Processes: Exploration Geophysics

PRRE1003
Resources, Processes & Materials Engineering

LECTURE 5

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Curtin University

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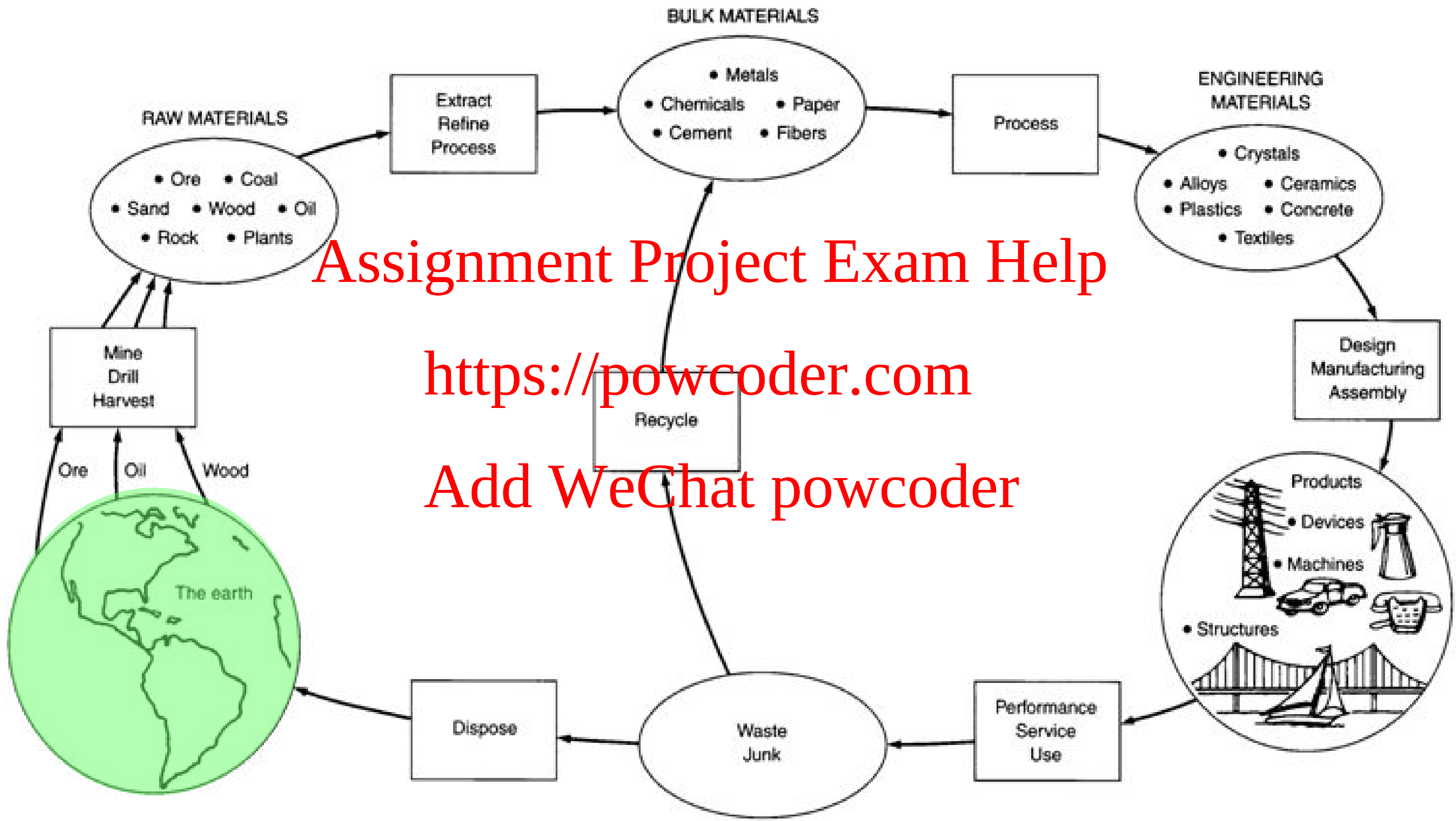
Lecture Focus



Reproduced from "Materials and Man's Needs", National Academy of Sciences, Washington D.C., 1974.

Lecture Overview

- What is geophysics?
- Rock Properties
- Geophysical Techniques
- Mineral and Water Resources
- Hydrocarbons Resources

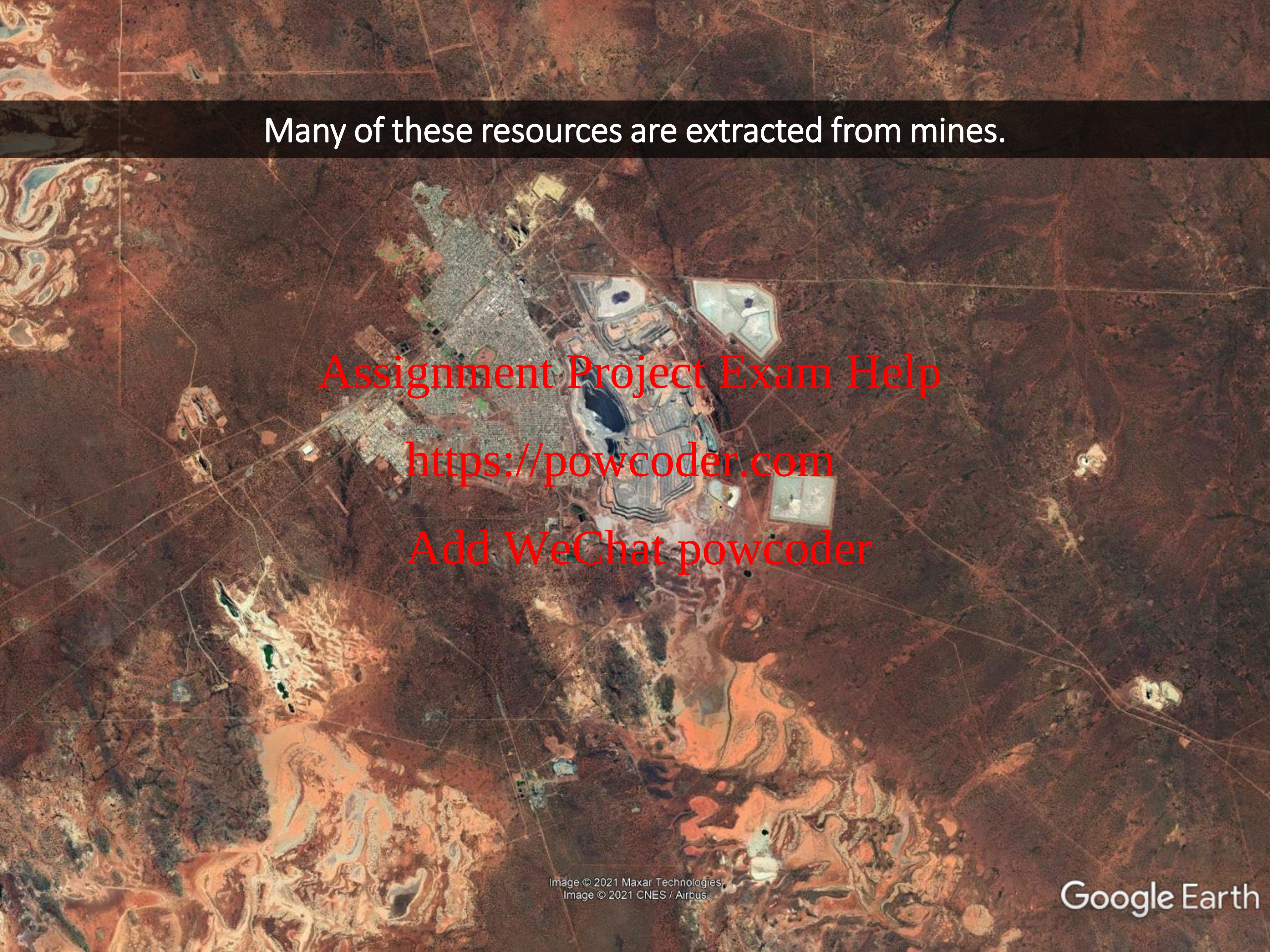
Seismic Acquisition : Curtin Oval, May 2021

iPHONE 6S
HERE'S WHAT'S IN IT:
CASE
ALUMINUM
The iPhone's case uses aerospace-grade aluminum with an anodized outside layer for extra protection. This layer is just five micrometers thick, thinner than paint.
CAMERA
SAPPHIRE GLASS
This synthetic material covering the lens rates a 9 on Mohs hardness scale, making it nearly as hard as a diamond.
BATTERY
The iPhone uses lithium cobalt oxide (LiCoO2) chemistry in its cathode, with 60% of it being made from cobalt. It also uses a graphite anode and aluminum casing.
COBALT
GRAPHITE
LITHIUM
ALUMINUM
BATTERY PROFILE
Specific Energy
Specific Power
Safety
Performance
Life Span
Cost
Source: Battery University
ELECTRONICS
MICRO-ELECTRICAL
Copper, gold, silver, and tungsten are used for electrical connections within the phone. Which metal is chosen depends on the need. For example, while silver is the most conductive metal, gold never tarnishes.
GOLD
SILVER
COPPER
TUNGSTEN
MICRO-CAPACITORS
Micro-capacitors regulate the electricity flow.
Apple managed to guarantee the use of
TANTALUM
PROCESSOR CHIP
SILICON
The phone's processor is mainly made from silicon, but it is bombarded by various elements to give it superior electrical properties.
Phosphorus
Antimony
Arsenic
Boron
Indium
Gallium
SOLDERING
COPPER
TIN
SILVER
SOUND + VIBRATION
To get lots of sound from a small place, high-powered neodymium magnets are used. They are made from neodymium, iron, and boron, and sometimes also contains smaller amounts of other rare earths.
The same magnets also power the phone's vibration function:
NICKEL
NEODYMIUM
PRASEODYMIUM
BORON
DYSPROSIUM
IRON

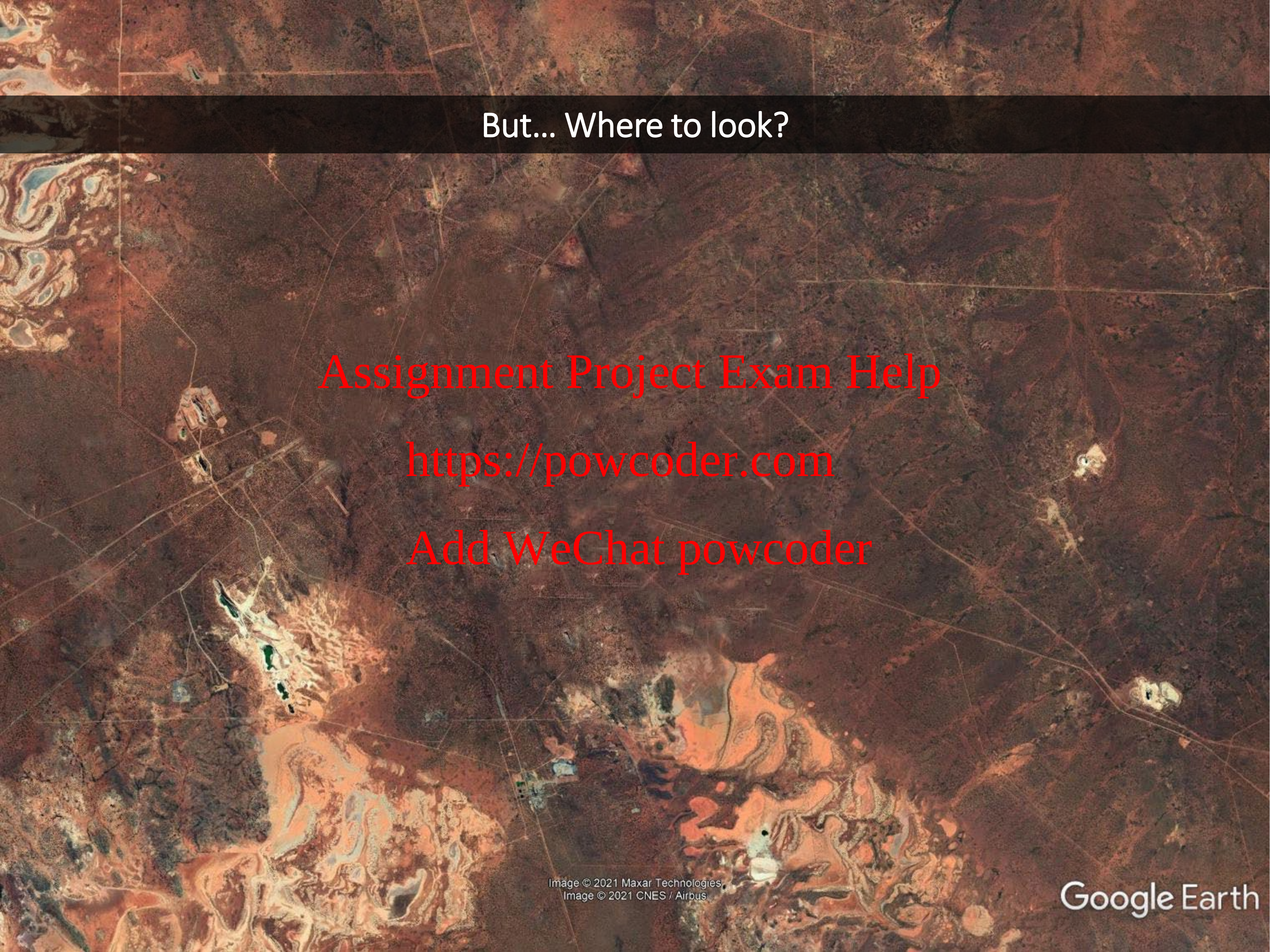
Most materials we use originate from

raw resources within or on the earth

Many of these resources are extracted from mines.



But… Where to look?



The Physical Properties of the Earth

Electrical
- Conductivity
- Electrical Permittivity
- Magnetic Permeability

Elastic
- Velocity (P and S wave)
- Density

Magnetic
- Magnetic Susceptibility

Radioactivity
- U^{238} / Th^{232} / K^{40}
- Spectral

And more…
- Chargeability
- Porosity
- Temperature
- Hydraulic Permeability
- Tortuosity
- etc…

Learning Outcome Check

- Natural resources are discovered by utilising their properties—Name 5 properties that have been used for exploration resources.

The Earth's composition changes with depth and distance.

With it, the physical properties of the Earth changes as well.

Some resources have unique physical properties.

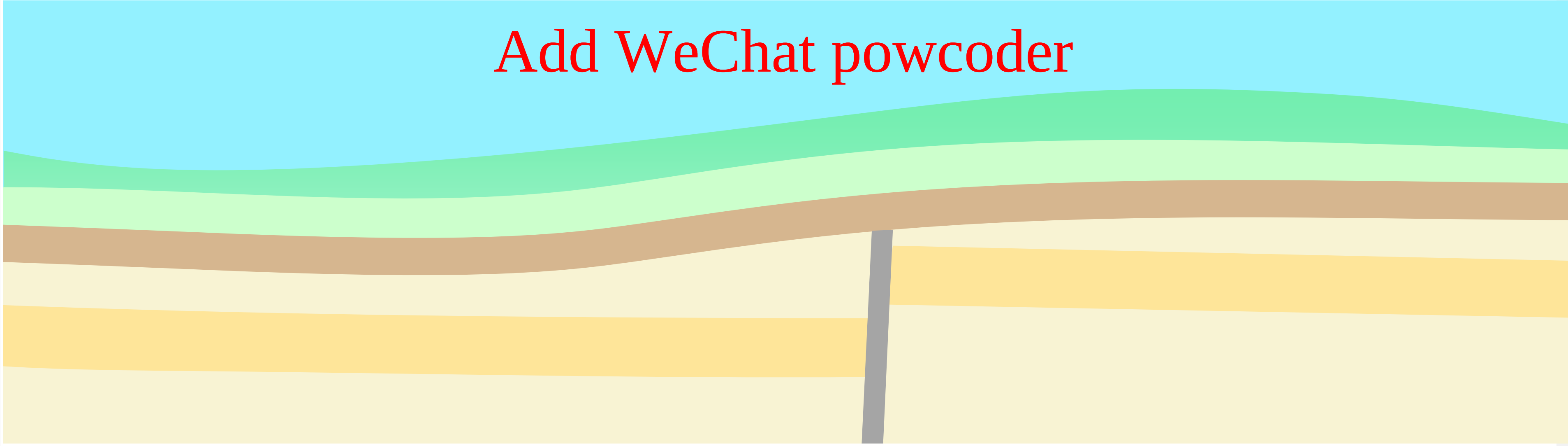
How do we measure these physical properties?

Geophysics

geo·phys·ics

(n.) a branch of natural science related to the study of Earth's composition and structure.

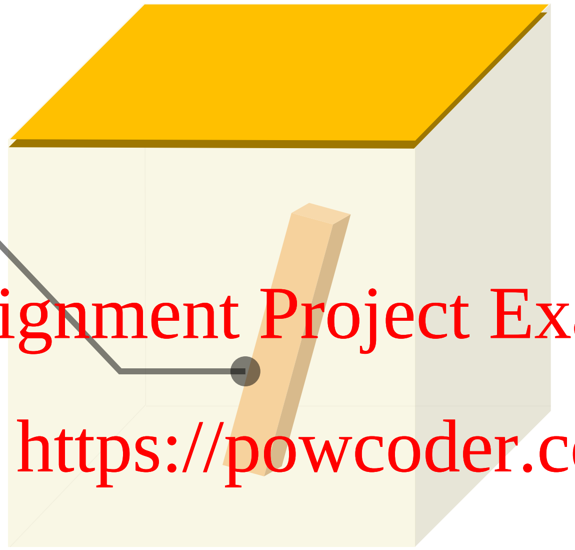
1. Applies principles of physics to predict or measure the geological makeup of the subsurface



Physical Properties

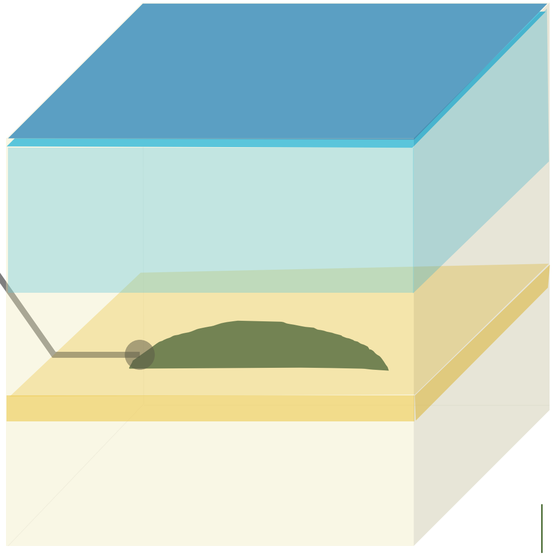
Mineral Deposit

- Conductivity
- Density
- Magnetic Susceptibility
- Velocity



Hydrocarbon

- Density
- Velocity
- Conductivity

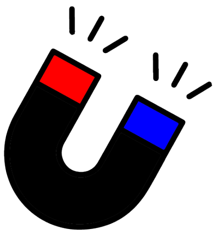


Gravity

Physical Property

We can estimate subsurface density by measuring the gravitational field over the earth

Force



Magnetics

Physical Properties

We can measure subsurface magnetic susceptibility by measuring the earth's Magnetic Field

Force

Electromagnetics

Physical Property

We can estimate subsurface electrical conductivity by transmitting and measuring an electromagnetic field

Force

Seismic

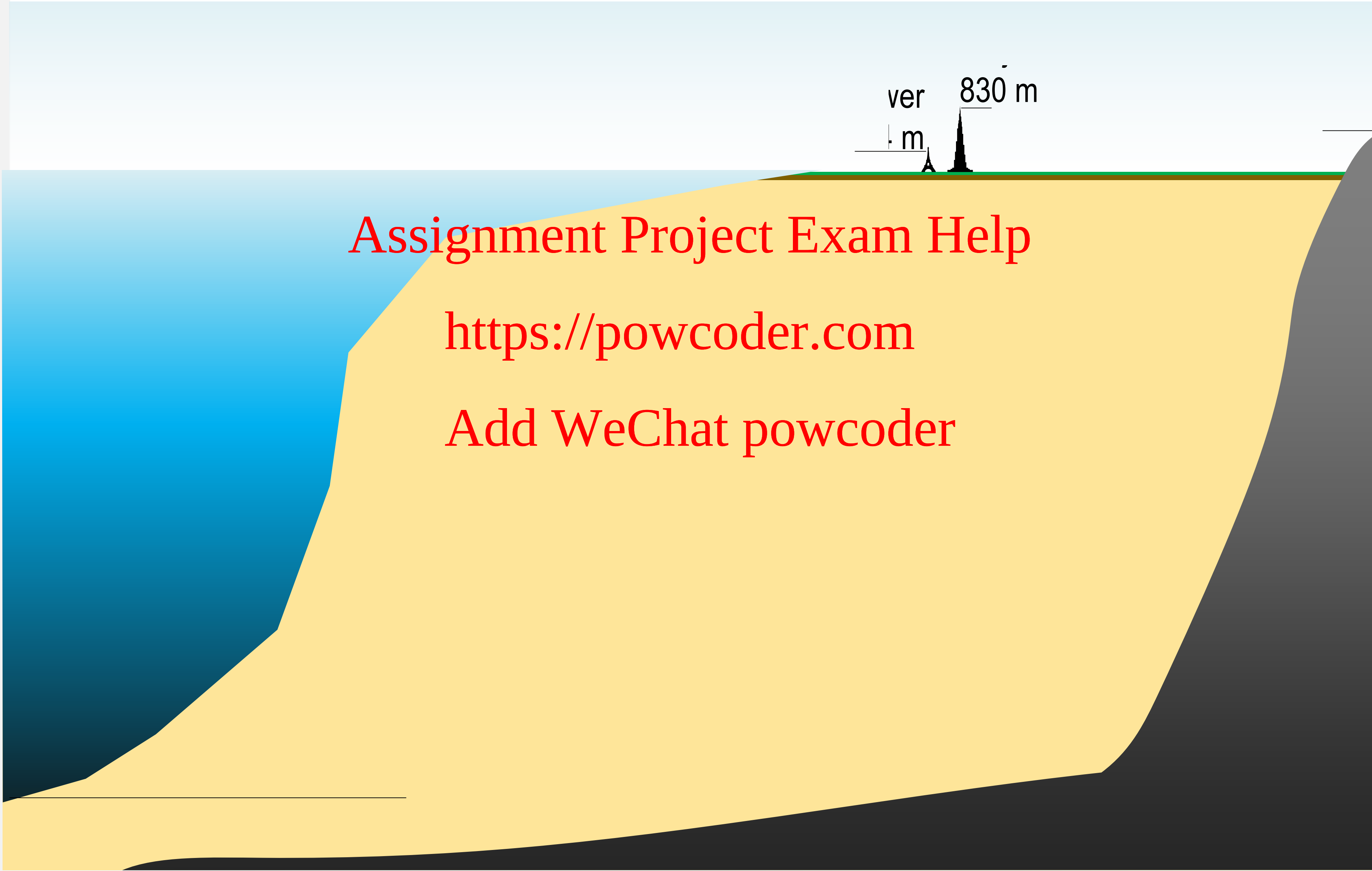
Physical Properties

We can measure subsurface density and velocity by transmitting and measuring Sound Waves

Force

How deep can we measure?

Depth of Investigation

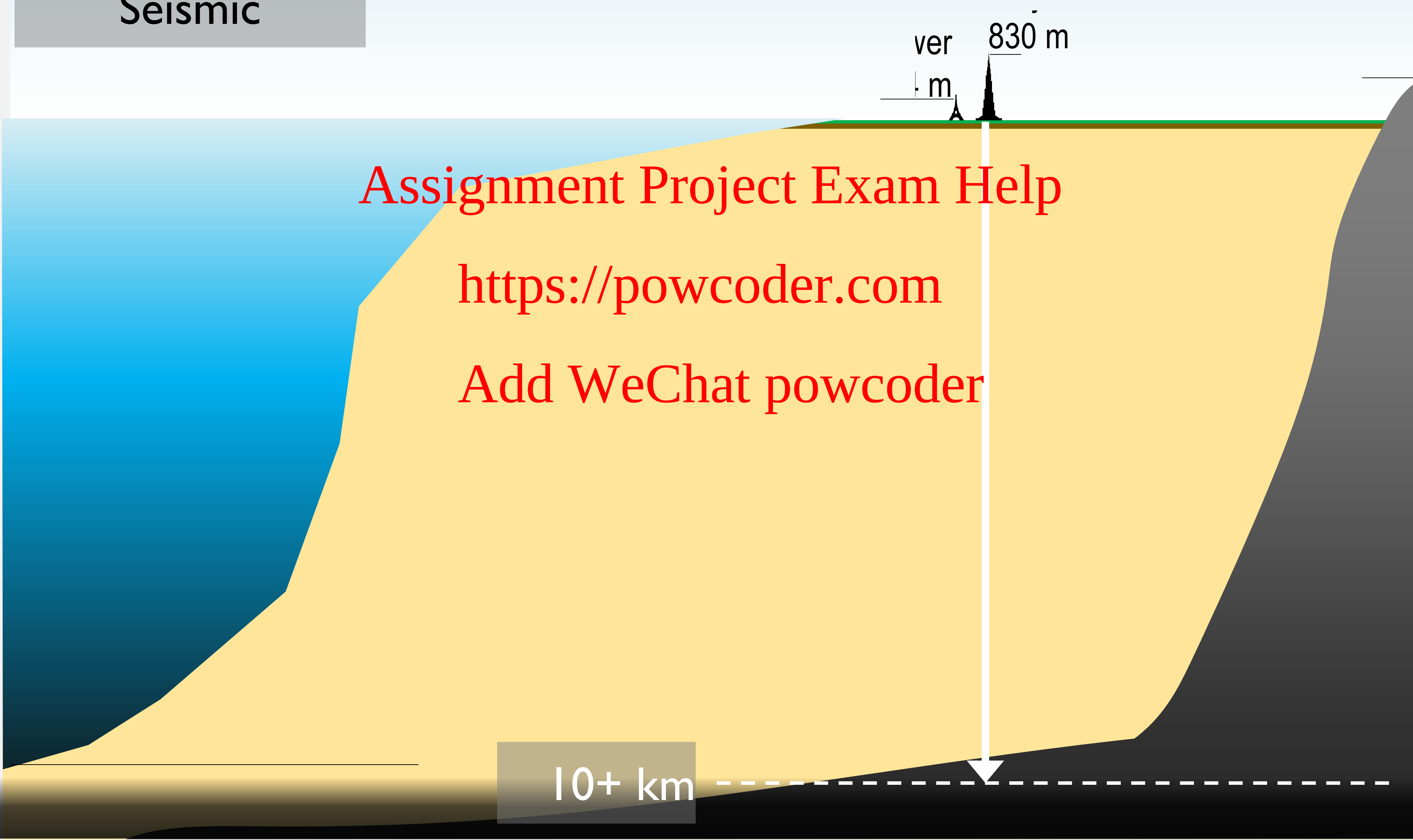


Depth of Investigation: Airborne Electromagnetics

Airborne Electromagnetics

Depth of Investigation: Active Seismic

Seismic



The depth of investigation is determined by the geophysical method. Methods such as ground penetrating RADAR can see centimetres into the earth— while methods such as seismic can see 10's of kilometres deep.

Learning Outcome Check

- The locations of valuable deposits can be detected by using the *differences* between their physical properties and that of their natural geological location. Explain how the following properties of material resources enable their detection:
  - Density
  - Velocity of sound waves
  - Magnetic susceptibility
  - Electrical conductivity

- Explain in your own words, what is meant by *seismic exploration*? Over what range of depth is it applicable?
- Explain in your own words, what is meant by *electromagnetic exploration*? Over what range of depth is it applicable?

What physical property should be measured to find a specific resource?

Resource	Mineralogical Parameter	Rock Property	Geophysical Method
Iron Ore	Magnetite	Magnetic Susceptibility	Magnetics
Gold	Magnetite /Pyrrhotite Hematite Pyrite	Magnetic susceptibility Density Electrical Conductivity Velocity + Density	Magnetics Gravity Electromagnetic Seismic
Uranium	Uraninite	Radioactivity (U238 decay)	Radiometrics (Scintillator)
Water	Sand / Shale / Salinity	Electrical Conductivity	Electromagnetic

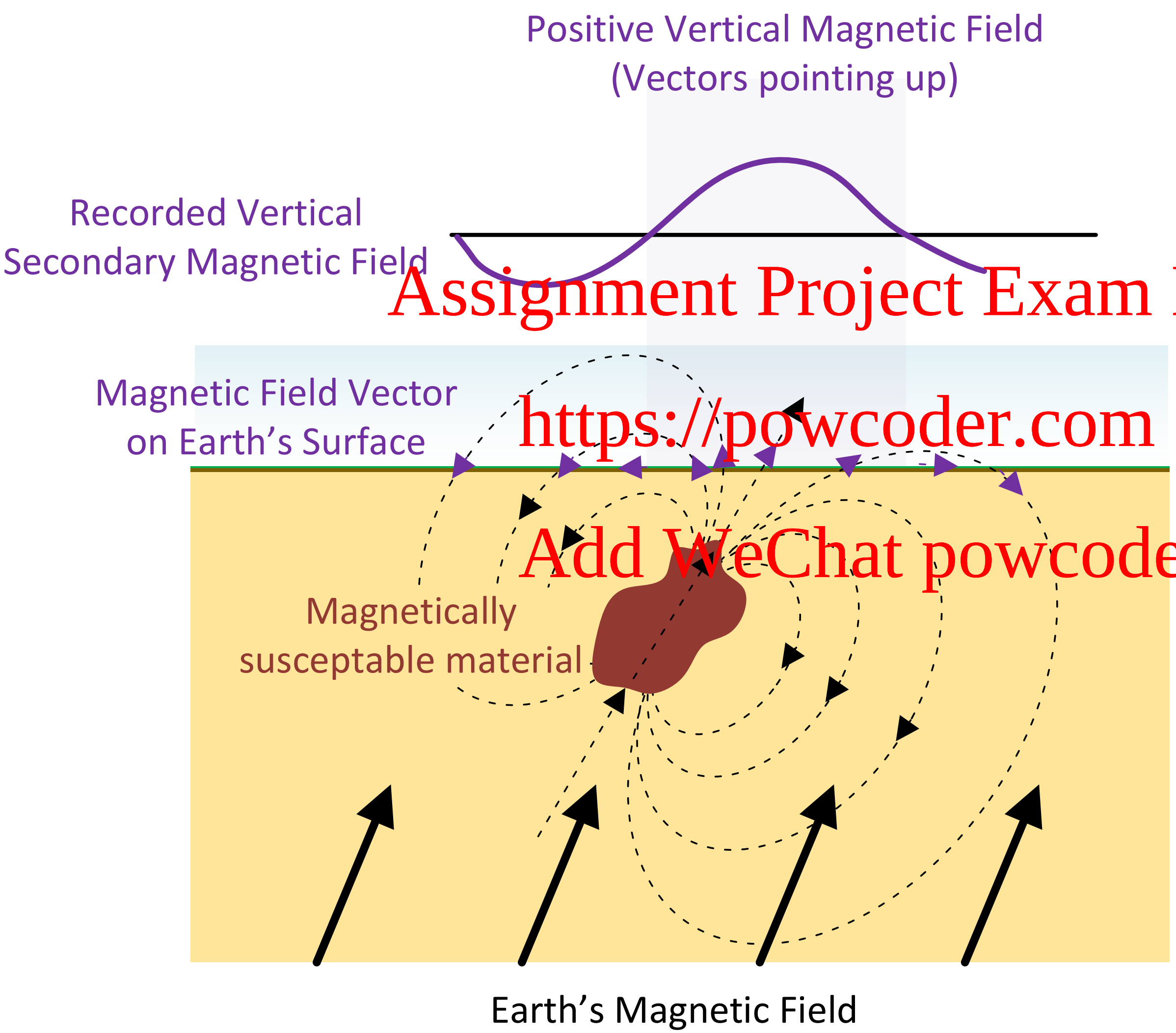
Each resource is hosted in rock with distinct mineralization.

These minerals have distinct physical properties….

We apply the specific geophysical method sensitive to the unique rock property of that resource.

How do we find mineral resources?

Magnetics: Recording the Magnetic Field



Description

The Earth's magnetic field interacts with magnetically susceptible rocks.

Minerals with higher magnetic susceptibility, such as Maghemite and Magnetite, the greater the induced magnetic field.

The magnetic field is measured with a magnetometer. This is attached to an airplane or carried on-top of the ground. In this schematic the recorded magnetic field is denoted by the purple arrows.

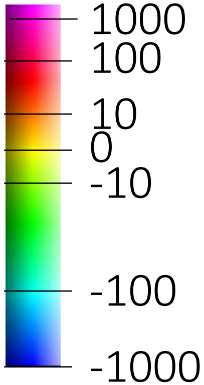
Magnetics Overview

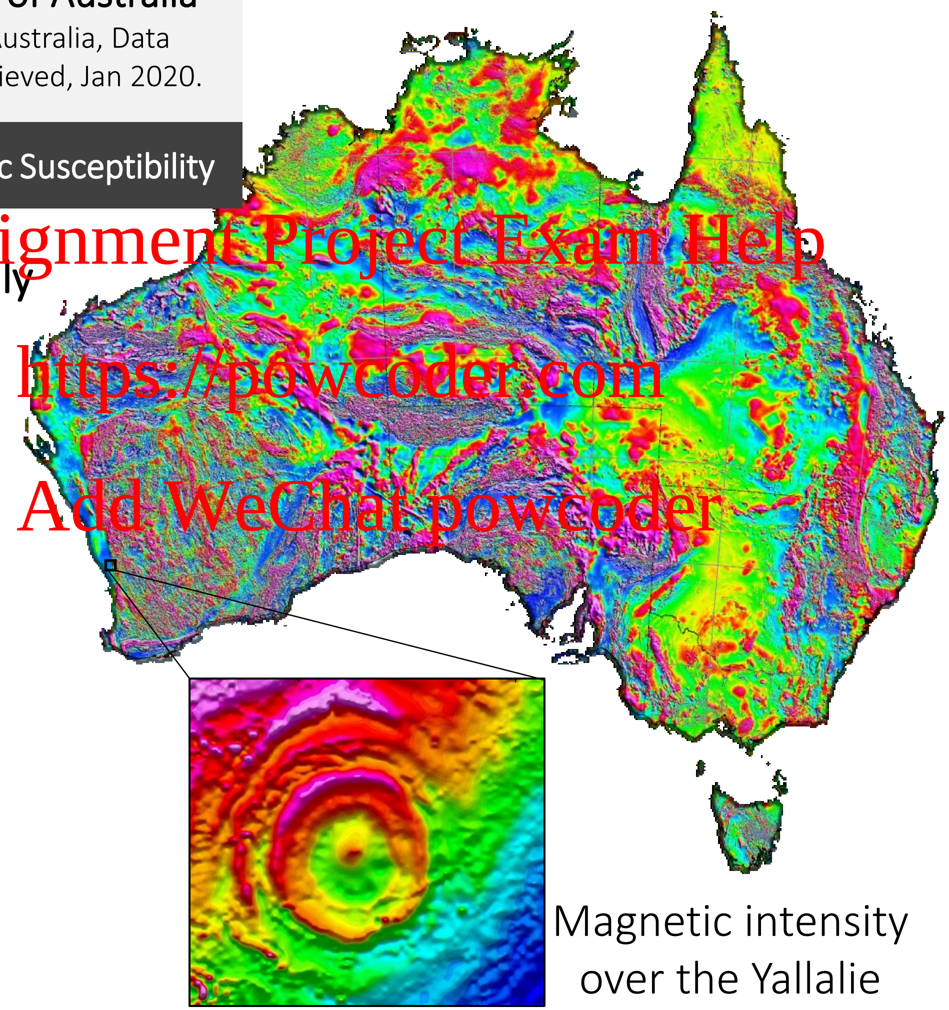
Magnetic Anomaly Map of Australia

Modified from "Geoscience Australia, Data Compilations, Geophysics", Retrieved, Jan 2020.

Property detected: Magnetic Susceptibility

Magnetic Anomaly (nT)

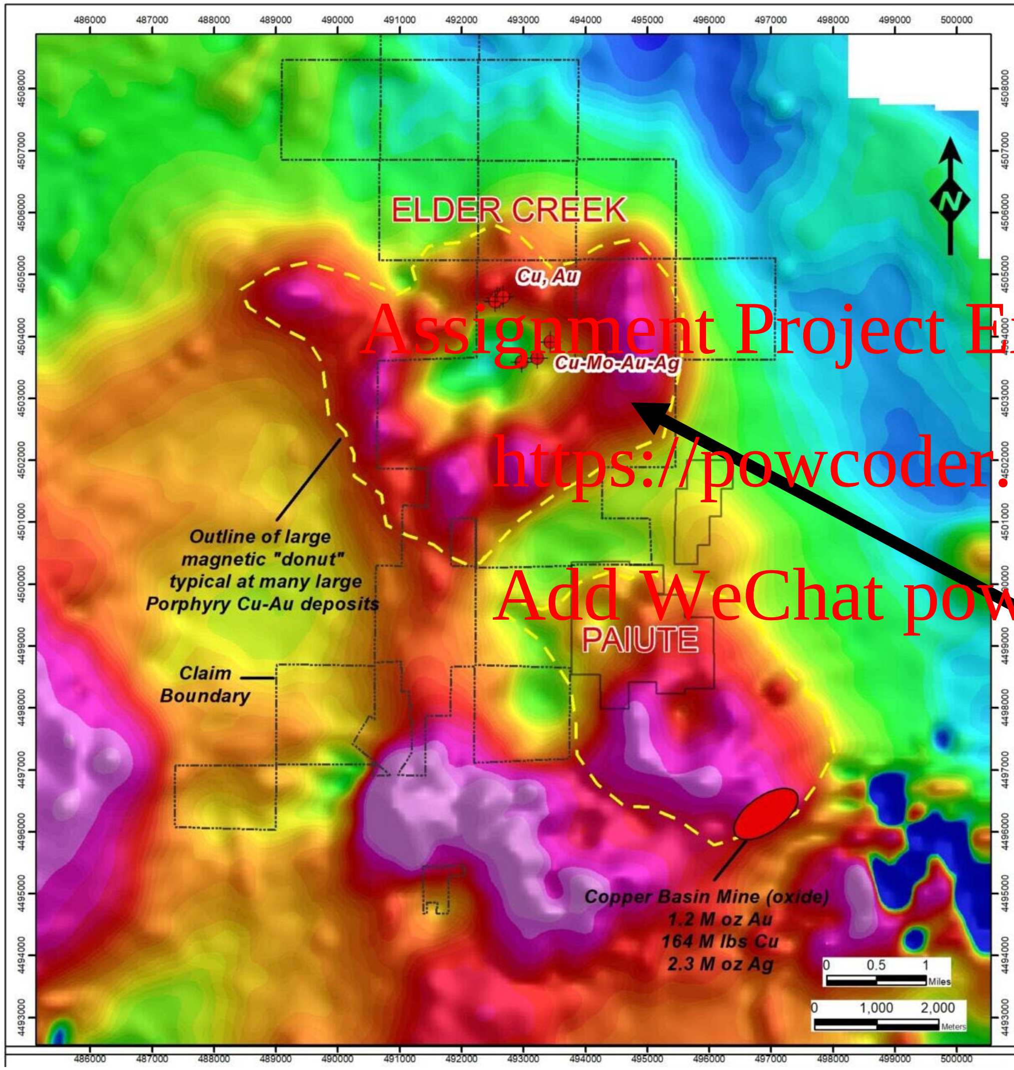




Magnetic intensity over the Yallalie Impact Crater

Reproduced from, Meteoritical Society WA Craters Excursion 2012: Yallalie.

Magnetics: Porphyry Deposit Example

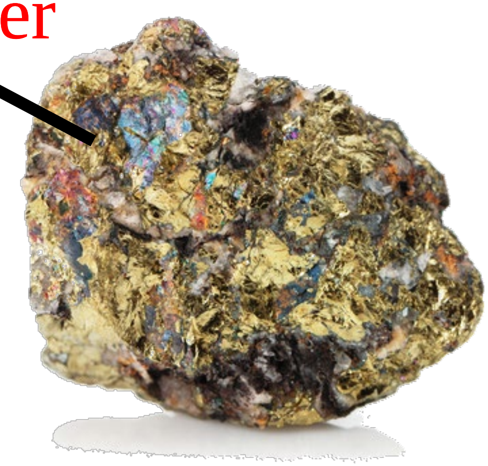


Reproduced from Timberland resources, 2020, Elder Resources, retrieved from "https://timberlineresources.co/project/elder-creek-overview/", Aug 2020.

Description

This is **Airborne Magnetic** dataset was acquired using a **magnetometer** over the Elder Creek **Porphyry deposit**.

The outer ring of the "donut" contains **Pyrrhotite**, a highly **magnetic susceptible material**. This produces a magnetic high (shown in red).



Porphyry Copper Ore

Reproduced from UMass Lowell, from http://faculty.uml.edu/nelson_eby/89.308/Instructor%20Pdfs/Chapter%2016%20-%20Economic%20Minerals.pdf

Learning Outcome Check

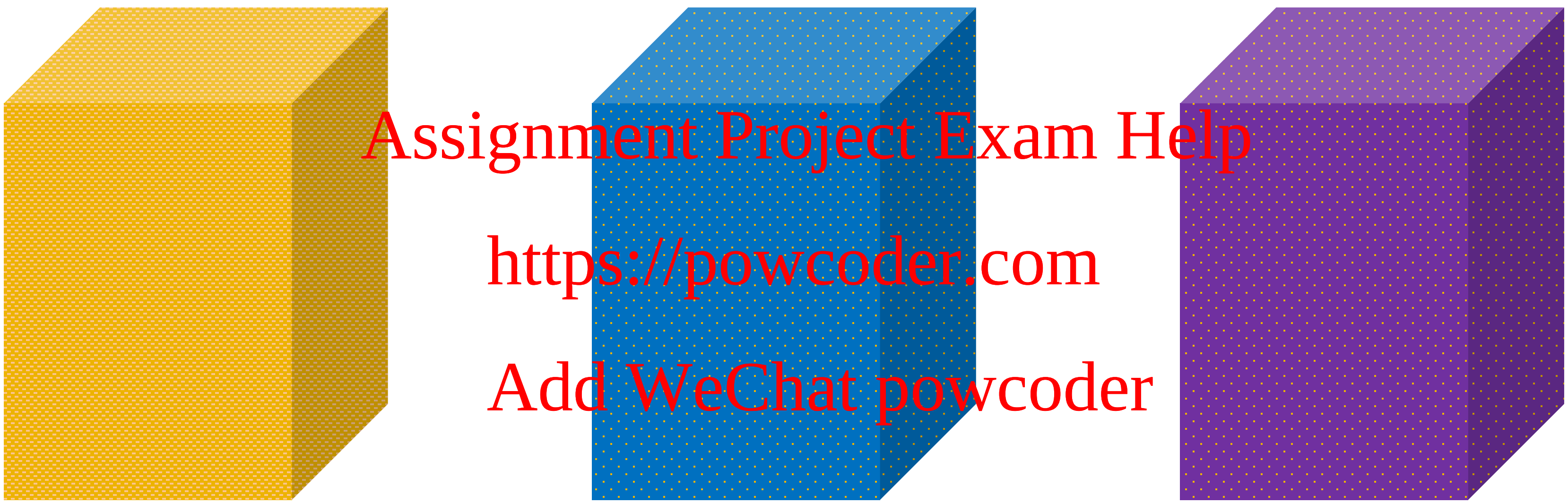
- Explain what geophysical technique would you apply to find a shallow high-magnetic susceptibility gold deposit.

How do we find Water resources?

Dry Sand

Sand saturated with water

Sand saturated with salt water



Which rock conducts electricity more easily?

Electromagnetic Rock Property: Electrical Conductivity

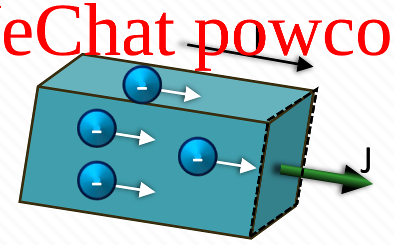
$$\mathbf{J} = \sigma \mathbf{E}$$

*Charges will flow in the presence of an electric field (**E**)*

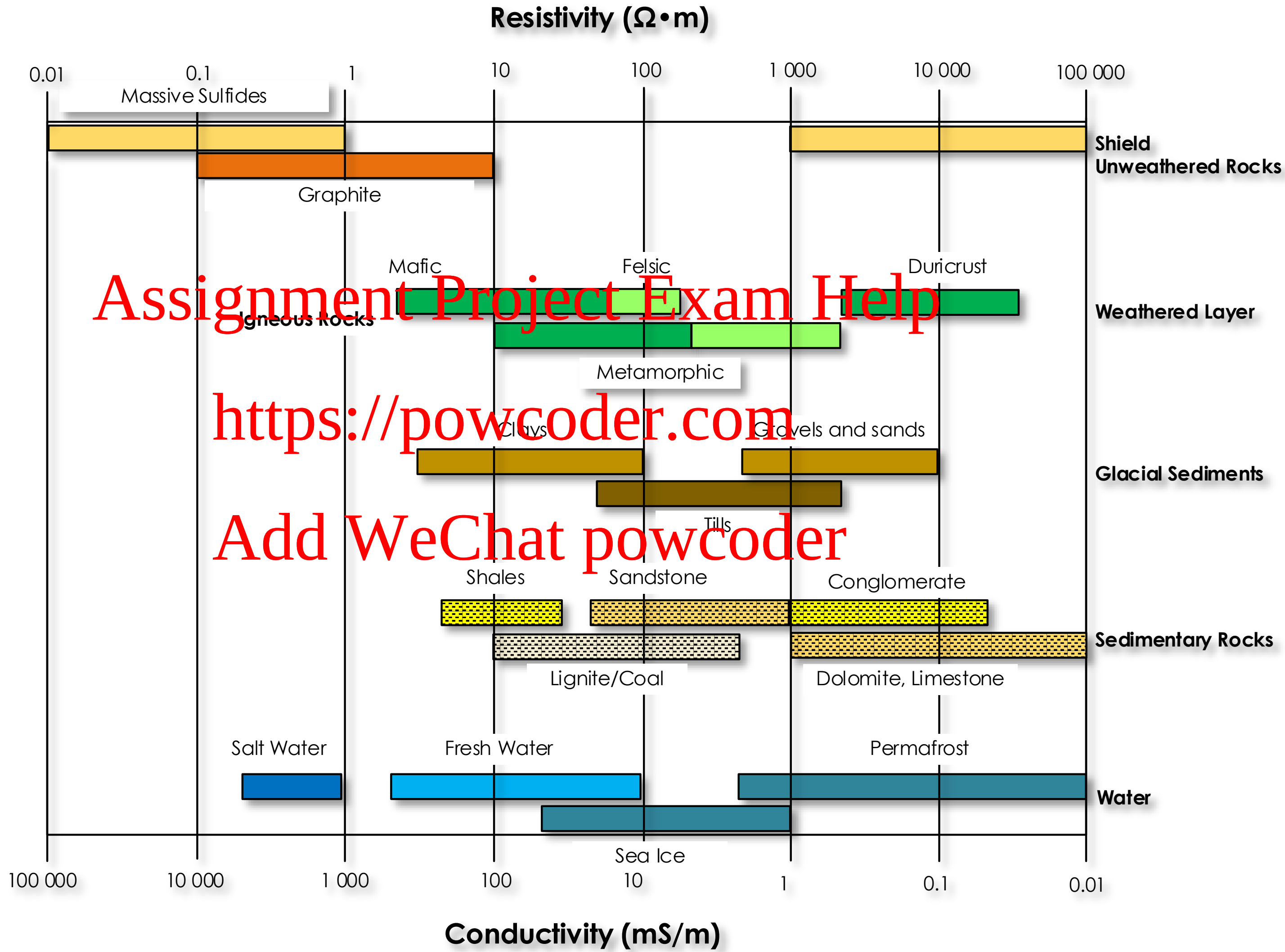
*The amount of electric current flowing per unit area (**J**) is determined by the material's electrical property (σ).*

An analogy can be made to Ohm's Law

$V = IR \leftrightarrow E = J\left(\frac{1}{\sigma}\right)$

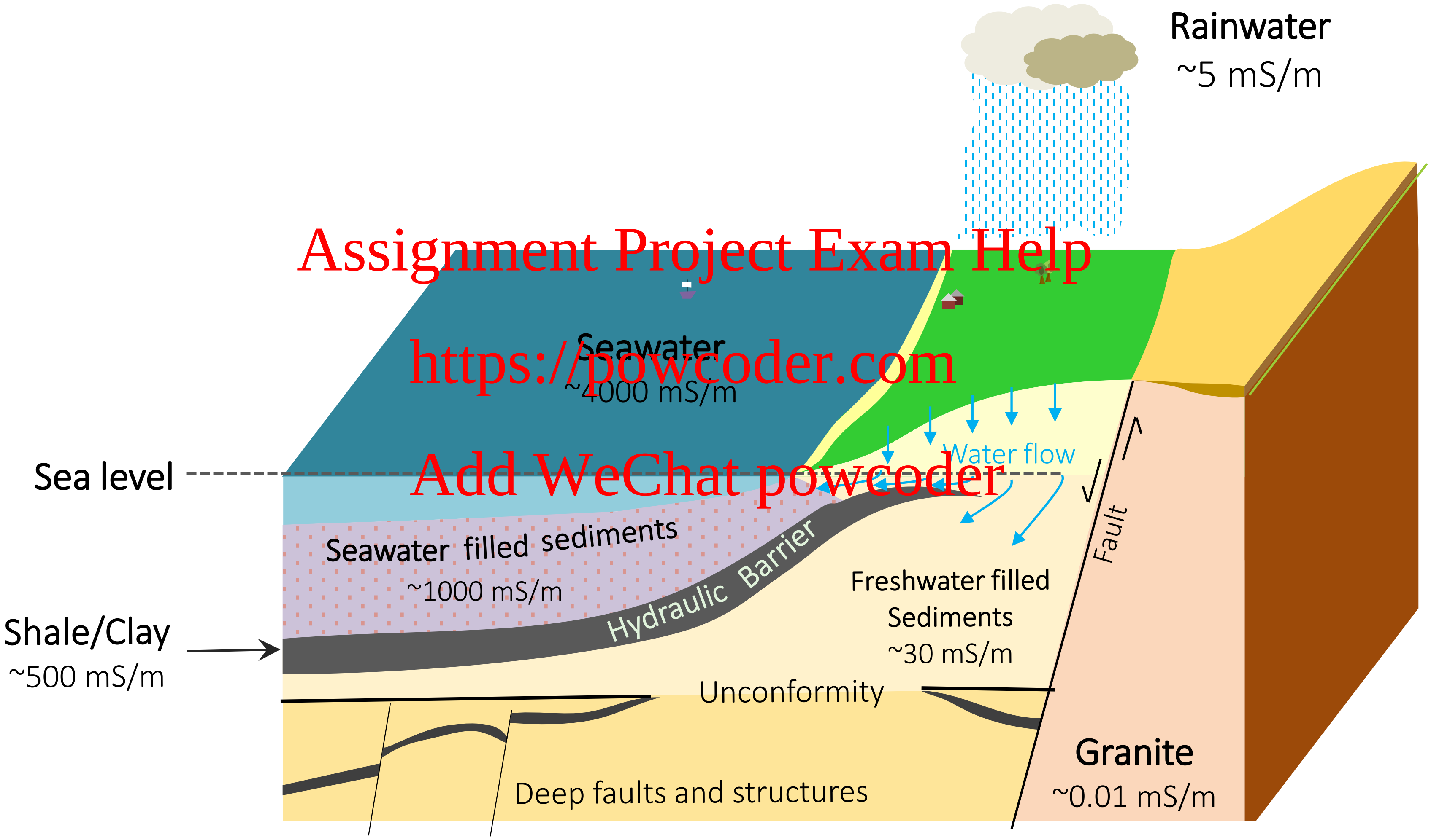
Current Density	Electrical Conductivity
J	σ
Current per unit cross sectional area	Measure of how easily current can flow through a medium
J has SI units A/m² **E** has SI units V/m	SI units mS/m ('S' siemens)
	$Air \quad \sim 5 \times 10^{-12}$ $Sea\ Water \quad 2000 - 4000$ $Fresh\ Water \quad < 5$

Measuring Conductivity in the Earth



Modified from Zonge, Kenneth L., L. J. Hughes, and M. N. Nabighian. "Electromagnetic methods in applied geophysics." *Electromagnetic methods in applied geophysics* (1991).

Viewing the Water System in terms of Electrical Conductivity



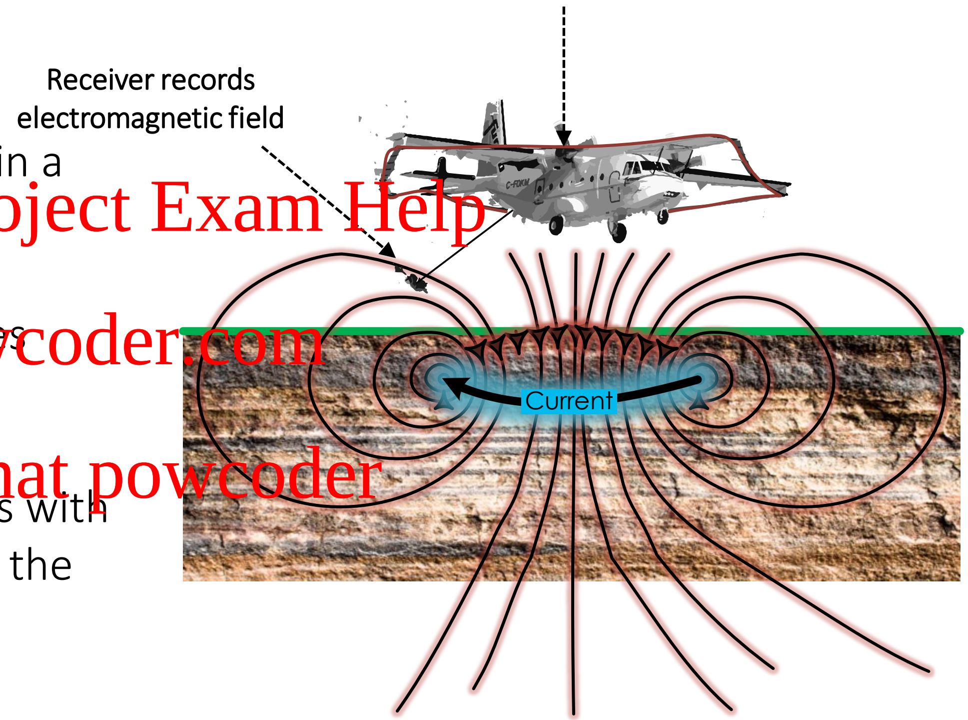
Transient Electromagnetics

1. Generate a transient electromagnetic field in a large coil loop

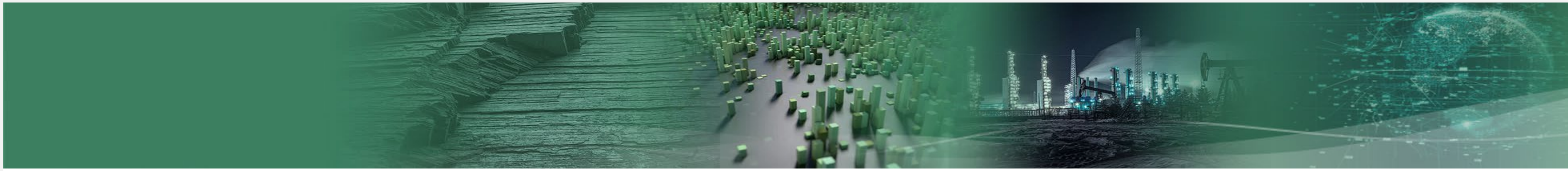
2. The generated electromagnetic field diffuses into earth.

3. The diffusing electromagnetic field interacts with the earth. The more conductive the ground— the higher amplitude the electromagnetic field.

4. Record the EM field in a receiving coil and convert the EM field signal into an distribution of <u>subsurface electrical conductivity</u>



A time varying electromagnetic field causes current to flow in the earth.



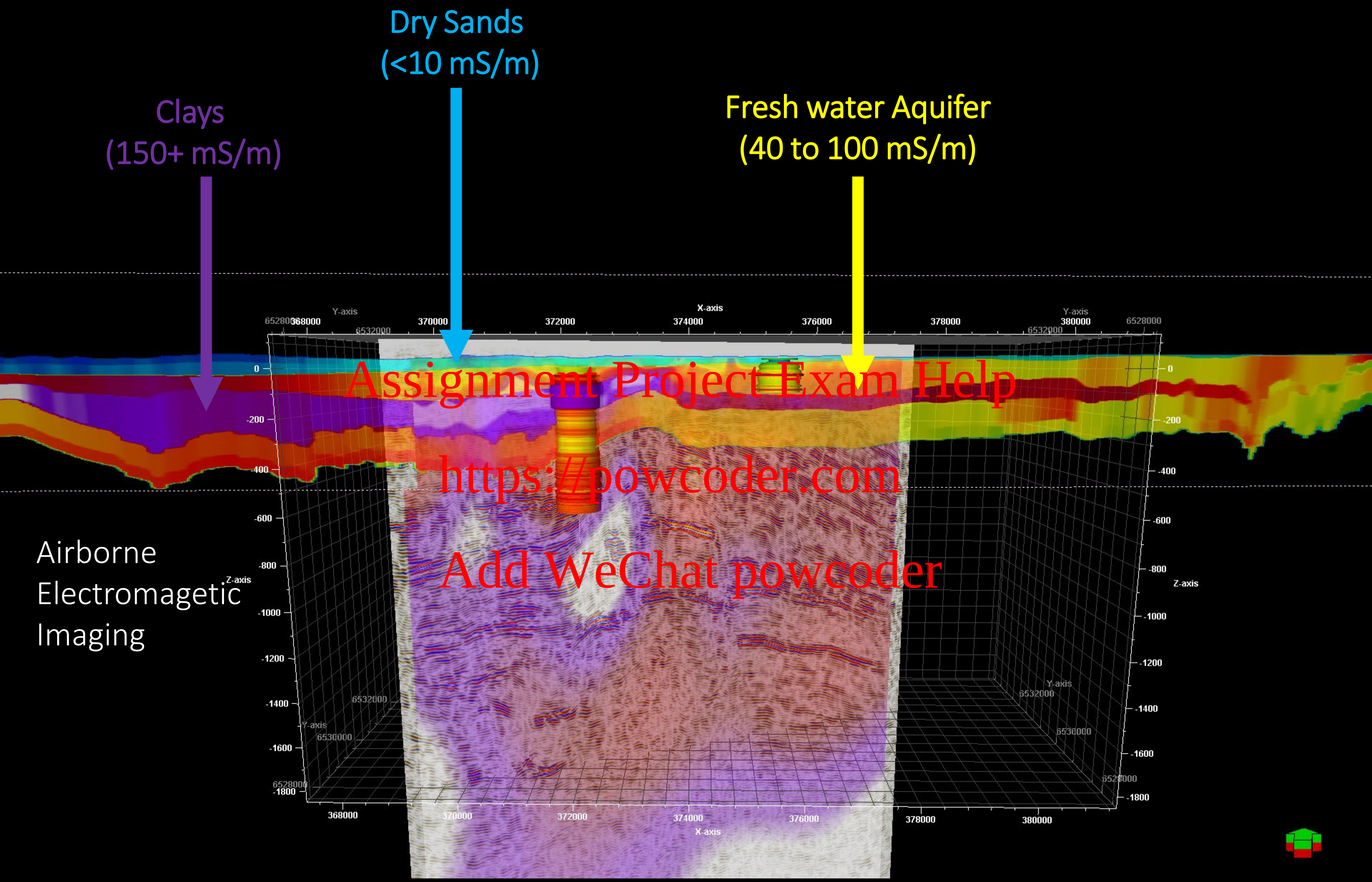
Assignment Project Exam Help

https://powcoder.com

Add WeChat powcoder

Measuring Conductivity in the Earth

https://www.youtube.com/watch?v=AR
NorgesGeotekniskeInstitutt



Airborne Electromagetic Imaging

Learning Outcome Check

- What electrical property can be used to find subsurface water resources?
- Why is salt water more electrically conductive than fresh water?
- What other property of water maybe useful for exploration?

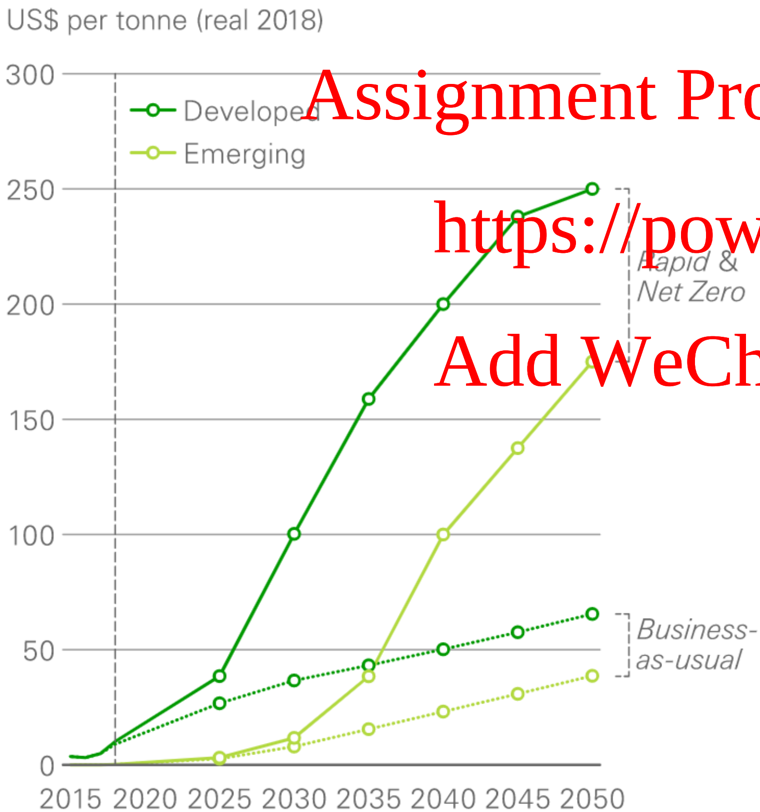
Process Overview

What resource?	"Copper"
Which rock/geological setting?	"Porphyry Deposits with Pyrrhotite and Pyrite"
Which physical rock property?	"High magnetic susceptibility, density and velocity"
Which geophysical method (s)?	"Magnetics and Seismic"
Acquire/interpret	Drill / Mine

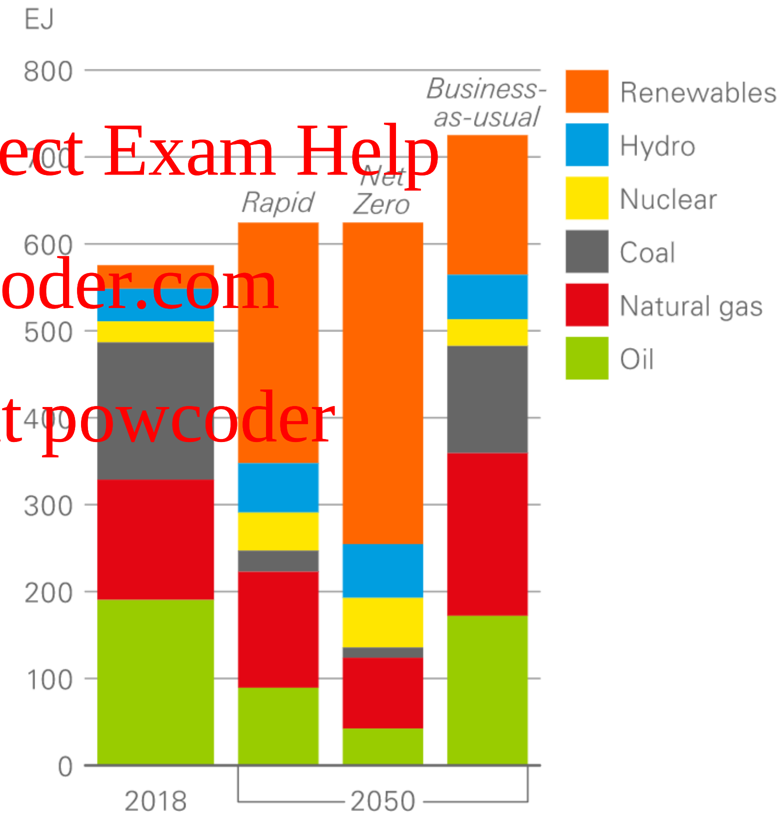
What are the energy resources?

Global Energy Resources

Average carbon prices in developed and emerging regions



Primary energy consumption by source



BP Energy Outlook, 2020

Retrieved from https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/introduction/overview.html, Aug 2021

Hydrocarbon Resources Introduction: Geological Setting

Hydrocarbon Resources; natural gas and crude oil

Origin of Hydrocarbon Resources; prehistoric plants and animals

In what settings can you find hydrocarbon;

Natural gas & Crude oil → buried in sediments – <u>oil and gas traps</u>

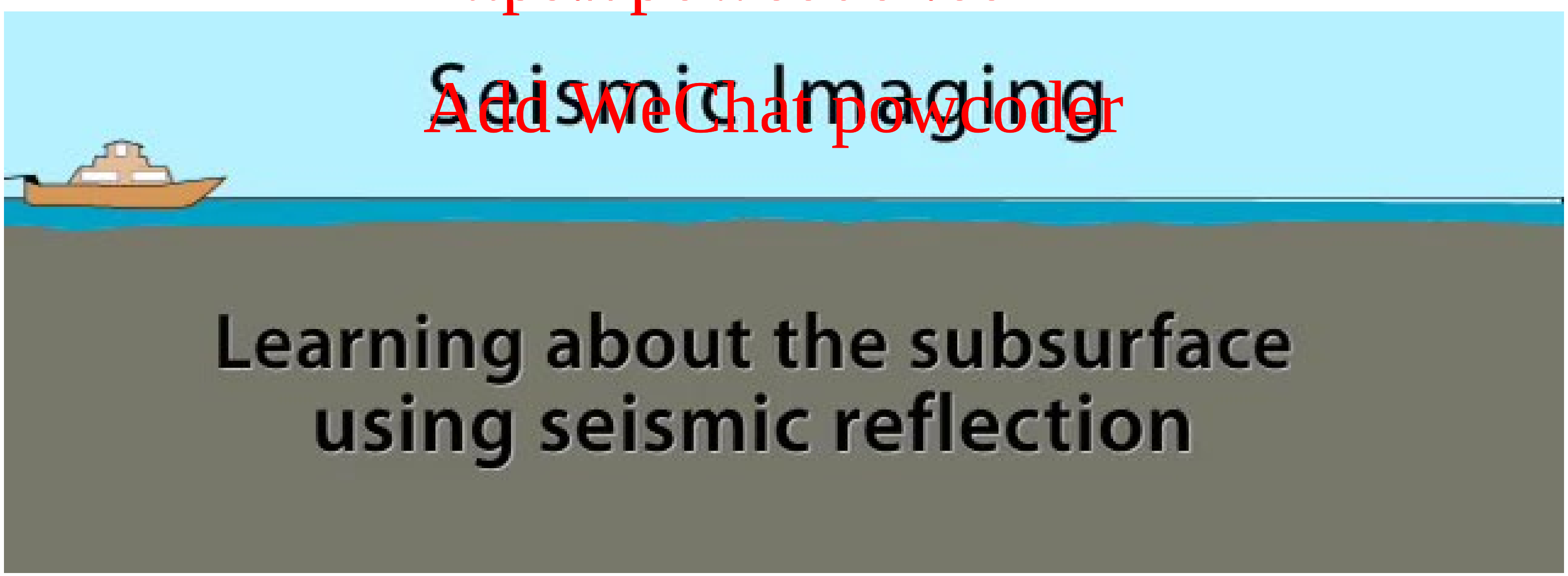
How do you find hydrocarbon? The primary method is Seismic Exploration.

How do we do seismic exploration?

Measuring Acoustics in the Earth

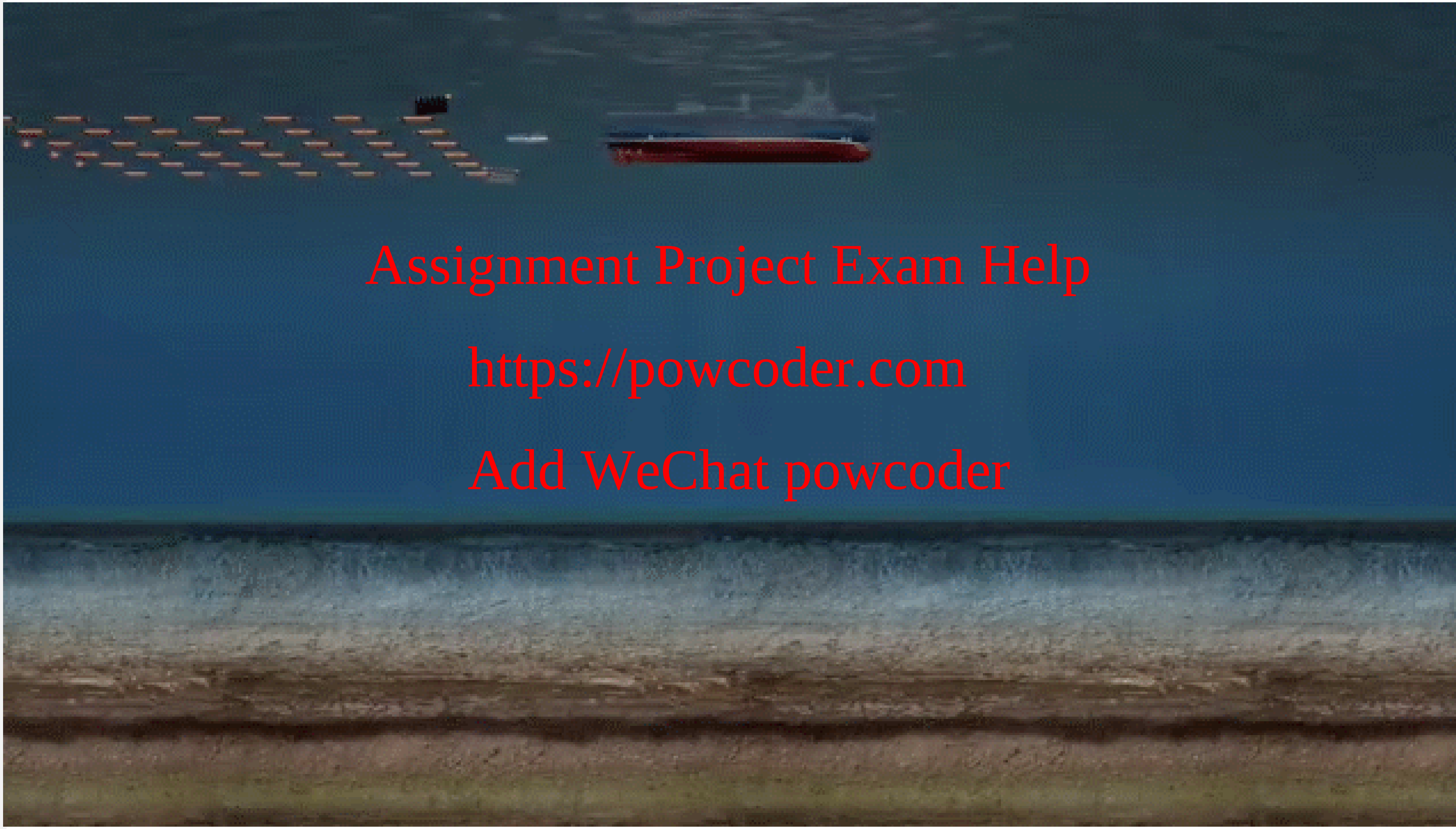
Seismic Exploration

1. Generate sound waves
2. Sound waves propagates through the earth
3. Record the reflected sound waves
4. Image subsurface



Animation is reproduced from https://www.iris.edu/hq/inclass/animation/reflection_seismology_seeing_below_the_ground

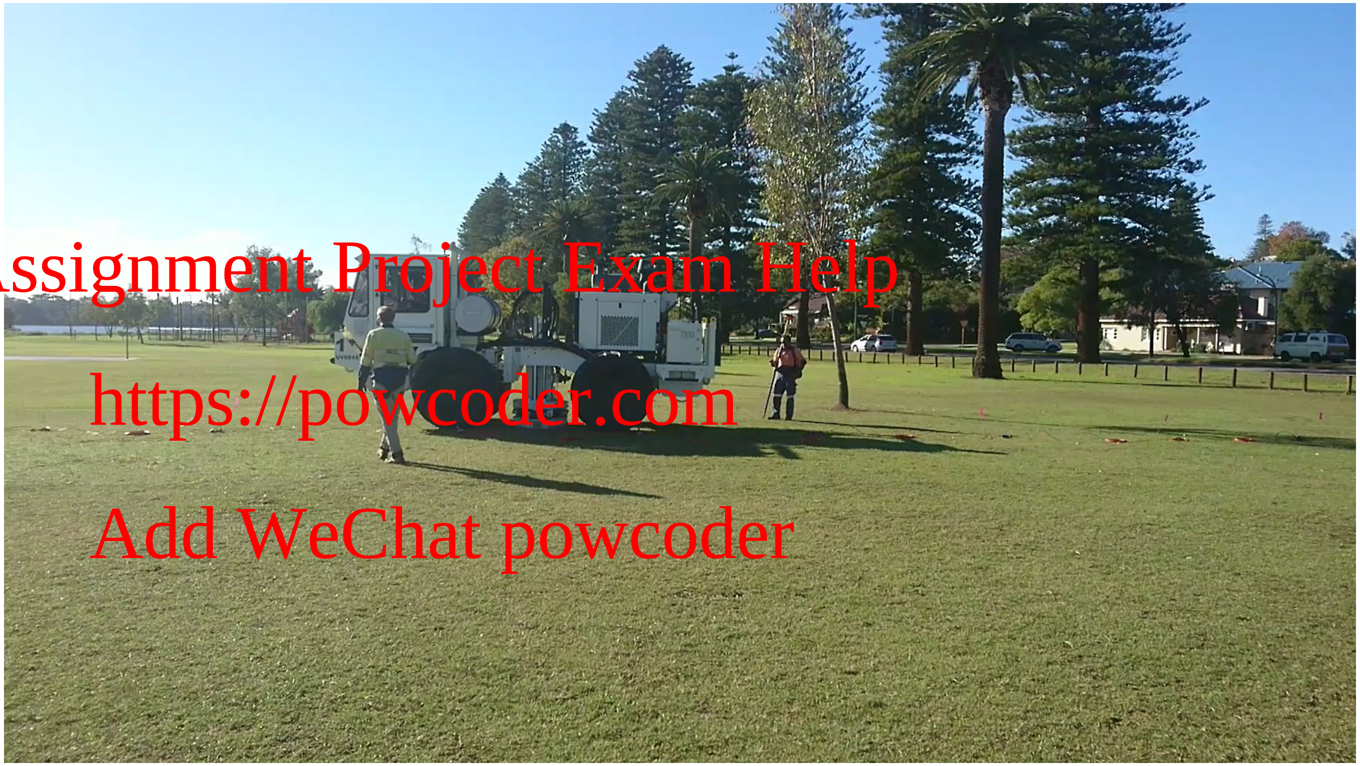
Animation: Acquisition



Modified from The American Petroleum Institute, retrieved from https://www.youtube.com/watch?v=FN8IAb0rG9A, Jan 2020.

Acquisition: Seismic Sources

- Airguns
- Explosives
- Hammer
- Weight Drop
- Vibrators
- Surface Orbital Vibrators

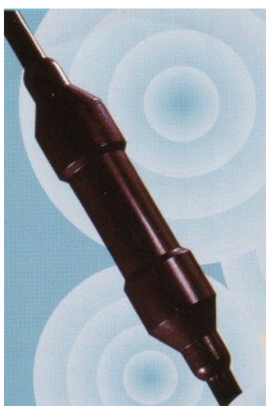


Vibroseis Truck
Lake Monger, Water Research
Curtin Exploration Geophysics, 2018.

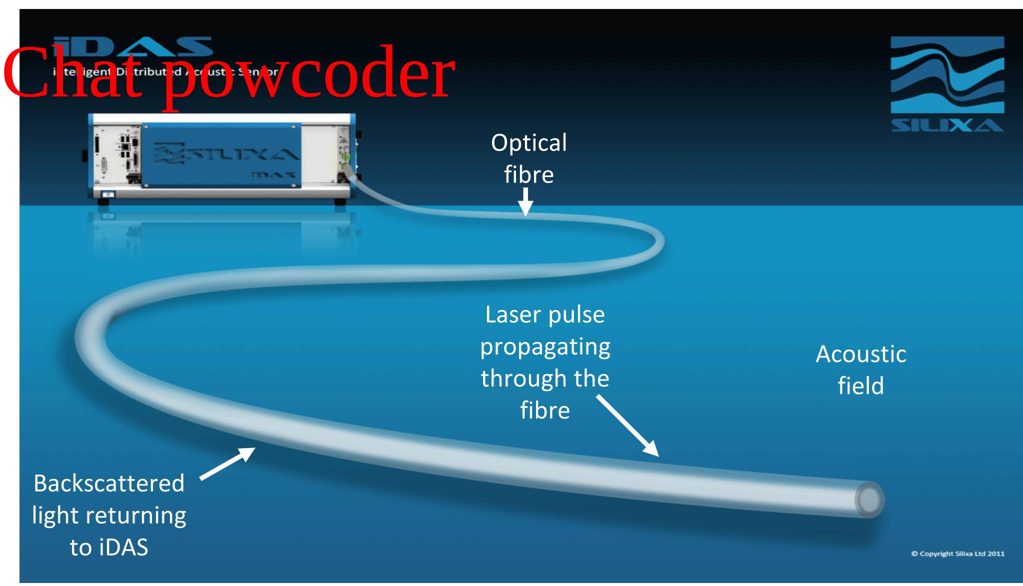
Acquisition: Seismic Receivers

- Geophones
- Hydrophones
- DAS (Distributed Acoustic Sensing)

Geophone, Curtin Exploration Geophysics, 2018



Active piezo polymer hydrophones, V Cable
Retrieved from http://www.seismics.net/rental-tools/, Jan 2020.



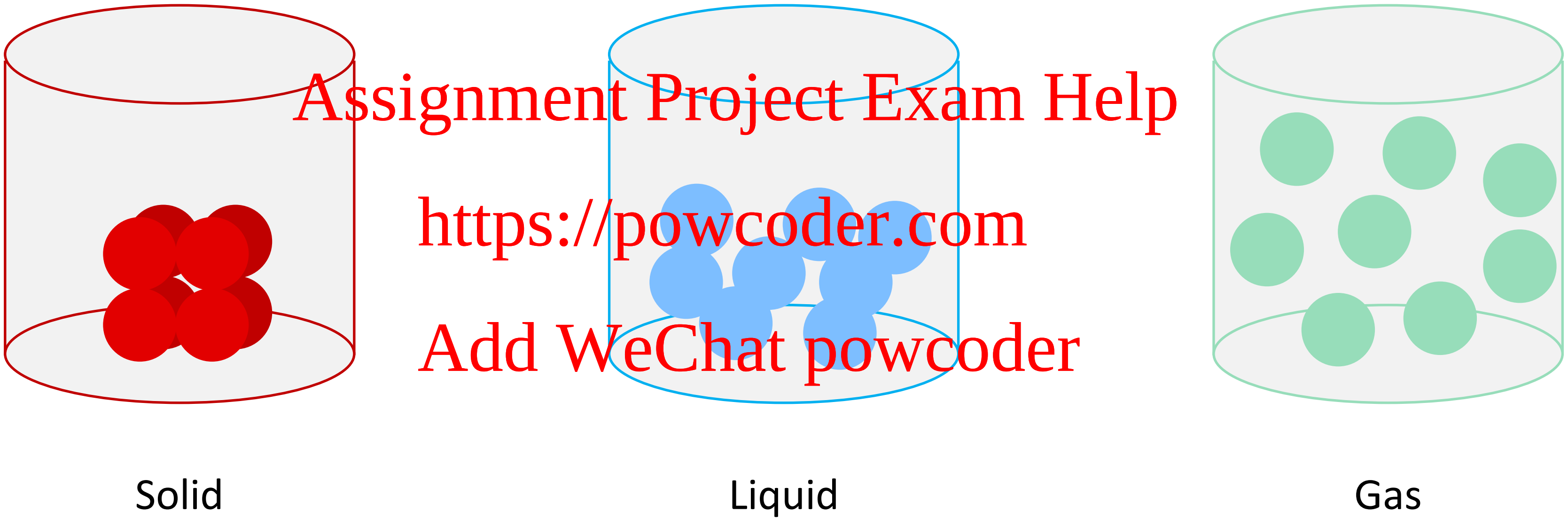
DAS, Courtesy of Silixa Pty Ltd., Jan 2020.

Learning Outcome Check

- Describe how we acquire seismic ?
- Which equipment do we use to generate sound waves?
- Which equipment do we use to listen/record the reflected sound waves?
- What creates the reflected sound waves?

How does seismic work?

State of Matter



Seismic Rock Property: Acoustic Impedance

$$Z=\rho \boldsymbol{v}$$

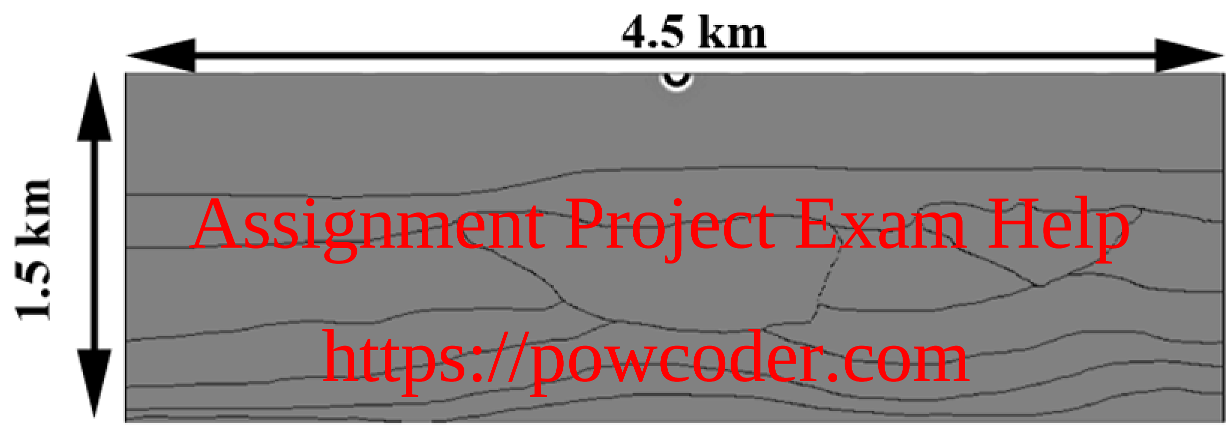
Acoustic Impedance Z is the product of density and seismic velocity. The differences in acoustic impedances between rock layers determine the reflection coefficients (R) *at normal incidence.*

Seismic velocity *is defined as the speed which a sound wave propagates through a medium*

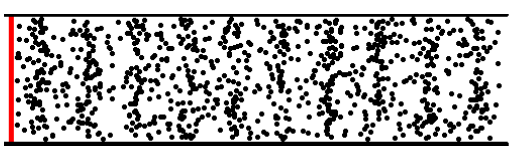
The **density** *here refers to the density of the medium through which the sound waves propagate. Not the density of the target resource!*

Density		Velocity	
ρ has SI units g/cm³		$\boldsymbol{v}$ has SI units m/s	
The amount of mass per unit of volume		A vector quantity of displacement per time and direction. It changes with stress, temperature, porosity, permeability, fluid saturation, crack density, etc	
Air	$\sim 1.2 \times 10^{-3}$	Air	330
$Water$	1	$Water$	1500
$Sedimentary$	$\sim 1.5 - 2.5$	$Landfill$	$500 - 2000$
$Matamorphic$	$\sim 2.5 - 3.2$	$Sand$	$500 - 2500$
$Igneous$	$\sim 2.3 - 3.5$	$Limestone$	$4000 - 5500$
		$Granite$	~ 6000

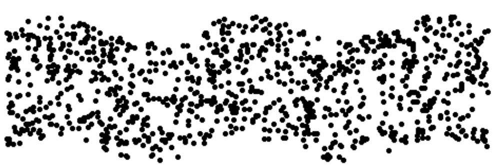
Sound Wave Propagation



Compressional Waves (v_p)



Shear Waves (v_s)

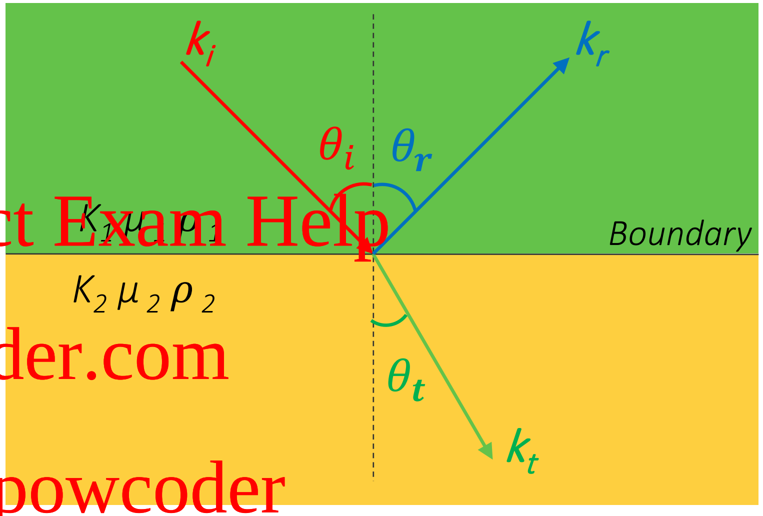


Retrieved from http://www.sjvgeology.org/oil/seismic_waves.html, Jan 2020.

Snell's Law

k_i the incident wave
k_r reflected wave
k_t transmitted wave

θ_i the incident angle
θ_r angle of reflection
θ_t angle of transmission

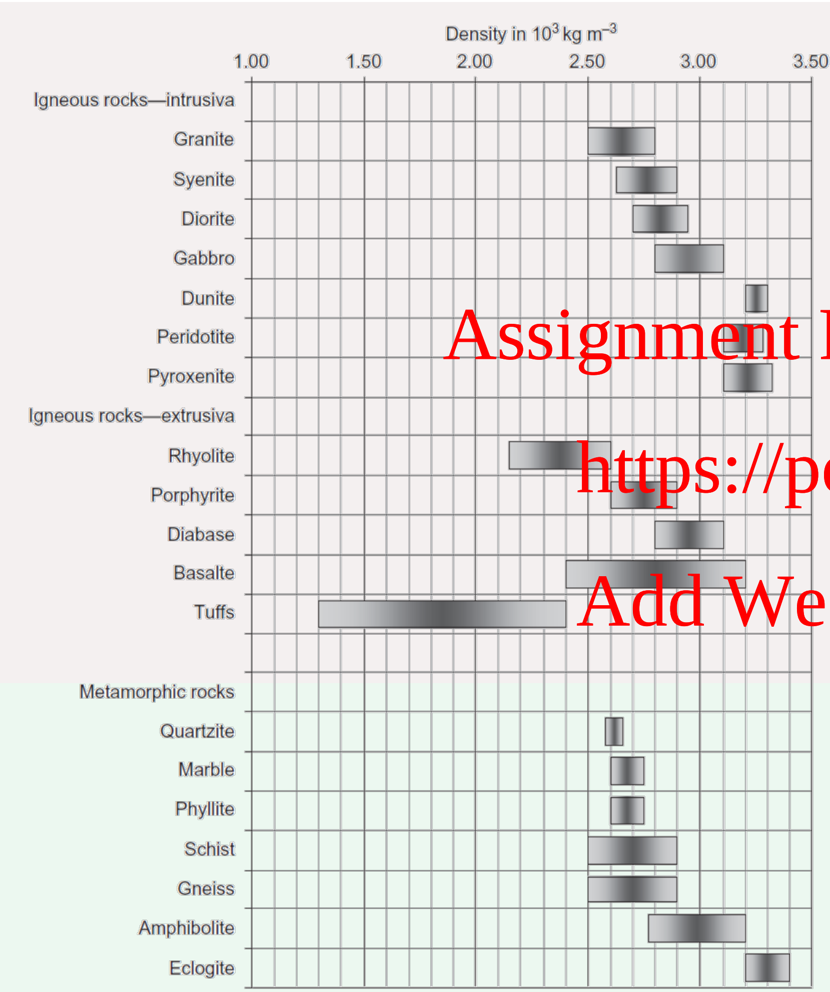


Homogeneous media physical properties such as ….

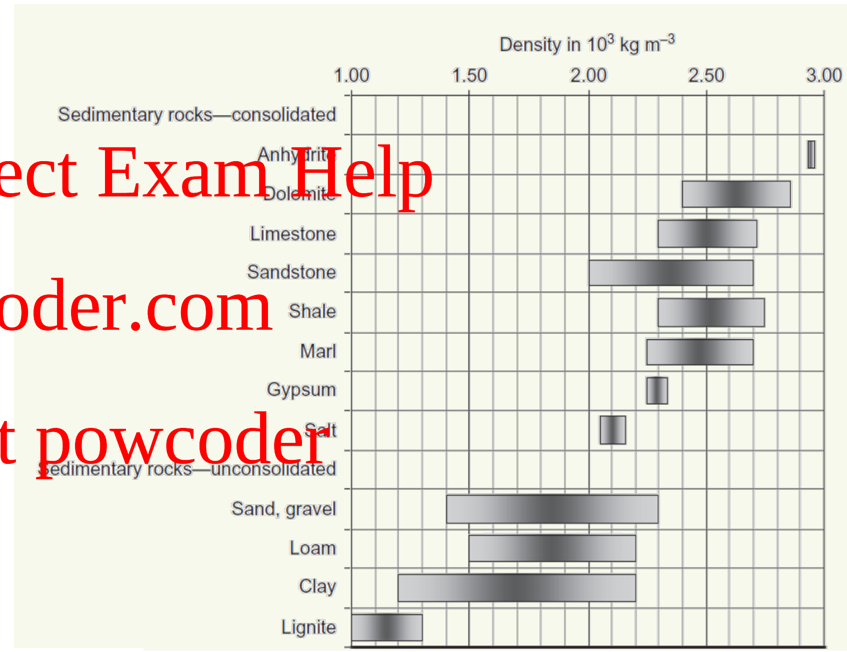
Snell's Law is the relationship between the path taken by a sound wave in crossing the boundary between two different media.

$$\text{Velocity } (v_p, v_s) \text{ and Density } (\rho) \text{ of media} \longleftarrow \frac{\sin\theta_i}{v_i} = \frac{\sin\theta_r}{v_r} = \frac{\sin\theta_t}{v_t}$$

Density Range of Rocks



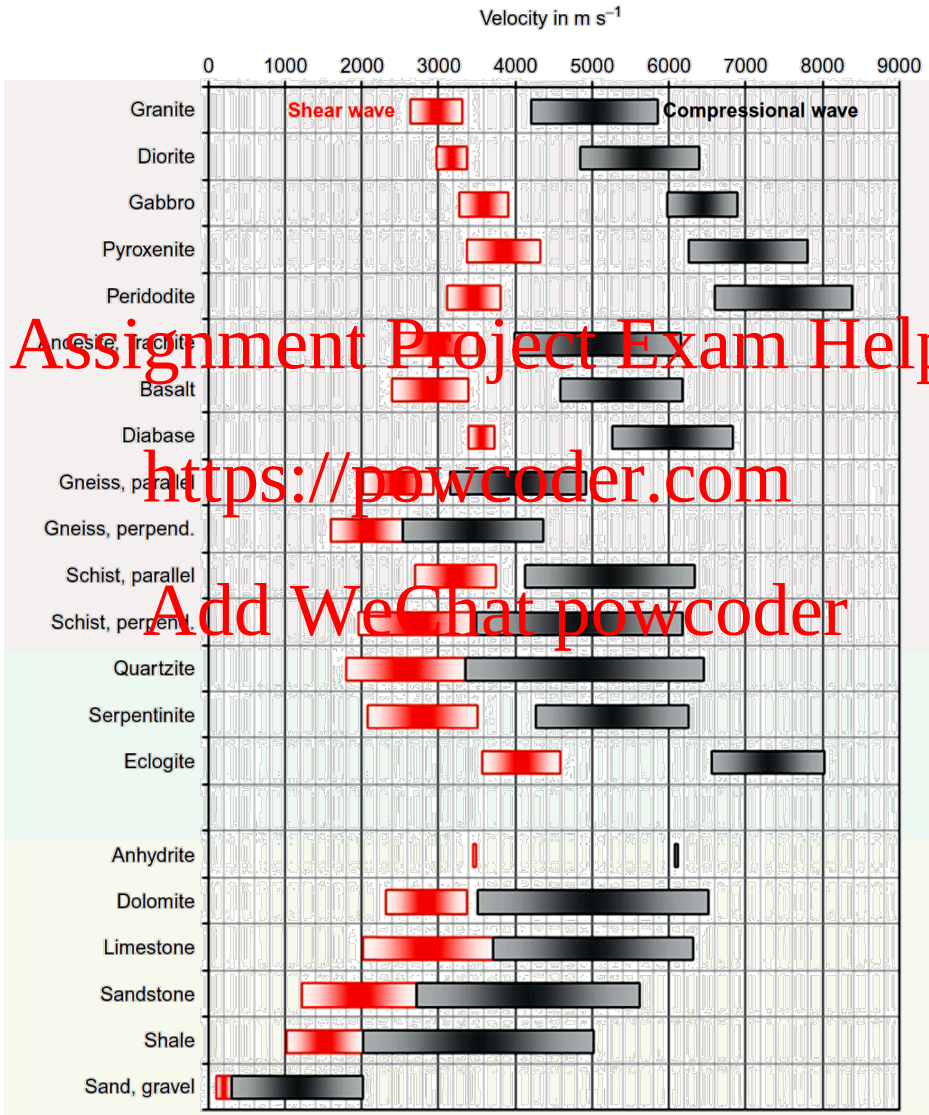
Mean range of density for igneous and metamorphic rocks.



Mean range of density for sedimentary rocks.

Schön, 2015.

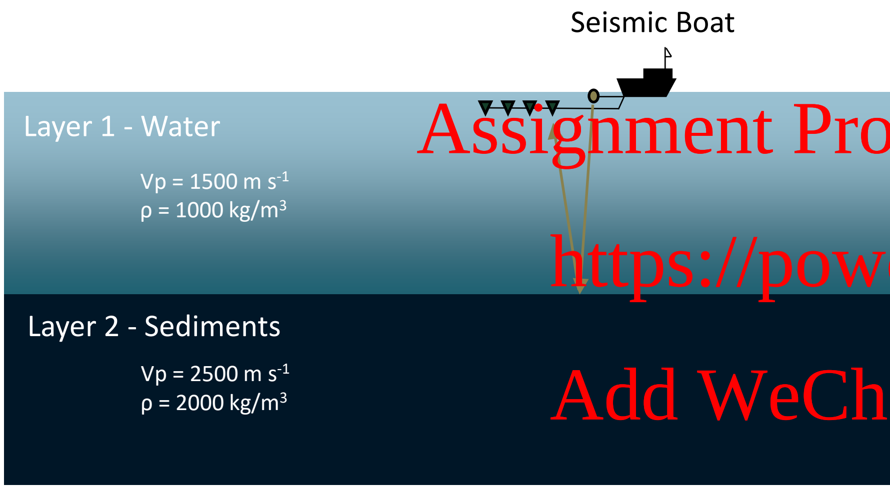
Velocity Range of Rocks



Range of compressional (grey) and shear wave (red) velocities for commonly occurring rocks.

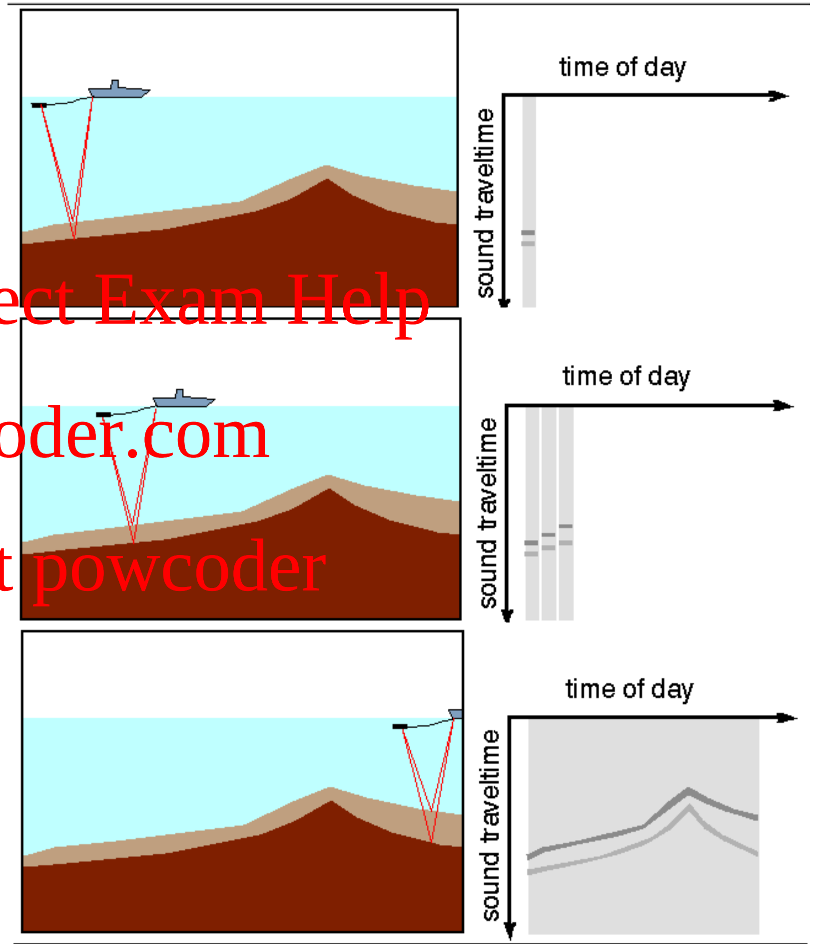
Schön, 2015.

Acoustic impedance vs Reflectivity



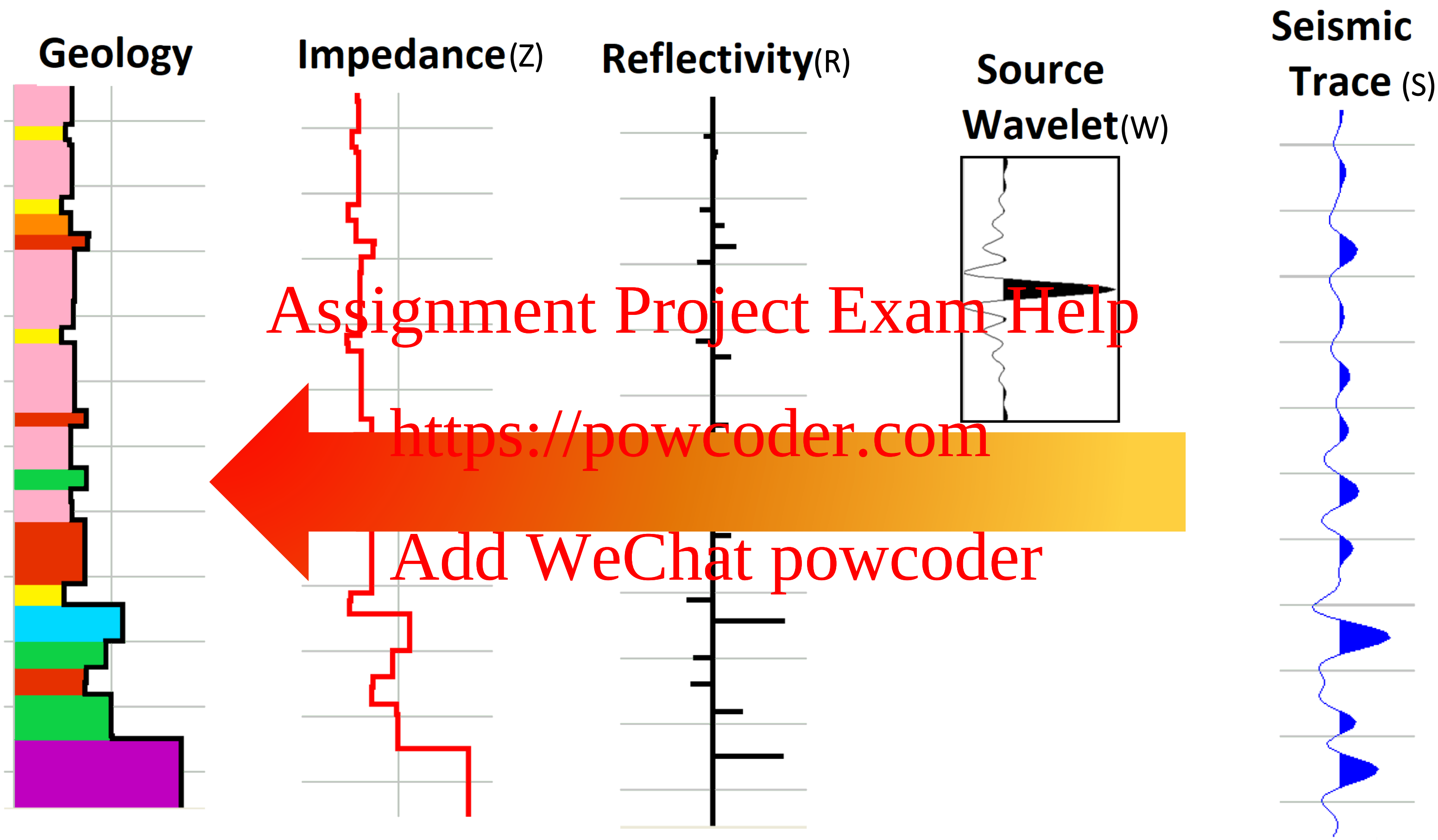
Acoustic impedance $Z = \rho\, v$

Reflectivity $R = Z_2 - Z_1 \,/\, Z_2 + Z_1$



Retrieved from: https://eesc.columbia.edu/courses/ees/lithosphere/labs/sonar/sonar.html, *April 2020*

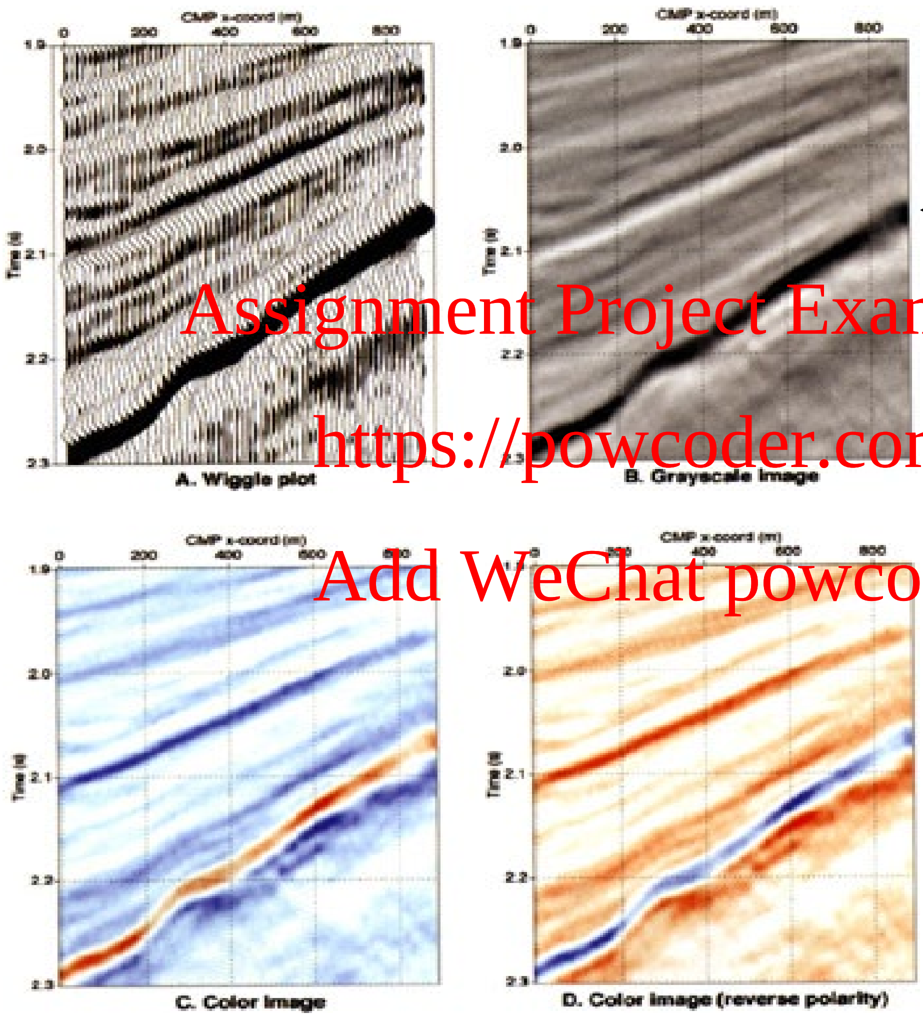
Geology to Seismic



$Z = \rho v$ $\quad R_i = Z_{i+1} - Z_i / Z_{i+1} + Z_i$ $\quad S = W * R + \text{Noise}$

Reproduced from CGG Veritas,
Hampson Russel Software, 2020.

How to plot seismic data?



‘Bright Spot’ Reflection

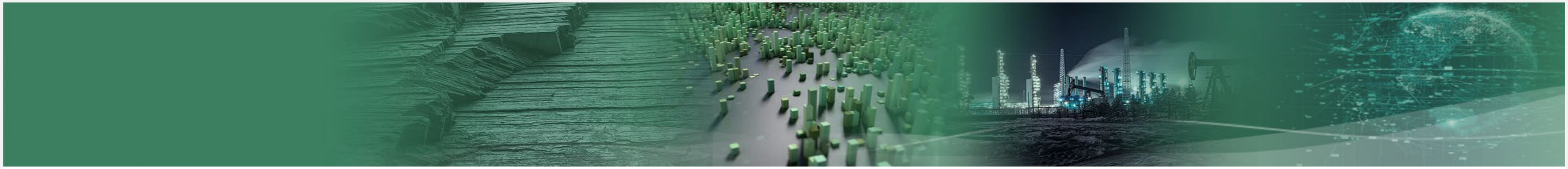
Big change in acoustic impedance

($\mathbf{Z} = \boldsymbol{\rho v}$)

Retrieved from: https://www.globalspec.com/reference/60325/203279/part-iv-color-plates, April 2020

Learning Outcome Check

- Define *acoustic impedance*.
- What property of the hydrocarbon resource is used in seismic exploration?
- Why do sound waves travel at different velocities through rocks? Which type of wave has a higher velocity through a given rock?
- In which types of rocks do we typically find our hydrocarbon resources?
- What is Snell's Law? Write it down and explain what the terms mean, in your own words. How is it used in seismic exploration?
- Use a seismic plot to identify the hydrocarbon resource.
- What is the difference in between ***acoustic impedance*** and ***reflectivity?***



How do we find hydrocarbon resources?

Fluid Properties – Oil and Gas Traps

Example Fluid Density and Compressional Wave Velocity (Gardner et al., 1974, Schön, 2015)

Fluid	Density (g/cm^3)	Vp (m/s)
Water	1	1500
Sea Water	1.025	1500
Crude Oil	0.8-0.85	~1035-1370
Air	~0.001	~260-390
Methane	~0.008	488

Crude Oil and Natural Gas Traps

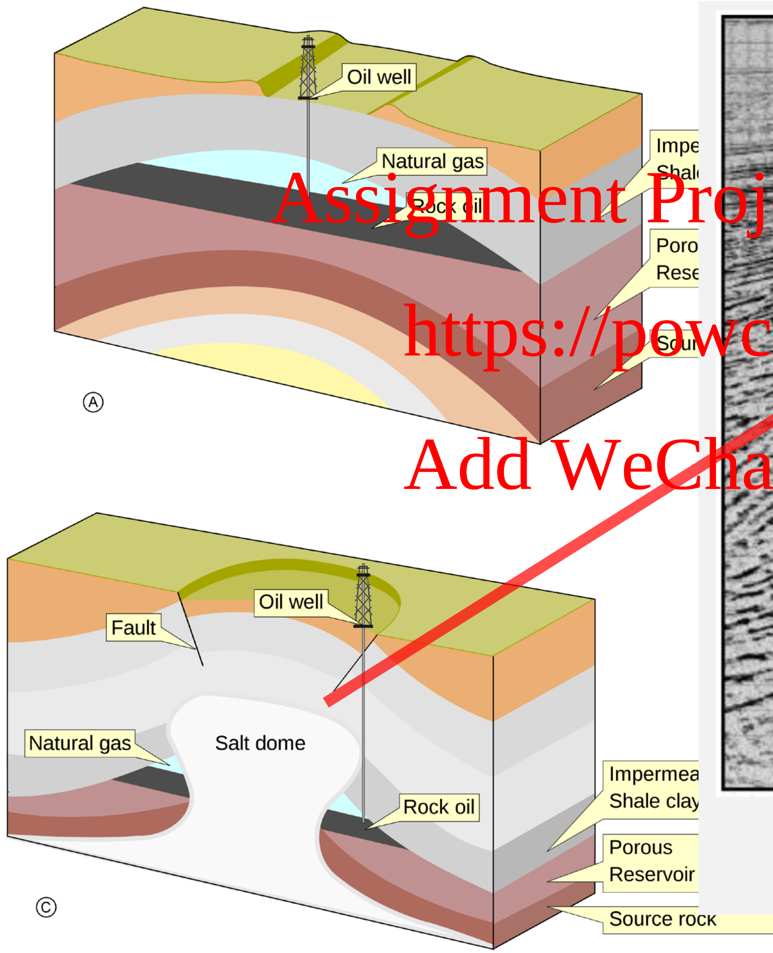


Image reproduced from https://energyeducation.ca /encyclopedia/Oil_and_gas_traps, Aug 2021.

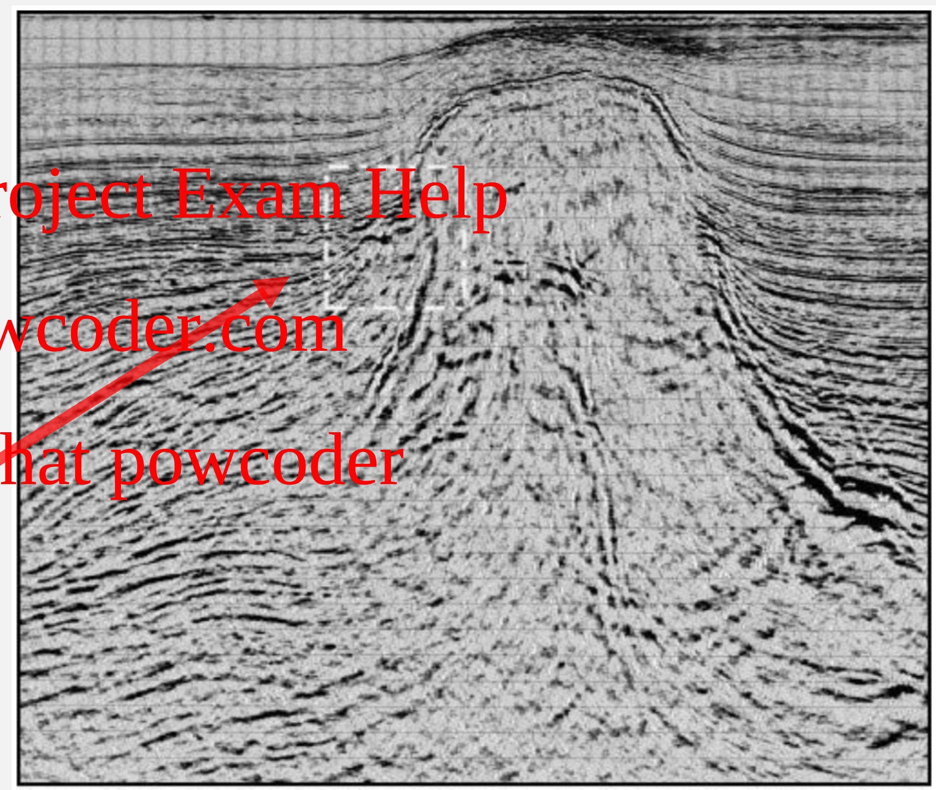


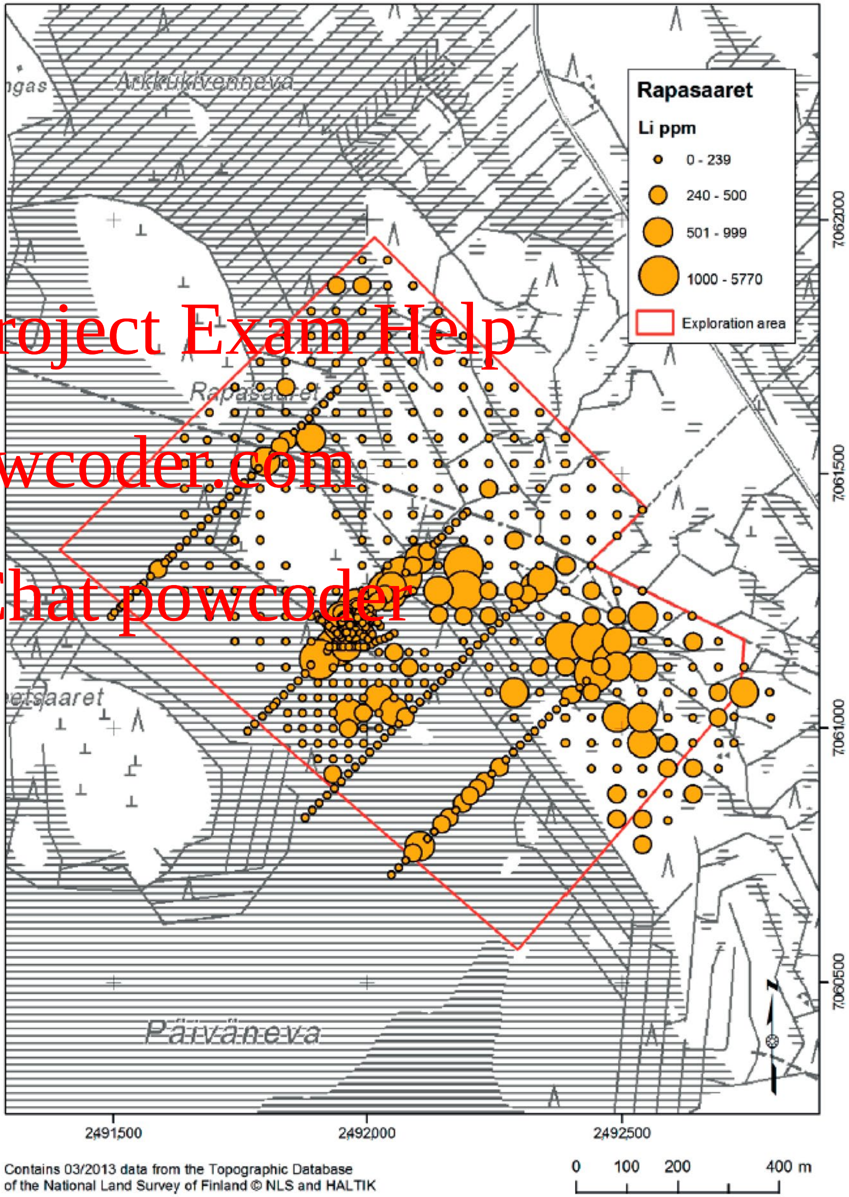
Image retrieved from http://www.glyfac.buffalo.edu/mib /class/325/Lecture/07/0701SeismReflect.pdf, Mar 2021.

Learning Outcome Check

- Explain the following terms in your own words:
  - Fault
  - Trap

- How do we identify rock layers on seismic data?
- How do we identify faults on seismic data?
- How do we identify oil and gas traps on seismic data?

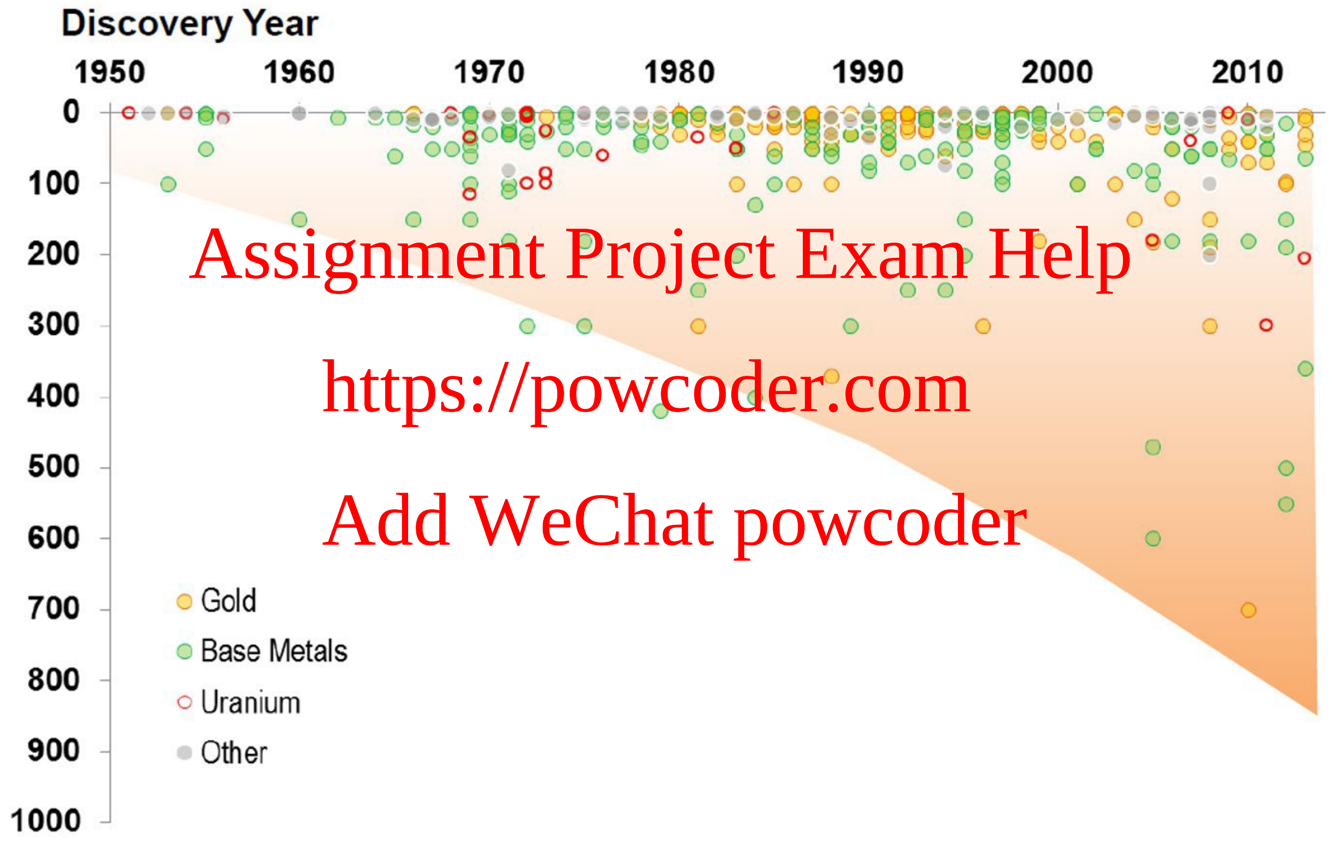
How do we find mineral resources?



Map of the till sampling grid (from Ahtola et al. (2015)) with plotted Li anomalies (in ppm) in the Rapasaaret target area, Kaustinen Li pegmatite province. Steiner, 2019

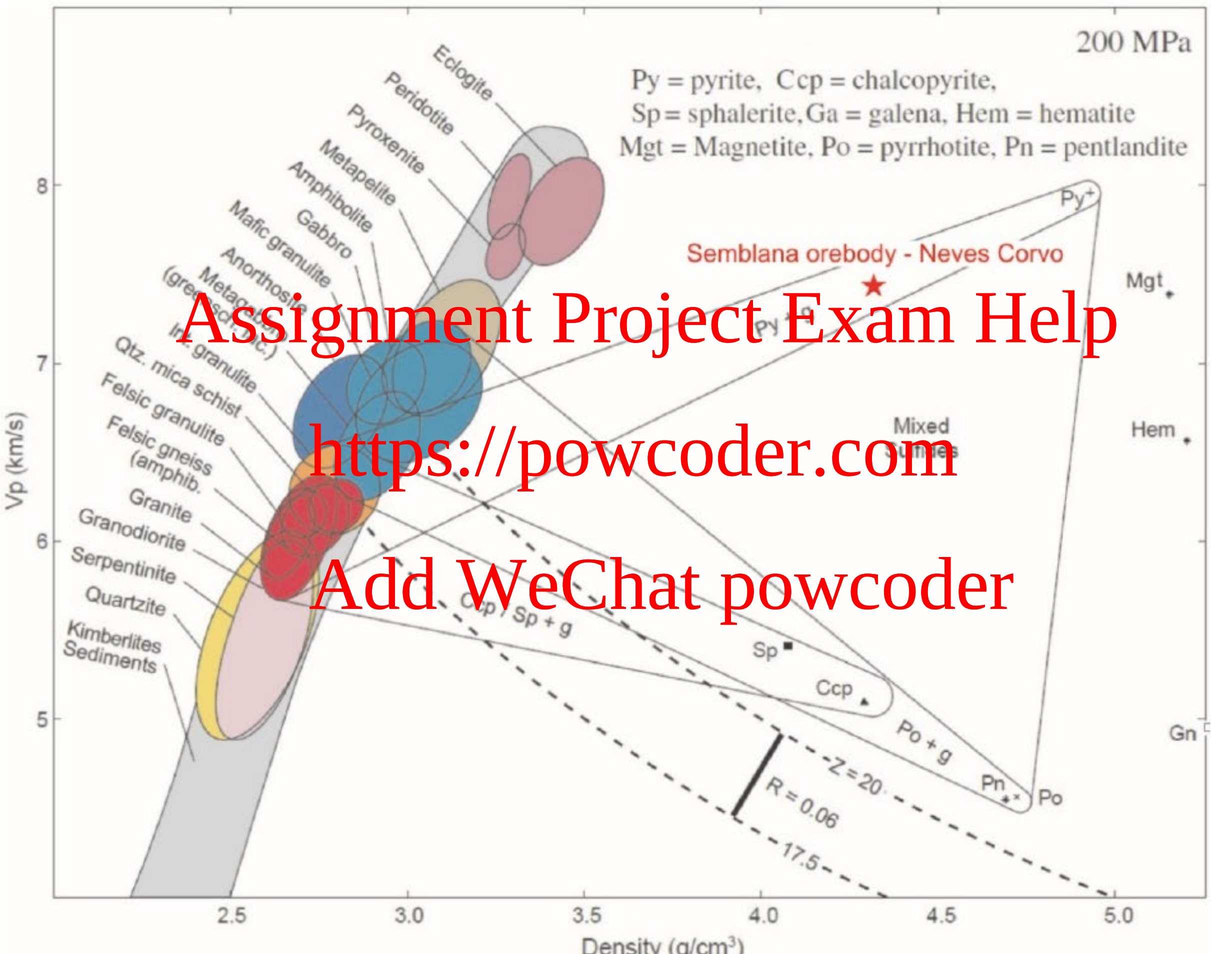
How do we find deep mineral resources?

The depth of cover for discoveries in Australia: 1950 – 2013



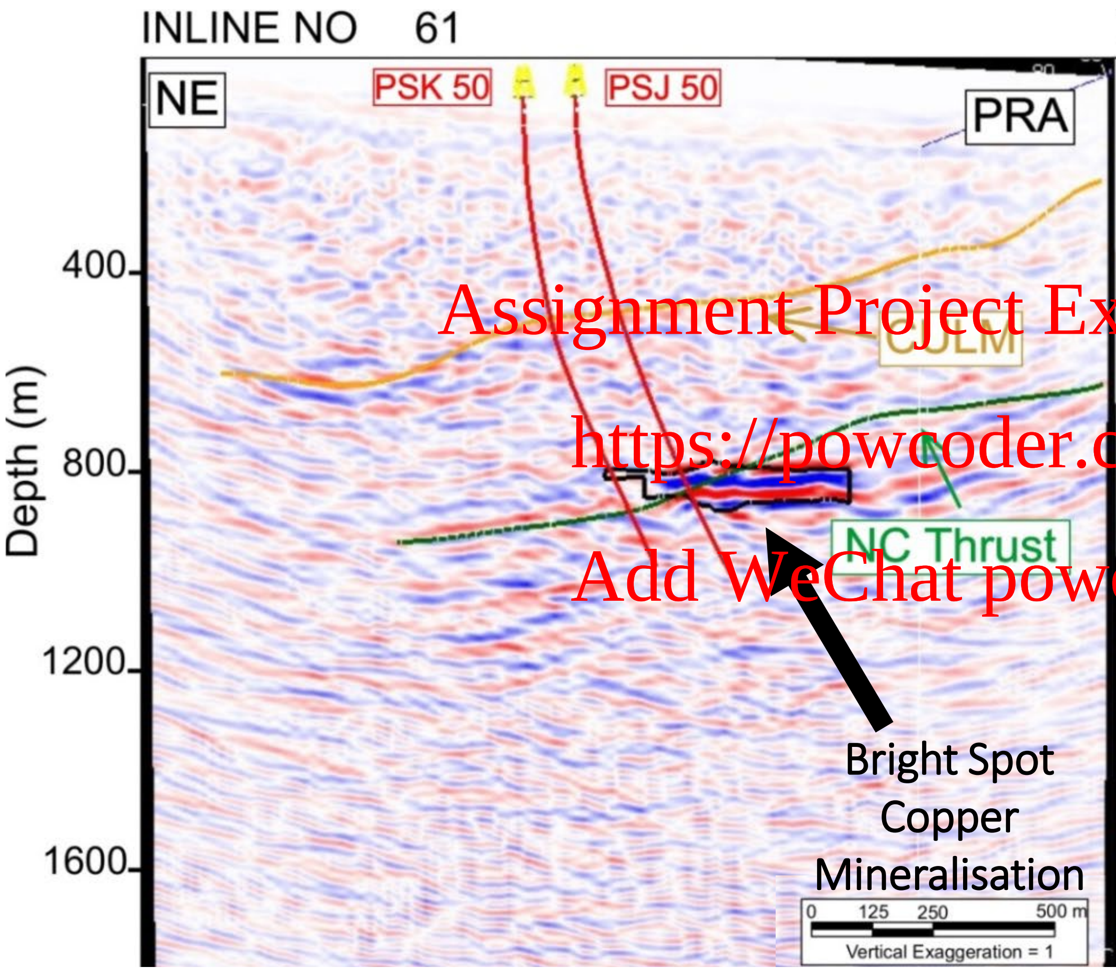
(MinEx Consulting, September 2014)

Direct Targeting of Mineral Resources



Acoustic properties of the most common crystalline rocks and ore mixtures (modified after Salisbury and Snyder 2007). P-wave velocity and density fields are displayed for common rocks on a Nafe-Drake curve (grey) with constant acoustic impedance iso-contours at a standard confining pressure of 200 MPa

Seismic: Copper Deposit



Description

This is **Seismic** imaging depth section shows the Semblana porphyry copper sulfide deposit (2011).

The mineralization is associated with pyrite which has **high density** and **high velocity.** This contrast in acoustic parameters compared with the surrounding rock produces a high amplitude reflection (see arrow).

Semblana copper sulfide mineralization, 2011 (Yavuz, 2015)

Learning Outcome Check

- What is the main exploration technique for exploring mineral resources?
- What makes seismic favourable in searching for deep mineral targets?
- How do we identify mineral targets on seismic data?

and ..

Curtin University

Carbon Capture and Storage (CCS)

Retrieved from CO2CRC, http://www.co2crc.com.au/whats-ccs-2/, Jan 2020.

Lecture Summary

The Physical Properties of the Earth

Electrical
- Conductivity
- Electrical Permittivity
- Magnetic Permeability

Elastic
- Velocity (P and S wave)
- Density

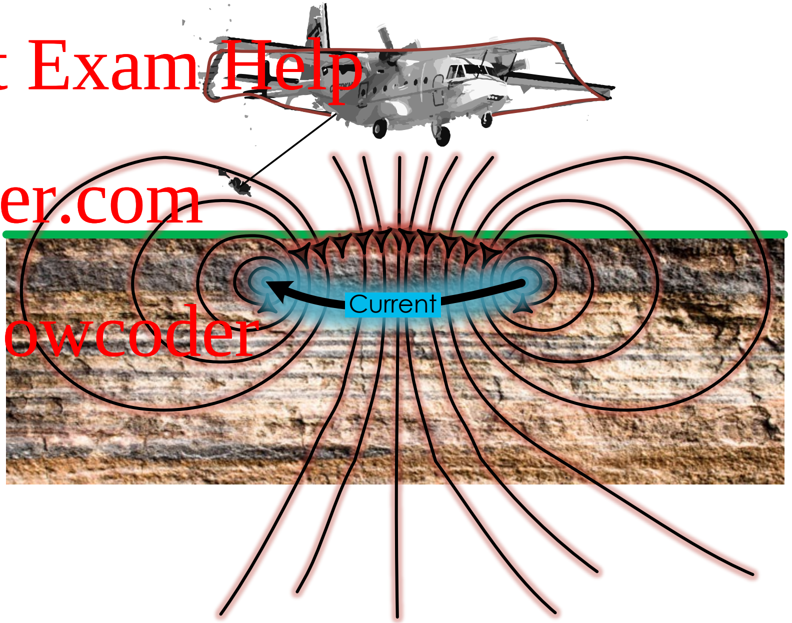
Magnetic
- Magnetic Susceptibility

Radioactivity
- U^{238} / Th^{232} / K^{40}
- Spectral

And more…
- Chargeability
- Porosity
- Temperature
- Hydraulic Permeability
- Tortuosity
- etc…

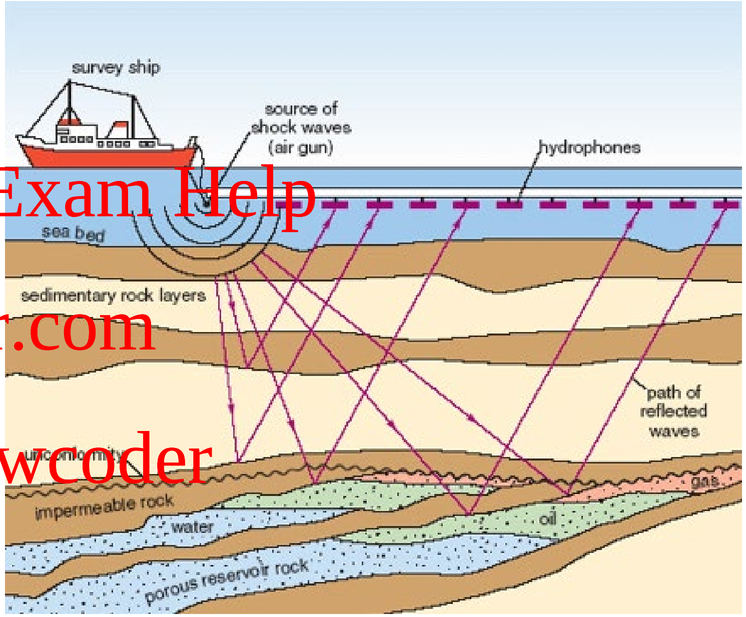
Lecture Summary: Mineral and Water Resources

- Each mineral and hydrogeological target has a **geological / mineralogical** (Iron Ore, Gold, Copper, Base metals and Water) setting
- Each target may have a unique **Rock Property** distribution (i.e., conductivity and magnetic susceptibility)
- We apply methods including **Magnetics** (magnetic susceptivity), **Electromagnetics** (electrical conductivity), **Seismic Exploration** (velocity and density) and **Gravity** (density) to resolve subsurface rock properties
- In magnetics we acquire data with a **magnetometer** and in electromagnetics we acquire data with **transmitting and receiving coils.**



Lecture Summary: Hydrocarbon Resources

- **Hydrocarbon Resources**; **natural gas, crude oil**, and **coal**
- Hydrocarbon Resources are found in **sediments – oil and gas traps, coal seams**
- Main method is **seismic exploration**, and the main physical property is acoustic impedance (**velocity** and **density**)
- The physics behind seismic exploration; **Snell's Law** and **Wave Propagation**
- How we acquire seismic data? **Seismic Sources and receivers**
- We can even explore **deep mineral resources** using seismic exploration.



Retrieved from https://www.petropedia.com/seismic-mapping-technology-that-has-changed-the-oil-production-mapping/2/9874, Aug 2020.

Lecture Summary

Overall, mineral, water and hydrocarbon resources are discovered by imaging physical rock properties using geophysical techniques.