Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Università degli studi di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE

Classe Scienze e Tecnologie Geologiche

Curriculum: Esplorazione Geologica

Anno accademico 2021 - 2022

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

Docente: **Michele Rebesco**

Modulo 1.2: Metodi

Outline:

Parte 1 (Metodi Geofisici): Prof Valentina Volpi

Parte 2 (Metodi Geologici): Prof Michele Rebesco

GEOPHYSICAL METHODS

- All geophysical methods remotely sense a material property of the earth
- (e.g. seismic velocity, rock density, electrical resistivity, magnetization etc).

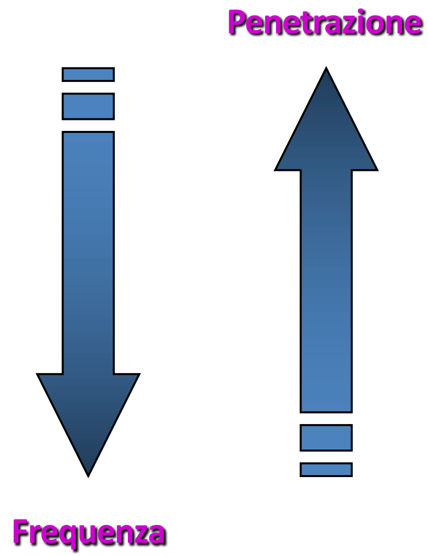
- Facies analysis of subsurface data depends on tools which delimit the surfaces and provide clues as to to the sediments they contain.

- **Seismics**
- **Well logs**
- **Gravity and magnetometry**
- **Geoelectrics**
- **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)

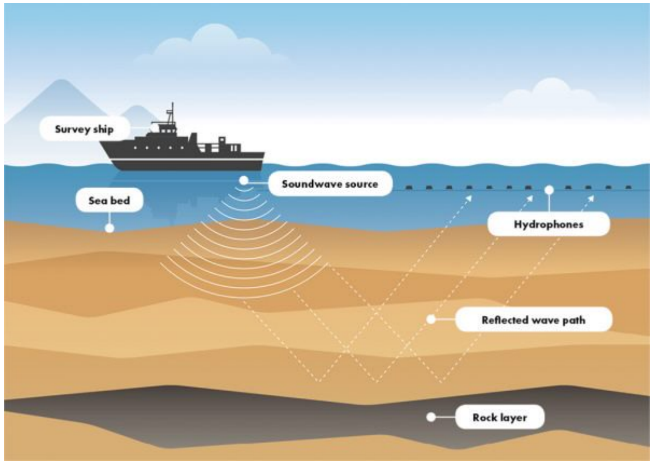


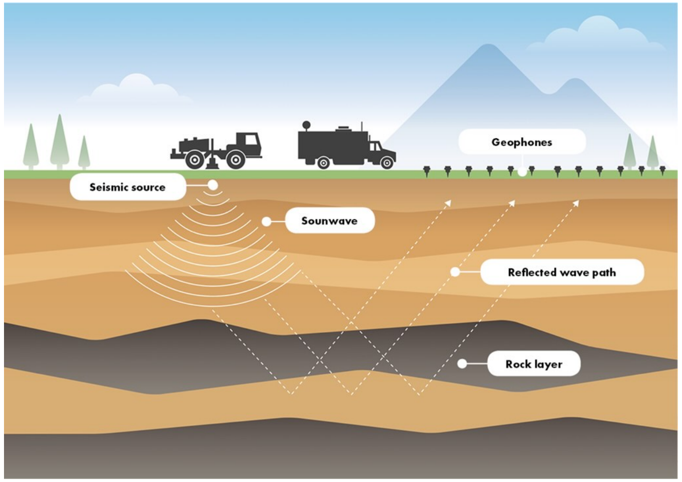
High frequency signals are used to study shallow sediments with higher resolution

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

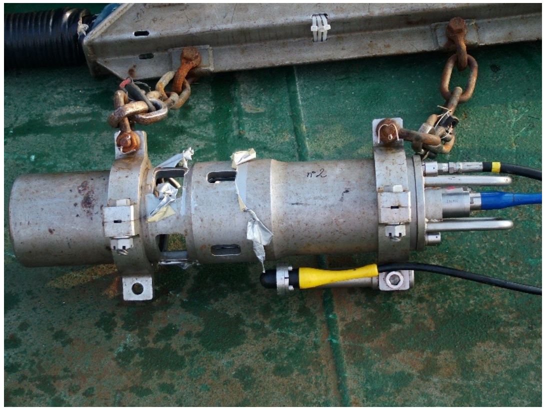


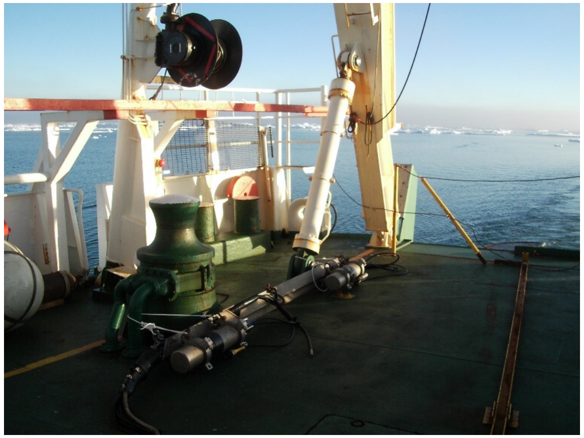


Land survey

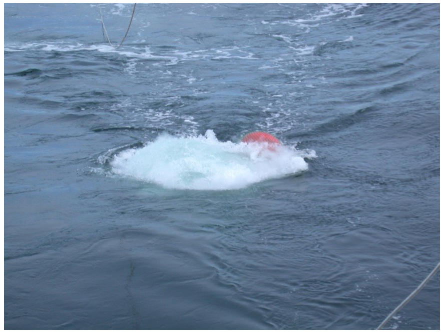
AIR GUNS

G.I. Gun



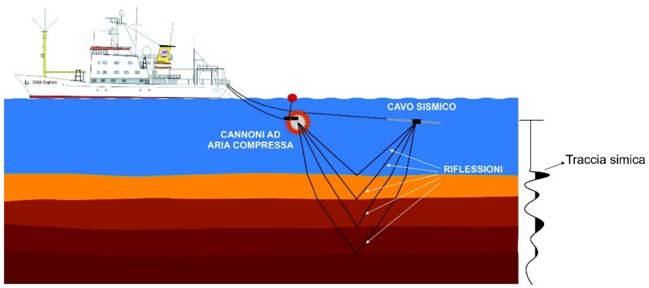


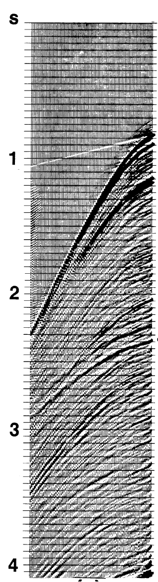
GUNS ARRAY



BUBBLE GENERATED BY A SHOT

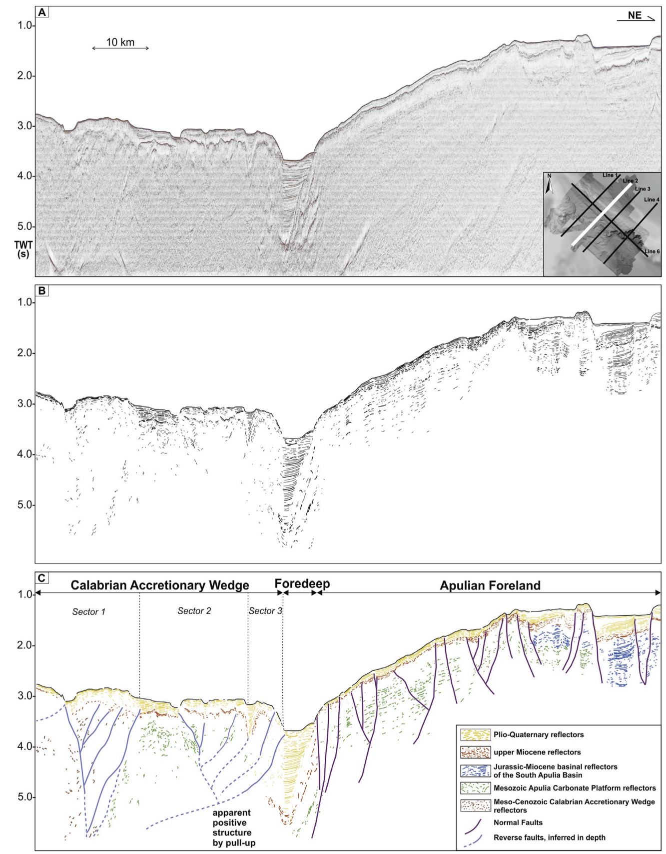
SEISMIC DATA





Reflection events

SHOT GATHER



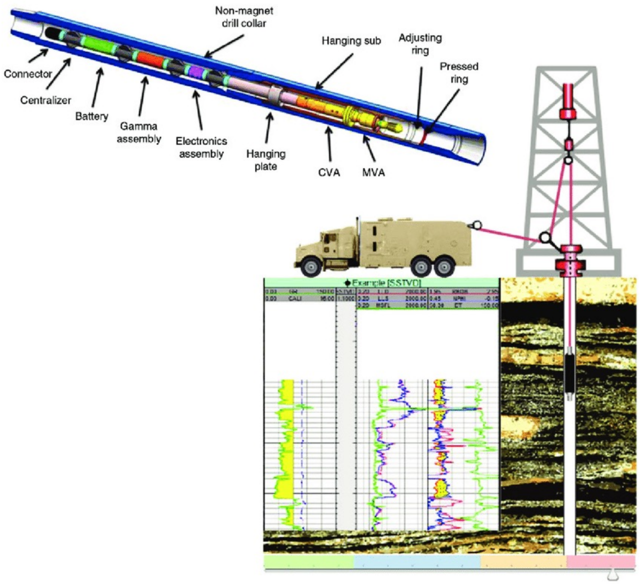
INTERPRETED SEISMIC SECTION

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.

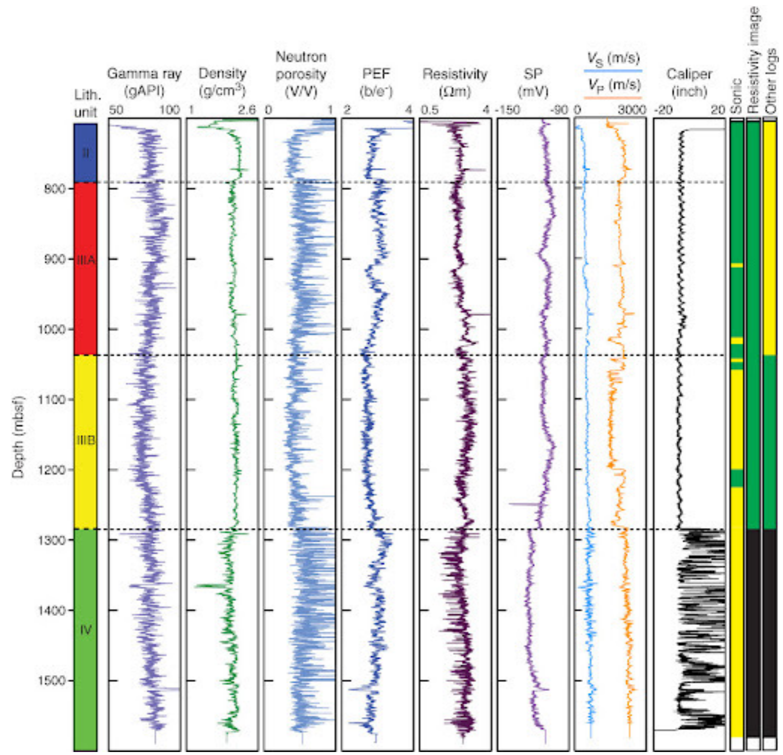
The data obtained from well logging reveals lithological classification as well as various physical, chemical, and structural properties of the formation around the borehole. Some of the detailed information that can be obtained from borehole logs includes:

- **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.)



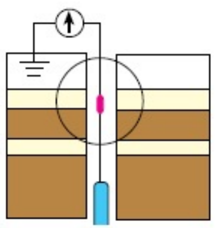
WELL LOGS

1. Electric
   - Spontaneous potential
   - Induction
2. Nuclear
   - Gamma ray
   - Density
   - Neutron porosity
3. Acoustic (sonic)
4. Other
   - Dipmeter
   - Photoelectric
   - Caliper
   - Imaging
   - NMR
   - …….



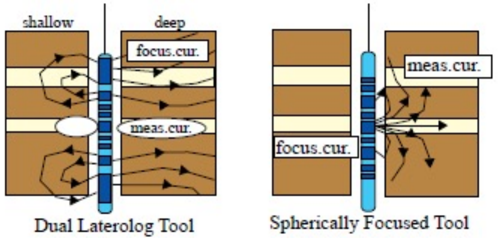
WELL LOGS - ELECTRICAL LOGS

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.

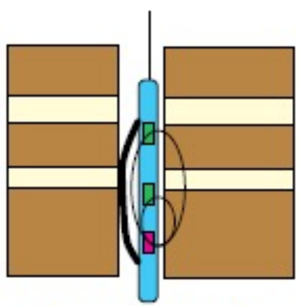
WELL LOGS - NUCLEAR LOGS

Neutron log

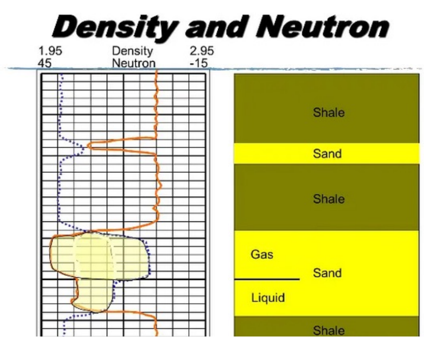
- a neutron source emits fast, high energy neutrons into the formation and measures the number of neutrons that are not slowed down and captured by the hydrogen atoms.
- porosity estimation
- lithology and gas indicator

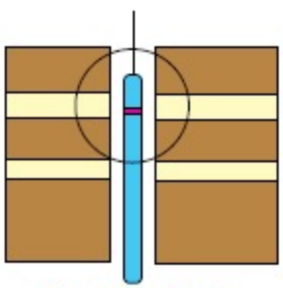
Gamma ray

- 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

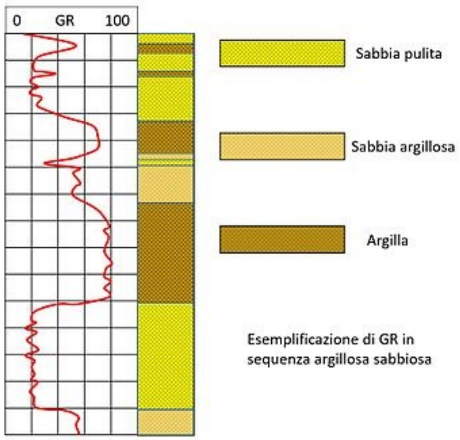


Neutron Porosity Tool





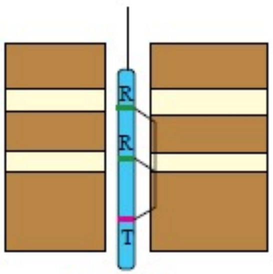
Gamma Ray Tool



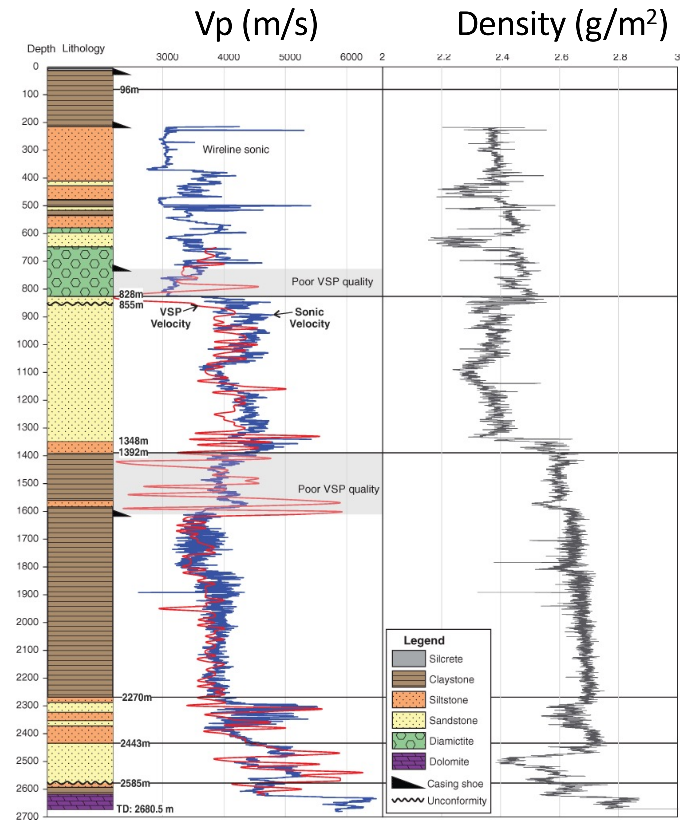
WELL LOGS - SONIC LOG

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 transmiter
- porosity estimation
- lithology and gas indicator
- seismic velocity calibration



Sonic Tool

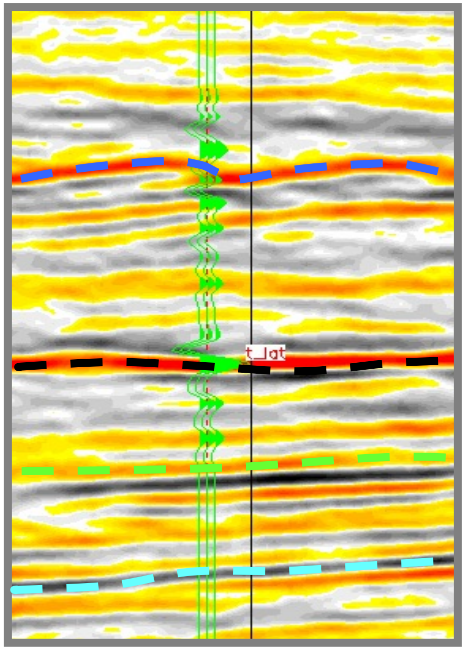


WELL SEISMIC TIES

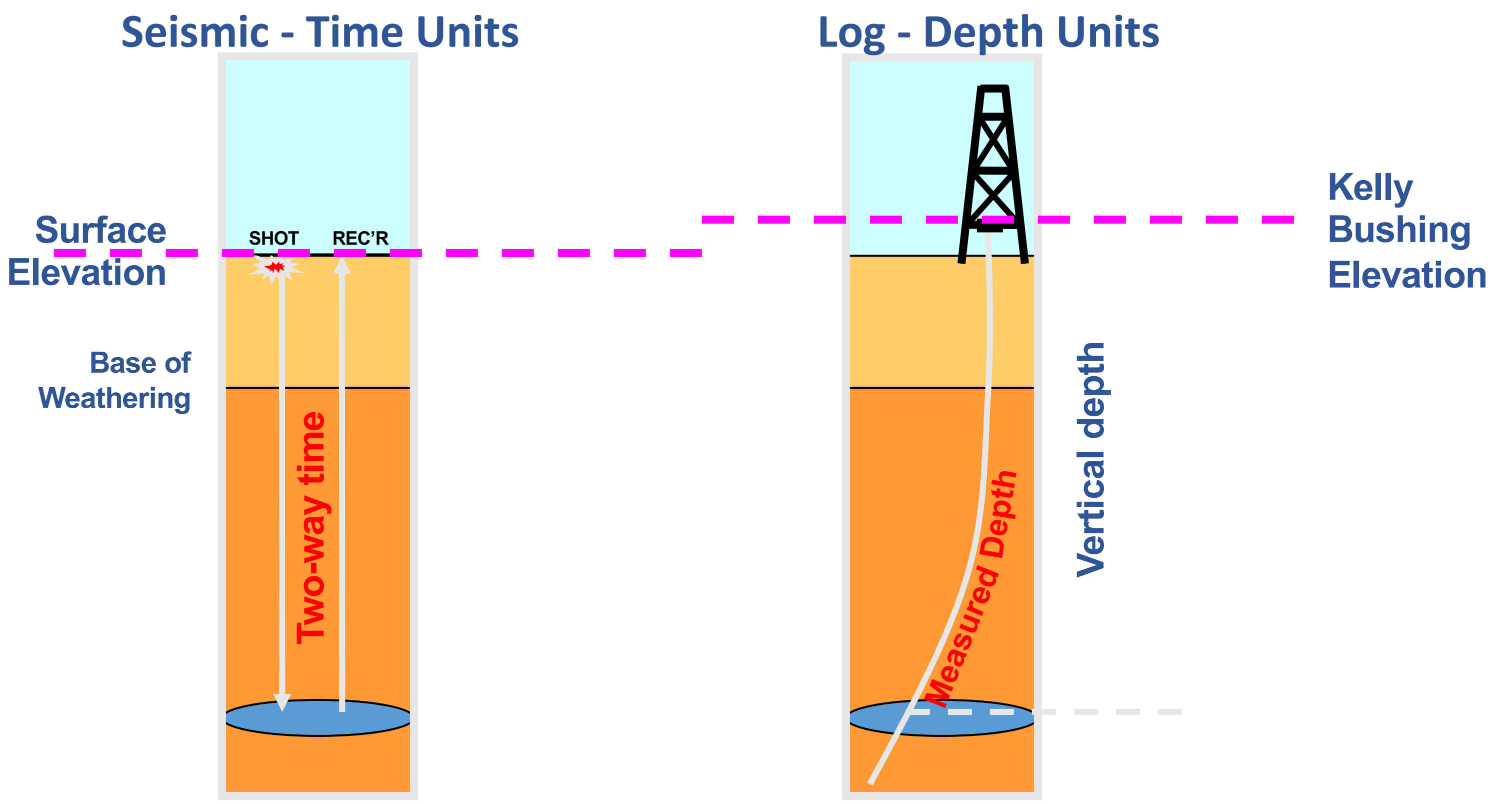
Objectives of Well-Seismic Ties

- 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

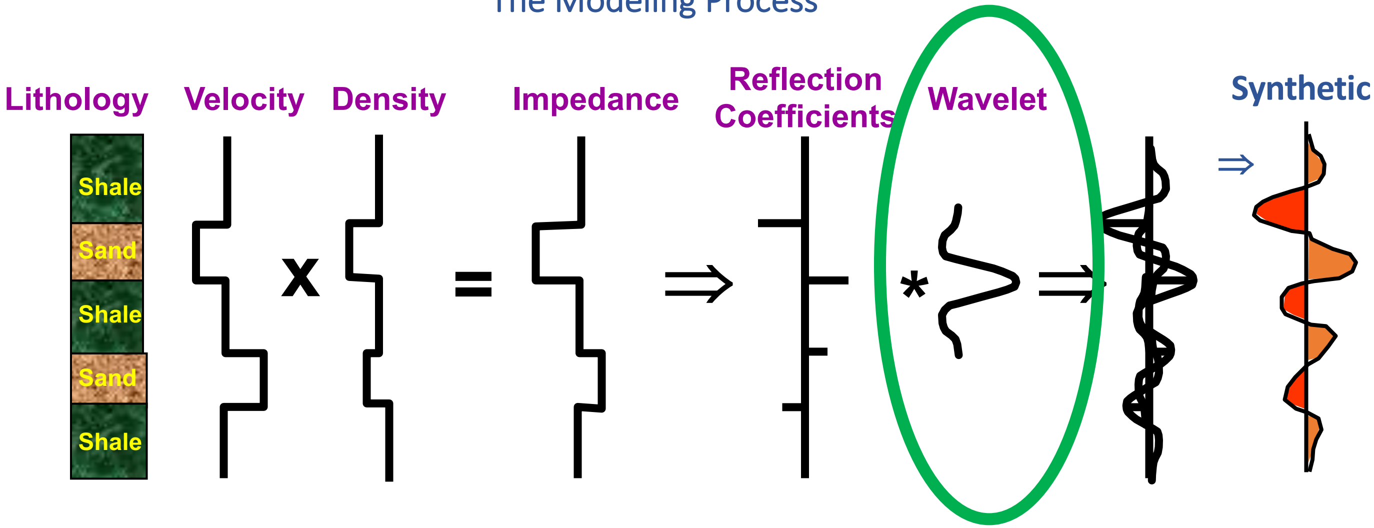
- Samples area and volume
- Low frequency 5 - 60 Hz
- Vertical resolution 15 - 100 m
- Horizontal resolution 150 - 1000 m
- Measures seismic amplitude, phase, continuity, horizontal & vertical velocities
- Time measurement

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

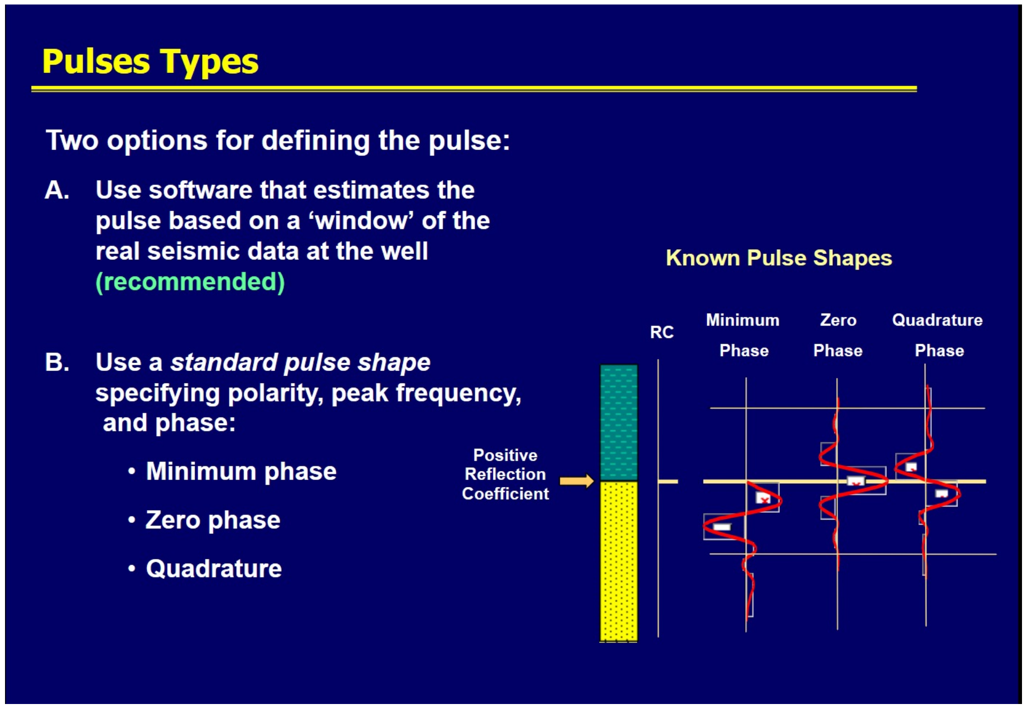
The Modeling Process



- 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

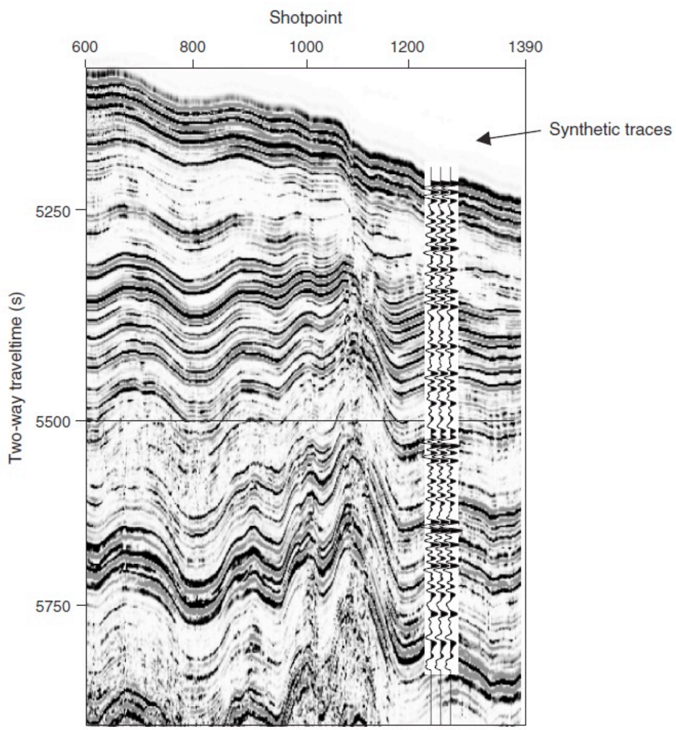
WELL SEISMIC TIES

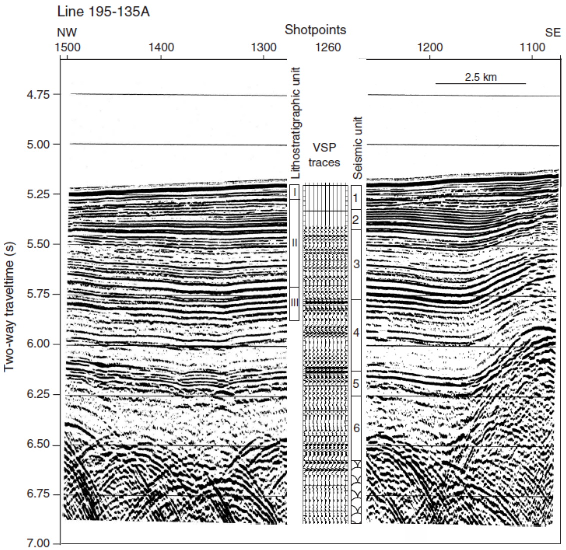
Wavelet (Pulse) – is the signal transferred to the subsurface from the seismic source.

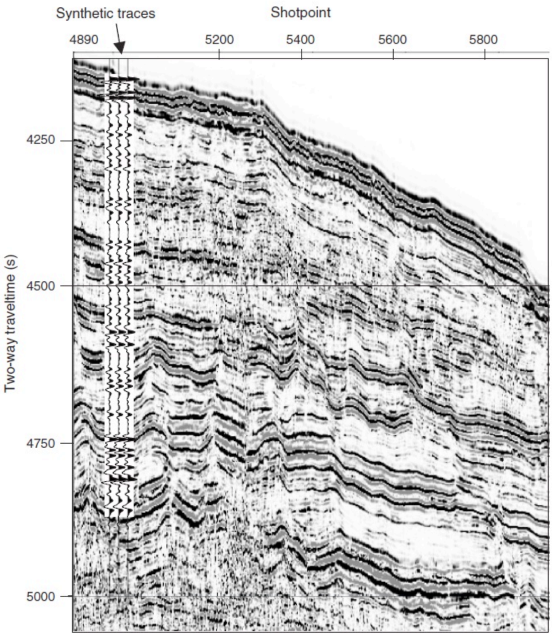


WELL SEISMIC TIES

Examples

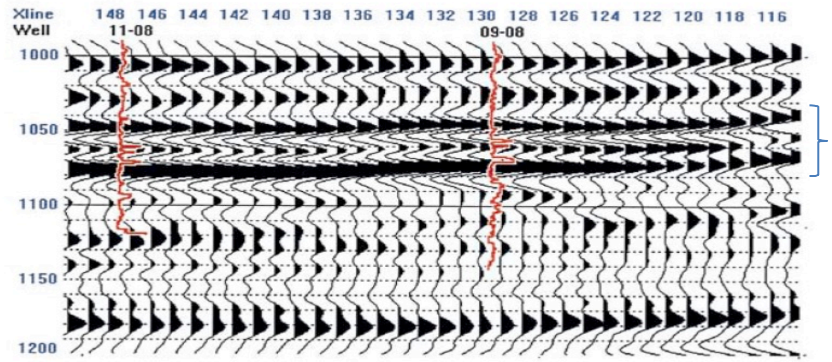




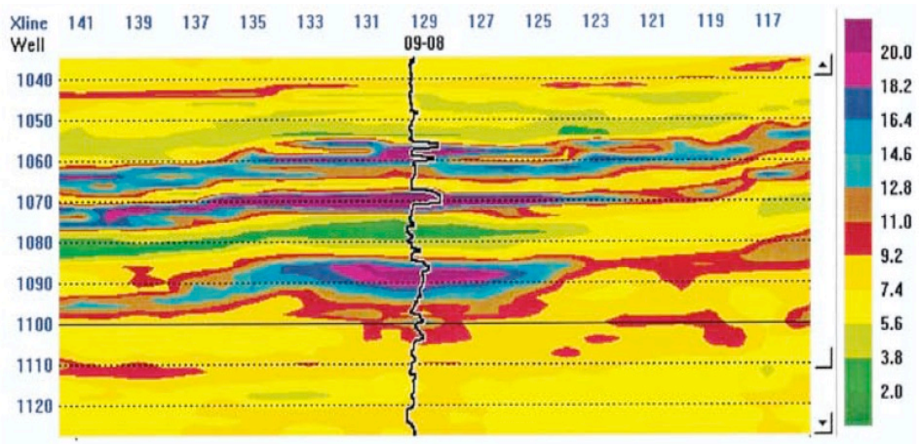


PETROPHYSICS

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 progate the information at well location also laterally along the crossed seismic line.



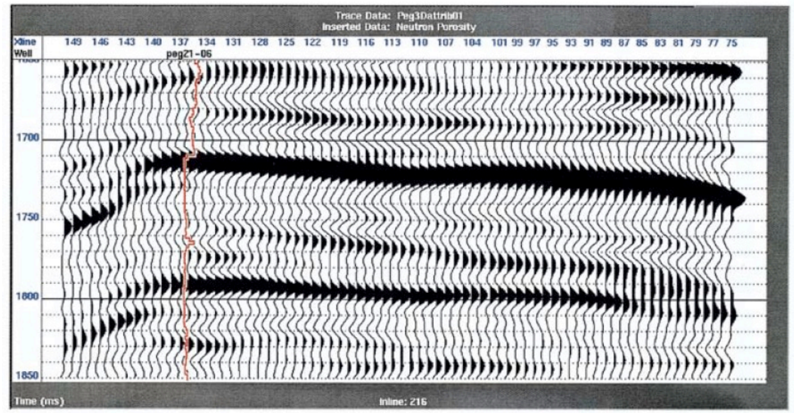
Alternation of shale/sand fill in a incised valley (CANADA)



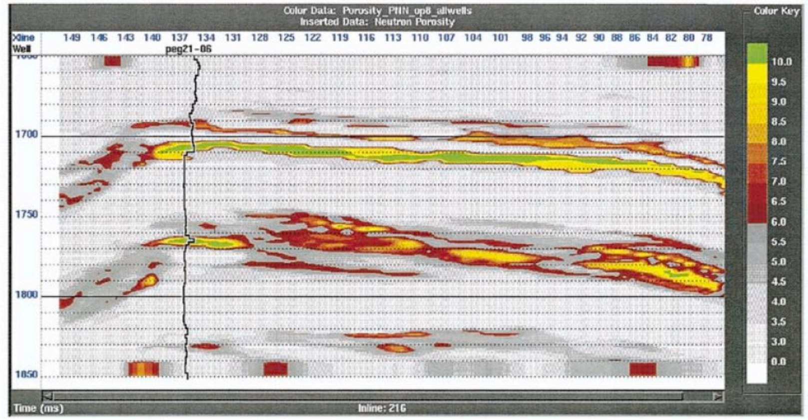
PETROPHYSICS

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: $F = G \frac{m1\ m2}{r^2}$

according to which any two masses m1 and m2 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:

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

g

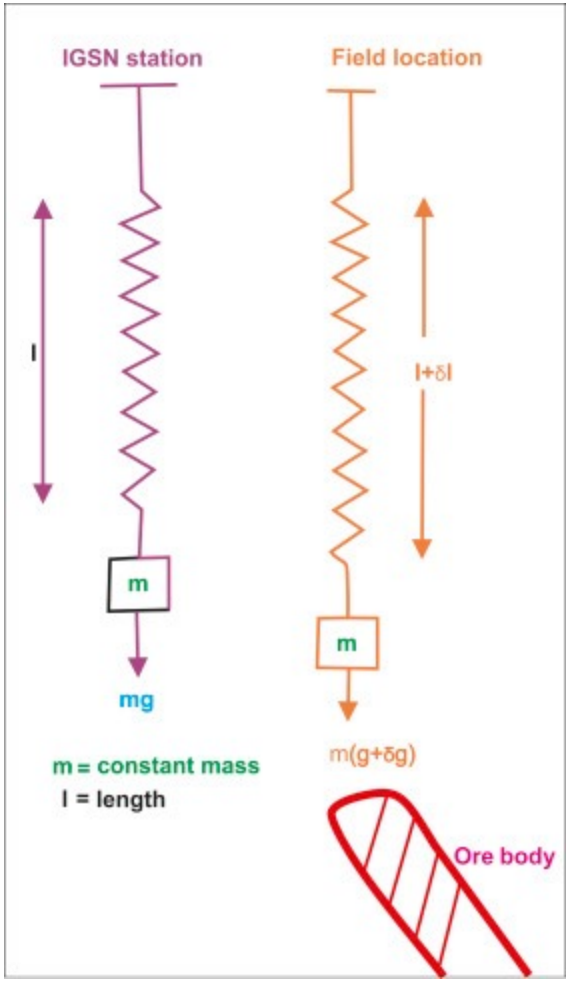
Force is related to mass by an acceleration and the term **g** is known as the gravitational acceleration or *gravity.* The weight of the mass is given by mg.

The Earth ellipsoidal shap, rotation, irregular surface relief and internal mass distribution cause gravity (gravity field) to varies 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:

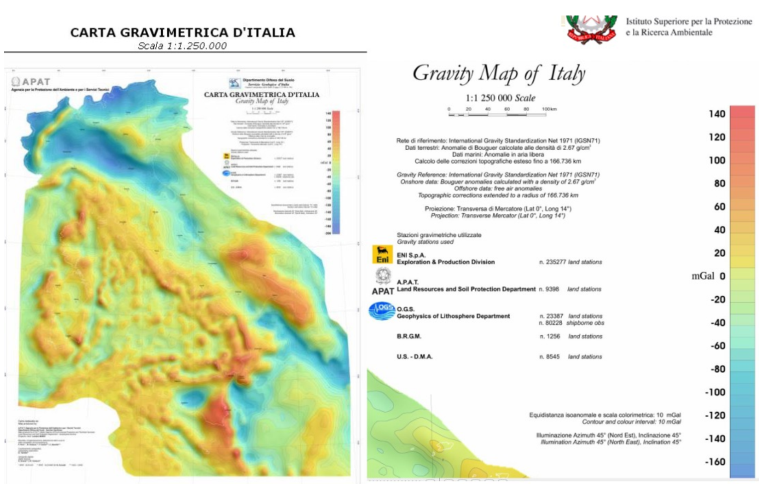
- **Absolute gravimeters** measure the local gravity in absolute units (Gal). Absolute gravimeters are used in the field. They work by directly measuring the acceleration of a mass during freefall in a vacuum. An accelerometer is rigidly attached to the ground.
- **Relative gravimeters** are extremely 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 + δg) 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.

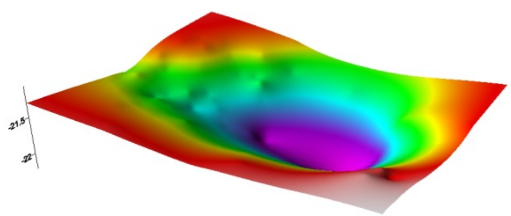


Relative gravimeter principle

GRAVITY METHOD

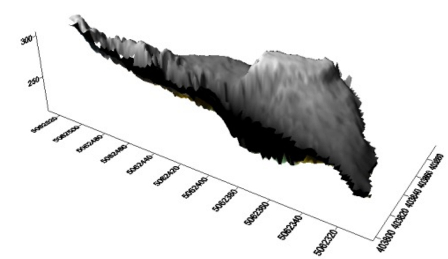
Gravity method plays an important role in the studies related to sedimentary basin modeling because detectable gravity anomalies can be observable on the surface of the Earth due to the presence of significant density contrast between sediment infill and the underlying basement. These observed gravity 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.





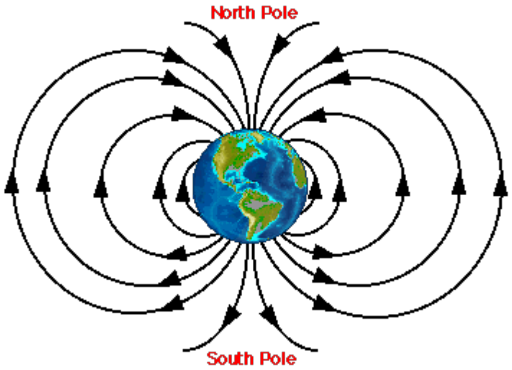
Gravity map of the Grotta Gigante

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 precede 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.

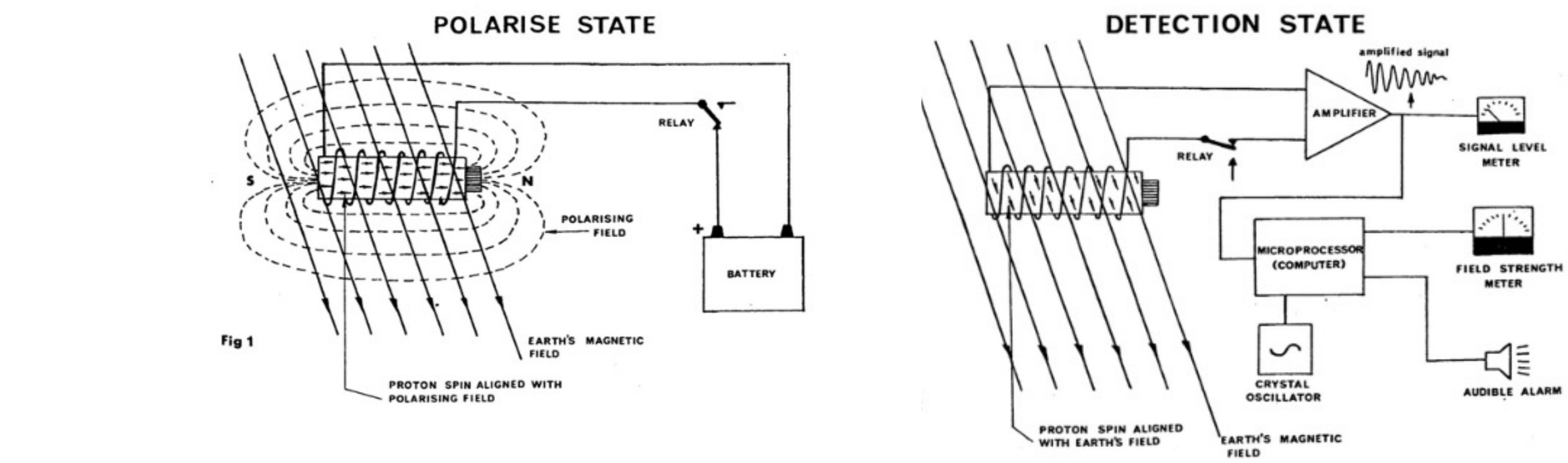
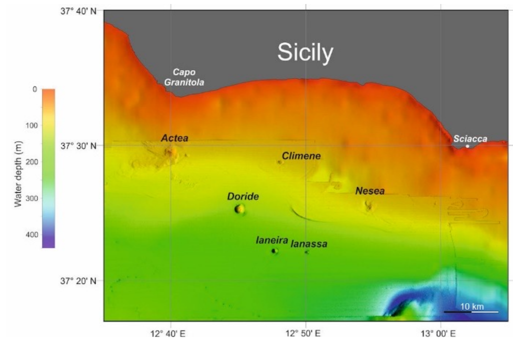
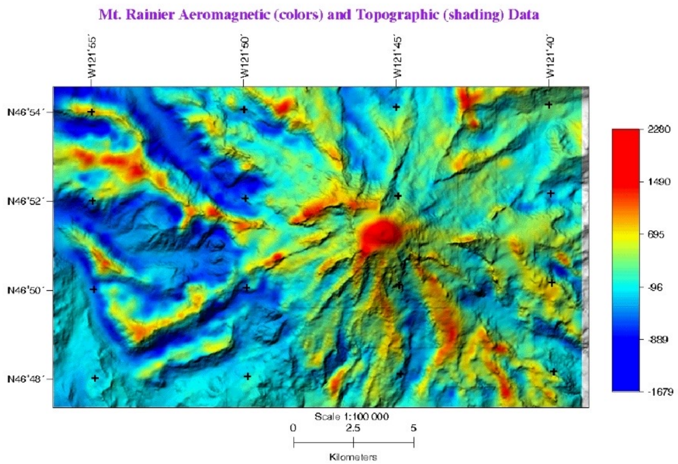


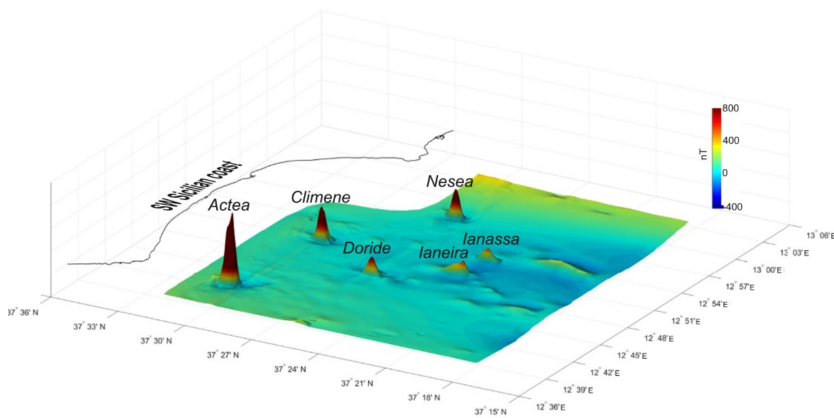
Fig 1

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).



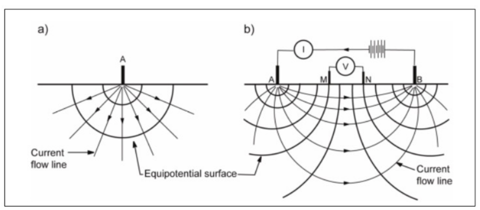




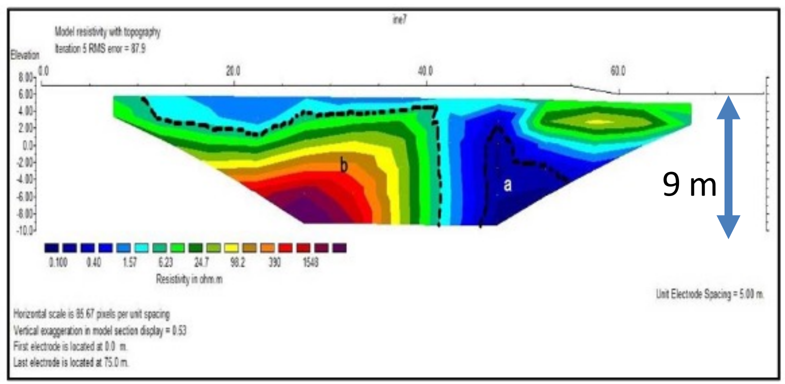
Lodolo et al., 2019

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



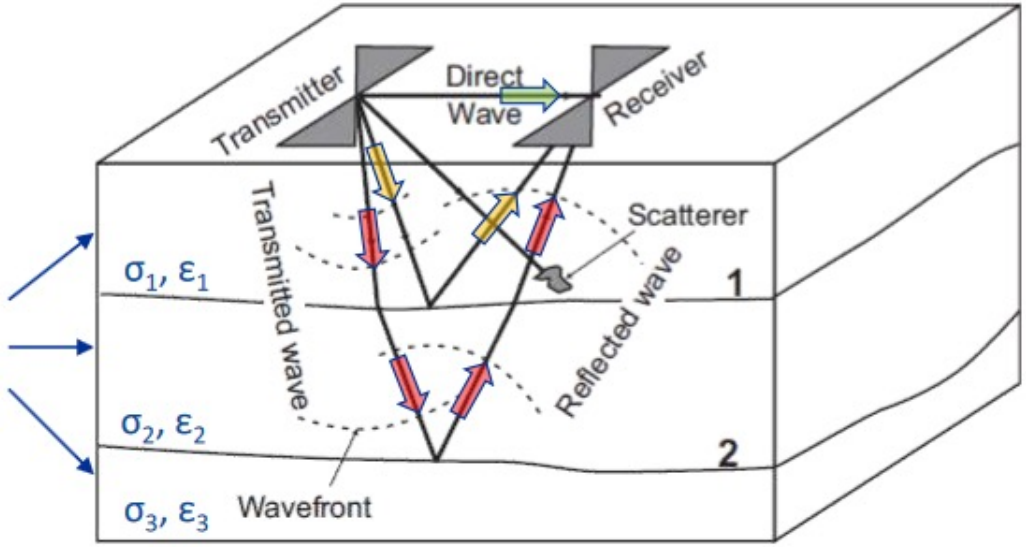
(a) showing resistivity values ranging from 0.1 - 0.2 Ωm which is estimated to be salt water intrusion based on the resistivity table of earth materials and region (b) which is a mixture of sand and clay material with a range of resistivity values between 1 - 1000 μm

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

Layers with different dielectric properties



ELECTROMAGNETIC METHOD

Ground penetrating radar - GPR

Material	Permittivity (ε_r) -	Resistivity (ρ) [Ωm]
Air	1	> $1\cdot10^{16}$
Ice	3–4	$1\cdot10^{5}$
Fresh water	80	$2\cdot10^{4}$
Salt water	80	0.3
Dry sand	3–5	$1\cdot10^{5}$
Wet sand	20–30	$1\cdot10^{3}$ - $1\cdot10^{5}$
Shales and clays	5–20	1 - $1\cdot10^{3}$
Silts	5–30	1 - $1\cdot10^{2}$
Limestone	4–8	500 - 2000
Granite	4–6	$1\cdot10^{3}$ - $1\cdot10^{5}$
(Dry) salt	5–6	$1\cdot10^{3}$ - $1\cdot10^{5}$

Dielectric permittivity

- Defines how strongly a material becomes electrically polarized under the influence of an electric field
- Determines the reflection and refraction of radiowave signals
- Impacts the velocity and then the wavelength of radiowave signals

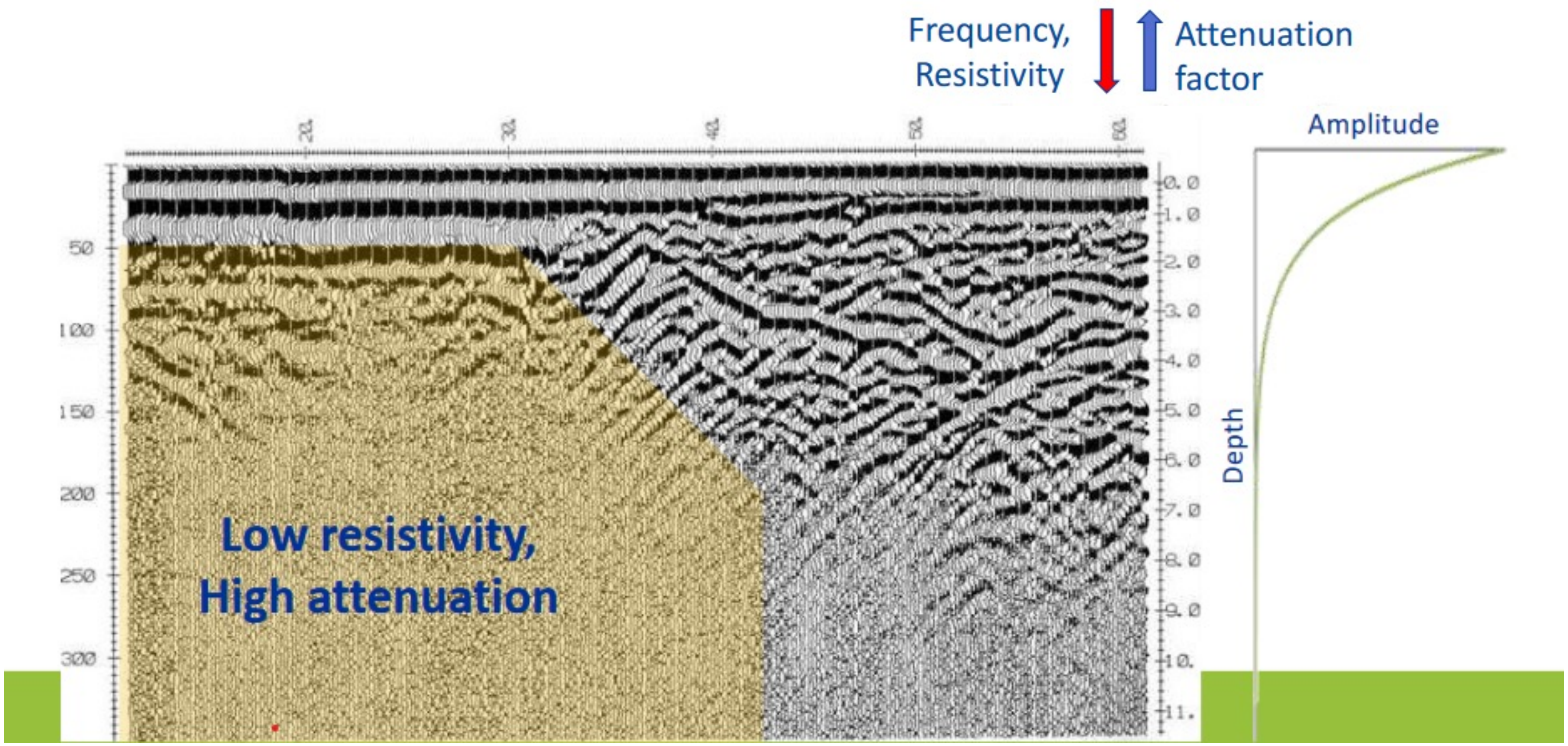
Resistivity

- Inverse of conductivity
- Impacts the attenuation of radiowave signals

ELECTROMAGNETIC METHOD

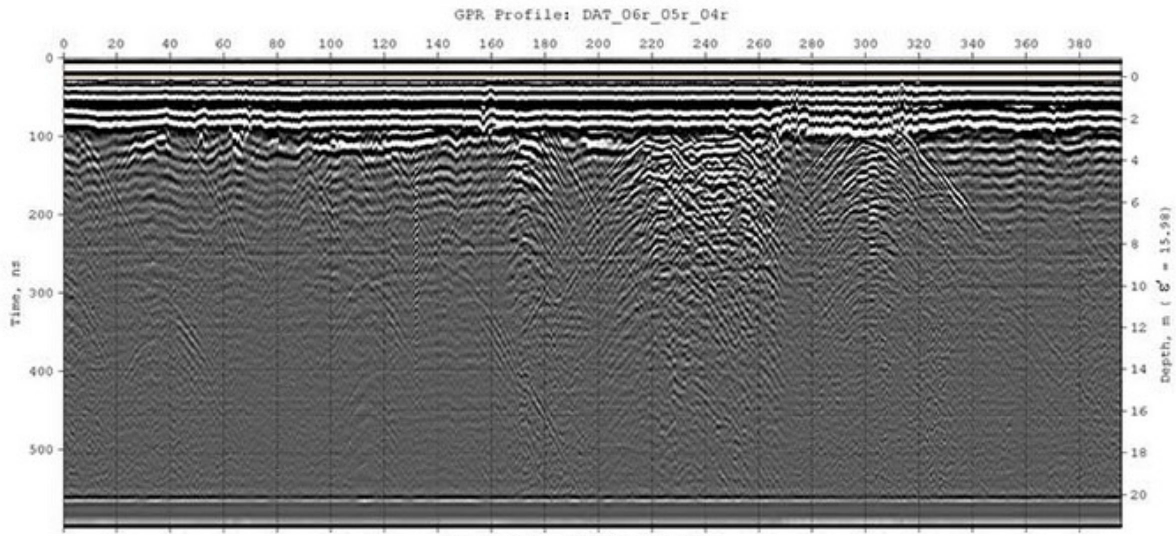
Ground penetrating radar - GPR

In the ground, radar waves cause currents to flow ⇨ loss of energy=attenuation
Radar signal amplitude shows an exponential decay with depth, which is proportional to an attenuation constant

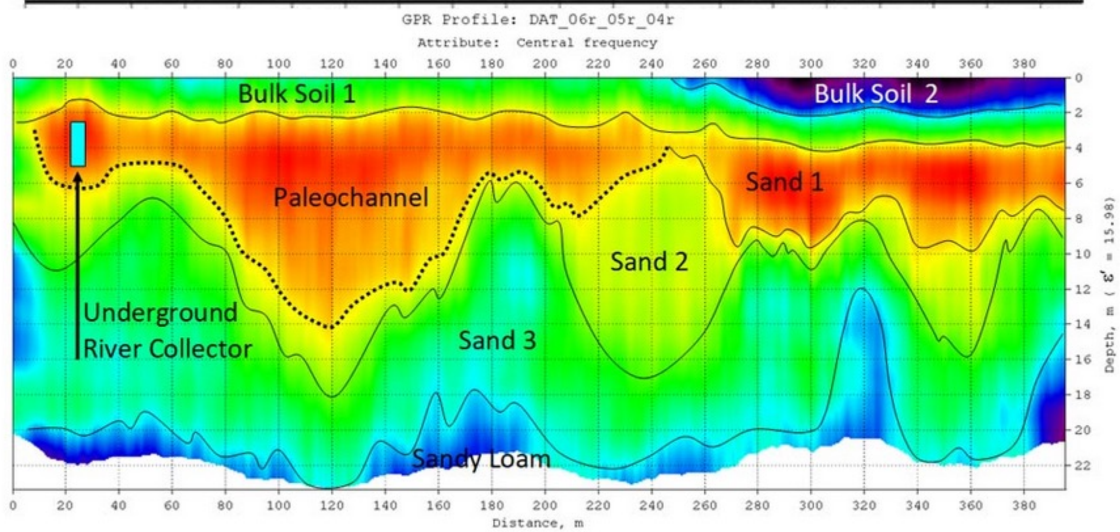


ELECTROMAGNETIC METHOD

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

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Metodi per l’analisi di bacini sedimentari

Parte 2

Metodi Geofisici: analisi indiretta di depositi nel sottosuolo
(+ o meno antichi, a terra e in mare) = lezione odierna di Valentina volpi

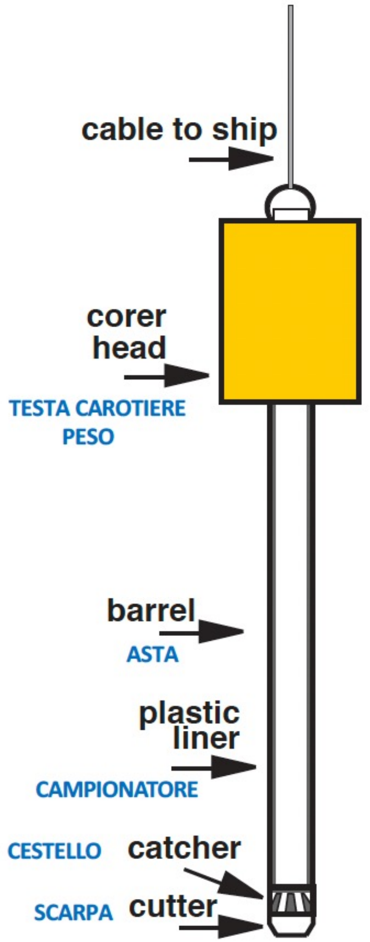
Metodi geologici in mare: carotaggi (depositi superficiali) e perforazioni (depositi più profondi/antichi/litificati) = Corso di Geologia Marina

Metodi geologici a terra: analisi degli affioramenti rocciosi, cartografia geologica, misura sezioni stratigrafiche… (deposti rocciosi riesumati).

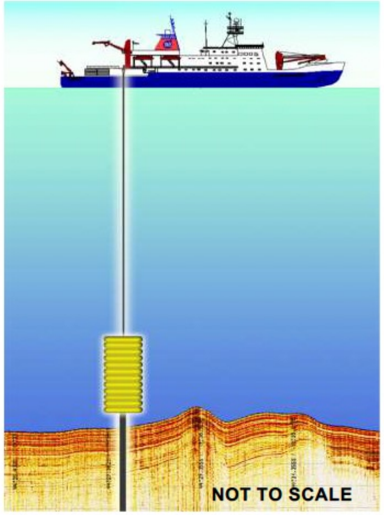
Metodi geologico/naturalistici: analisi di depositi recenti: cartografia storica, trenches, …

Carotaggi in mare

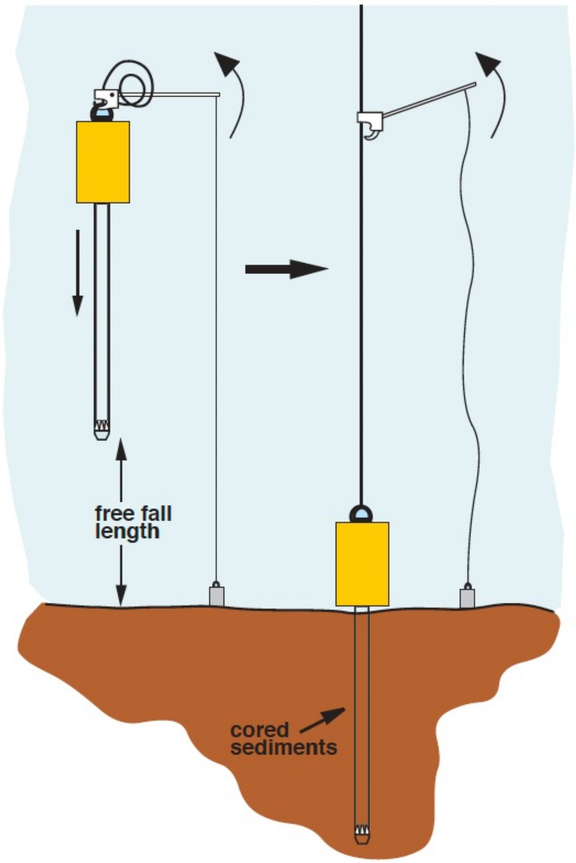
Sediment coring system



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

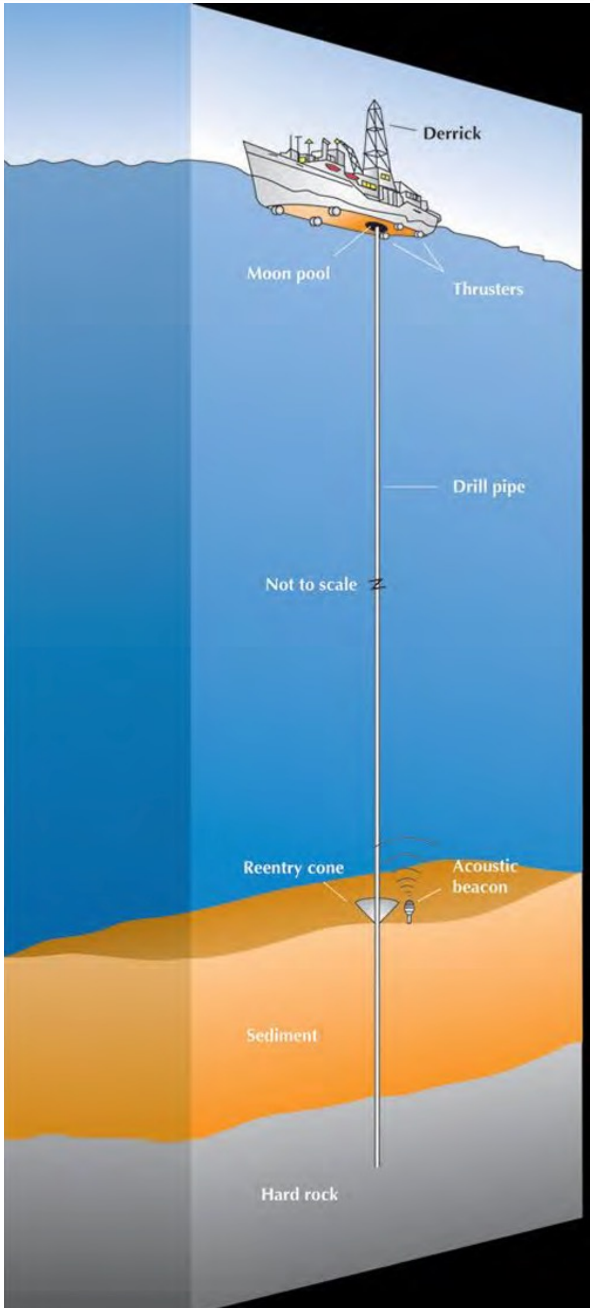


Courtesy: R.G. Lucchi

Perforazioni

IODP INTERNATIONAL OCEAN DISCOVERY PROGRAM

Joides Resolution



Affioramenti

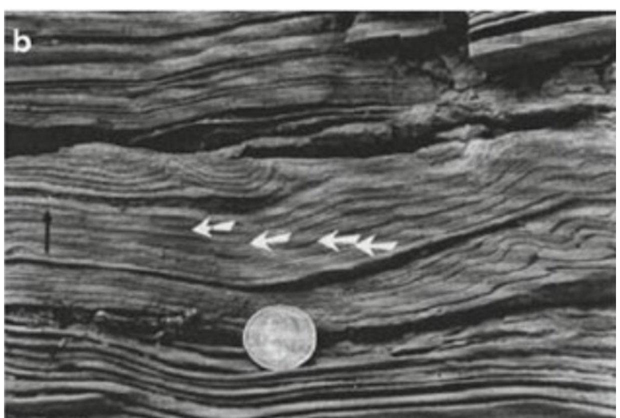
La Baronia

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

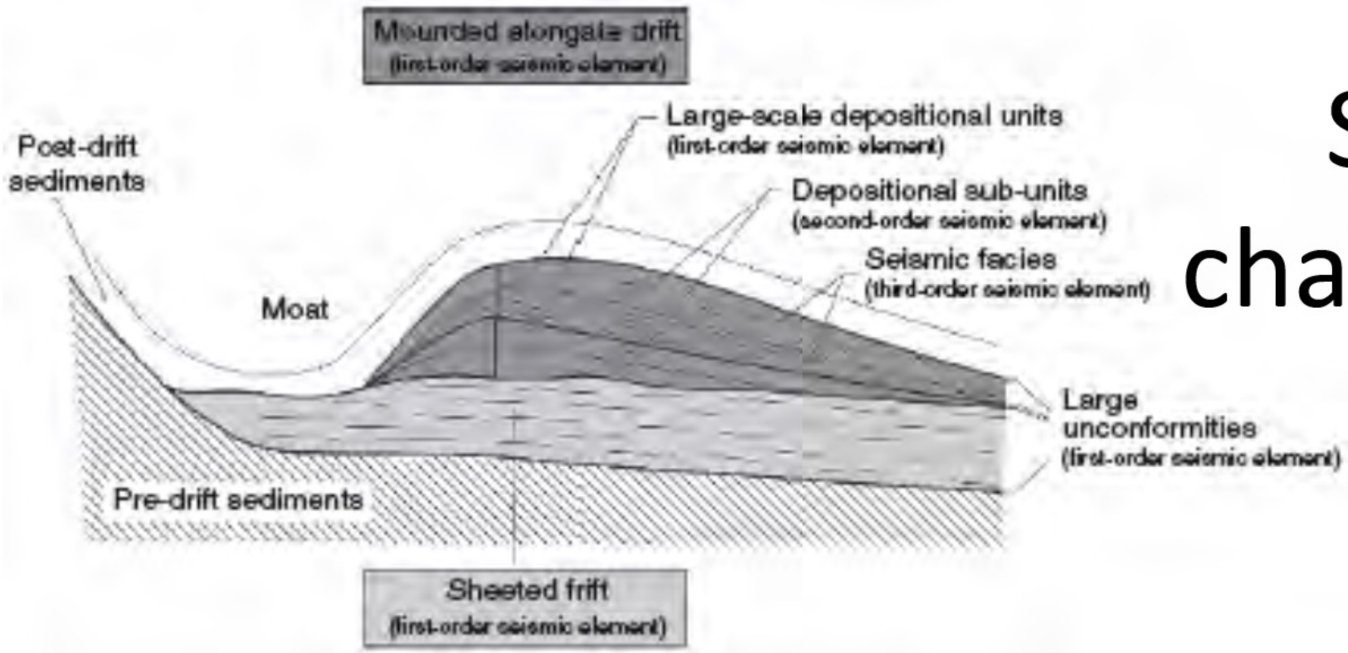
A three-scale approach to distinction for all deep-water facies types should be attempted wherever possible, including:
large-scale (oceanographic and tectonic setting),
regional-scale (architecture and association)
and small-scale (sediment facies) observations.

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

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



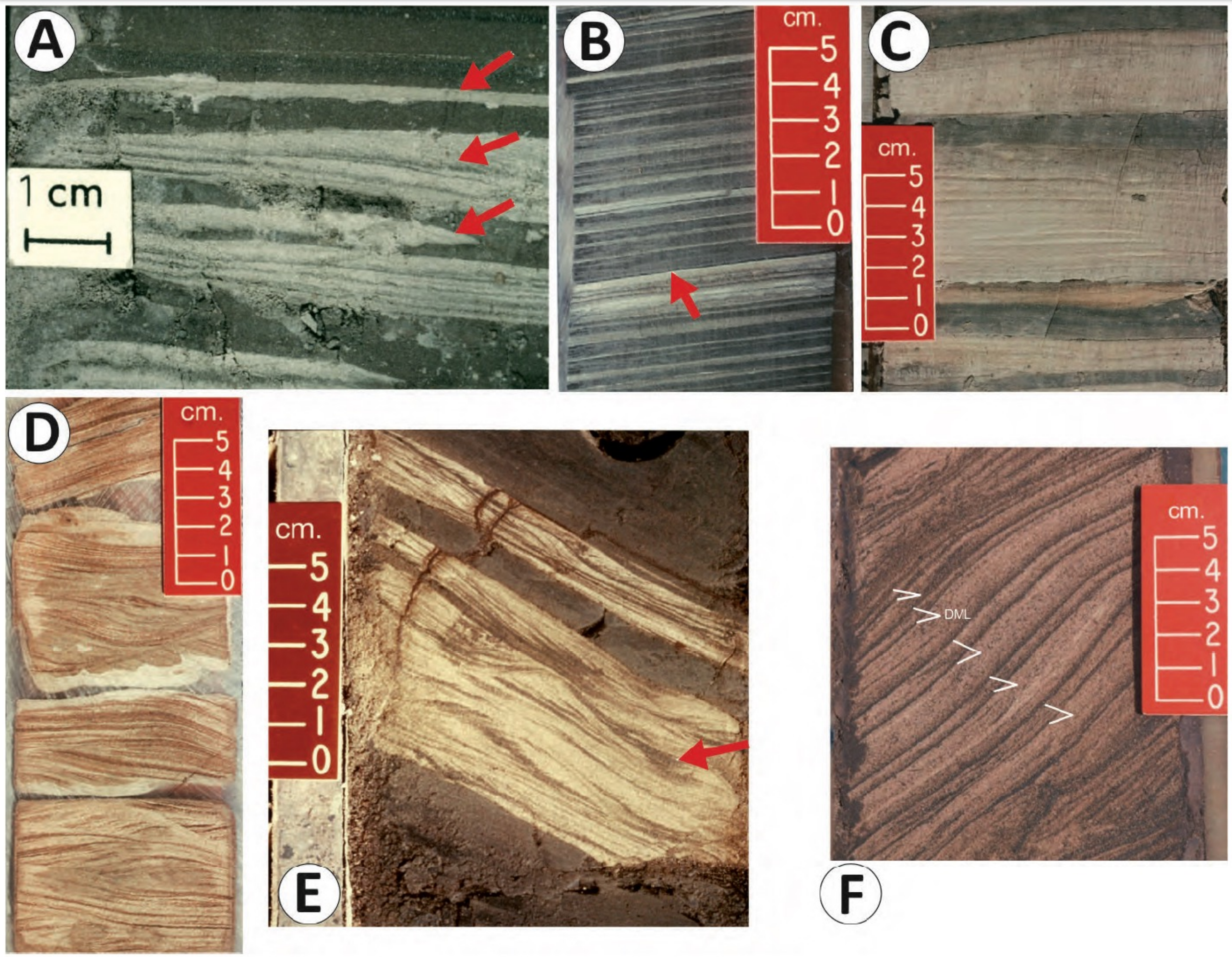
triple-scale approach that involves 3 ''orders of seismic elements''.

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



Shanmugan, 2008; Shanmugam et al., 1993; Shanmugam, 2012

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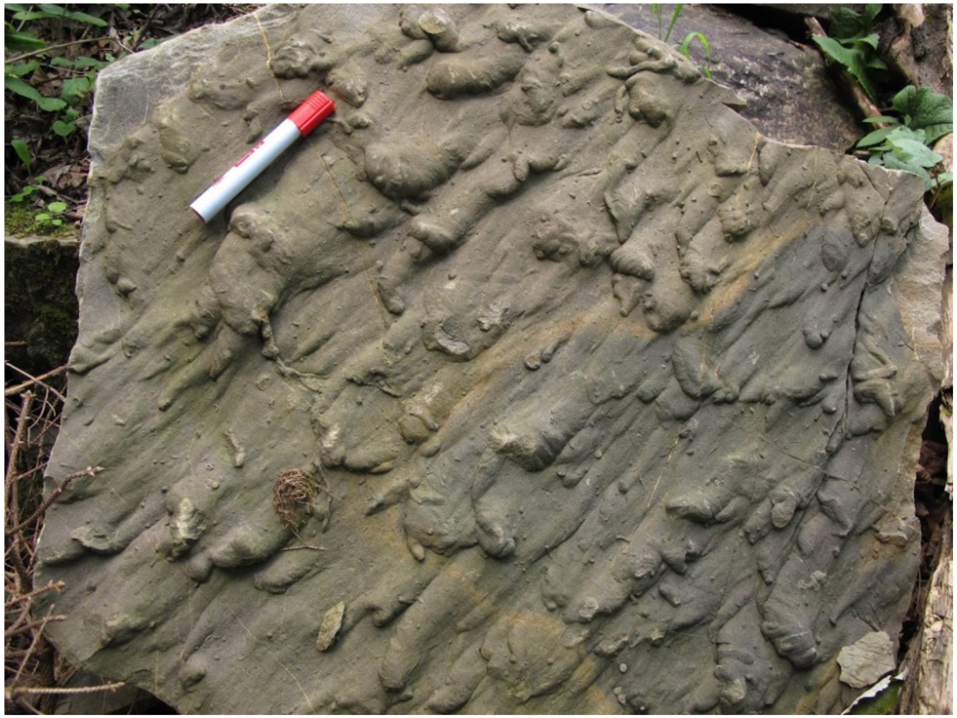
Sedimentary structures in outcrops

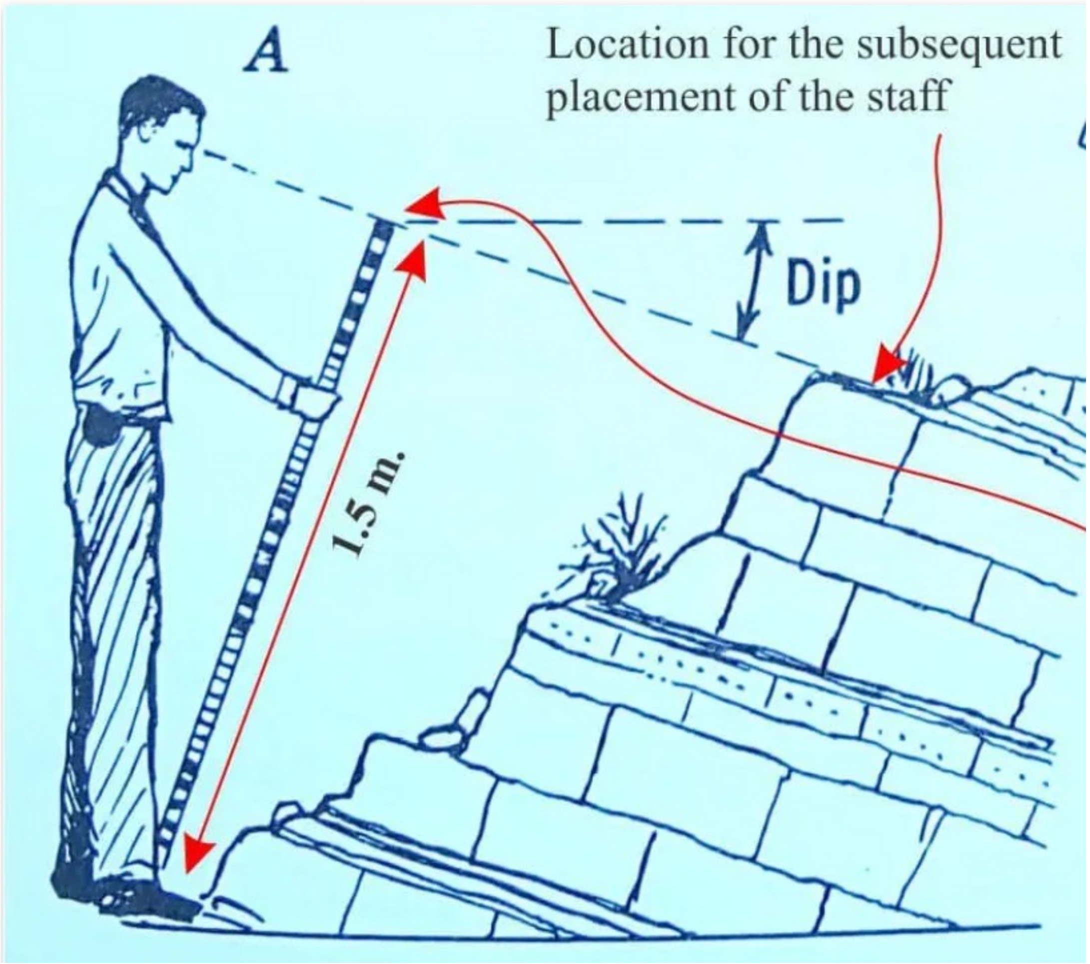
https://uhlibraries.pressbooks.pub/historicalgeologylab/chapter/chapter4-sedimentary-structures/

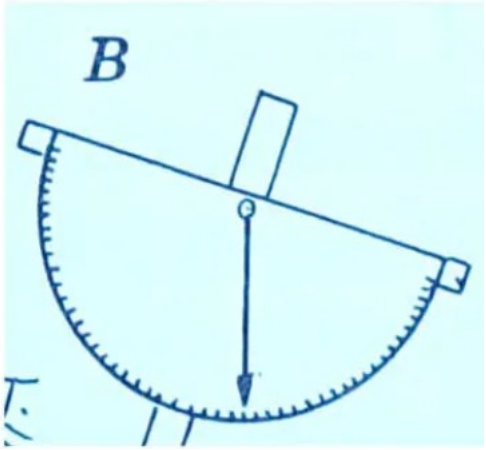


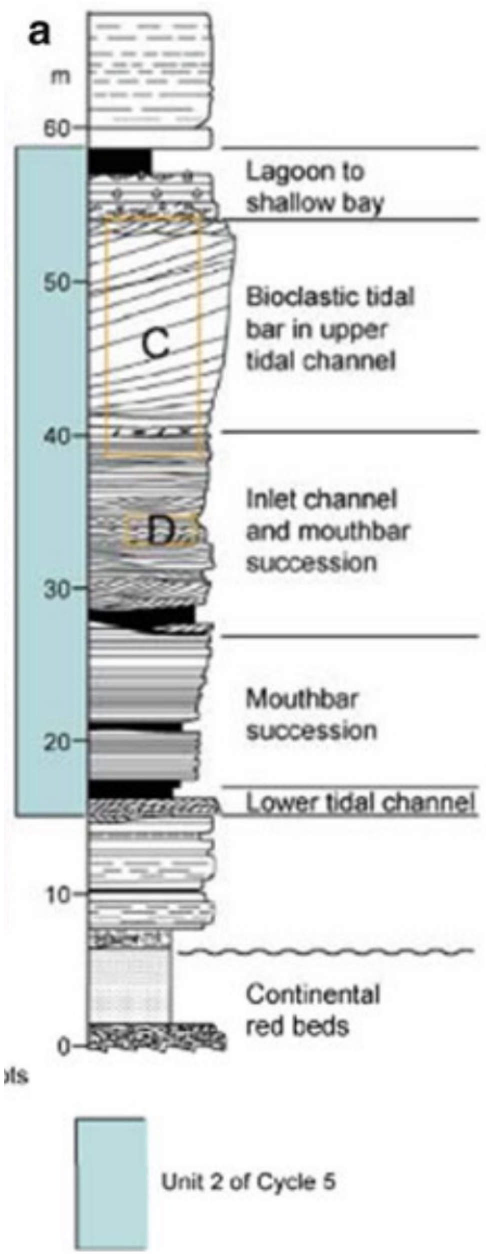
Flute casts from the central Alps, Switzerland. The view is from the underside of the rock. Image credit: Chris Spencer

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

Jacob's staff

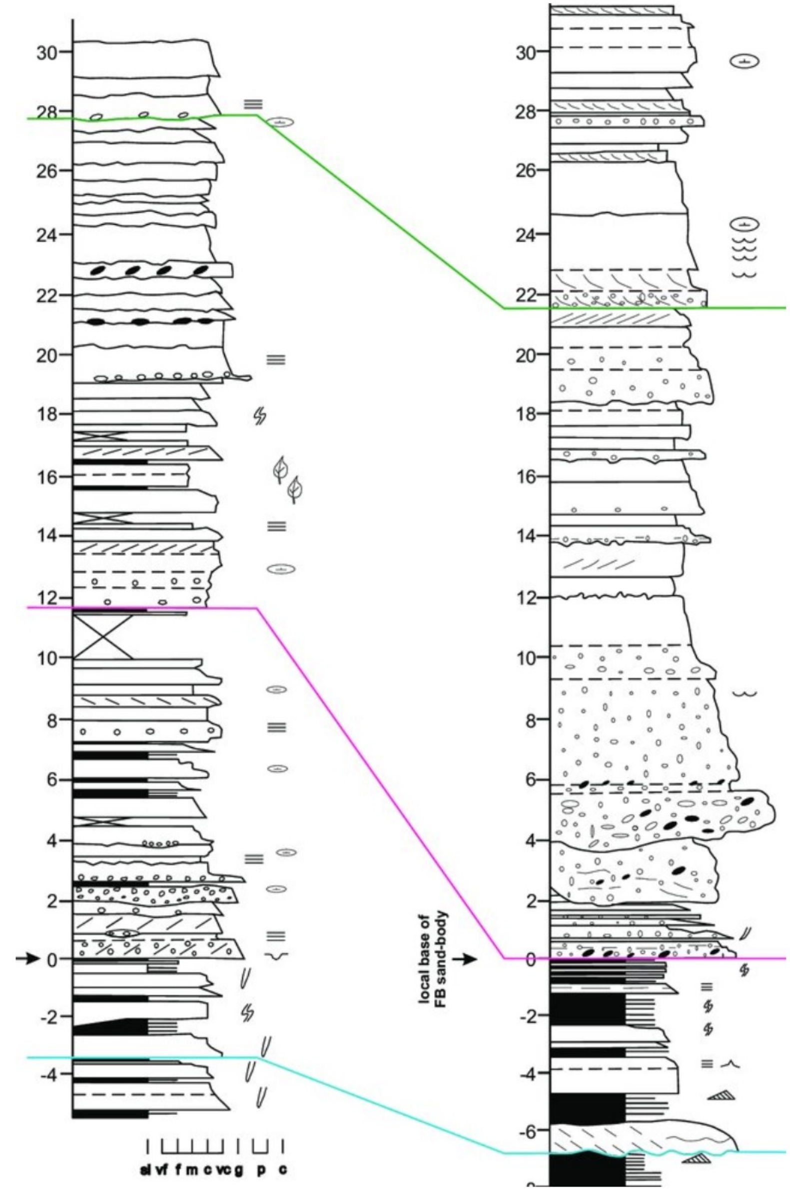






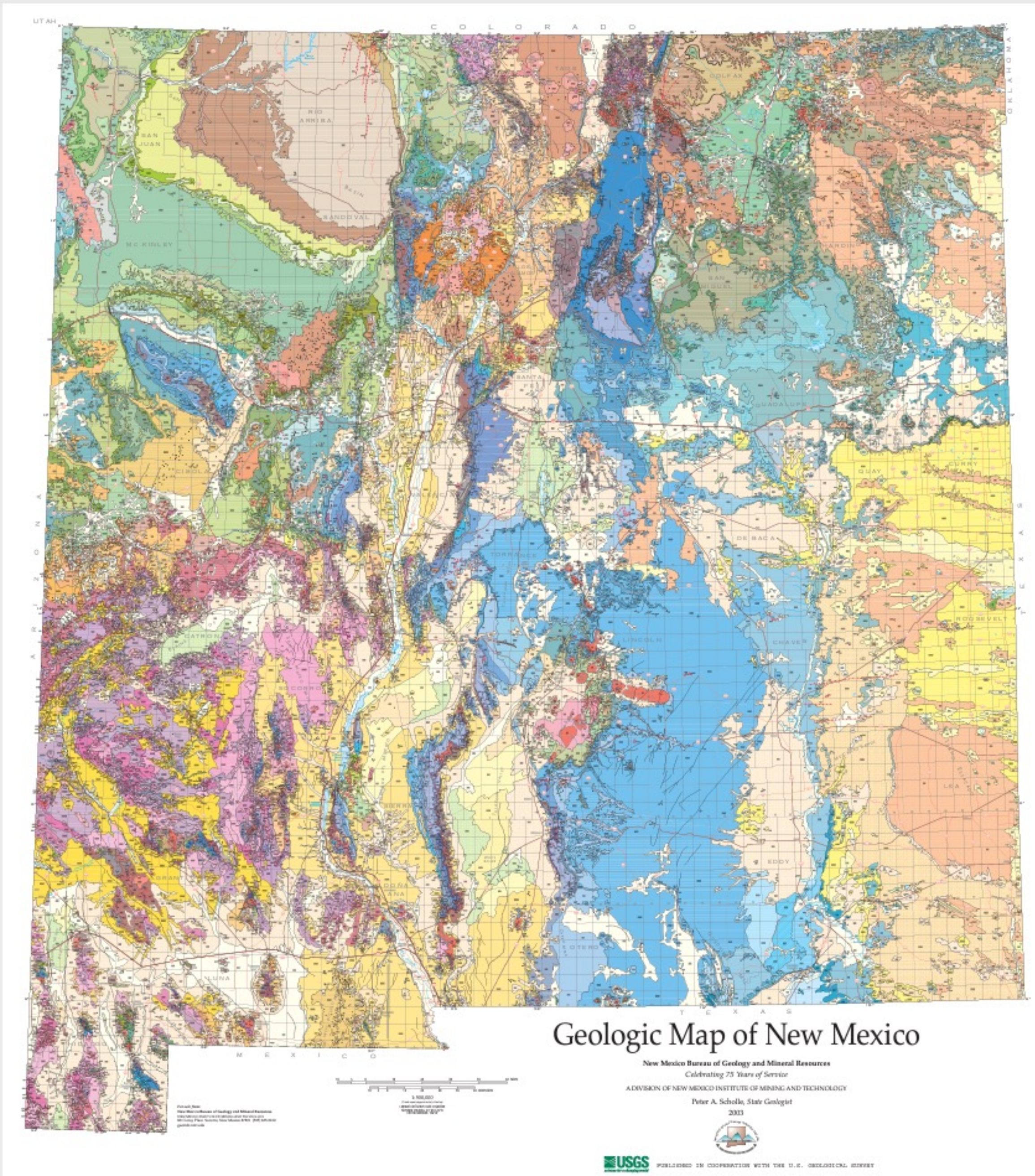
Sezioni stratigrafiche

Sedimentary logs



Come si stima la granulometria?

Cartografia geologica

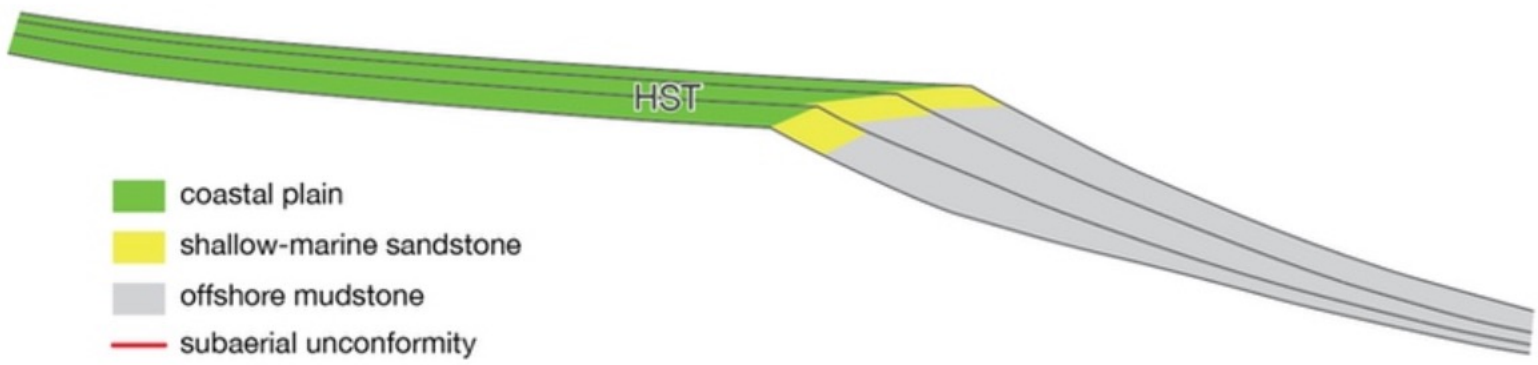


Litologia

La litologia di un'unità rocciosa è una descrizione delle sue caratteristiche fisiche visibili in affioramento, o con microscopia a basso ingrandimento. Le caratteristiche fisiche includono colore, consistenza, granulometria e composizione.

La litologia è alla base della suddivisione delle sequenze rocciose in singole unità litostratigrafiche ai fini della mappatura e della correlazione tra le aree.

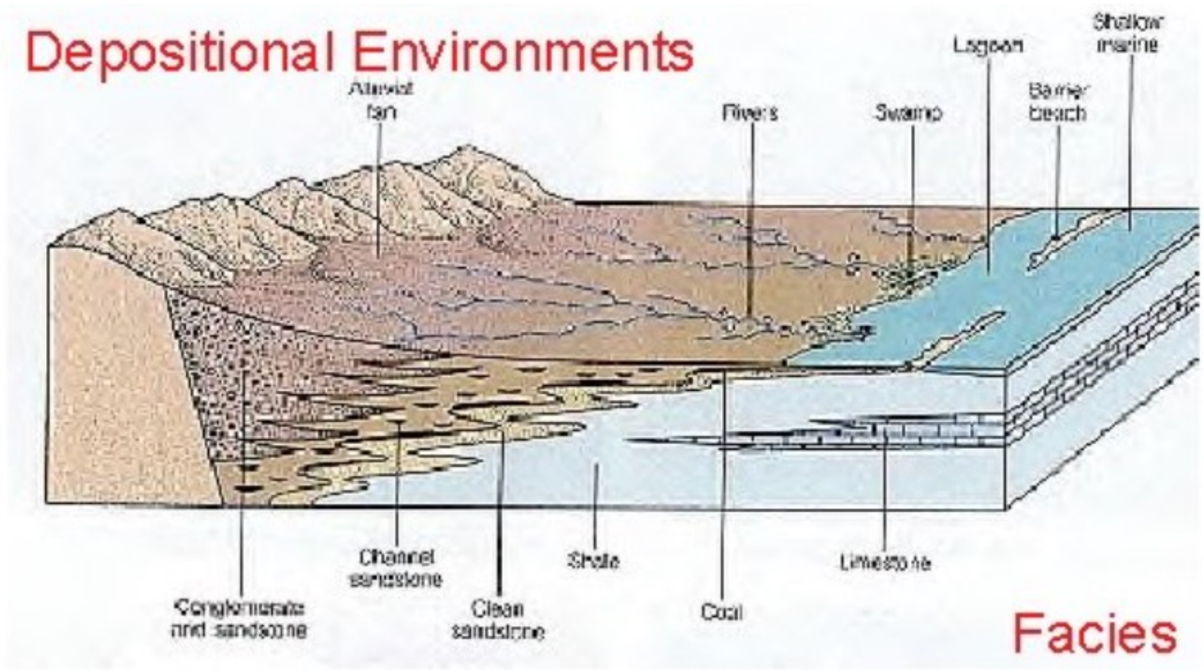
Sequenze cronostratigrafiche



Facies

Le caratteristiche complessive di un'unità rocciosa che riflettono la sua origine e differenziano l'unità da altre intorno ad essa.

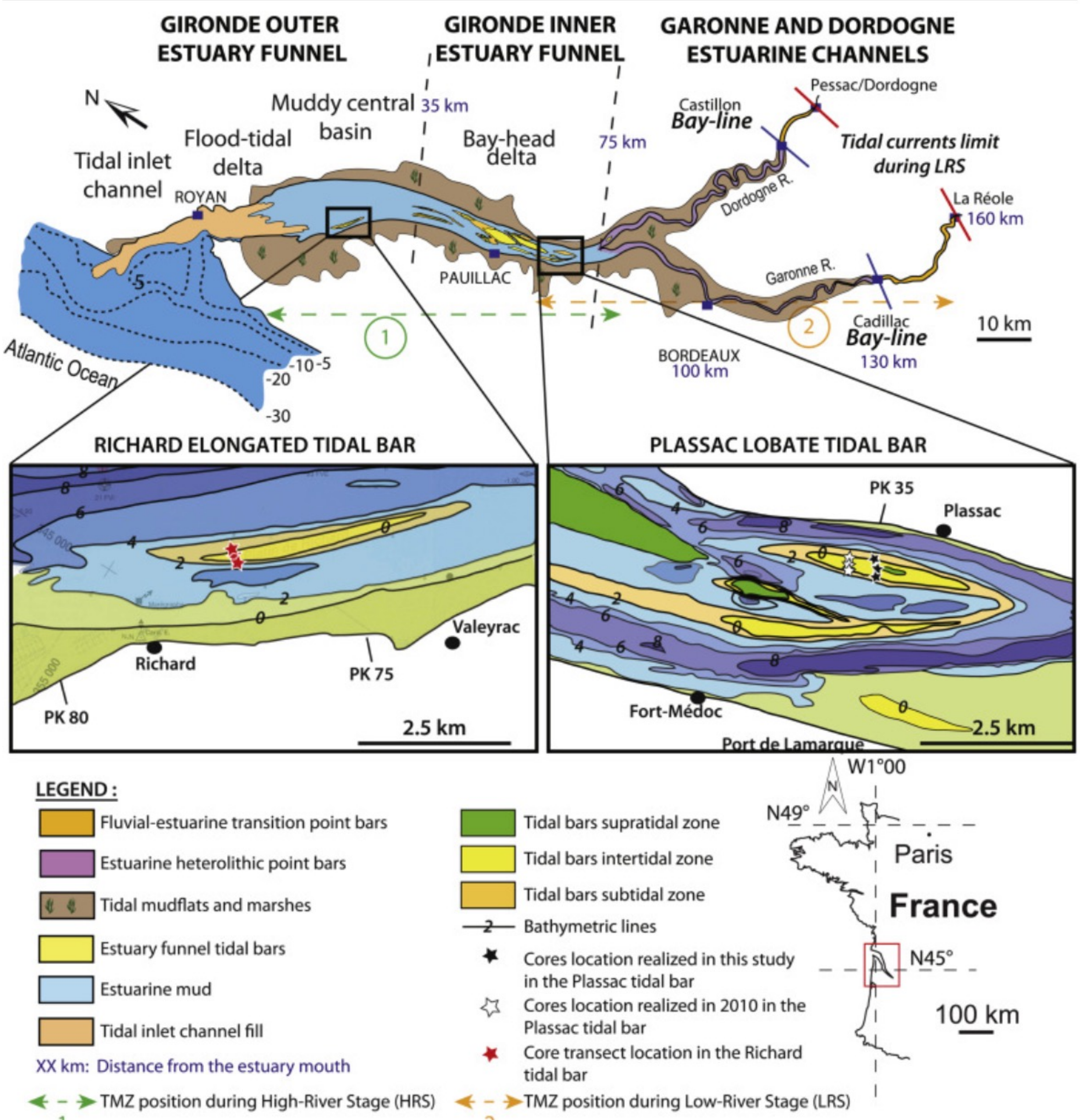
All'interno delle facies si possono distinguere ad es litofacies (unità stratigrafica distinta dalle adiacenti in base alla litologia),
Biofacies,
Microfacies
Ichnofacies
Seismic facies
…



Modern analog

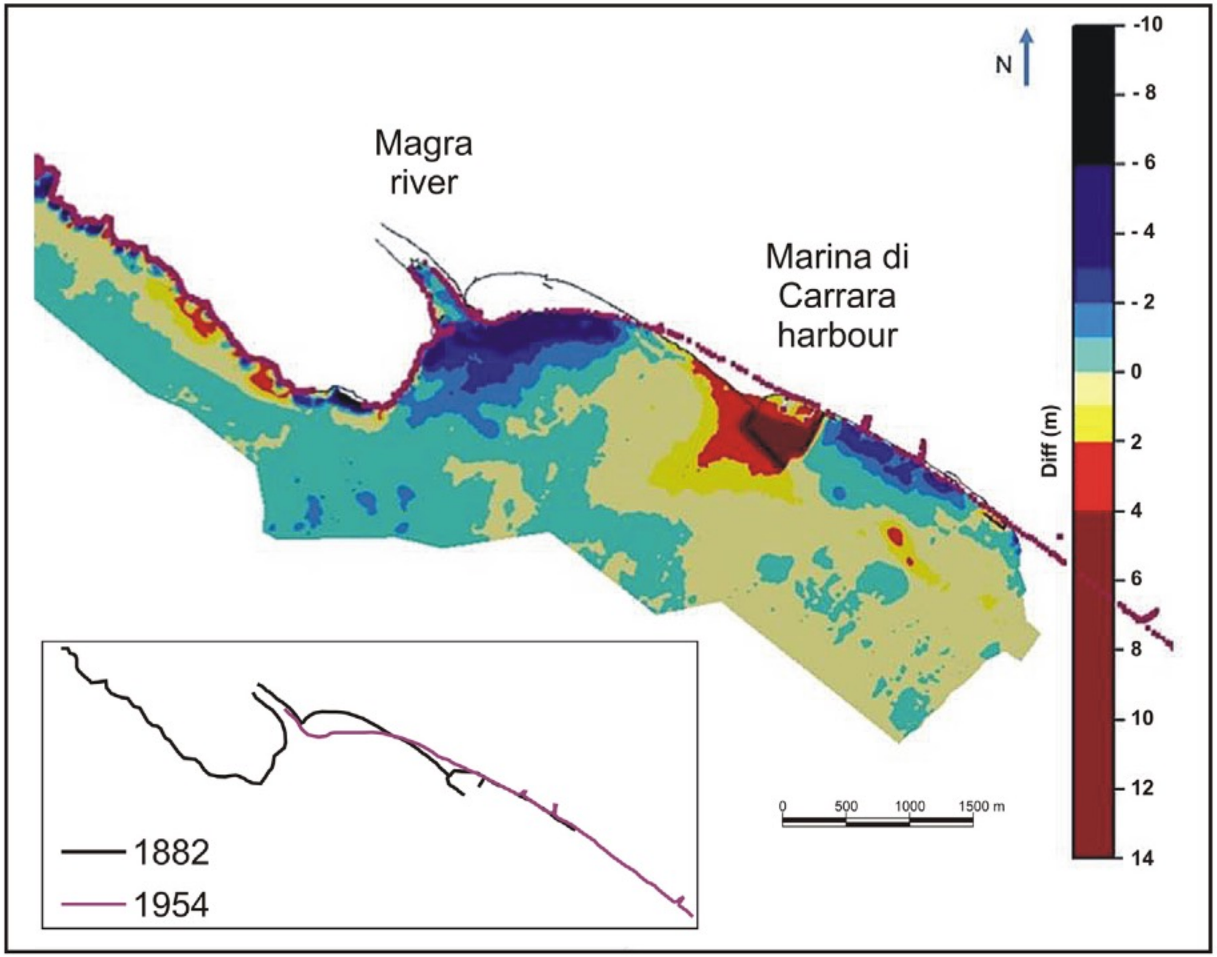
Gironde estuary tidal bars: A modern analogue for deeply buried estuarine sandstone reservoirs

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