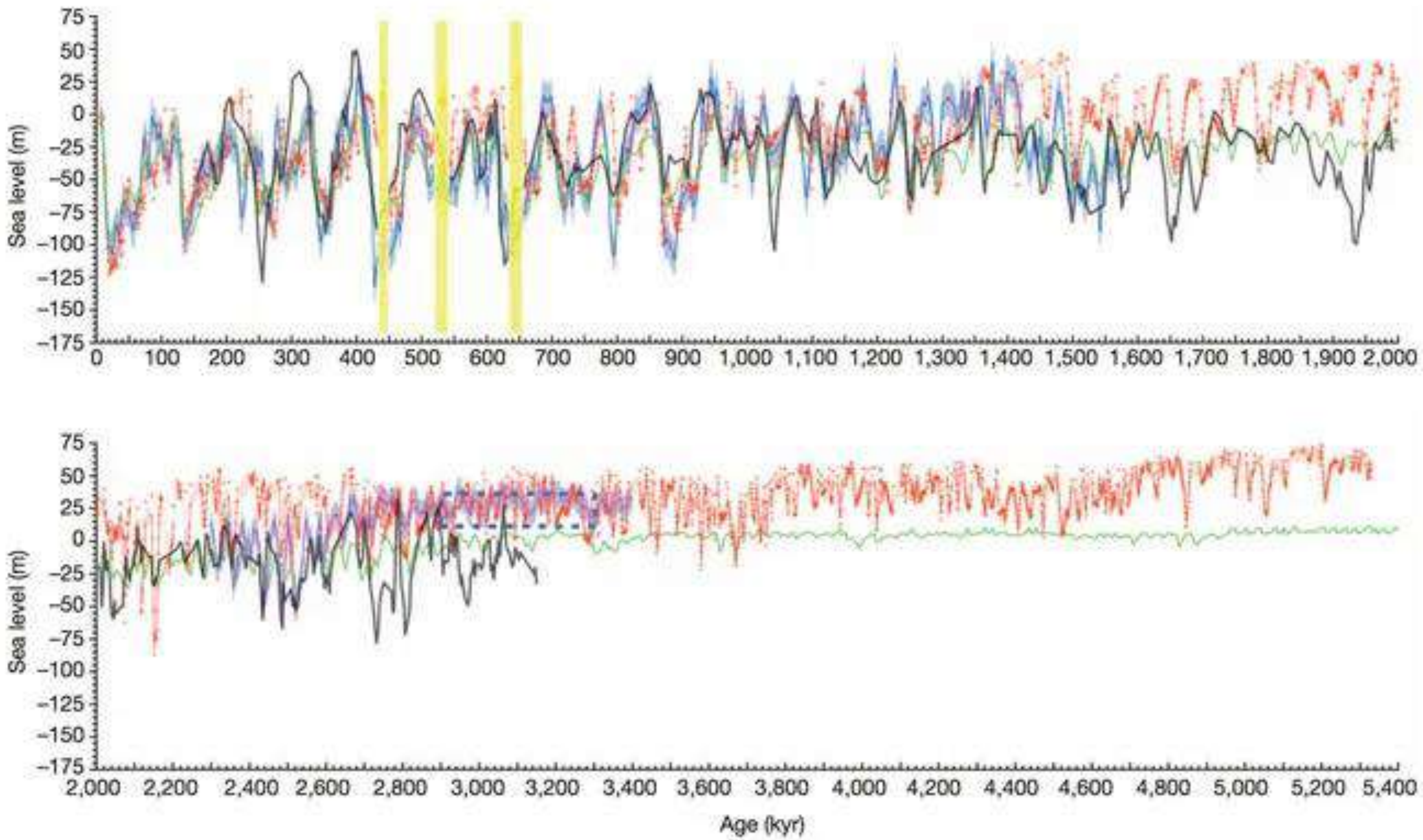
Climex maps Italy, Vai et al., 2004

s.l. during LGM -149m

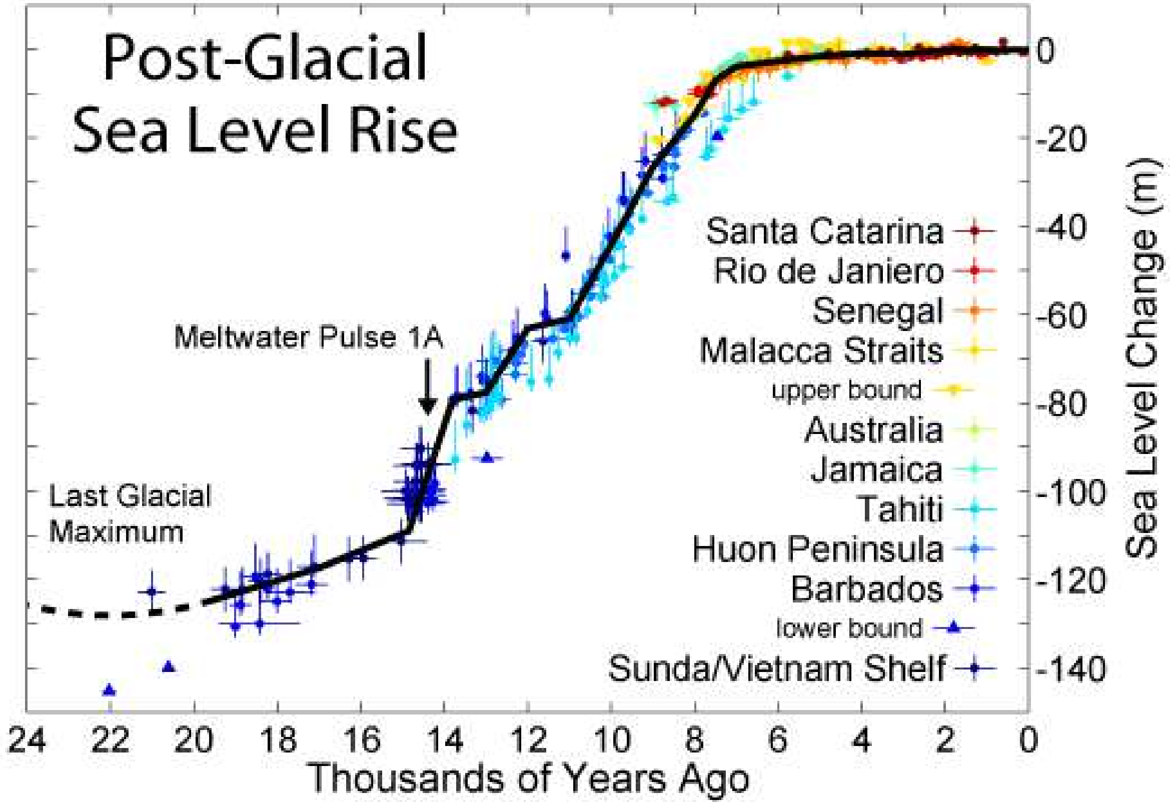
Una lunga storia…

- 215.000 years ago the sea level was at -18 m;
- 125.000 years ago the sea leval was at +8 m;
- 81.000 years ago the sea level was at -25 m;
- 21.000 years ago the sea level was at -135 m;
- 2500 years ago the sea level was at -1.8 m;
- 2000 years ago the sea level was at -1.3 m;
- 1.000 years ago the sea level was at -0.3 m

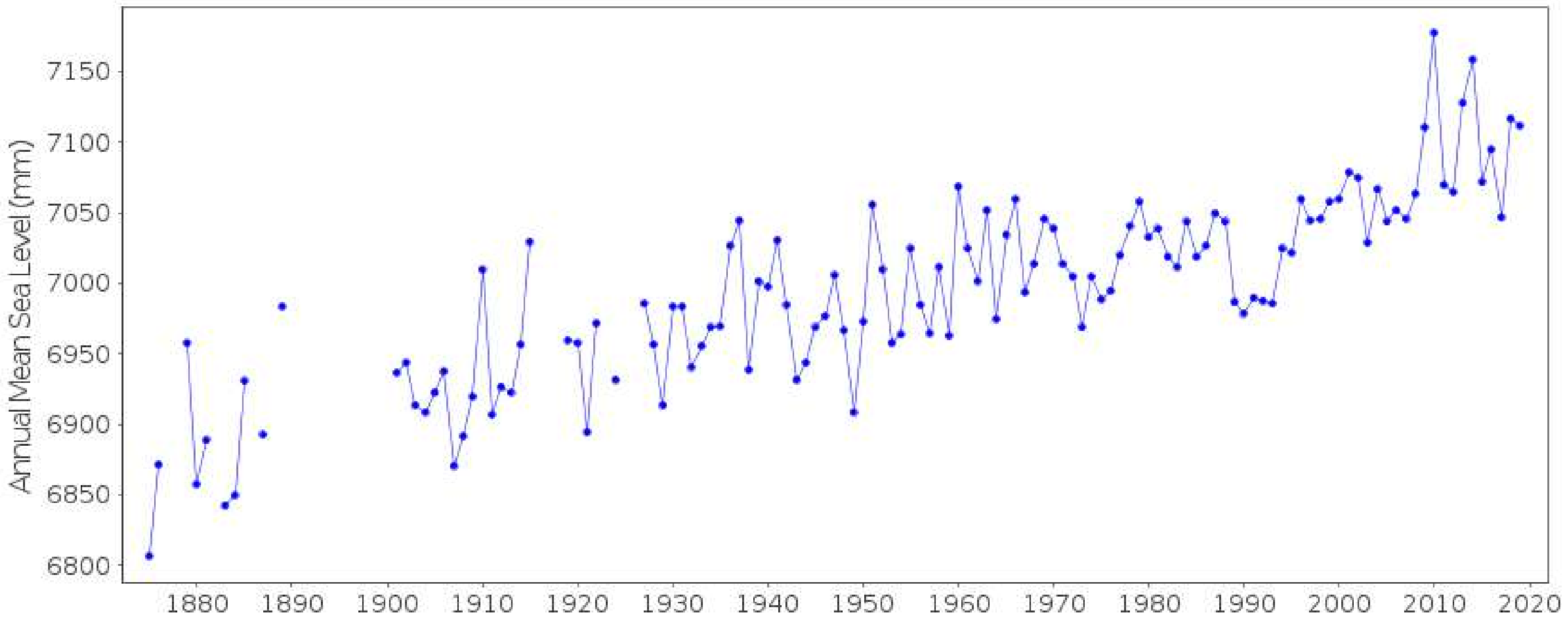
Sle in the geological history



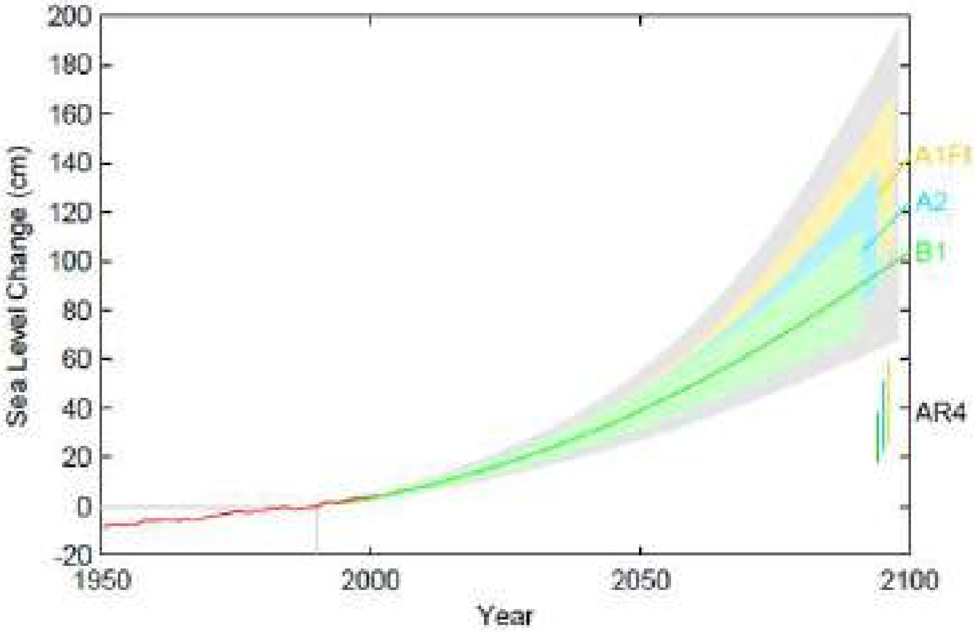
Post-glacial sea level rise



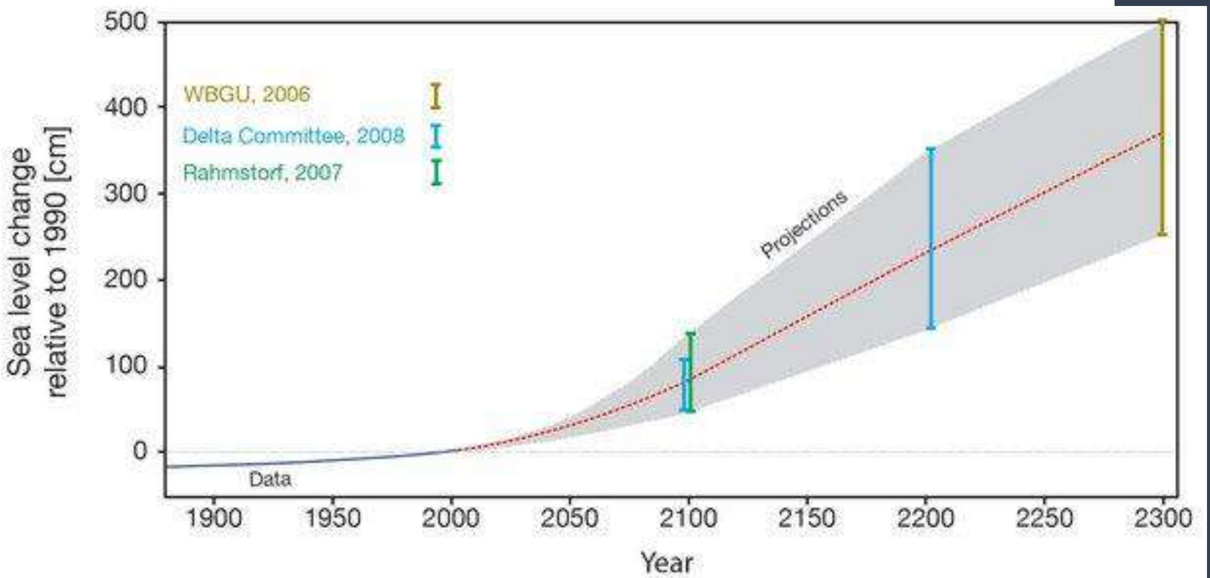
The tide gauge in Trieste

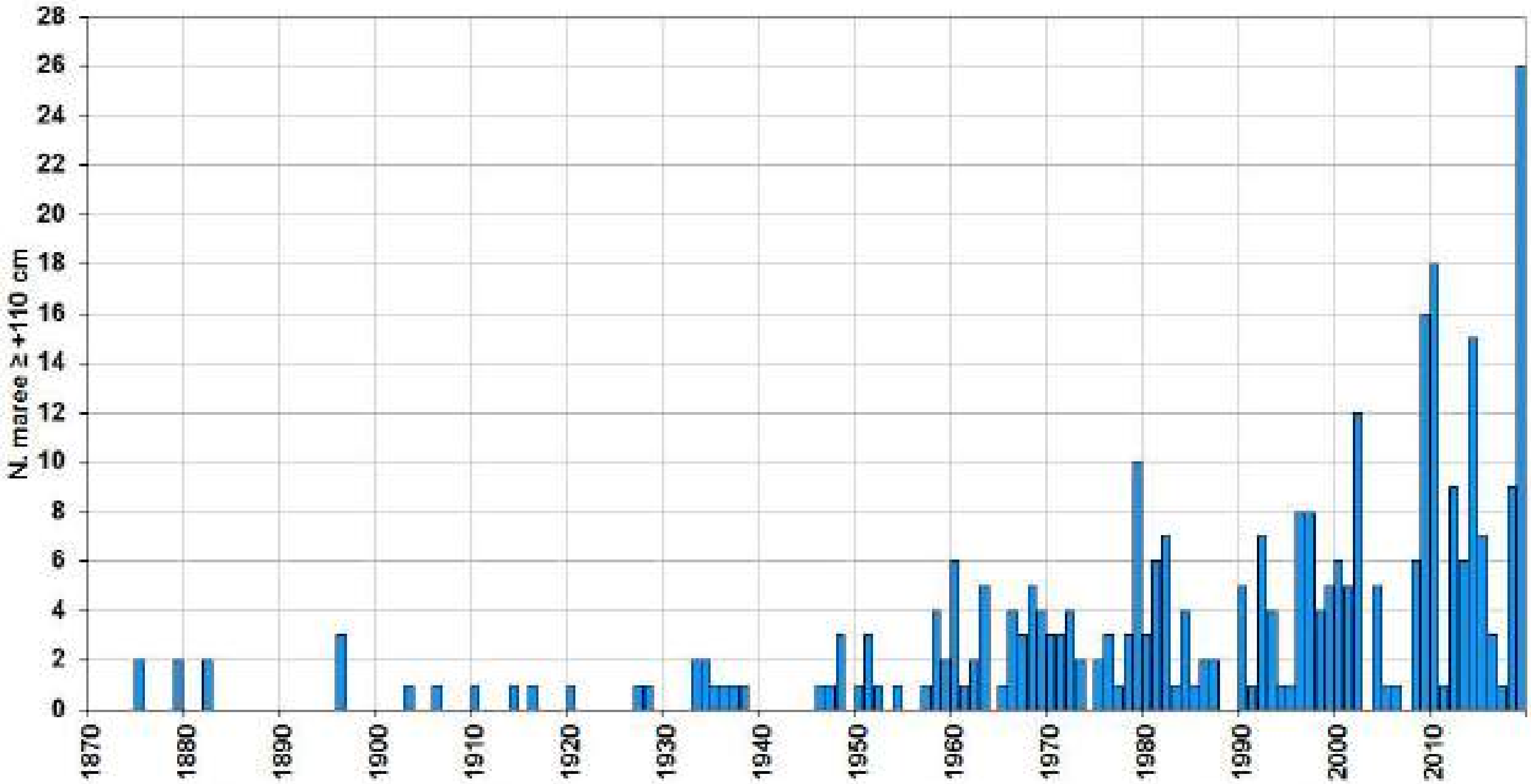


From: PSMSL (Permanent Service for mean Sea Level)



Projections of slr in the future





Distribuzione annuale delle alte maree >= +110 cm registrate a Venezia, dal 1872 al 2019

Yearly distribution of high tides >=+110 cm recorded in Venice, from 1872 to 2019

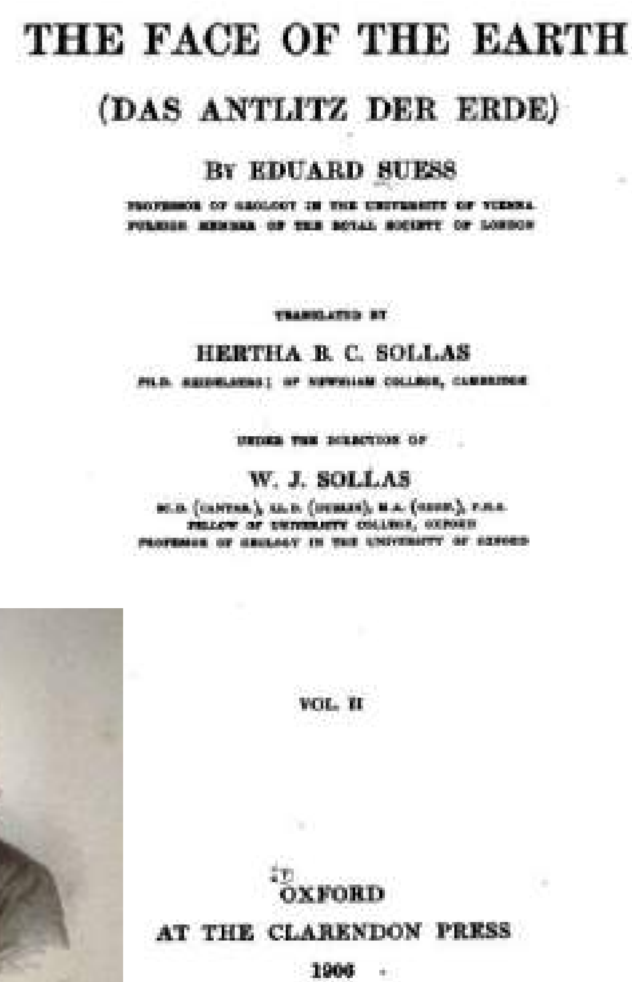
Centro Previsioni e Segnalazioni Maree

THE UPS and DOWN of eustasy

Eustasy: a global model of sea level change

- Suess (1880) proposed the eustatic model of sea level change

- it is the phenomenon of raising or lowering the average sea level on a global scale, that is, not dependent on local phenomena



THE FACE OF THE EARTH

(DAS ANTLITZ DER ERDE)

BY EDUARD SUESS

TRANSLATED BY

HERTHA B. C. SOLLAS

UNDER THE DIRECTION OF

W. J. SOLLAS

VOL. II

OXFORD

AT THE CLARENDON PRESS

1906

Come misurare le variazioni del livello del mare?

The past

- Sea level markers
    - Archaeological
    - Geological/geomorphological
    - Sedimentological
    - Others

The present

- Instrumental data
  - Tide gauges
  - Satellites

The future

- During the last 100 years the sea level rised 18 cm

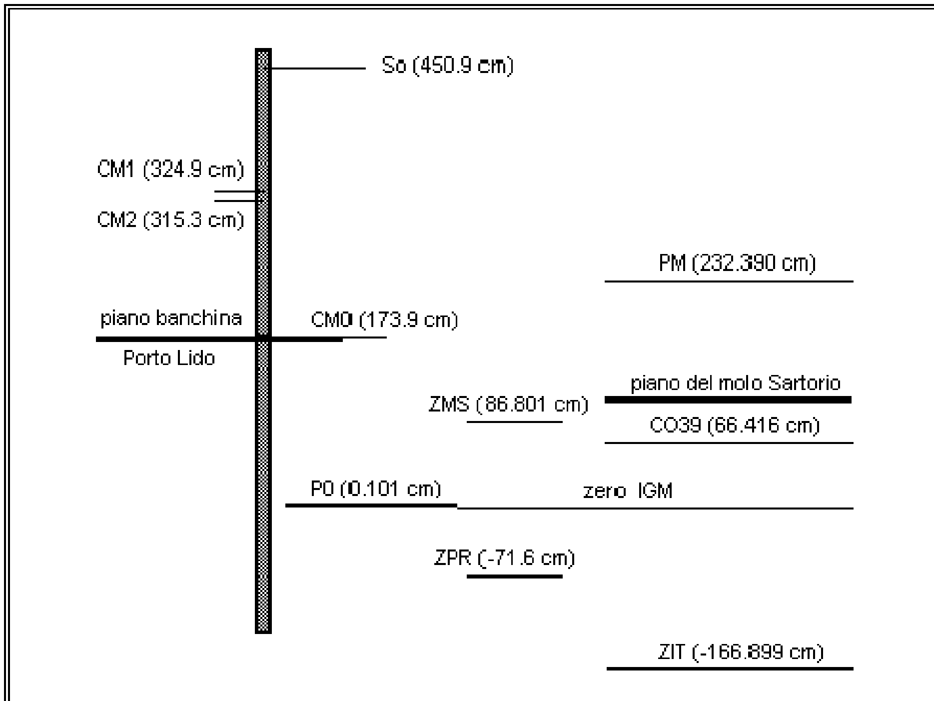
- it could rise by more than 1 m in 2100, due to global warming

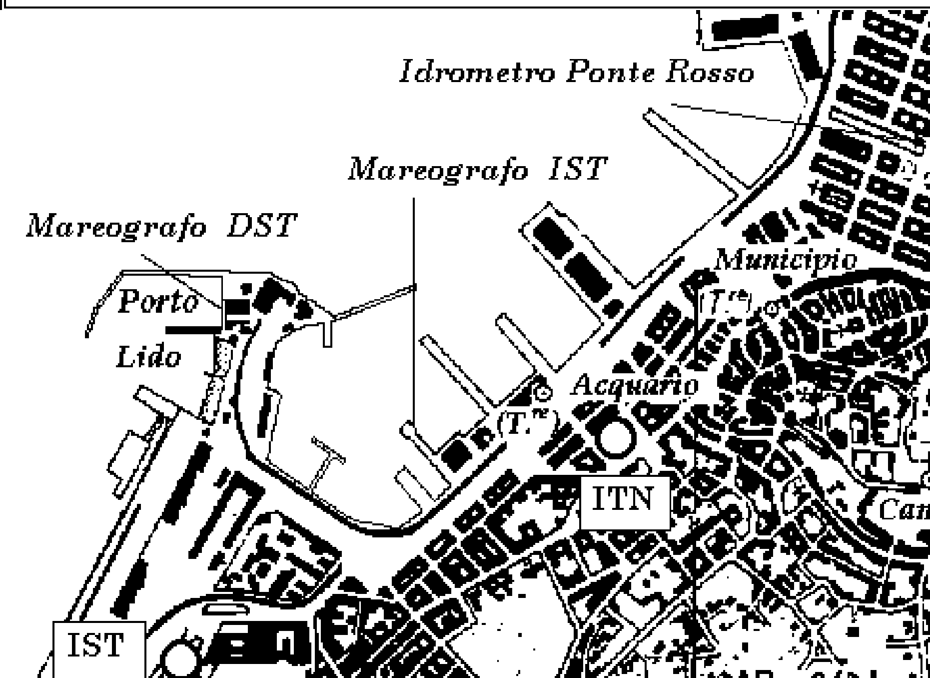
Let’s start from the sea level…
How can be defined the mean sea level?

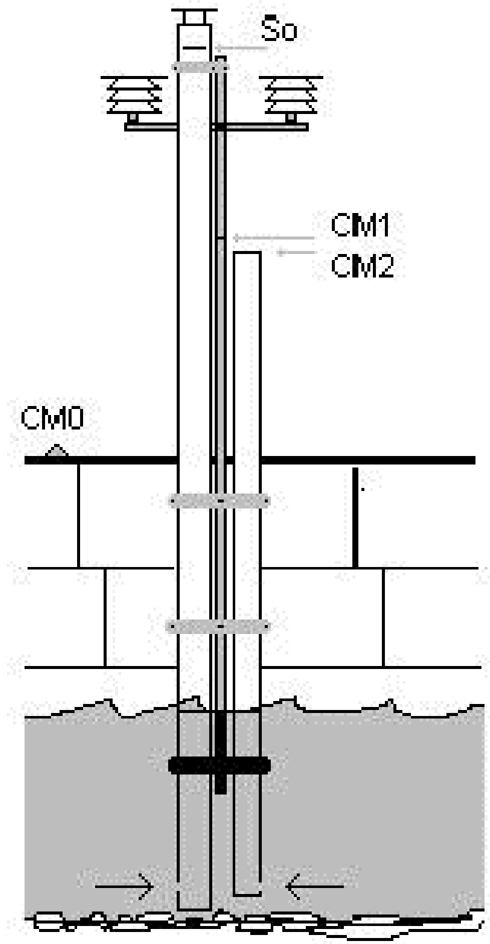
- Sea surface can be considered an unstable entity, because of tides, waves, pressure, winds, temperature and salinity variations, …;
- …after filtering all the periodic (eg. Tides) or random movements, the mean sea level can be calculated;
- The altitude above or below the mean sea level of every nation corresponds to a particular reference level, a conventional tide gauge;
- in Italy Genova, in France Marseille, etc.

Tide gauge, Trieste (NE Italy)

Tide gauge, Marseille (France)


So (450.9 cm)
CM1 (324.9 cm)
CM2 (315.3 cm)
PM (232.390 cm)
piano banchina
Porto Lido
CM0 (173.9 cm)
piano del molo Sartorio
ZMS (86.801 cm)
CO39 (66.416 cm)
P0 (0.101 cm)
zero IGM
ZPR (-71.6 cm)
ZIT (-166.899 cm)


Idrometro Ponte Rosso
Mareografo IST
Mareografo DST
Municipio
Porto Lido
Acquario
ITN
IST


So
CM1
CM2
CM0

Natural or human-induced?

The question:

What is the sea level rise?

The sea level rise represents an increase in global mean sea level due to an increase in the volume of water in the world's oceans

Sea level rise is mainly attributed to changes in global climate by thermal expansion of the oceans and by melting of ice sheets and glaciers on land

The melting of icebergs at sea would raise sea levels only by about 4 cm

Sea level changes are considered relative variations due to the sum of eustatic, tectonic and isostatic factors

The total amount of water in the oceans

- It depends from the global hydrological balance that is the sum of the following parameters:

  - A+O+L+R+M+B+S+U+I=k

- **K is a constant**

- A=atmospheric water (13000 **km3**, 36 mm EWD*)
- **O=Oceans and seas (1370*106, 3.8 km)**
- L=Lakes and reservoirs (125000, 35 cm)
- R=Rivers and channels (1700, 5 mm)
- S=Swamps (3600, 10 mm)
- B=Biological water (700, 2 mm)
- M=Moisture in soils, unsaturated zone (65000, 18 cm)
- **U=Ground water (4-60*106, 11-166 m)**
- **I=Frozen water (32.5*106, 90 m)**

- An increasing of 1°C (on 4.000 m) produces a sea level rise of 60 cm;

- A variation in salinity of 4 psu produces the same result;

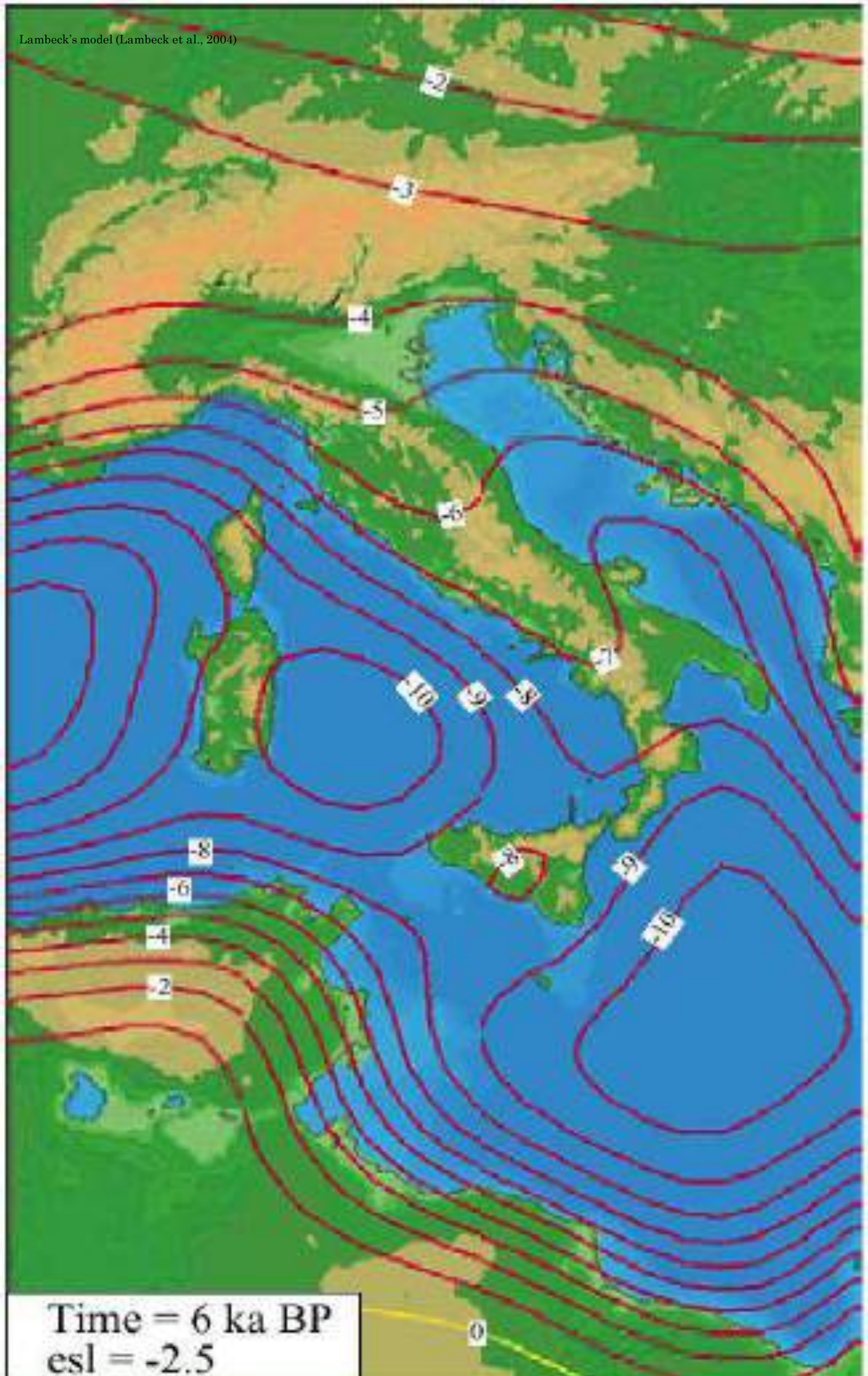
- These effects are higher along the coasts, because of the effects of fluvial input of freshwaters;

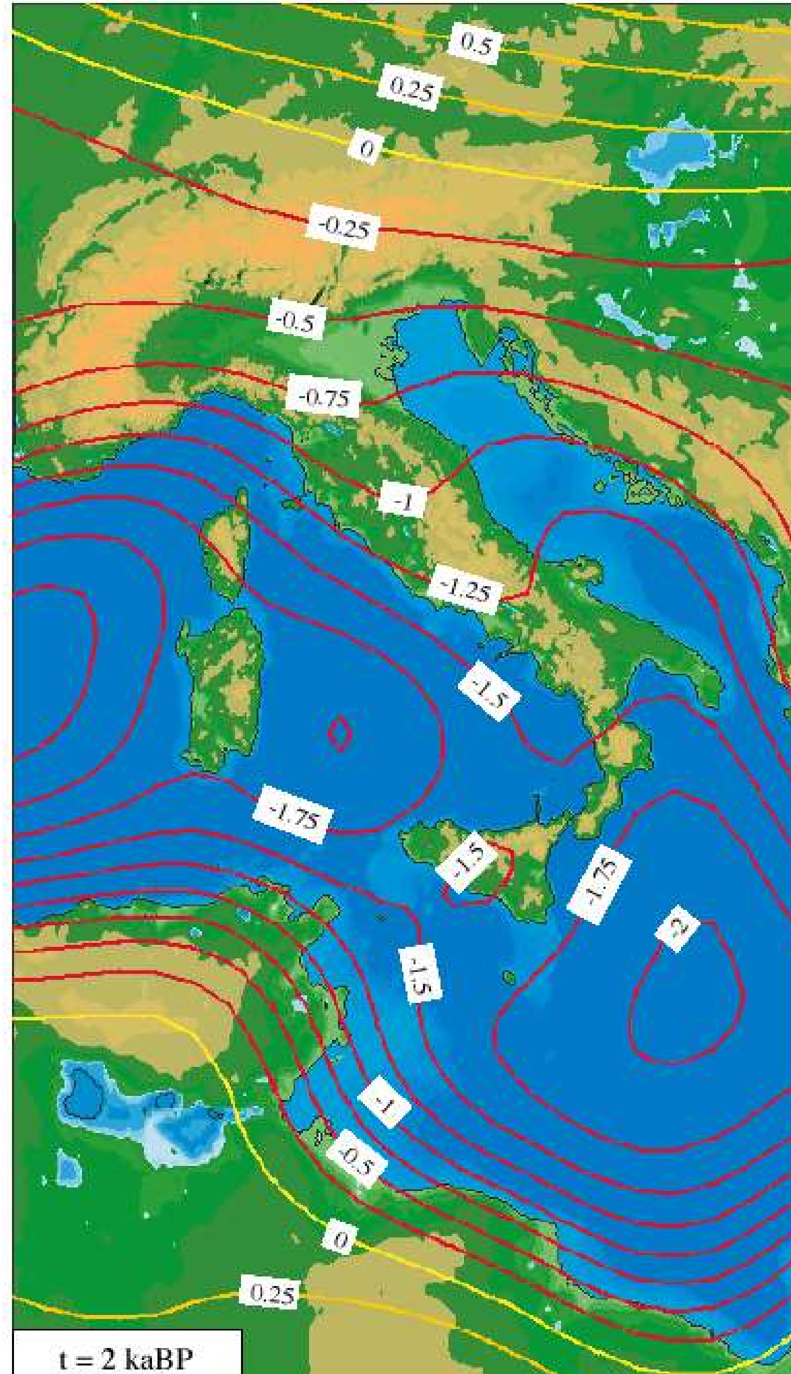
- During LGM, the sea was more salty (36 psu instead of 35) and cooler, therefore it was denser than nowadays.

Sea level rise implications

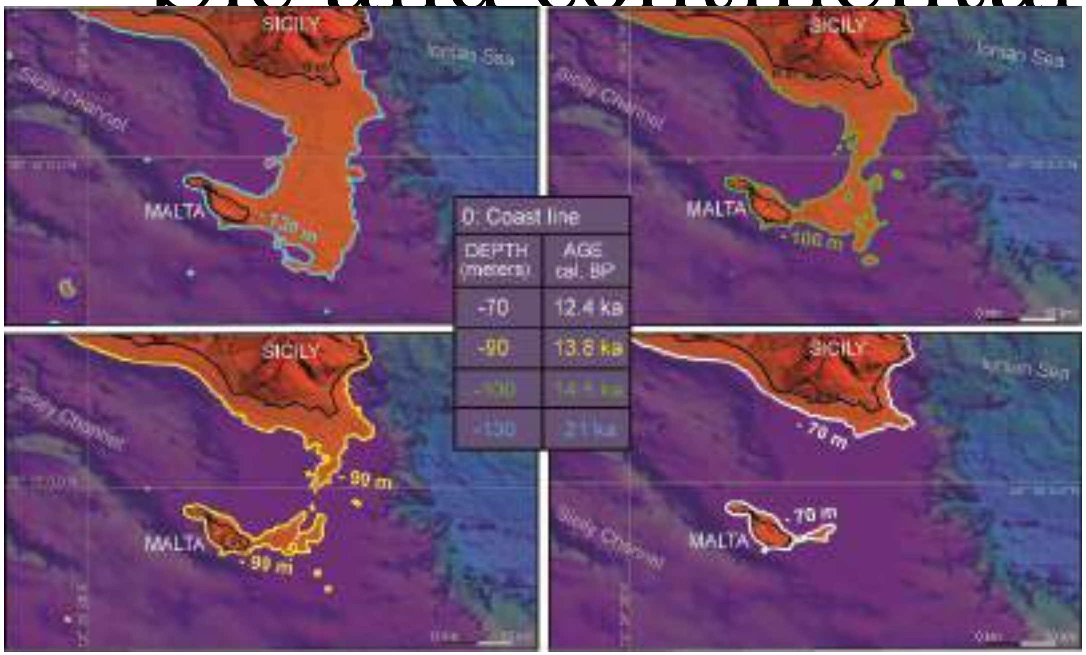
The main impacts of sea level rise are:

- land loss and increased coastal erosion;
- increased risk of flooding during extreme events;
- increasing groundwater levels up to several kilometers inland;
- salt water intrusion;
- coral reefs and coastal ecosystems, such as mangrove forests, turtle nesting beaches or coastal wetlands in danger.

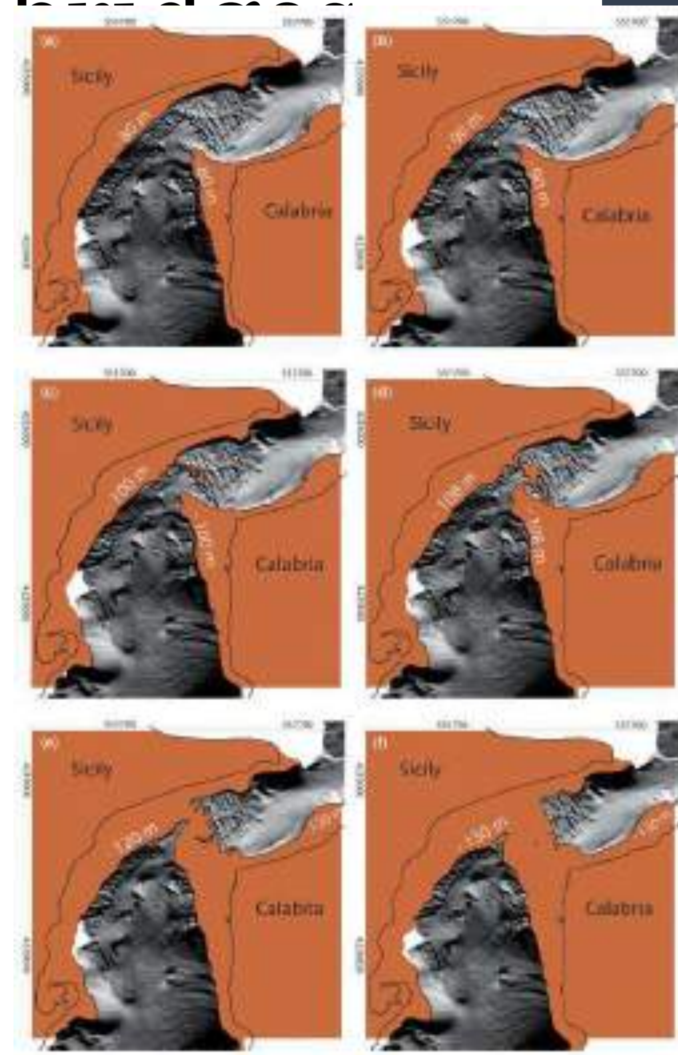

Lambeck's model (Lambeck et al., 2004)
-2
-3
-4
-5
-6
-7
-10
-9
-8
-8
-6
-4
-2
-8
-9
-10
0
Time = 6 ka BP
esl = -2.5


0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-1.5
-1.75
-2
-1.5
-1
-0.5
0
0.25
t = 2 kaBP

Slc and continental bridges



Furlani et al. (2013, QI)



Antonioli et al. (2014, GSL)

Venice in the future

Atolls, coastal erosion

Sea level markers

Geomorphological, archaeological and sedimentological indicators of slc

What are sea level markers?

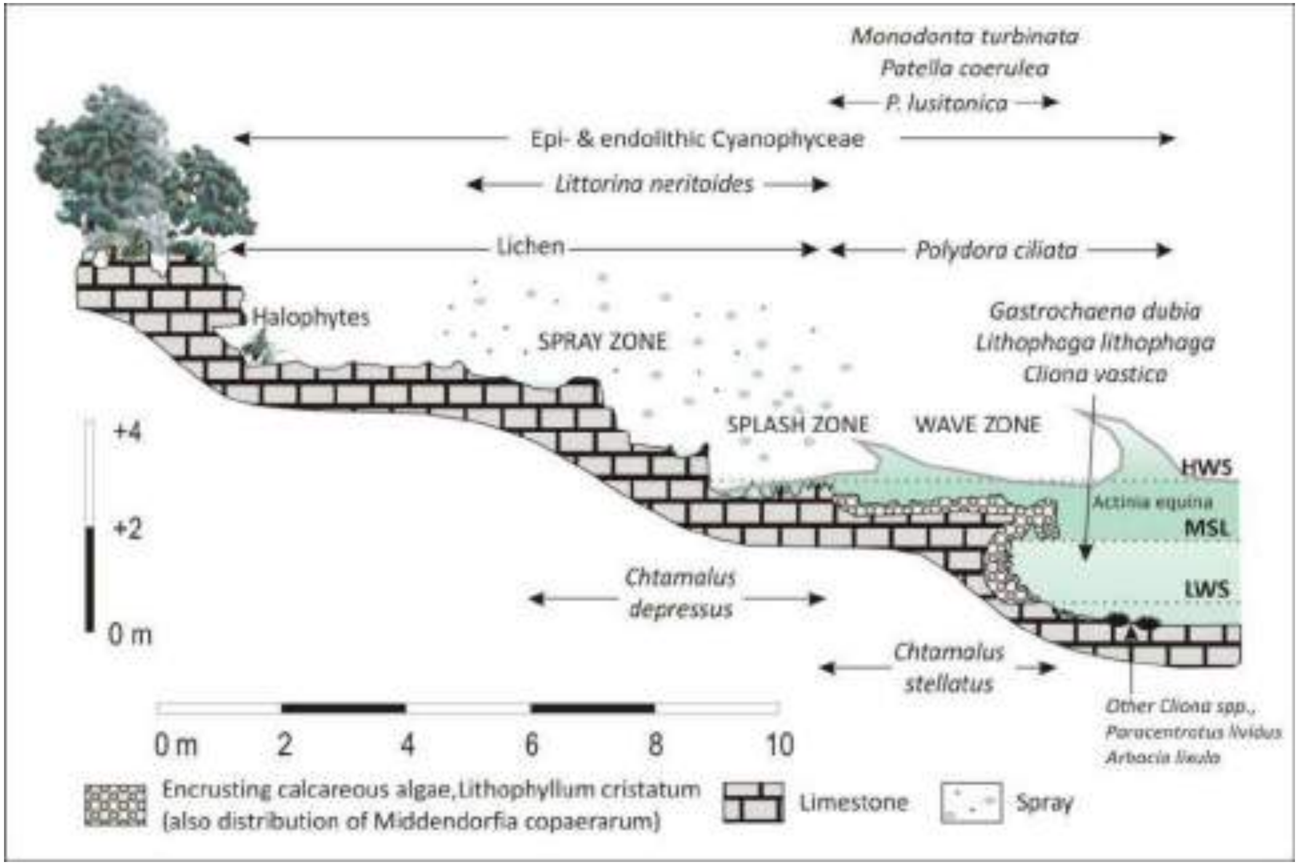
- Coastal objects closely related to sea level are called sea level markers
- Their nature depend on the site in which they have been found
- Sea level markers can provide different degrees of precision depending upon the nature of marker


What happens around the mean sea level?

what happens around sea level?

- Biological activity
- Erosion
- Human activities
- …

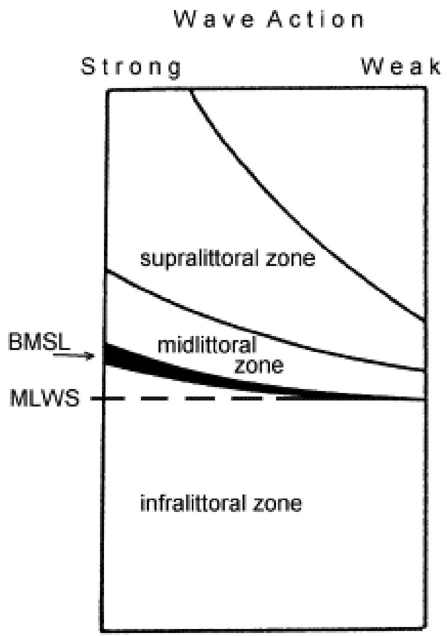
…some examples…
Biological zonation of carbonate coasts

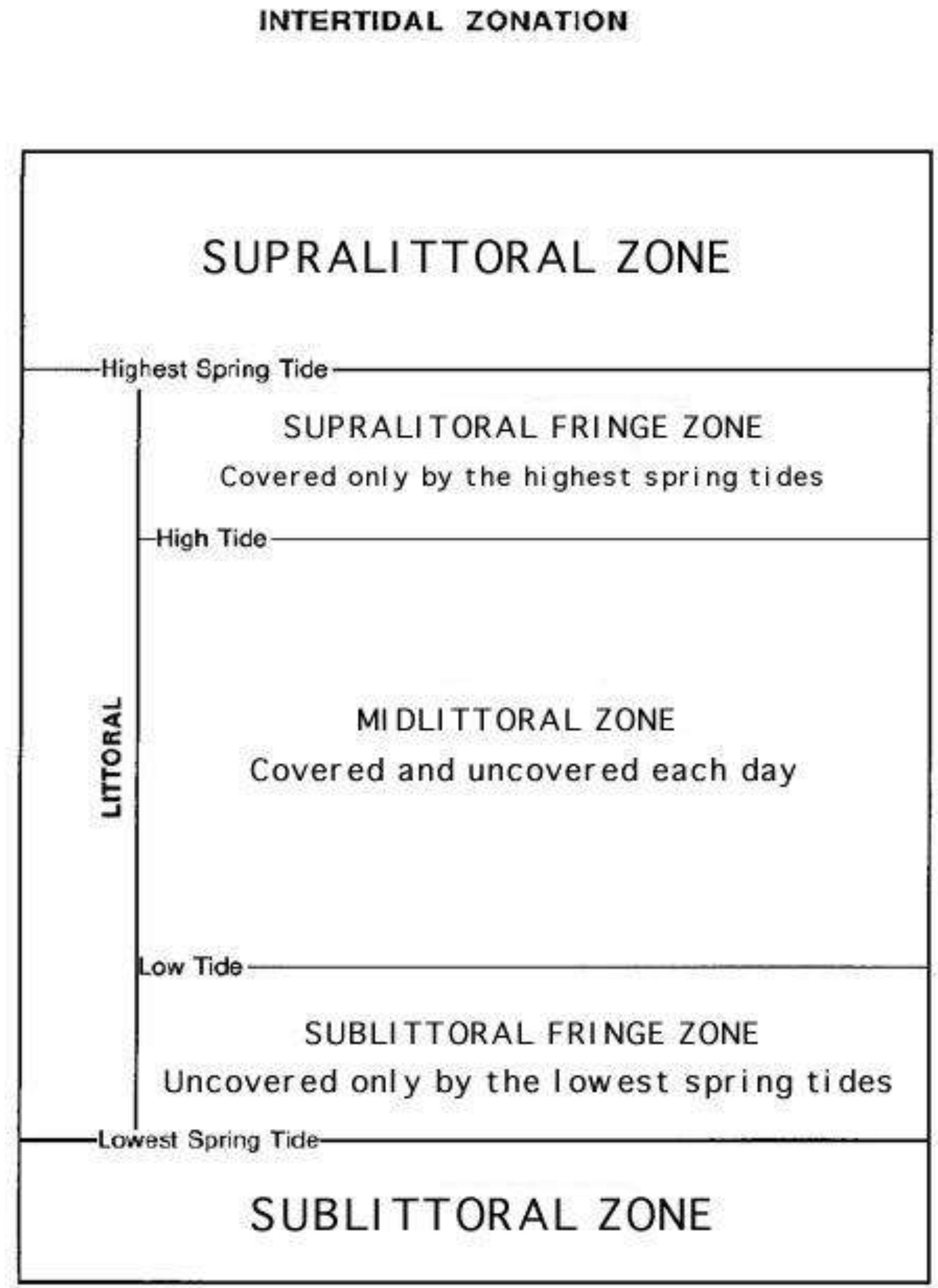


Furlani et al., GSL, 2014

Zonation

- Littoral fringe, or supralittoral zone
- Midlittoral (or eulittoral) zone andor intertidal (or tidal) zone
- Sublittoral zone, or infralittoral






Supratidal zone
Intertidal zone

…erosion

Shore platform (from Wikipedia)

human-made structures

The harbour of Palermo (from Wikimedia)

Archaeological markers

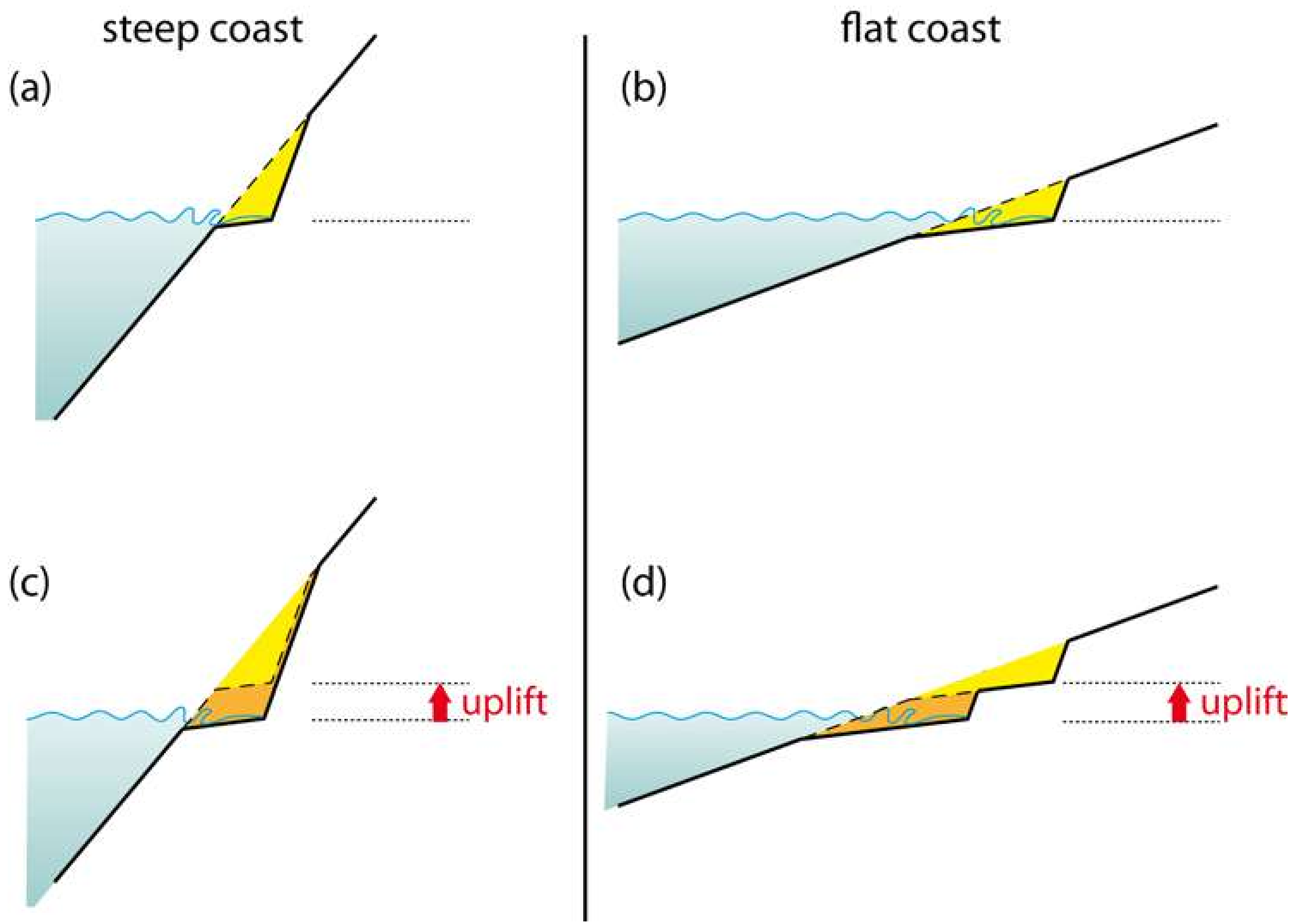
Docks, fishponds, quarries, tombs, etc

Geomorphological markers

Tidal notches, marine terraces, etc

Vermetid terrace
(San Vito lo
Capo, Sicily)


Upper platform
Lower platform
Chthamalus depressus
(upper mesolitoral)
Balanid rim
(Lower shoreline)



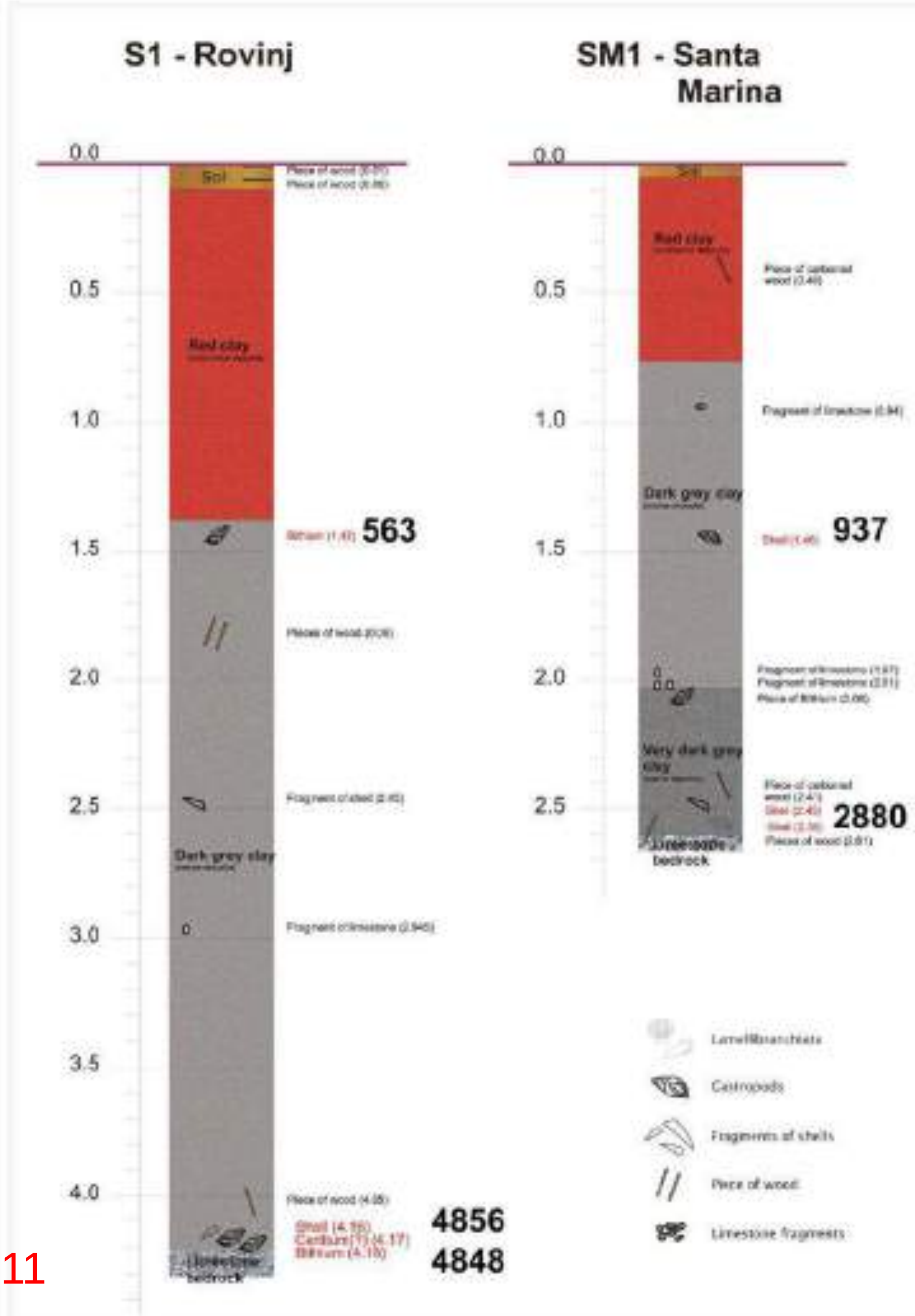
steep coast
flat coast
(a)
(b)
(c)
uplift
(d)
uplift

Speleothems

Chemical deposits in submerged caves

Sedimentological markers

Shells, peat, etc

Faivre et al., 2011