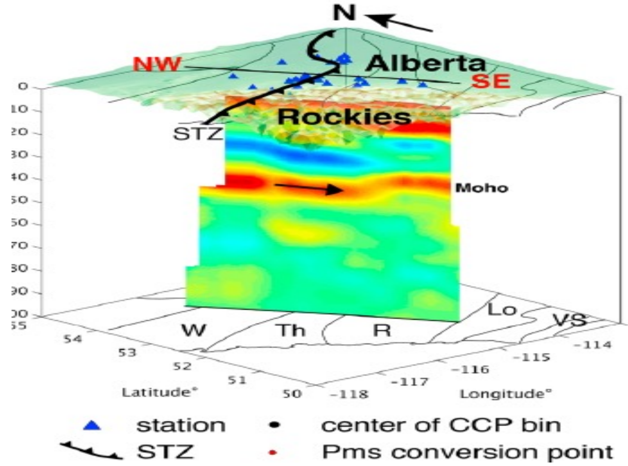
GEOPH 438/538: Seismic Data Processing

Jeff Gu

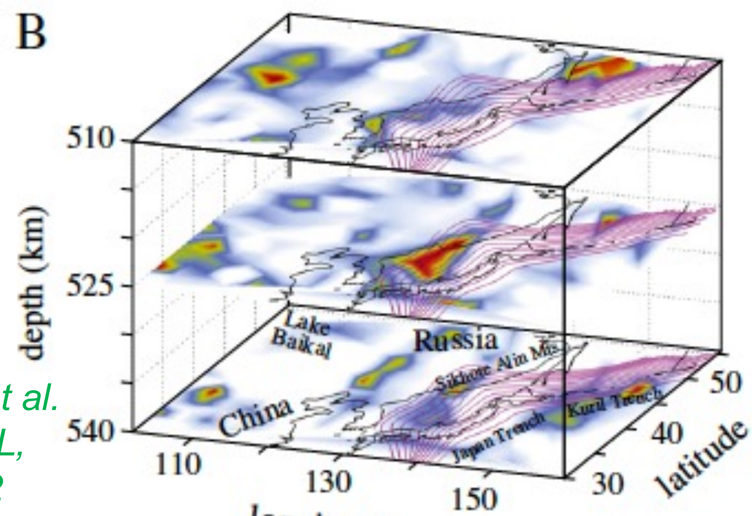
University of Alberta, Canada

Special thanks to: Mirko van der Baan, Jingchuan Wang
Songyun Huang

Crustal Structure



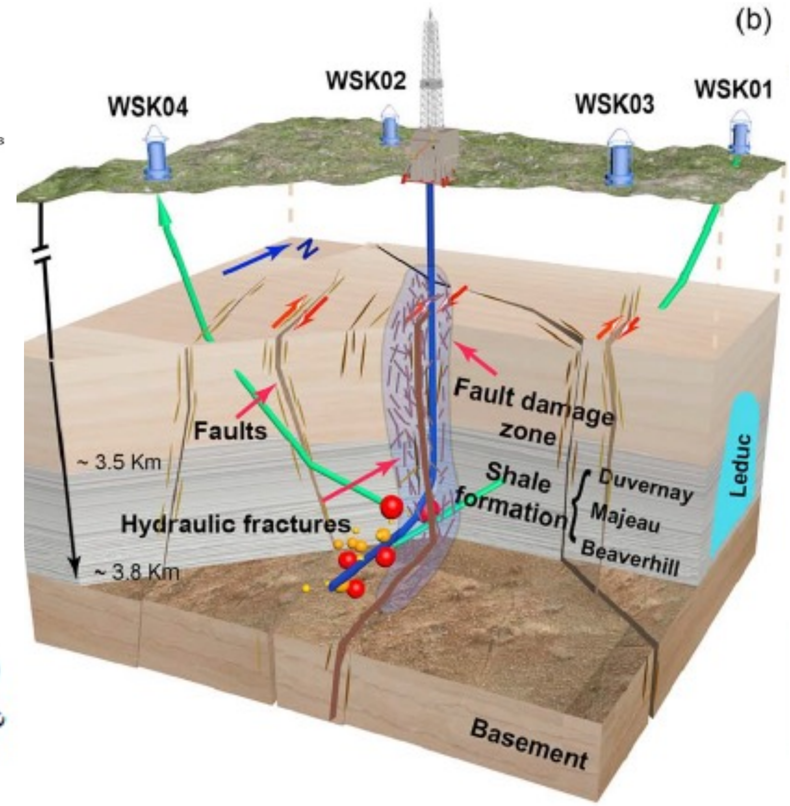
Gu et al., Tectonics, 2018



Gu et al. EPSL, 2012

Mantle structure

Natural + Induced Earthquakes



Li, Gu et al.,GRL, 2019

*Regional & global crustal seismology
*Natural and induced earthquakes
*Computations, ultrasound imaging

Has taught:

Physics 144, 234
Geoph 224, 421, 426, 499, 624

X

Geoph 438/538

- Instructor: jeff Gu
  - Office: CCIS building, room 3-107
  - Office hours: Tue, Wed 10:00-11:30
    - email to arrange for other times

- TA:
  - None

Course notes and assignments

- Accessible via course webpage

https://www.ualberta.ca/~ygu/courses/geoph438/index.html

- Upon further instructions, some may be posted on eclass
  - https://eclass.srv.ualberta.ca/

Course goals

- Be able to write software for performing a variety of common data processing tasks
- Analyze and display geophysical data
- Communicate concepts in data processing via written reports with adequate justification for chosen parameter choices

Learning Outcomes

- Develop critical skills in report writing and data analysis
- Familiarity with Matlab for coding and a commercial package for seismic data processing
- Be able to transform theoretical knowledge such as equations into a working software program to read, display and process geophysical data
- Be aware that choices at the beginning of a processing sequence can have profound consequences on data quality in later stages
- Use critical thinking and self-defined criteria for evaluating processing outcomes.

Course assessment

- The course is assessed via
  - Four lab assignments:
    - Some Excel-based calculations
    - Many computer-based using
      - programming exercises in Matlab (4x)
      - Some exercises on commercial processing software (Vista)
  - Give a presentation

- **All assignments are to be done individually**

- **Plagiarism: a can of worms!**

More on Graded Components

The dates are the best estimates, exceptions may occur.

Lab Assignments	WEIGHTING	APPROX. DUE DATE
Attendance/participation	6%	
Lab Assignment #1	20%	Friday Jan 31*
Lab Assignment #2	20%	Tues Feb 18*
Lab Assignment #3	20%	Tues March 18*
Lab Assignment #4	20%	Tues April 8*
Final Presentation	14%	TBD**

538-- each homework assignment requires a small 12 min presentation of your results. The focus and requirements will be specified in the lab assignment handouts. The total weight is 5% (i.e., if 20% is the total weight of an assignment, then 15% will be given to the submitted assignment).

Recommended literature

- Data processing:
  - Yilmaz O. (1987) Seismic data processing: SEG. **(in library)**

  - **Free** E-book: https://library.ualberta.ca/catalog/8297271
  - Choose the university login option, enter University of Alberta in the search option. Then when found, enter CCID and password. The access link to the book will be displayed. Click the link.

  - It's definitely worth browsing through chapter 1

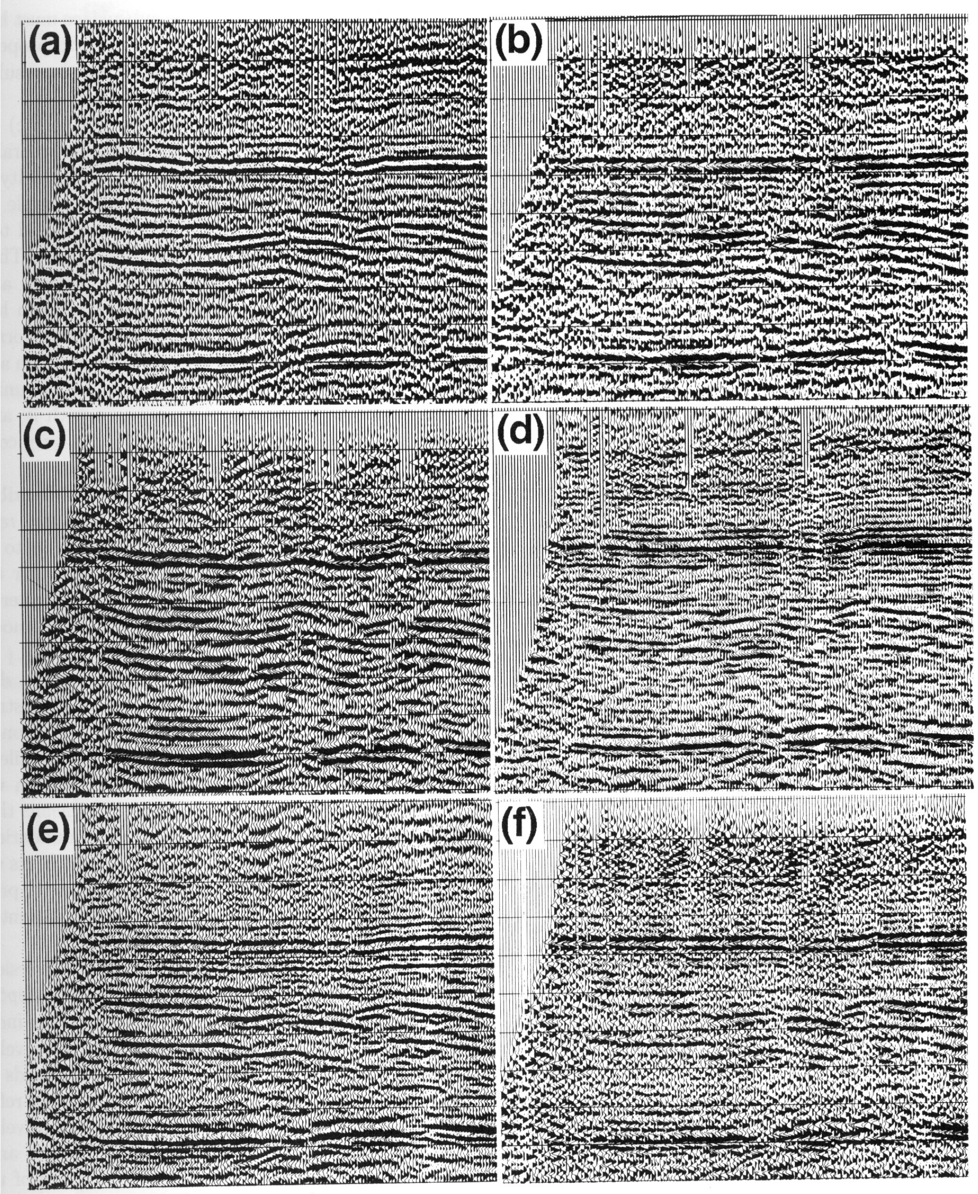
Introduction

This course is data-driven

Type 1: Seismic

- Different processing companies can produce different results …

- Not always clear who is right!



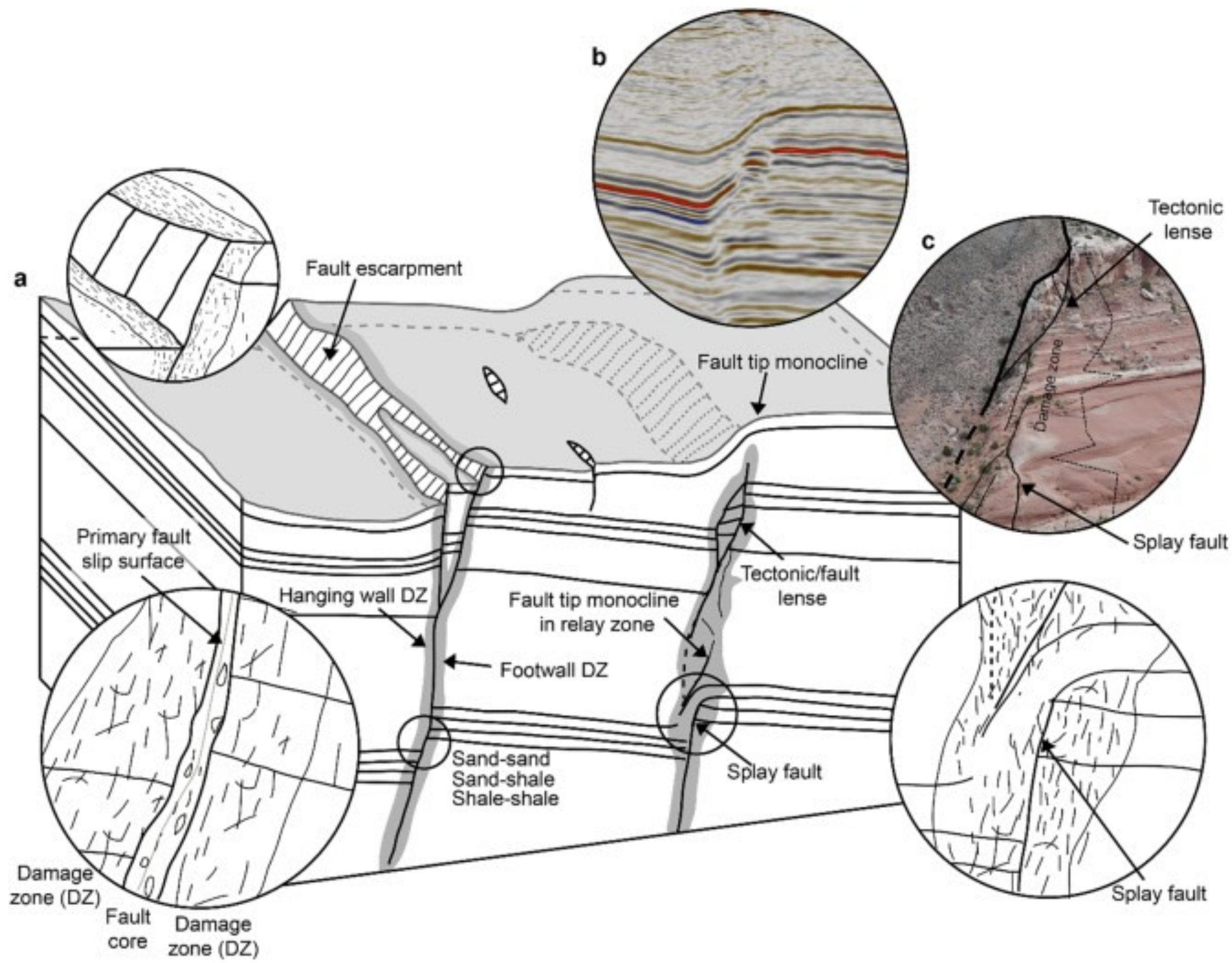
I-12. A seismic line processed by six different contractors. (Data courtesy British Petroleum Development, Ltd.; ss Exploration Ltd.; Clyde Petroleum Plc.; Goal Petroleum Plc.; Premier Consolidated Oilfields Plc.; and Tricentrol Oil oration Ltd.)

Yilmaz (1987)

Type 1: Seismic

Seismic Sections

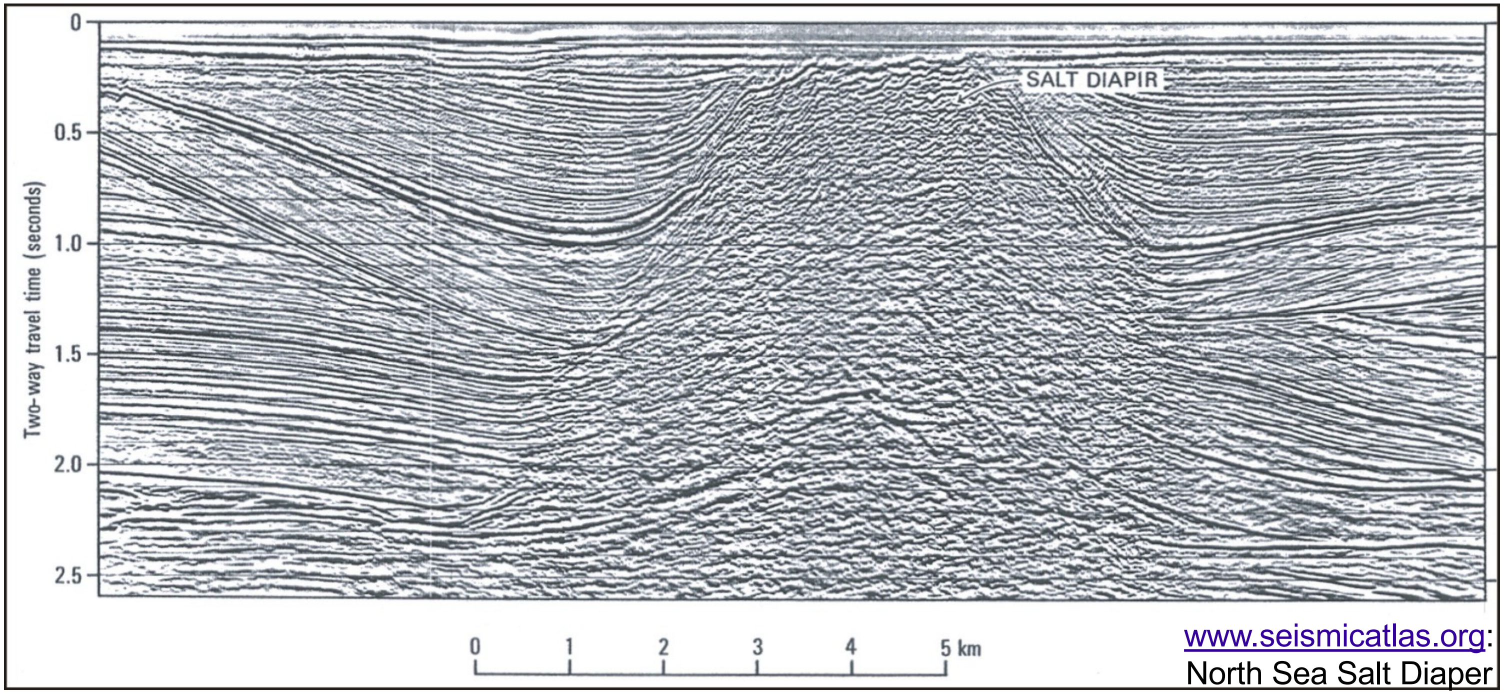
Sample section of a normal fault



GOAL OF DATA PROCESSING

- Ultimate objective: Final sections reveal subsurface geology
- How to get there: refine the data sets, emphasize the essential features (in this case, salt diapir), remove noises

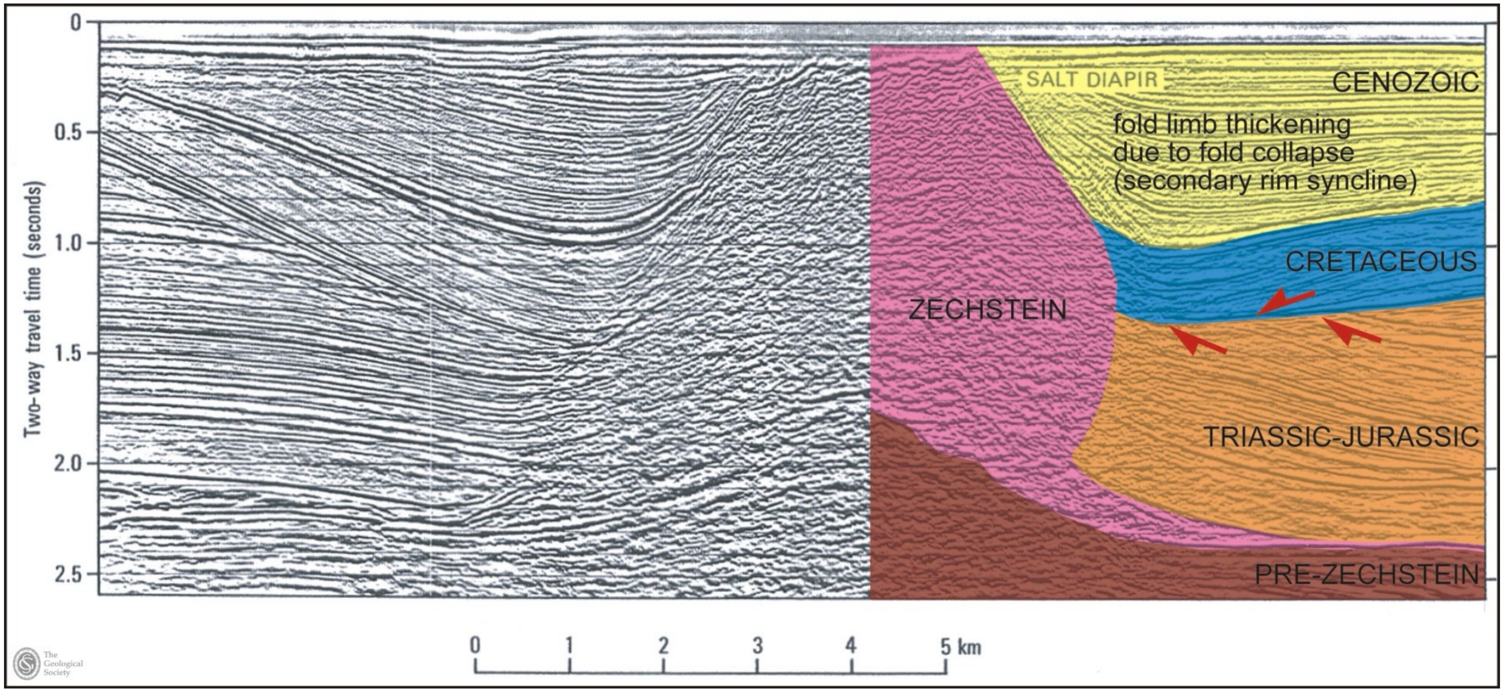
Below is a seismic section



www.seismicatlas.org: North Sea Salt Diaper

Introduction

- Ultimate objective: Then, after all these processing steps, interpret the subsurface geology

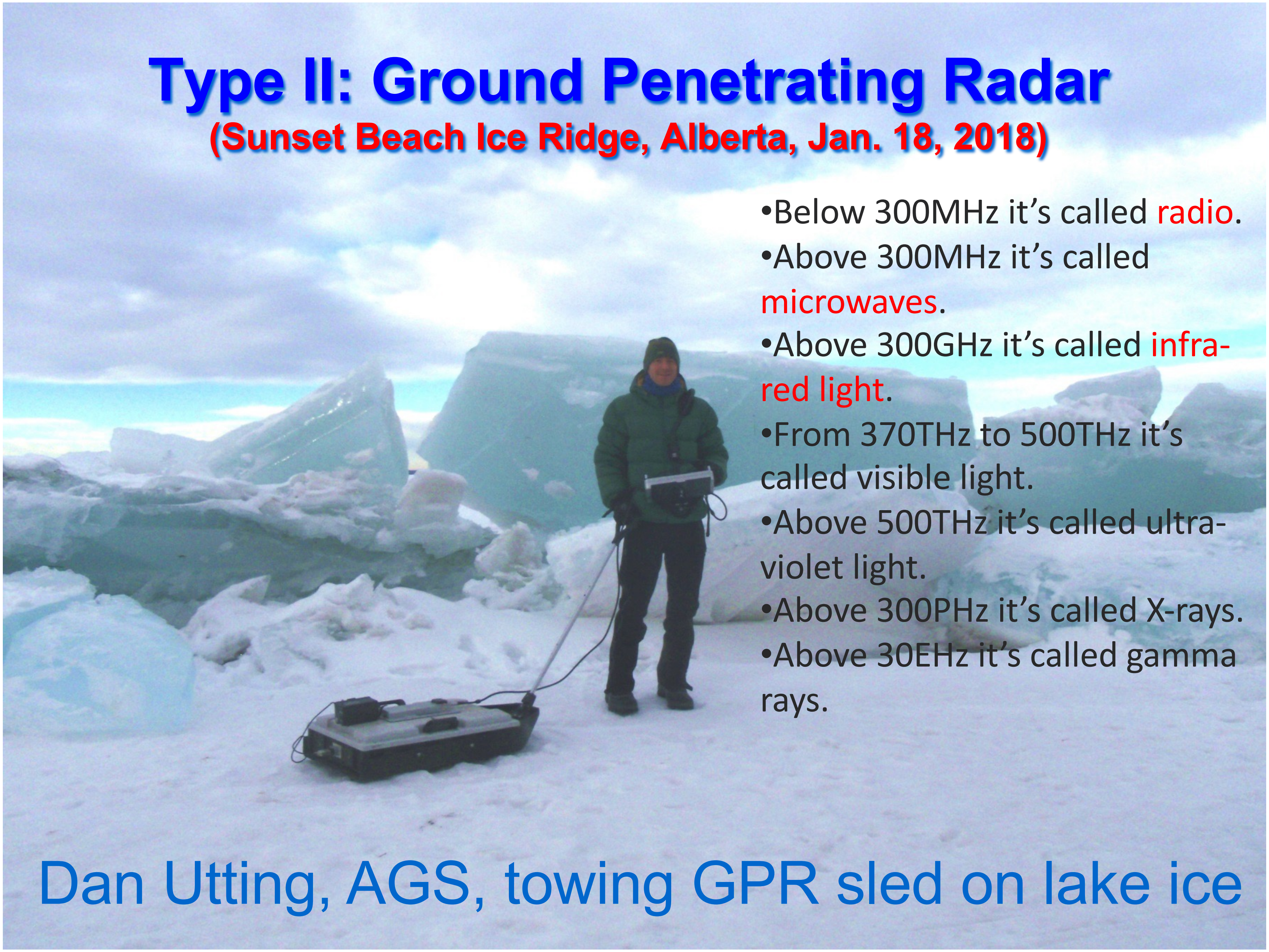


Zechstein: Permian aged sedimentary rock (Europe)

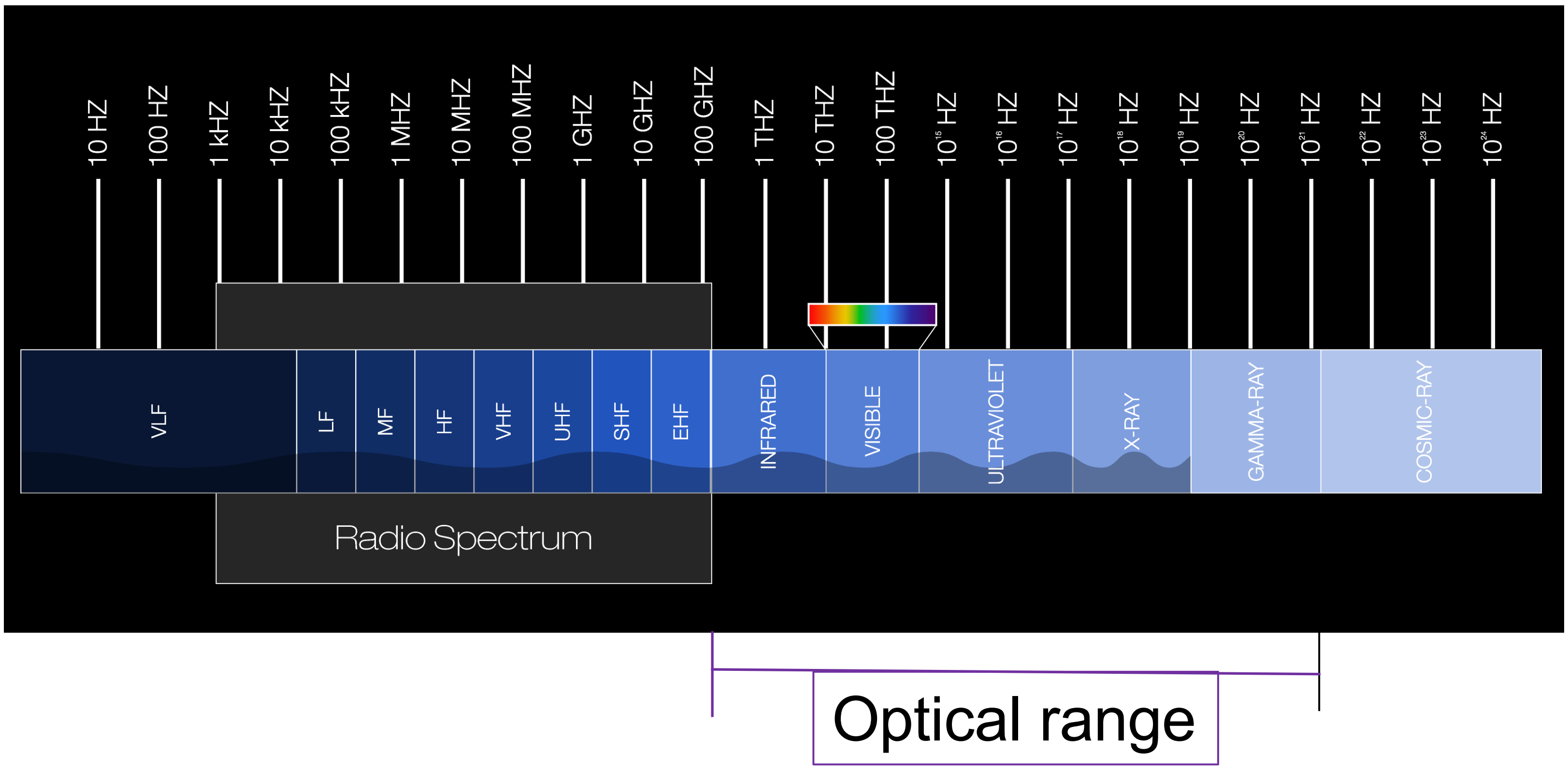
www.seismicatlas.org:
North Sea Salt Diaper

Zechstein Reef

Coral reef 250 millions years old, evaporite (salt) exploration


Type II: Ground Penetrating Radar
(Sunset Beach Ice Ridge, Alberta, Jan. 18, 2018)
•Below 300MHz it's called radio.
•Above 300MHz it's called microwaves.
•Above 300GHz it's called infra-red light.
•From 370THz to 500THz it's called visible light.
•Above 500THz it's called ultra-violet light.
•Above 300PHz it's called X-rays.
•Above 30EHz it's called gamma rays.
Dan Utting, AGS, towing GPR sled on lake ice

Frequency



https://www.nasa.gov/directorates/somd/space-communications-navigation-program/radio-vs-optical-spectrum/

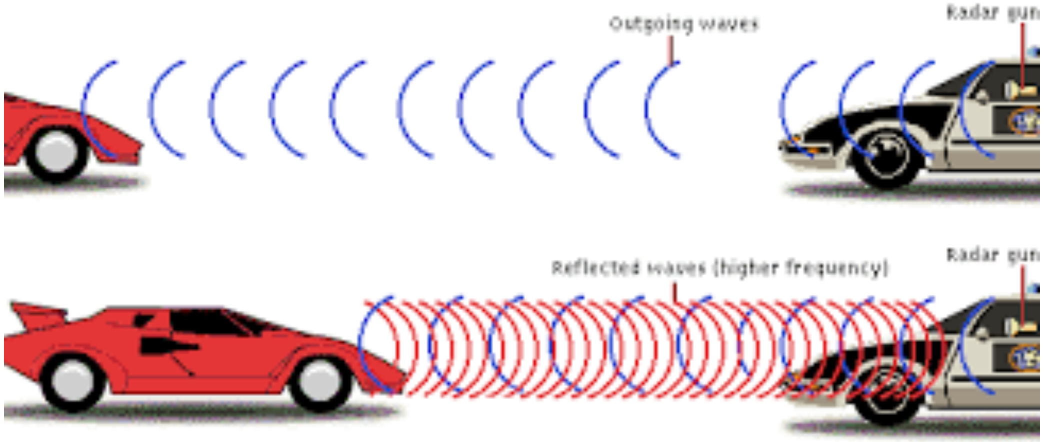
Connection to everyday life

- Radio waves and antennas

  Electromagnetic waves of certain frequency

GPR is very similar to Police radar guns, but frequency range different (police radio = 18-30 GHz). Also different in what is being measured.

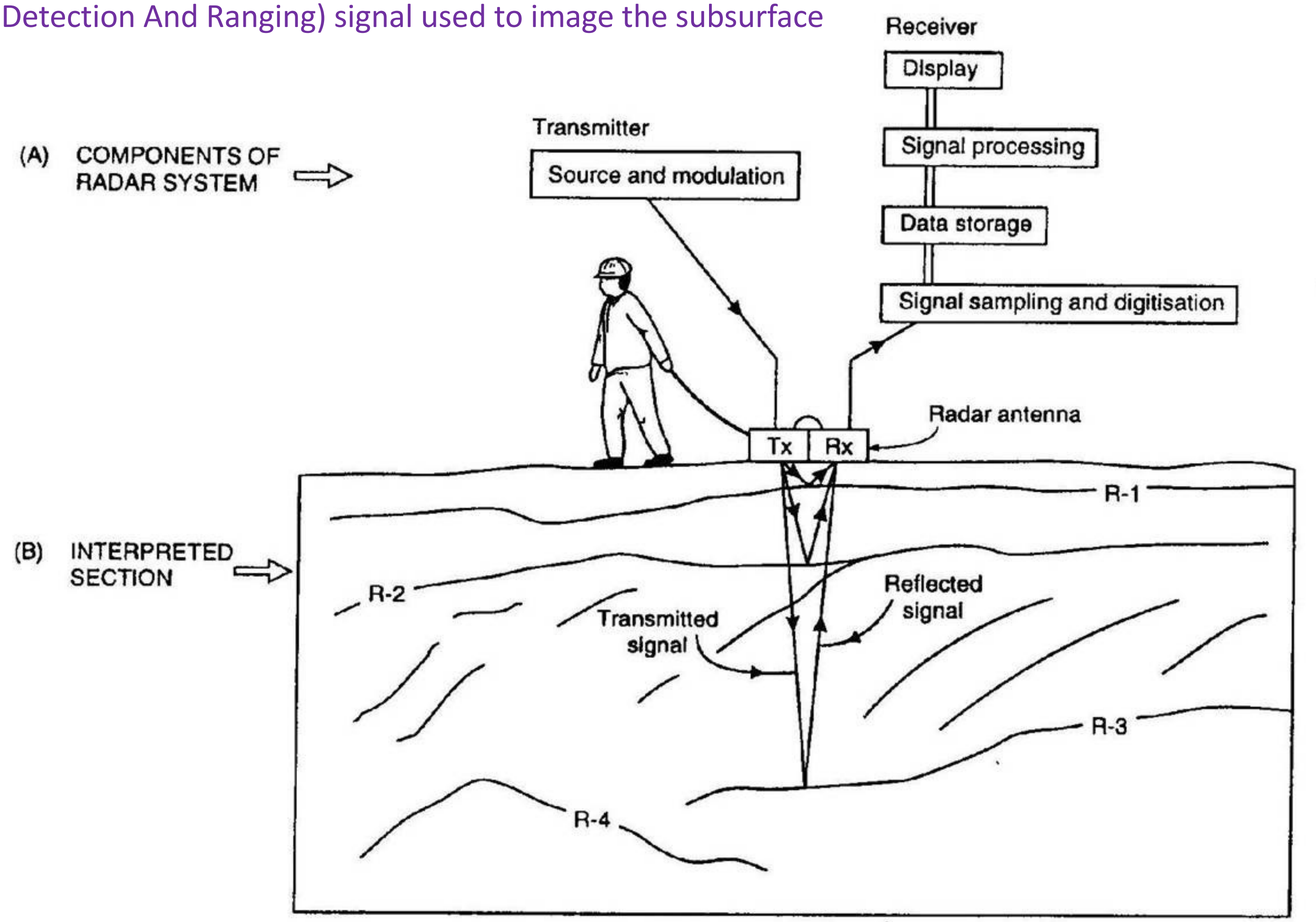
Doppler effect



Radar guns uses shifts in frequency of reflected waves to determine incoming vehicle speed.

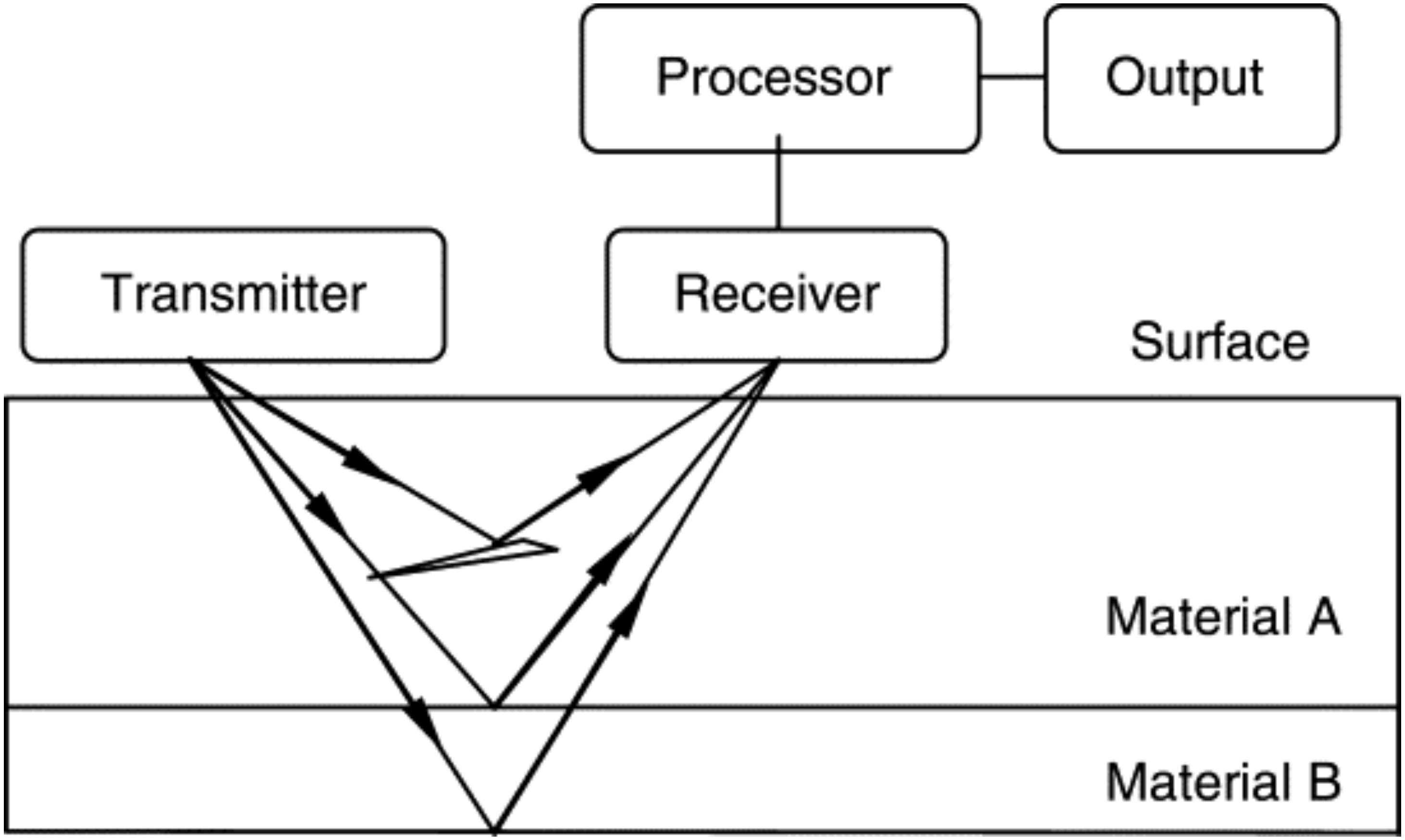
GPR deployment

GPR uses high-frequency pulsed radio waves that are generated by and spherically spread out from a transmitter antenna. The portion of the transmitted wave field that penetrates and propagates through the subsurface is the radar (i.e., Radio Detection And Ranging) signal used to image the subsurface



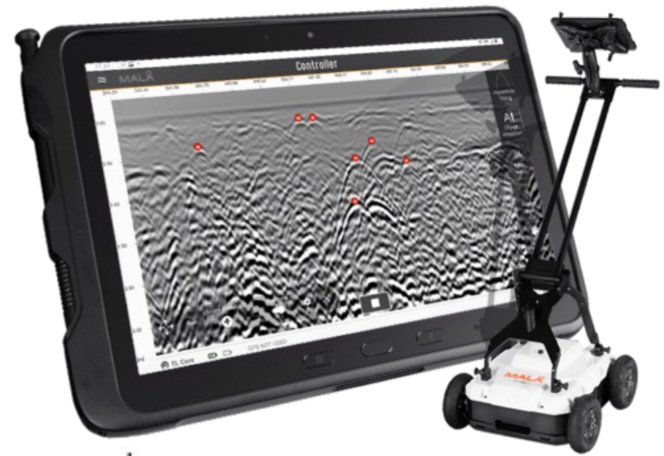
For engineering purposes (metal detection, pipeline, burials, water table), faults, ice sheet, coast line topography

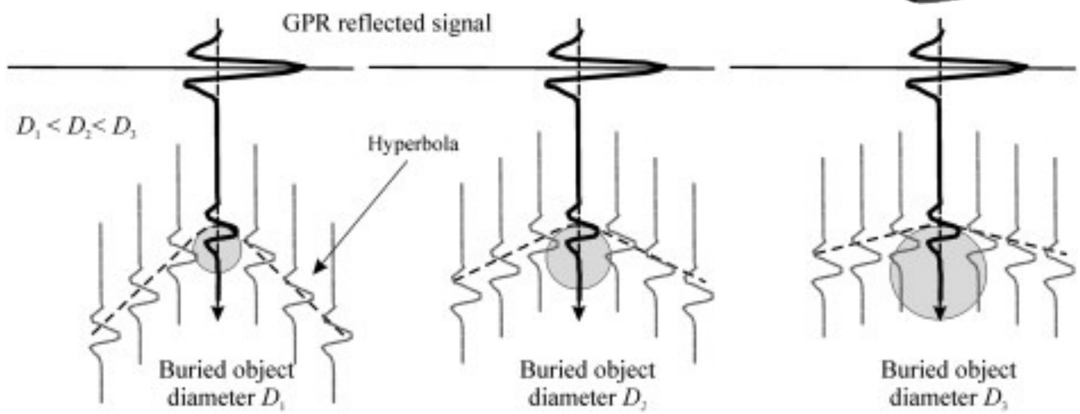
Basic GPR principles



A GPR device (resembling a lawn mower) contains a transmitter and a receiver, which generates and receives GPR waves. Then, depending on the model, the receiver signal could be partially analyzed for convenient viewing and interpretation.

GPR Equipment





From sciencedirect.com

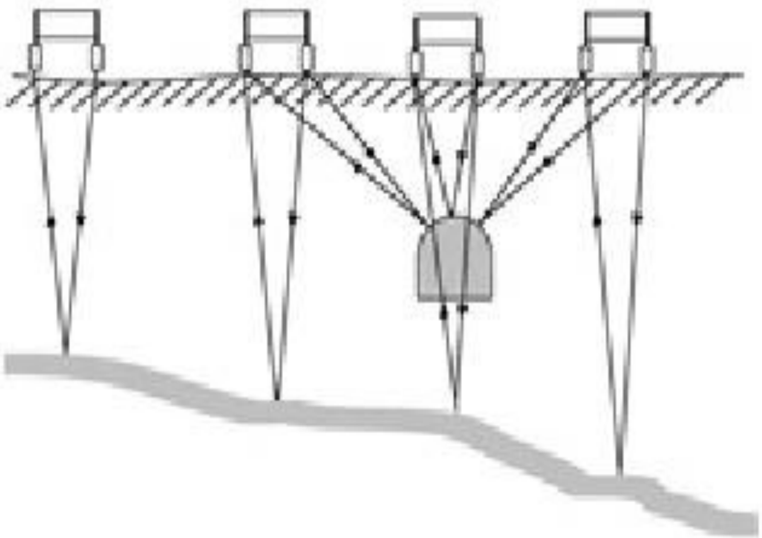
Frequency: 10 MHz - 3 GHz (electromagnetic wave)

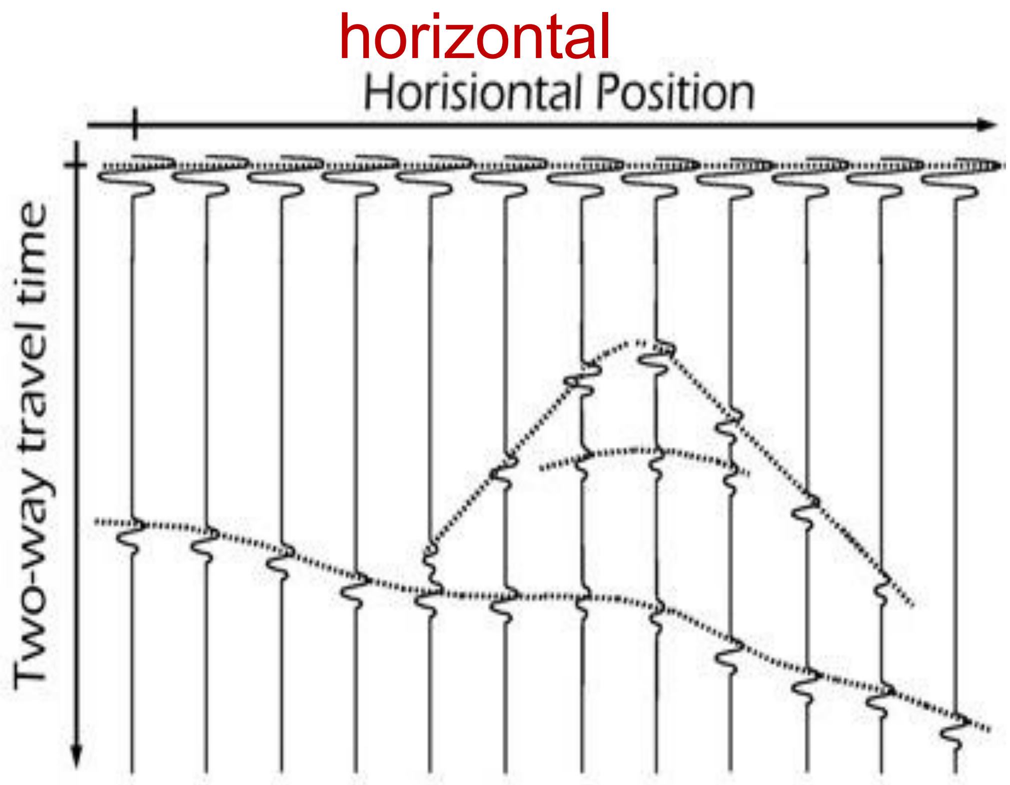
-- comparison with seismic (acoustic wave): 0.001 - 1000 Hz

-- comparison with Magnetotellurics (EM wave, 1 Hz – 20 KHz)

Depth: down to a few meters (frequency dependent)

How to generate a GPR section



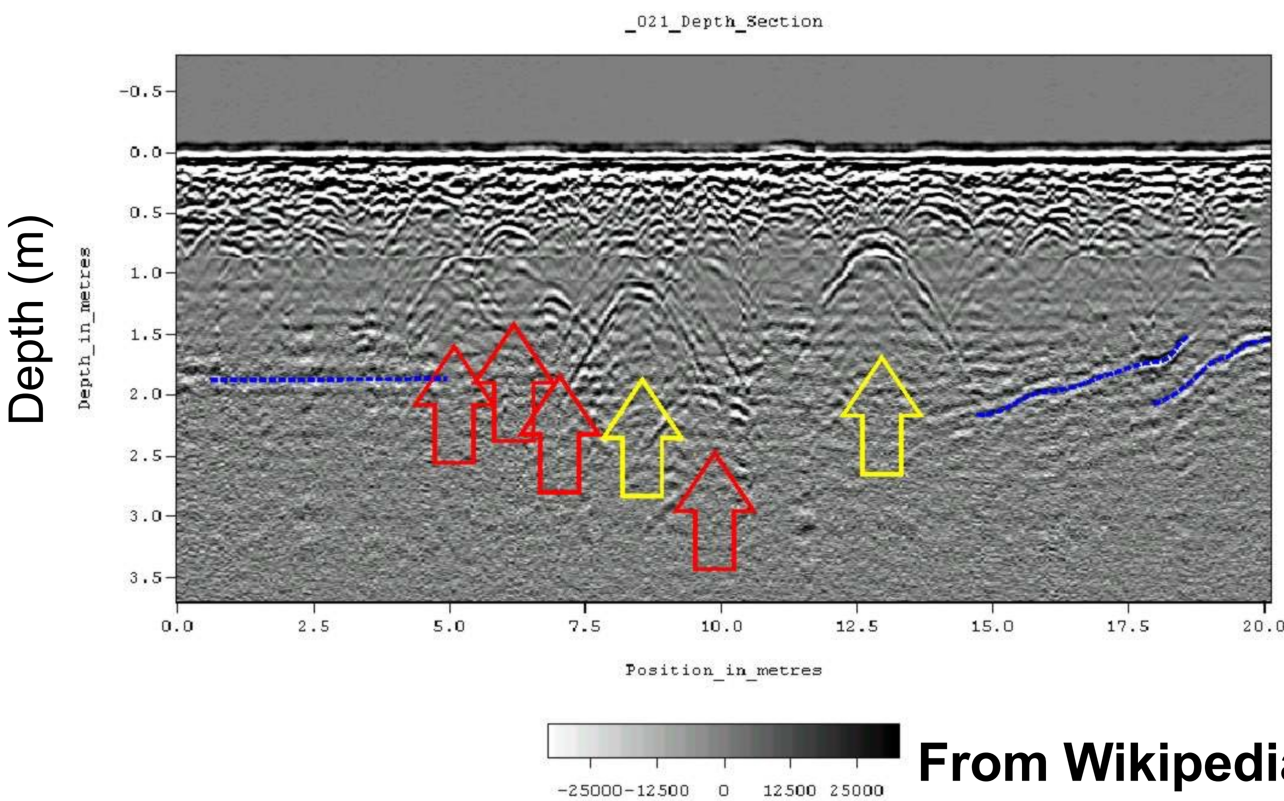


Recorded waves: 1. reflections from deep interface
2. shallow reflection from flat, thin layer
3. scattered waves from reflecting object

From: https://www.eoas.ubc.ca/courses/eosc350/content/exercises09/GPR/GPD_lab.htm

(radio waves --- a specific range of electromagnet wave/signal)

- GPR and seismic surveying = non-destructive remote sensing using EM/sound waves
  - Eg used for hydrocarbon exploration

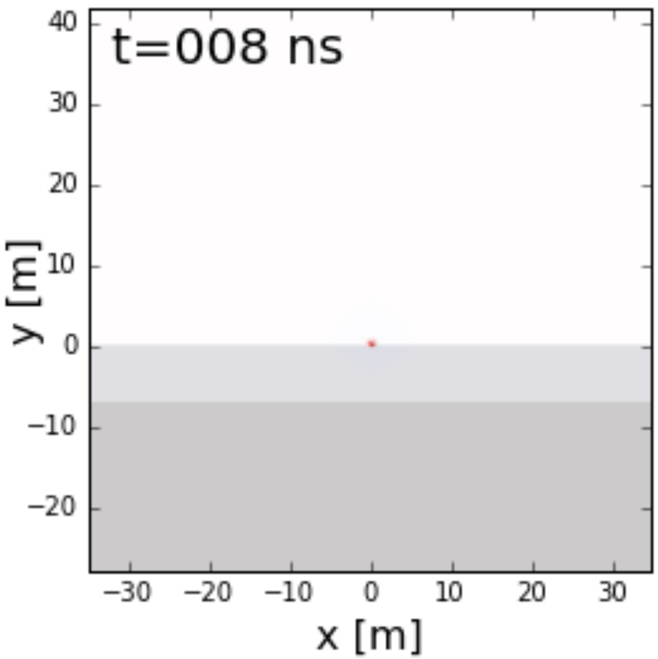


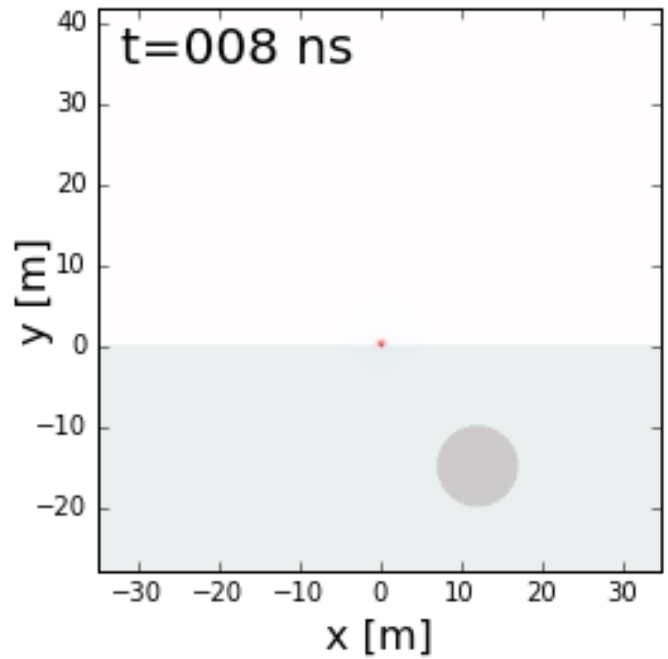
A ground-penetrating radargram collected on a historic cemetery in Alabama, US. Hyperbolic arrivals (arrows) indicate the presence of diffractors buried beneath the surface, possibly associated with human burials. Reflections from soil layering are also present (dashed lines). I believe that this has been migrated to remove reflections.

From Wikipedia

Freq range: 10 MHz – 3 GHz (part of Radio wave, a type of electromag wave)

GPR radio wave propagation (similar to seismic P, S or surface waves), but more related to light and does not require a transmitting medium (i.e., vacuum is OK)





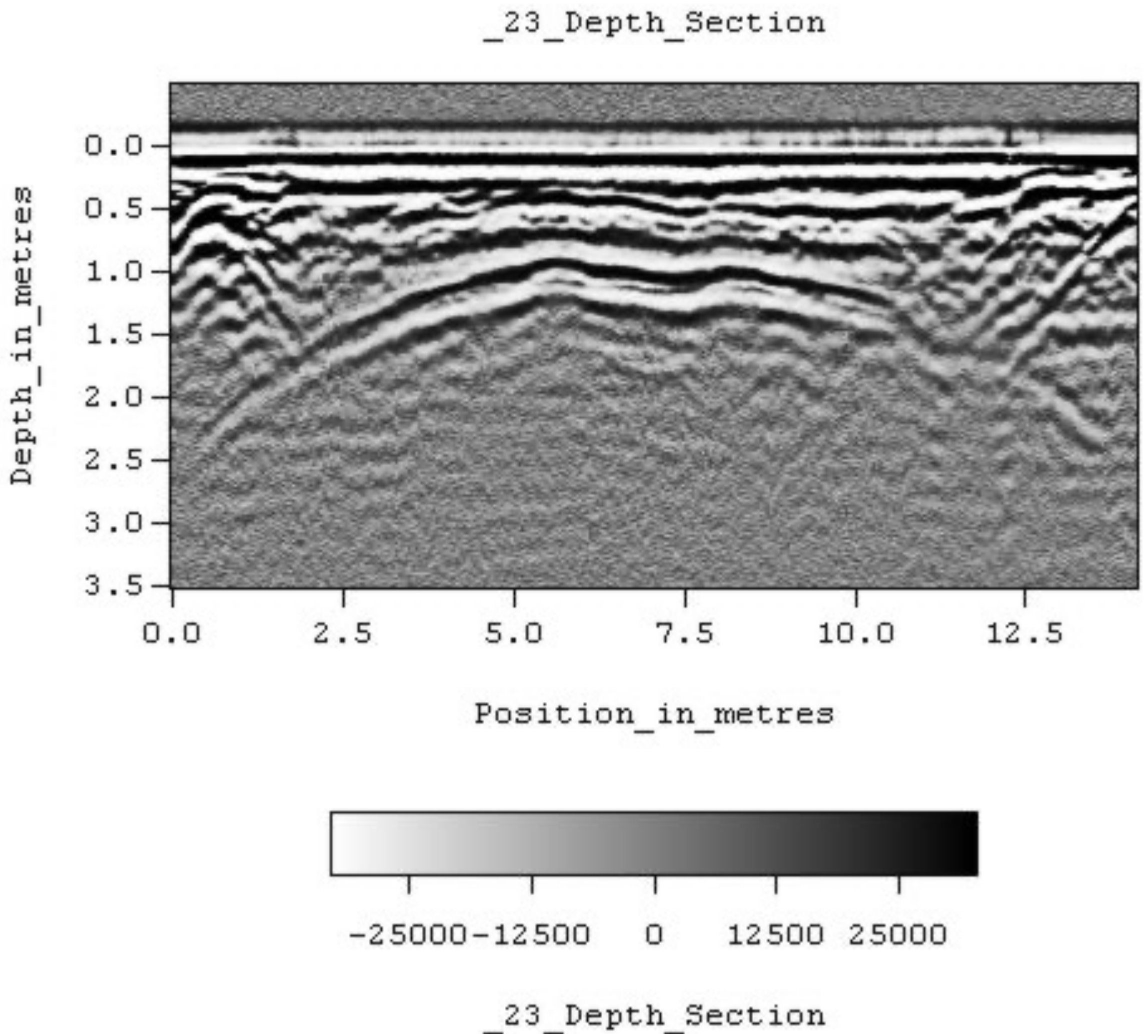
https://gpg.geosci.xyz/content/GPR/GPR_fundamental_principles.html

Speed: fraction of meters/ns

Fastest = air (0.3 m/ns), slowest = water (0.033310 m/ns)

GPR Application

Crypt below ground, with domed roof of the crypt between 1-2.5 km depth



Hyperbola in GPR profile

- Scattered radio wave from buried tank

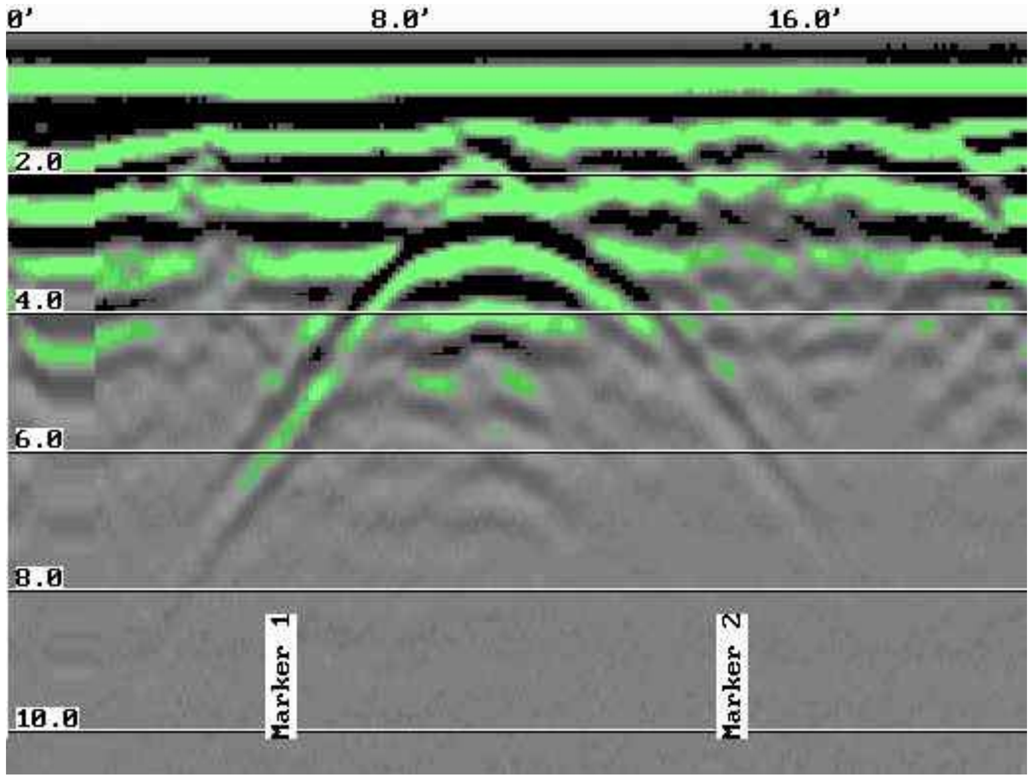
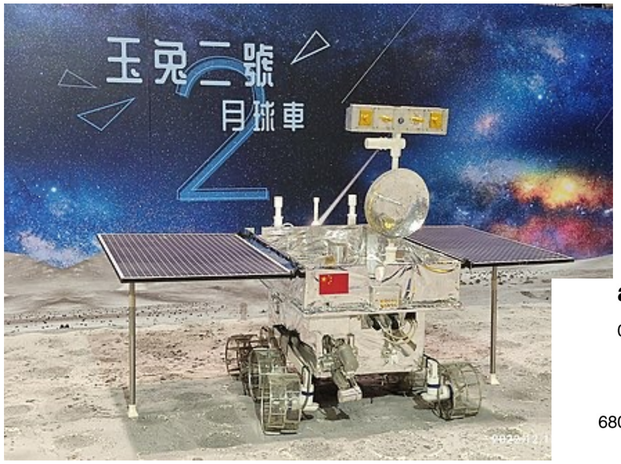
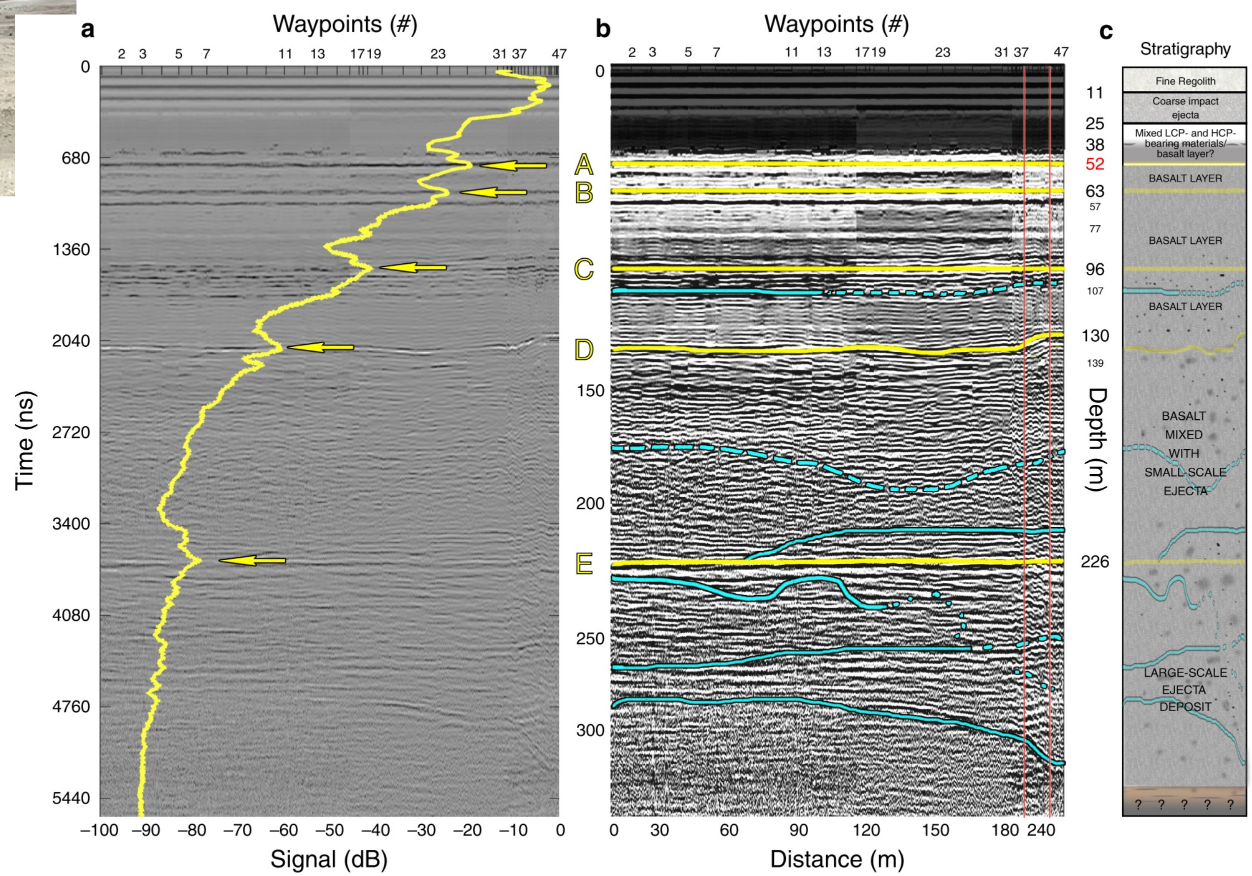


image from
www.naevageophysics.com/gpr.html



GPR image of the Moon

Image has been' gained'



From WIKI

YuTU2 land Rover on the far side of moon (2018)

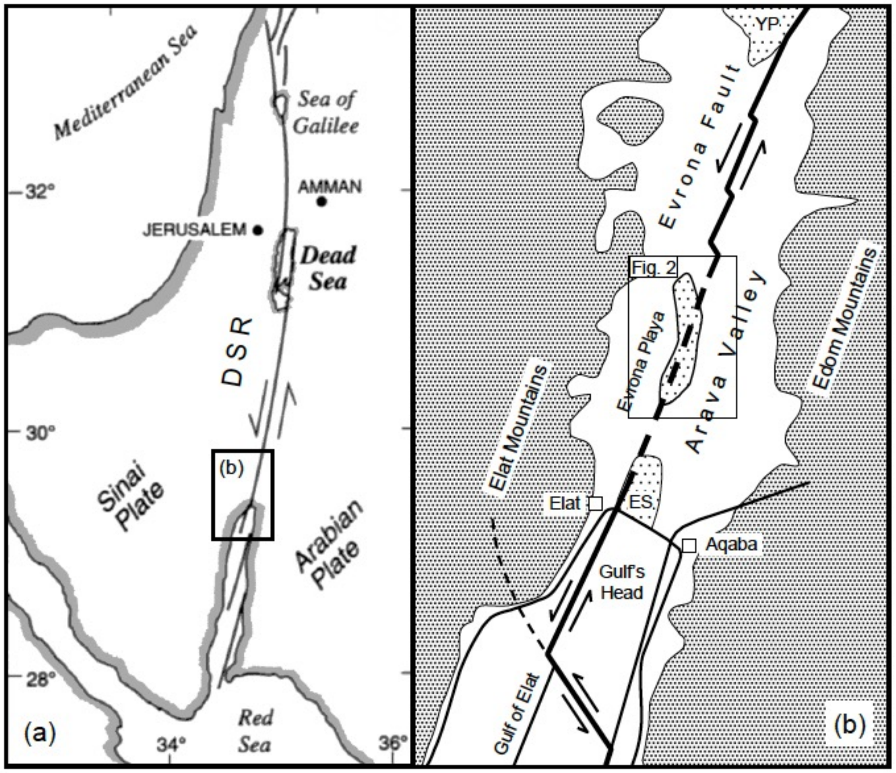
Decibels (dB) = 10 log(P2/P1)

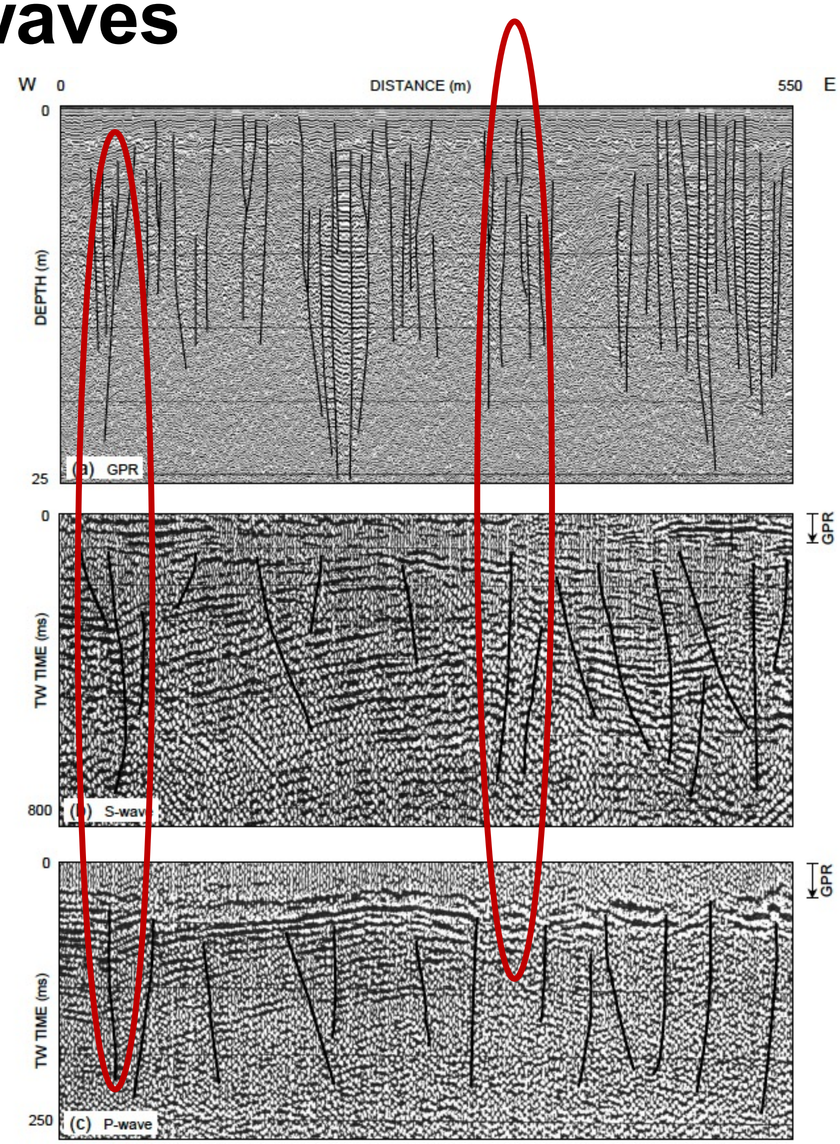
P1 is ref. amp

Lai et al., 2020, Image from Nature Communications

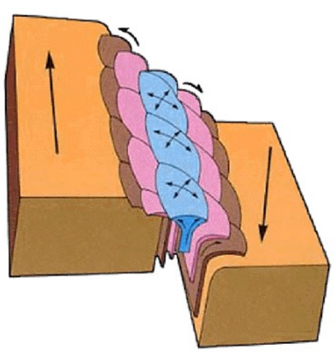
Found different layers of volcanic activities (intrusions from mantle?). This result argues for more recent (50 Myr) volcanism rather than 3 Gyr.

There are similarities between GPR & Seismic waves



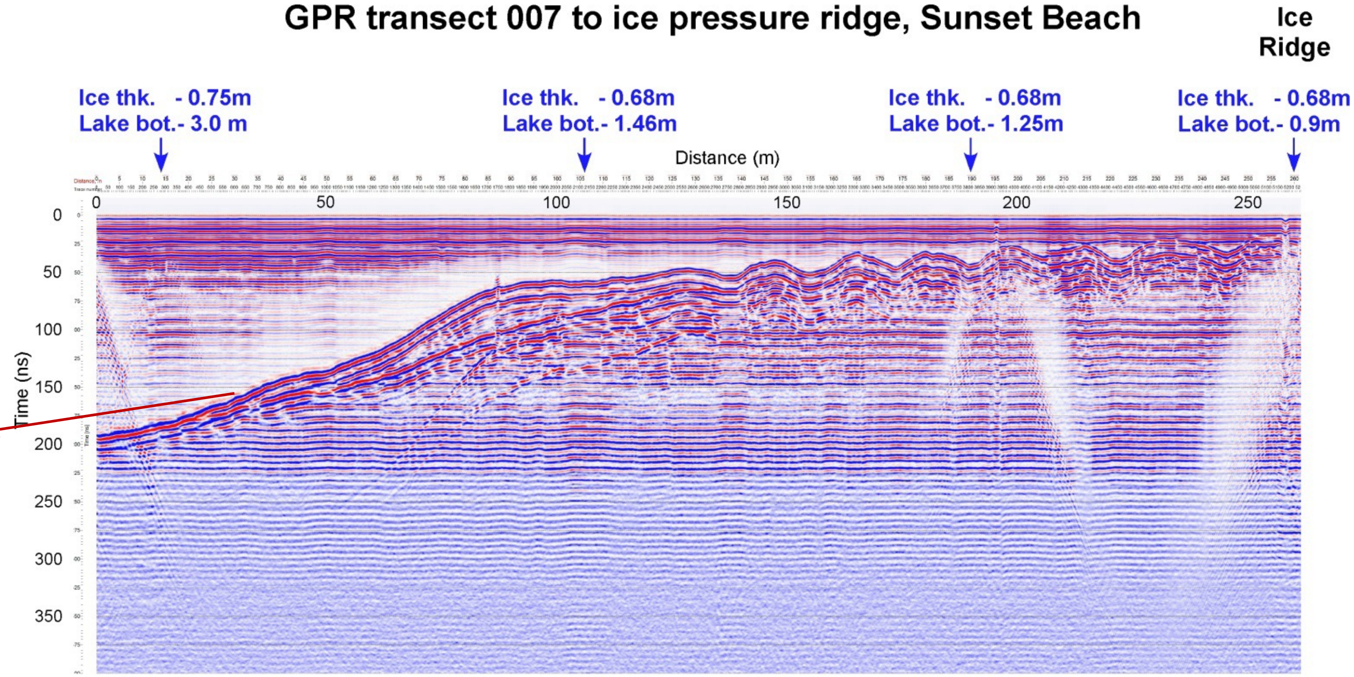


Right figure: near vertical/flower type of faults.



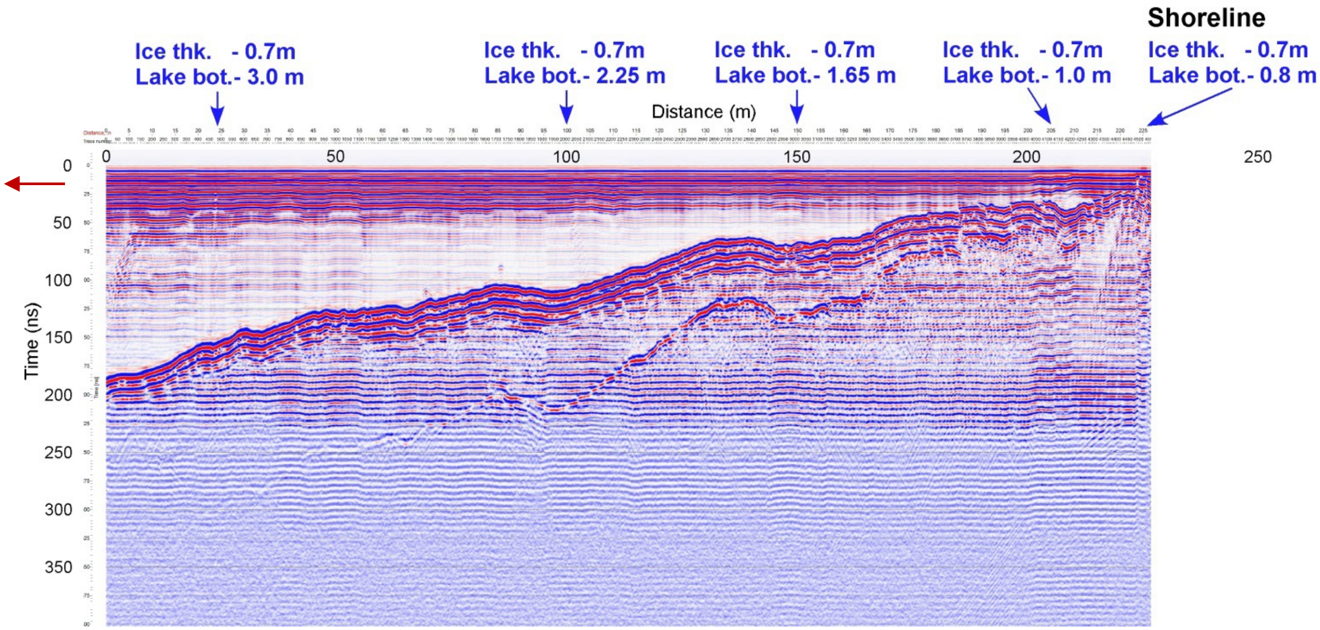
GPR profiles, Sunset Beach, Alberta, Jan. 18, 2018

GPR transect 007 to ice pressure ridge, Sunset Beach



Bottom of the icy layer

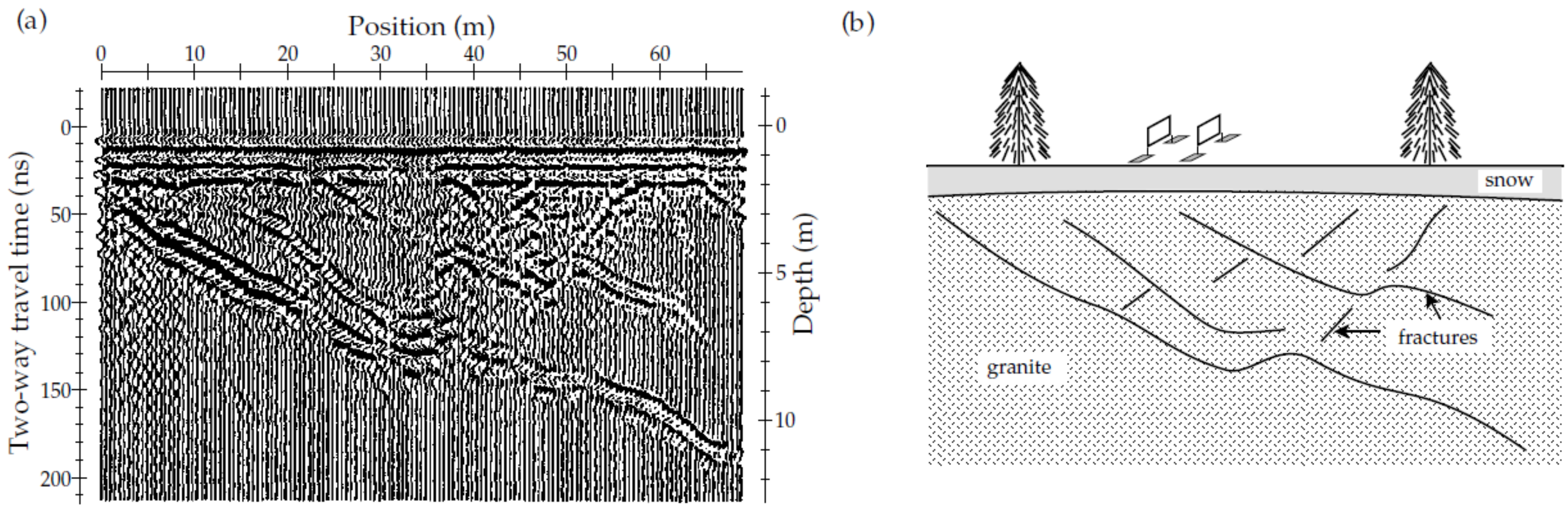
GPR transect 008 to displaced shoreline, Sunset Beach



Note: Since the transmitter and receivers are above ground, much of these high amplitude signals at the start are *reflections from Earth surface in the air + snow layer + complex source wavelets*.

GPR application

- Finding fractures in bedrock (using reflections and scattered waves)



Multiple pulses, correspond to reflections from 1. top of snow layer, 2 bottom of snow layer

Image from https://creep-it.gm.univ-montp2.fr/

GPR – Turtle Mountain, AB

- Not all data equally high quality, but shows parallel but dipped bedding planes with different debris

Source: Unknown

1903 landslide

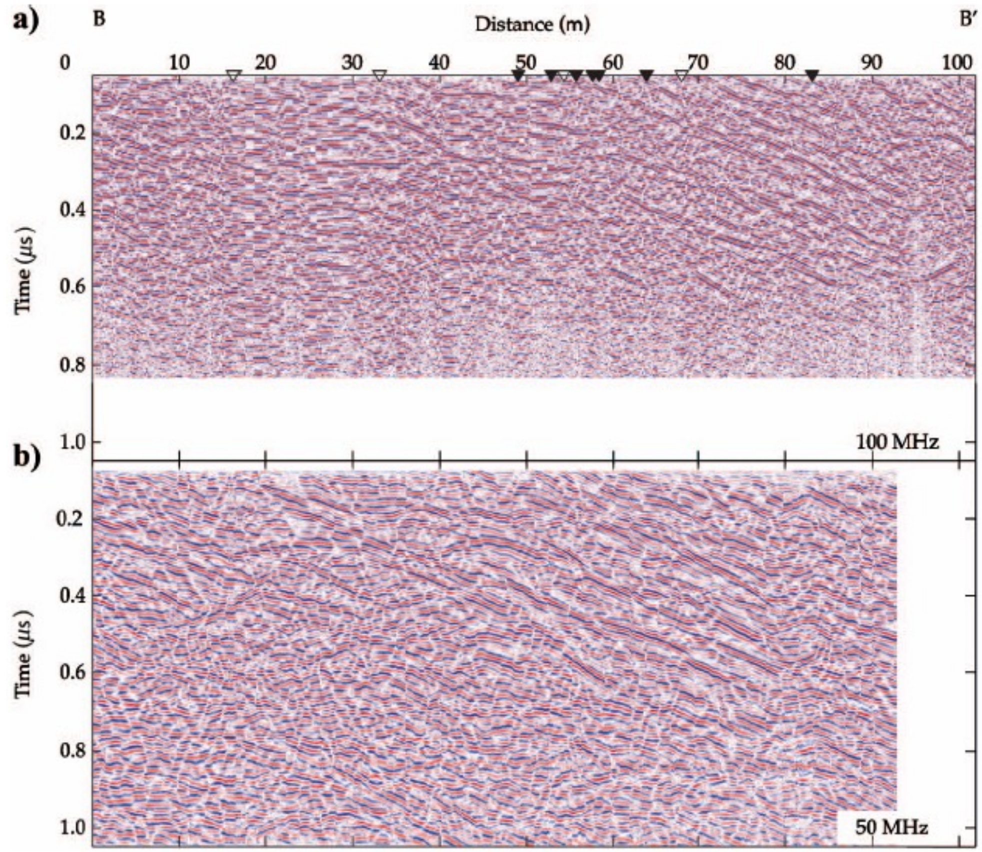
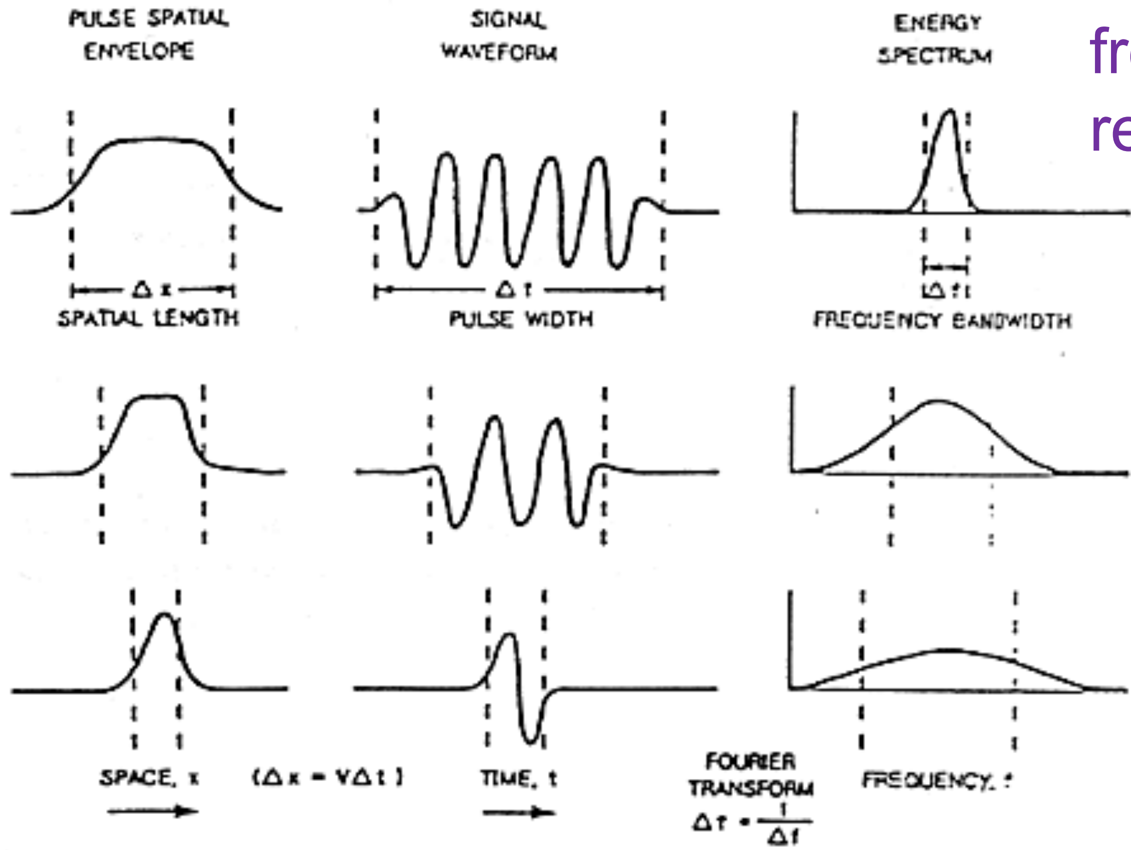


Figure 7. GPR data acquired at the west slope of Turtle Mountain (Figure 4); data were modified by basic processing. (a): Processed 100-MHz data. Filled and open triangles indicate locations of fractures at the surface, along the profile. Black triangles indicate fractures visible at the surface, on the line of profile; white triangles indicate fractures at the surface, but to the left or right of the line of profile. (b) Processed 50-MHz data. In both profiles, bedding planes are shown as coherent events that dip from left to right.

Source property of GPR signal

Time and frequency are reversed



https://www.eoas.ubc.ca/courses/eosc350/content/methods/gpr-06.htm

* Measures voltage
* Wide energy spectrum, so usually a short time pulse is used (bottom case)
* Center frequency f, and a band width of about 1.5*f

Terminology and Key GPR Equations

- **Dielectric permittivity (e)**

--→ **Relative dielectric permittivity (e_R):** permittivity relative to that of vacuum (e.g., 20=20 times)

$e = e_R$ * e_vacuum

- **Electrical Conductivity σ= 1/resistivity** (Siemens/meter = 1/(ohms*meter))

Reflection Coefficient

R = **[sqrt(e1)-sqrt(e2)]/[sqrt(e1)+sqrt(e2)]**

Dispersion relationship (V=velocity, f = frequency, λ=wavelength)

Wavelength λ = V* sqrt (e_R)/f

Parameters related to GPR signal

Material	permittivity.	velocity (m/ns).	Attenuation (db/m)
Air	1	0.3	0
Ice	3-4.	0.16	0.01
Fresh water.	80	0.033	0.1
Salt water	80	0.01	1000
Dry sand.	3-5	0.15	0.01
Wet sand	20-30	0.06	0.03-03
Shales/clay.	5-20	0.08	1-100
Limestone	4-8	0.12	0.4-1
Salt (dry)	5-6	0.13	0.01-1

Decibels

(dB) = 10 $\log_{10}$(A/A_air)

Resistivity (inverse of conductivity)
The more conductive, the higher the attenuation,
the less the useful GPR signal. Salt water is super conductive!

Velocity: the higher the Permittivity, the lower the speed, e.g., fresh water.

Skin depth (depth to which radio signals falls to 1/2.71828 of starting amp)

Frequency and conductivity dependence

Antenna Center Frequency (MHz)	Approx. Depth in Dense, Wet Clay	Approx. Depth in Clean, Dry Sand
100 MHz	40 ft. (12m)	100 ft. (30m)
250 MHz	14 ft. (4.5m)	30 ft. (9m)
500 MHz	6 ft. (1.8m)	14.5 ft. (5m)
1000 MHz	2 ft. (60cm)	6 ft. (1.8m)

Terminology and Key GPR Equations (2)

Velocity Calculation

$$v = \frac{c_0}{\sqrt{\varepsilon_r'}}$$

c_0 = speed of light in air (300 K km/s)
$\varepsilon_{r'}$ = real part of relative dielectric permittivity (to free air)

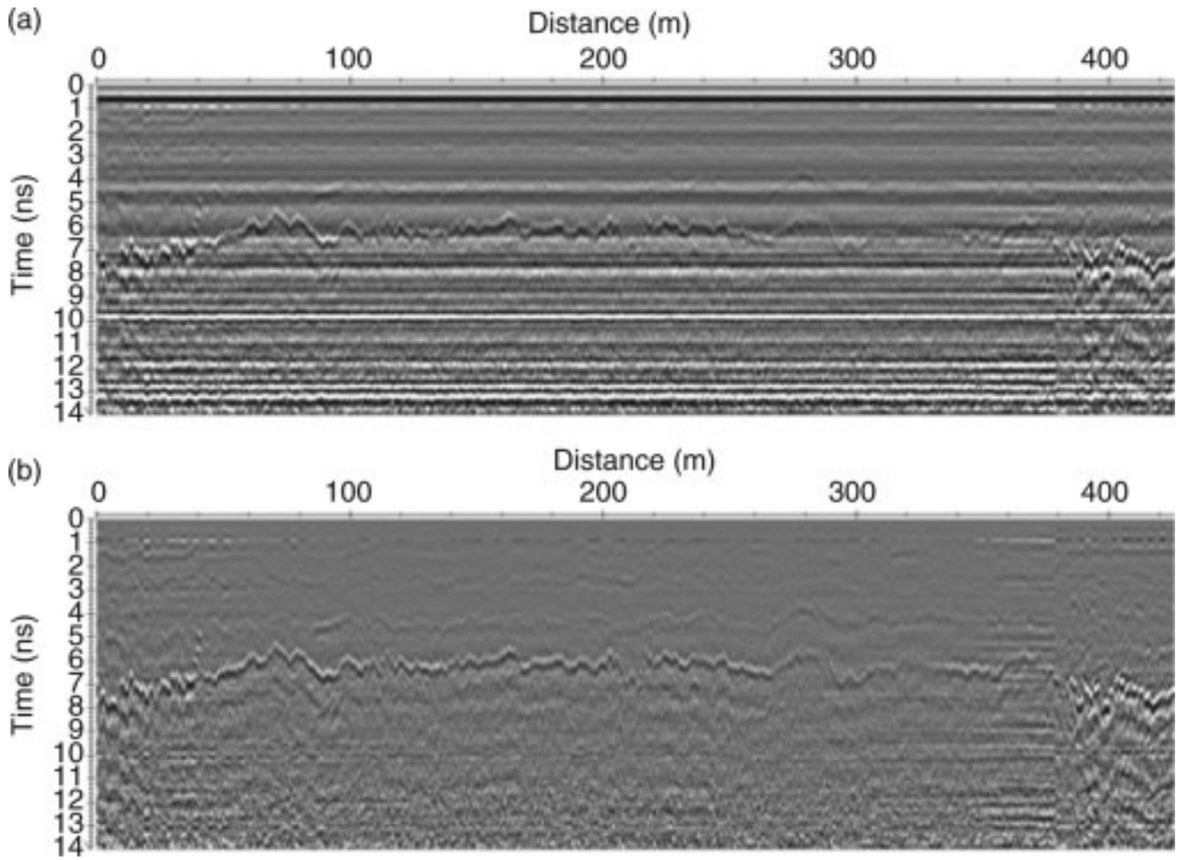
Resolution

$$s_{min} = \frac{\lambda_0}{2\sqrt{\varepsilon_{r,m}}}$$

λ_0 = wavelength in m
$\varepsilon_{r,m}$ = relative dielectric permittivity (to free air)

Resolution=size of the finest details that we could image = About 1/4th of wavelength of center frequency for common Earth material such as sand, limestone, salt..

Data processing aspects (time 0 correction, dewowing, finding the difference between traces, filtering, geometric spreading correction, Gain control)



From Wikipedia

GPR signals (or seismic signals) come with a lot of clutter. Soil or small rock scattering, reflections from external anomalies. These often show up as ‘ringing’ (horizontal stripes). Any idea of a simple removal technique (shown in panel B here)?