SAPIENZA
UNIVERSITÀ DI ROMA

Environmental geophysics

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Introduction

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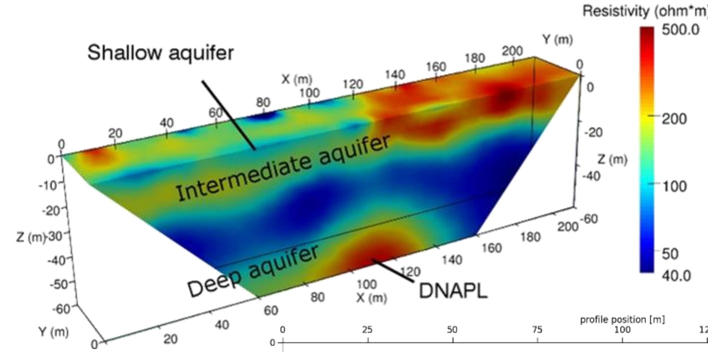
Environmental Geophysics

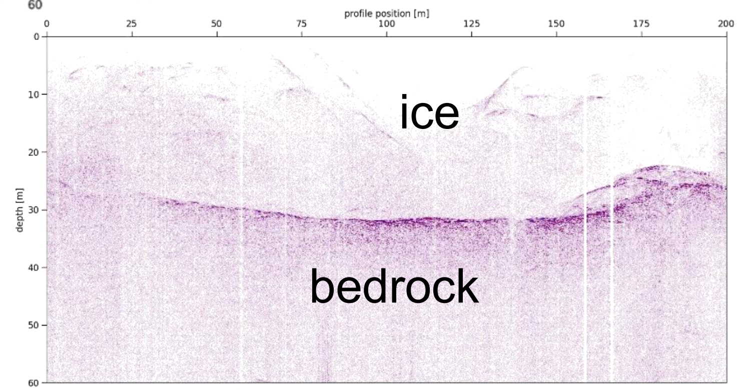
Q. What is **Environmental Geophysics?**

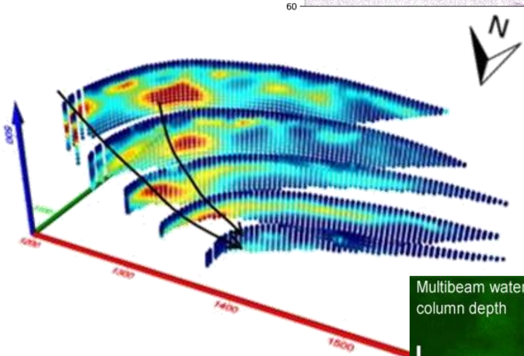
A. Environmental Geophysics is a relatively new branch of Applied Geophysics, mainly used to **map and monitor groundwater resources** (quantity and quality), **contaminants, landfills, aquatic compartments** (seas, rivers, lakes), **glaciers, landslides, subsidence** down to a depth of ~ 100 meters (**near-surface region**).

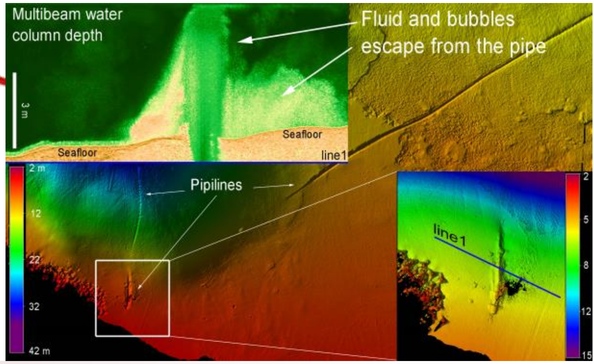
This region has a daily impact on our lives and **deals with climate change phenomena**.

Geophysics is cited in the National and European environmental regulations









Geophysics for Climate Change Adaptation & Mitigation

Environmental Geophysics is a key enabler of data-driven climate strategies, bridging science and sustainability for:

- **Monitoring Earth systems**: groundwater, soil, permafrost, and ice dynamics
- **Supporting renewable energy**: geothermal exploration, carbon capture & storage (CCS), offshore wind site assessment
- **Disaster risk reduction**: mapping hazards (floods, landslides, coastal erosion)
- **Enhancing resilience** of antropogenic features to climate-related stresses

We can map and monitor the environment through non-invasive methods using the physical principles (i.e. field or wave propagation)

Contribution to SDGs

Groundwater mapping and sustainable use

Geophysical tools for geothermal and wind energy

Hazard monitoring and resilient planning

Protecting aquatic ecosystems through monitoring of seas, rivers, lakes

Monitoring carbon storage and climate-sensitive ecosystems

Protecting land ecosystems through subsurface monitoring

Environmental Geophysics

Q. What is **Environmental Geophysics?**
A. It is a physically-based subject for **SEEING THE UNSEEN** by **SENSING the physical properties of the subsurface for environmental applications**

Diviner

Supernatural powers

Geophysicist

All natural powers: resilience, math./phys. knowledge, etc.…

Outcomes

General outcomes

The main goal of the course is to train students in the basic principles of **geophysical methods applied to environmental engineering**, with reference to **risk assessment, environmental monitoring and mapping** of subsurface **for climate change mitigation and adaptation.**

Specific outcomes

- **Select, acquire, process and interpret** seismic, electric and electromagnetic **geophysical data** both for **terrestrial and marine environments**.
- **Select the most suitable** geophysical **method for the specific case,** through an assessment of potential and limits of each technique.
- **Practice geophysical instruments, technical software** (Excel) and **develop simple codes in Python**.

Programme – Wave propagation methods

Introduction

1. Seismic methods

- Introduction to seismic waves. Seismic waves in elastic media. Seismic properties of rocks, soils and fluids.
- Seismic equipment
- Down-hole and cross-hole methods
- Seismic waves at interfaces: refraction method
- Seismic tomography method: introduction to data inversion

2. Acoustic methods

- SONAR methods: Multi Beam echo-sounder (MBES) and Sub-Bottom Profiling (SBP)

3. RADAR (high-frequency EM) methods - *Ground Penetrating Radar (GPR)*

- Electromagnetic (EM) properties of rocks, soils and fluids
- Introduction to EM waves. Propagation of EM waves in air and ground
- GPR data acquisition and equipment
- GPR data processing

Programme – Field methods and data integration

4. Low-frequency EM (LFEM) methods

- Basic principles of EM induction. Frequency-domain EM (Slingram method): data acquisition and processing

5. DC Electrical methods

- Direct-current (DC) methods: basic principles, electric potential for a point-source: 3D field equation. Vertical Electrical soundings.
- Electrical resistivity tomography (ERT): data acquisition, processing and inversion
- Time-domain induced polarization (TDIP): data acquisition, processing and inversion

6. Data integration

- Geophysical data integration: qualitative, semi-quantitative, joint inversion
- Machine-Learning (ML) approaches. Integration of direct information and geophysical models

Conclusions

Lectures, notes, exams…

Lectures: To learn the theory of geophysical methods

Exercises: Geophysical data processing with Excel (I part) and Excel/Python (II part).

Field demonstrations: Field data acquisition at the end of each module

Notes

- **Your lecture notes!!!** Recommendation: listen & write carefully during lectures
- **Lecture .pdf notes (only slides)** on the **e-learning platform** "Sapienza" Moodle (**elearning.uniroma1.it**): login with user & psw (**envgeo26#)** e then go to the course page
- **Exercises on Google Drive:** https://drive.google.com/drive/folders/0B8EApe6R6ST-fkJxdklGb0xhRDBZX0VpZUliSkUwZ2dtbGhSdUdYRU5lVkJ2RS1Eci1OOG8?resourcekey=0-AxsuFSrcOAd4hk4jP4MlZQ&usp=sharing
- **Database of closed-ended and open-ended questions and past exams on Drive.**

Exams

- **Written** (10 pts.): 5 closed-ended questions(1 pt. each) + 1 open-ended question on theory (5 pt.)
- **Practical** (10 pts.): 2 exercises on 1st (5 pts.) and 2nd (5 pts.) parts of the course
- **Oral** (10 pts.): 1 question on the studied methods

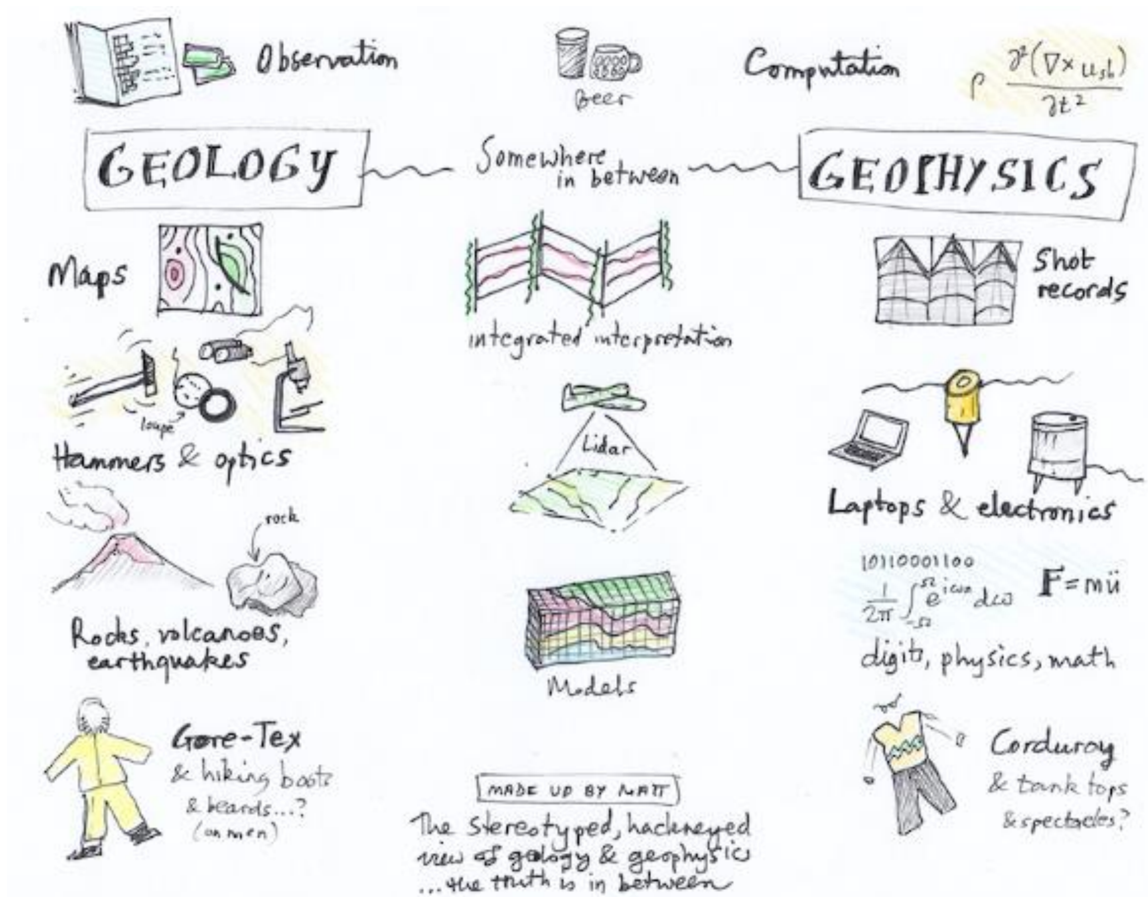
Meetings: Tuesday 11-13 a.m. (RM034 building), room L022– intercom: **25078**

Geophysics

- **Definition**

  "*A branch of earth science dealing with the* ***physical processes and phenomena*** *occurring especially in* ***the earth and in its vicinity***"

Differences between geology and geophysics



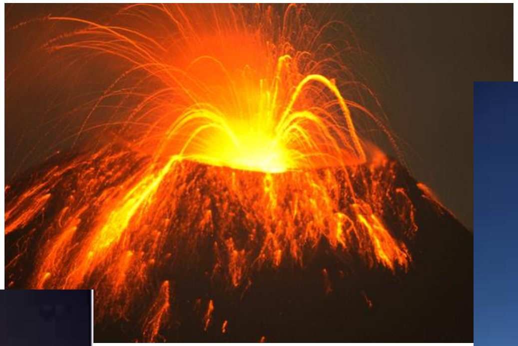
- **<u>Definition</u>**

  "A branch of earth science dealing with the ***physical processes and phenomena*** *occurring especially in* ***the earth and in its vicinity****"*

Which are these phenomena?

Earthquakes

Volcanoes



Geomagnetic storms

Geysers

Application of geophysics to practical purposes

Applied geophysics uses the same principles of natural phenomena (propagation of seismic waves, electro-magnetic field, etc.) but with man-made sources generally located on the Earth's surface.

Seismic source
Impact of a hammer

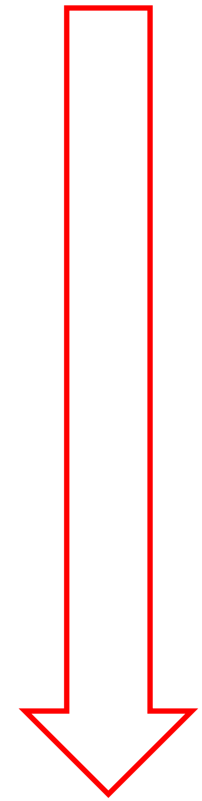
DC Electrical source
Direct-current injection with a 12V battery

AC Electrical source
Generating an electro-magnetic field

Application of geophysics to practical purposes

- oil & gas exploration
- mineral prospecting
- **geothermal exploration**
- **groundwater exploration**
- **engineering applications**
- **environmental impact assessment**
- archaeological research
- safeguard of cultural heritage

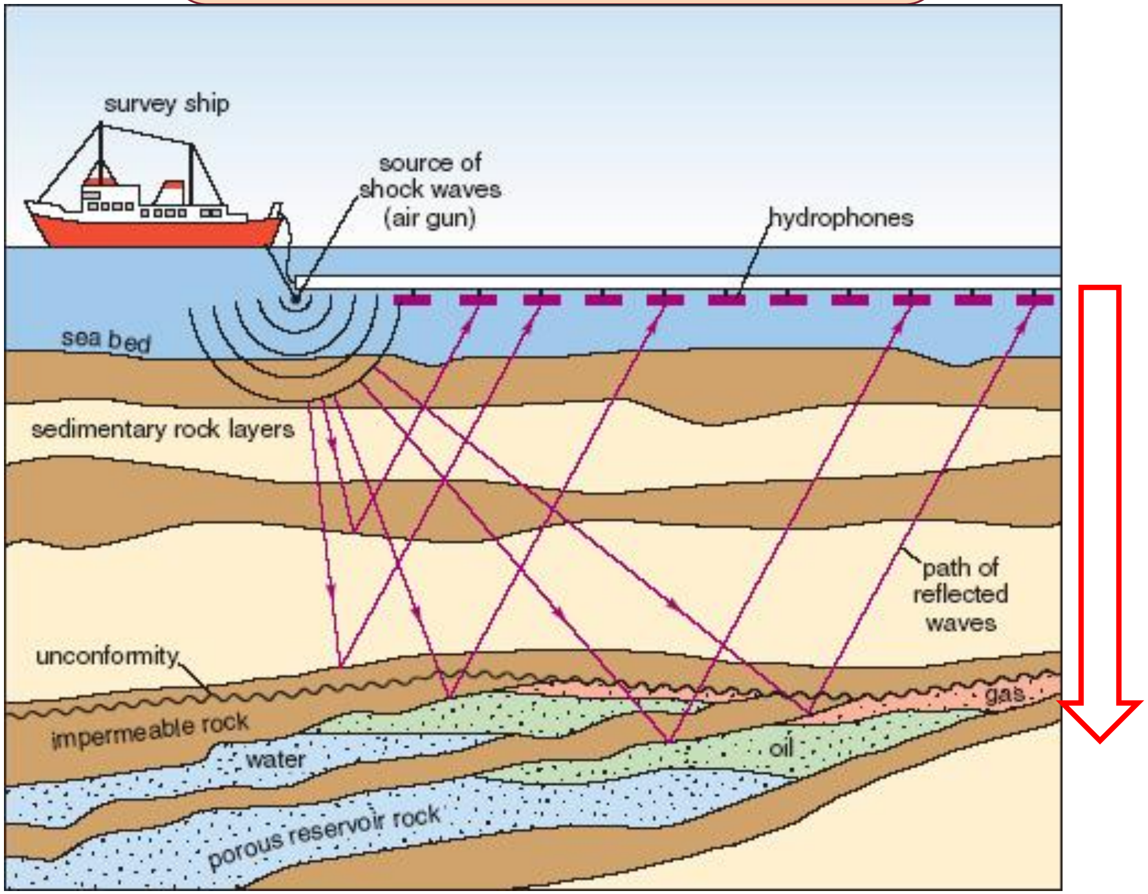
Big and deep targets



Small and shallow targets

Deep geophysics

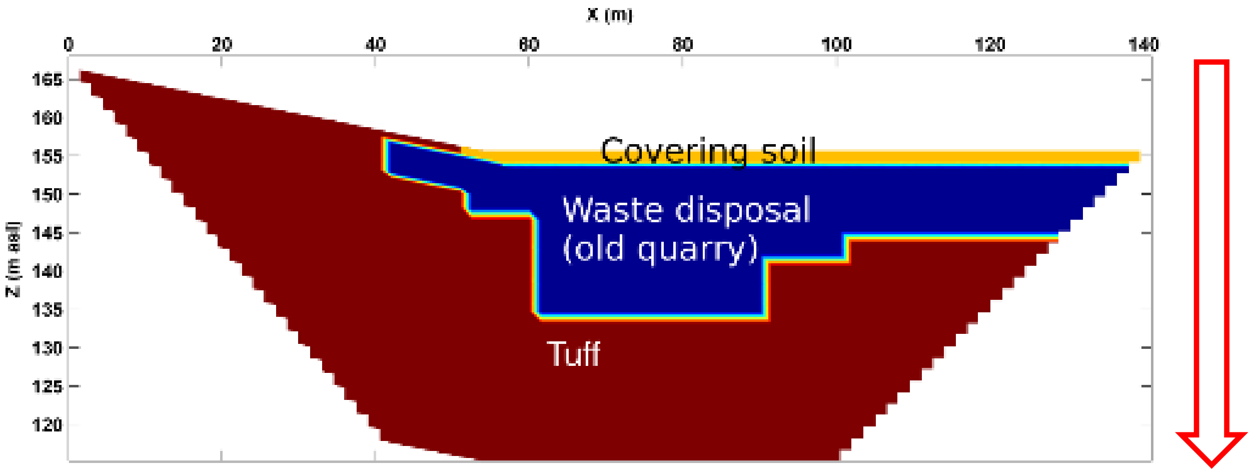
Oil & gas exploration (deep prospection)



Depth: some km

Investigated volume: some km^3

Environmental geophysics
(near-surface prospection)

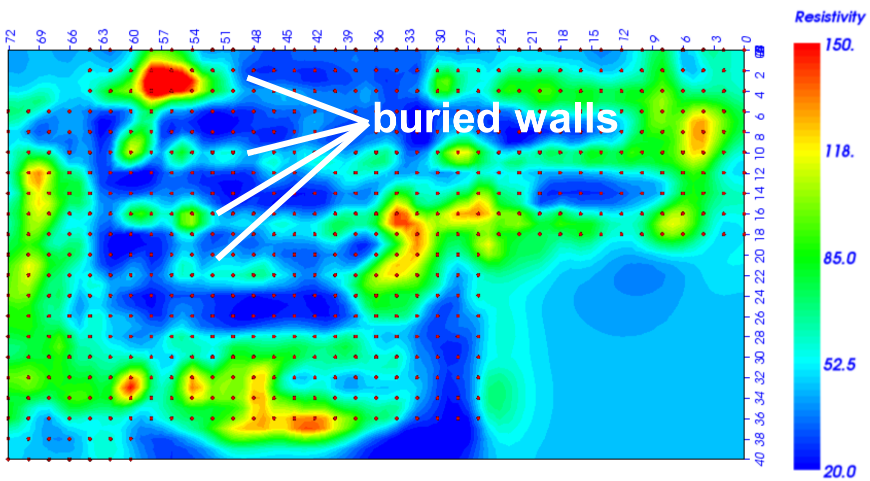


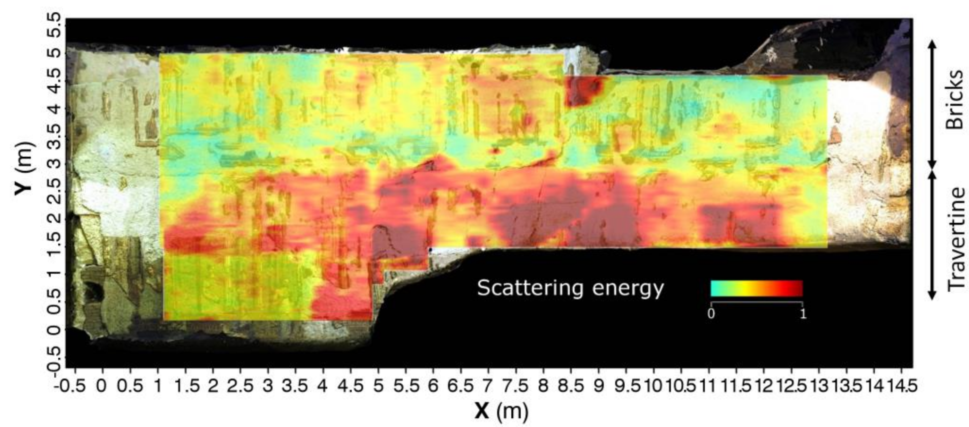
Depth: 1-100 m

Investigated volume: some m^3

Archaeological research

Safeguard of existent structures and artworks





Depth: 1-10 m
Investigated volume: some m^3

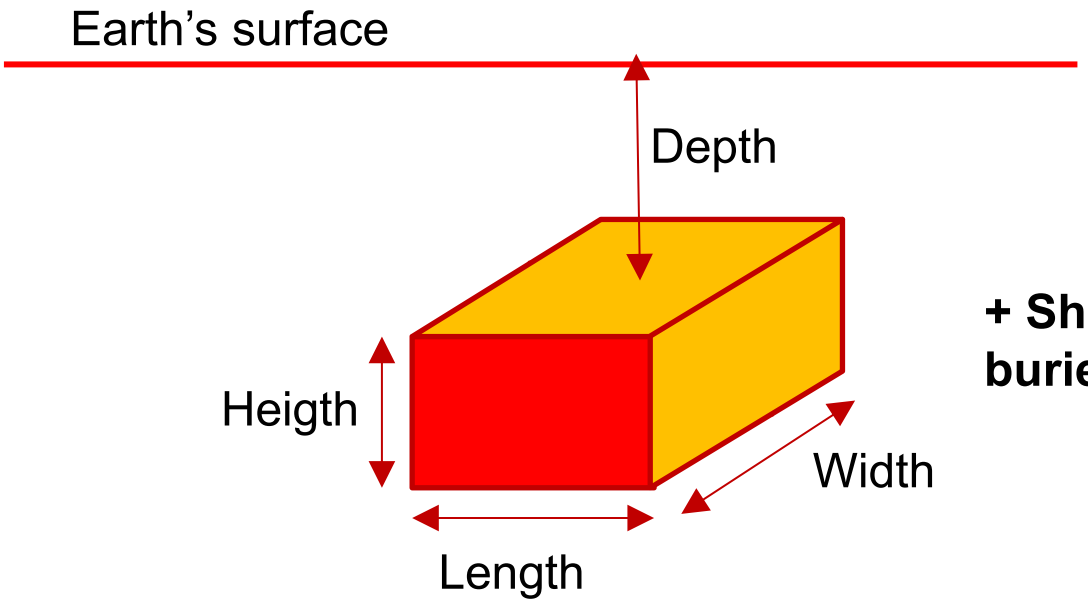
Depth: few cm – few m
Investigated volume: few cm^3 – few m^3

Environmental engineering

How can geophysics help?

We can locate buried targets without any damage to the subsoil (non-invasive method)

To this end we should get shape, type, depth and size (3-D) of the buried target (6 unknowns)



+ Shape and type of buried target

Which physical parameters are sensed by geophysical methods?

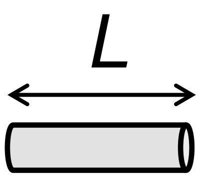
- **Electrical resistivity**
- **Velocity of seismic (or acoustic) waves**
- **Time variation of electric signals (electrostatic potential or e.m.f.)**
- **Scattering and reflection of EM (or acoustic) waves**
- Density
- Magnetic properties
- Temperature

How physical parameters of an investigated medium can be derived?

Directly

We can directly measure the parameter of interest

Ex. 1



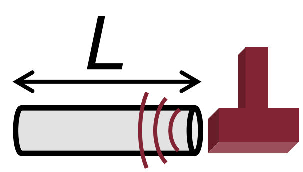
With a common ruler we can measure the length of the sample.

Indirectly

We cannot directly measure the parameter of interest - We need to infer it from other measurements

In geophysics we fall almost only in this case

Ex. 2



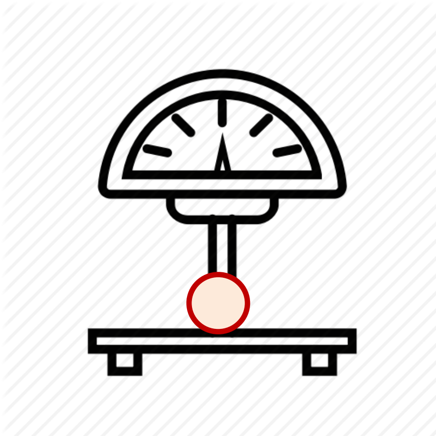
$$v = \frac{L}{t_v}$$

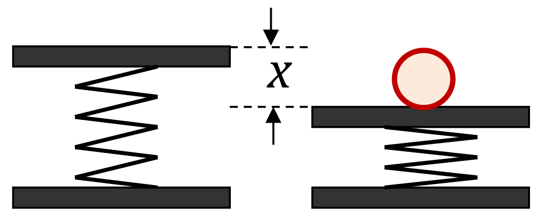
Knowing the length L of the sample we aim to get the velocity of the acoustic wave caused by a hammer impact.

We need to measure the wave travel time t_v and then we can calculate v.

Geophysical measurements - Inversion

Ex. 3 I would measure the mass of a certain body





$$m = \frac{kx}{g}$$

$$F = ma$$

We can measure it **directly** through a **weighing scale**

We can measure it **indirectly** by **measuring the displacement** *x* caused by the mass on a spring having an elastic constant *k* **and then calculating *m*** using the Newton's II law

The indirect calculation is called INVERSION

Geophysical methods for retrieving physical parameters

Gravity: measuring variations in the gravitational field of the earth

Magnetic: measuring variations in the magnetic field of the earth

Electromagnetic: measuring the secondary EM field induced by an external primary EM source

Electrostatic: measuring electric potential induced by an external electric current

→ **Field (or potential) theory**

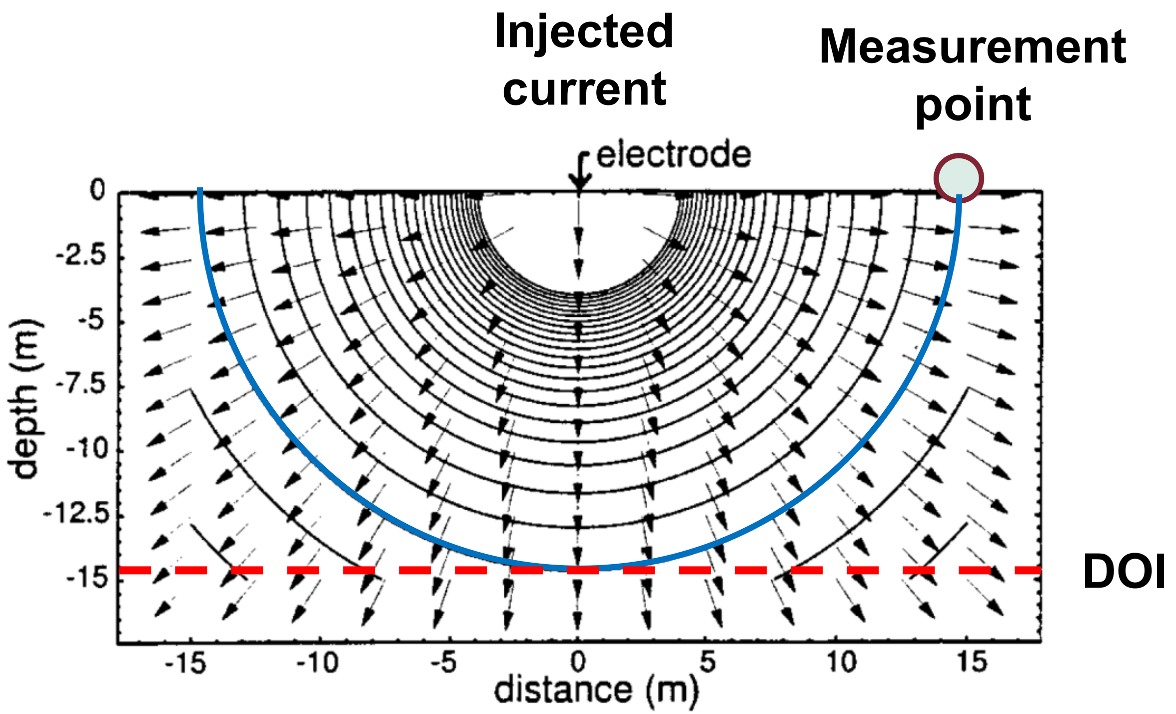
Seismic (Acoustic): measuring the time required for a seismic wave to travel from a source to a receiver

Ground penetrating radar: measuring the time required for a EM pulse to travel from a source to a receiver

→ **Wave propagation theory**

Field (or potential) methods

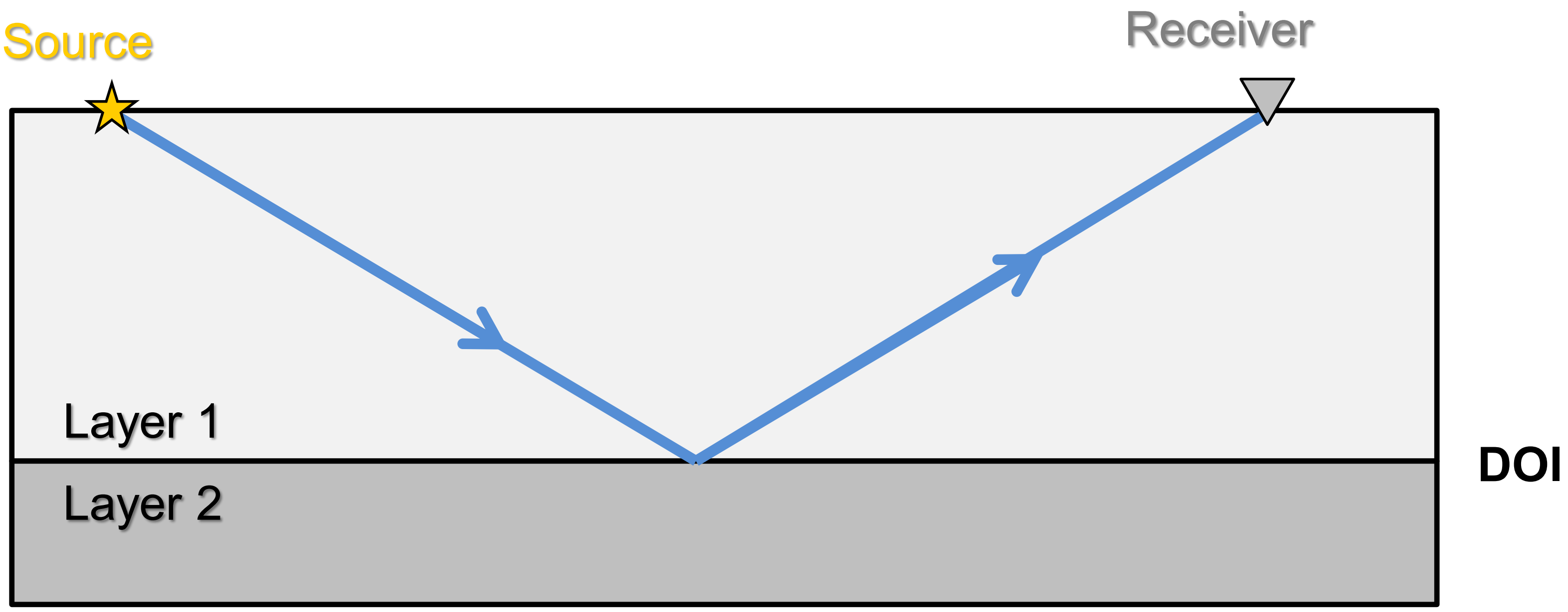
The depth of investigation (DOI) is the maximum depth where the effect of the applied field can be measured on surface



We are able to investigate the volume within the equipotential line

Wave propagation methods

The depth of investigation is the maximum depth the wave has travelled within that can be seen on surface



Depth of investigation depends on the wavelength of the signal. The higher is the wavelength the lower will be the depth of investigation

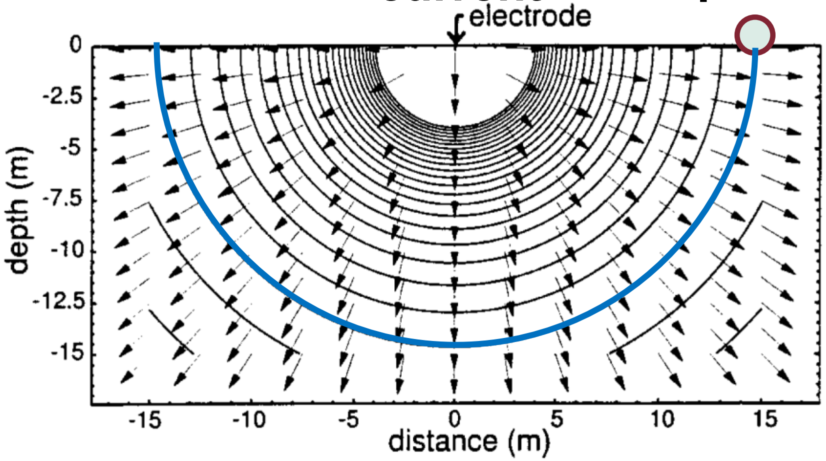
Geophysical measurements – Resolution

The resolution is the capability to discern two adjacent objects

Potential methods

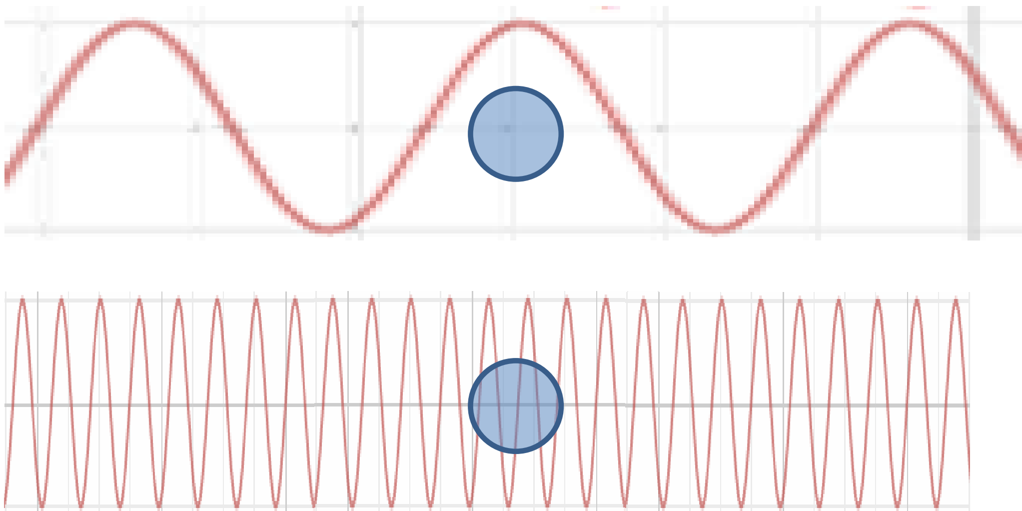
Injected current

Measurement point



Resolution rapidly decreases with depth proportionally to the spacing of equipotential lines

Wave propagation



Resolution depends on the wavelength of the signal

Objects to be detected → Rule-of-thumb

Earth’s surface

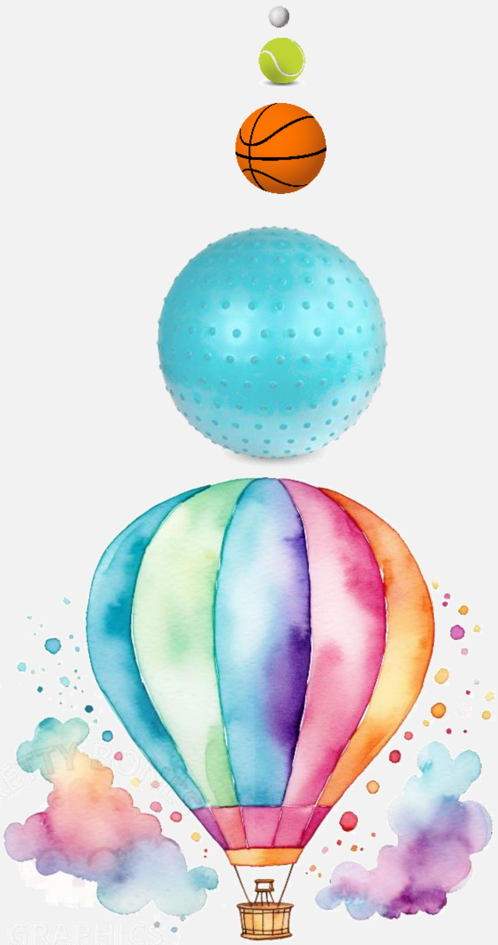
ultra-shallow ~ 10 cm

~ 1 m

~ 10 m

~ 100 m

very deep ~ 1 km



Geophysical methods

Method	Measured quantity	Physical parameter
Gravity	Gravitational field	Density
Magnetic	Magnetic field	Magnetic susceptibility
Electromagnetic (EM)	Electromagnetic field	Electrical conductivity (or resistivity)
Electrostatic (ERT+IP)	Electric potential	Electrical resistivity & chargeability
Seismic and acoustic	Seismic (acoustic) wave traveltime	Seismic (acoustic) wave velocity
Ground Penetrating Radar (GPR)	EM wave traveltime	Dielectric constant

These are the methods analysed in this course

Geophysical methods - Workflow

Geophysical investigations are organized into 4 different phases

1. **Design**
2. **Acquisition**
3. **Processing**
4. **Interpretation and/or integration**

All phases are important for achieving a good result, even though **for certain techniques can have different weights**

Failing one or more phases can lead to a poor geophysical model and therefore to a reduction of the benefit/cost ratio

During the course we will cover the whole workflow of geophysical surveys: from design to interpretation/integration