



# **Università degli studi di Trieste**

## **LAUREA MAGISTRALE IN GEOSCIENZE**

**Classe Scienze e Tecnologie Geologiche**

### **Curriculum: Esplorazione Geologica**

**Anno accademico 2022 - 2023**

## **Analisi di Bacino e Stratigrafia Sequenziale (426SM)**

**Docente: Michele Rebesco**



Visita alla  
rompighiaccio  
**Laura Bassi**

**Lunedì 10**

Appuntamento alle  
**9:45**

In Riva Giovanni da  
Verrazzano,  
5/c, (di fronte a  
Officine Quaiat)

# Homework: find this paper

Rebesco, M., Camerlenghi, A., Munari, V.,  
Mosetti, R., Ford, J., Micallef, A., Facchin, L.  
(2021)

Bottom current-controlled Quaternary  
sedimentation at the foot of the Malta  
Escarpment (Ionian Basin, Mediterranean).  
Marine Geology 441, 106596

# Module 1.2: Methods

## Outline:

Part 1 (Geophysical methods): Prof Valentina Volpi

Exercise

Part 2 (Geological methods): Prof Michele Rebesco



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## **Analisi di Bacino e Stratigrafia Sequenziale (426SM)**

### **Modulo 1.2 – Metodi geofisici**

**Docente: Valentina Volpi**

## **GEOFYSICAL METHODS**

- All geophysical methods remotely sense a material property of the earth
- (e.g. seismic velocity, rock density, electrical resistivity, magnetization etc).
  
- Facies analysis of subsurface data depends on tools which delimit the surfaces and provide clues as to the sediments they contain.

### ➤ **Seismics**

### ➤ **Well logs**

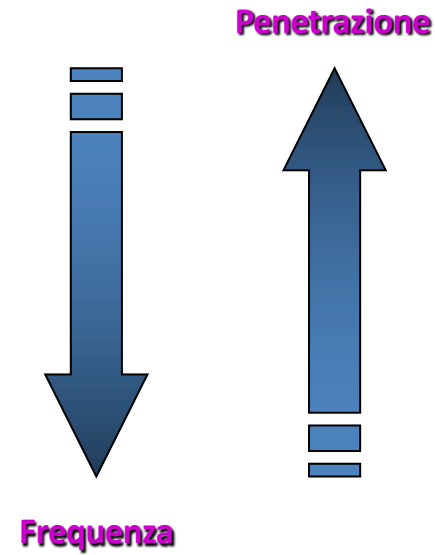
### ➤ **Gravity and magnetometry**

### ➤ **Goelectrics**

### ➤ **Georadar**

## **GEOPHYSICAL INVESTIGATION ACOUSTIC METHODS**

- **Seismics** ( frequencies up to 100 Hz)
- **Sub-bottom profiler (CHIRP)** (frequencies of a few kHz)
- **Morphobathimetry** (frequencies of hundreds of kHz)

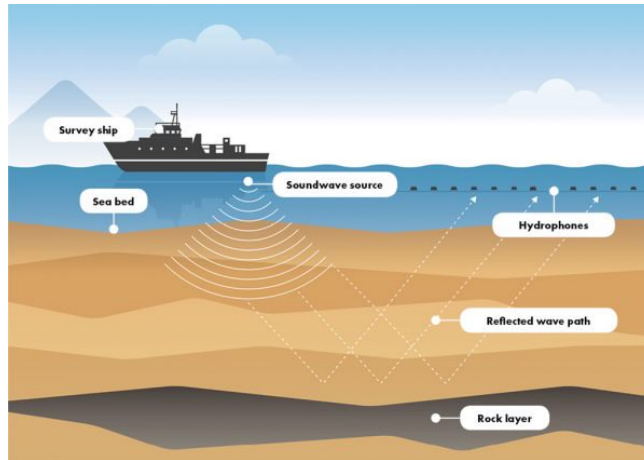


High frequency signals are used to study shallow sediments with higher resolution

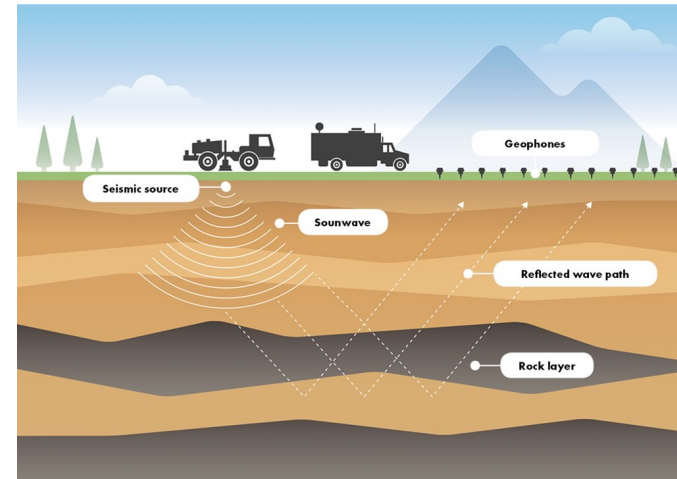
## REFLECTION SEISMICS

The multi-channel reflection seismic is based on the study of the propagation of seismic waves (low frequency sound waves) which are artificially generated through the sudden expansion of compressed air by means of a battery of “GUNS” dragged by the ship or the signal could be generated at the surface and detected by an array of geophones layed on the surface .

Marine survey



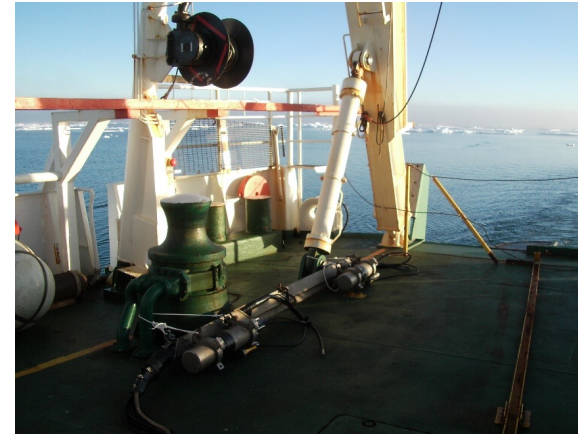
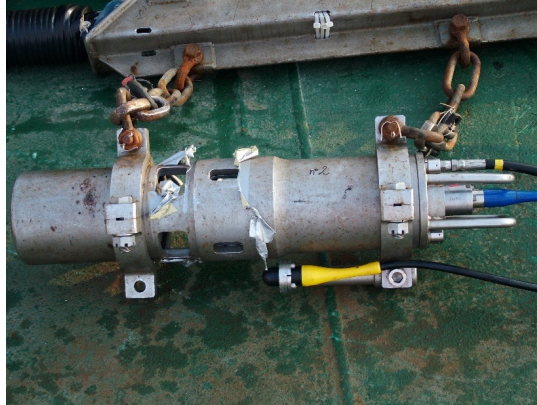
Land survey





## AIR GUNS

**G.I. Gun**

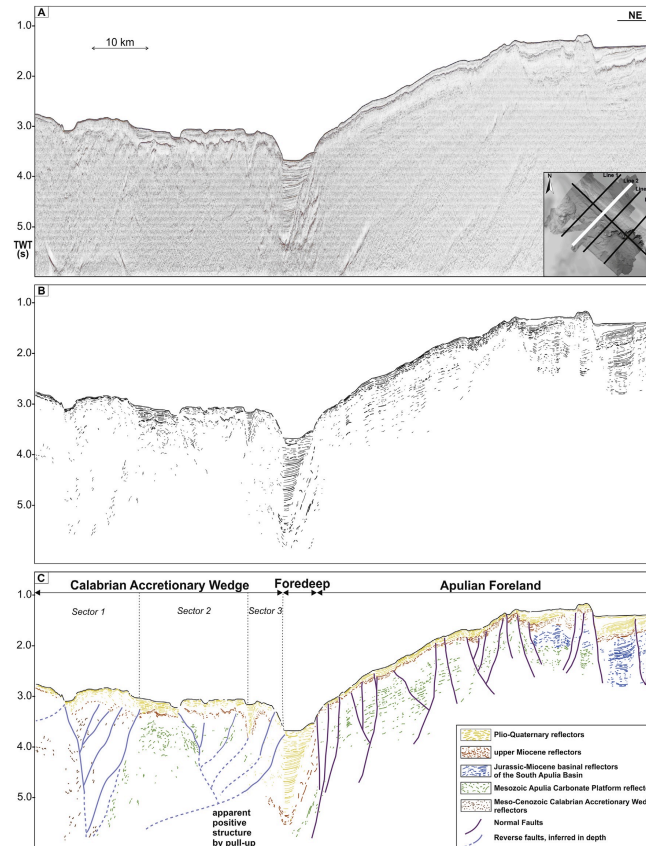
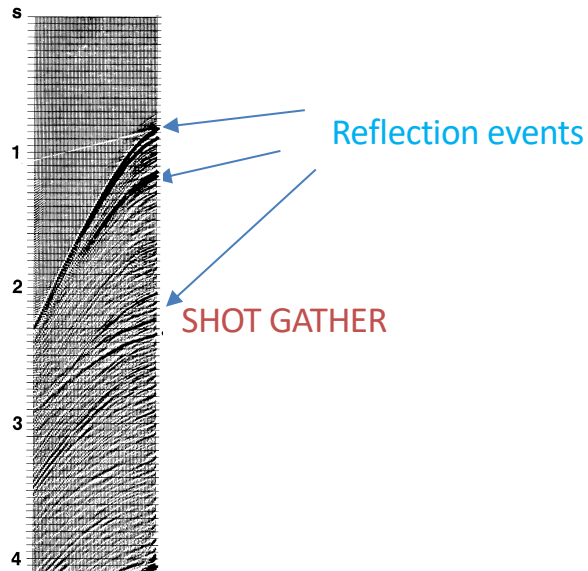
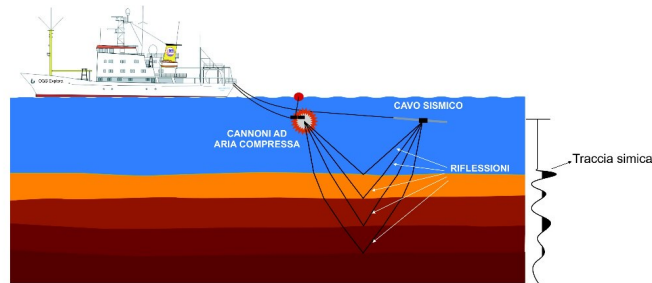


**GUNS ARRAY**



**BUBBLE GENERATED BY A SHOT**

## SEISMIC DATA



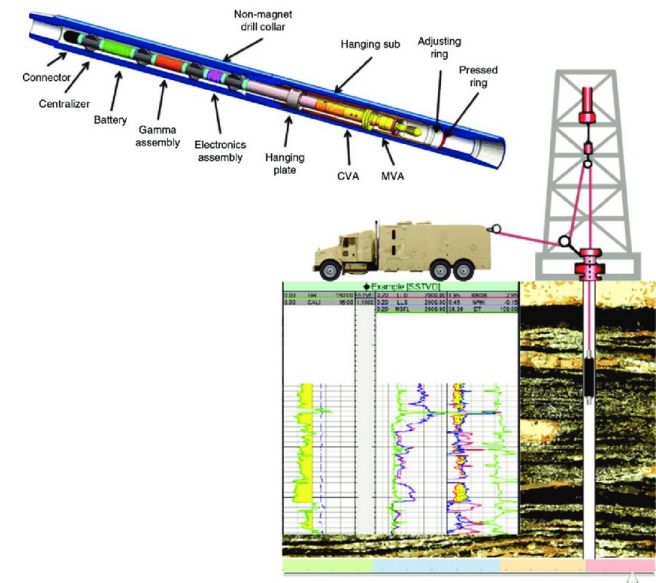
INTERPRETED SEISMIC SECTION

## DOWNHOLE LOGGING

During well logging, the logging tool is lowered into the borehole via a cable. Relevant data is transmitted electrically through the cable to the surface, where they are digitally and continuously recorded as a function of the depth of the formation.

The data obtained from well logging reveals lithological classification as well as various physical, chemical, and structural properties of the formation around the borehole. Some of the detailed information that can be obtained from borehole logs includes:

- **Rock composition:** information on strata types (limestone, shale, sandstone, etc.)
- **Rock characteristics:** porosity, permeability, presence of liquids
- **Rock integrity:** presence of structural weaknesses, risk of cave-ins
- **Borehole dimensional properties:** size, shape, borehole trajectory
- **Fluid presence:** properties of the fluids (if any) present in the borehole (e.g., salinity, pressure, saturation, etc.)



## WELL LOGS

### 1. Electric

- Spontaneous potential
- Induction

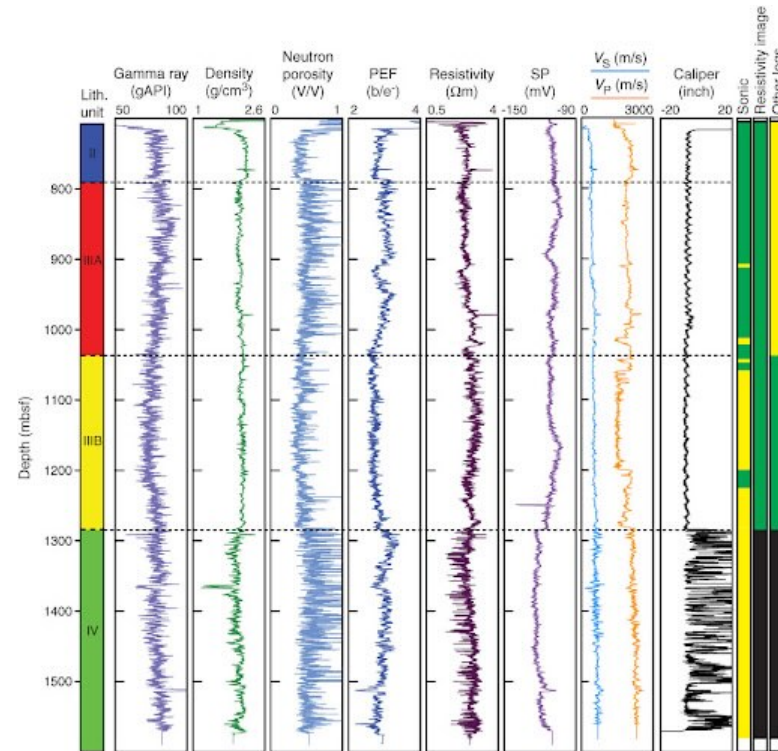
### 2. Nuclear

- Gamma ray
- Density
- Neutron porosity

### 3. Acoustic (sonic)

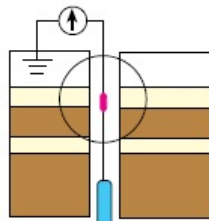
### 4. Other

- Dipmeter
- Photoelectric
- Caliper
- Imaging
- NMR
- .....



## WELL LOGS - ELECTRICAL LOGS

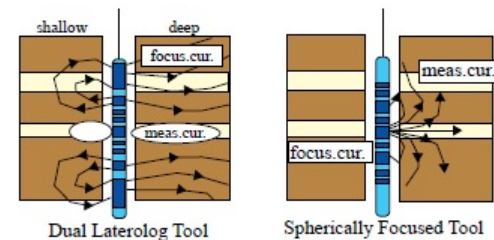
### Spontaneous potential (SP)



- Measure voltage difference between a movable electrode in the borehole and a fixed surface electrode
- Shale positive, sand negative
- Identifies permeable zones (usually sandstone)



### Resistivity



- Measures resistance of flow of electric current
- Distinguishes type of fluids; hydrocarbon, fresh water and brine
- Many types and names differ largely in depth of penetration
- Short penetration reflects drilling mud; longer is due to formation water

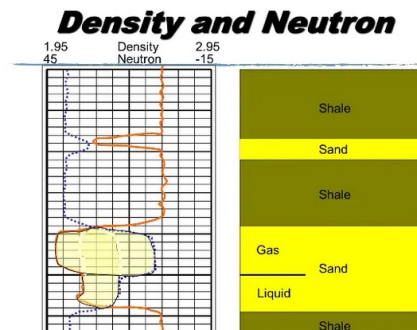
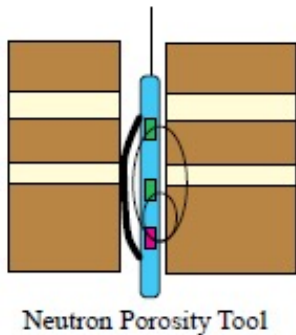
Rocks, hydrocarbons are resistive; current can only flow through rocks containing fresh water.



# WELL LOGS - NUCLEAR LOGS

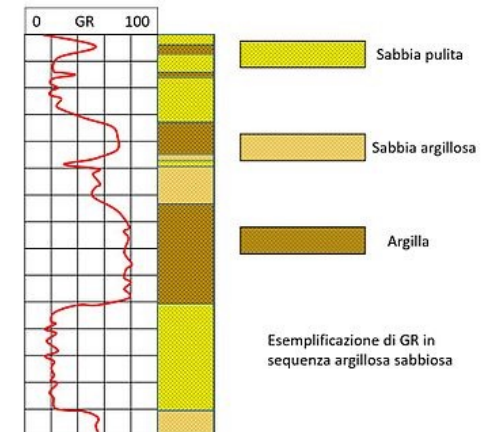
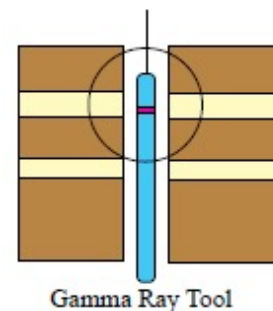
## Neutron log

- a neutron source emits fast, high energy neutrons into the formation and measures the number of neutrons that are not slowed down and captured by the hydrogen atoms.
- porosity estimation
- lithology and gas indicator



## Gamma ray

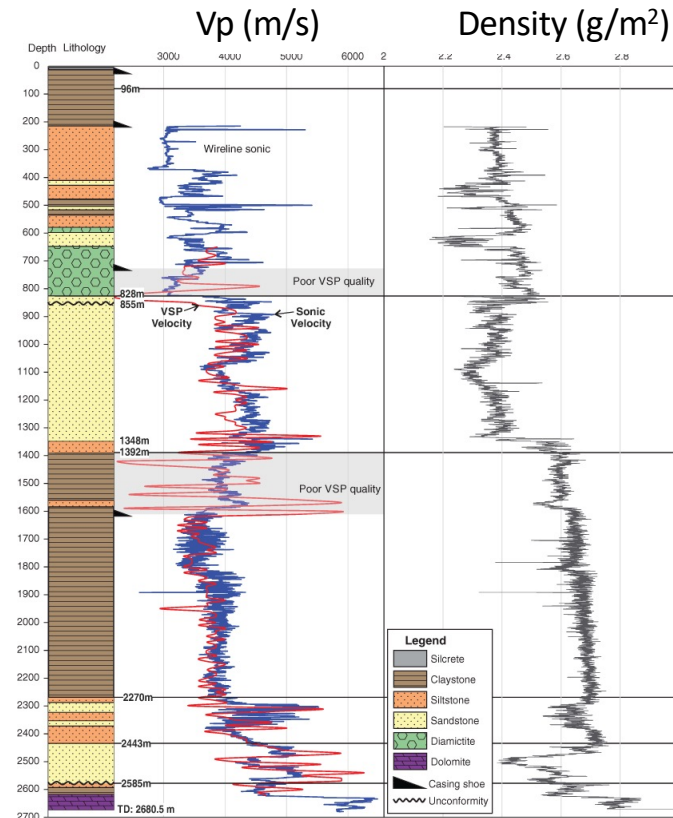
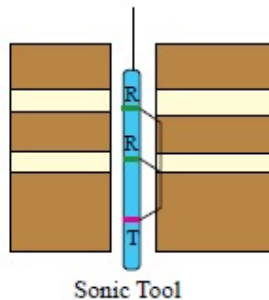
- measure the natural gamma ray emissions from the rock formations adjacent to the borehole. The emissions origin from the decay of radioactive isotopes (Pt, U, Th) contained in the rock formations.
- sandstone and carbonate low values, shale-clay high values
- porosity estimation



## WELL LOGS - SONIC LOG

### Sonic log

- recording against depth of the travel time of acoustic pulses through formation close to the borehole. This is done by measuring the pulse arrival time at two receivers spaced at different distances from an acoustic transmitter
- porosity estimation
- lithology and gas indicator
- seismic velocity calibration

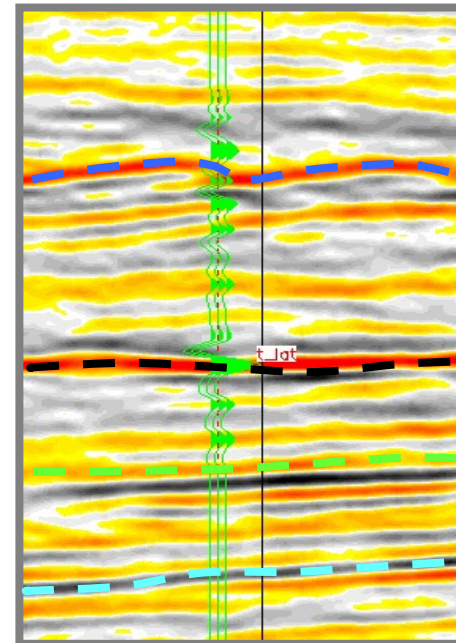


## WELL SEISMIC TIES

### Objectives of Well-Seismic Ties

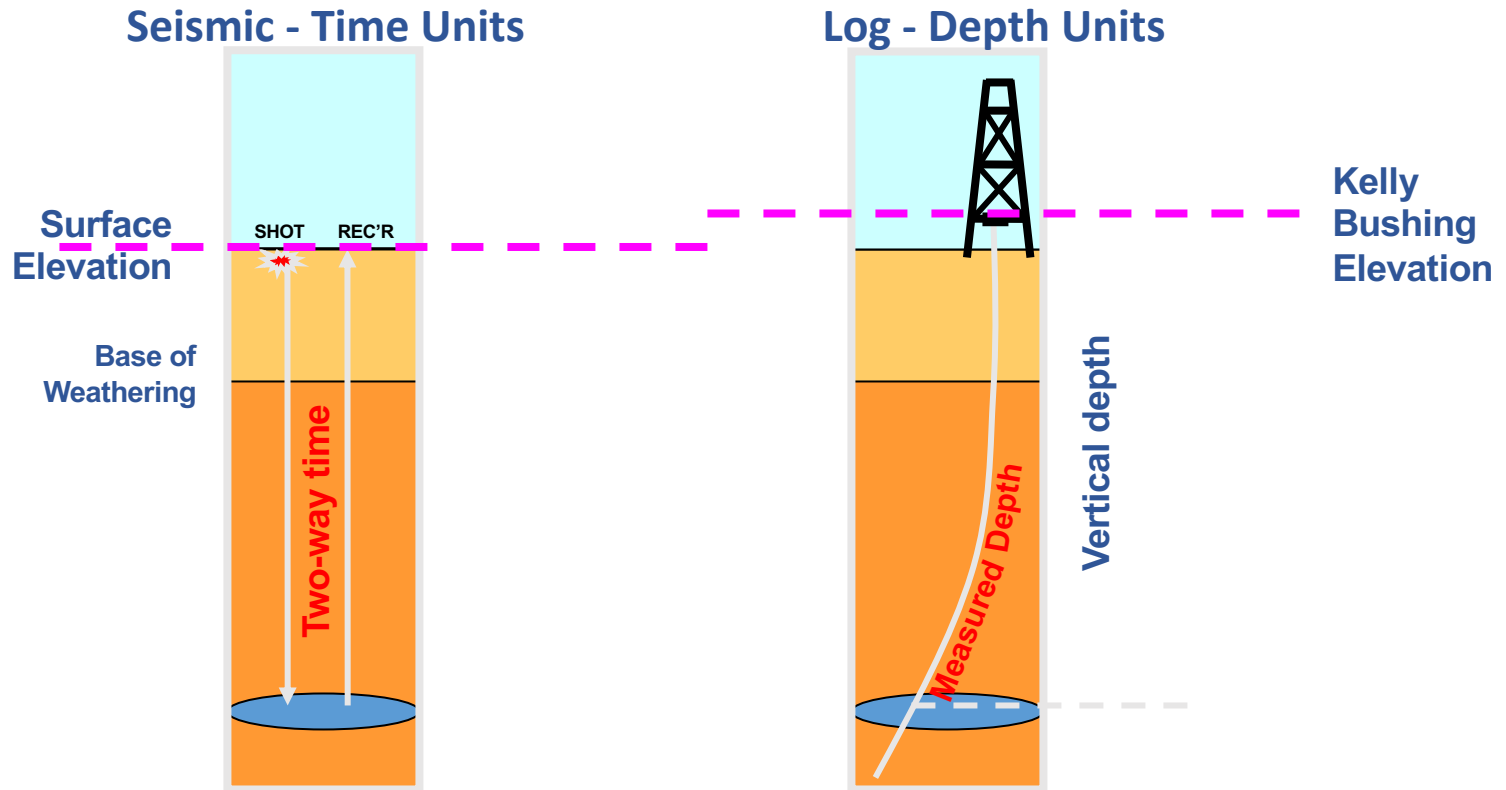
- Well-seismic ties allow well data, measured in units of depth, to be compared to seismic data, measured in units of time
- This allows us to relate horizon tops identified in a well with specific reflections on the seismic section
- We use sonic and density well logs to generate a synthetic seismic trace
- The synthetic trace is compared to the real seismic data collected near the well location

### Synthetic Trace





## WELL SEISMIC TIES



## WELL SEISMIC TIES

### Comparison of Seismic and Well Data

#### Seismic Data

- Samples area and volume
- Low frequency 5 - 60 Hz
- Vertical resolution 15 - 100 m
- Horizontal resolution 150 - 1000 m
- Measures seismic amplitude, phase, continuity, horizontal & vertical velocities
- Time measurement

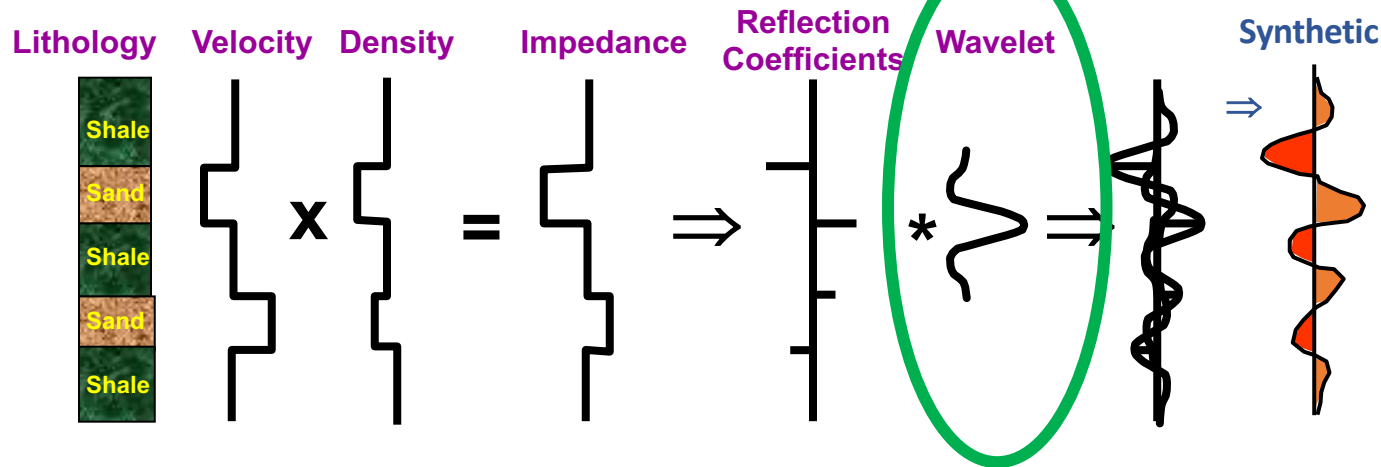
#### Well Data

- Samples point along well bore
- High frequency, 10,000 - 20,000 Hz
- Vertical resolution 2 cm - 2 m
- Horizontal resolution 0.5 cm - 6 m
- Measures vertical velocity, density, resistivity, radioactivity, SP, rock and fluid properties from cores
- Depth measurement



## WELL SEISMIC TIES

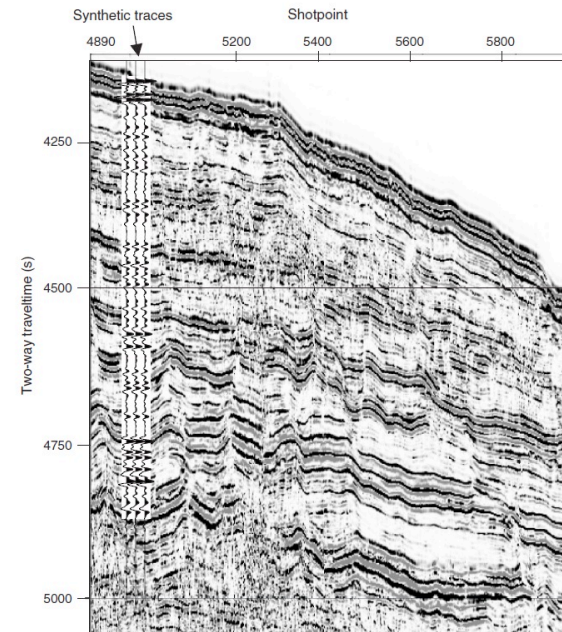
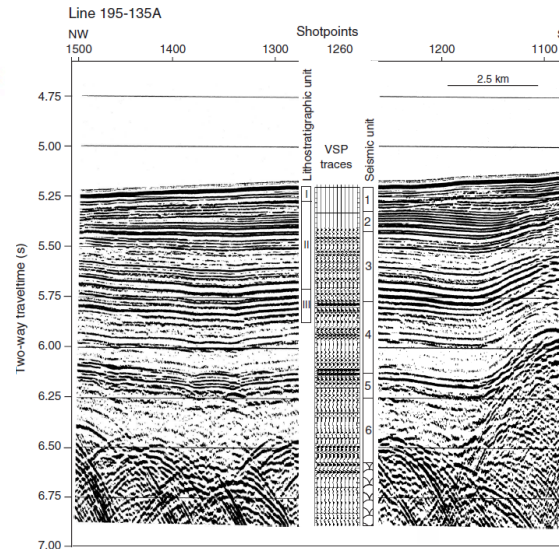
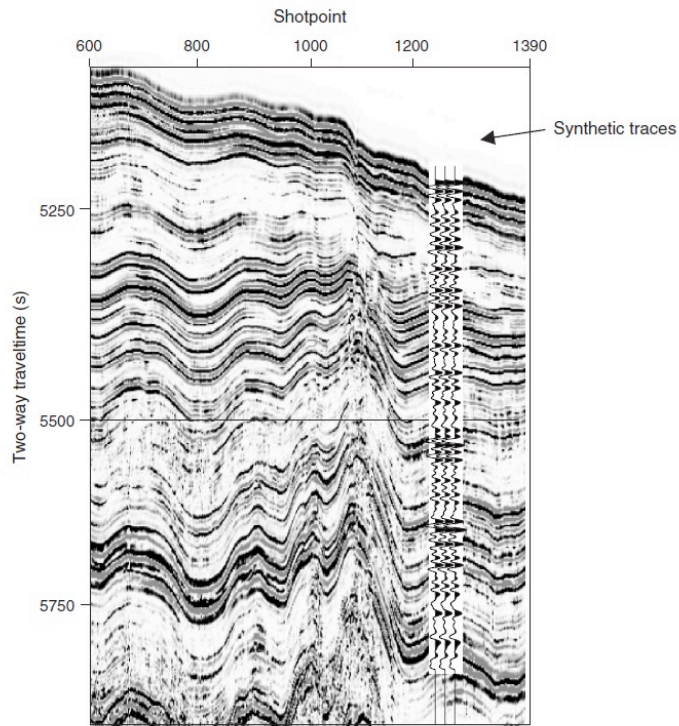
The Modeling Process



- We 'block' the velocity (sonic) and density logs and compute an impedance 'log'
- We calculate the reflection coefficients at the step-changes in impedance
- We convolve our pulse with the RC series to get individual wavelets
- Each RC generates a wavelet whose amplitude is proportional to the RC
- We sum the individual wavelets to get the synthetic seismic trace

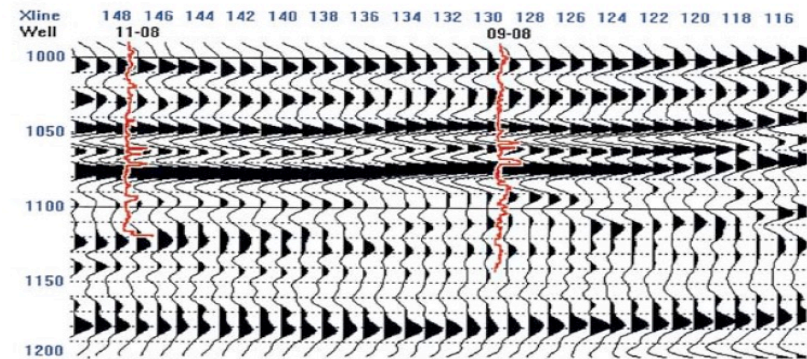
## WELL SEISMIC TIES

### Examples

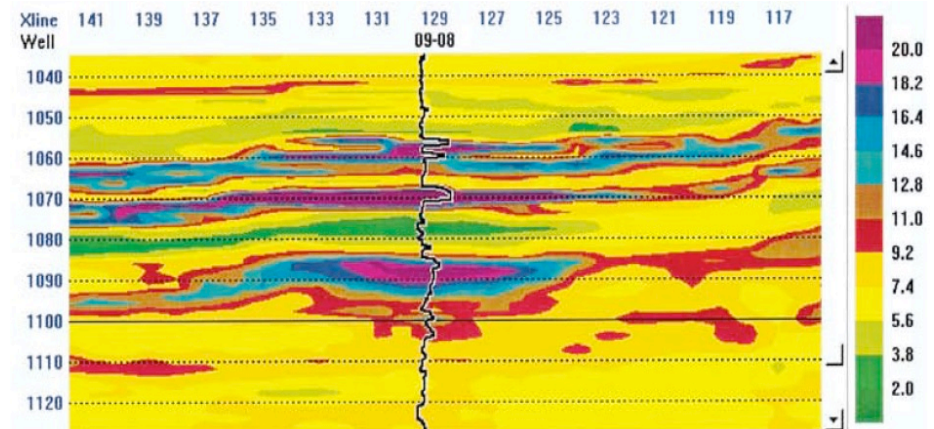


## PETROPHYSICS

The integration of well-log and seismic data has been a consistent aim of geoscientists; it allows to exactly locate along the seismic data the measured petrophysical log properties (porosity, density, P-Wave velocity...). Well logs provides a punctual information on the properties of the subsurface while seismic data allow to propagate the information at well location also laterally along the crossed seismic line.



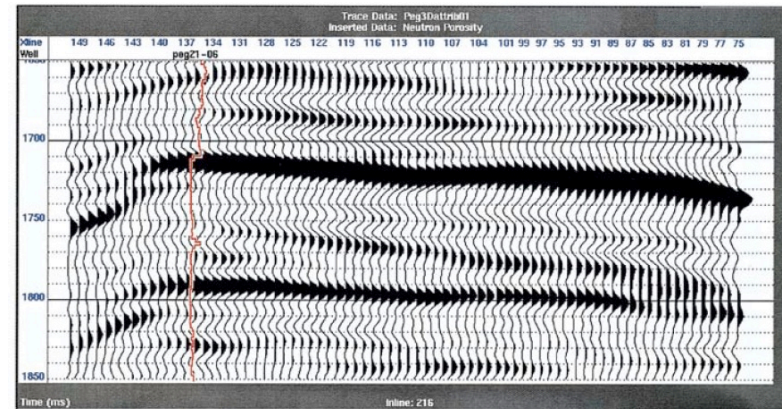
Alternation  
of  
shale/sand  
fill in a  
incised  
valley  
(CANADA)



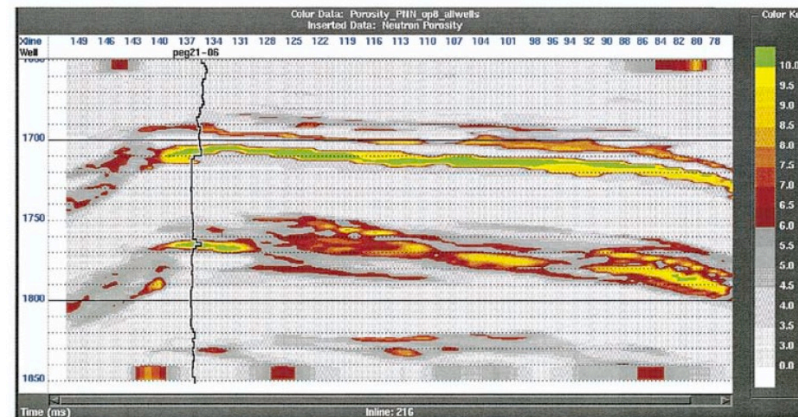
## PETROPHYSICS

The log porosity for the Peg 21-06 well is displayed as a red curve in the seismic line.

The section above is the porosity estimate along the seismic line. Thin high-porosity zones in the middle represent hydrocarbon layers in a vertically stacked reservoir, structurally trapped in a faulted anticline.



3d seismic line



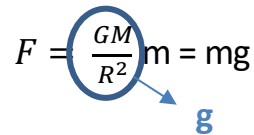
Porosity

## GRAVITY METHOD

The universal law of gravitation (Isaac Newton) is:  $F = G \frac{m_1 m_2}{r^2}$

according to which any two masses  $m_1$  and  $m_2$  placed at a distance  $r$  attract each other with a force  $F$ .

Considering the Earth as an homogenous and spherical mass  $M$  and radius  $R$  the gravitational attraction on a small mass  $m$  located on its surface is:

$$F = \frac{GM}{R^2} m = mg$$


Force is related to mass by an acceleration and the term  $g$  is known as the gravitational acceleration or *gravity*. The weight of the mass is given by  $mg$ .

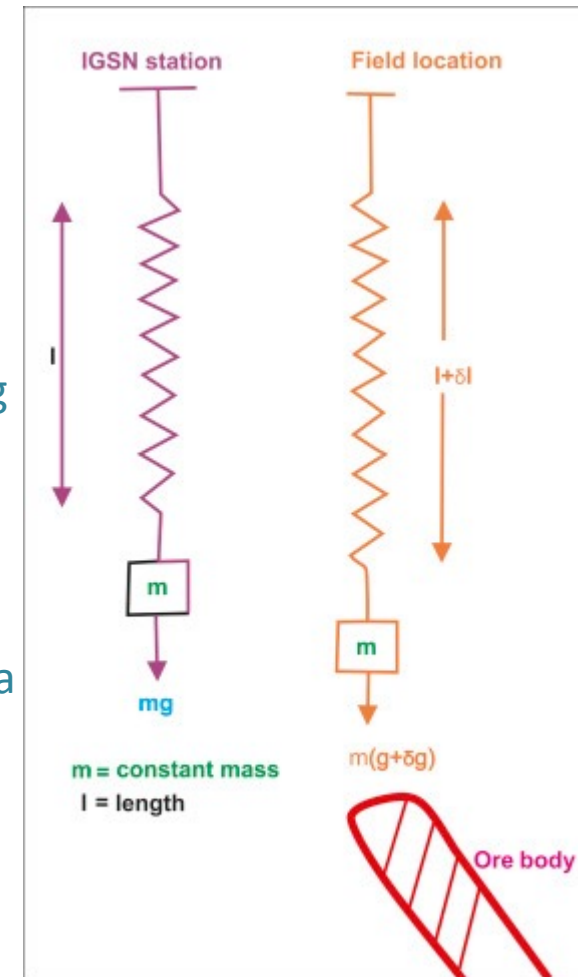
The Earth ellipsoidal shape, rotation, irregular surface relief and internal mass distribution cause gravity (gravity field) to vary over its surface.

The gravity method measures the different earth materials having different bulk densities (mass) that produce variations in the measured gravitational field.

## GRAVITY METHOD

The **gravimeter** is the measuring instrument of the gravitational field of Earth at specific locations. The instrument works on the principle of measuring constant downward acceleration of gravity. There are two types of gravimeters:

- **Absolute gravimeters** measure the local gravity in absolute units (Gal). Absolute gravimeters are used in the field. They work by directly measuring the acceleration of a mass during freefall in a vacuum. An accelerometer is rigidly attached to the ground.
- **Relative gravimeters** are extremely sensitive, specially assembled, spring-based instruments carrying a fixed mass ( $m$ ). The principle is that the changes in gravity will result in a change in weight of fixed mass  $g(m + \delta g)$  with change of location. Thus the length of the spring will differ slightly with change of location. The spring extension is recorded by suitable optical, mechanical, or electrical amplifications with high precision.

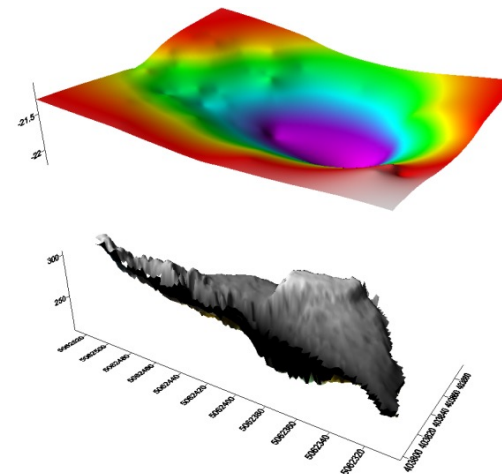
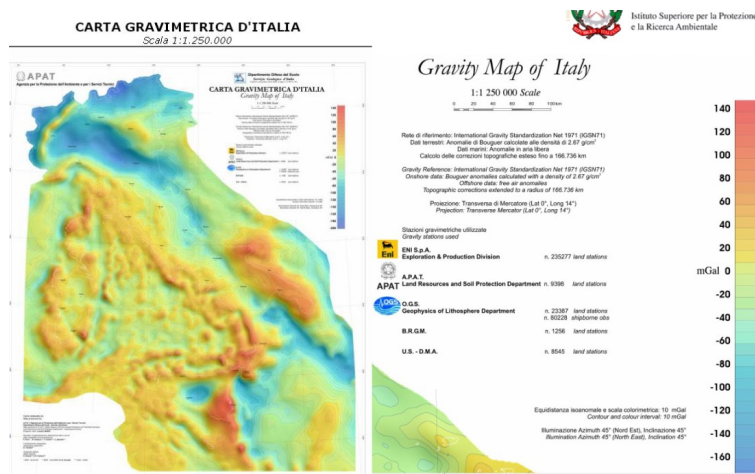


Relative gravimeter principle



## GRAVITY METHOD

Gravity method plays an important role in the studies related to sedimentary basin modeling because detectable gravity anomalies can be observable on the surface of the Earth due to the presence of significant density contrast between sediment infill and the underlying basement. These observed gravity anomalies, considered to have been made on topographic elevations, can be modeled to decipher the geometry of the basement structure below the sedimentary load. Due to deficit in density of sedimentary rocks (negative anomaly) with the underlying basement complex, negative gravity anomalies are usually observed over sedimentary basins.

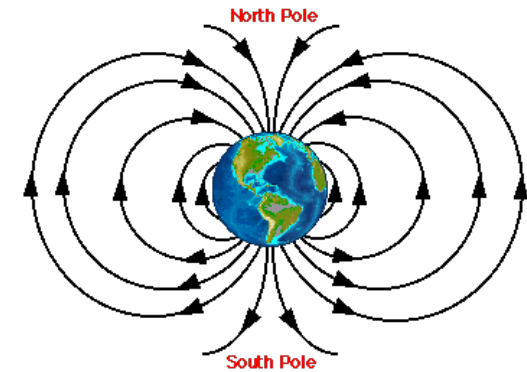


Gravity map of the Grotta Gigante Federazione Speleologica Regionale del Friuli Venezia Giulia (<https://www.fsrfvg.it/?p=4007>).

Relief of the cave

## MAGNETIC METHOD

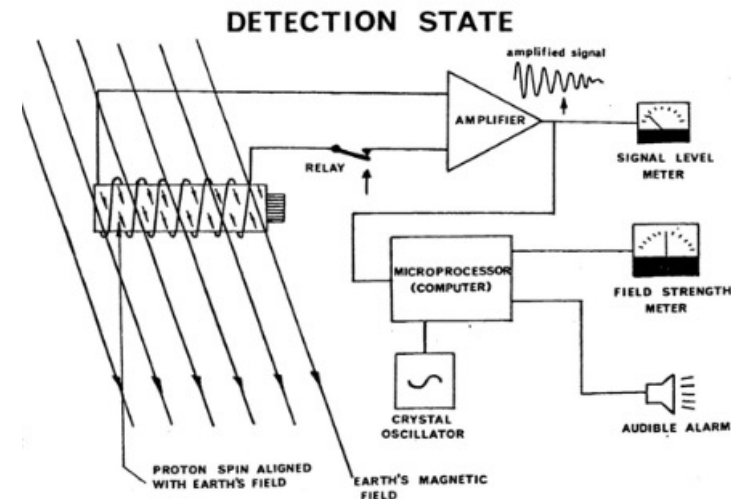
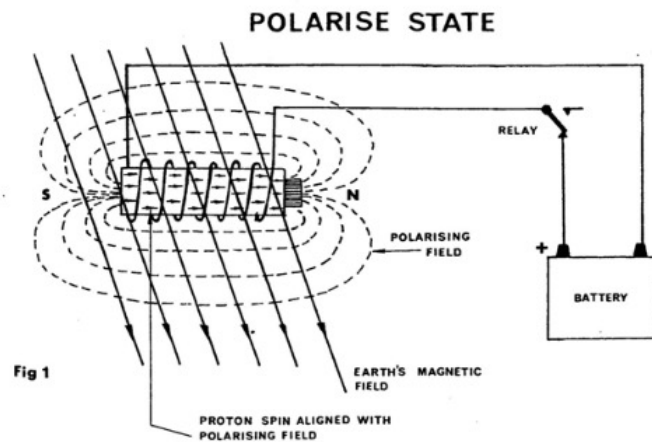
- The aim of a magnetic survey is to investigate subsurface geology on the basis of anomalies of the *Earth magnetic field* resulting from the magnetic properties of the underlying rocks.
- The earth behaves like a uniformly magnetized sphere, as there was a magnetic bar located at its core (magnetic dipole), giving rise to a magnetic flux, the Earth's magnetic field.
- When a material is placed in a magnetic field (i.e. earth magnetic field) it may acquire a magnetization in the direction of the external field. This occurs in rocks types containing sufficient magnetic minerals (iron minerals: hematite, magnetite), and the magnetic field sums over the external one. The anomalies are measured in nTesla.



## MAGNETIC METHOD

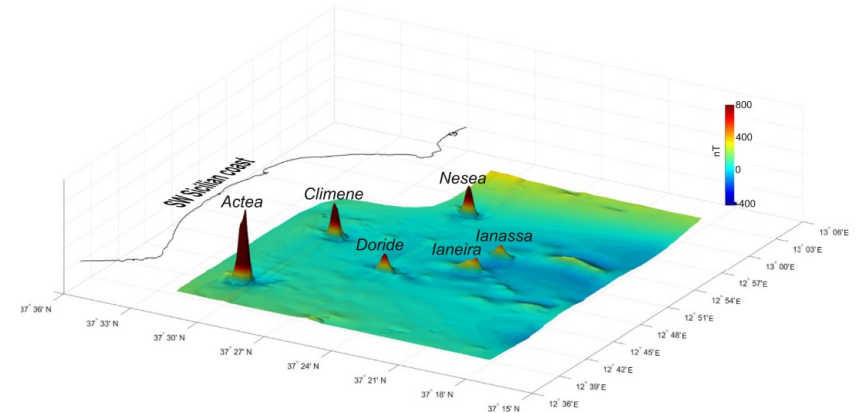
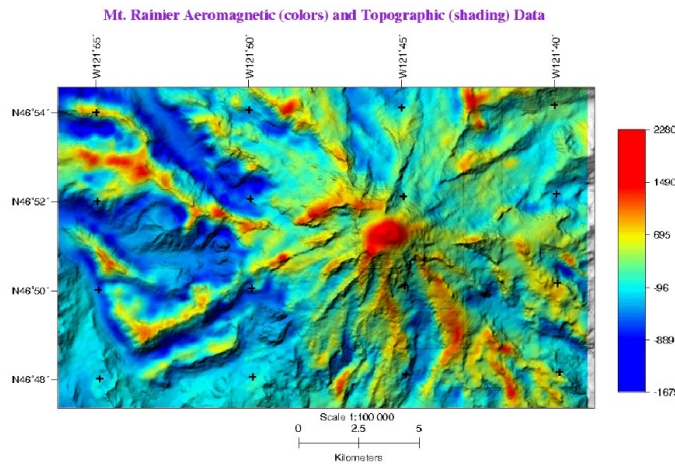
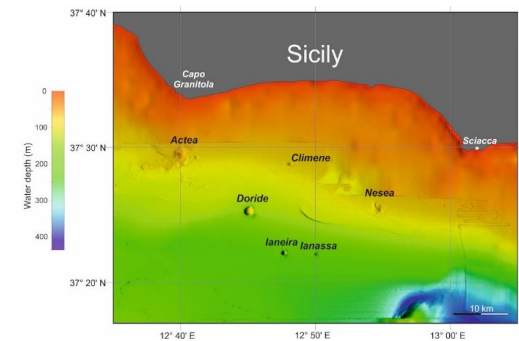
The **proton magnetometer** measures a radio-frequency voltage induced in a coil by the reorientation (precession) of magnetically polarized protons in a container of ordinary water.

The systems operate on substantially similar principles using proton-rich fluids surrounded by an electric coil. A momentary current is applied through the coil, which produces a corresponding magnetic field that temporarily polarizes the protons. When the current is removed, the protons realign or precess in the orientation of the Earth's magnetic field. Precession generates a small electric current in the surrounding coil, at a direct frequency proportional to the strength of the local magnetic field.



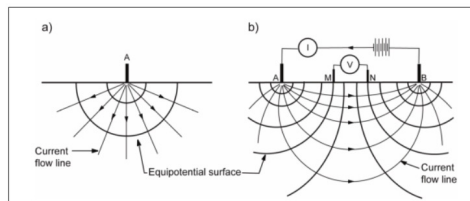
## MAGNETIC METHOD

- Sedimentary rocks generally have a very small magnetic susceptibility compared with igneous or metamorphic rocks, which tend to have a much higher magnetite (a common magnetic mineral) content. Most magnetic surveys are designed to map the geologic structure on or inside the basement rocks (the crystalline rocks that lie beneath the sedimentary layers) or to detect magnetic minerals directly.
- Data are usually displayed in the form of a contour map of the magnetic field, but interpretation is often made on profiles. From these maps and profiles geoscientists can locate magnetic bodies (even if they are not outcropping at the surface).

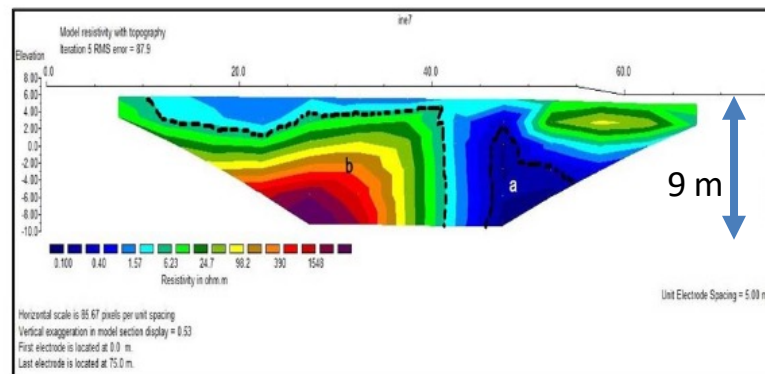


## GEOELECTRICAL METHOD

- The geoelectrical method is a method that uses the principle of electric current flow in investigating the subsurface structure of the earth. The flow of electric current in the soil, through the rocks, is strongly influenced by the presence of groundwater and salt contained in the rock, high metal, and heat minerals.
- A geoelectrical measurement is carried out by recording the electrical potential arising from current input into the ground with the purpose of achieving information on the resistivity structure on the ground.
- Geoelectrical methods are used extensively in groundwater mapping; the clay content of the formation shows low resistivity, and sandy permeable formation shows high resistivity.



Acquisition pattern

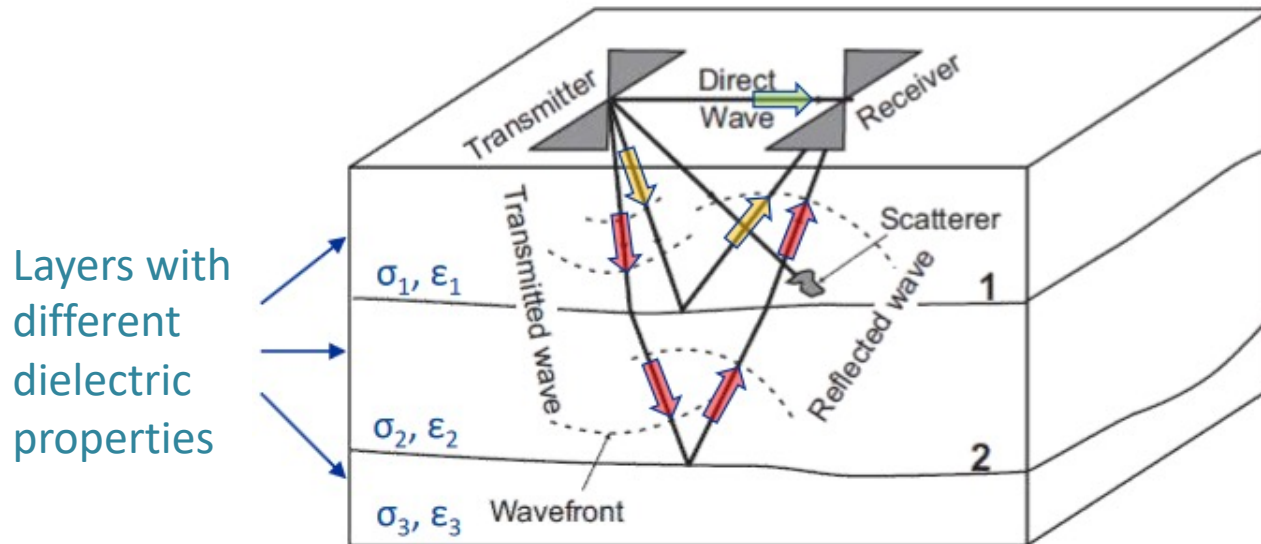


(a) showing resistivity values ranging from 0.1 - 0.2  $\Omega\text{m}$  which is estimated to be salt water intrusion based on the resistivity table of earth materials and region (b) which is a mixture of sand and clay material with a range of resistivity values between 1 - 1000  $\mu\text{m}$

## ELECTROMAGNETIC METHOD

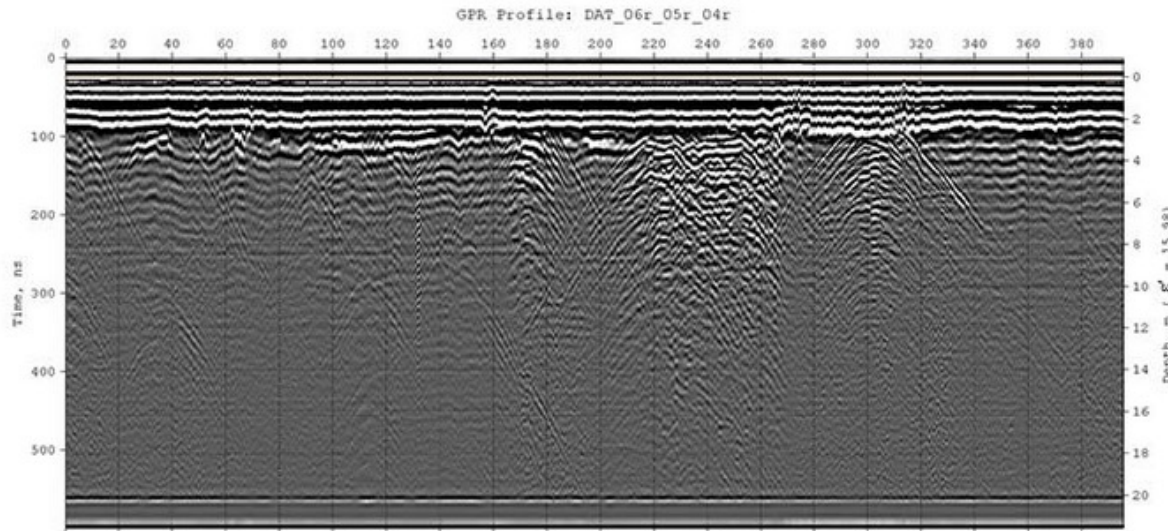
### Ground penetrating radar - GPR

- Operates by transmitting pulses of EM waves of frequencies 10 MHz –4 GHz through a transmitting antenna
- Changes in dielectric properties cause parts of the signal to be reflected back to the surface, where it is recorded and amplified by the receiving antenna
- The amount of reflected energy is dependent on the contrast in electrical properties
- Applied in identification of bedrock, soils, groundwater; engineering (buried structures, pipes); archeology

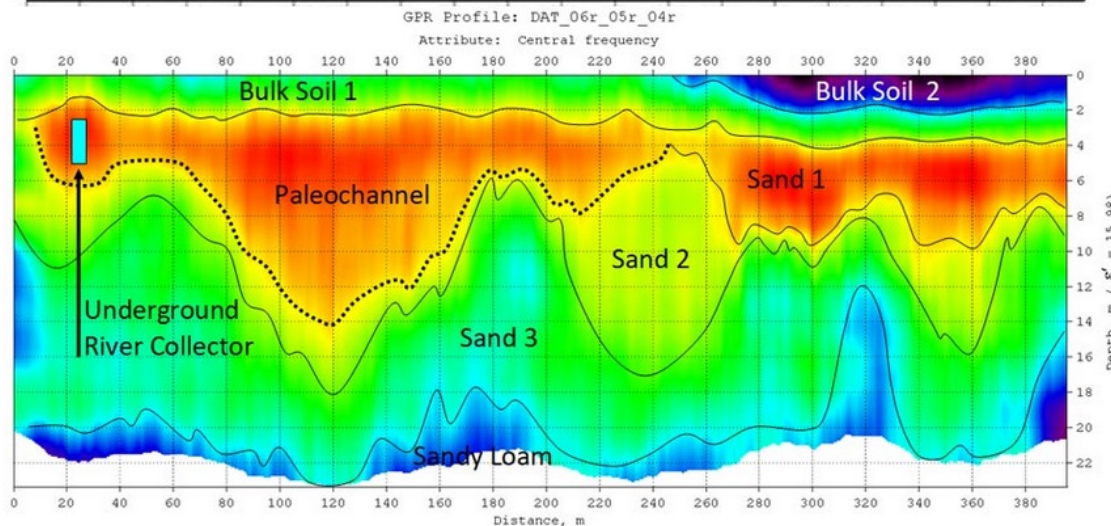


# ELECTROMAGNETIC METHOD

## Ground penetrating radar - GPR



GPR profile



Frequency-related resistivity section

## RESUME

- ❑ geophysical surveys are always developed in 4 main phases: design, field survey, data processing and interpretation.
- ❑ geophysical investigations should never be considered separately from the geological context
- ❑ the choice of the most appropriate methodologies must be made on the basis of the target and the expected contrasts, also with the preparation of physical models of the subsoil
- ❑ the best approach is the integration of different methodologies in order to minimize the interpretative errors related to the limits of the different techniques



## **ESERCITAZIONE**

3 profili sismici:

1. Linea sismica multicanale (Penisola Antartica)  
parametri: shot interval 25 m  
lunghezza record: 12 sec (TWT)
2. Linea sismica monocanale (Prydz Bay – Antartide)  
parametri: distanza tracce 33 m  
lunghezza record: 1,4 sec (TWT)
2. Linea sismica multicanale (Canale di Sicilia)  
parametri: scala orizzontale 3 km  
lunghezza record: 2,2 sec (TWT)

# Methods for the analysis of sedimentary basins

## Part 2

**Geophysical methods:** indirect analysis of deposits in the subsoil  
(+ or less ancient, on land and at sea) = today's lesson by Valentina Volpi

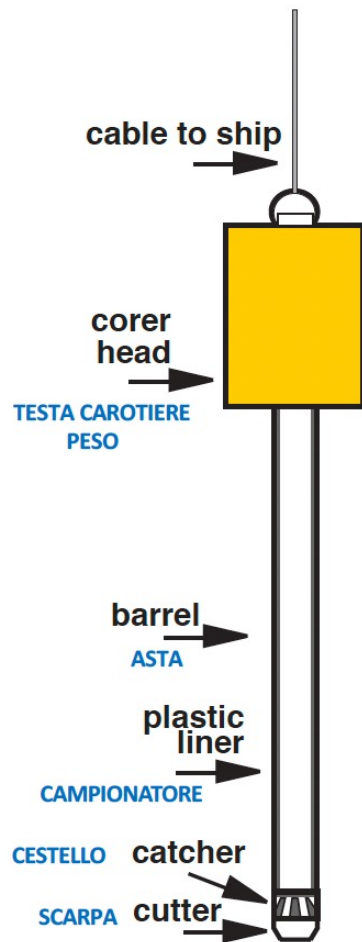
**Geological methods at sea:** coring (superficial deposits) and drilling (deeper /  
ancient / lithified deposits) = Course of Marine Geology

**Geological methods on land:** analysis of rocky outcrops, geological cartography,  
measurement of stratigraphic sections... (exhumed rock deposits).

**Geological / naturalistic methods:** analysis of recent deposits: historical  
cartography, trenches, ...

# Coring of marine sediment

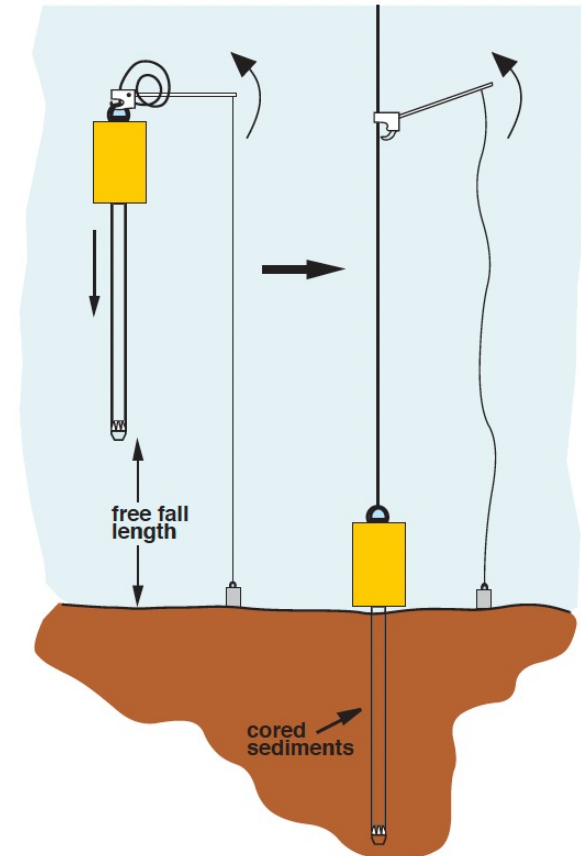
## Sediment coring system



A sediment coring system is composed by a weight (corer head) that is used to force the barrel into the sea bottom. Inside the barrel there is a plastic liner that will hold the sampled sediments. At the base of the barrel the core catcher prevents the sampled sediments to flow out the barrel after sampling, and the cutter facilitate the detach of the sampling system from the ground.



This system can work with or without a triggering system



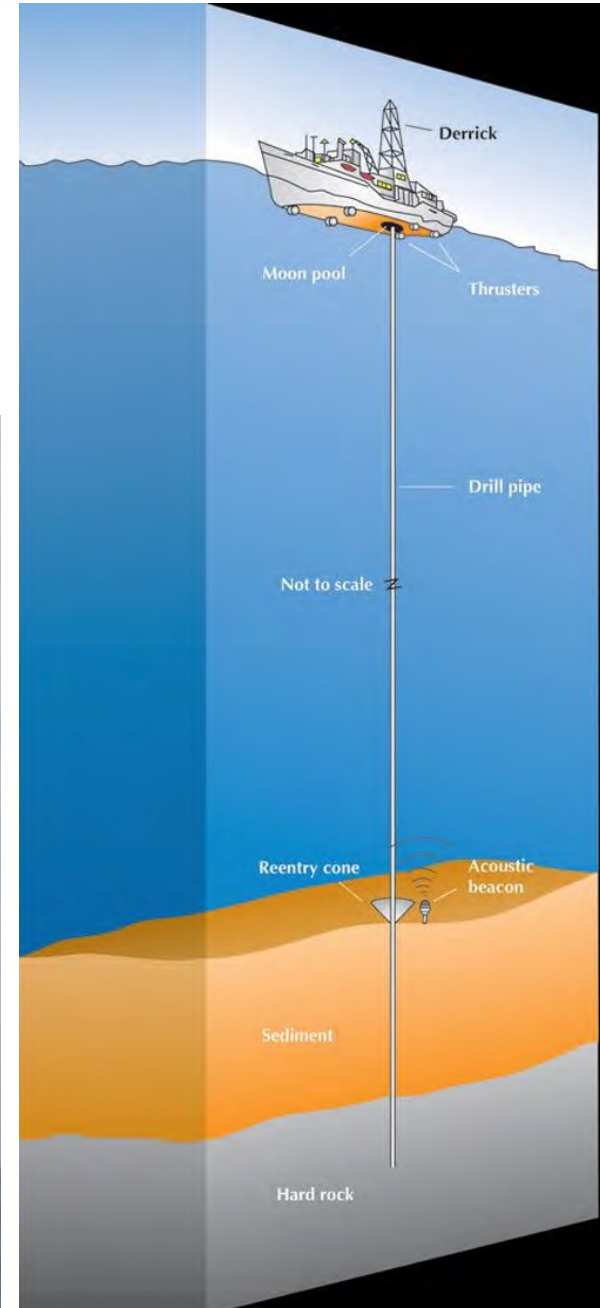
Courtesy: R.G. Lucchi

# Drilling



**IODP**  
INTERNATIONAL OCEAN  
DISCOVERY PROGRAM

Joides Resolution



# Outcrops

## La Baronìa



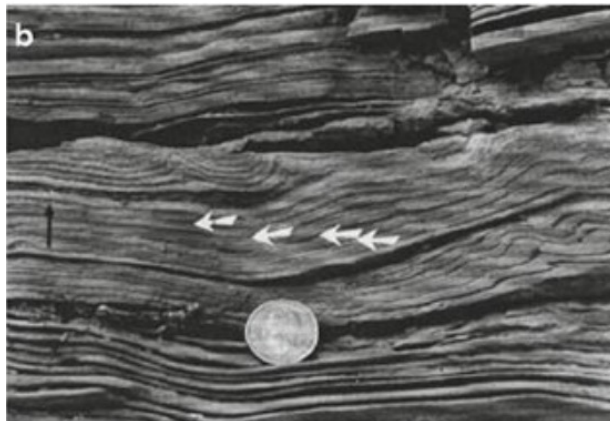
Large scale (outcrop)

10 m



Mid scale (bed)

50 cm



2,5 cm Small scale (Sedimentary structure)

Martinius, 2011

DOI: 10.1007/978-94-007-0123-6\_18

# Three-scale approach

A three-scale approach should be attempted, wherever possible, for distinguishing the various facies types (especially the deep-water ones).

It includes:

large-scale (oceanographic and tectonic setting),  
regional-scale (architecture and association)  
and small-scale (sediment facies) observations.

Stow and Smillie, 2020 *Geosciences*, 10(2), 68;  
<https://doi.org/10.3390/geosciences10020068>



Courtesy  
of D.A.V.  
Stow

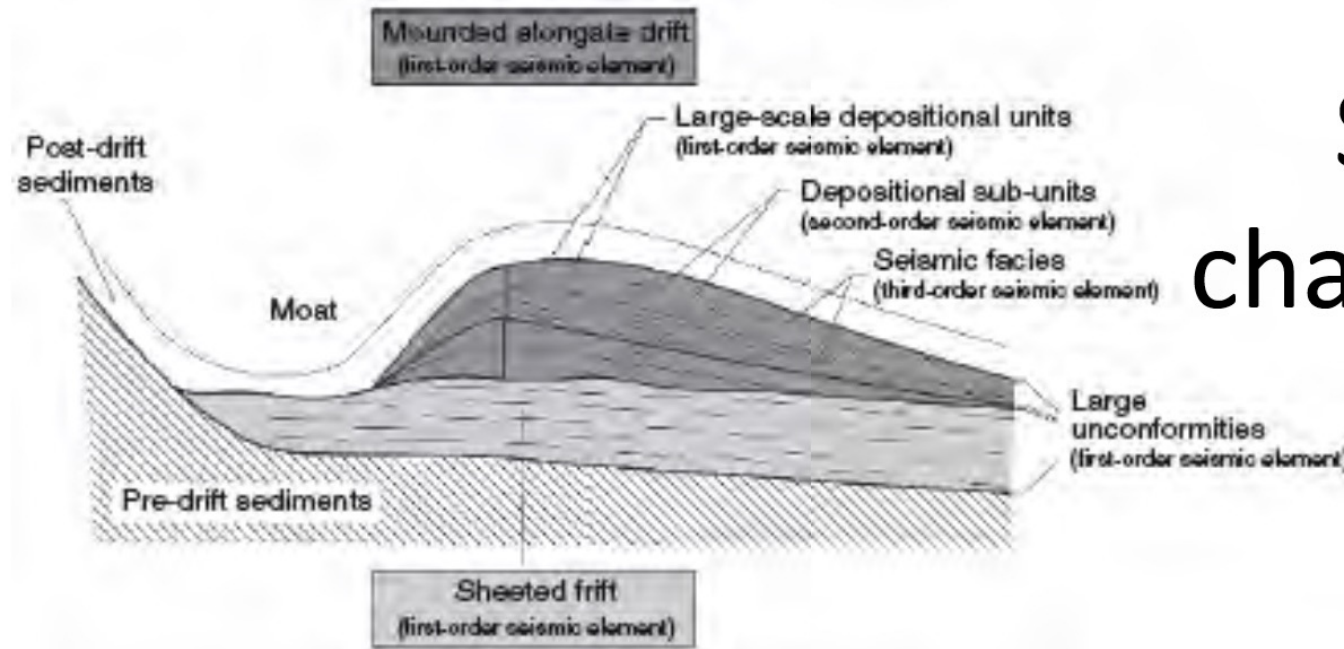


Rebesco & Camerlenghi (2008)

Recognizing contourite deposits in ancient sedimentary series presently exposed on land, is a difficult task. The distinction between contourites and reworked turbidites is controversial.

Diagnostic criteria are their **facies and ichnofacies, texture and sequences, microfacies and composition**. **Sedimentary structures** are also “diagnostic indicators”, but for their interpretation its full context should always be considered. **Medium-scale criteria** (hiatuses and condensed deposits, variation in the thickness, geometry, palaeowater depth, geological context) can be definitive. **Large-scale criteria** (palaeoceanographic features and continental margin reconstructions) are essential, but generally more problematic to apply on outcrops.

# Seismics characteristics



triple-scale approach  
that involves 3 “orders  
of seismic elements”.

Large scale (overall architecture): I-order elements (major changes in current strength and sediment supply): External geometry, Bounding reflectors, Gross internal character.

Medium scale (internal architecture): II-order seismic elements (reflecting smaller fluctuations): lens-shaped, upward-convex geometry; uniform stacking pattern; down-current migration or aggradation; downlapping reflector terminations

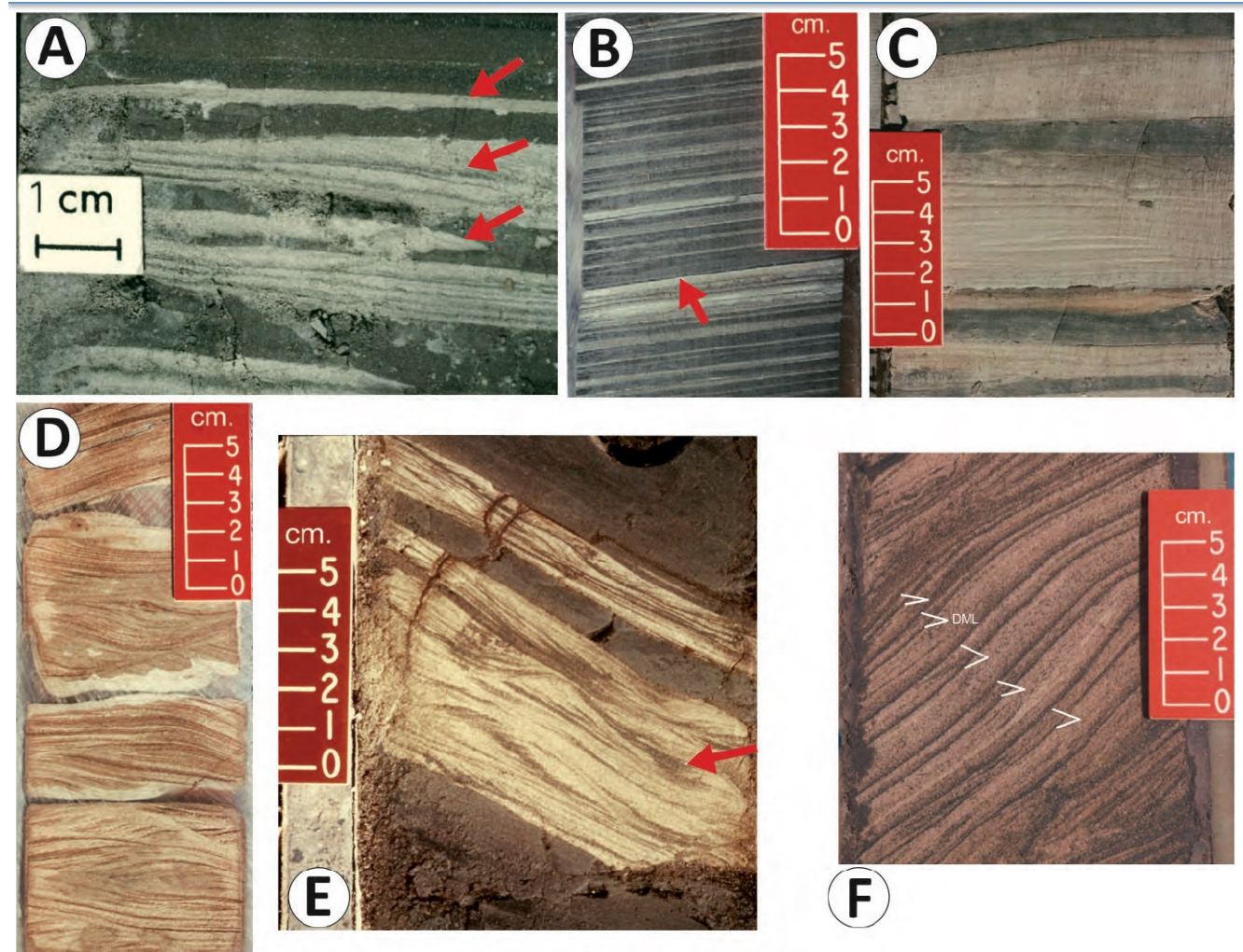
Small scale (internal acoustic character): III-order seismic elements: facies analysis (continuous, (sub)parallel, wavy, structureless), and attribute analysis (bedforms).



# Sedimentary structures in cores

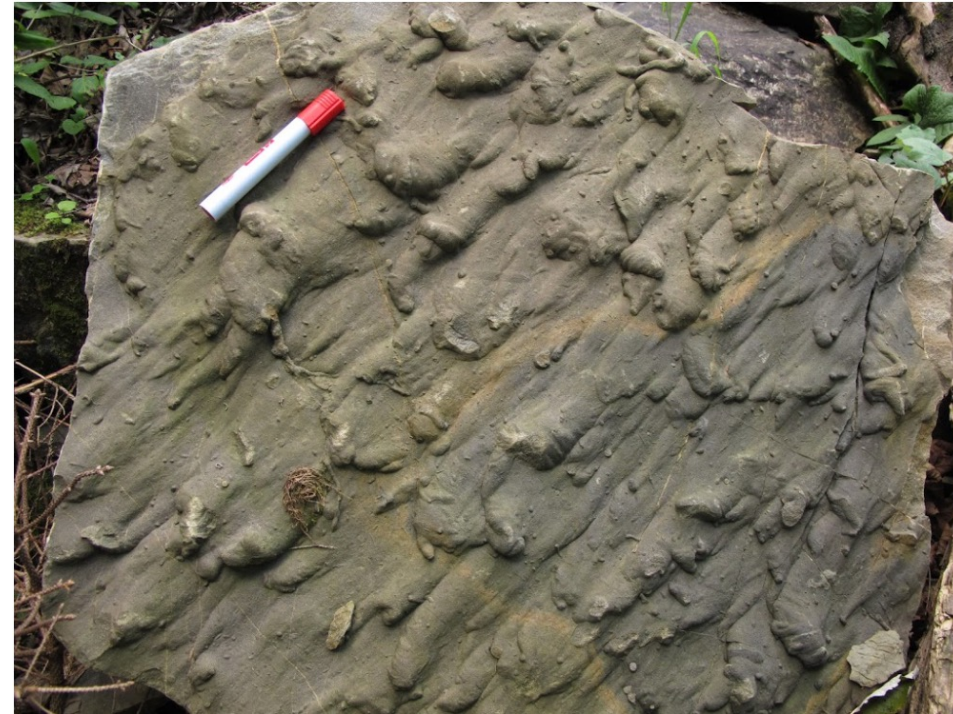
From Rebesco M.,  
Camerlenghi A.,  
(Eds.) 2008.  
Contourites,  
Developments in  
Sedimentology, 60,  
Elsevier, 666 pp.

Originally in:  
Shanmugan, 2008;  
Shanmugam et al.,  
1993;  
Shanmugam, 2012



# Sedimentary structures in outcrops

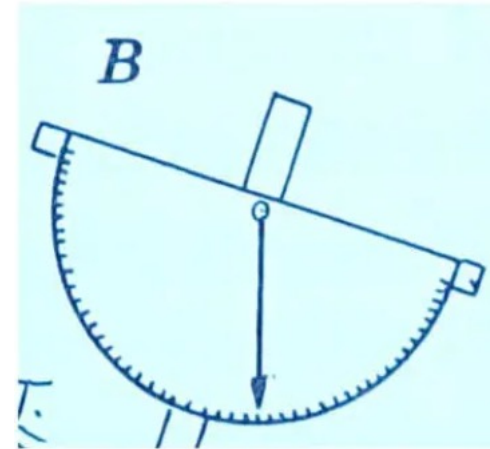
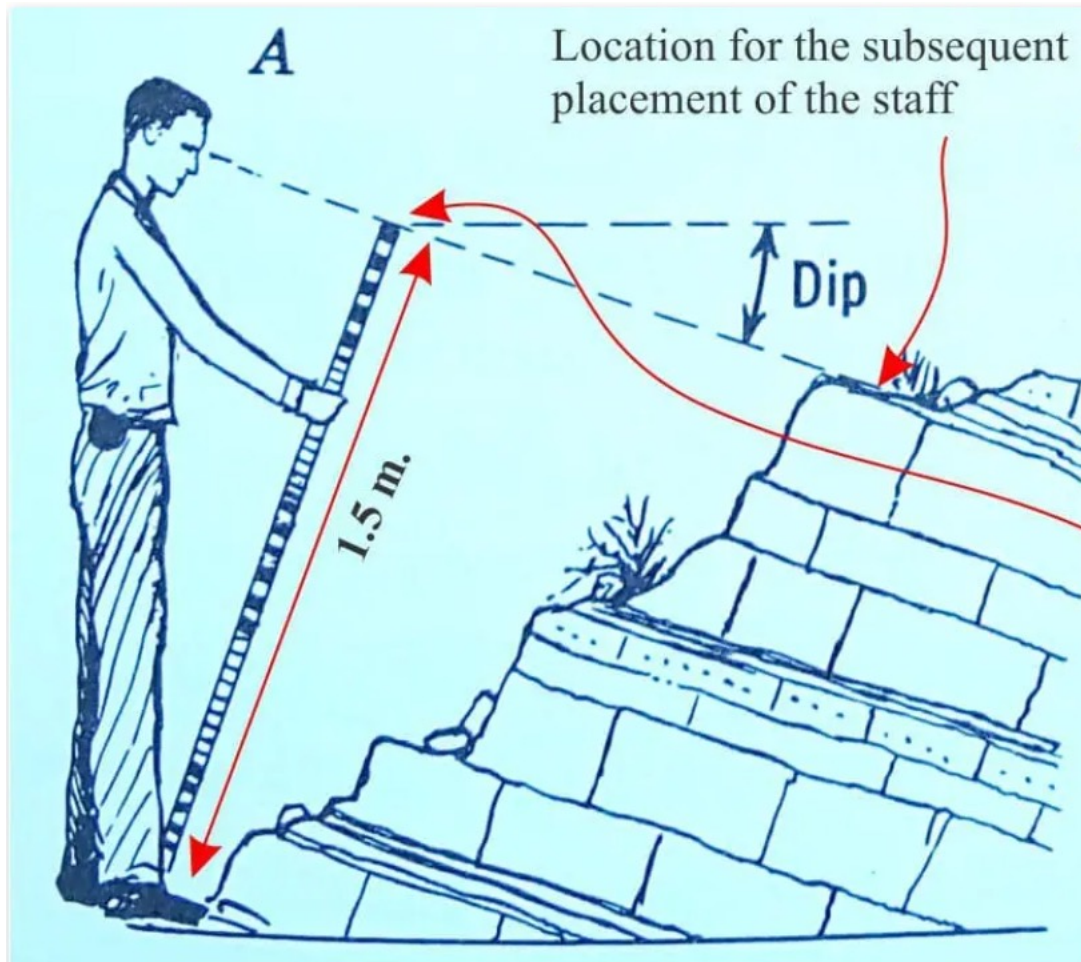
<https://uhlibraries.pressbooks.pub/historicalgeologylab/chapter/chapter-4-sedimentary-structures/>

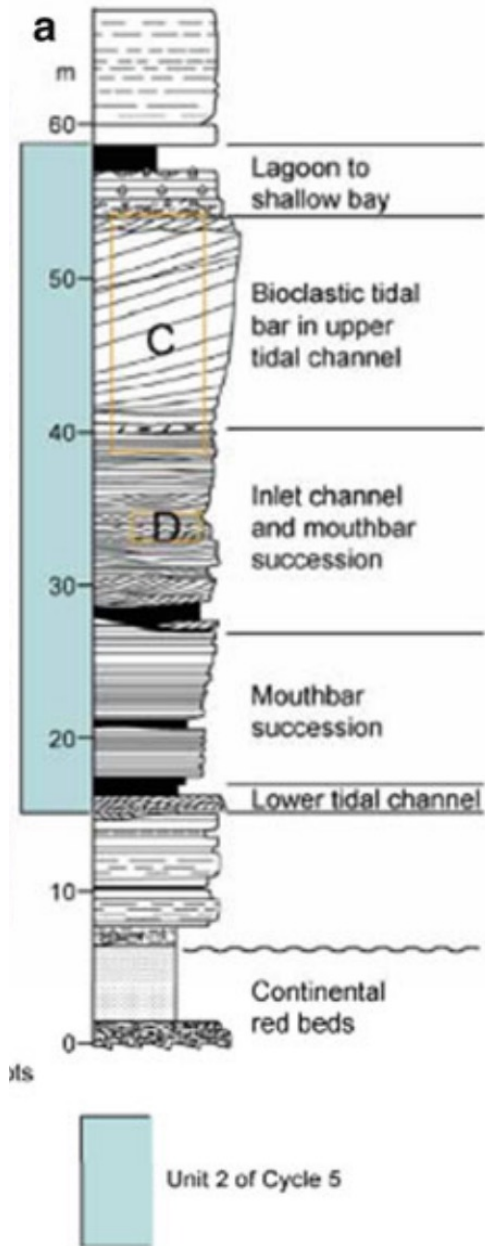


Flute casts from the central Alps, Switzerland. The view is from the underside of the rock. Image credit: Chris Spencer

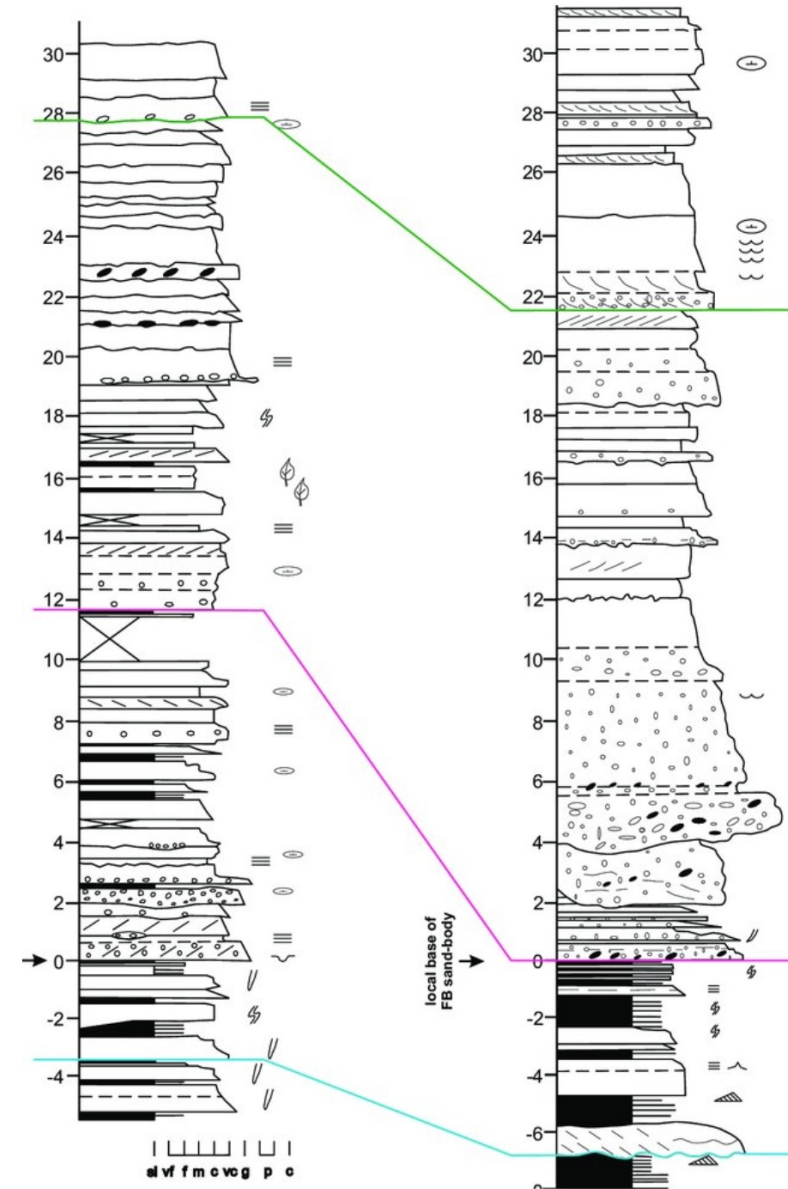
Symmetrical ripples in Devonian-Mississippian age sandstone from Ohio, USA. These are all views from the top. Image credits: James St. John,

# Jacob's staff





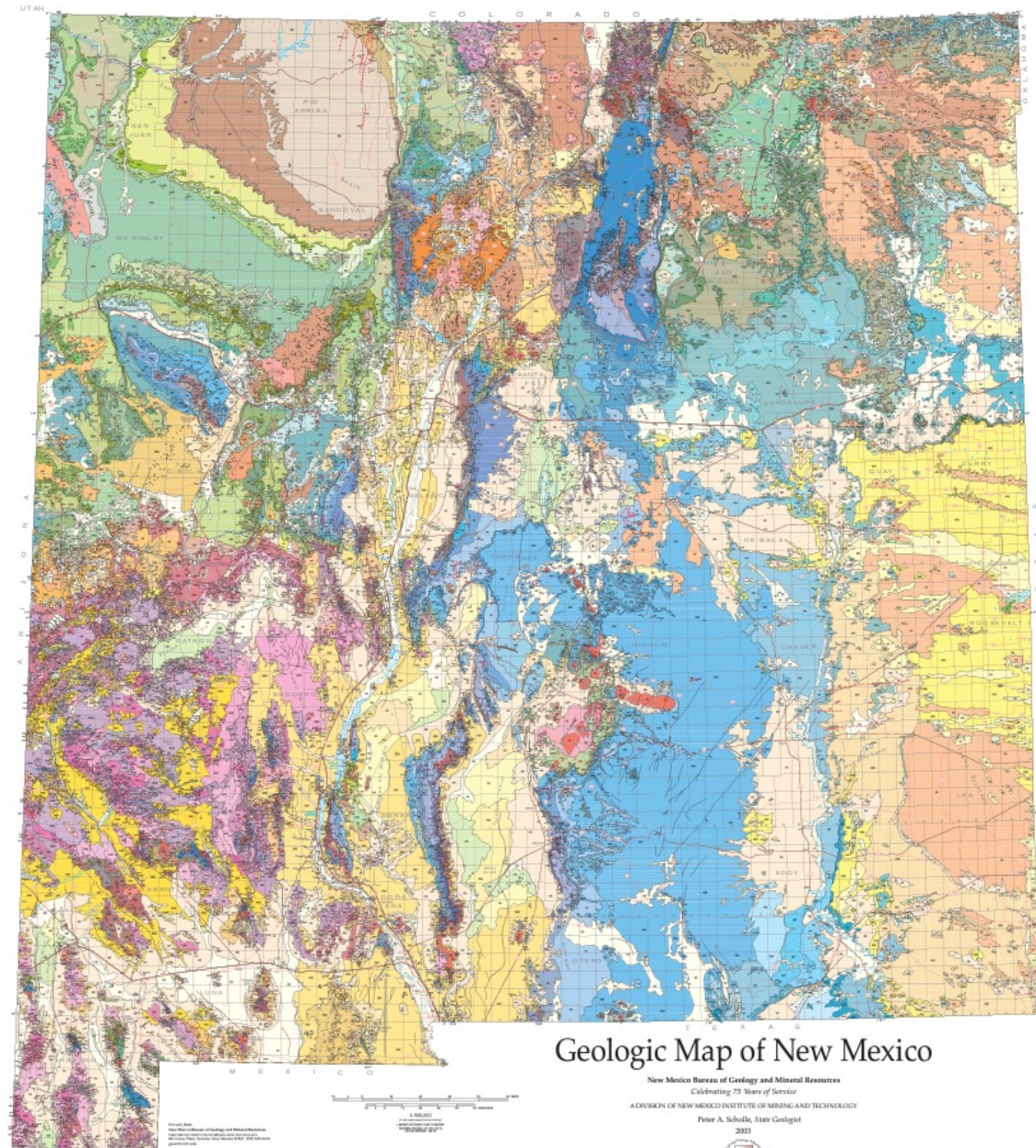
# Sedimentary logs



# How do you estimate grain size?



# Geological mapping

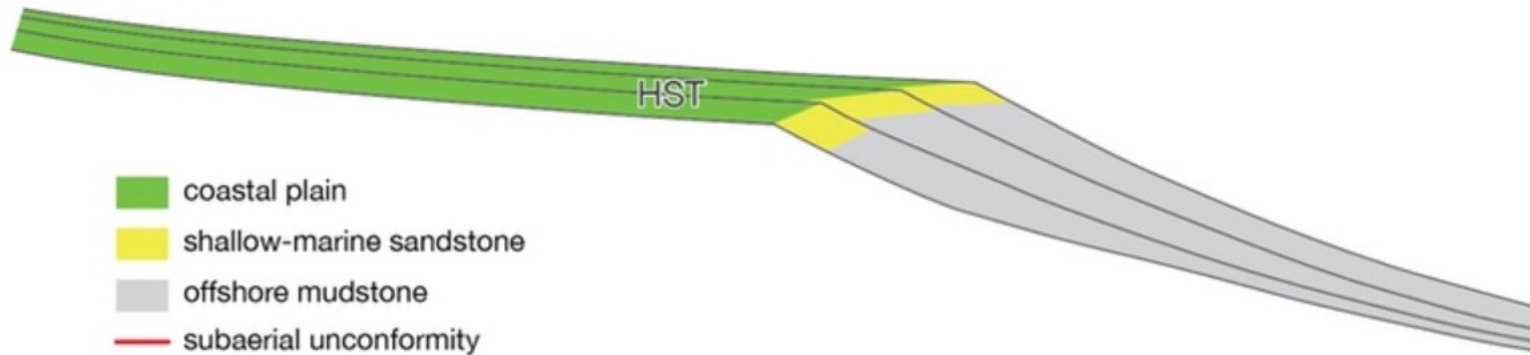


# Lithology

The lithology of a rock unit is a description of its physical characteristics visible in outcrop, or with low magnification microscopy. Physical characteristics include color, texture, grain size and composition.

The lithology is the basis of the subdivision of the rock sequences into single lithostratigraphic units for the purposes of mapping and correlating the areas.

# Chronostratigraphic sequences





# Facies

The facies is the sum of the overall characteristics of a rock unit, which reflect its origin and differentiate the unit from others around it.

Within the facies, we can distinguish eg lithofacies (stratigraphic unit distinct from the adjacent ones based on lithology),

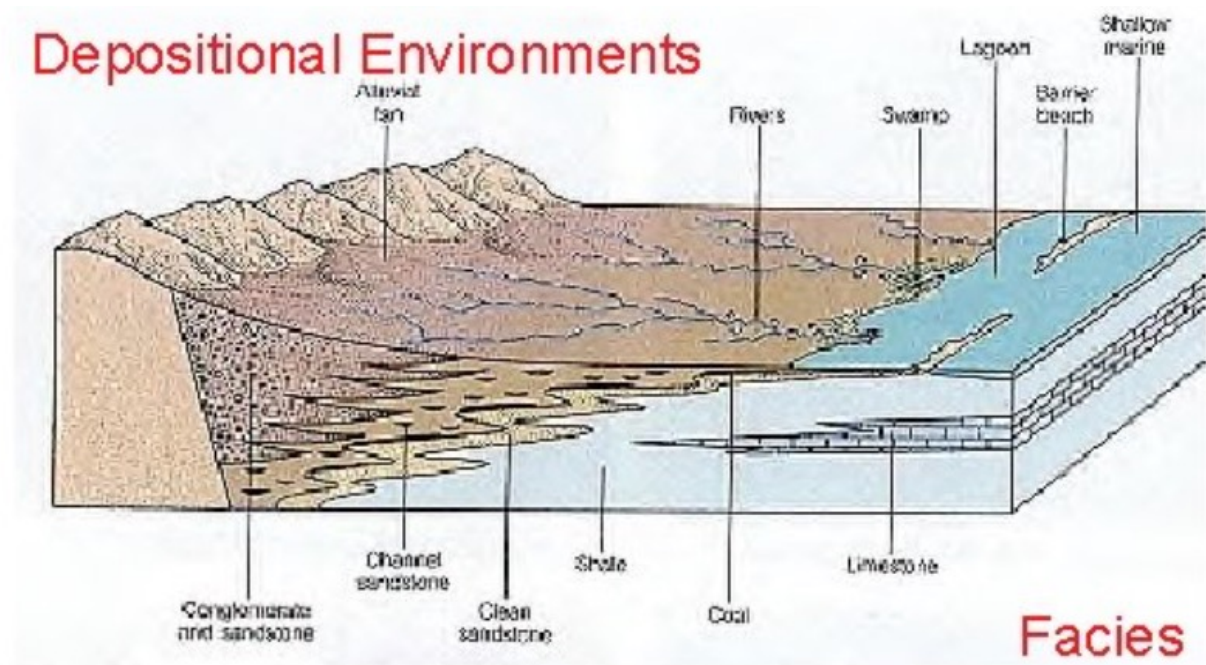
Biofacies,

Microfacies

Ichnofacies

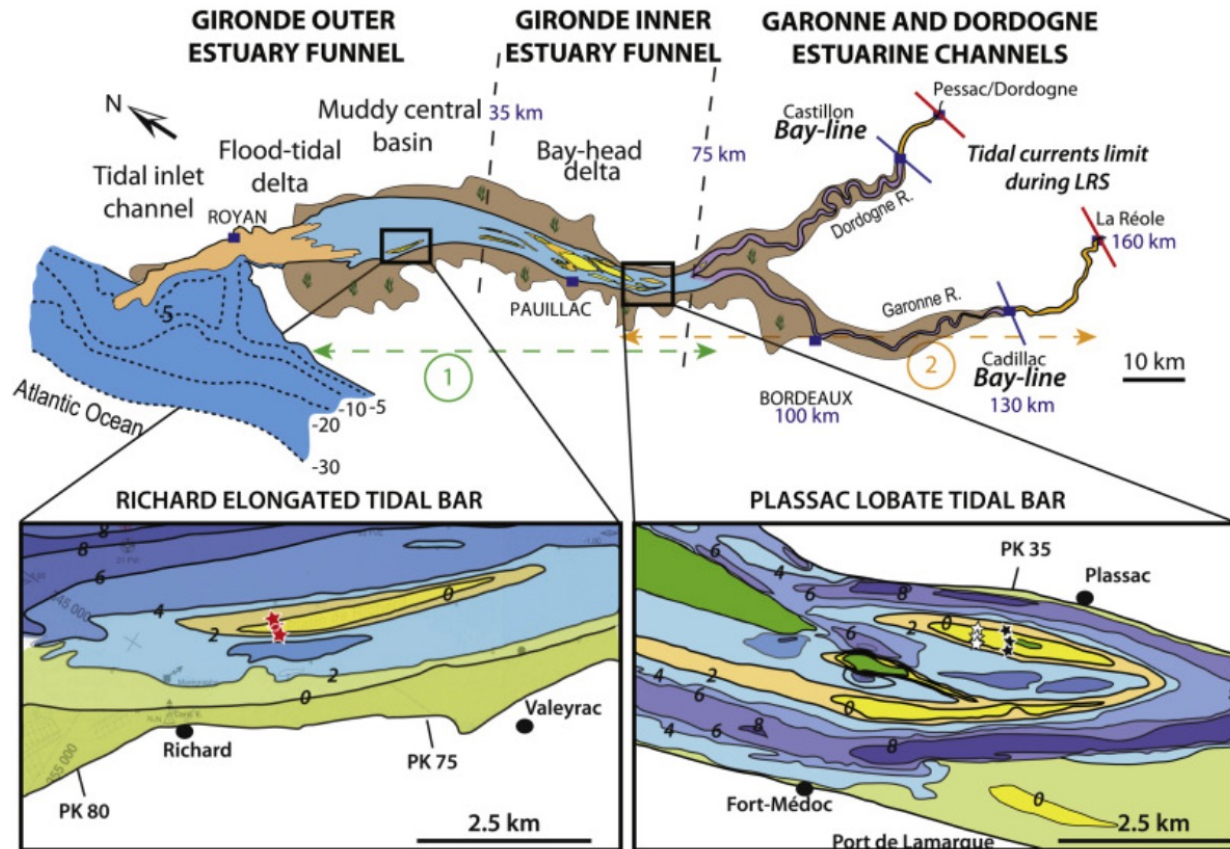
Seismic facies

...



# Modern analog

Gironde estuary tidal bars: A modern analogue for deeply buried estuarine sandstone reservoirs



**LEGEND:**

- Fluvial-estuarine transition point bars
- Estuarine heterolithic point bars
- Tidal mudflats and marshes
- Estuary funnel tidal bars
- Estuarine mud
- Tidal inlet channel fill

- Tidal bars supratidal zone
- Tidal bars intertidal zone
- Tidal bars subtidal zone
- Bathymetric lines

- Cores location realized in this study in the Plassac tidal bar
- Cores location realized in 2010 in the Plassac tidal bar
- Core transect location in the Richard tidal bar

XX km: Distance from the estuary mouth

TMZ position during High-River Stage (HRS)

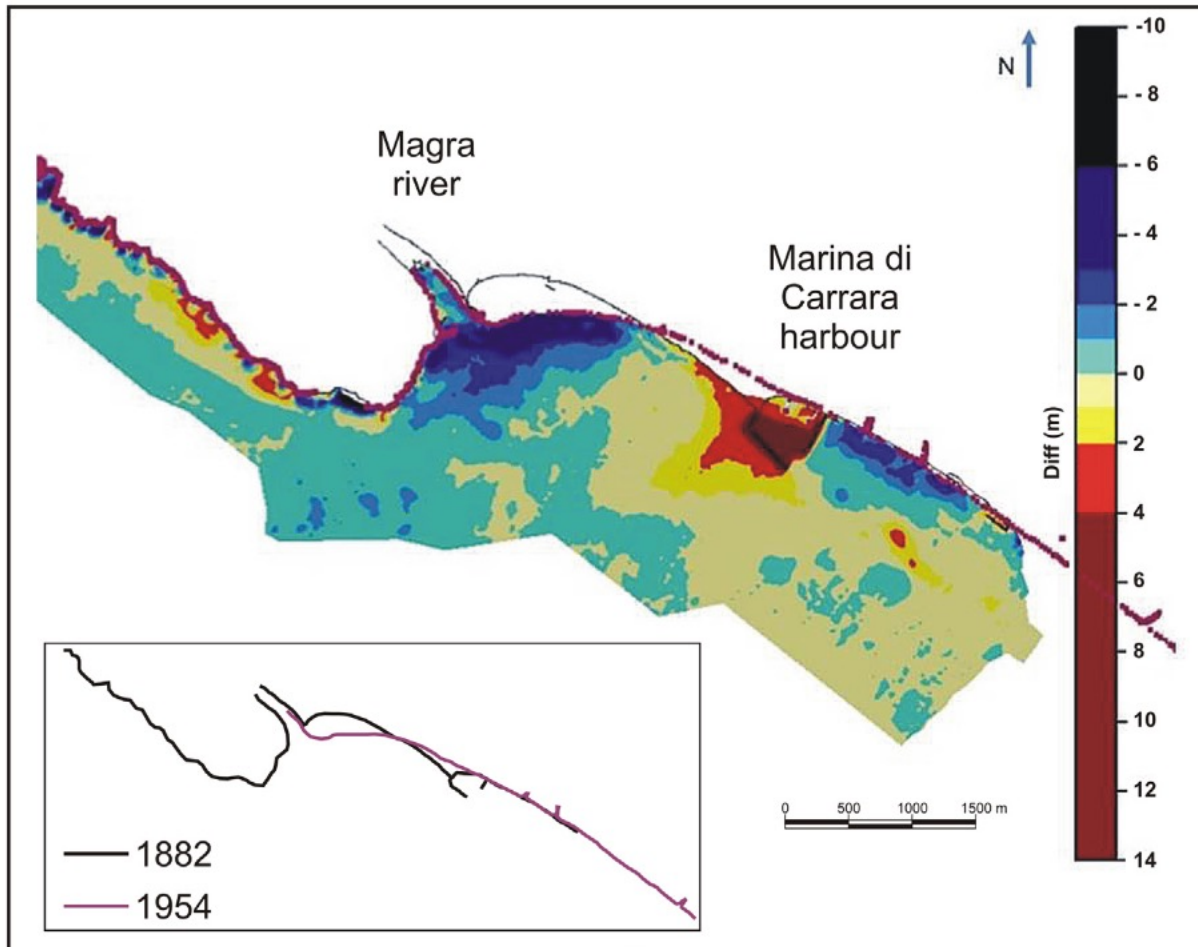
TMZ position during Low-River Stage (LRS)



Virolle et al., 2020.  
Marine Petroleum Geology

# Historical data

River-mouth geomorphological changes over > 130 years, Pratellesi et al., 2018. Marine Geology



Difference surface between the 1882 and 1954 bathymetry; erosion areas are represented in blue and accretion ones in red (values are expressed in meters). Black and purple lines in the inset delineate, respectively, the 1882 and 1954 msl contour lines.

# Trenches



stratigraphic soil layers, Vjosa Valley, Albania