Near-Surface-Geophysics

Ground Penetrating Radar

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Introduction

Basics

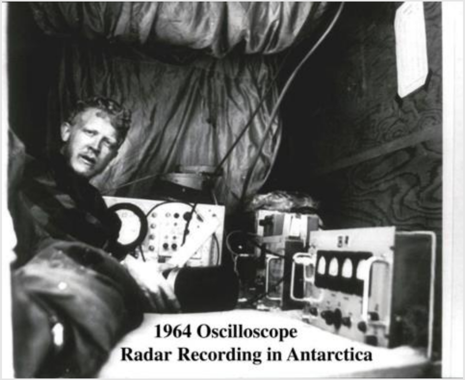
- GPR is a geophysical measurement technique which can be applied to explore near-surface underground structures.
- The measurement principle is based on the transmittance (transmitting antenna) of high-frequency (50MHz – 2.5 GHz) electromagnetic pulses into the ground. Reflection or Refraction at inhomogeneities are received (receiving antenna).
- Travel time and amplitude give information about the structure and depth of the inhomogeneities.

Introduction

Applications

- **Geological**
  - Detection of cavities and fissures
  - Mapping of superficial deposits, subsidence, soil stratigraphy, fractures, etc.
  - Mineral exploration and resource evaluation
  - (Paleo-) Lake and riverbed mapping
- **Environmental**
  - Contaminant plume mapping
  - Location of gas leaks
  - Groundwater-level
  - Mapping of pollutants within groundwater
- **Glaciological**
  - Ice thickness and snow stratigraphy

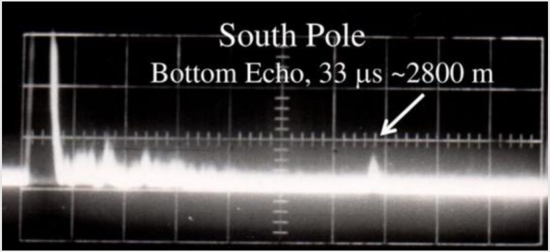
Applications

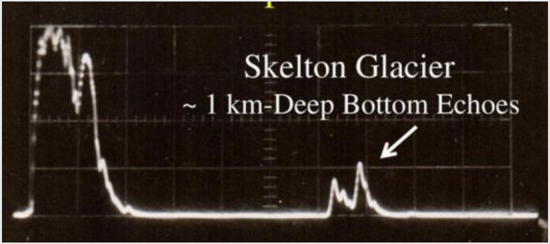


Radio Sounding Skelton Glacier 1964

Introduction

Applications





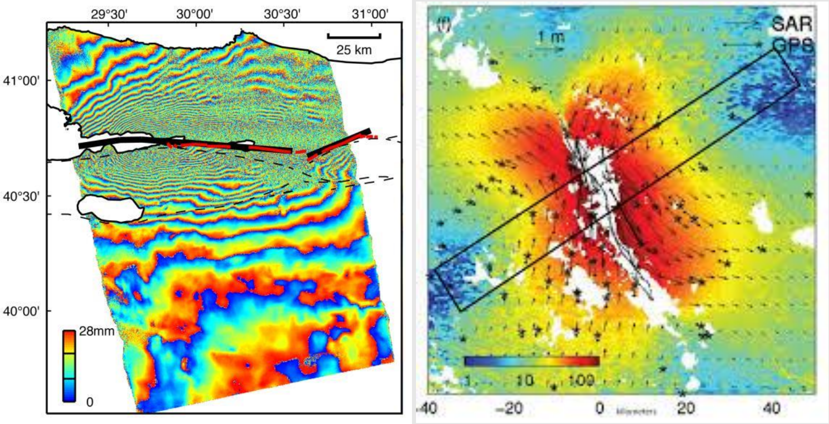
Introduction

Applications

- **Engineering and construction**
  - Void detection
  - Road pavement
  - Concrete testing
  - Location of public utilities
- **Archaeology**
  - Location of buried structures
  - Pre-excavation mapping
  - Location of graves, crypts, etc.
- **Forensic science**
  - Location of buried corpses

Introduction

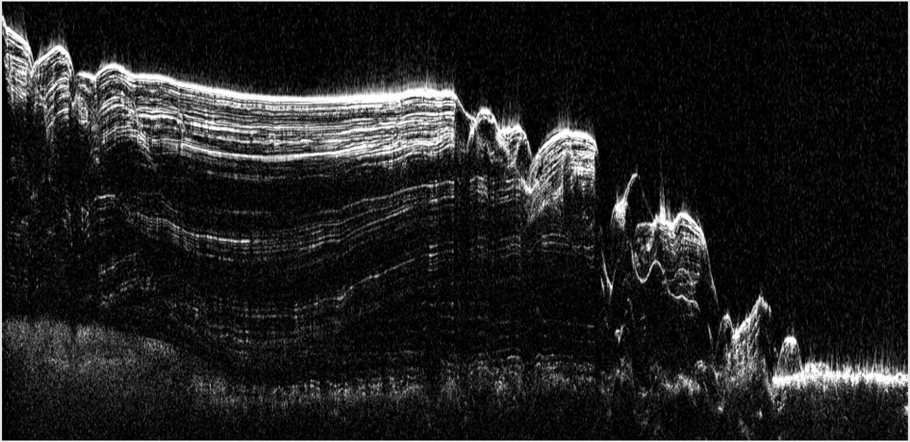
Interferometric synthetic aperture radar - InSAR



Interferogram produced using ERS-2 data from 13 August and 17 September 1999, spanning the 17 August Izmit (Turkey) earthquake. (NASA/JPL-Caltech)

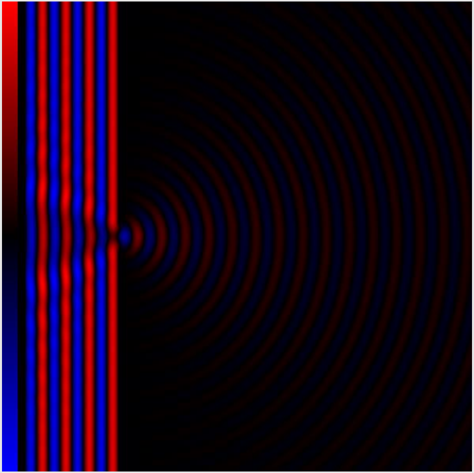
Introduction

Shallow radar sounder - SHARAD



Radargram of north pole layered deposits (ASI, Mars Reconnaissance Orbiter)

Diffraction



Diffraction of a scalar wave passing through a 1-wavelength-wide slit (Wikipedia)

Basic Terms

Propagation of electromagnetic waves

- **The emitted electromagnetic waves are affected by**
  - •Dielectric properties ε_r
  - •Magnetic susceptibility μ_r
  - •Electrical conductivity σ_e

- **Reflection coefficient**
  - •Describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium.
  - •Of a plane (fraction of the reflected energy at the plane for normal inclination is:

$$R = \frac{v_1 - v_2}{v_1 + v_2} = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$

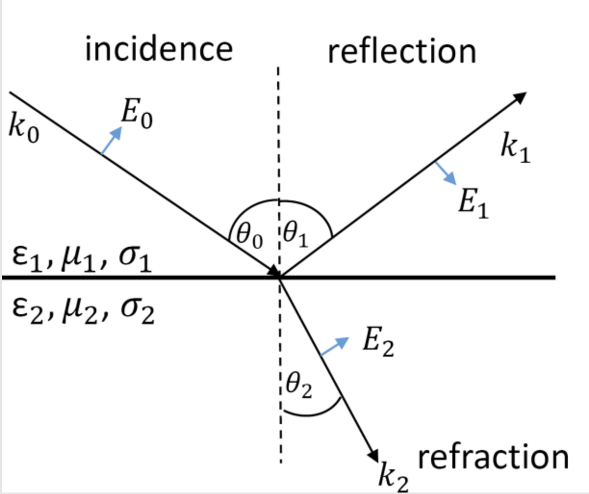
Propagation of electromagnetic waves

Material	ε_r
Air	1
Ice	3
Dry Sand	5
Granite	6
Dry Salt	6
Limestone	8
Shale	15

Material	ε_r
Saturated Sand	25
Silts	30
Clays	40
Fresh Water	80
Sea Water	80
Metal	∞

Table from Telford 1990 Applied Geophysics

Propagation of electromagnetic waves



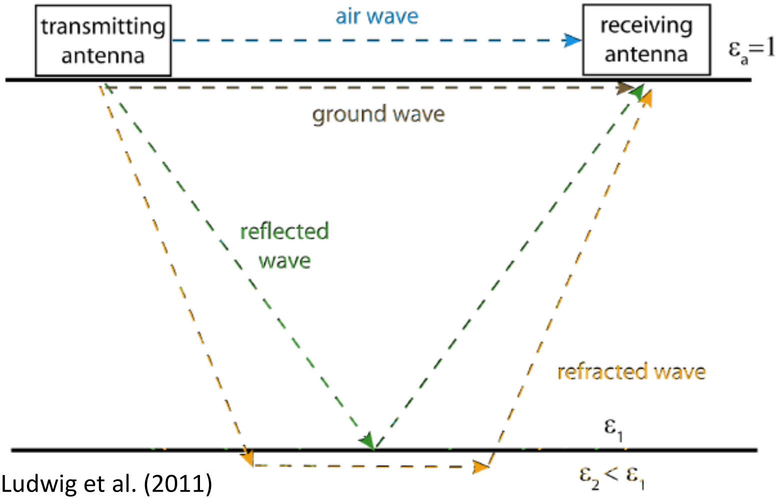
Basic Terms

Measurement principle

- The standard system consist of a transmitting and receiving antenna. The radar wave propagates through the soil while the velocity of the wave depends on the dielectric properties of the ground. At interfaces, where the dielectric properties of the different media change, the electromagnetic wave is partially reflected. The travel time and amplitude of the wave is recorded by the receiving antenna.

Basic Terms

Measurement principle



Ludwig et al. (2011)

Basic Terms

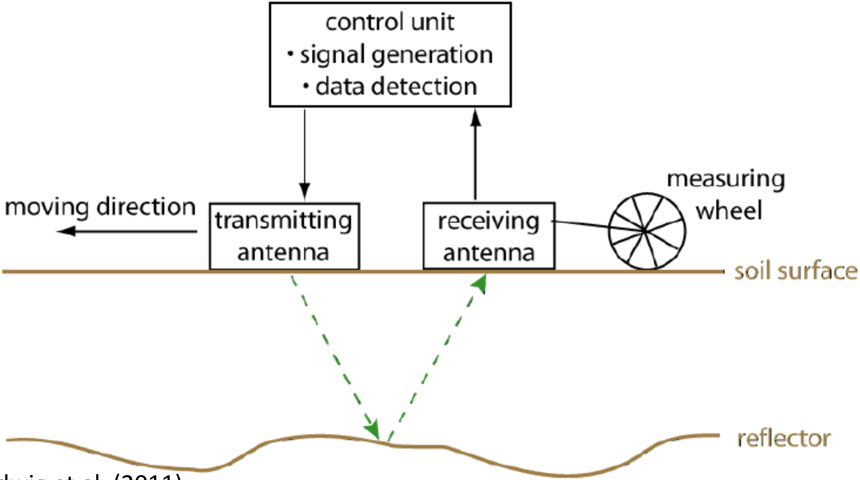
Measurement principle

- In a standard GPR measurement, the antennas are pulled along the survey track while traces are triggered at a fixed interval by a measurement wheel which is connected to the back of the antenna. This results in a series of traces which are finally displayed by the measurement software as a function of position and time in a so-called radargram.

- The sampling interval and the antenna frequency has to follow the Nyquist-Shannon sampling theorem:
- $f_{Nyq} = \frac{1}{2\Delta t} > fmax\ (fmax\ is \sim antenna\ frequency + 50\%)$

Basic Terms

Measurement principle

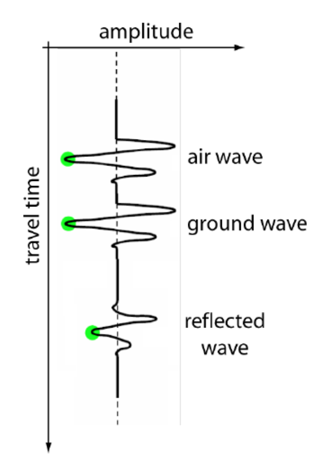


Ludwig et al. (2011)

Basic Terms

Measurement principle

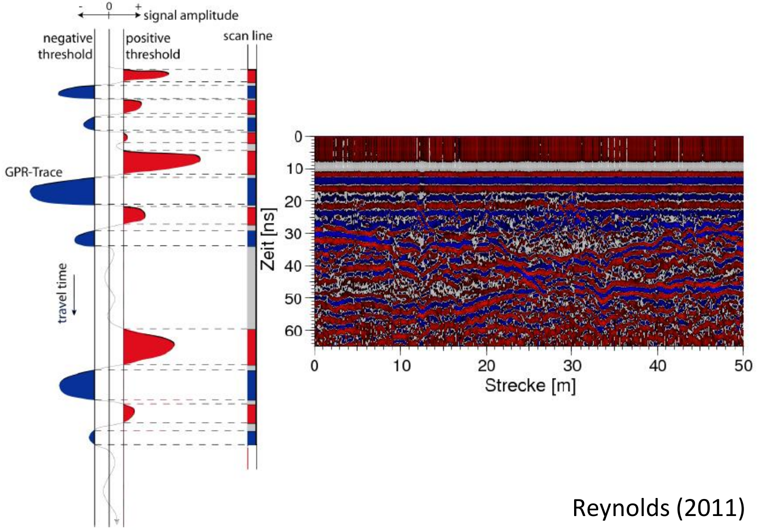
- The signals of the emitted waves reach the receiving antenna at different times. Plotting the recorded amplitudes as a function of time results in a so-called “trace”.



Ludwig et al. (2011)

Basic Terms

Measurement principle



Reynolds (2011)

Survey Layout

Common offset (CO)

- Is the simplest and most widespread GPR measurement technique. Transmitter and receiver antenna are moved along the survey track while the distance between both antenna is kept constant. Electromagnetic pulses are emitted at equidistant intervals which are controlled by the survey wheel.
- From the measured travel time *t* of the reflected signal the depth *d* of a horizontal reflector can be determined by:

$$s = 2 \cdot \sqrt{d^2 + \left(\frac{a}{2}\right)^2} = \sqrt{4d^2 + a^2}$$

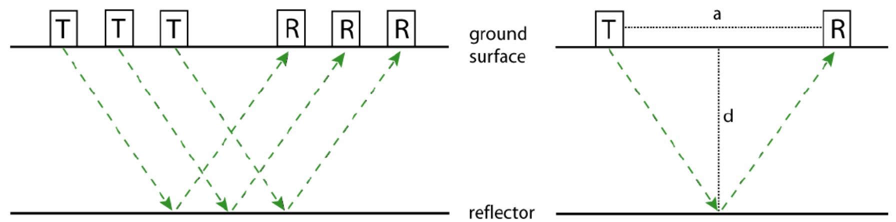
with a as distance between antennas.

- Assuming a homogeneous medium the travel time is determined by:

$$t = \frac{s}{v} = \frac{\sqrt{4d^2 + a^2}}{\frac{c}{\sqrt{\varepsilon}}}$$

Survey Layout

Common offset (CO)



Ludwig et al. (2011)

Survey Layout

Multi offset: Common midpoint

- In a common-midpoint measurement (CMP) transmitter and receiver are moved away from each other in equidistant steps. The resulting radargram displays the travel time as a function of the antenna separation.

Survey Layout

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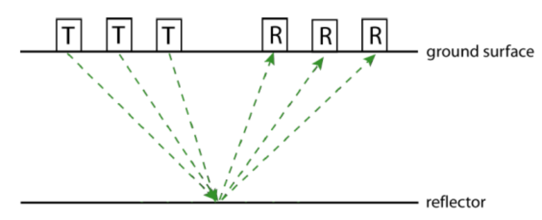
Multi offset: Common midpoint



Survey Layout

Multi offset: Common midpoint

- Air and ground wave travel directly between the antenna.
- Linear relationship between the travel time t and the antenna separation a with the constant of proportionality $\frac{1}{v}$:

$$t = \frac{a}{v}, \text{with } v = c \text{ (airwave) and } v = \frac{c}{\sqrt{\varepsilon}} \text{ (groundwave)}$$

- Reflector depth below the midpoint between the transmitting and the receiving antenna: the relation between travel time t reflector depth is given by:

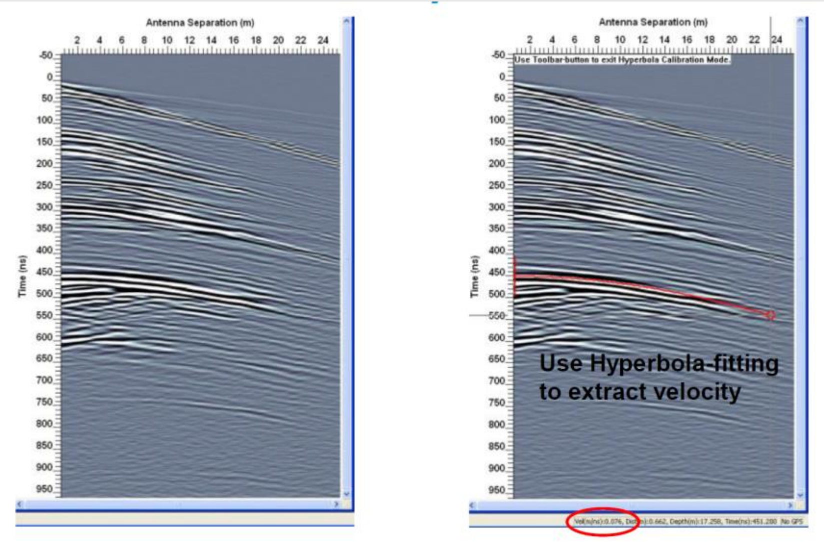
$$s = 2 \cdot \sqrt{d^2 + \left(\frac{a}{2}\right)^2} = \sqrt{4d^2 + a^2}$$

- Plotting the measured data in a t^2-a^2-diagram, leads to a linear relationship between t and a:

$$t^2 = \frac{1}{v^2} a^2 + \frac{4h^2}{v^2}$$

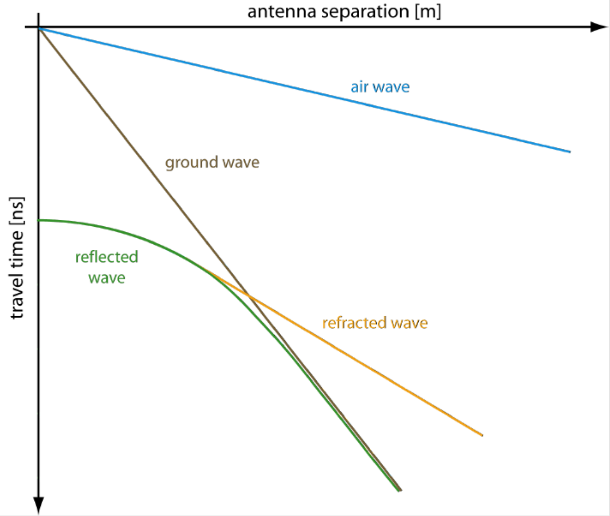
Survey Layout

Multi offset: Common midpoint



Survey Layout

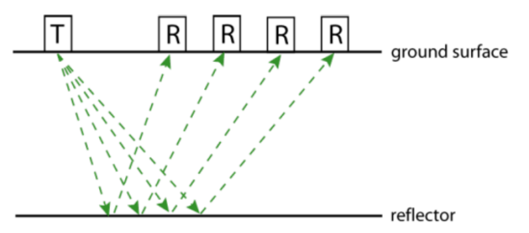
Multi offset: Common midpoint



Survey Layout

Multi offset: Wide Angle Reflection and Refraction (WARR)

- Only the transmitting or receiving antenna is moved along the measurement line while the other antenna stays stationary.
- In principle, a WARR measurement follows the same relationships concerning travel time as a CMP measurement. The difference is that the reflection point moves along the reflector. This is why a WARR measurement strictly is only applicable in the presence of horizontal or slightly sloping reflectors and material properties are homogeneous.



- CMP and WARR measurements provide more information than a CO measurement. The drawback of these techniques is the high measurement effort since both procedures only provide point information for a specific location. Both method are hardly applicable along long measurement lines

Survey Layout

Field example

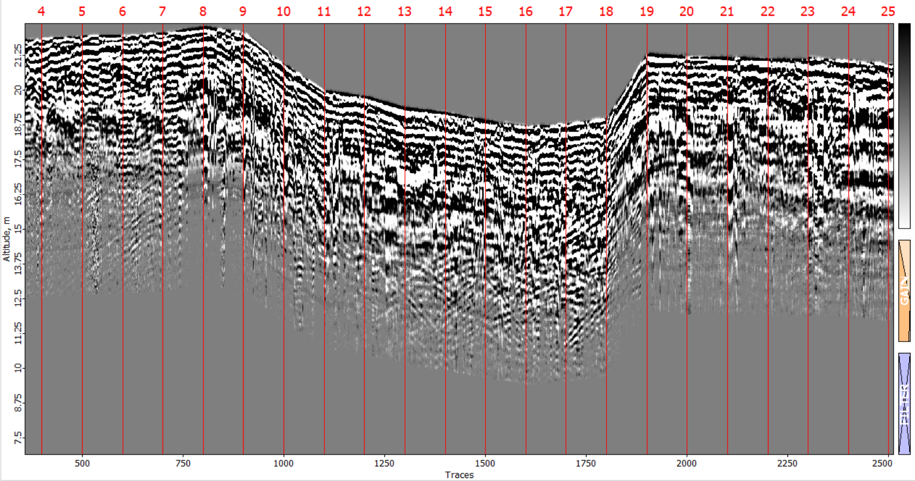
Fieldwork with ZOND 100 and 300 MHz antennas

Survey Layout

Field example

Survey Layout

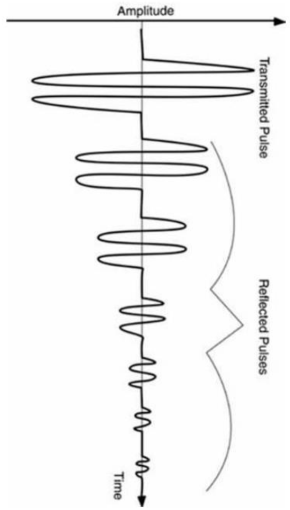
Field example



Radargram Kaali Crater, Estonia

Signal Processing

Energy loss and Penetration



1) Signal Attenuation (absorption)

2) Signal scattering

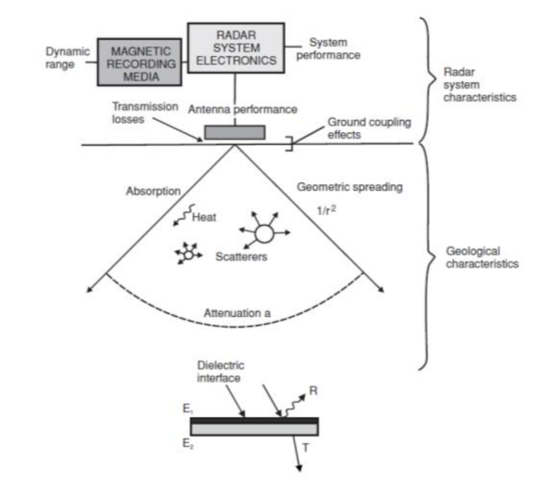
3) Spherical Spreading

Reynolds, (2011)

Signal Processing

Energy loss and Penetration

- The electromagnetic signal is attenuated by different processes on its way through the soil.



Reynolds, (2011)

Energy loss and Penetration

- The largest amount of energy loss results from damping of free charge carrier movement. The material dependent attenuation is induced by the direct current electric conductivity σ_{dc} of the investigated medium. Depending on the traveled distance x the amplitude E of the electromagnetic wave decreases exponential with respect to its starting value E_0:

$$E(x) = E_0 \mathrm{e}^{-\beta x}, \qquad with\ \beta = \frac{\sigma_{dC}}{2c_0\varepsilon_0\sqrt{\varepsilon}}$$

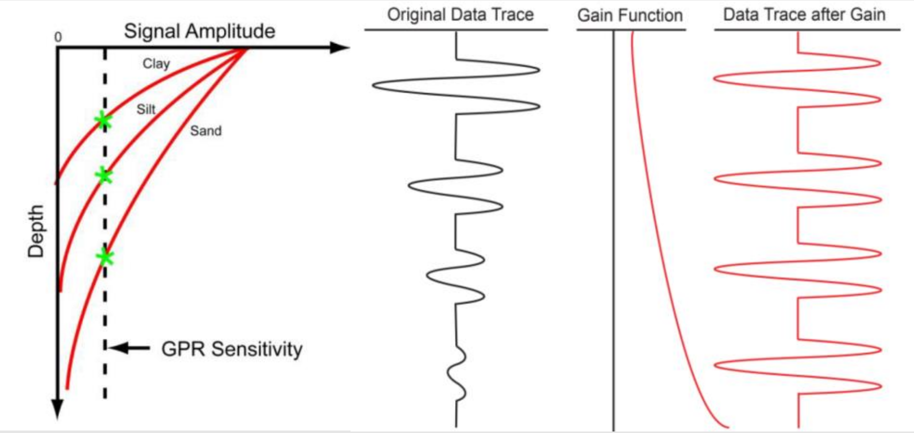
- The higher σ_{dc} of the medium, the higher is the attenuation of the electromagnetic wave. In soils, electrical conductivity for example increases due to an increasing in soil moisture content, clay content or amount of dissolved solutes in the solution.

- The penetration depth of the electromagnetic waves reduces with increasing electrical conductivity of the medium. For salt water the penetration depth is only 1cm:

$$\delta = \frac{1}{\beta}$$

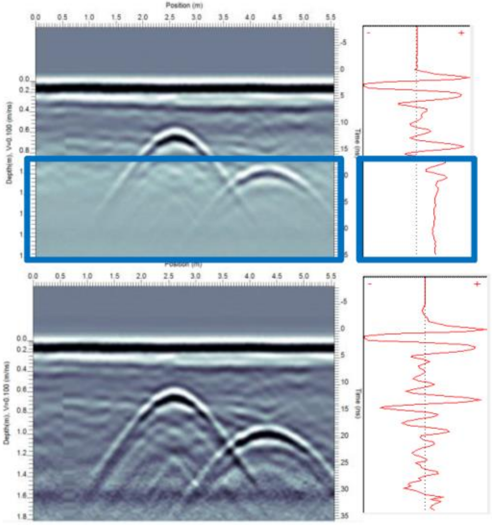
Signal Processing

Energy loss and Penetration



Signal Processing

DEWOW

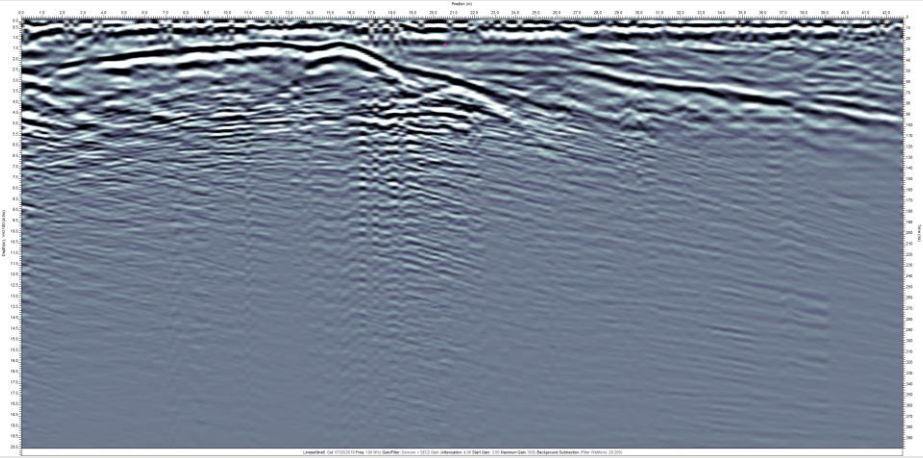


Trace and Data Section with WOW

Trace and Data Section after applying DEWOW filter

Interpretation

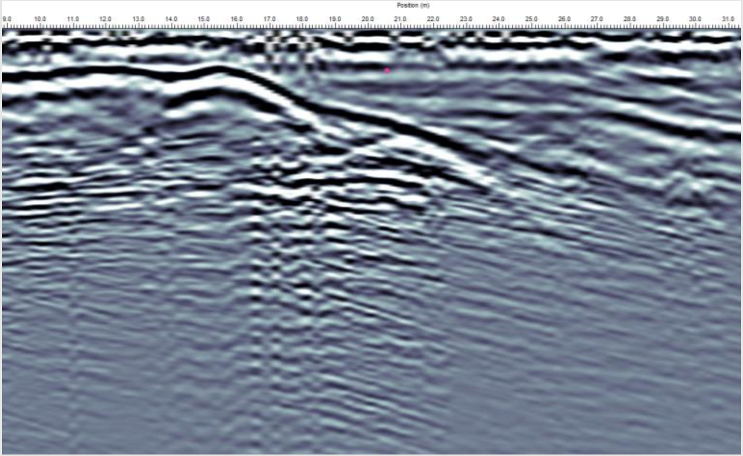
Pitfalls



100 MHz; time window: 400 ns; common offset profile; length: 59 m; DEWOW + Gain (attenuation = 4); v = 115 mm/s

Interpretation

Pitfalls



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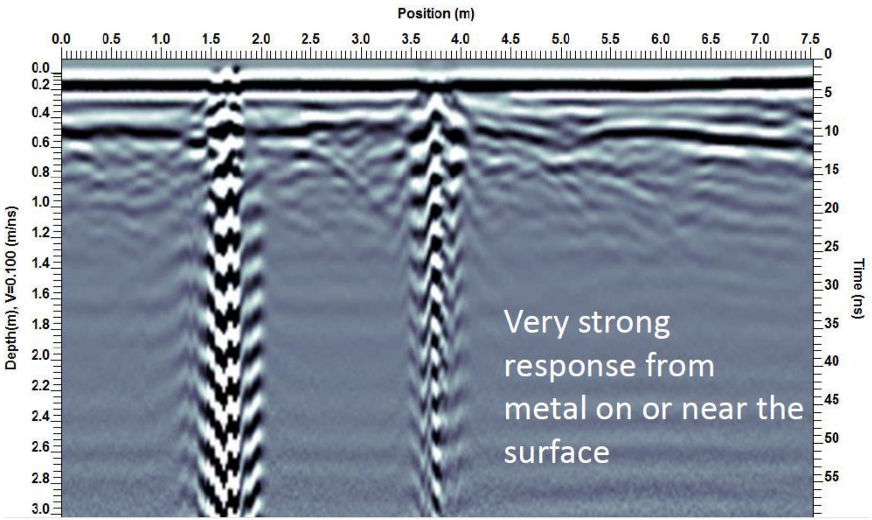
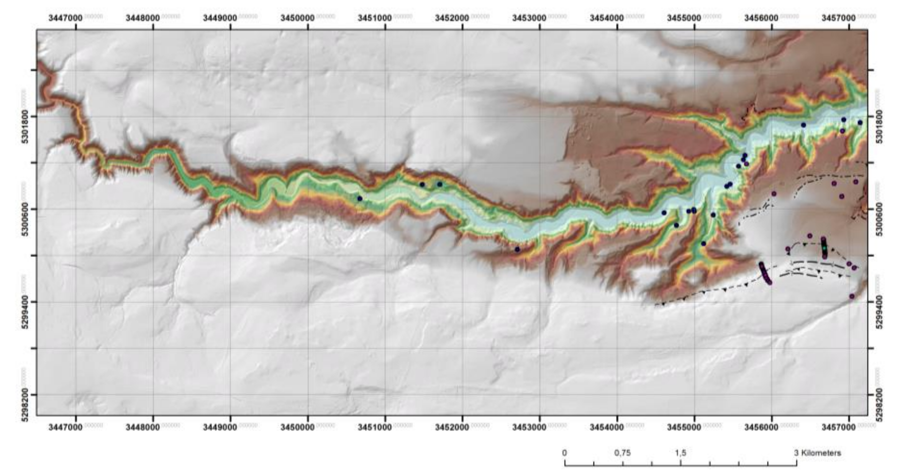


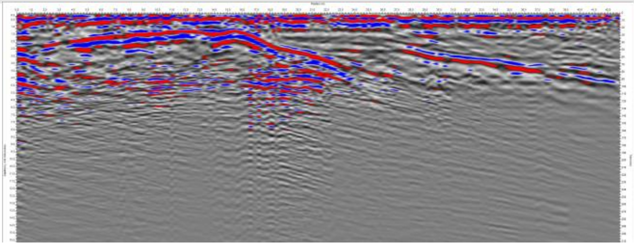
Interpretation

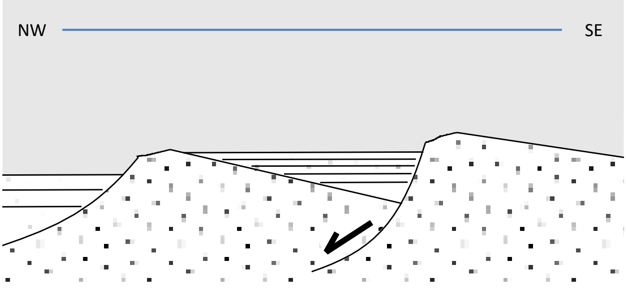
Fieldexample



Interpretation

Field example

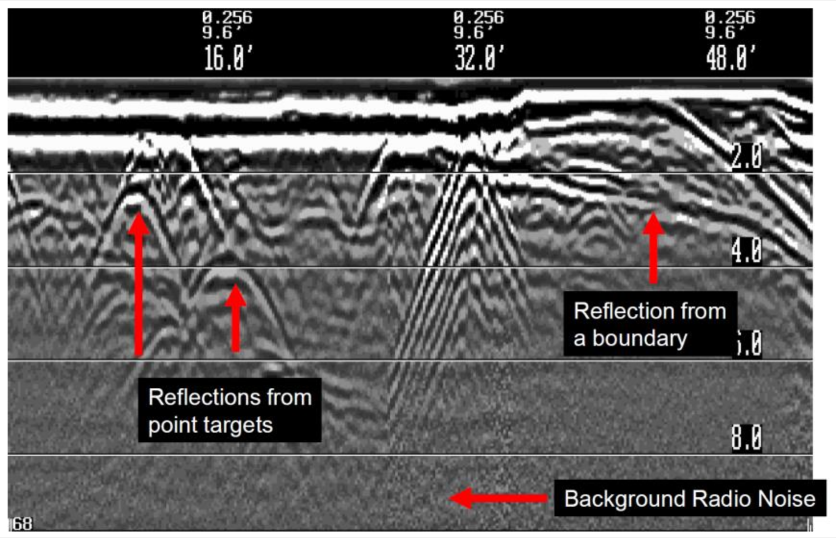




view NE - from upper to lower terrace

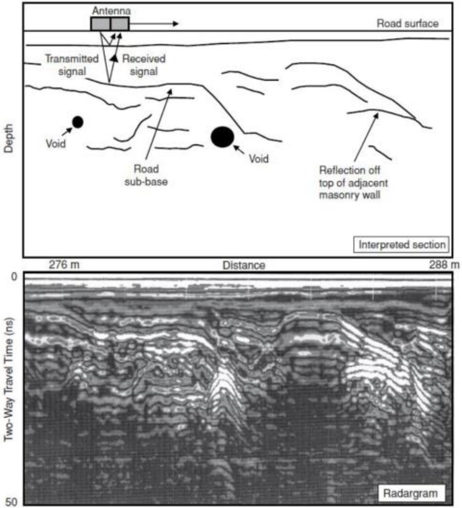
Interpretation

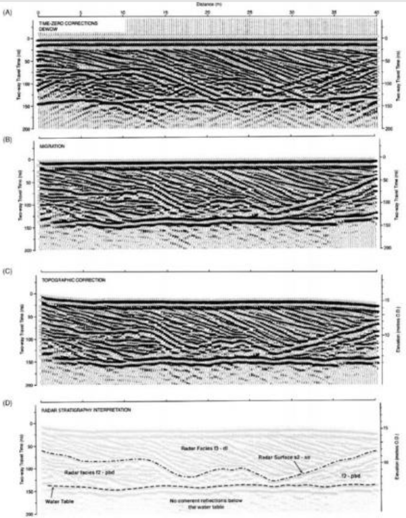
Field example



Interpretation

Field example





Reynolds, (2011)