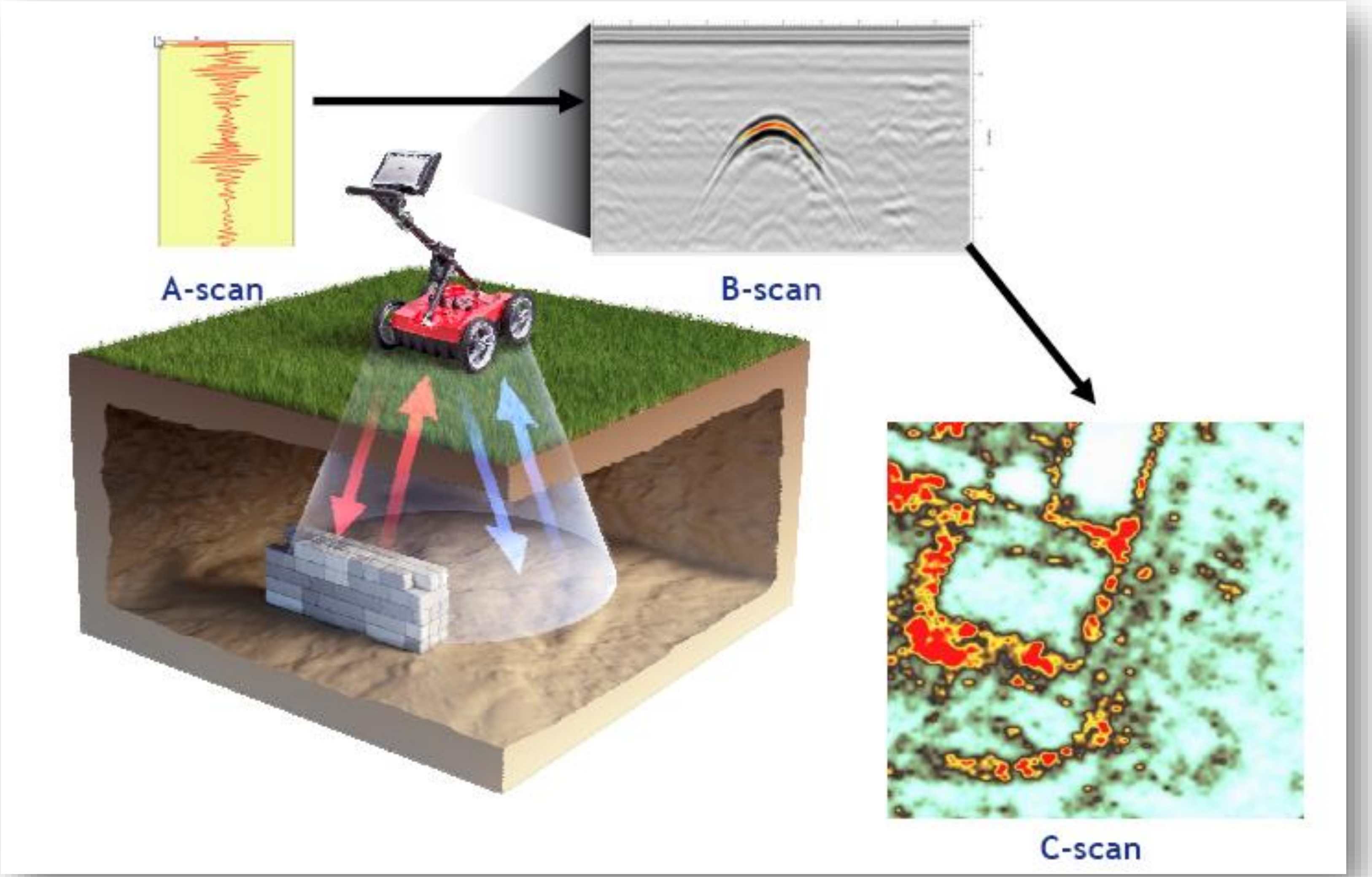
Ground Penetrating Radar

With Special Focus on Importance of Simulation



“The Engineer’s first problem in any design situation is to discover what the problem really is”

About PARSAN

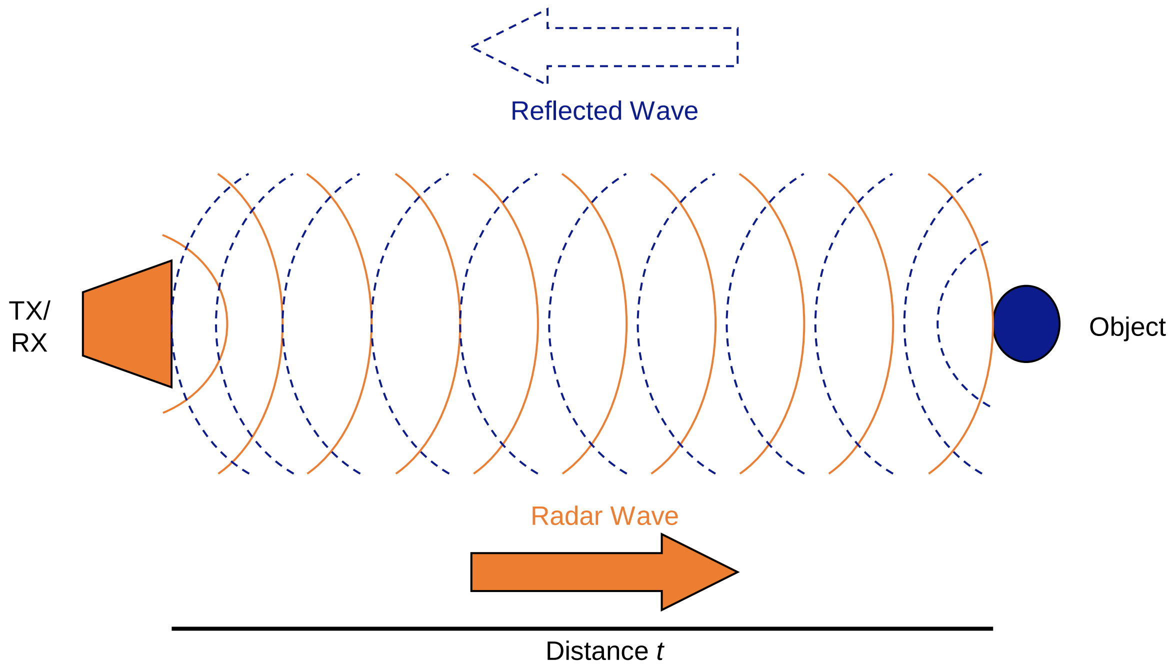
- An ISO 9001:2015 certified geophysical company
- Promoters recognized as leaders in region for launching new technology. Responsible for launch of:
  - Ground Penetrating Radar Technology- 1996
  - Shear Wave Seismic Refraction- 1997
  - High Resolution Seismic Tomography- 1998
  - Passive Seismic Tomography for Oil Exploration- 2008
  - Innovative use of geophysical methods for high resolution non-destructive testing of dams- 1998
- Highly experienced and trained staff.
- Offices in Delhi, Kolkata, Bhopal, Bahrain & Saudi Arabia
- Work experience in India, Nepal, Bhutan, Saudi Arabia, Bahrain, Kuwait, Oman, Afghanistan, Singapore, Greece, Iran, Algeria, Georgia…….

About Speaker (Dr. Sanjay Rana)

- Professional Geophysicist, with **31 years** of work experience. Chairman AF Academy & Managing Director, PARSAN, An engineering geophysics company
- **Gold Medalist**, University of Roorkee (Now IIT-Roorkee)
- Member of various working committees for development of Code of Practices and Standards, **including BIS, IRC, IndSTT, TAI**.
- Lead geophysicist for Delhi Metro underground corridor- **1996 (First commercial use of GPR in India).**
- **Pioneered use of GPR in India in 1996.**
- Experienced of working with most of the available GPR models like GSSI, Mala, Sensor & Software, Pipe Hawk, and Zond. Overseas GPR experience- Canada, Singapore, Saudi Arabia, Oman, Afghanistan, Nepal, Bhutan, and Bahrain.
- Conducted **first ever city level utility mapping project** for city of Tirupur, way back in **1999**.
- Various Papers & Publications, including "Advanced Technologies for Preparation of Utility Maps of Cities", which initiated many projects in India.
- Initiated the concept of **SUE in India in 2001**.
- **Principal author of Indian code/ standard for Subsurface Utility Engineering**

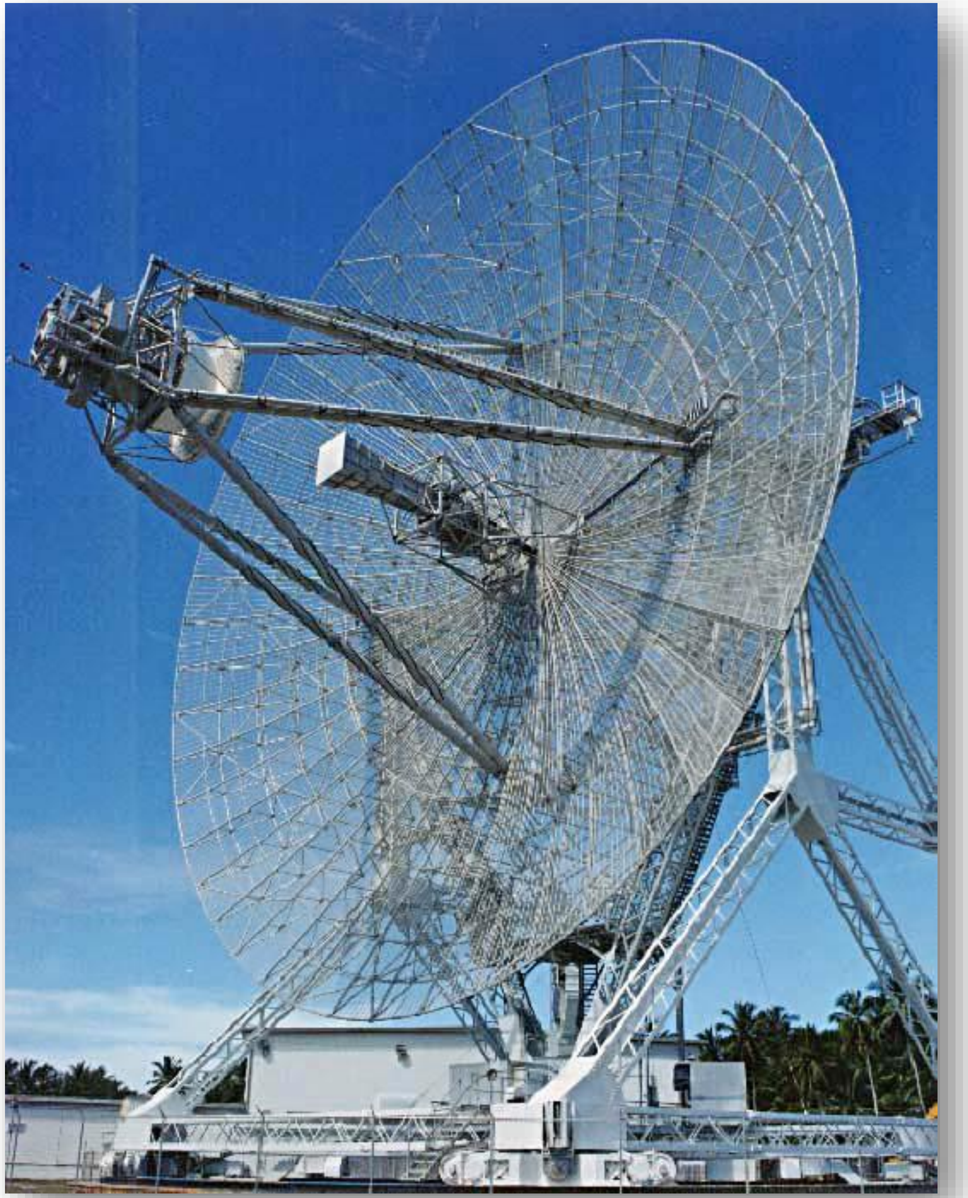
What is Radar?

- RADAR is an acronym coined from the phrase:
  - **RA**dio **D**etection **A**nd **R**anging



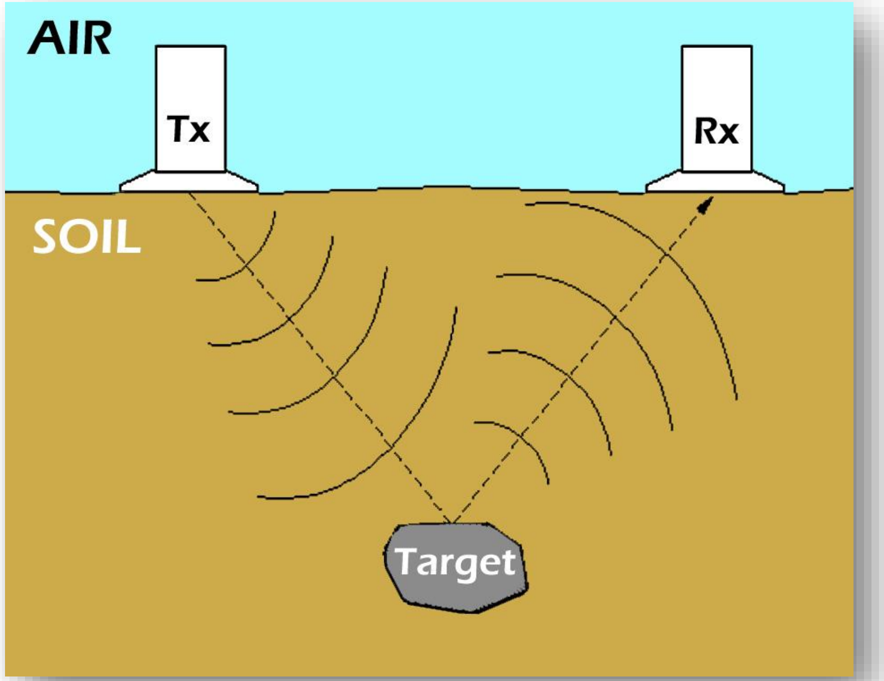
What is Radar?

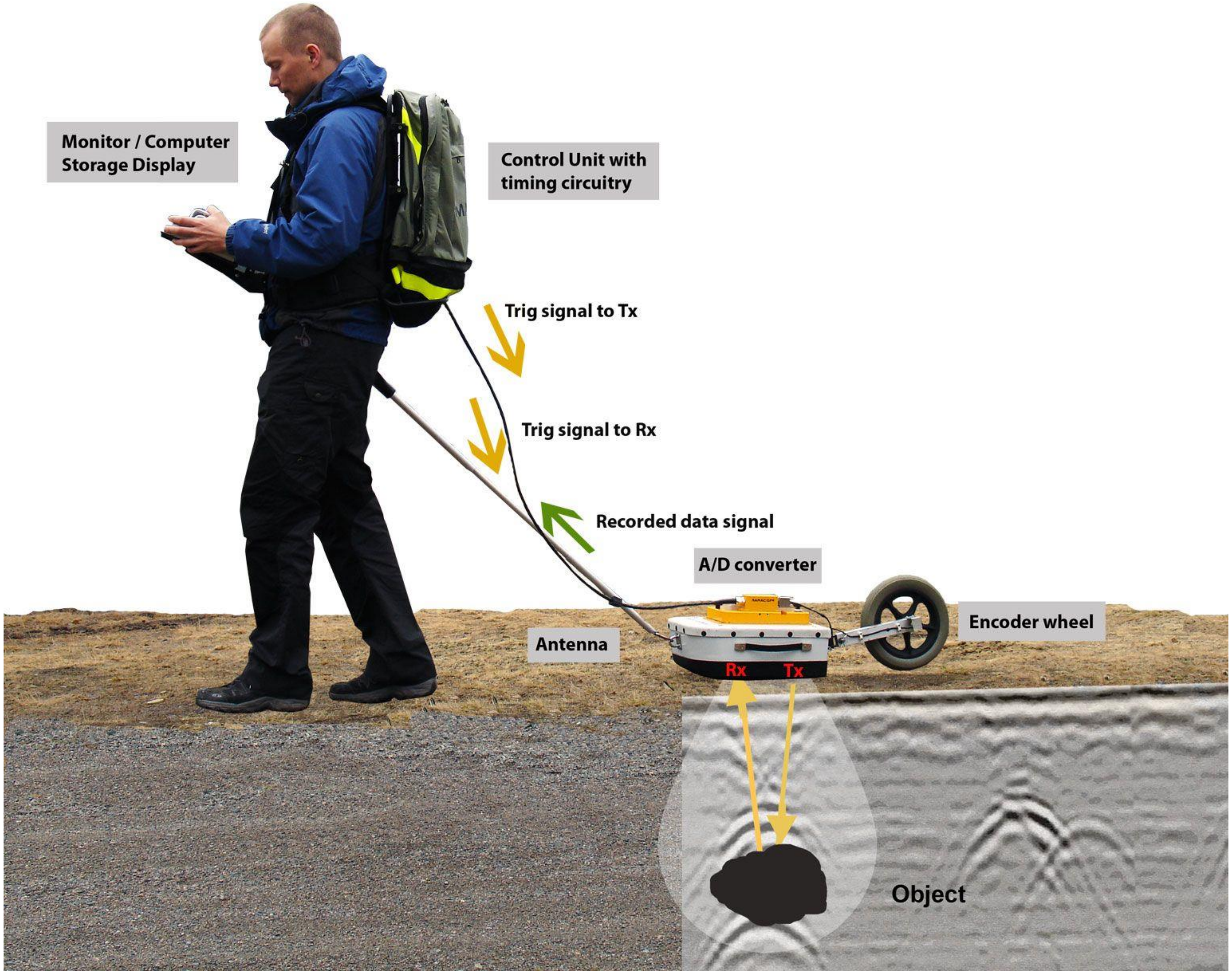
- The first useful RADAR systems were used in free space (air) primarily for military applications:
  - Navigation of aircraft and shipping
  - Detection of enemy craft and positioning
  - Weapons guidance



What is GPR?

- GPR is an acronym coined from the phrase:
  - **G**round **P**enetrating **R**ADAR

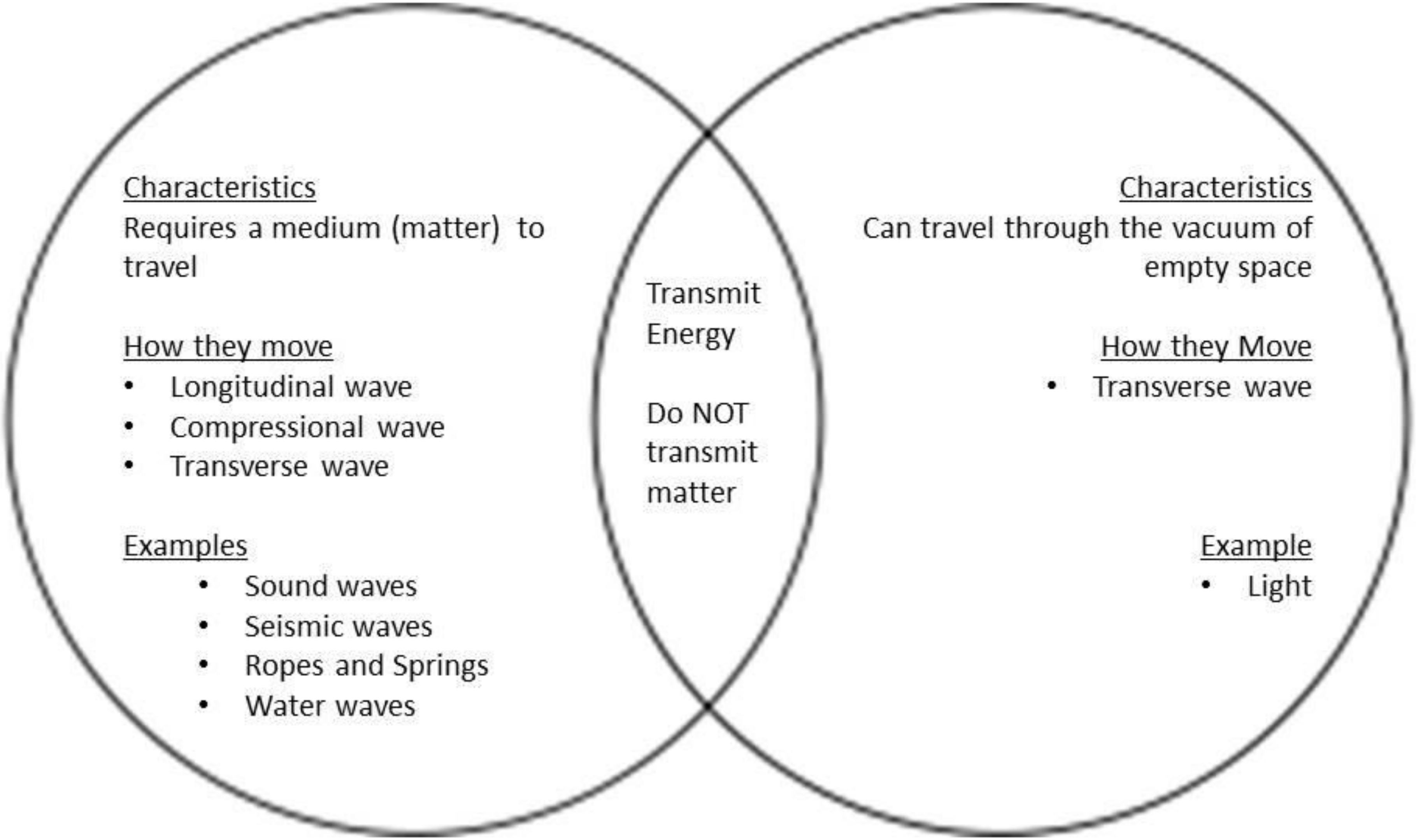


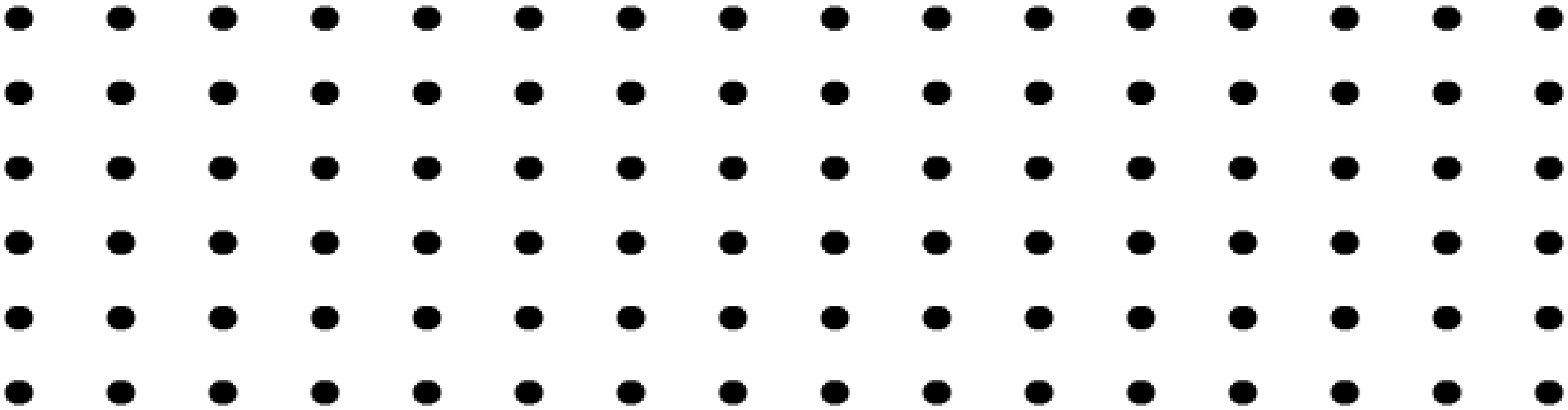


Monitor / Computer
Storage Display
Control Unit with
timing circuitry
Trig signal to Tx
Trig signal to Rx
Recorded data signal
A/D converter
Antenna
Encoder wheel
Rx
Tx
Object

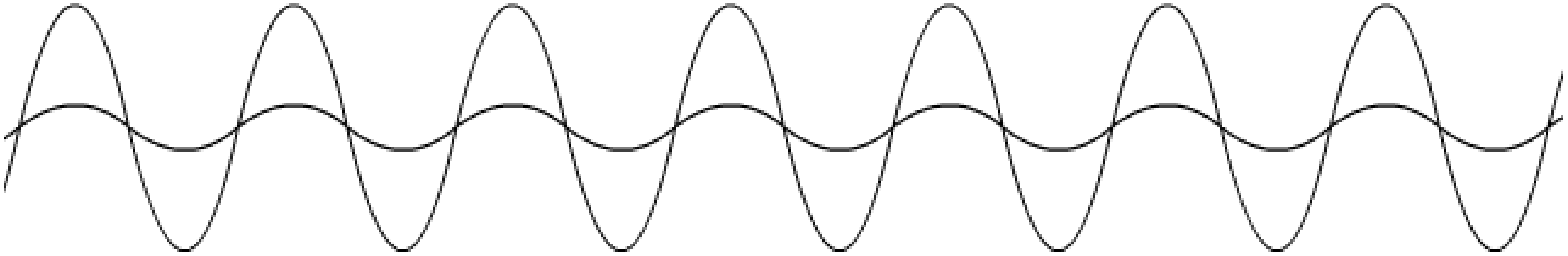
Mechanical Waves

Electromagnetic Waves

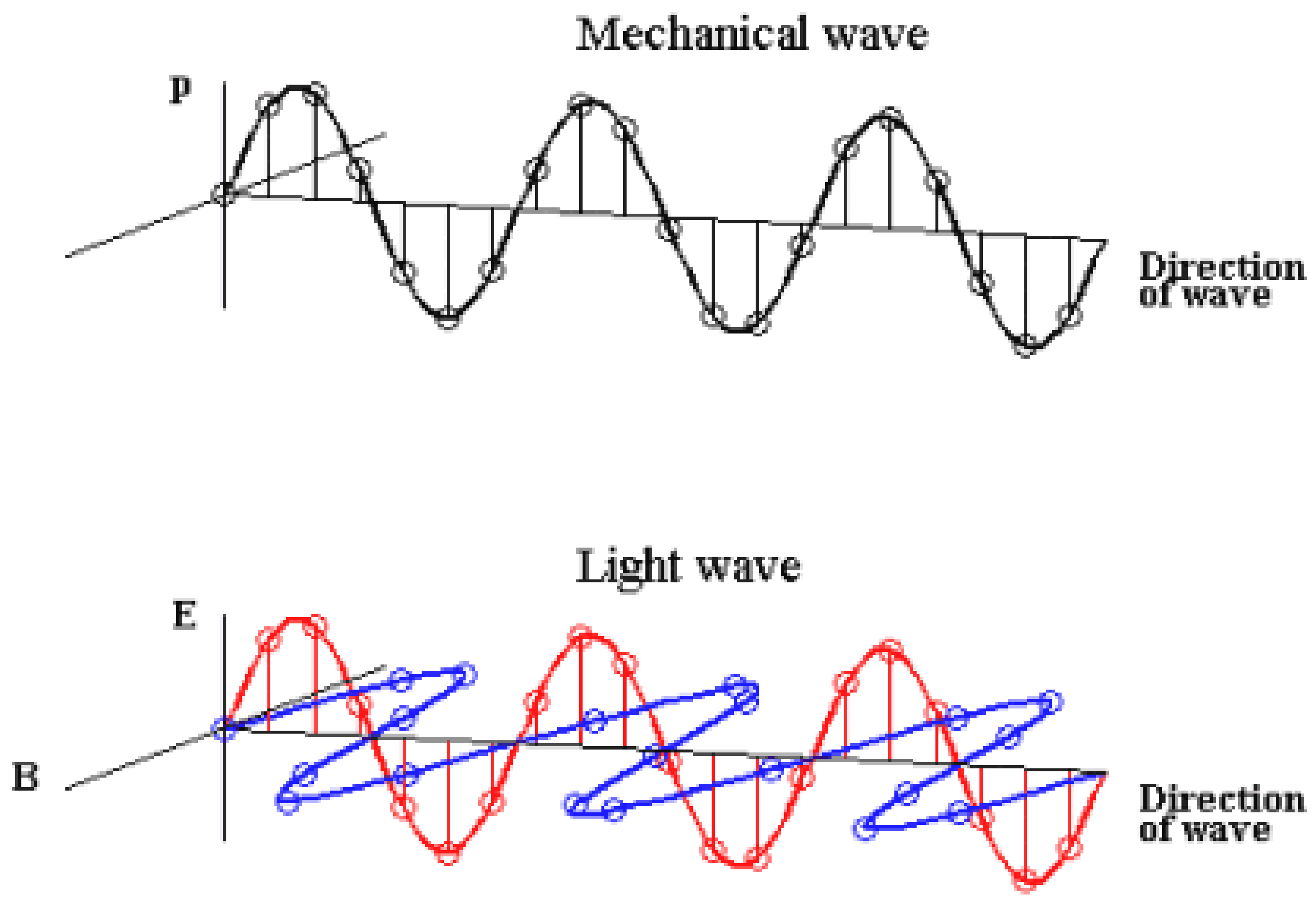




Mechanical Wave (Medium Necessary)



Electromagnetic Wave (No Medium Necessary)

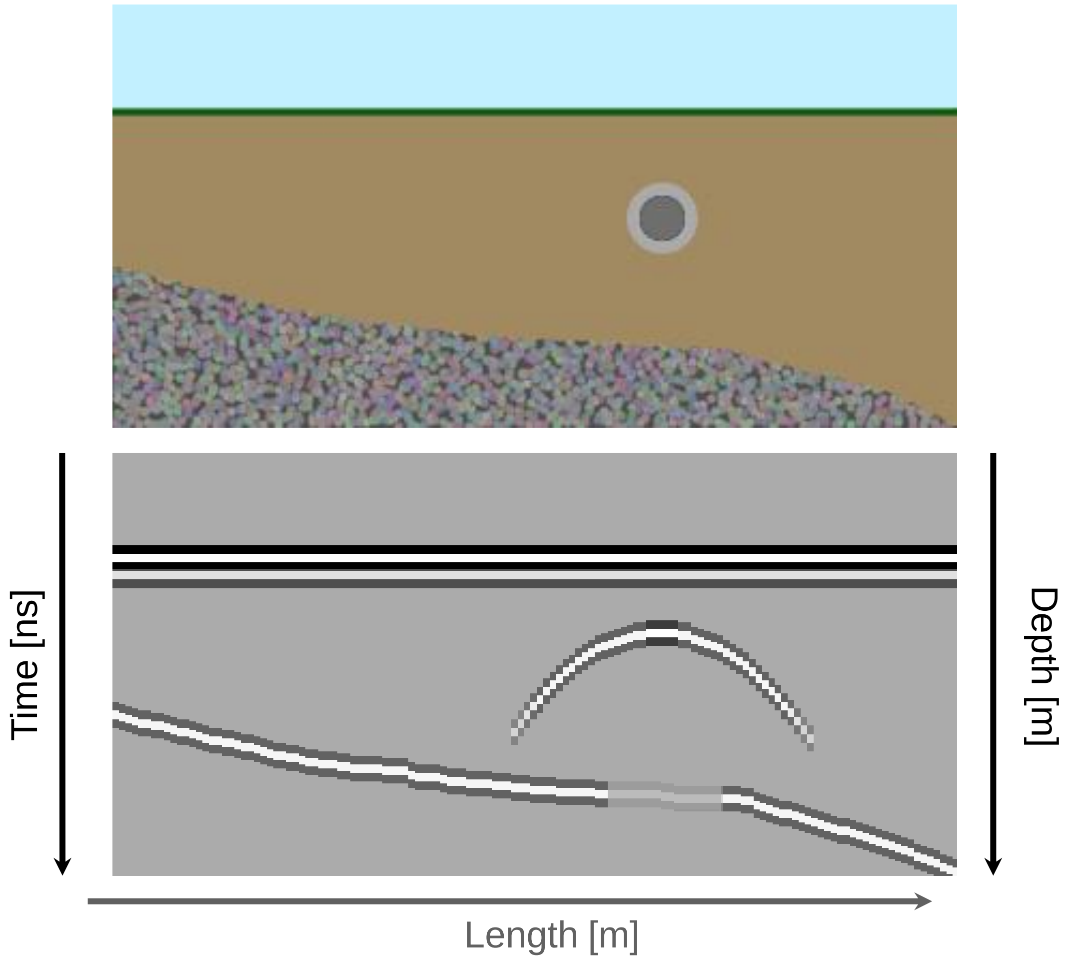


Mechanical wave
p
Direction of wave
Light wave
E
B
Direction of wave

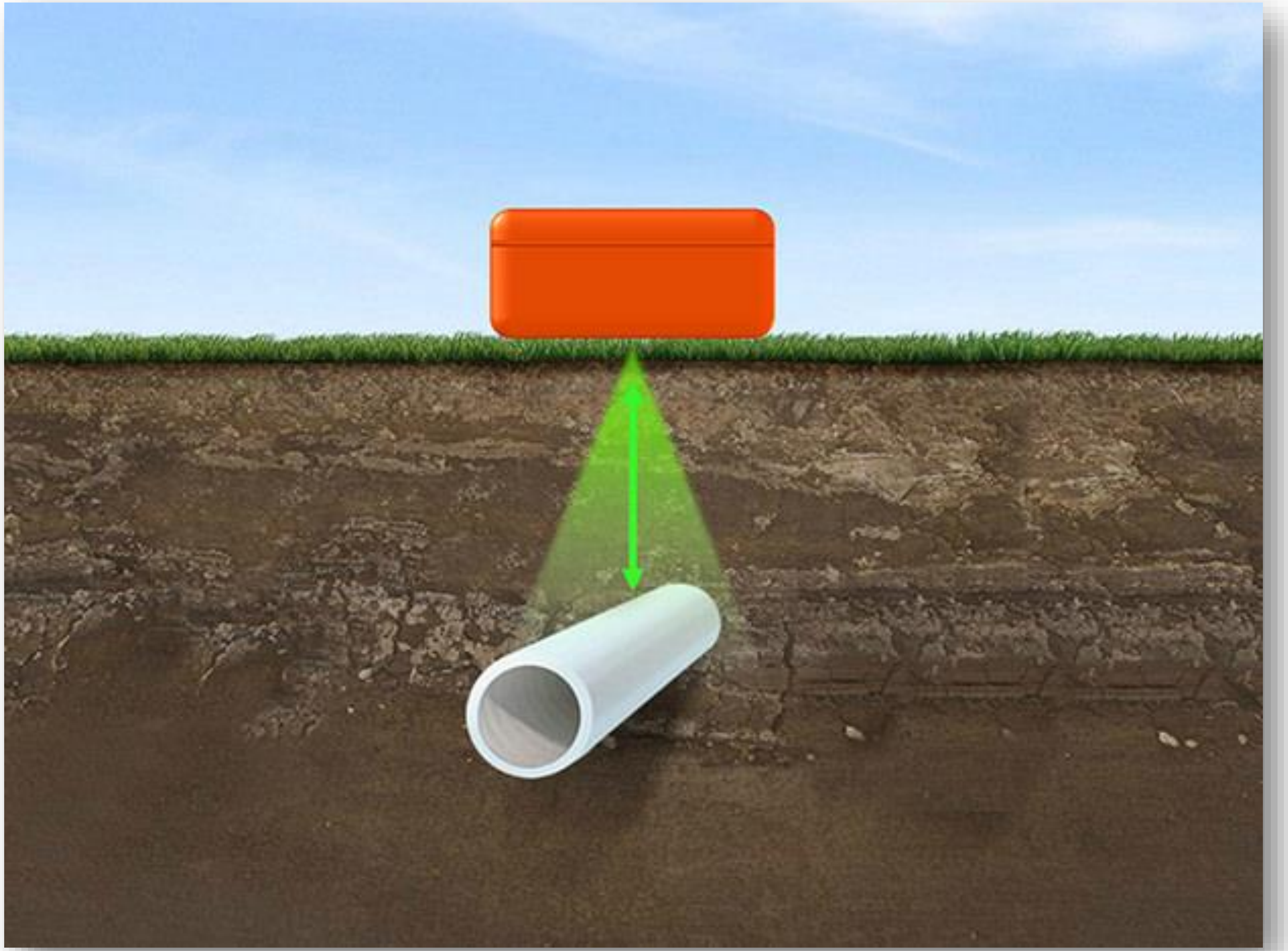
isvr

Ground Penetrating Radar uses Electromagnetic Waves

Basic Principle…Animation

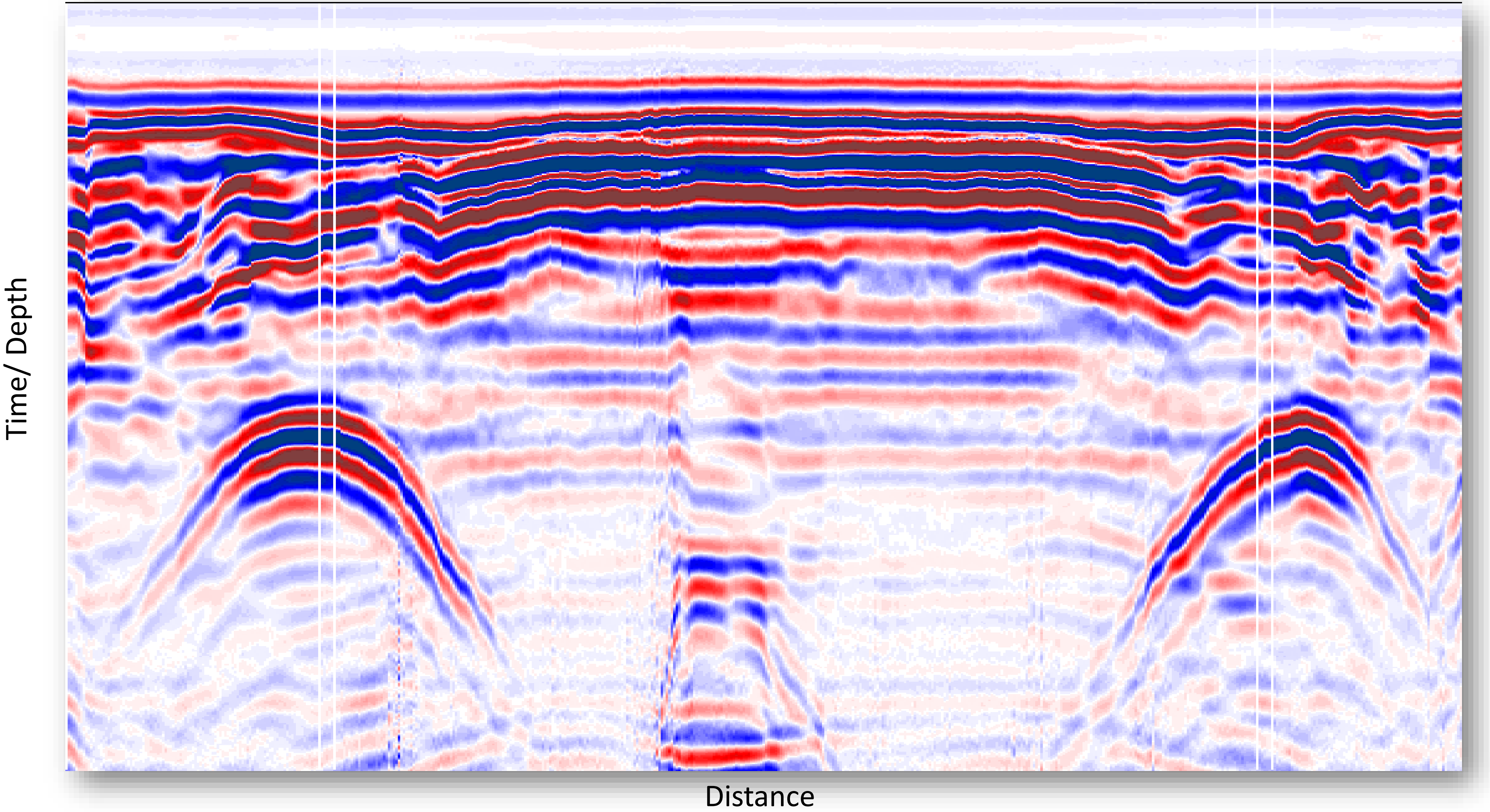


Basic Theory…Antenna footprint

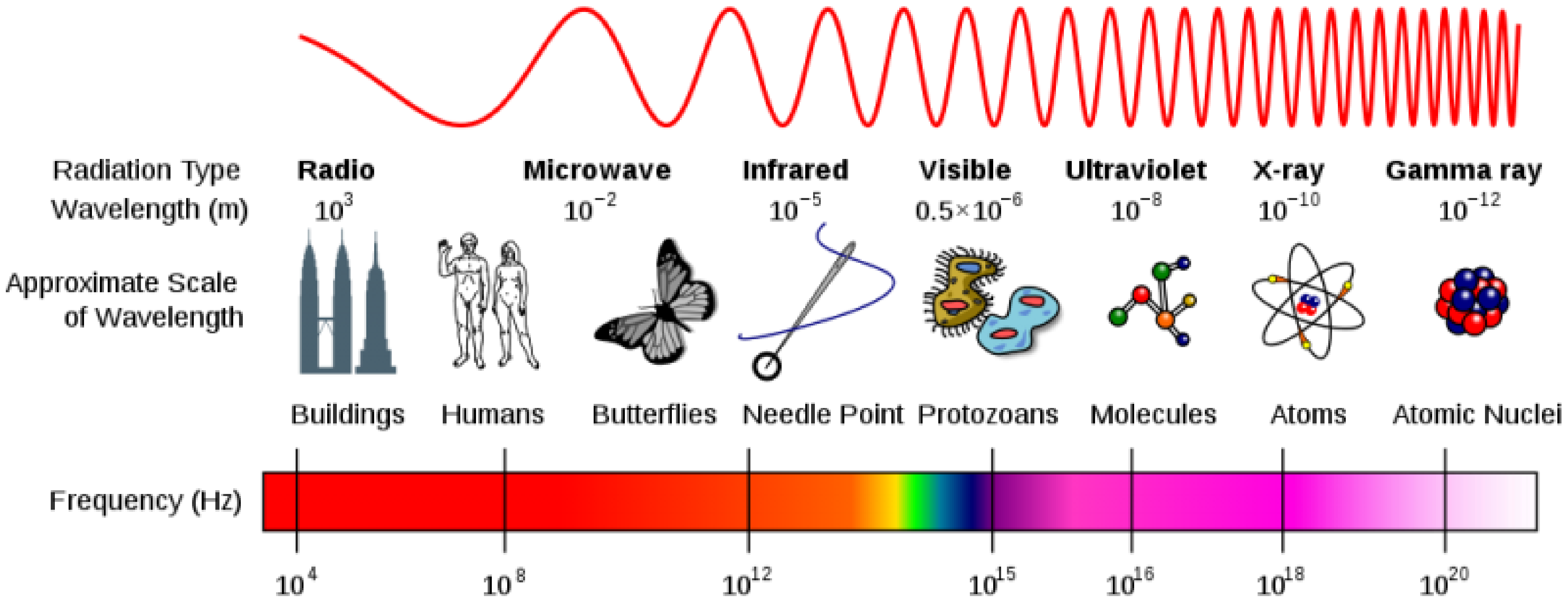


Photograph: GSSI

Field Example…Pipes

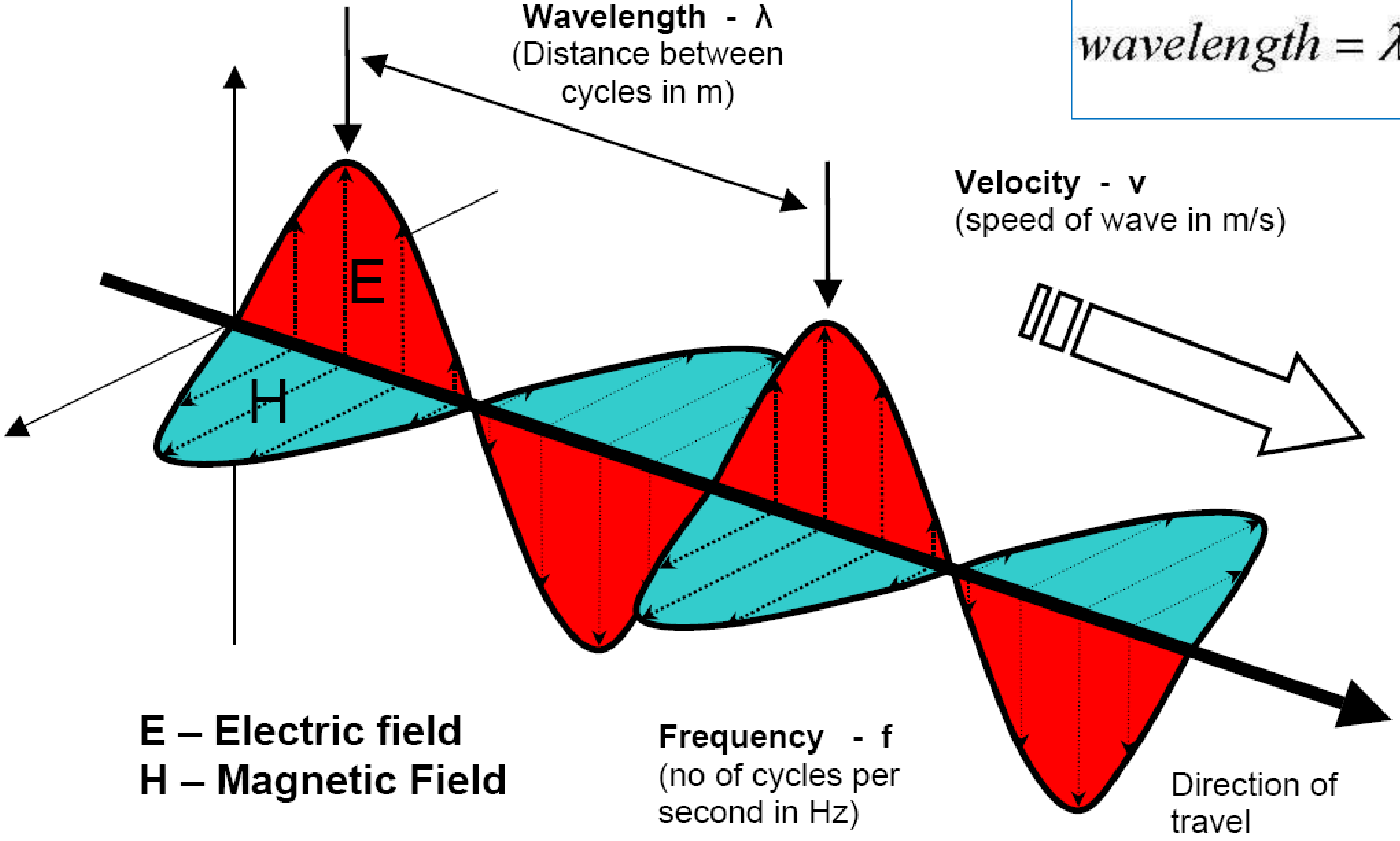


Electromagnetic Spectrum



GPR waves are ***electromagnetic waves*** (EM) in the radio wave spectrum of ~10MHz - 2GHz.

Electromagnetic Wave Propagation in a Material



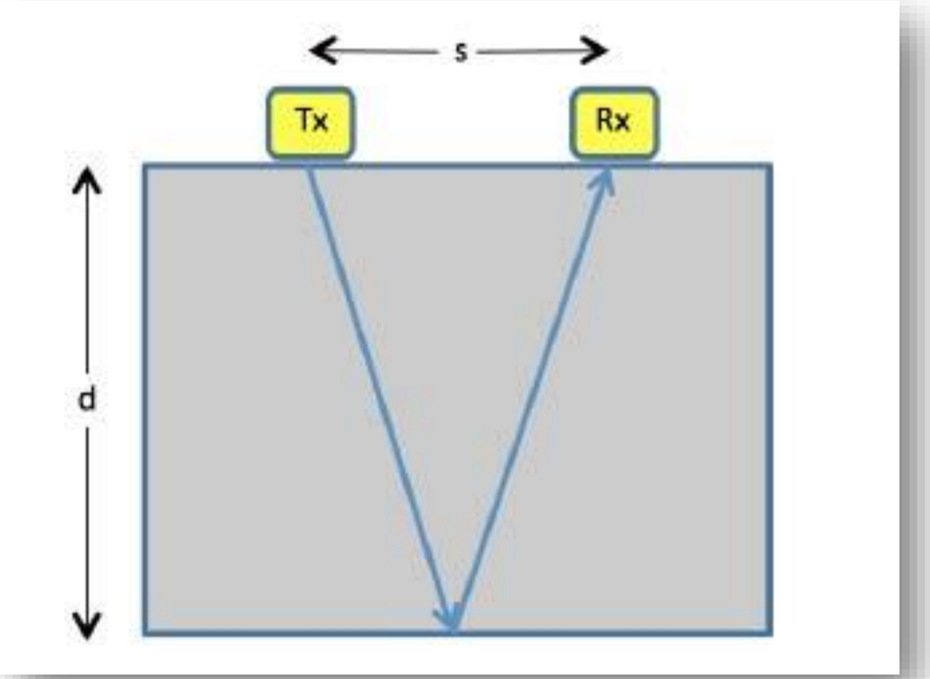
$$wavelength = \lambda = \frac{v}{f}$$

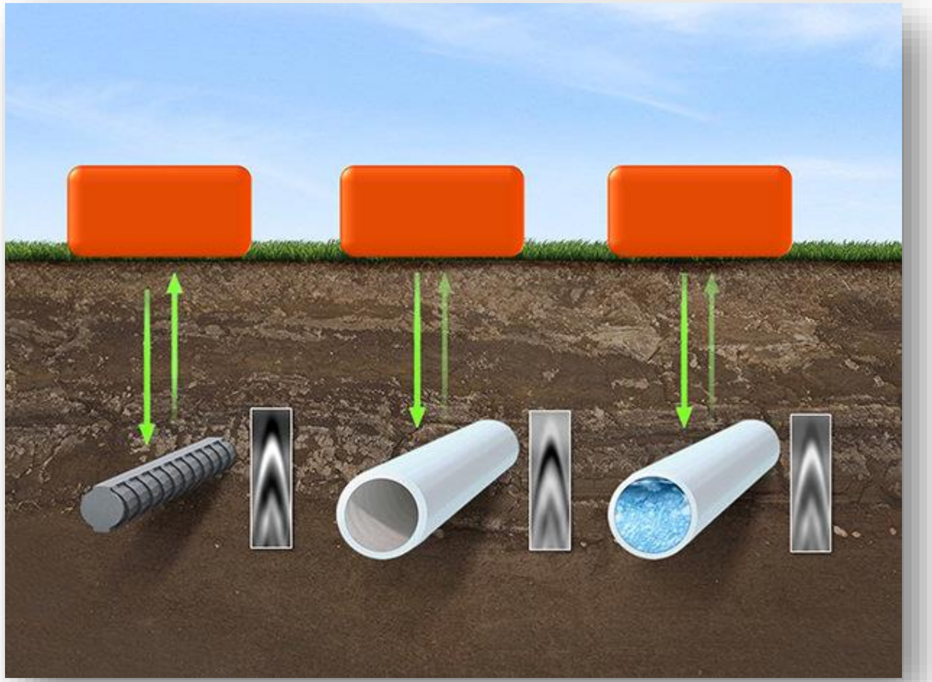
Ground Penetrating Radar Measures Travel Time & Amplitude

Propagation- Travel Time

Propagation is defined as the ability to travel at a certain speed. So if waves travel at a certain speed in a given material, and you can figure out that speed, then you can directly measure distances…or depths!

In case of GPR, working on principle of EM reflection, it's always Two Way Travel Time (TWTT)





Propagation- Velocity

$$\sqrt{K} = \frac{C}{V}$$

K = RDP

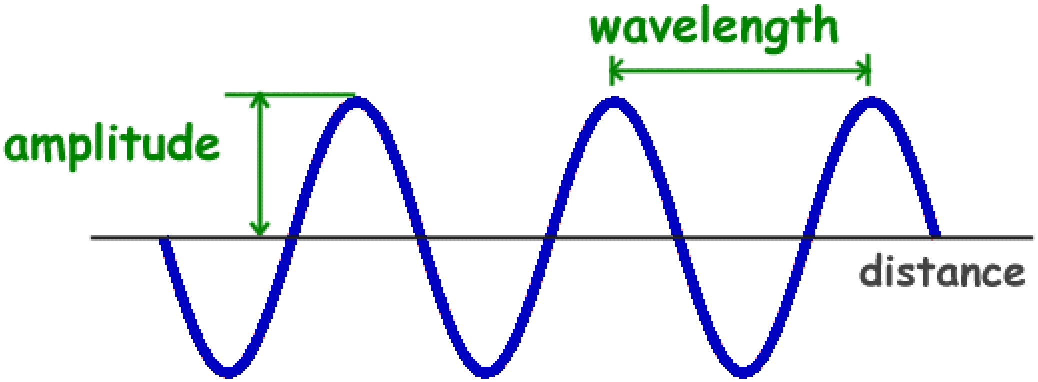
C = Speed of light

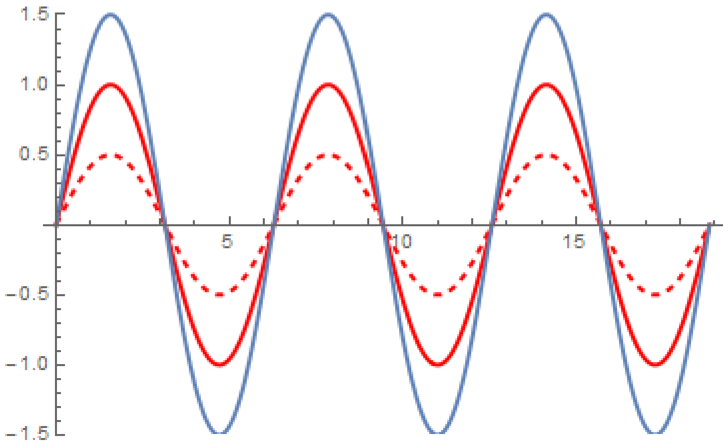
V = Velocity of radar energy

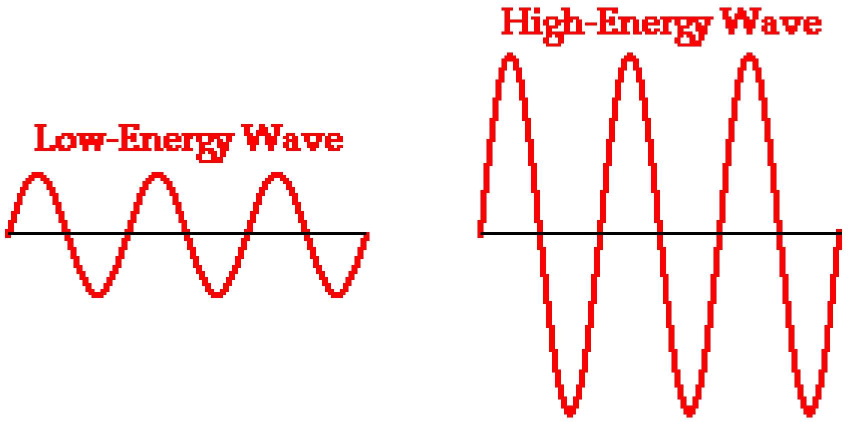
$$v = {c}/{\sqrt{\varepsilon_r}}$$

Medium	Relative Permittivity	Velocity [m/μs]
Air	1	300
Fresh water	81	33
Limestone	7 – 16	75 - 113
Granite	5 – 7	113 - 134
Concrete	4 – 10	95 - 150
Clay	4 – 16	74 - 150
Silt	9 – 23	63 - 100
Sand	4 – 30	55 - 150
Moraine	9 – 25	60 - 100
Ice	3 – 4	150 - 173
Permafrost	4 – 8	106 - 150

Amplitude







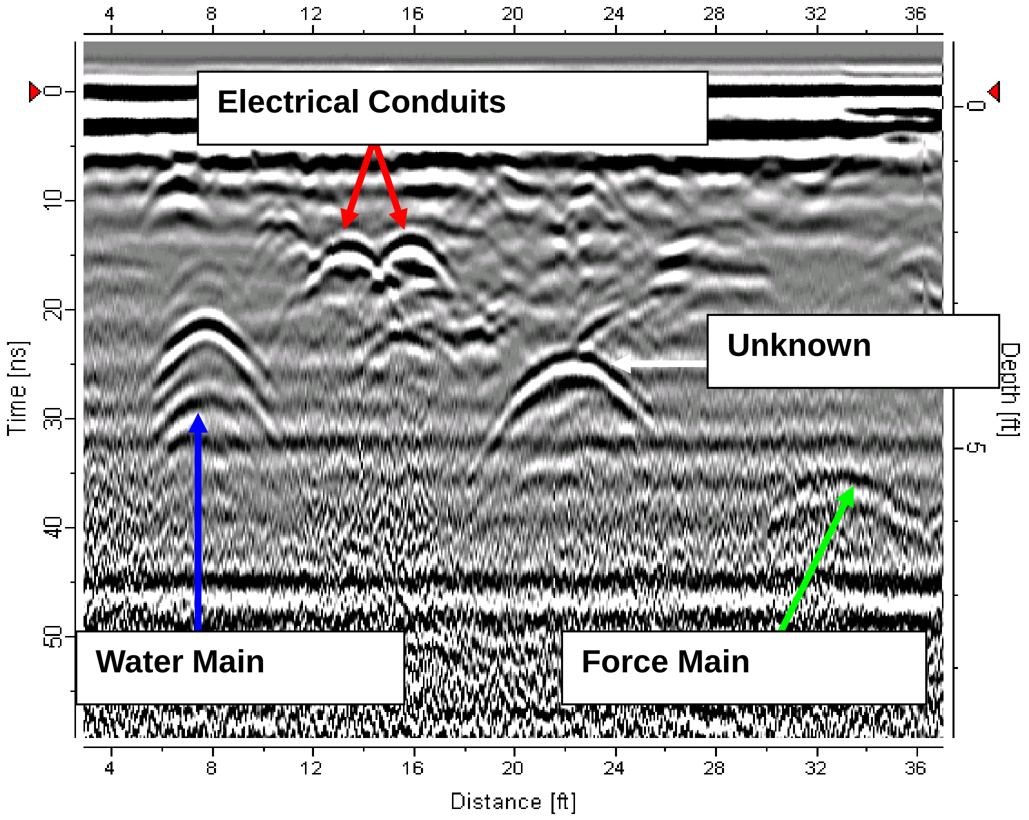
The amplitude of a wave is related to the energy which it transports.

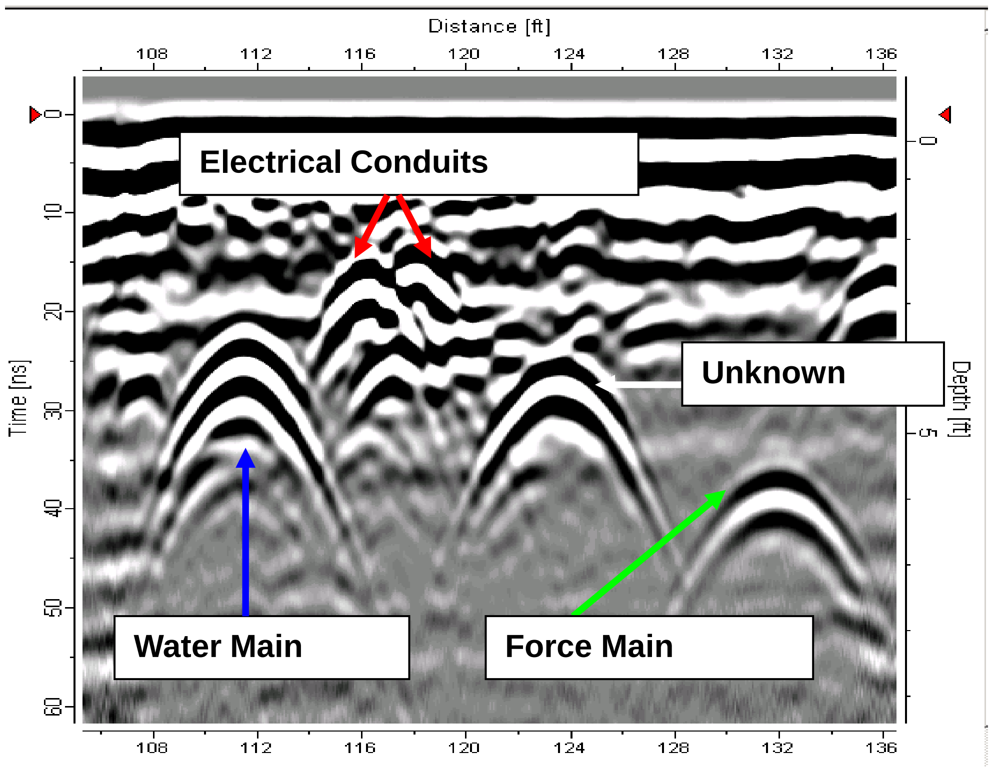
Wavelength v/s Velocity

Antenna frequency (MHz)	Approximate target size in a damp soil (m)	Approximate target size in very dry sand (m)
1500	0.03	0.06
1000	0.1	0.3
500	0.2	0.4
250	0.3	0.6
100	0.5	1
50	1	2
20	2	4

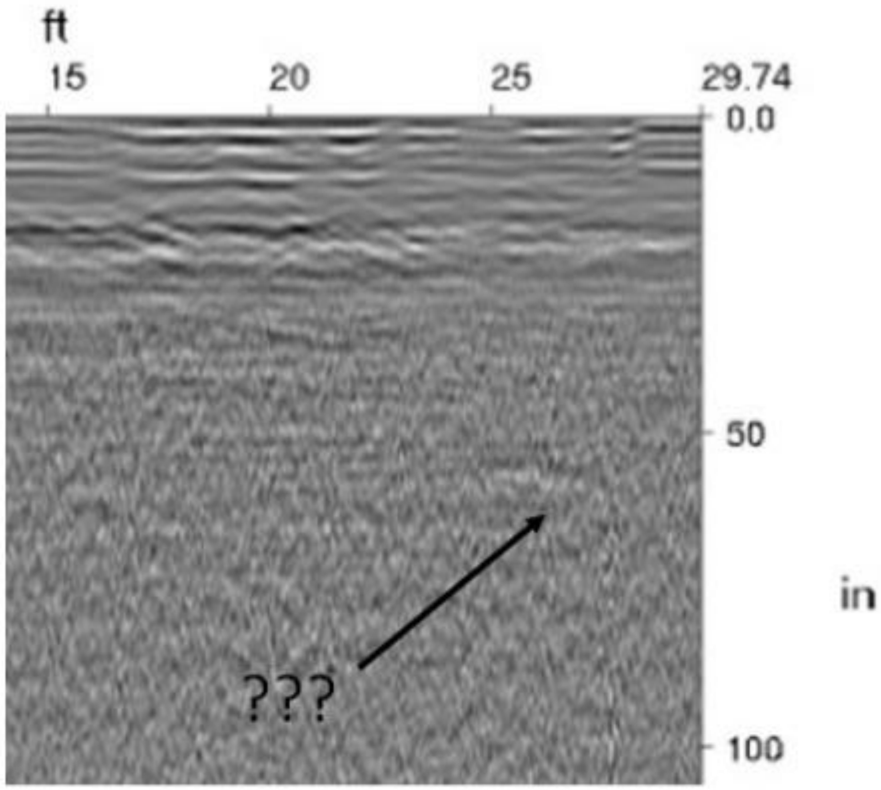
Antenna Frequency & Resolution:

- Comparison between 500 MHz and 350 MHz antenna responses. This illustrates the effect antenna frequency has on depth penetration and resolution.

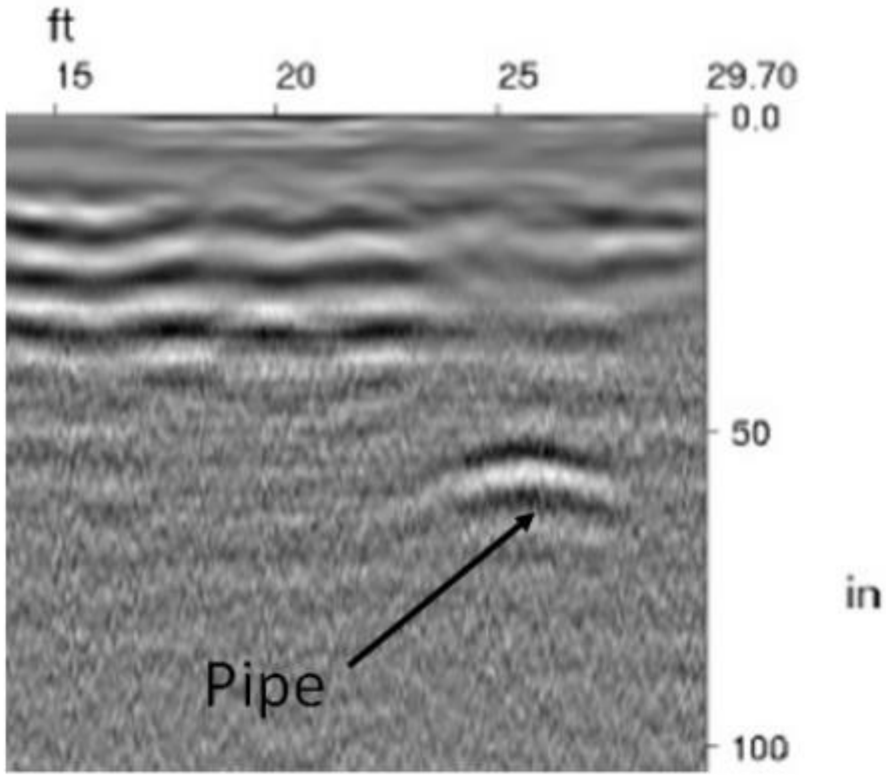




Antenna Frequency & Resolution:



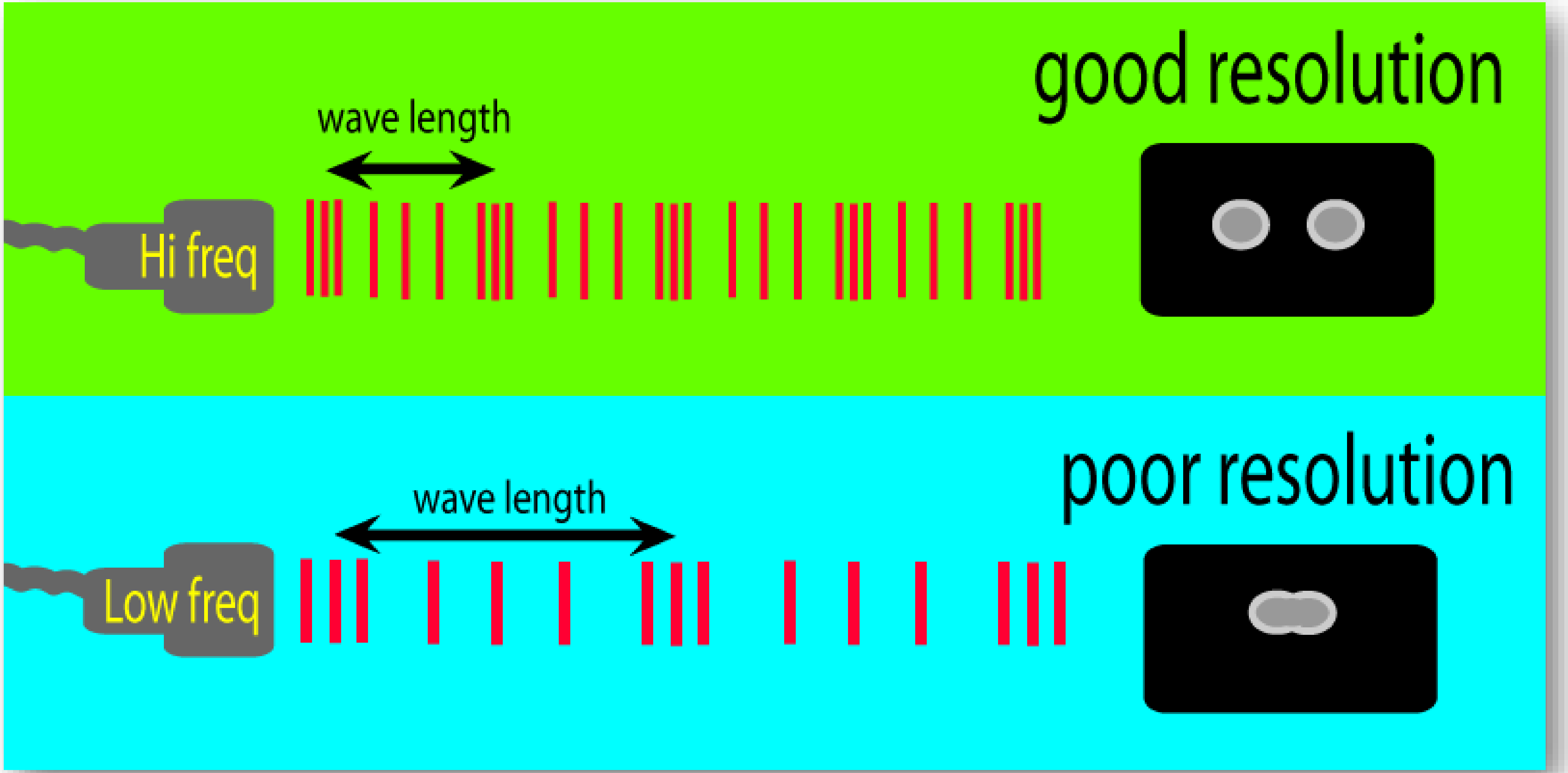
700 MHz



250 MHz

Reference: A Handbook for Ground Penetrating Radar Users by Daniel P. Bigman

Antenna Frequency & Resolution:



Material Properties of Mixtures

Pretend that you are working on a site that is composed of dry sand (an RDP of 6 for our example). You survey and locate all day long, but this is a multi-day project. So you head back to the hotel. When you wake up you find that it rained hard overnight. Now your soils are saturated with 10 percent water (an RDP of 81).

$$RDP = [(6 \text{ x } .9) + (81 \text{ x } .1)]$$

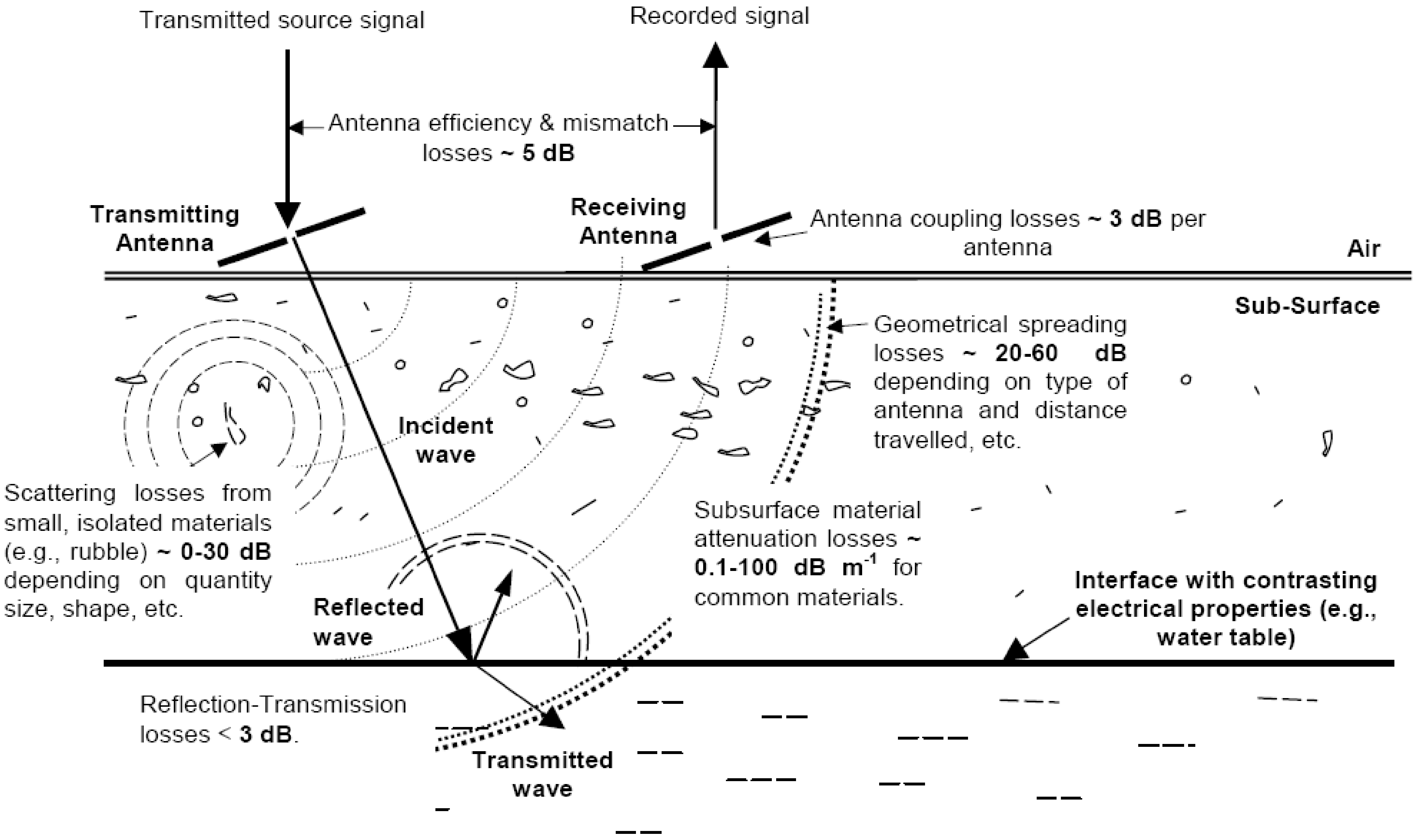
Now your site went from an RDP of 6 to an RDP of 13.5 and the conductance of the soil increased. This will create a totally different set of conditions for the second day of work, but you push on. You survey and locate all day and return to your hotel. When you wake up you find that it has rained again. Now your soils are saturated with 15 percent water.

$$RDP = [(6 \text{ x } .85) + (81 \text{ x } .15)]$$

Now your site has an RDP of 17.25 and again increased in conductance making your signal deteriorate even quicker.

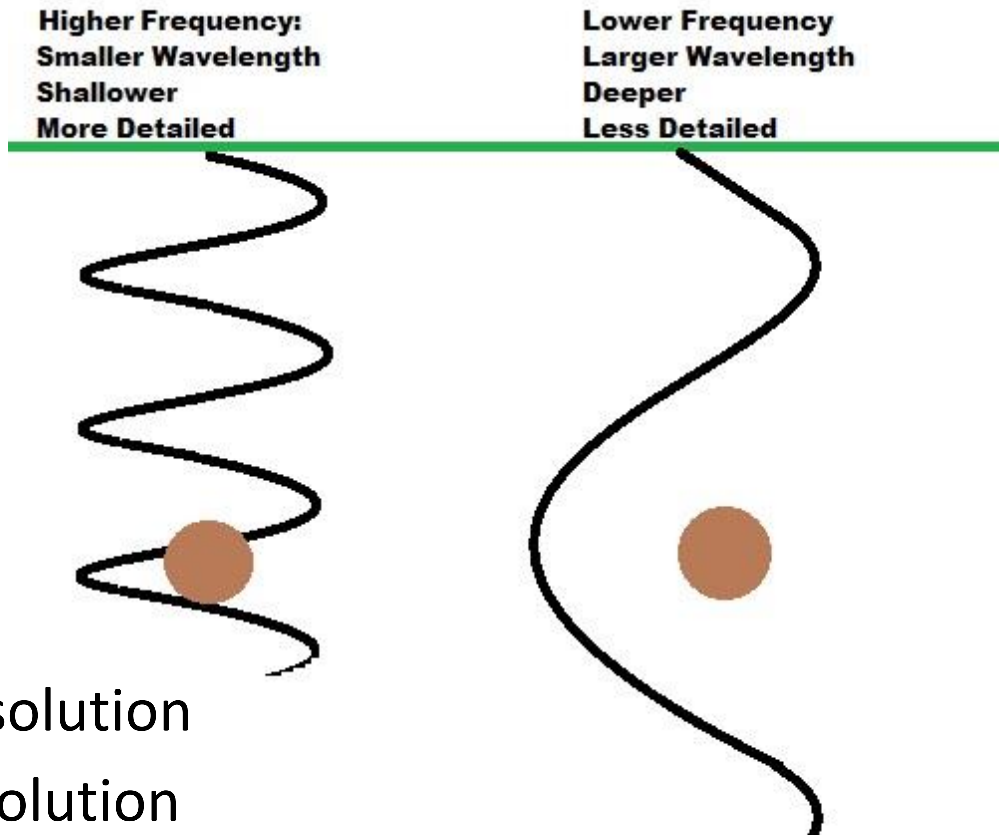
Reference: A Handbook for Ground Penetrating Radar Users by Daniel P. Bigman

GPR Signal Attenuation Paths



Factors affecting GPR penetration

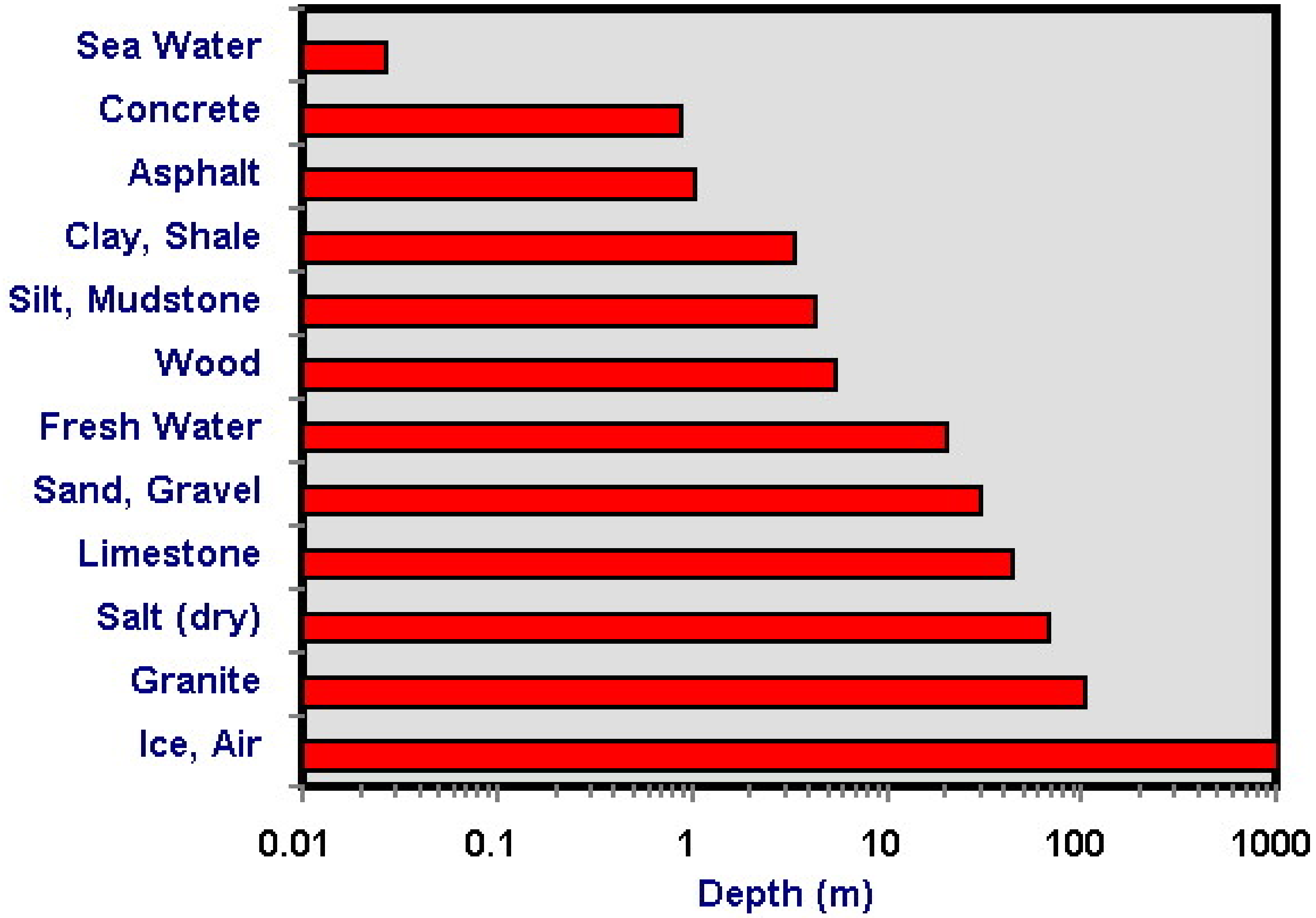
- Transmitted power,
- Dynamic range of the receiver,
- Attenuation of the ground material,
    - Conductivity losses,
    - Heating losses
    - Scattering losses
- Centre frequency of the transmitting antenna.
    - High Frequency- Low Penetration…High Resolution
    - Low Frequency- High Penetration…Low Resolution



GPR Suitability…Practical Note:

- **Above 100 Ohm-m**, GPR is usually a good method. Given that the other limitations does not prevent the use, GPR will be able to give cost effective results
- **Between 50 and 100 Ohm-m** the GPR technique may present good results. The conductivity though starts to become a factor to account for, especially if it is close to the lower limit.
- **Between 30 and 50 Ohm-m**, GPR may not be a good method. Severe limitation on penetration capabilities will occur, some results may be possible to achieve though.
- **Below 30 Ohms-m**, GPR is not a good technique. Other methods should be considered.

Potential Exploration Depth



GPR Blind Zone

	Antenna						
Parameter	2 GHz	900 MHz	500 MHz	300 MHz	150 MHz	75 MHz	38 MHz
Resolution, m	0.06-0.1	0.2	0.5	1.0	1.0	2.0	4.0
"Blind" zone, m	0.08	0.1-0.2	0.25-0.5	0.5-1.0	1.0	2.0	4.0

Detectability

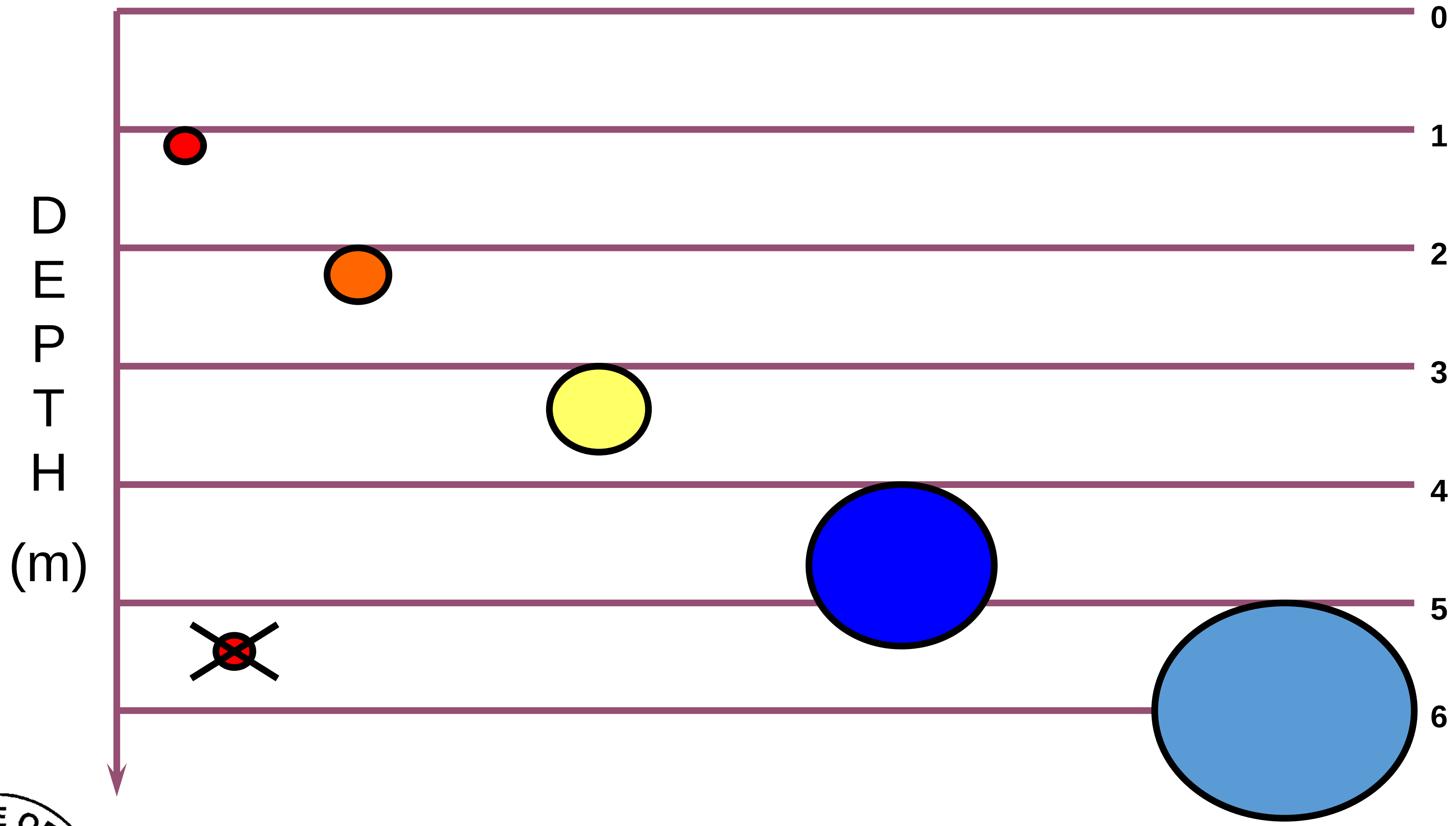
- Penetration depth and the ability to locate targets at any depth is strongly dependent upon local soil properties.

- Depth of penetration is also limited by the presence of highly conductive materials. **Highly conductive soils can render the GPR method ineffective**

- There must be a sufficient electrical contrast between the target and the host material to see a reflection.

- ¼ of the size of the wavelength
- A GPR target with a diameter of approximately 10% of the target depth
- A target with a diameter of 1 inch for every foot of penetration.

Target Size v/s Depth



- A GPR target with a diameter of approximately 10% of the target depth
- A target with a diameter of 1 inch for every foot of penetration.

Reflection Targets

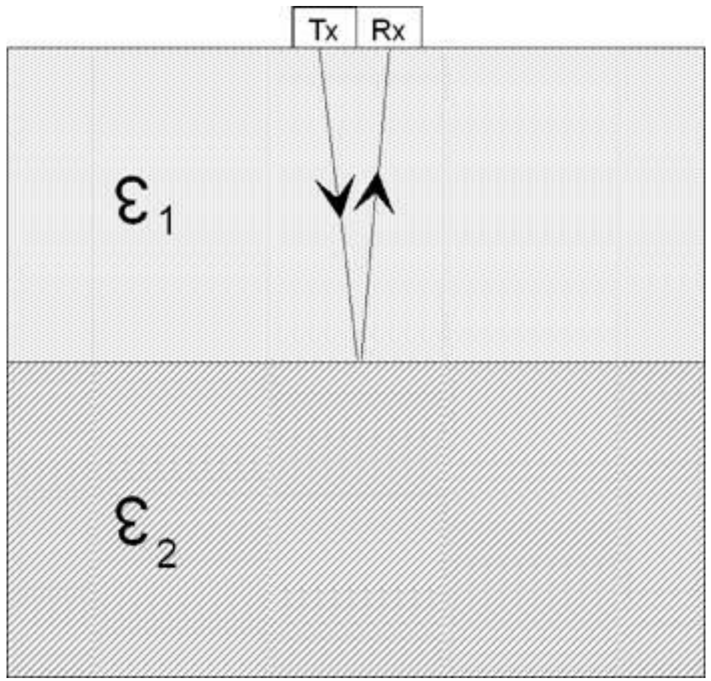
- Subsurface features, which may cause such reflections include:
  - Man made objects such as utilities, i.e. cables and pipes (**metallic and non-metallic**).
  - Underground Storage Tanks (UST).
  - Road construction…material layers.
  - Natural geologic conditions such as changes in soil composition, supporting layers, ice, groundwater table, bedrock, boulders, voids and more.

Strength of Reflection:

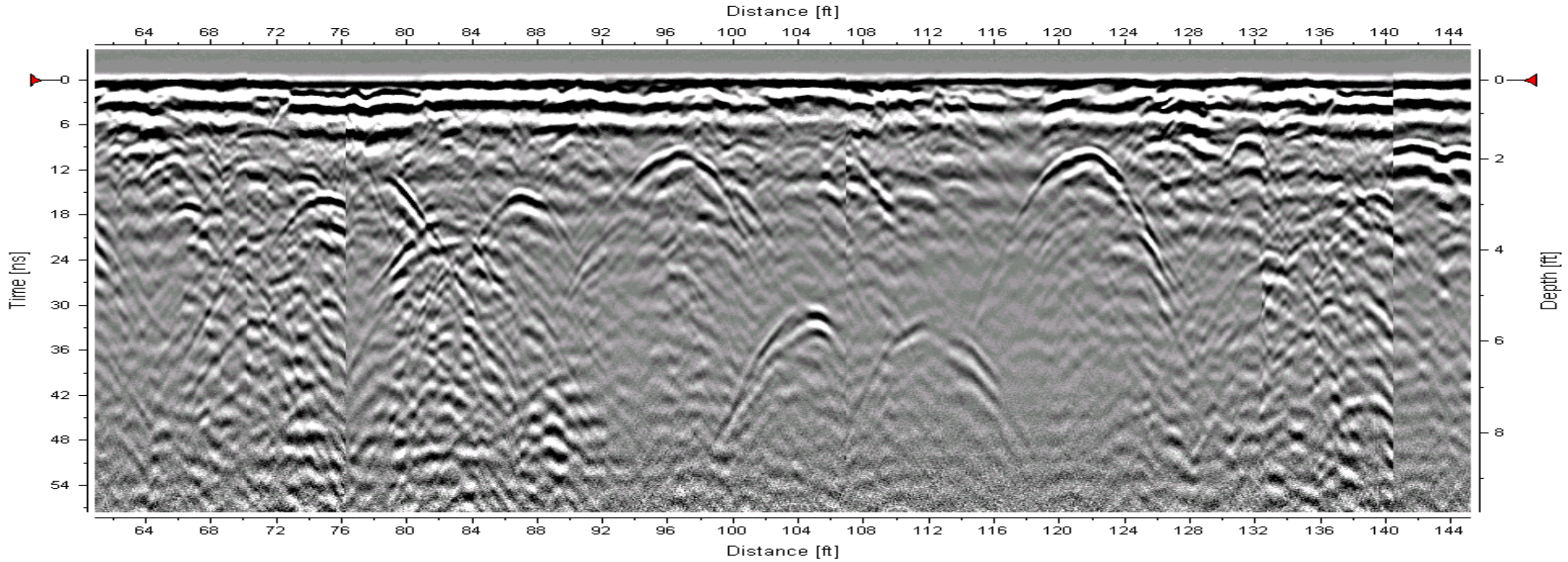
$$\text{Reflection Strength} = \sqrt{\varepsilon_1} - \sqrt{\varepsilon_2} \;/\; \sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}$$

ε_1: RDP of first material

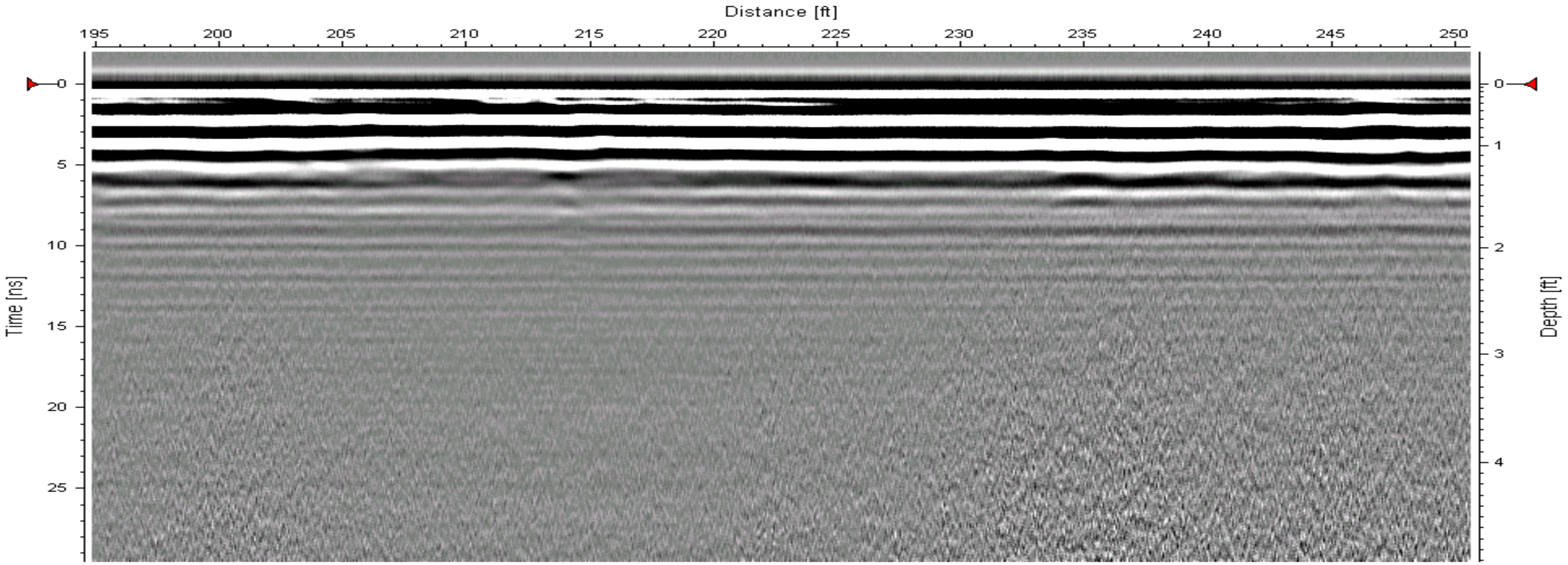
ε_2: RDP of second material



Site dependent performance example of GPR:



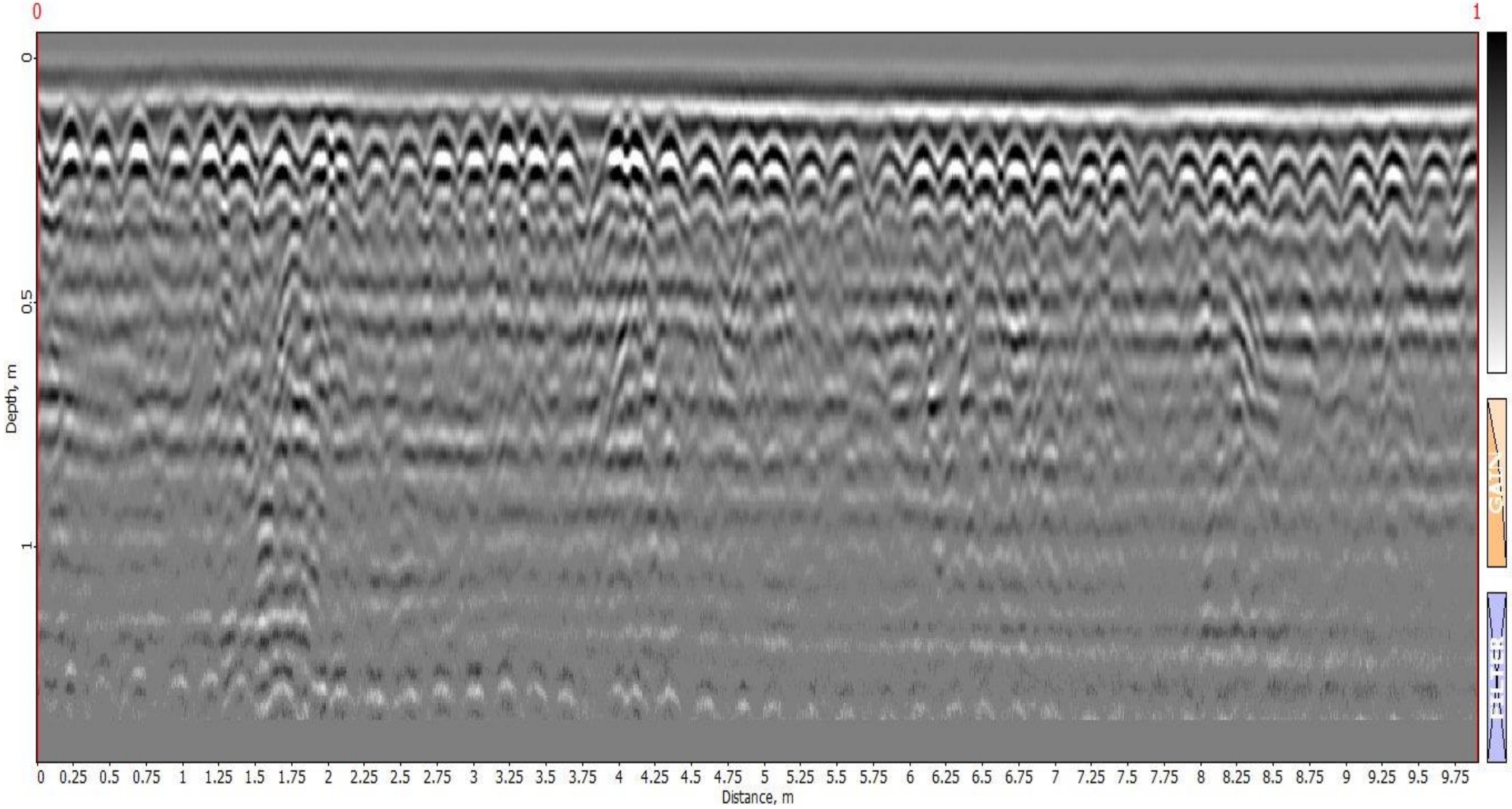
Silica Sand



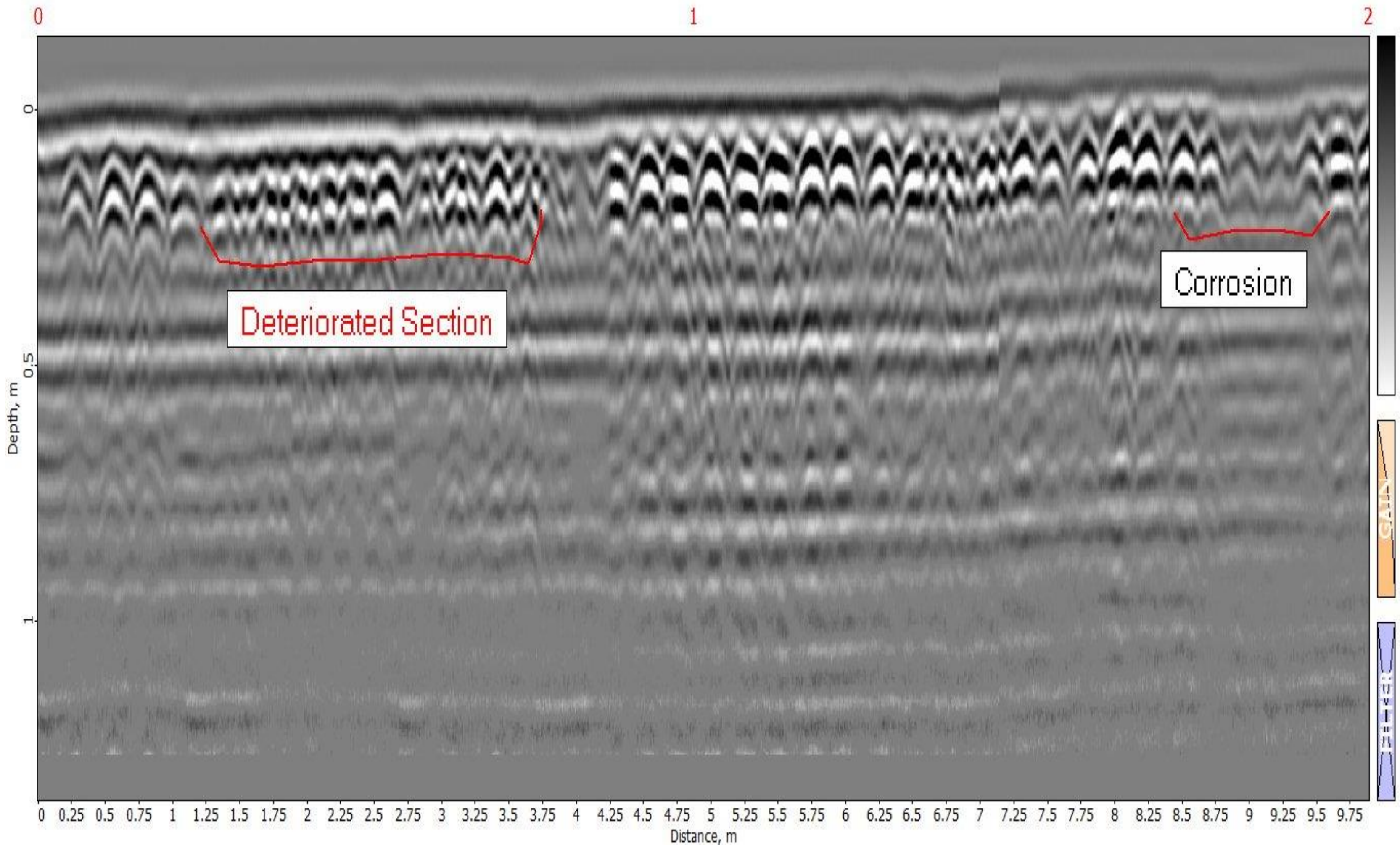
Clay

Applications:

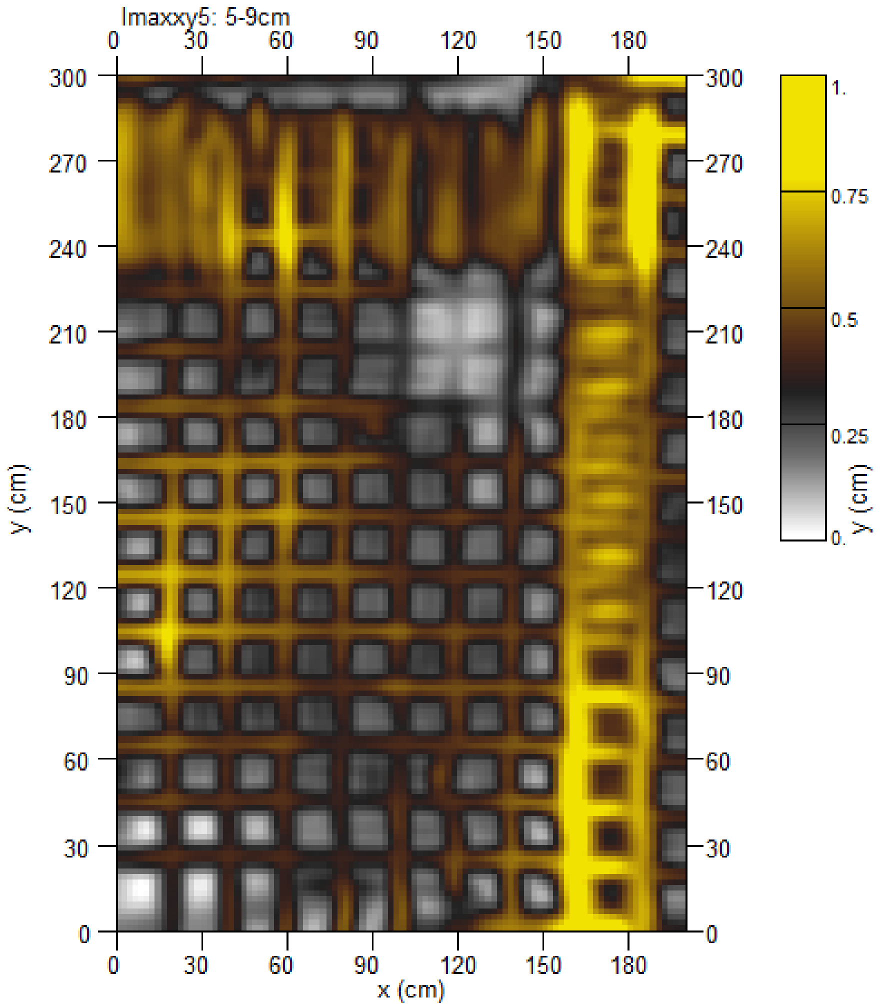
- Civil/ Structural Engineering
  - Utilities, rebar and voids. Pre-studies for Horizontal Directional Drilling (HDD)
  - Roadways and railroad tracks
  - Bridge deck and bridge foundation studies
- Environmental
  - Hazardous waste mapping, underground storage tanks (UST),
  - Sedimentology studies
  - Ice, snow
- Geotechnical
  - Stratigraphic mapping, cavities and sinkholes, groundwater, mining hazards, fracture detection, Earth dam studies, foundation studies, tunnel investigations.
- Military
  - Ordinance detection (UXO), runway integrity, clearing of trenching routes
- Archaeology
  - Site mapping, grave detection, artifacts

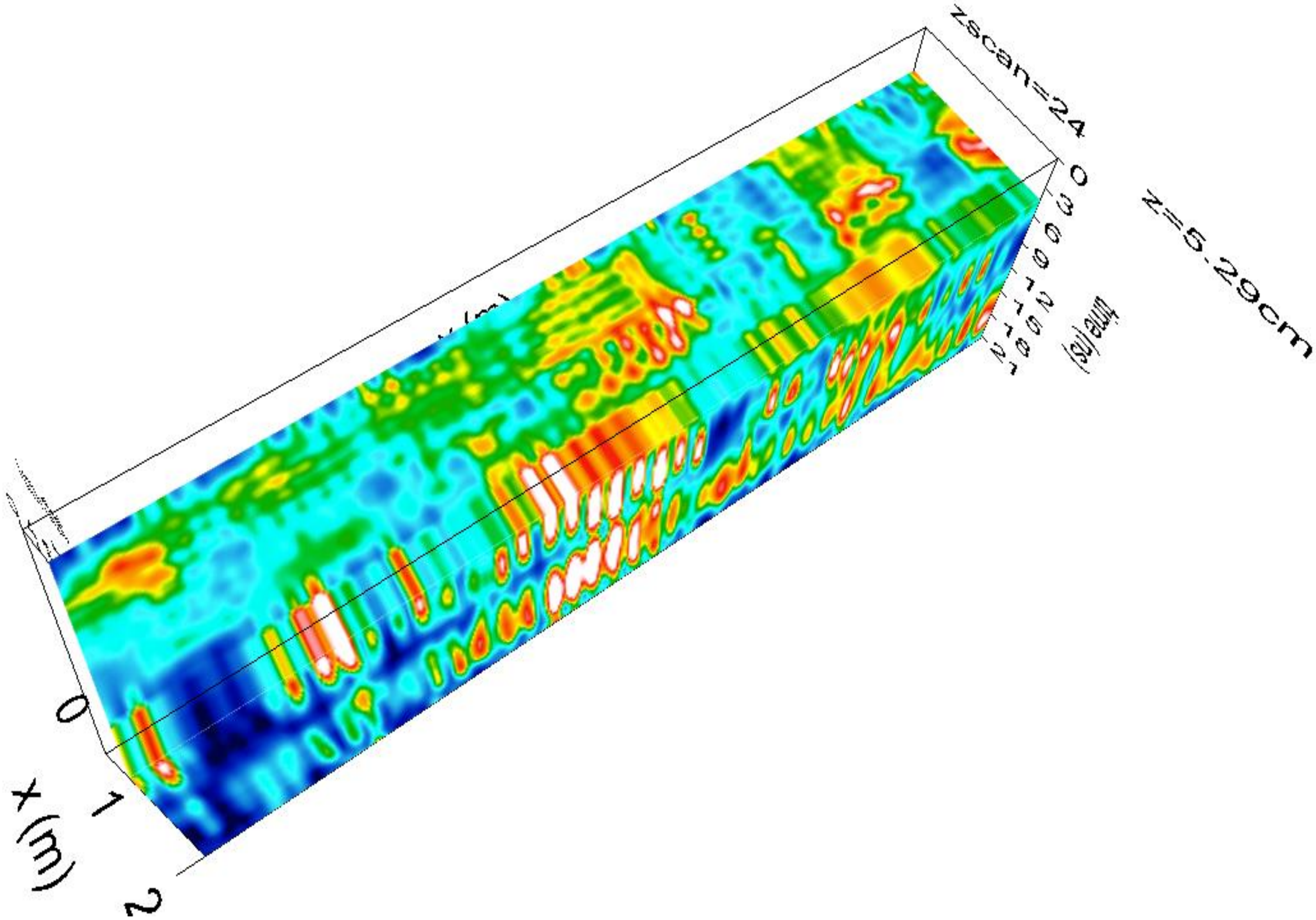


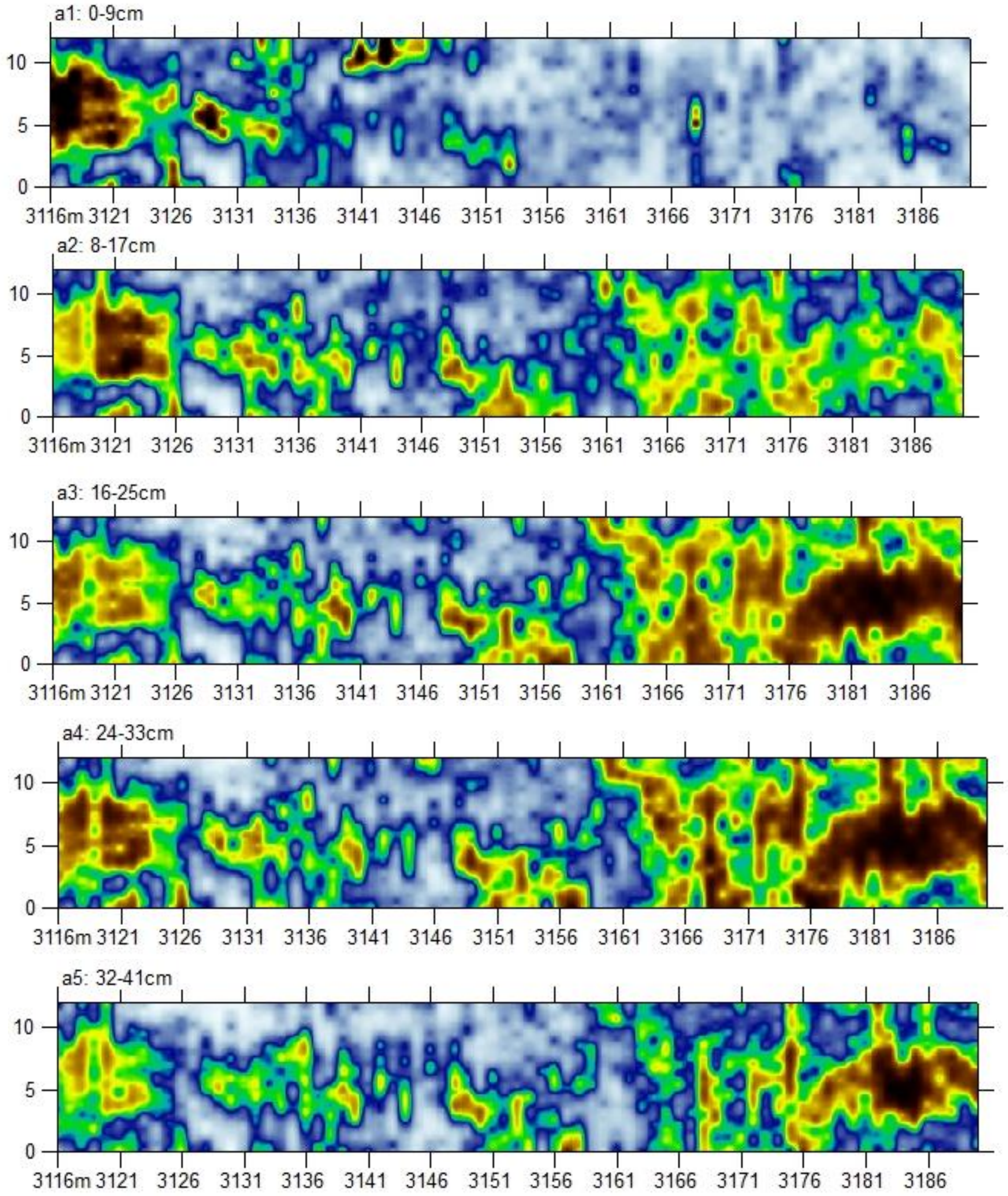
0
1
0
0.5
1
Depth, m
0 0.25 0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5 2.75 3 3.25 3.5 3.75 4 4.25 4.5 4.75 5 5.25 5.5 5.75 6 6.25 6.5 6.75 7 7.25 7.5 7.75 8 8.25 8.5 8.75 9 9.25 9.5 9.75
Distance, m

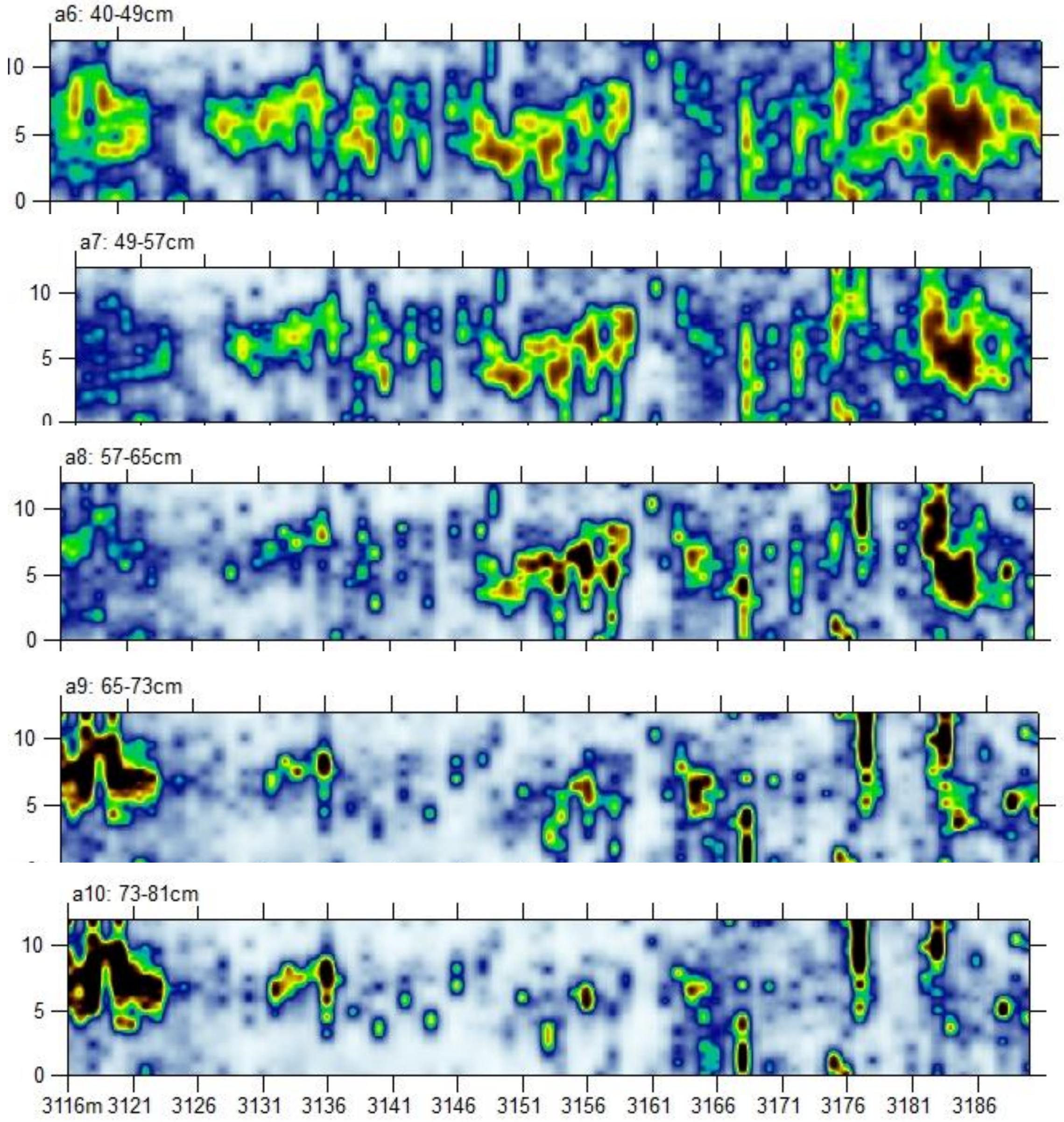


0
1
2
Deteriorated Section
Corrosion
Depth, m
Distance, m
0
0.5
1
0 0.25 0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5 2.75 3 3.25 3.5 3.75 4 4.25 4.5 4.75 5 5.25 5.5 5.75 6 6.25 6.5 6.75 7 7.25 7.5 7.75 8 8.25 8.5 8.75 9 9.25 9.5 9.75

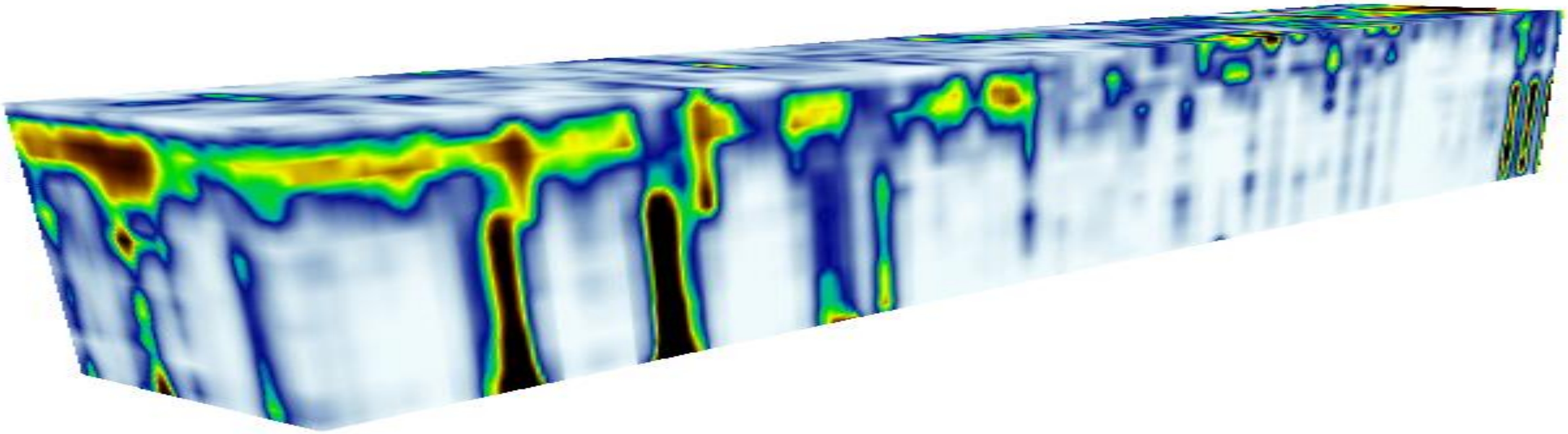

Imaxxy5: 5-9cm
x (cm)
y (cm)
0
30
60
90
120
150
180
210
240
270
300
1.
0.75
0.5
0.25
0.
y (cm)

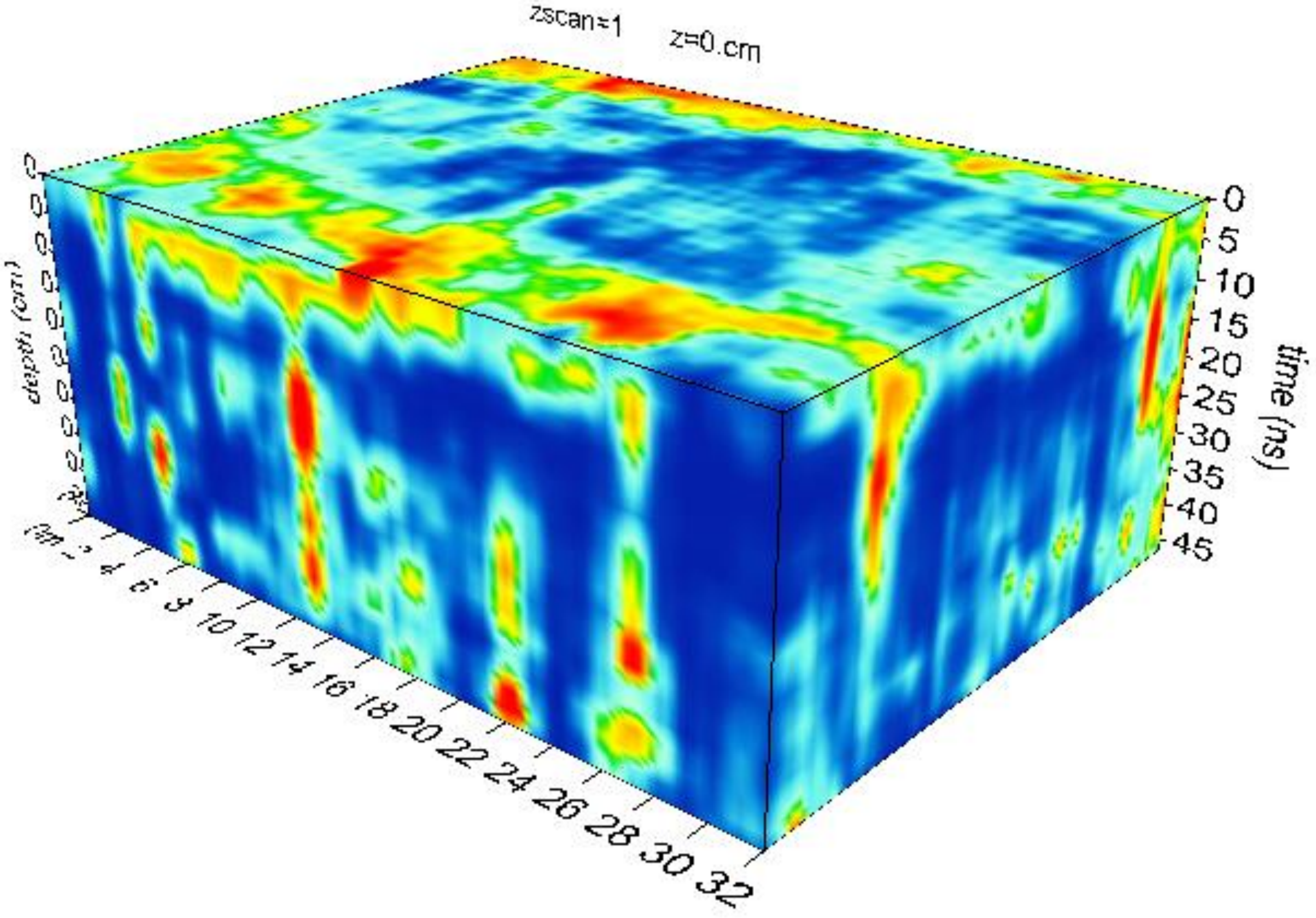

zscan=24
z=5.29cm
x (m)
0
1
2
time(ns)
0
3
6
9
12
15
18
21

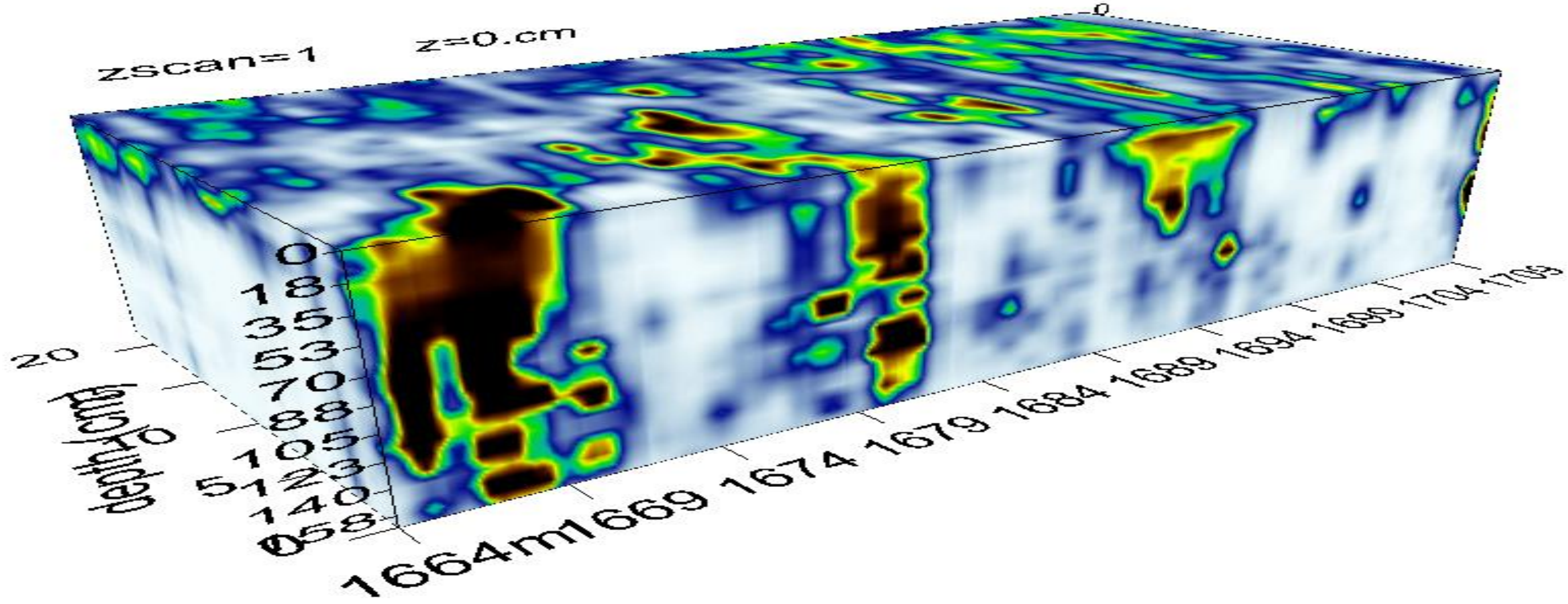

a1: 0-9cm
a2: 8-17cm
a3: 16-25cm
a4: 24-33cm
a5: 32-41cm
10
5
0
3116m 3121 3126 3131 3136 3141 3146 3151 3156 3161 3166 3171 3176 3181 3186



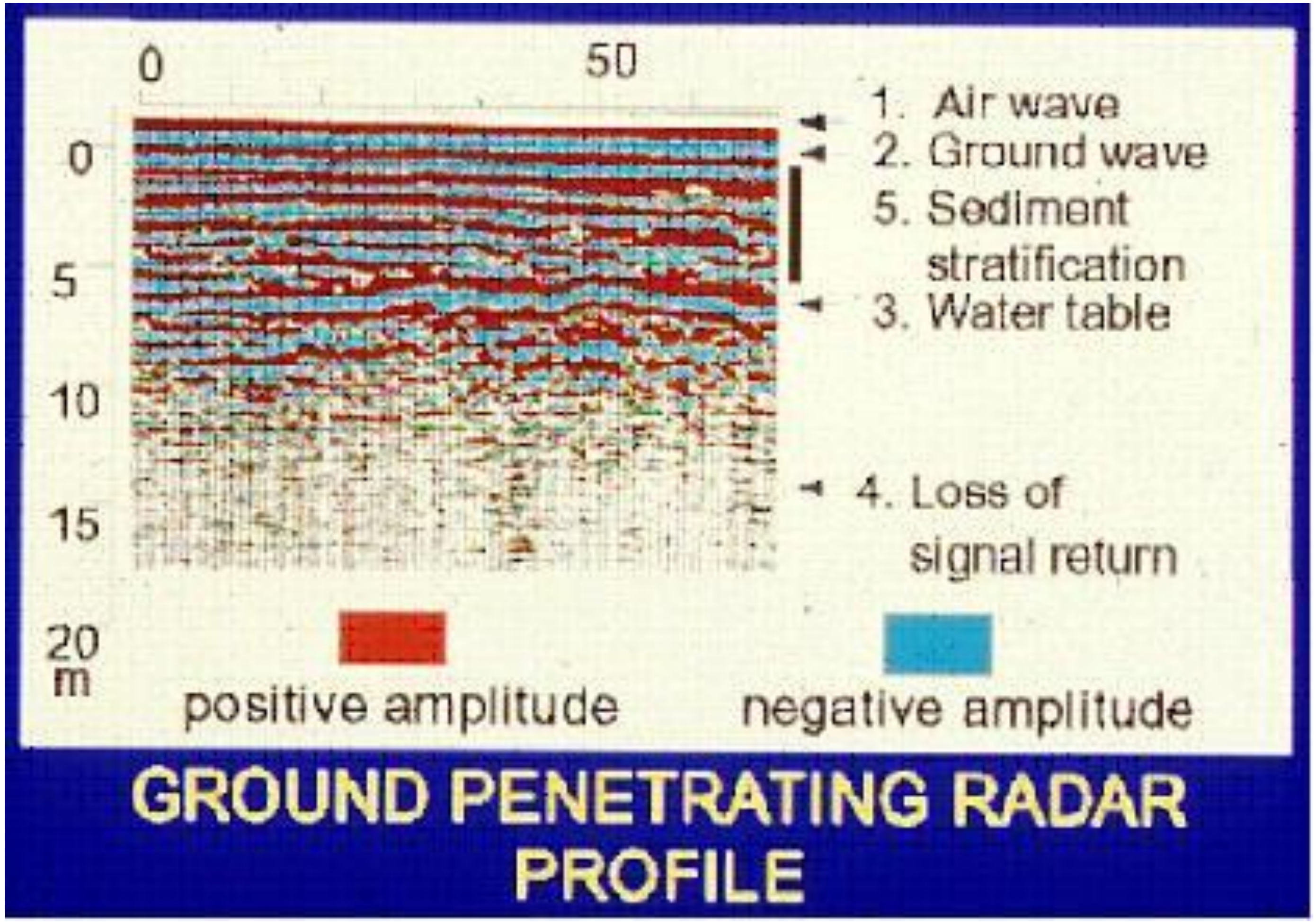
a6: 40-49cm
a7: 49-57cm
a8: 57-65cm
a9: 65-73cm
a10: 73-81cm
10
5
0
3116m 3121 3126 3131 3136 3141 3146 3151 3156 3161 3166 3171 3176 3181 3186



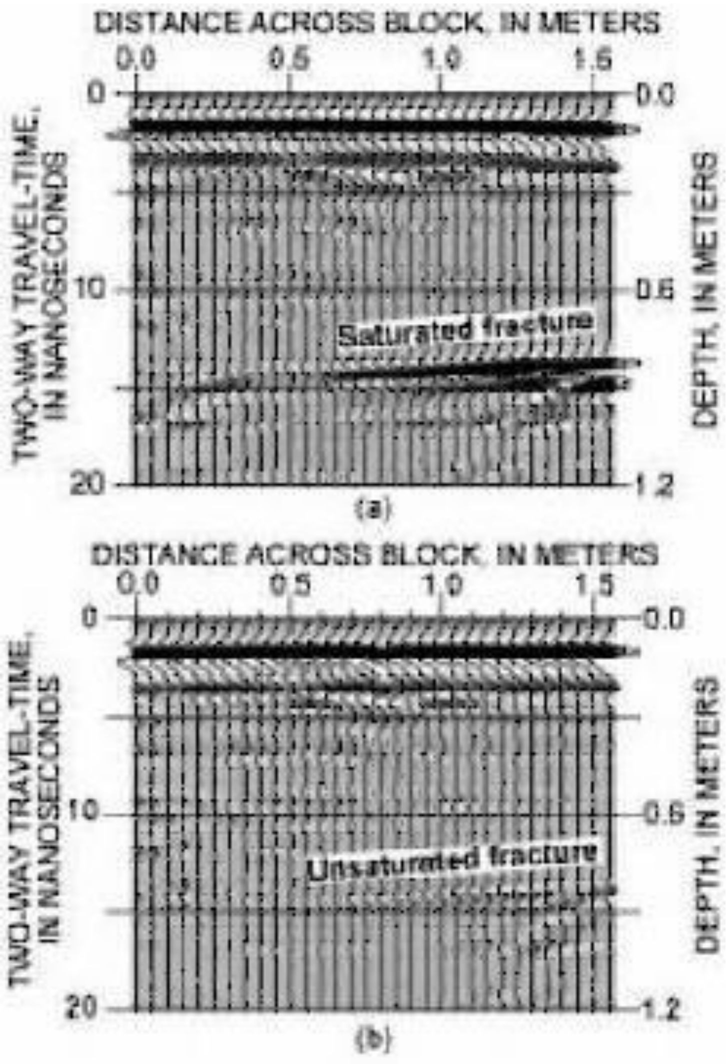

zscan=1
z=0.cm
depth (cm)
time (ns)
0
5
10
15
20
25
30
35
40
45
4
6
10
12
14
16
18
20
22
24
26
28
30
32


zscan=1
z=0.cm
0
18
35
53
70
88
105
123
140
158
20
depth/cm
1664m
1669
1674
1679
1684
1689
1694
1699
1704
1709

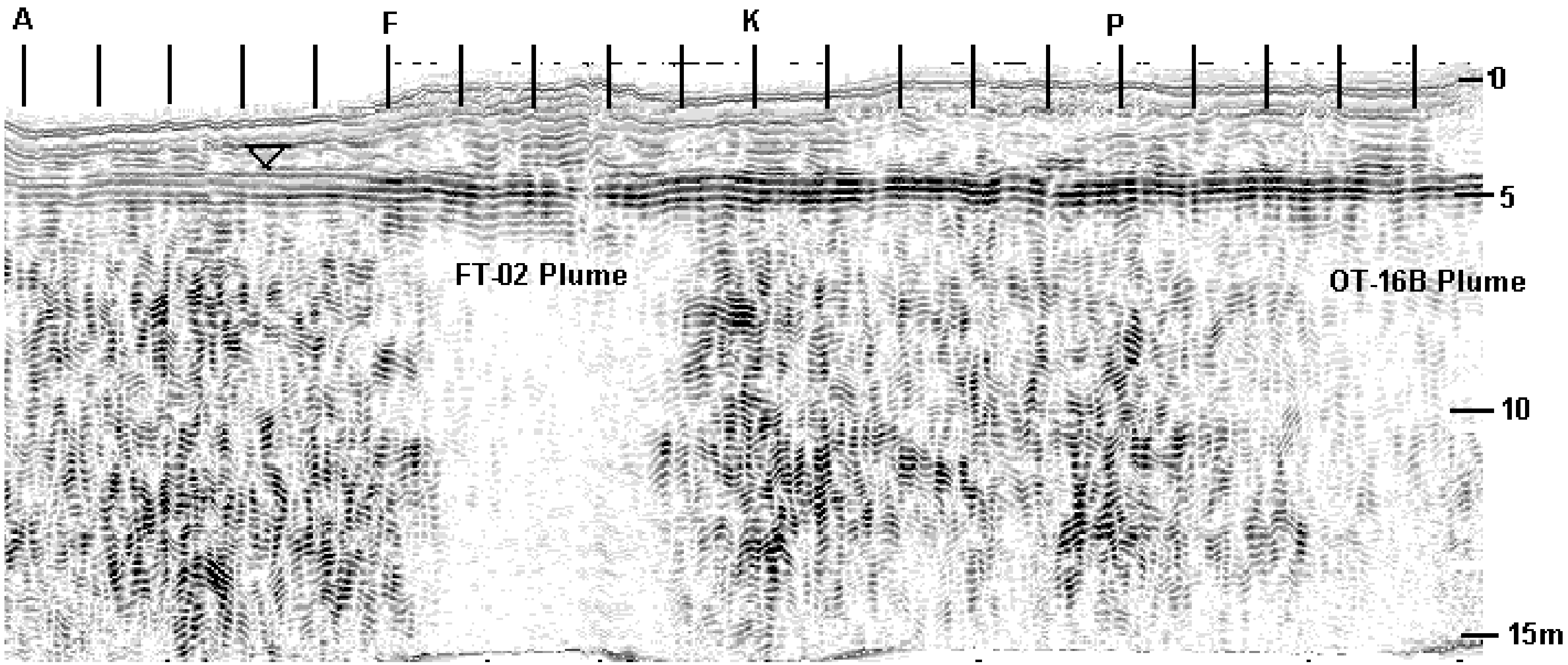
Water Table Mapping…….



Fractures……

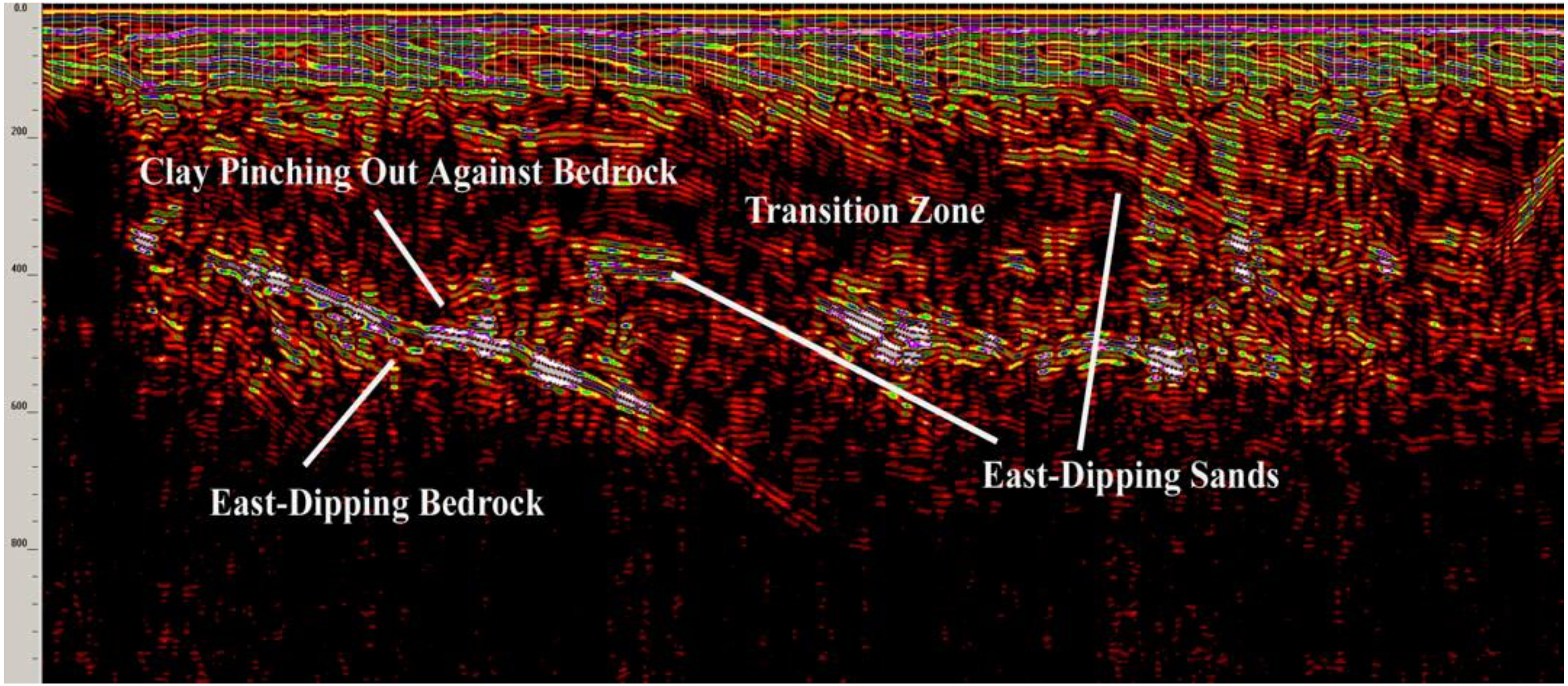

DISTANCE ACROSS BLOCK, IN METERS
0.0
0.5
1.0
1.5
0
10
20
0.0
0.6
1.2
TWO-WAY TRAVEL-TIME, IN NANOSECONDS
DEPTH, IN METERS
Saturated fracture
(a)
DISTANCE ACROSS BLOCK, IN METERS
0.0
0.5
1.0
1.5
0
10
20
0.0
0.6
1.2
TWO-WAY TRAVEL-TIME, IN NANOSECONDS
DEPTH, IN METERS
Unsaturated fracture
(b)

Direct Mapping of Plume……



Ground penetrating radar profile of Line 14 showing the strong amplitude shadow caused by the proximal end of the neighboring FT-02 plume, and the somewhat weaker shadow at the right end caused by the OT-16b plume. Source: EPA-542-R-00-003

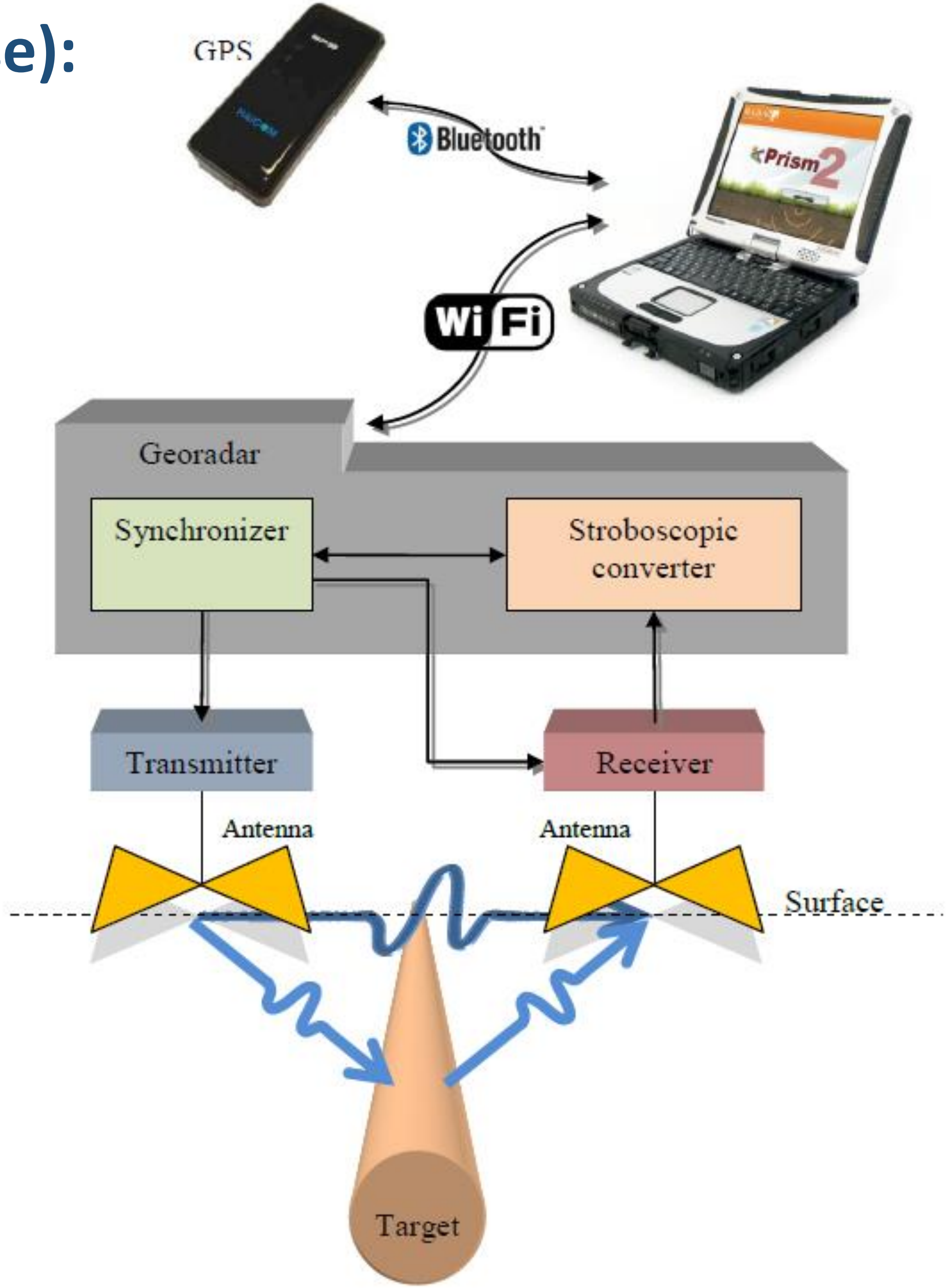
Stratigraphy……



A portion of the record for GPR Line 12c showing east-dipping sands and bedrock, as well as clay pinching out against the bedrock (near bedrock "notch").
Source: Hager GeoScience, Inc., Woburn, MA

Choice of Equipment

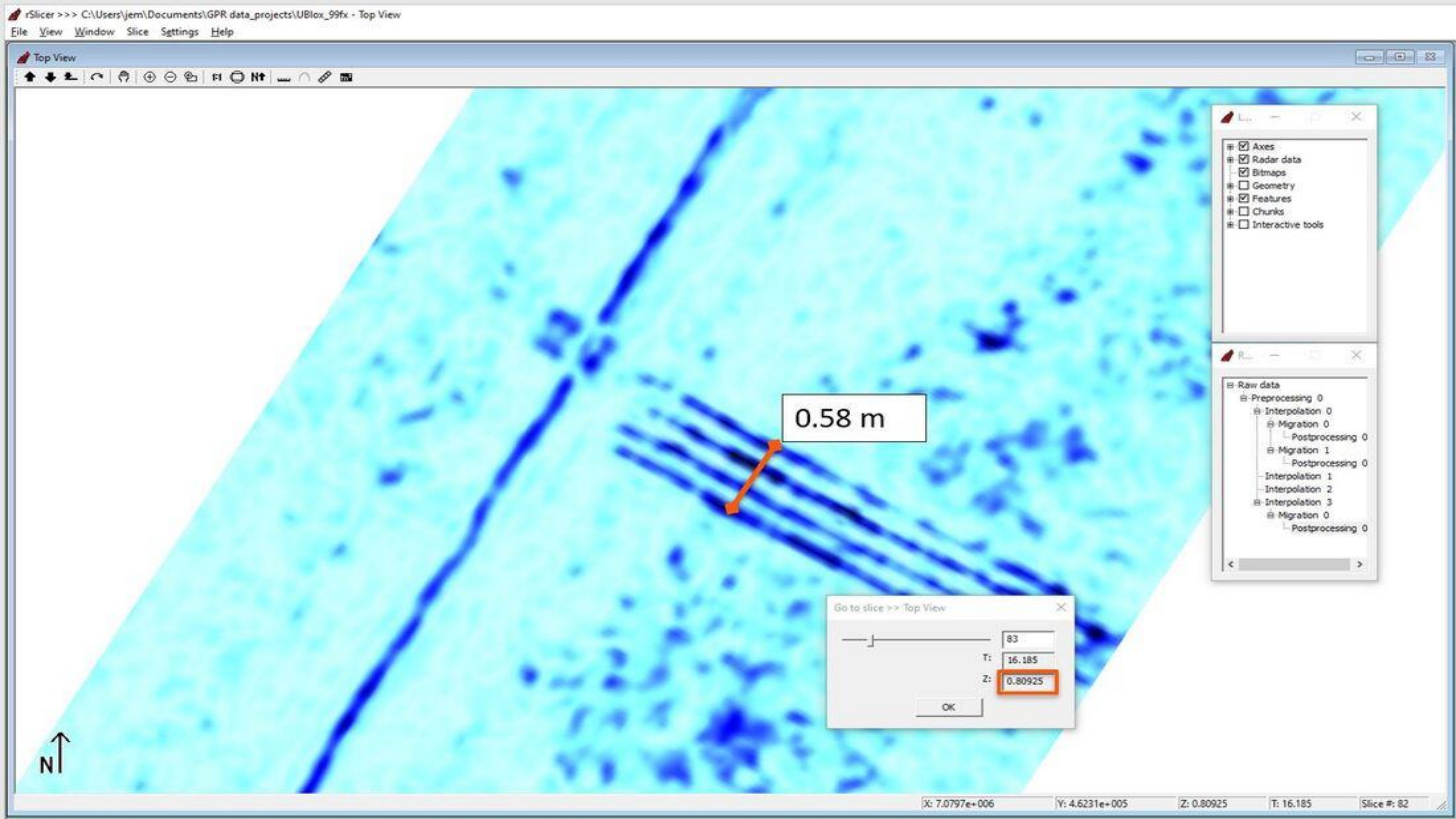
GPR Equipment (Impulse):



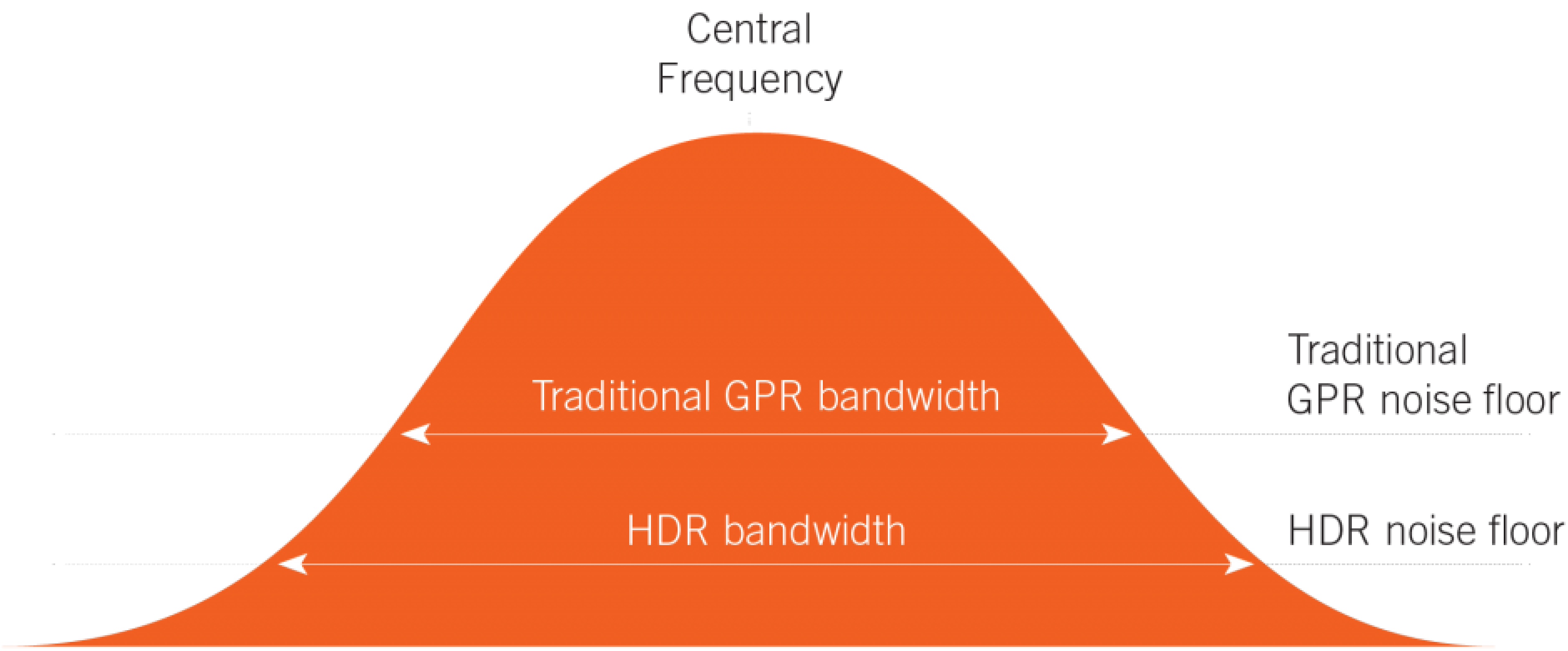
Single Frequency GPR…

Dual Frequency GPR…

Multi Channel GPR…

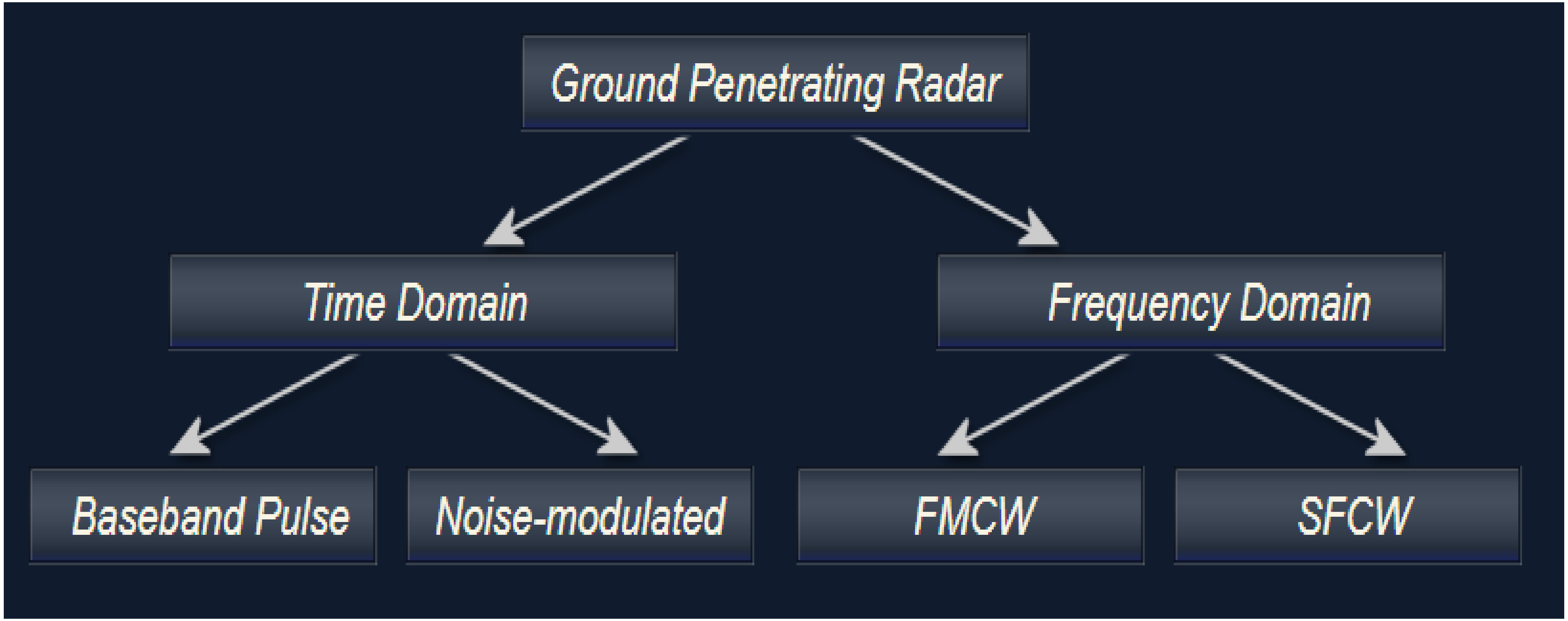

rSlicer >>> C:\Users\jem\Documents\GPR data_projects\UBlox_99fx - Top View
File View Window Slice Settings Help
Top View
Axes
Radar data
Bitmaps
Geometry
Features
Chunks
Interactive tools
Raw data
Preprocessing 0
Interpolation 0
Migration 0
Postprocessing 0
Migration 1
Postprocessing 0
Interpolation 1
Interpolation 2
Interpolation 3
Migration 0
Postprocessing 0
0.58 m
Go to slice >> Top View
83
T: 16.185
Z: 0.80925
OK
N
X: 7.0797e+006
Y: 4.6231e+005
Z: 0.80925
T: 16.185
Slice #: 82

HDR Antenna…



Central
Frequency
Traditional GPR bandwidth
Traditional
GPR noise floor
HDR bandwidth
HDR noise floor

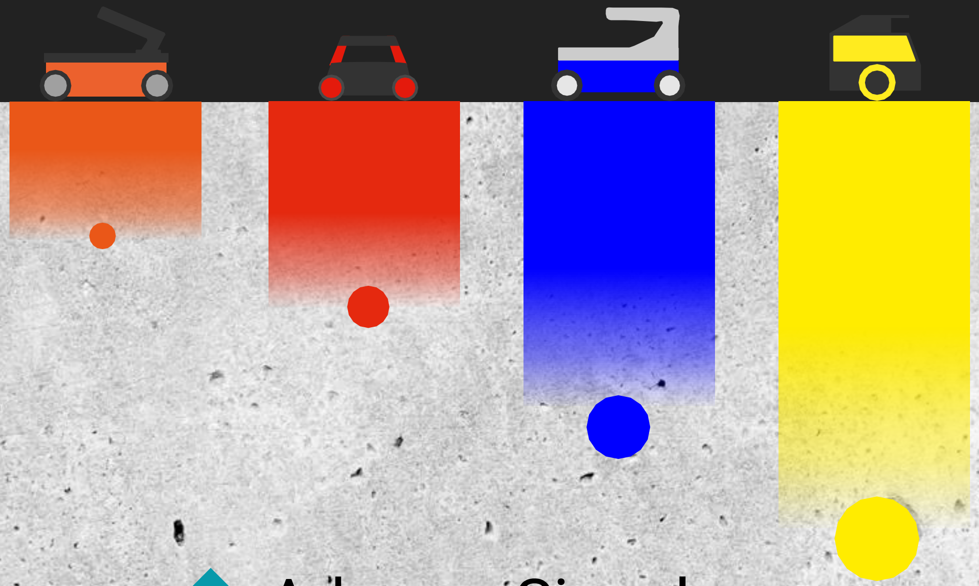
Types of GPR:



- **Frequency-modulated continuous-wave**
- **Step Frequency Continuous Wave Radar**

Time Domain GPR Limitations...

Frequency 2.6 2.0 1.6 1.0 GHz



Antenna Frequency

Adverse Signal Effects

Sensitivity to Discontinuities

Penetration Depth

Resolution

Stepped-Frequency Continuous Wave (SFCW) GPR

Equipment Selection….

Proceq GPR Subsurface

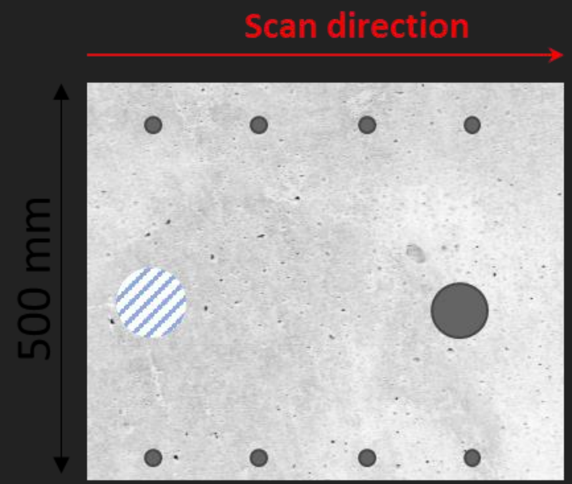
GS8000

The one solution for locating objects and mapping the underground world using SFCW ground penetrating radar technology.

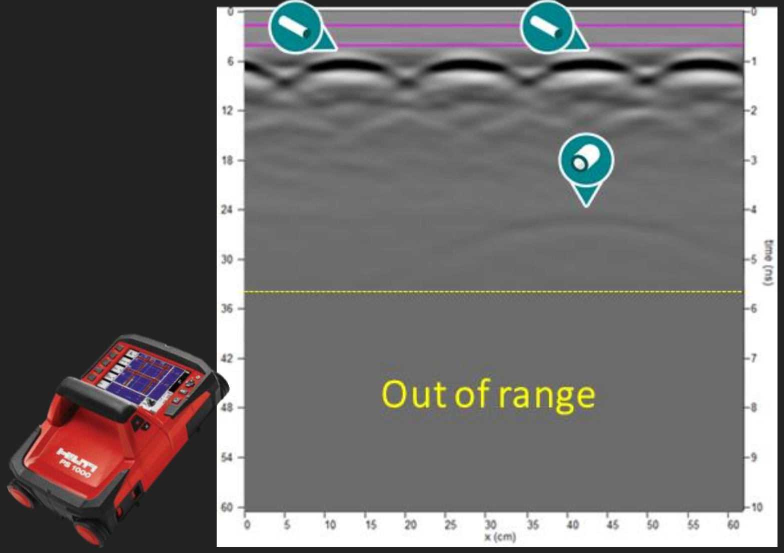
- Superior clarity of data, accurately geo-referenced
- It adapts to different terrains and applications
- Access to your data from anywhere, anytime

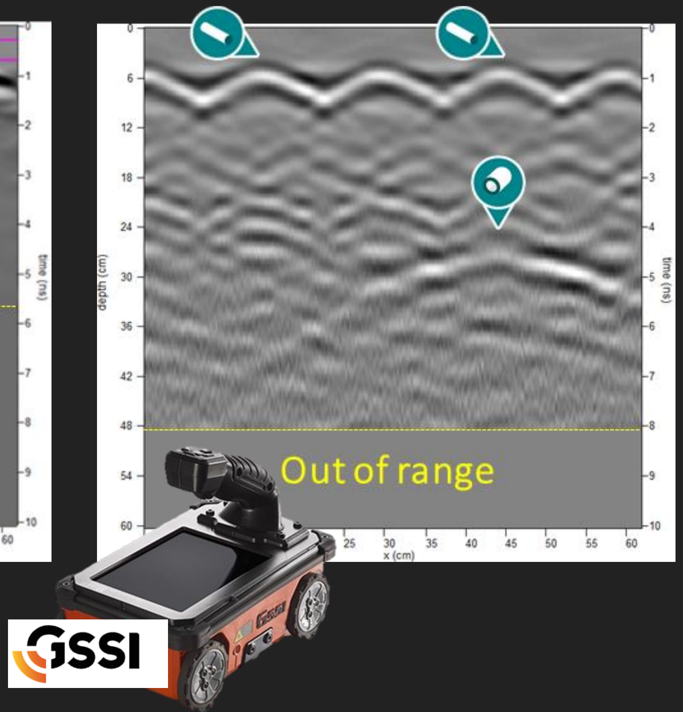
Applications:

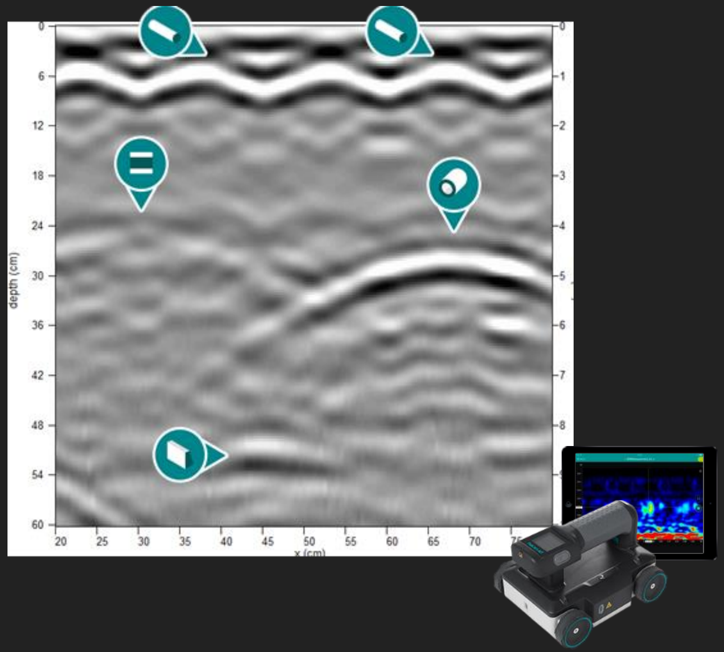
Utility strike prevention / Subsurface utility engineering (SUE) / Asset inspection (bridges, asphalt) / Geophysical investigations / Archeology / Forensics



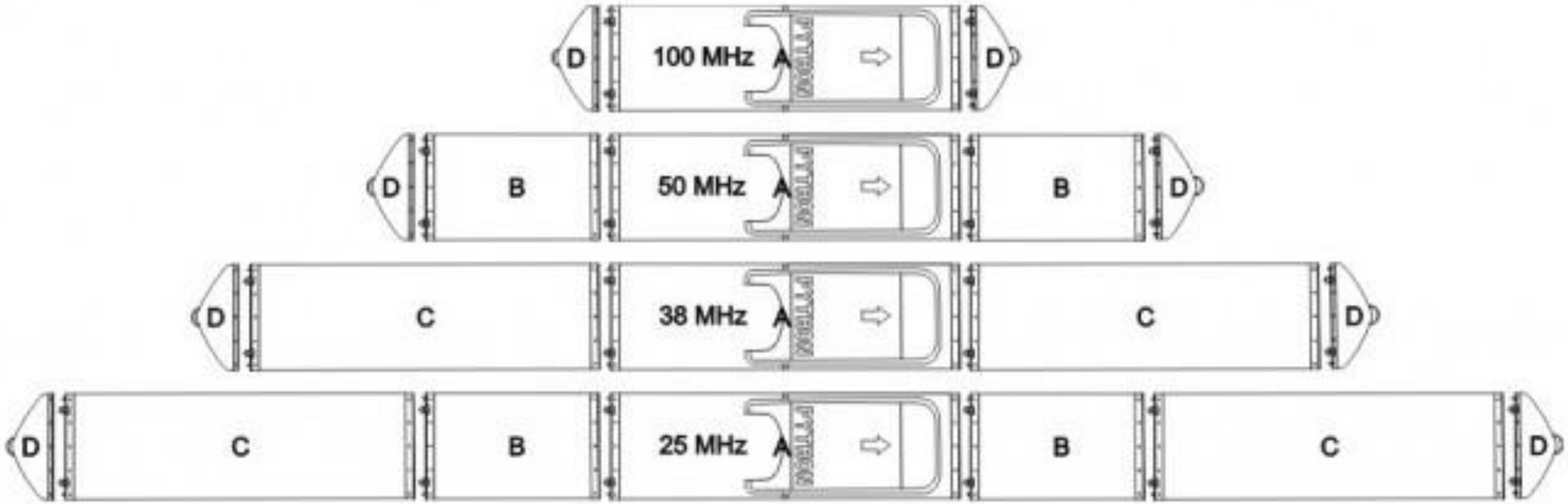
What impact does SFCW GPR have in concrete scans?

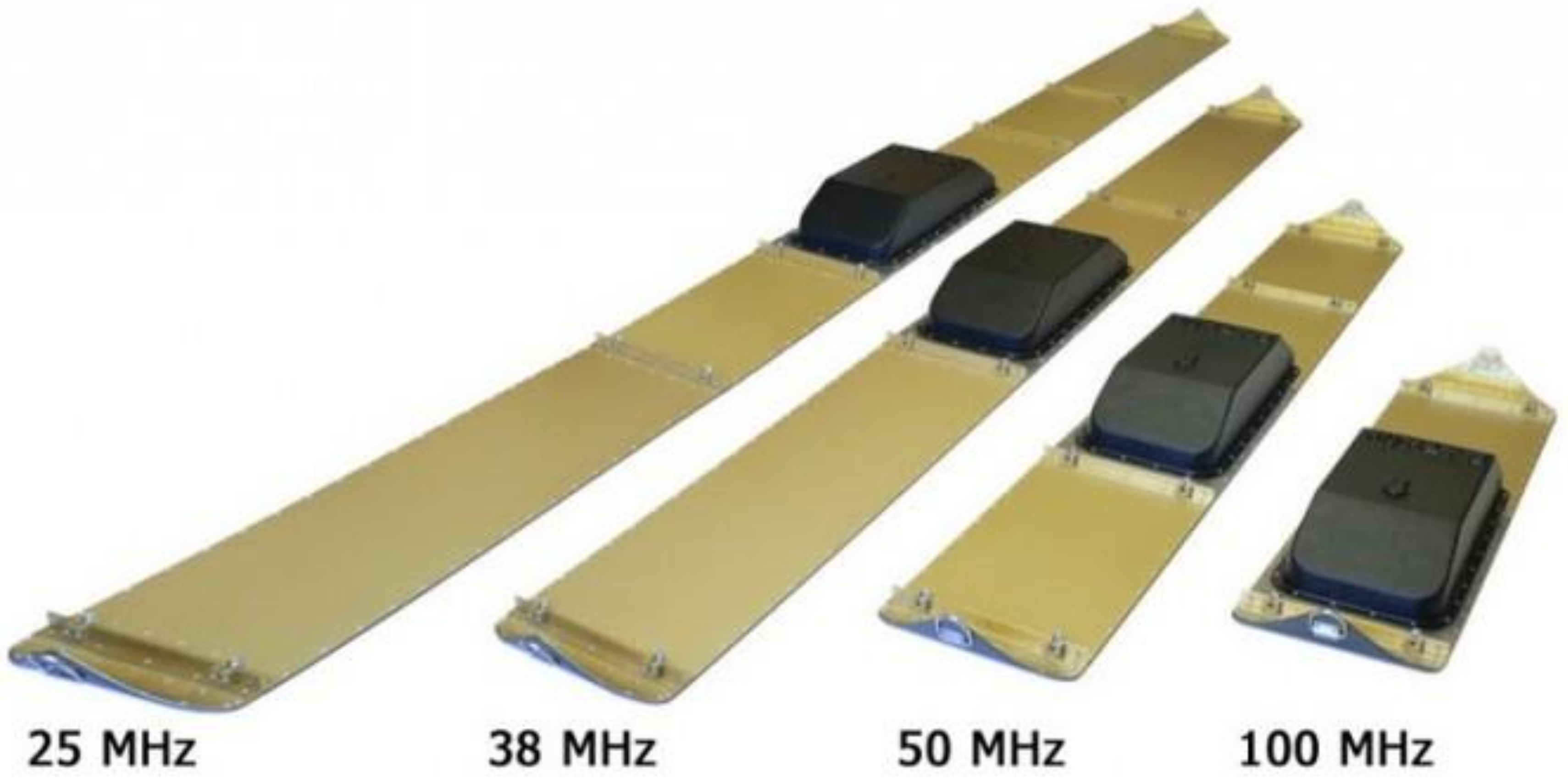


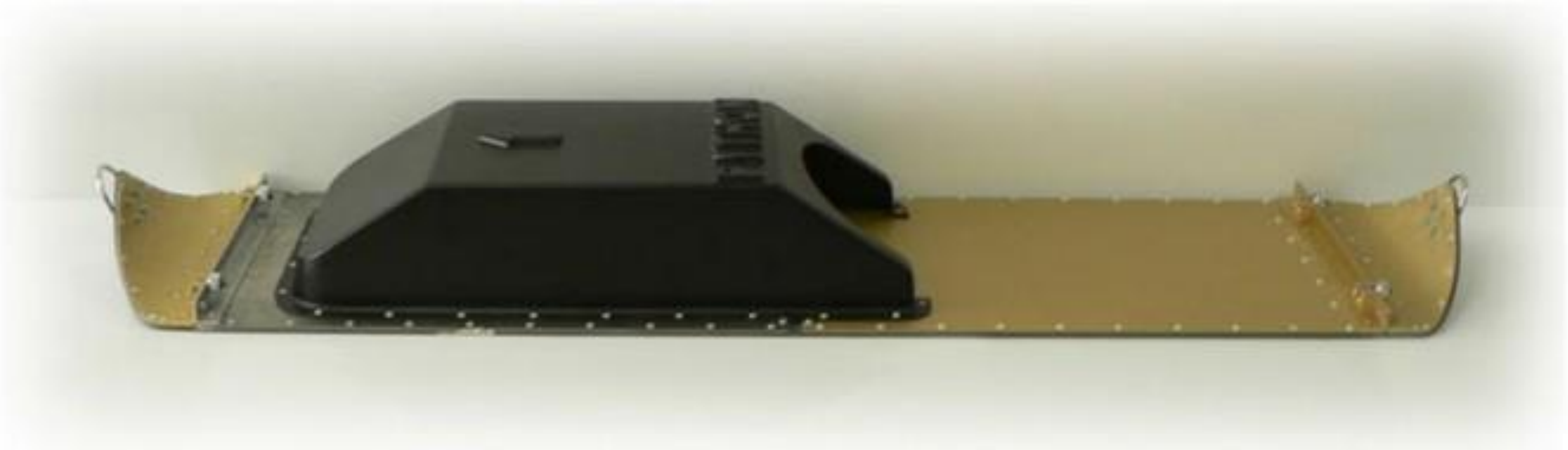




Snake Antenna...


D
100 MHz
A
D
D
B
50 MHz
A
B
D
D
C
38 MHz
A
C
D
D
C
B
25 MHz
A
B
C
D


25 MHz
38 MHz
50 MHz
100 MHz



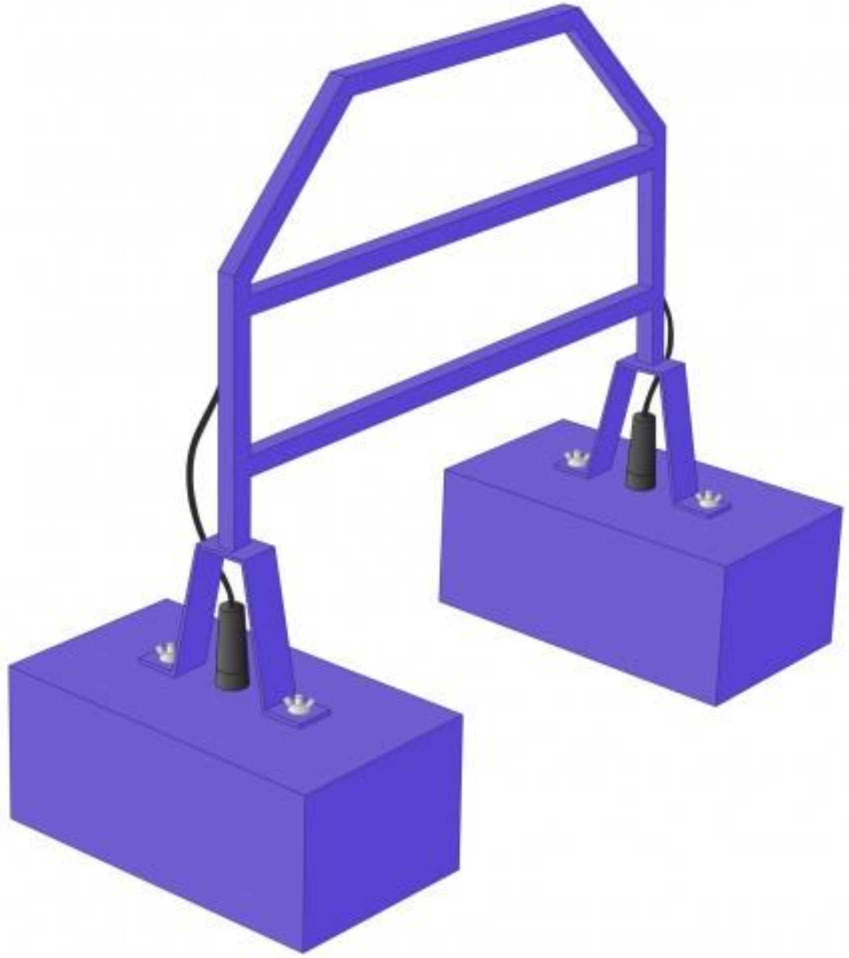

100 MHz


50 MHz


38 MHz


25 MHz

Shielded Air launched Antenna…



Un-shielded Air launched Antenna…

Best Practices- Survey Design

Before Designing GPR Survey…

In order to design an effective GPR survey, it is important to ask the following questions:

- What **survey configuration** would be best for resolving the target?
- What is the optimum position and **orientation** for the transmitter and receiver antennas?
- **How deep** into the Earth do I need to image?
- What are the smallest features I need to image? **What resolution** is required?
- What **operating frequency** should be used?
- What are the **physical properties of the Earth** and how do they impact my survey?
- How should I **orient my survey profile** relative to a geophysical target?
- What is the ideal **station spacing** and transmitter-receiver separation?

Is GPR the Right Tool?

Project Location:

- Logistical issues/ Site accessibility
- Ground cover- Metal cover, Bushes, tall grass, forest, and other obstructions on the ground can make it difficult to acquire GPR data on a project site
- Sources of noise such as airport communication systems or medical testing equipment can impact the clarity of GPR data.
- Hazards, Toxic contamination, Explosive Environment

Is GPR the Right Tool?

Project Objectives:

- Feasibility Issues: Some projects are not feasible because the goals are beyond the capacity of GPR. For example, using GPR to map geological layers is possible and making interpretations of layer composition can be supported with boreholes, but without this context it is virtually impossible to characterize rock types or hardness exclusively with GPR data.

- Ethical Issues: Example- Unauthorized Treasure Hunting

Is GPR the Right Tool?

Target Electrical Properties:

- For GPR to work, there should be contrast in in electrical properties to the host environment.

- Two different geological formations can have different mechanical properties but similar electrical properties. GPR is NOT the right tool then. Seismic is.

Is GPR the Right Tool?

Target size, depth, geometry, and orientation:

- Big enough to be detected
- Within detection range of GPR. rule-of-thumb for estimating exploration depth

$$D= 35/\sigma \text{ meters}$$

Where σ is conductivity in mS/m. While not as reliable as the RRE, this helpful rule is quite useful in many geologic settings.

- Vertical pipe
- Height, Length, Width
- Strike, dip

Selecting the right frequency

- The best antenna to use on any project is the one that records your target with the finest resolution.

- According to Utsi (2017; cf. Daniels 2004) the maximum depth that any antenna may prospect in optimal soil conditions is **<u>20 times the wavelength (absolute maximum).</u>**

- The lower the frequency is, the lower it can prospect, but the lower the resolution of your recorded data

- Choosing the **<u>highest frequency antenna that can prospect as deep as a potential target will be most appropriate</u>** because it will detect the target with the best possible resolution.

Estimating the time window

- The way to estimate the time window required is to use the expression Time Window= 1.3 x (2 x Depth)/Velocity, where maximum depth and minimum velocity likely to be encountered in the survey area are used.

$$W = 1.3\frac{2(depth)}{velocity}$$

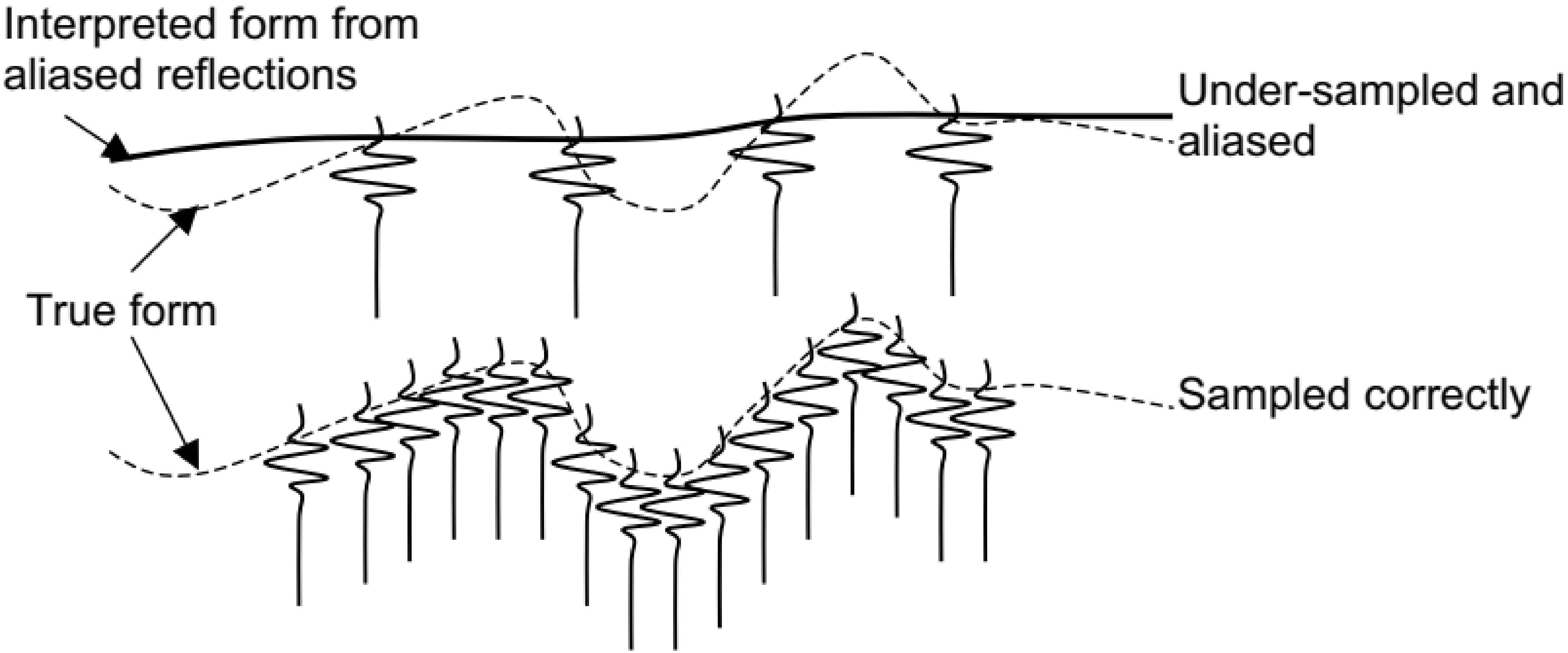
- The above expression increases the estimated time by 30% to allow for uncertainties in velocity and depth variations.

Choosing Pulse Stacking

- This is the number of repeat pulses of energy sent in to the ground by the GPR system for a particular data collection point. The more repeat pulses you send (varies from typically 4 to 64 or more) the better the signal-to-noise ratio becomes. In essence, coherent signals (reflections, etc.) become relatively stronger with more pulse stacks. However, data collection takes longer with more stacks.

- GPR Good Practice Tip – 0-8 stacks is okay in low noise environments, 8-16 stacks is typical, 32 in noisy environments, and more than 32 is usually overkill.

Selecting Spatial Increment

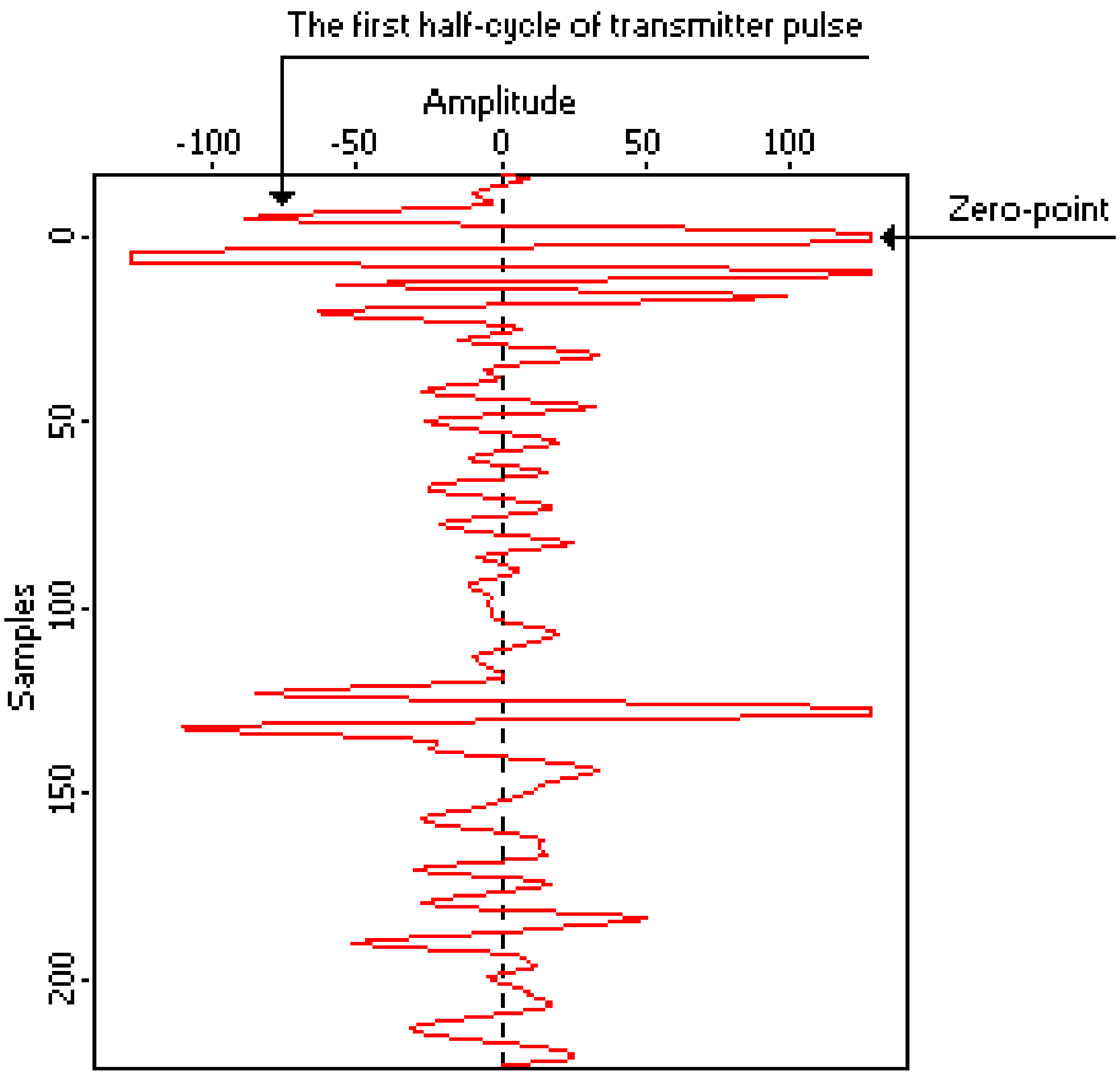


Effect of aliasing on reflection interpretation

In general, we need to sample at **spacing of no less than 1/4 wavelength** to avoid aliasing.
For typical materials:

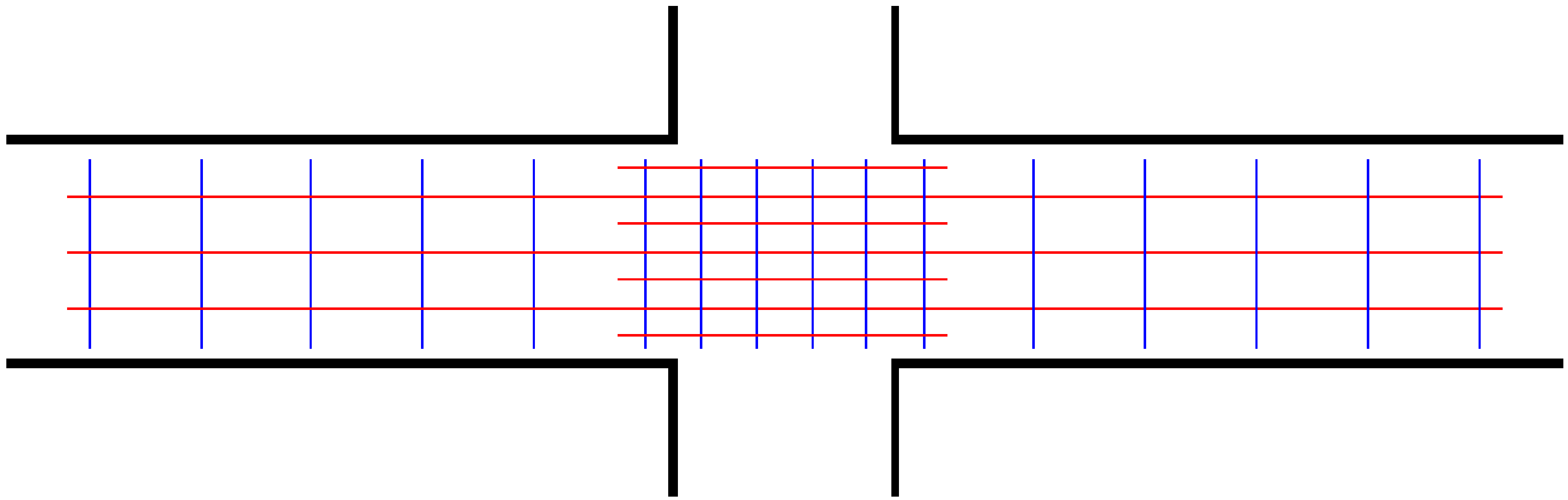
Best Practices- Setup & Acquisition

Zero Time



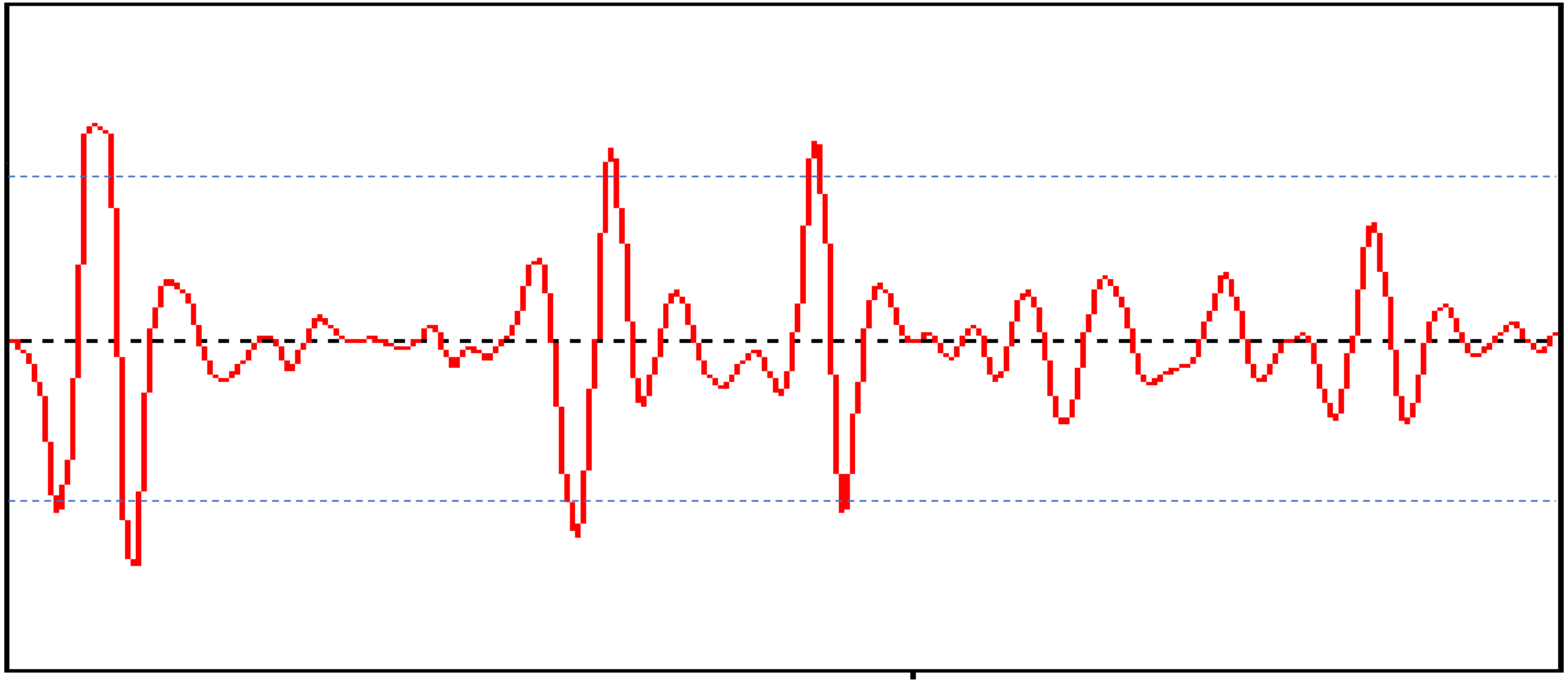
The first half-cycle of transmitter pulse
Amplitude
-100
-50
0
50
100
Zero-point
Samples
0
50
100
150
200

Survey Grid........

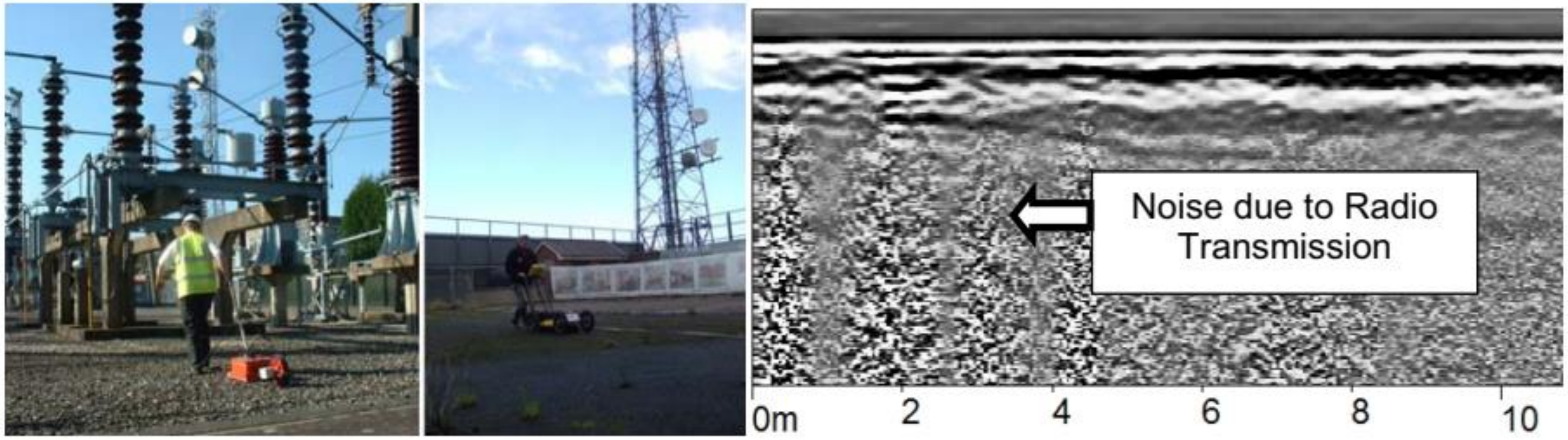


TYPICAL GEORADAR LINE POSITIONING ON ROAD

Gain Setting Rule of 1/4th to 3/4th

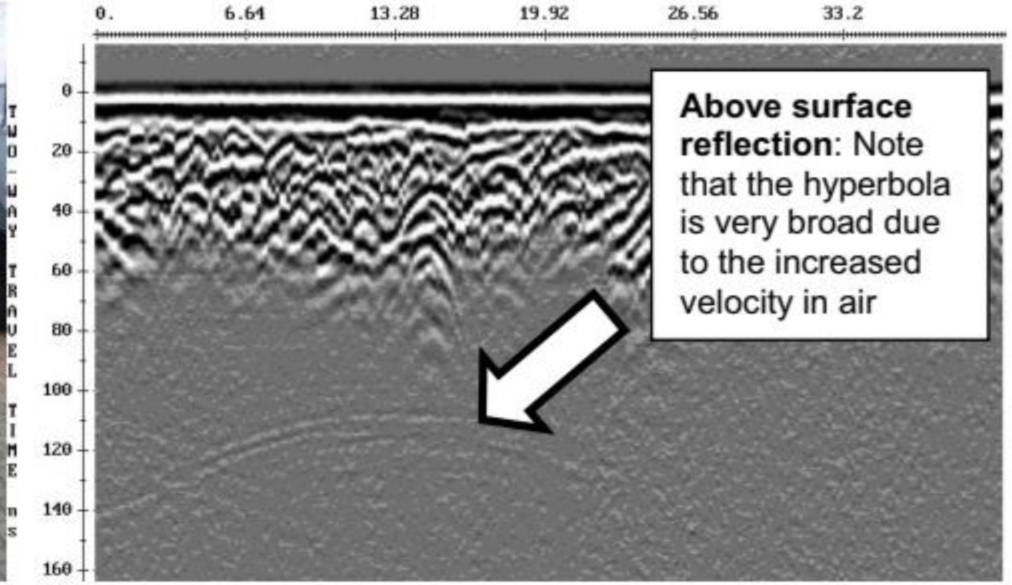


Data Acquisition Tips



Avoid environments with high levels of electrical noise

Data Acquisition Tips



Don’t survey near big lumps of metal

Data Acquisition Tips

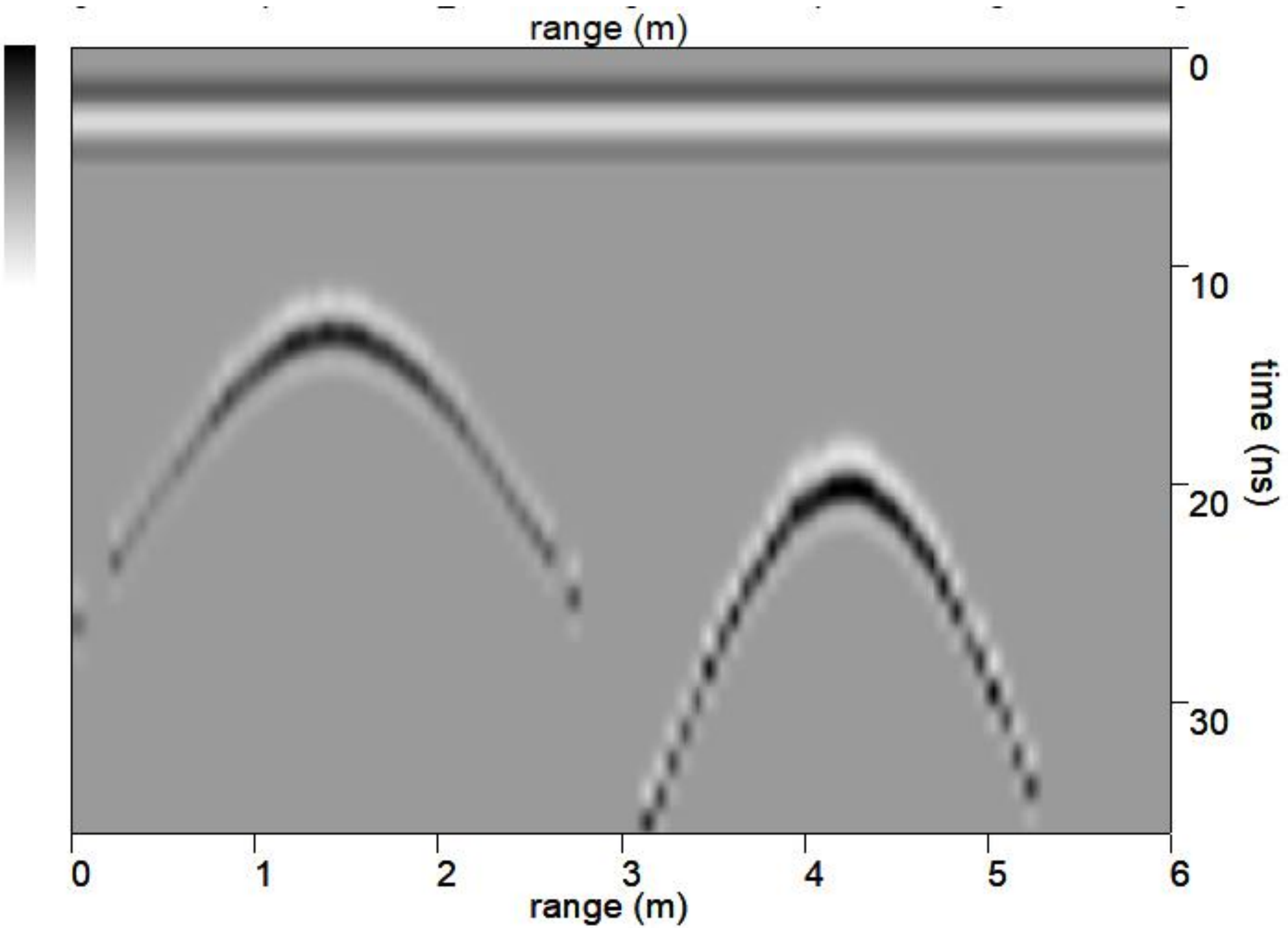
Try to retain good antenna-to-coupling to avoid reverberation in the signal

Data Acquisition Tips

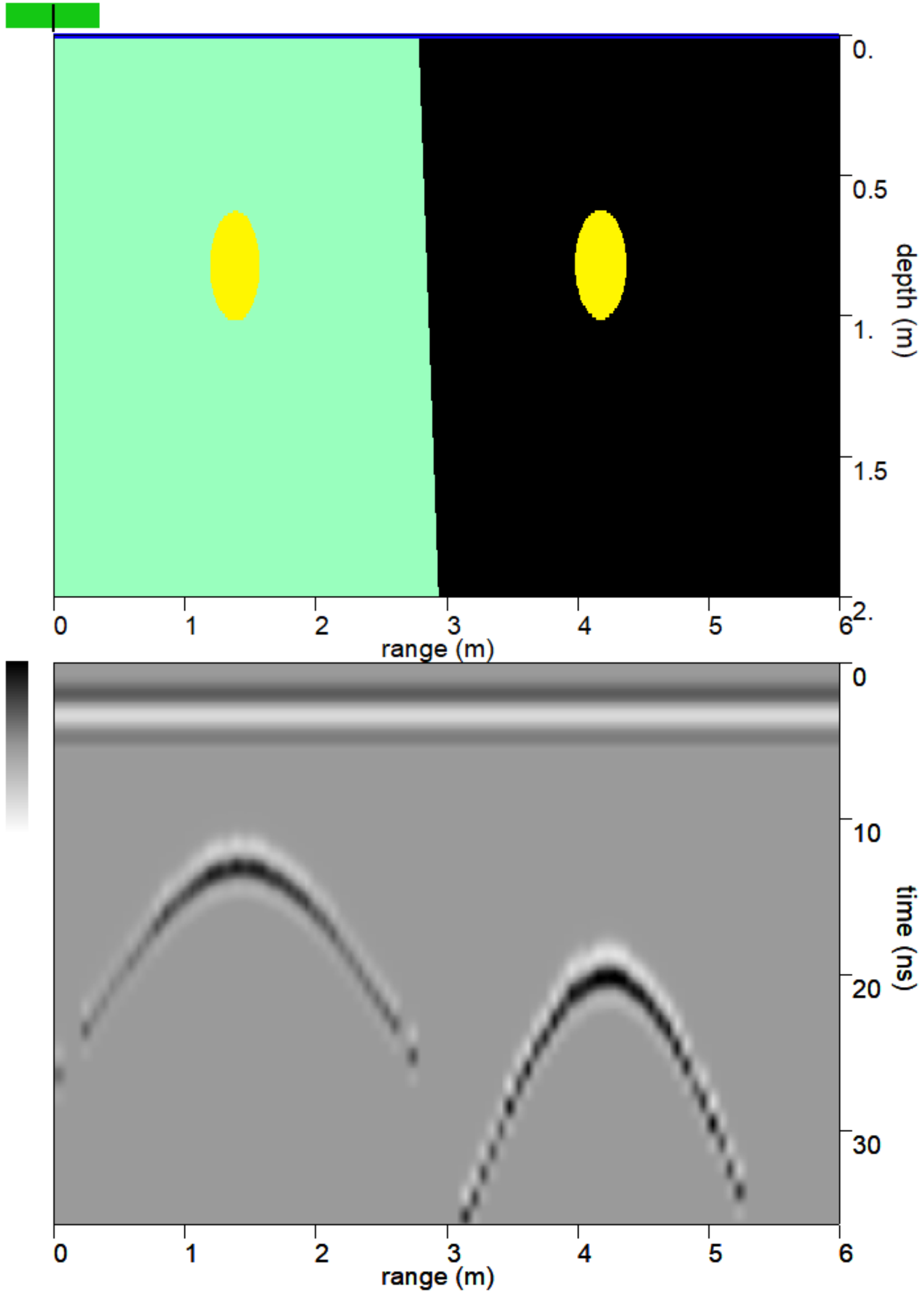
Be aware of what you are walking over and make a note of all observable features.

Other Sources of Radio Signals

Best Practices- Simulate



range (m)
0
10
20
30
time (ns)
0
1
2
3
4
5
6
range (m)

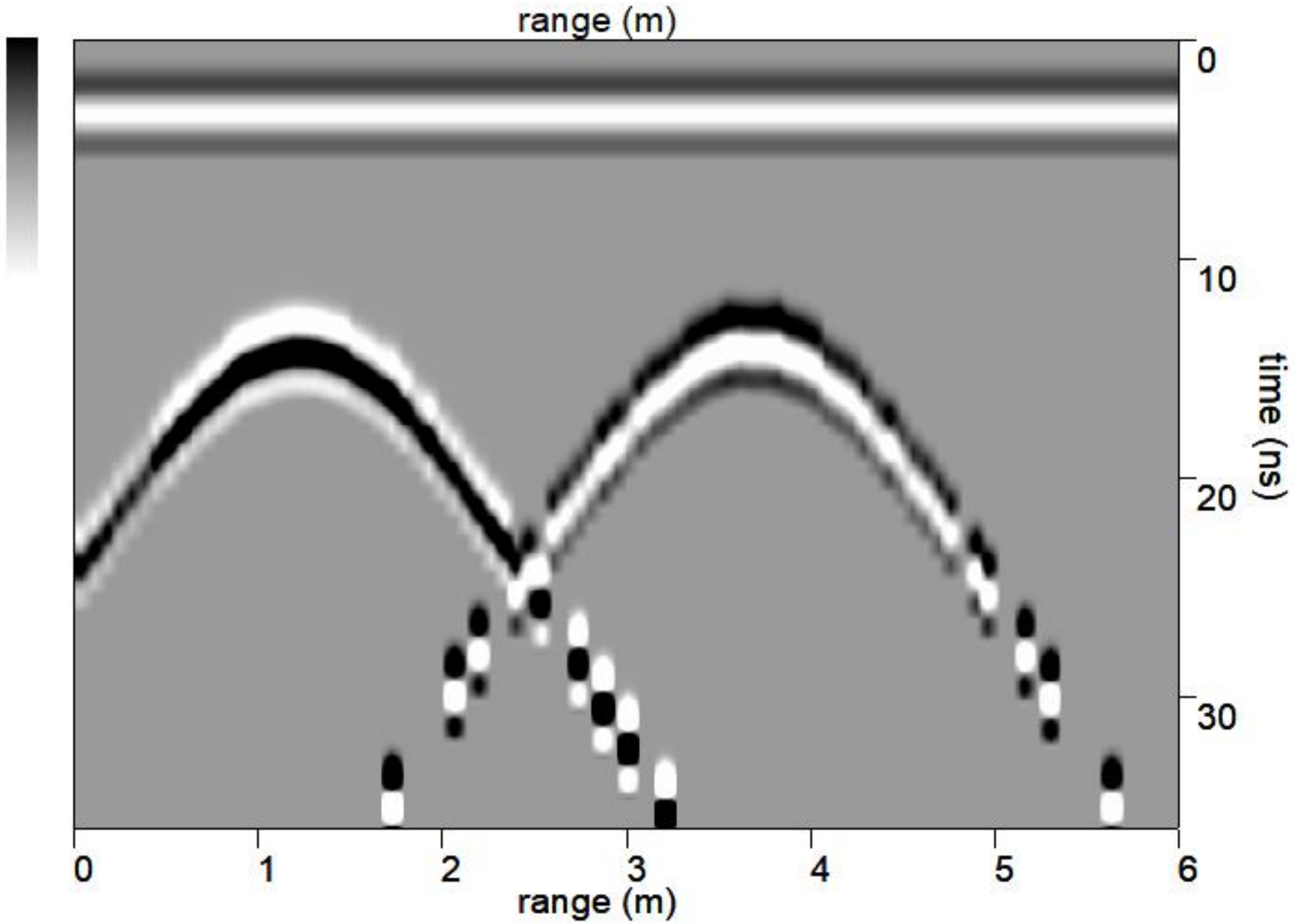
Variable depth targets



	Material	Er	C.mho/m
	air	1.	0.
	soil1	6.	0.001
	soil5	18.	0.001
	copper	1.	5.8

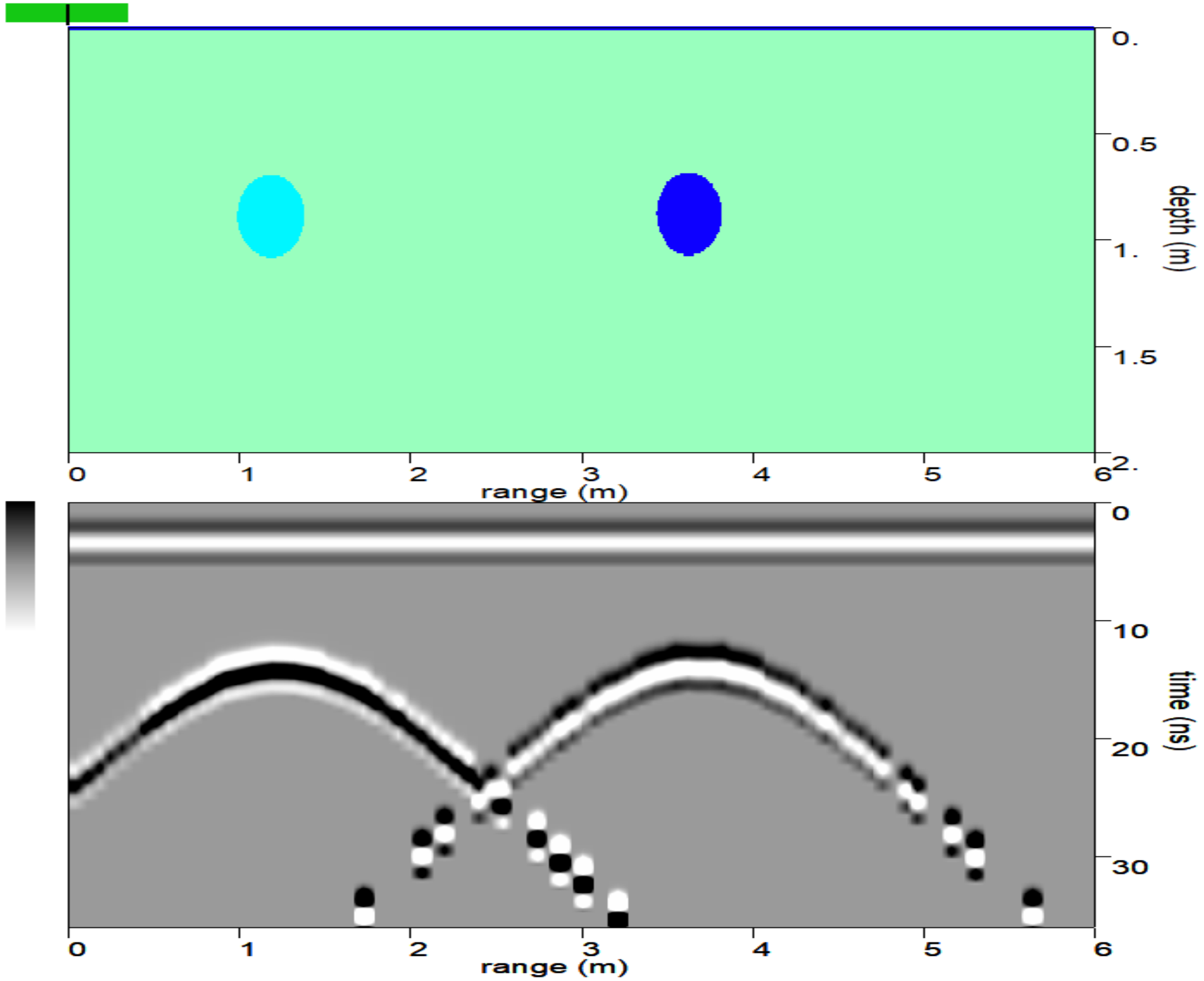
Simulation Parameters

antenna=400MHz
scan/m=15.
samples=512
range(ns)=36
gain=5
lin.gain=4
exp.gain=2
rays/deg=-2
aperture(m)=.7



range (m)
0
10
20
30
time (ns)
0
1
2
3
4
5
6
range (m)

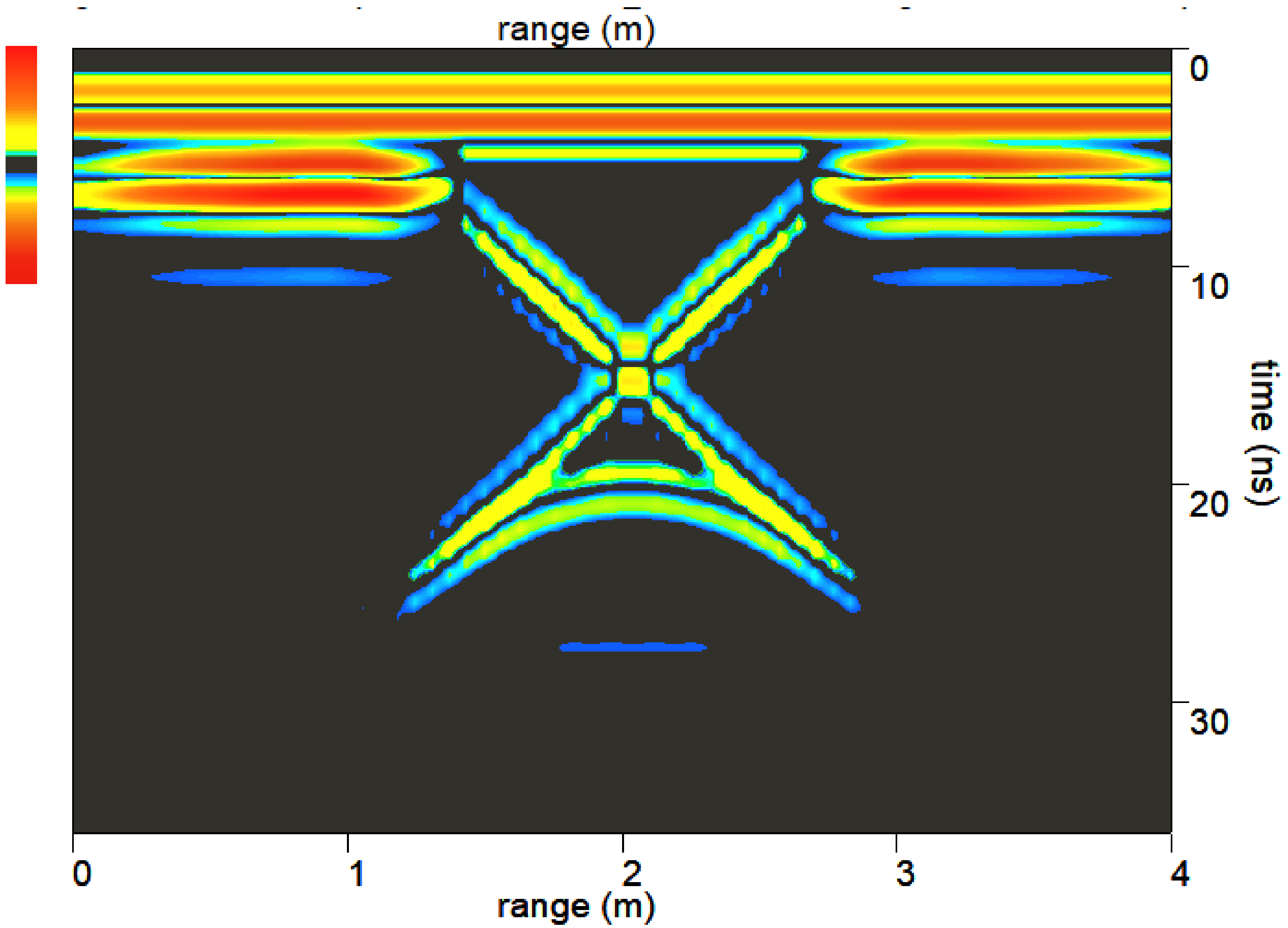
Variable depth targets

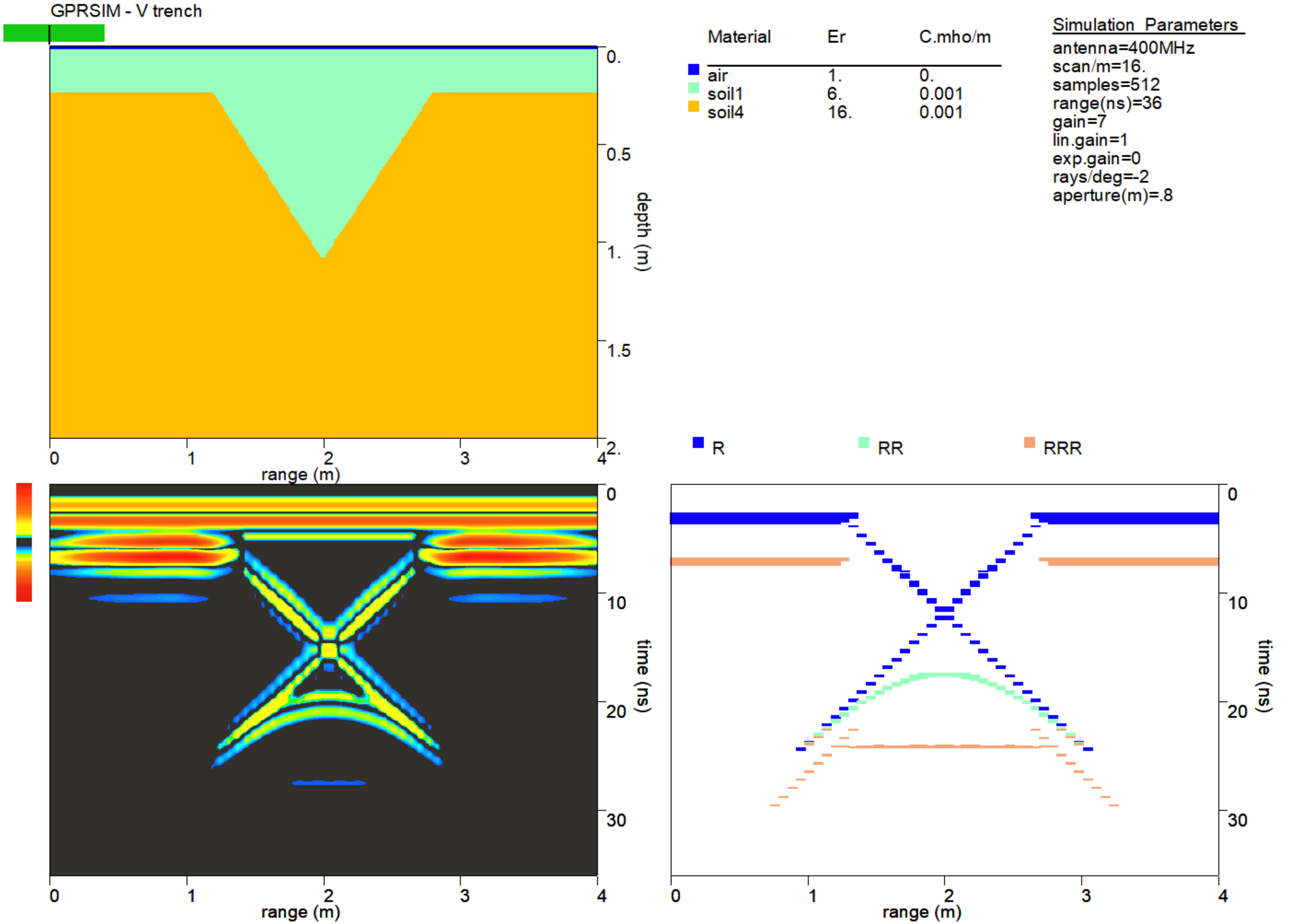


Material	Er	C.mho/m
air	1.	0.
soil1	6.	0.001
water	81.	0.01

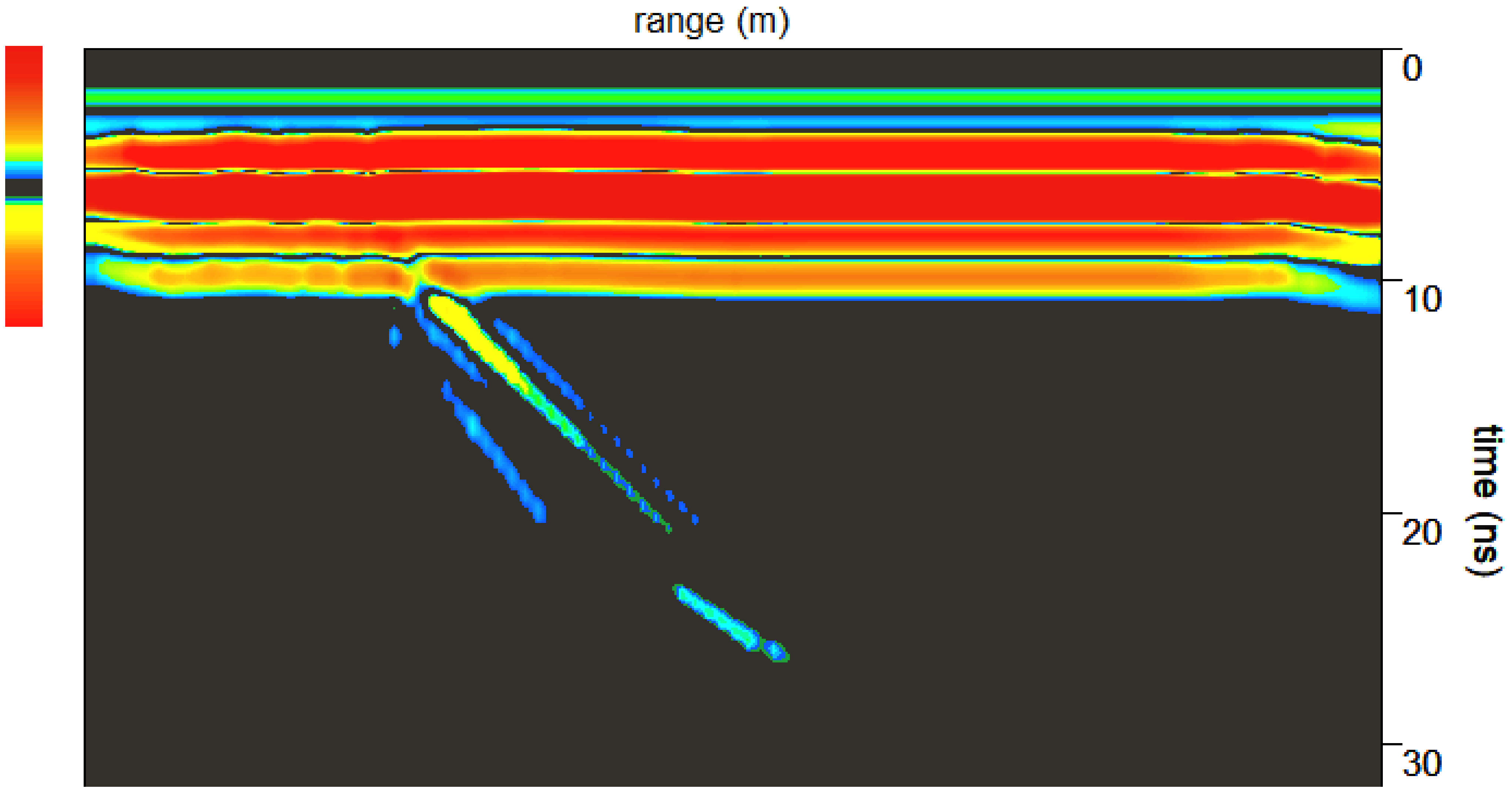
Simulation Parameters

antenna=400MHz
scan/m=15.
samples=512
range(ns)=36
gain=5
lin.gain=10
exp.gain=4
rays/deg=-2
aperture(m)=.7

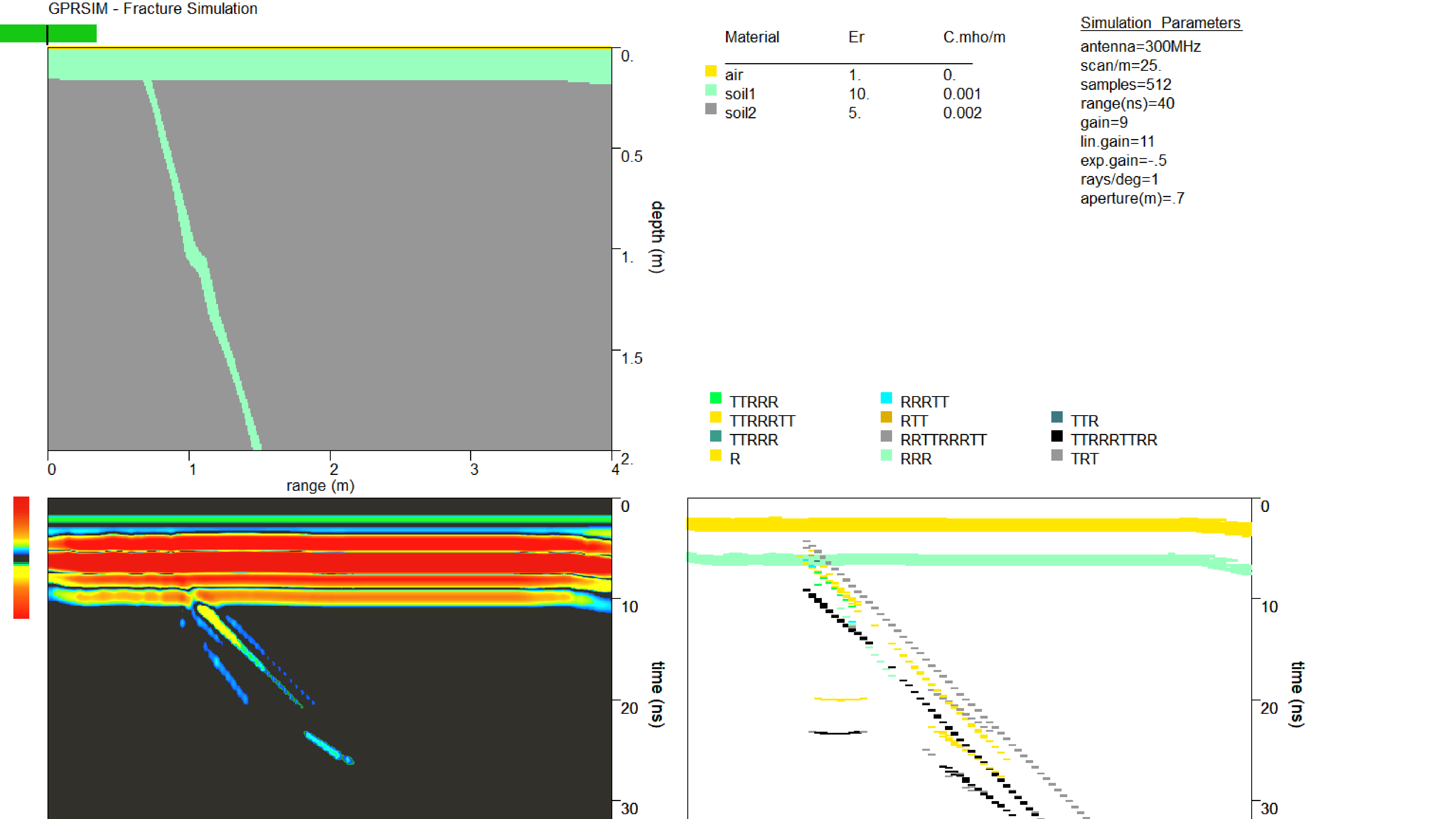

range (m)
0
10
20
30
time (ns)
0
1
2
3
4
range (m)



GPRSIM - V trench
Material Er C.mho/m
air 1. 0.
soil1 6. 0.001
soil4 16. 0.001
Simulation Parameters
antenna=400MHz
scan/m=16.
samples=512
range(ns)=36
gain=7
lin.gain=1
exp.gain=0
rays/deg=-2
aperture(m)=.8
depth (m)
range (m)
time (ns)
R
RR
RRR

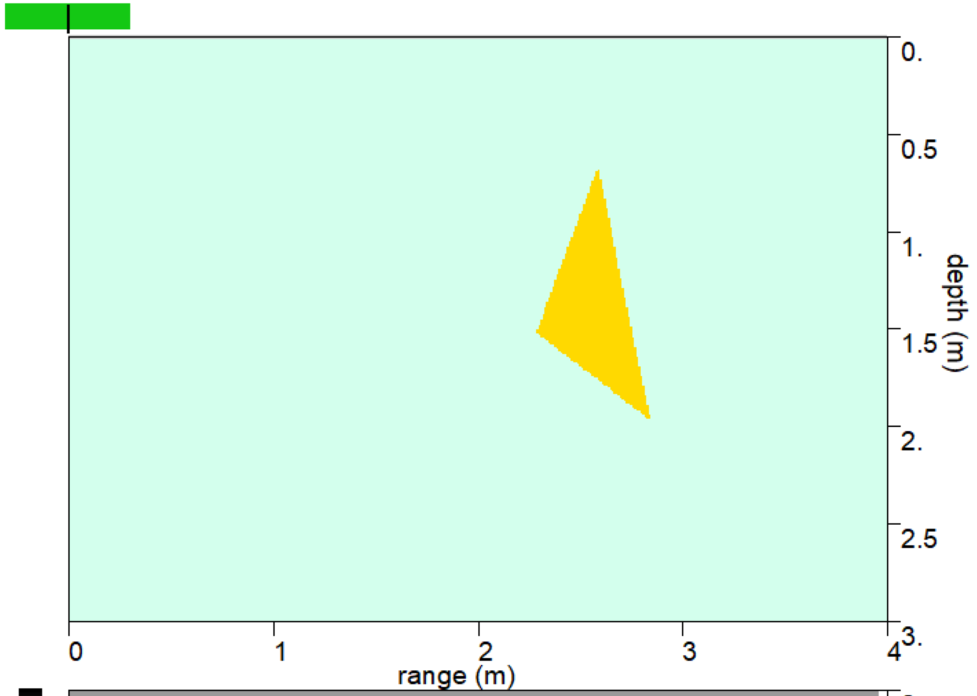


range (m)
time (ns)
0
10
20
30



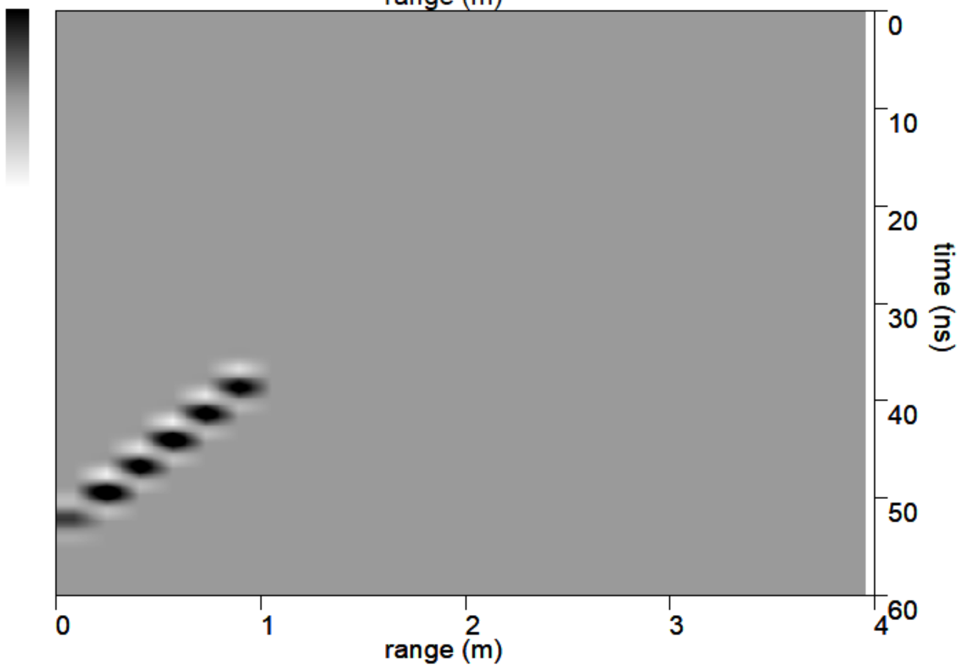
GPRSIM - Fracture Simulation
Material
Er
C.mho/m
air 1. 0.
soil1 10. 0.001
soil2 5. 0.002
Simulation Parameters
antenna=300MHz
scan/m=25.
samples=512
range(ns)=40
gain=9
lin.gain=11
exp.gain=-.5
rays/deg=1
aperture(m)=.7
0.
0.5
1.
1.5
2.
depth (m)
0
1
2
3
4
range (m)
TTRRR
TTRRRTT
TTRRR
R
RRRTT
RTT
RRTTRRRTT
RRR
TTR
TTRRRTTRR
TRT
0
10
20
30
time (ns)
0
10
20
30
time (ns)

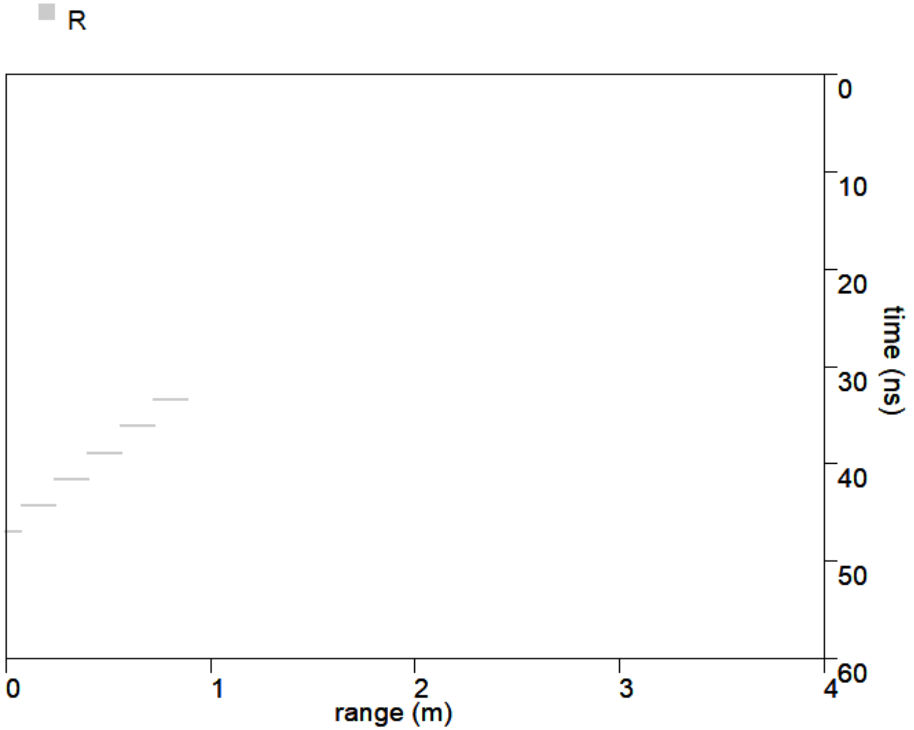
THE GOLDEN TRIANGLE + A Round Edge

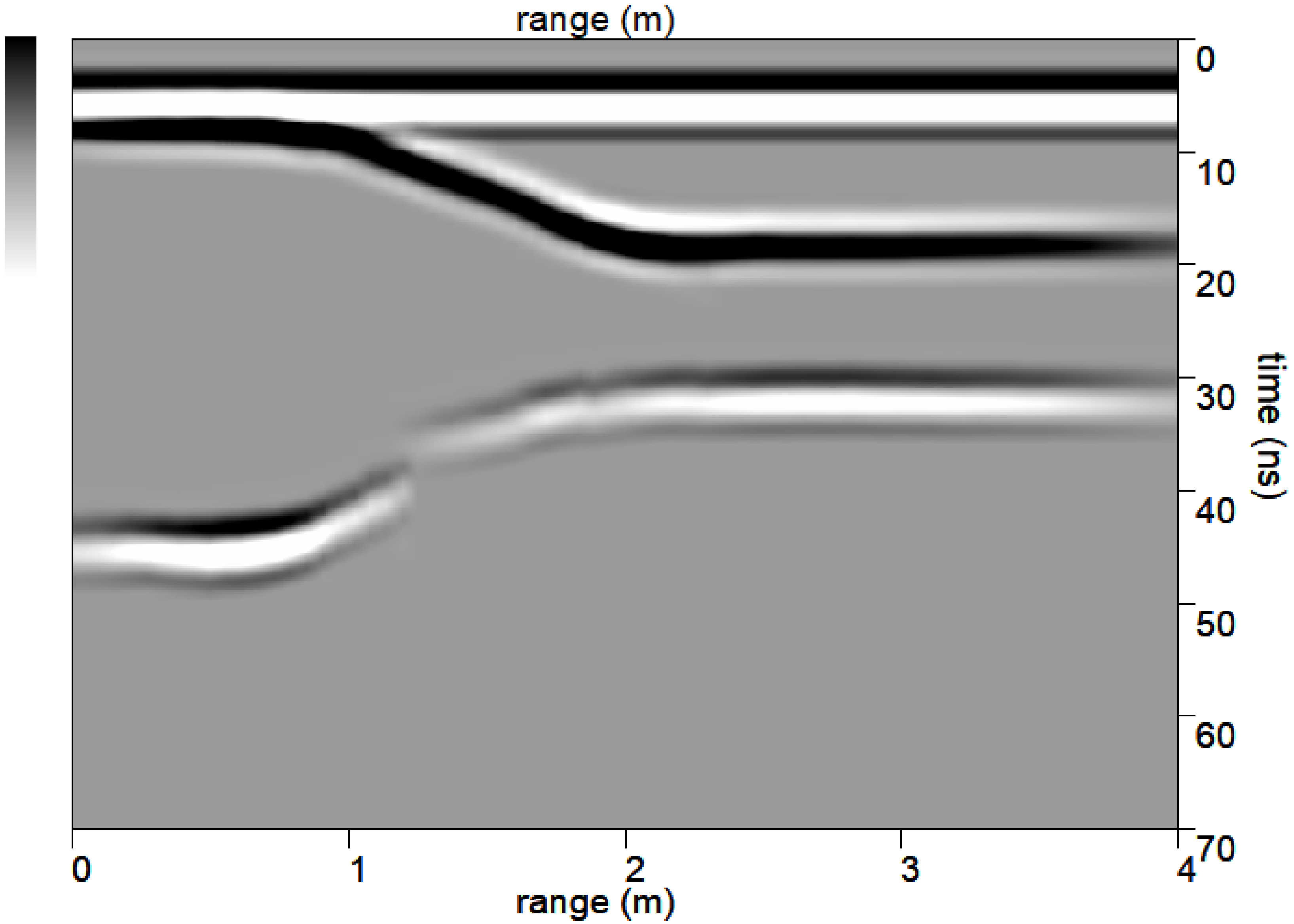


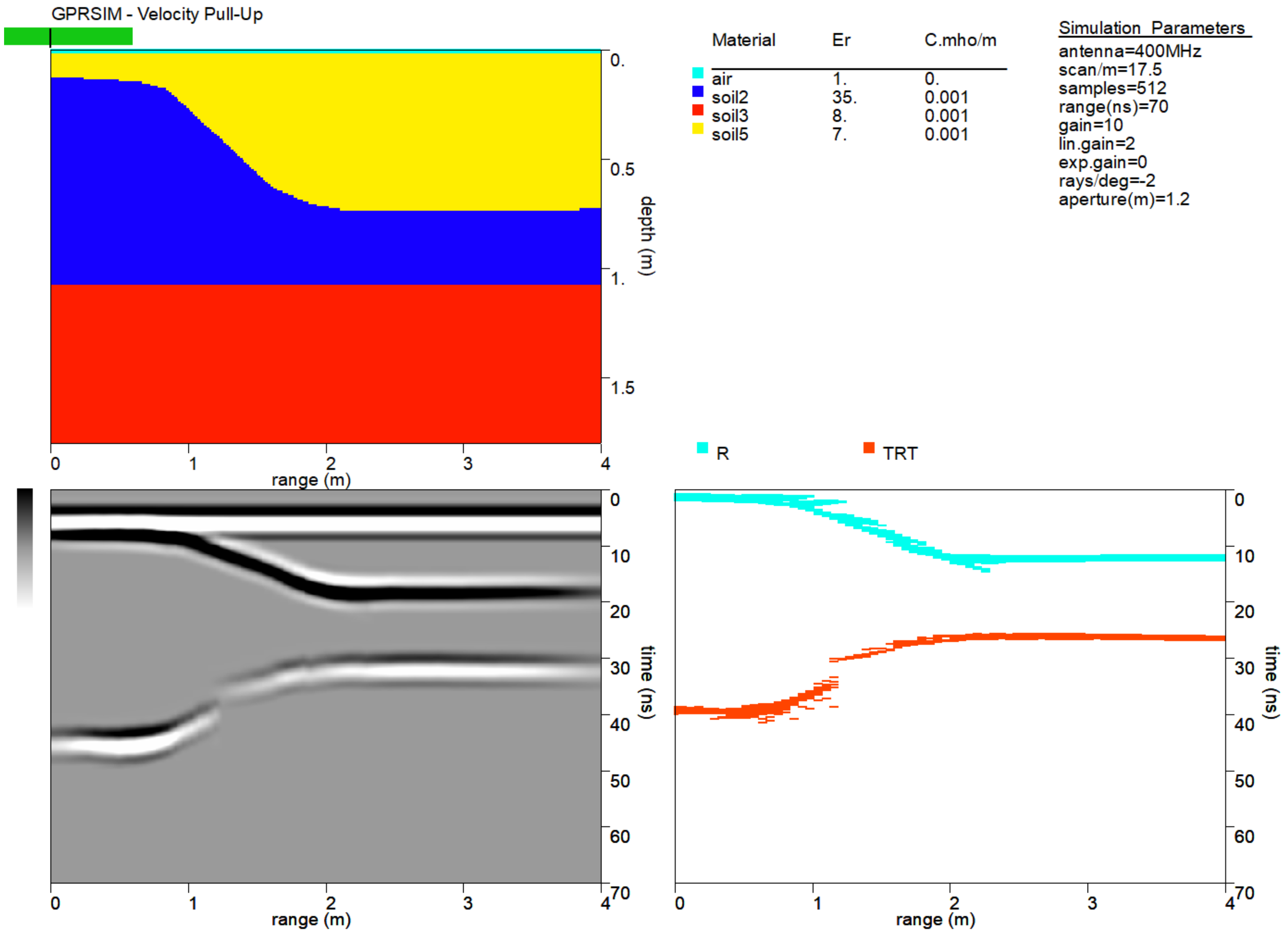
Material	Er	C.mho/m
air	1.	0.
soil1	7.	0.001
GOLD	1.	5.8

Simulation Parameters
antenna=900MHz
scan/m=6.25
samples=512
range(ns)=60
gain=10
lin.gain=5
exp.gain=2
rays/deg=-1
aperture(m)=.6

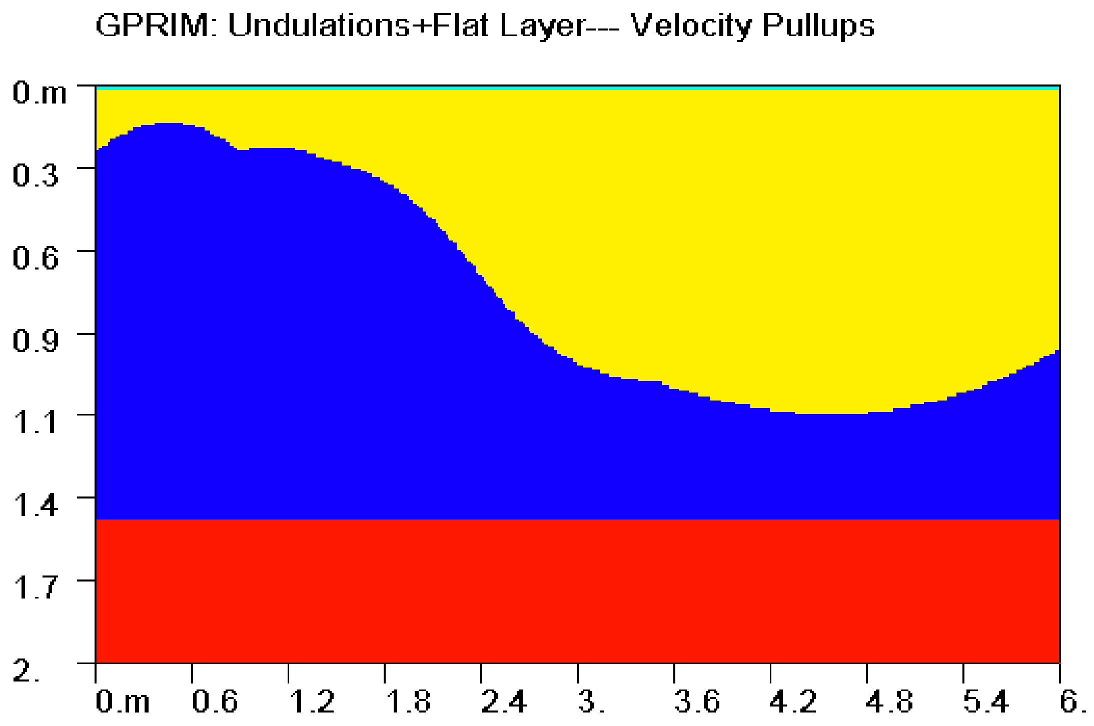





range (m)
0
10
20
30
40
50
60
70
time (ns)
0
1
2
3
4
range (m)

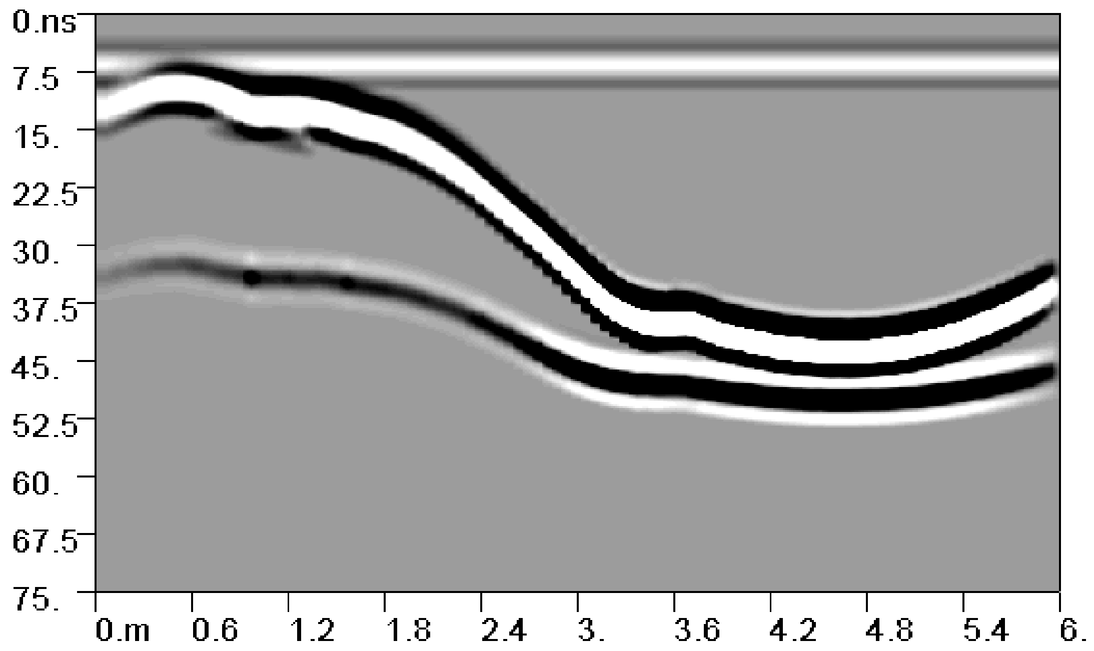


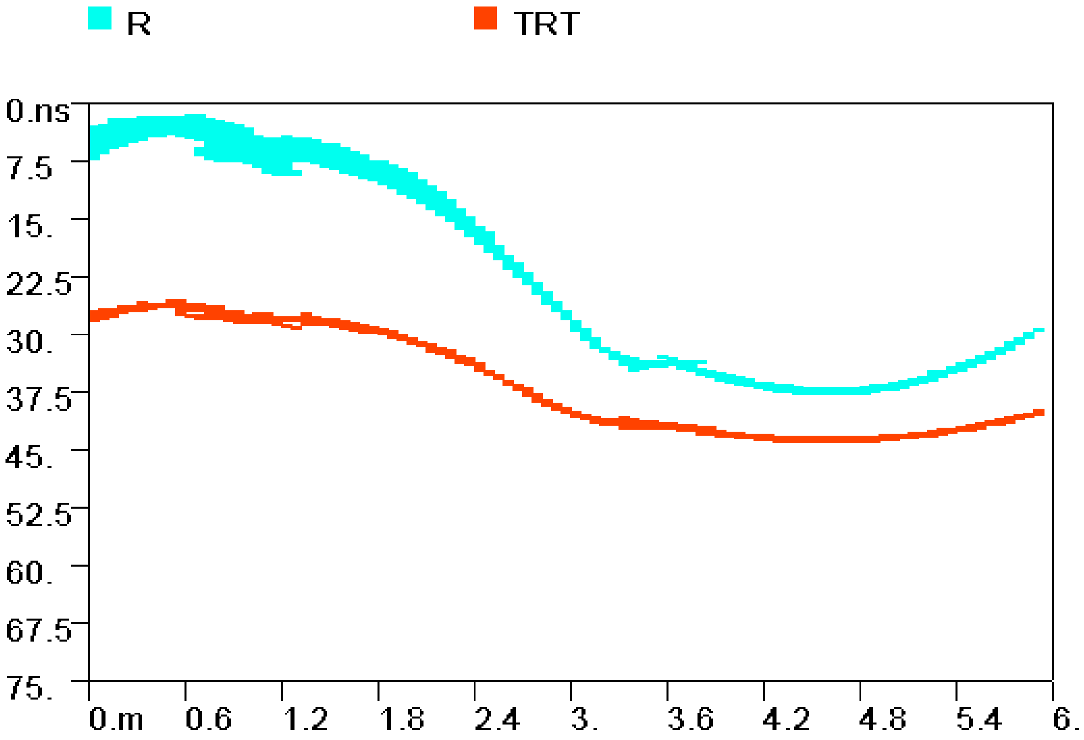
GPRSIM - Velocity Pull-Up
Material Er C.mho/m
air 1. 0.
soil2 35. 0.001
soil3 8. 0.001
soil5 7. 0.001
Simulation Parameters
antenna=400MHz
scan/m=17.5
samples=512
range(ns)=70
gain=10
lin.gain=2
exp.gain=0
rays/deg=-2
aperture(m)=1.2
depth (m)
range (m)
time (ns)
R
TRT



Material	Er	C.mho/m
air	1.	0.
soil2	6.	0.001
soil3	8.	0.001
soil5	25.	0.001

The effects of an undulating subsurface layer has on a deeper flat layer is shown. Particularly in the case when upper layers have significant velocity contrasts, deeper flat layers will have what are called “velocity pull-ups” and these flat layers will not have flat reflection patterns from GPR profiling.





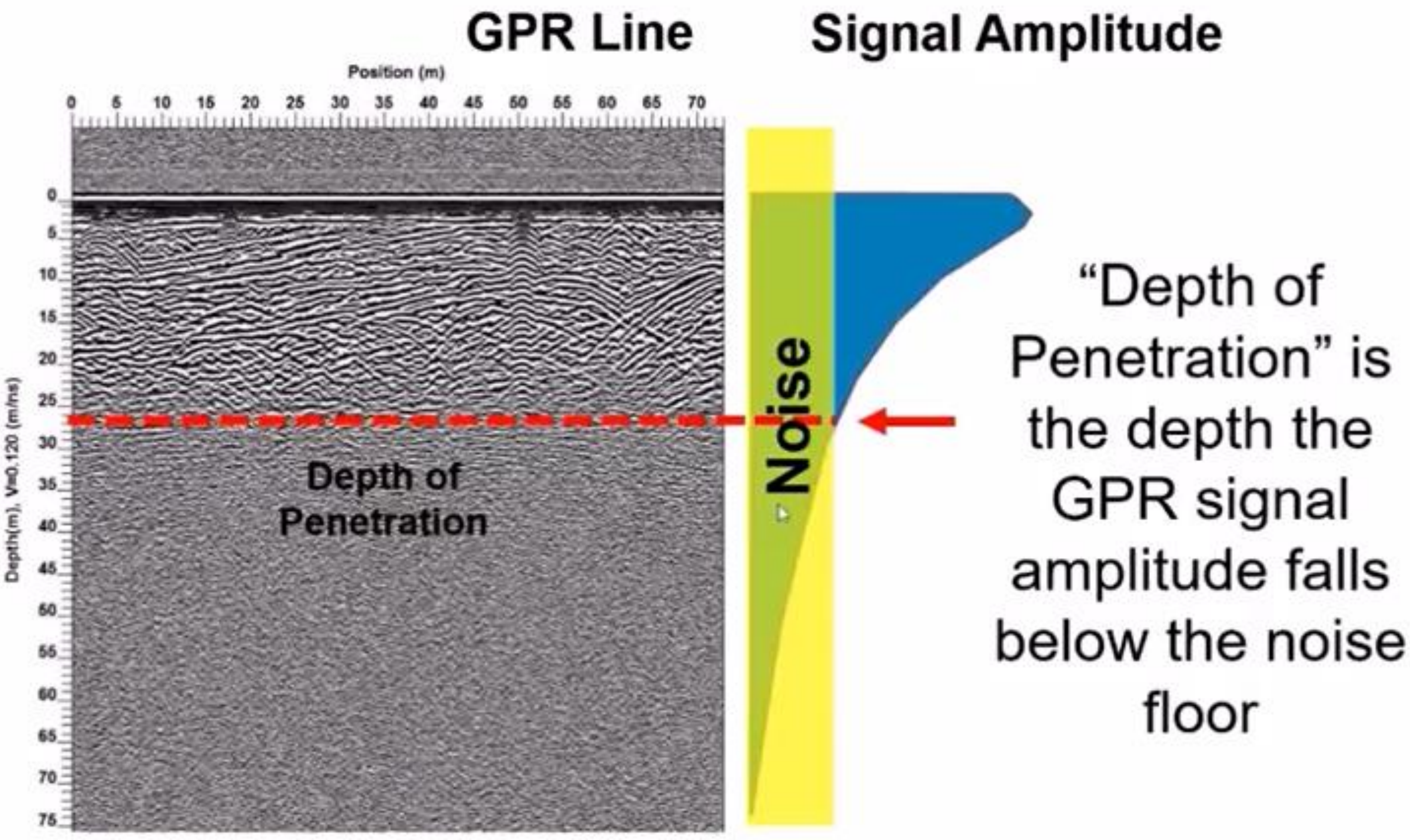
Remember

Maximum Depth of Penetration

Maximum depth of penetration in ideal conditions is less than 20 times the wavelength

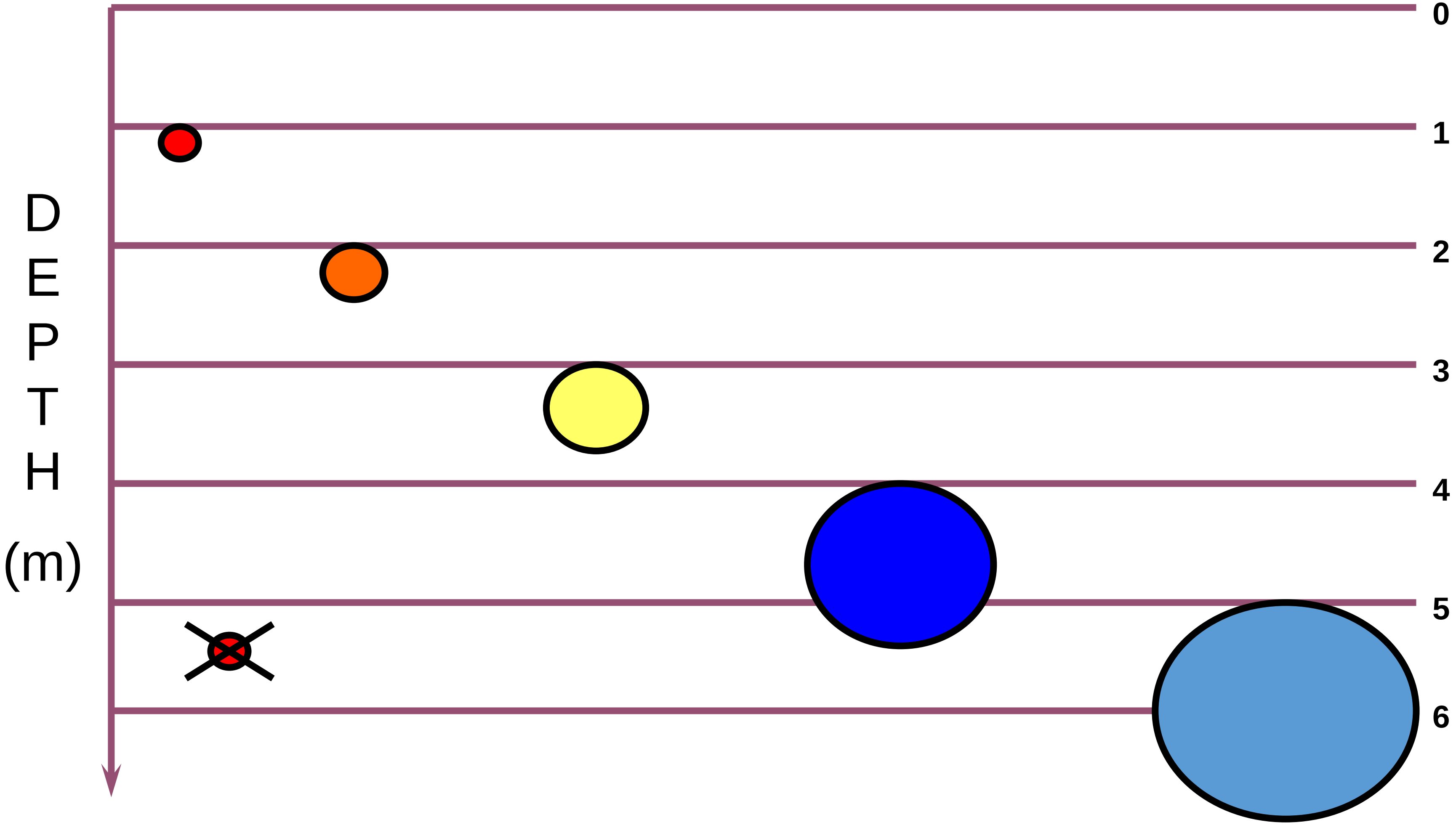
$$D < 20\lambda$$

In most site conditions, but depending on the electromagnetic properties of the ground, the depth of penetration will be considerably less than 20 wavelengths.



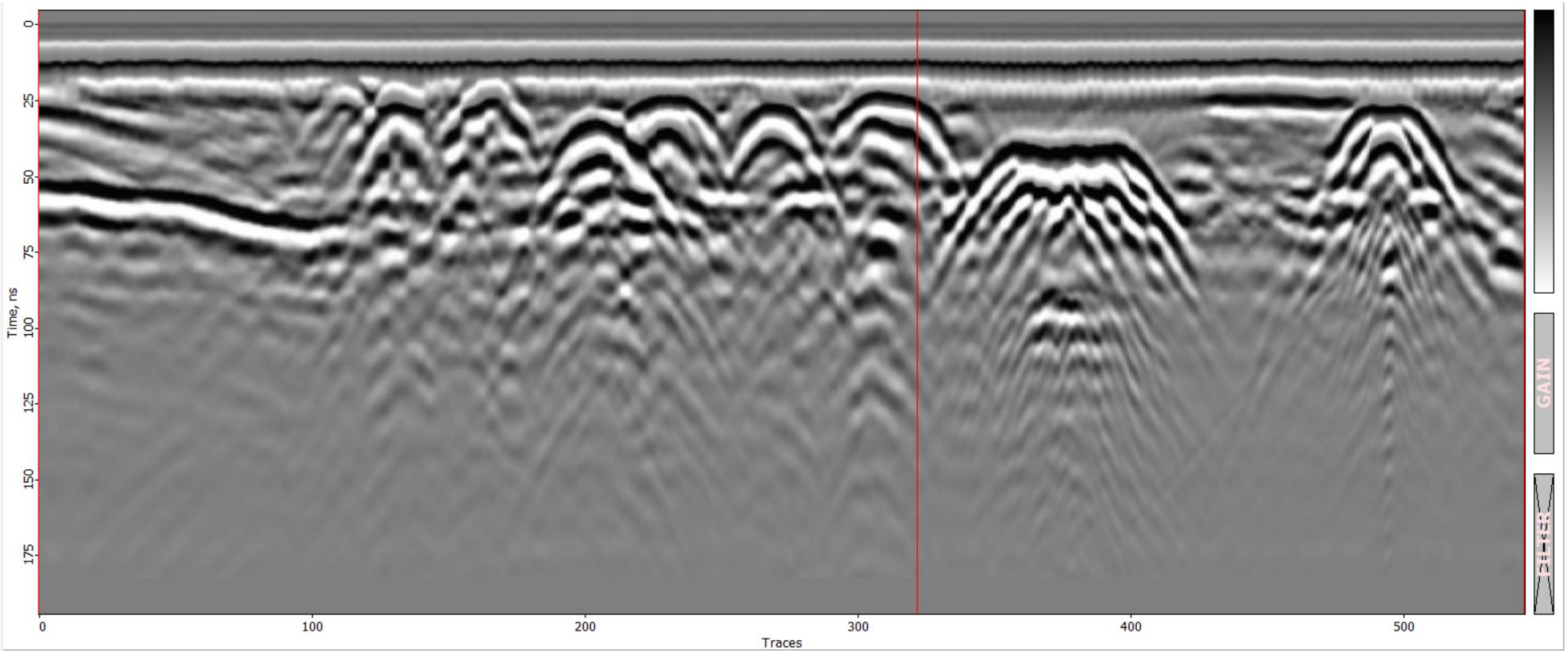
Smallest Detectable Target

Object size must be atleast 1/10th of the size of the wavelength of the center frequency



Closely Spaced Targets

Targets within a half wavelength of each other will result in a combined signal. A good rule of thumb therefore for both targets to be detectable is that they should be separated from one another by 1 wavelength.



Can we see under reinforcement?

If metallic grids have been used as reinforcement, then it is important that each rebar is spaced **<u>at no less than 1 wavelength from its neighbor</u>**.

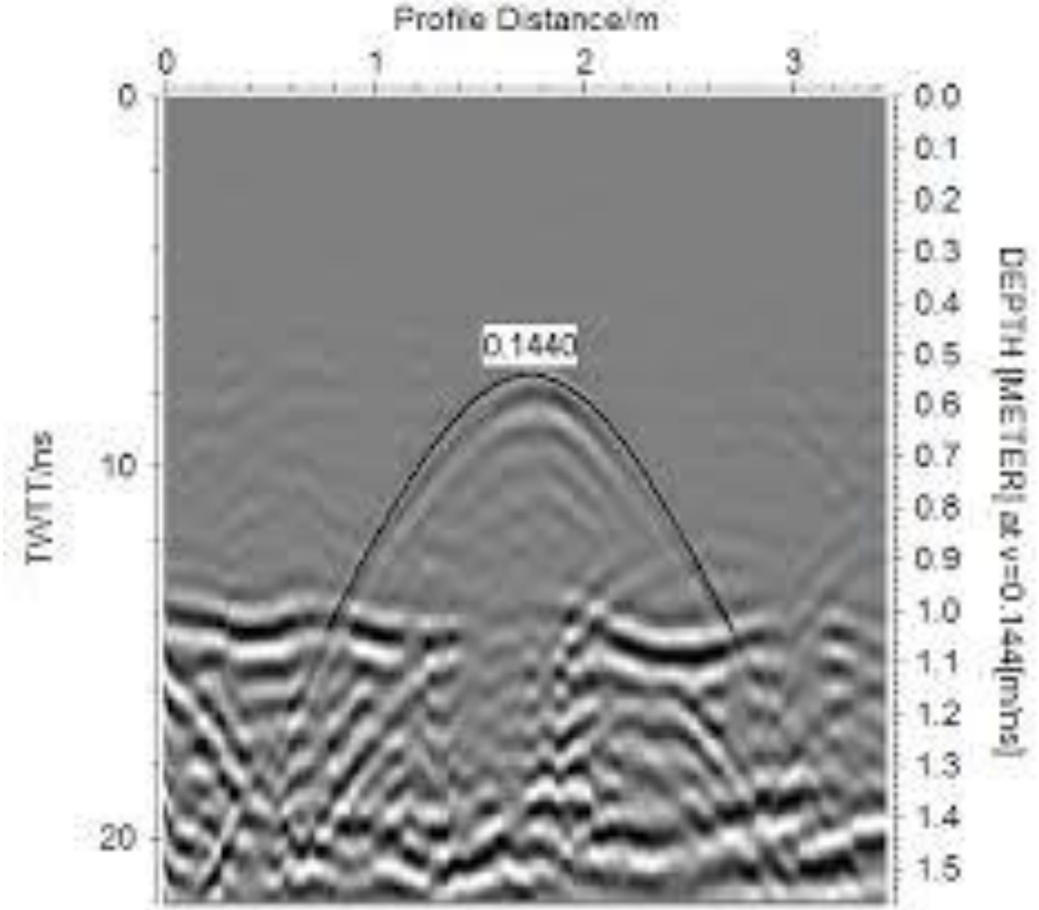
If the spacing is less than a wavelength, then the signals will merge and the reinforcement layer will appear to be continuous, as though there were a **<u>metal sheet in place.</u>**

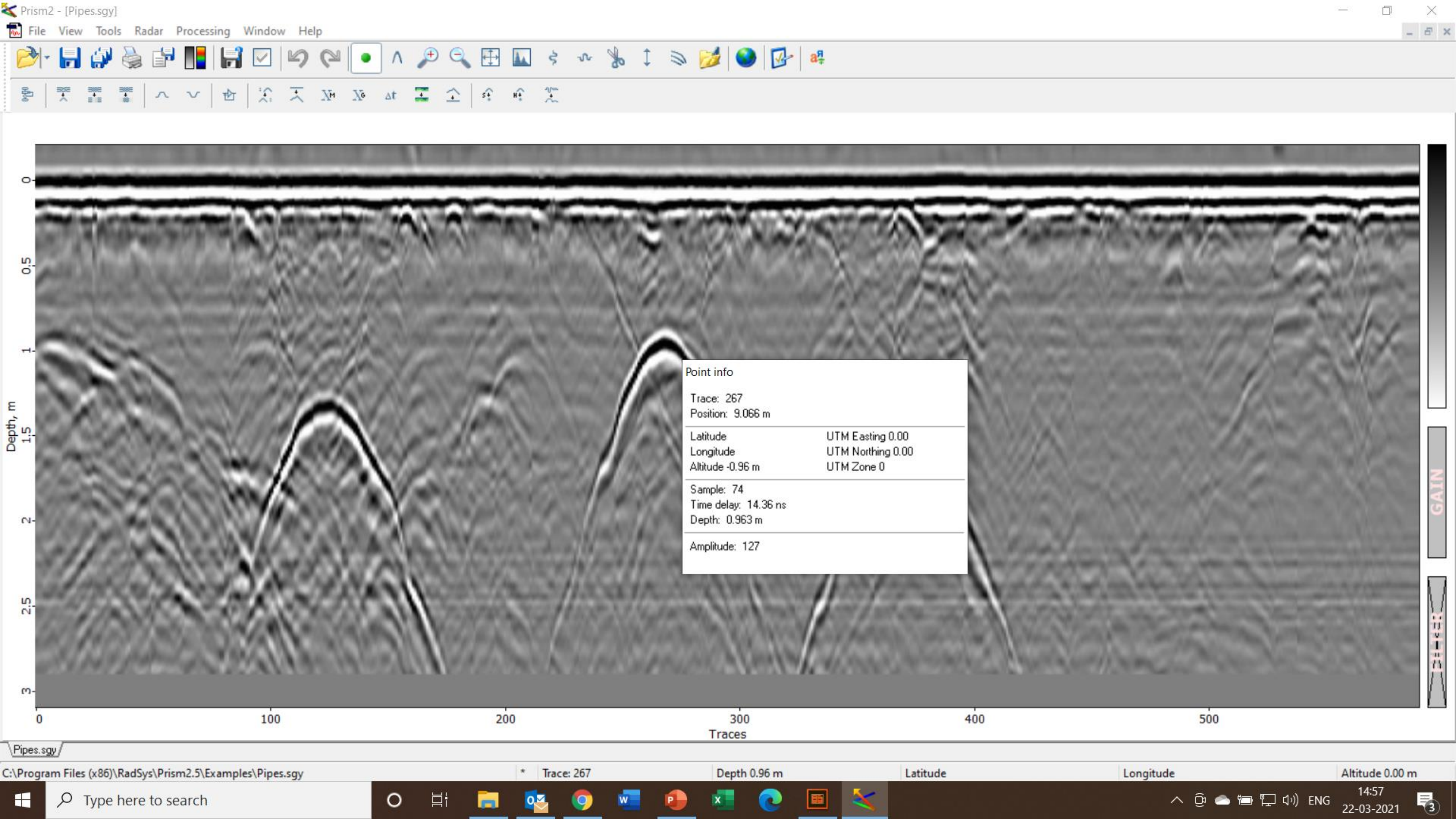
How accurate is the depth? Rule of thumb:

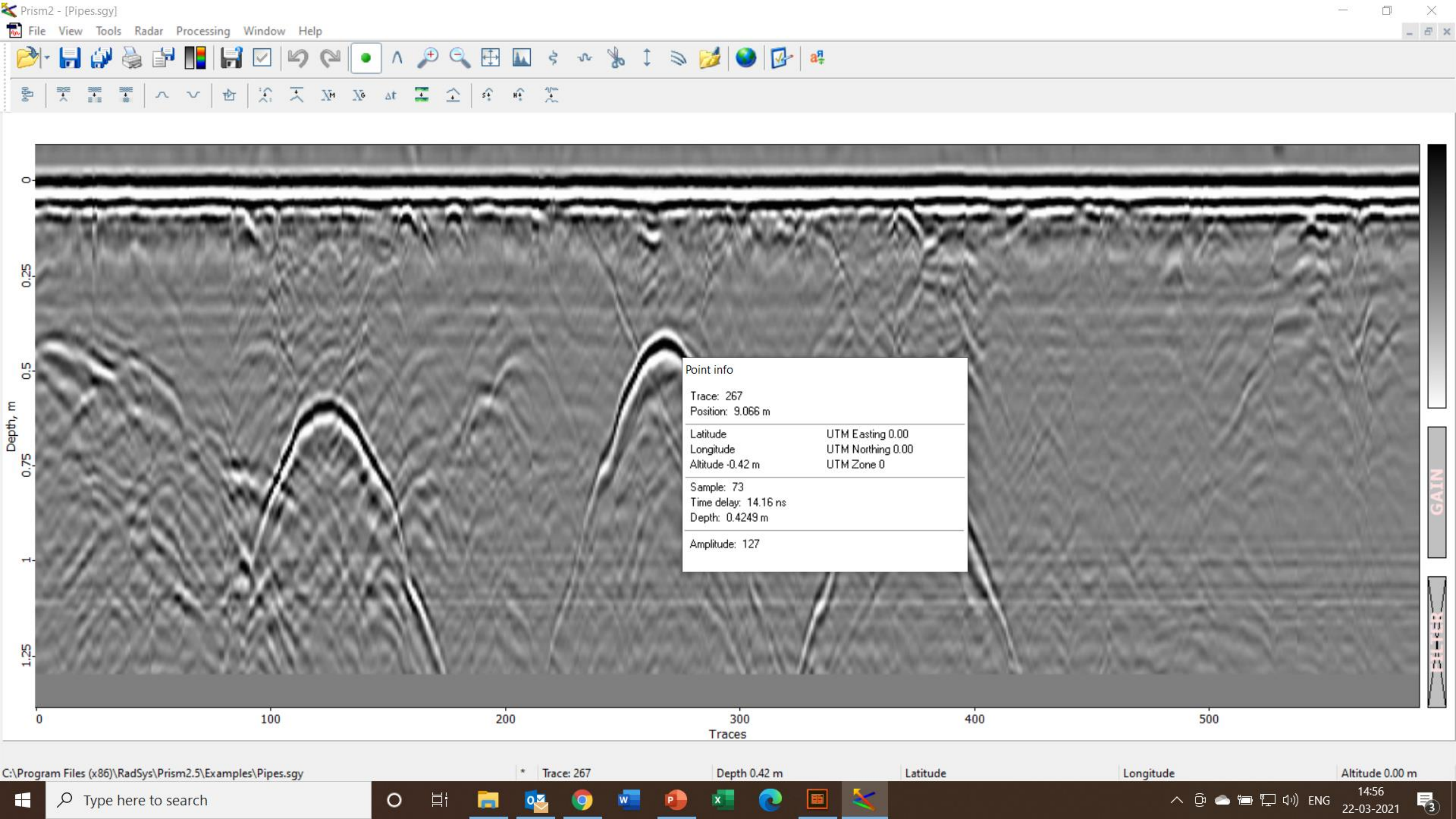
$$\text{Depth Accuracy} = 1/4^{th} \text{ of } \lambda$$

Best Practices- Always Calibrate Velocity

Importance of velocity calibration: Double Y axis

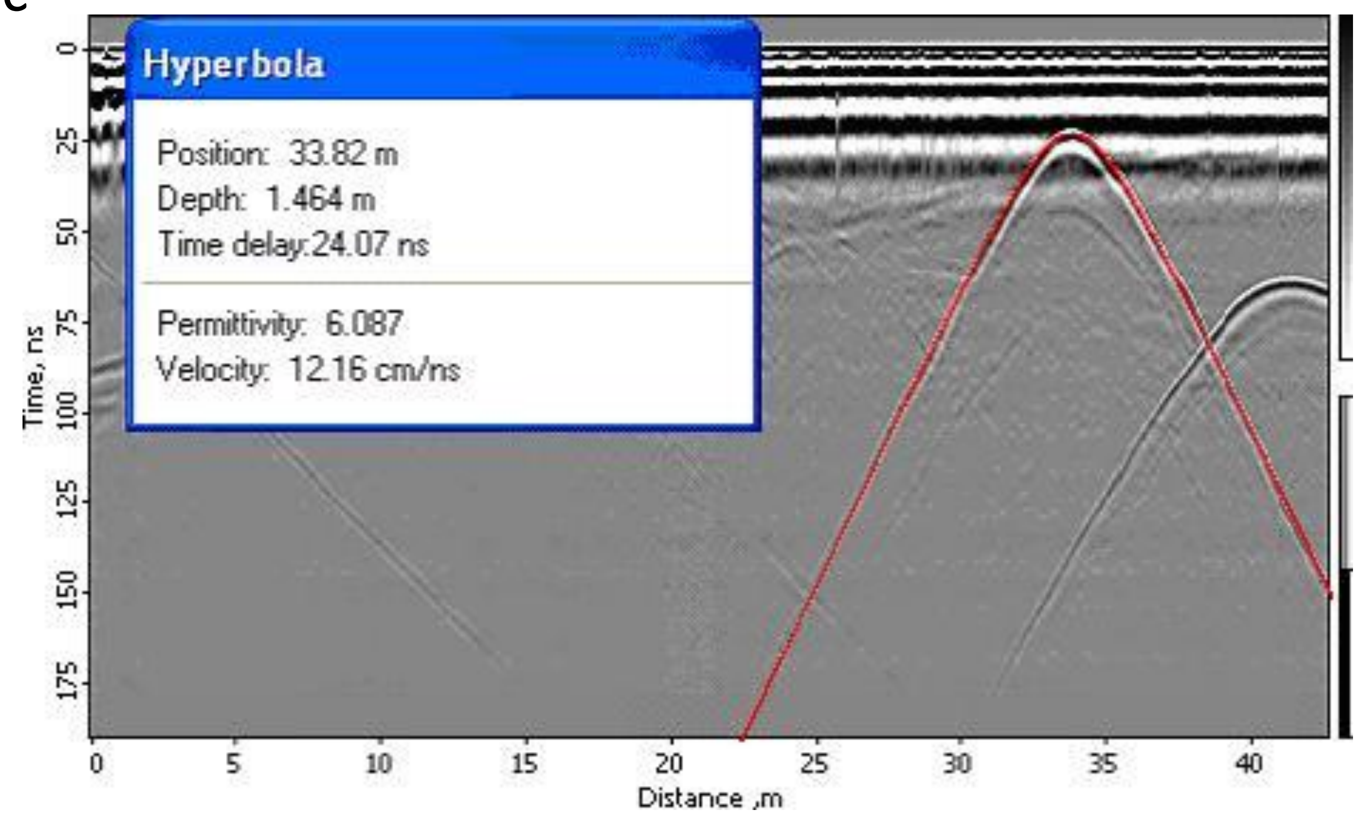



Prism2 - [Pipes.sgy]
File View Tools Radar Processing Window Help
Depth, m
0
0.5
1
1.5
2
2.5
3
0
100
200
300
400
500
Traces
Point info
Trace: 267
Position: 9.066 m
Latitude
Longitude
Altitude -0.96 m
UTM Easting 0.00
UTM Northing 0.00
UTM Zone 0
Sample: 74
Time delay: 14.36 ns
Depth: 0.963 m
Amplitude: 127
GAIN
Pipes.sgy
C:\Program Files (x86)\RadSys\Prism2.5\Examples\Pipes.sgy
Trace: 267
Depth 0.96 m
Latitude
Longitude
Altitude 0.00 m
Type here to search
ENG
14:57
22-03-2021


Prism2 - [Pipes.sgy]
File View Tools Radar Processing Window Help
0
0.25
0.5
0.75
1
1.25
Depth, m
Point info
Trace: 267
Position: 9.066 m
Latitude
Longitude
Altitude -0.42 m
UTM Easting 0.00
UTM Northing 0.00
UTM Zone 0
Sample: 73
Time delay: 14.16 ns
Depth: 0.4249 m
Amplitude: 127
GAIN
0
100
200
300
400
500
Traces
C:\Program Files (x86)\RadSys\Prism2.5\Examples\Pipes.sgy
Trace: 267
Depth 0.42 m
Latitude
Longitude
Altitude 0.00 m
Type here to search
ENG
14:56
22-03-2021

Calibration by Curve Fitting

The cursor is placed over the hyperbolic signal in the data at a zero crossing point. The zero crossing occurs at the interface between the positive and negative parts of the signal. This is the first interface between the black and white banding. It does not matter whether this is black to white or white to black, the curve should be fitted to the dividing line between the two. The value of transmission velocity is adjusted until the two hyperbolas follow the same outline

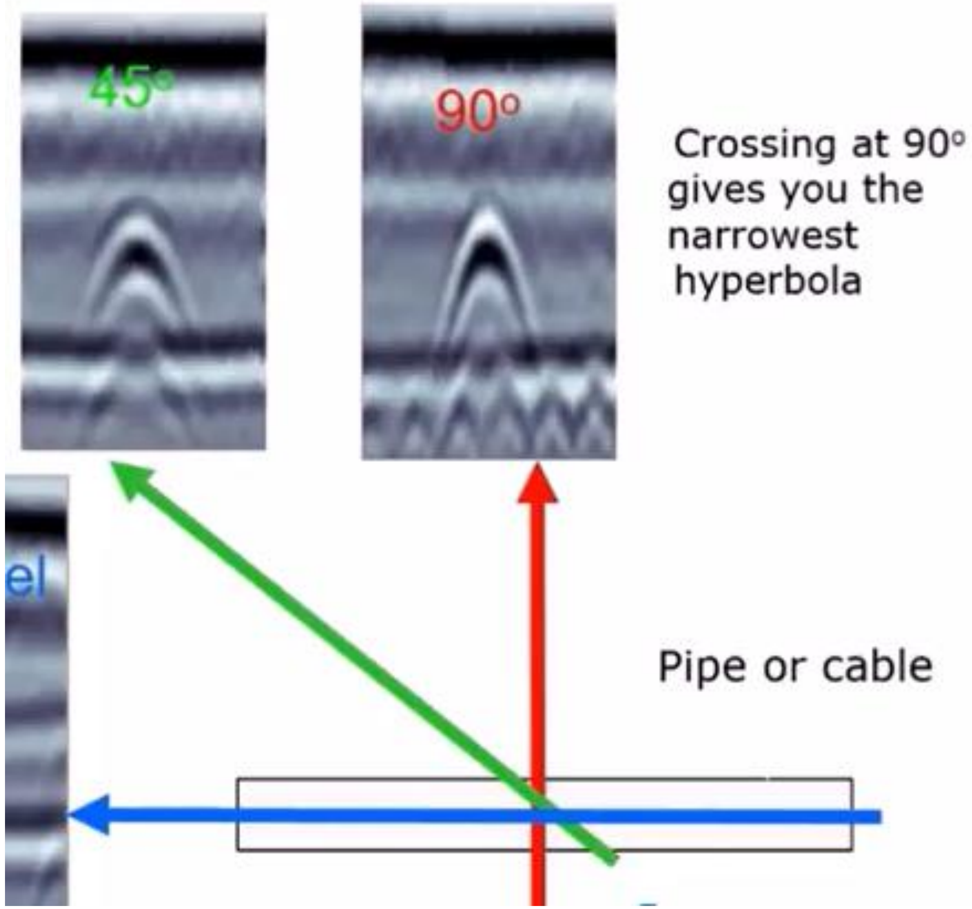


Calibration by Curve Fitting

- Where the target is large relative to the wavelengths transmitted by the GPR, the target may have a measurable size. For larger targets, it will be necessary to adjust the radius of the hyperbola to allow for the size of the object as well as adjusting the transmission velocity. Without the additional adjustment of the size, it would not be possible to fit the cursor to the data.

- The object should be crossing the GPR survey line at 90^0 else hyperbola matching will be misleading

- Large pipes hyperbola fitting can be done separately at edges

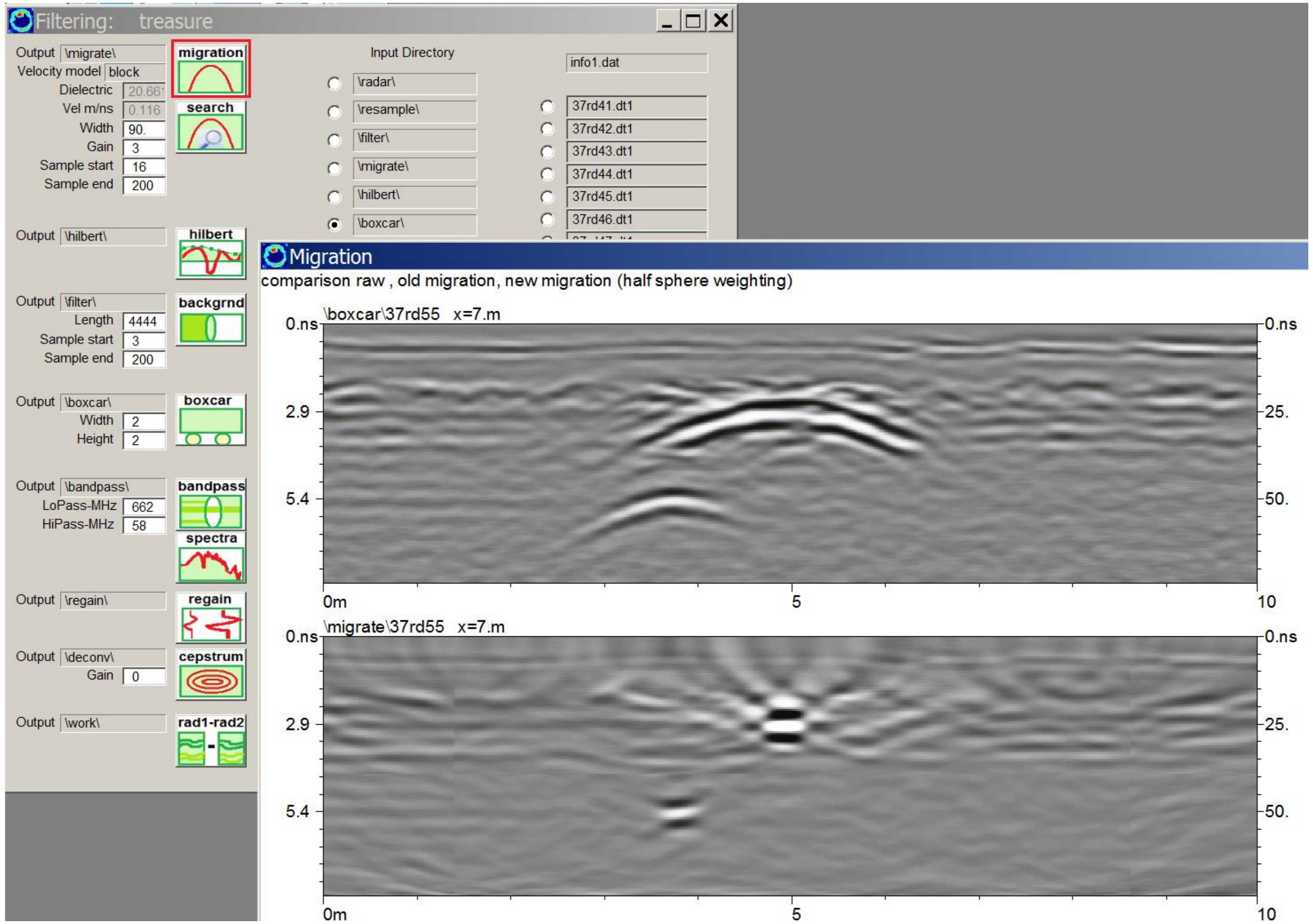


Calibration by Curve Fitting- Limitations

1. The data must contain several **<u>sufficiently clear hyperbolas</u>** or it will not be possible to use this method. A lack of hyperbolas or too much clutter in the data can make it impossible to curve fit.
2. There is a certain amount of leeway in fitting an appropriate velocity. In other words, there is usually a **<u>small range of values which will fit the same hyperbola outline</u>**. This latter problem, however, can be refined to greater accuracy by the use of a mathematical technique known as migration.

Migration

The primary parameter required to collapse the hyperbola into a point is the transmission velocity. This makes the migration process one way of increasing the accuracy of curve fitting since the process only works correctly if the transmission velocity applied is accurate.



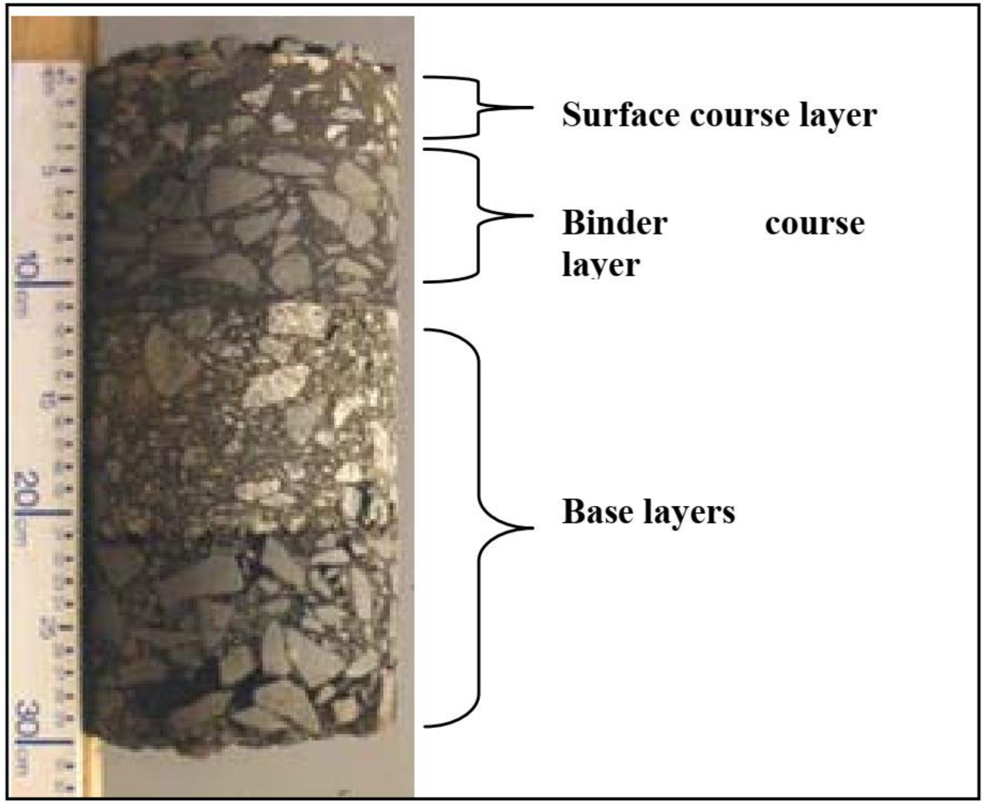
Migration

REMEMBER

Different velocities might be needed at different depths of hyperbolas

Known Layer or Layers

For this method of calibration, it is necessary to know the depth of at least one subsurface layer accurately, in one or more locations. It is commonly used on man-made layered materials, e.g. in road, bridge deck, and airport investigations. It is also a common method of calibrating velocity in environmental investigations. For multiple layers, each layer reading can be used to calibrate the transmission velocity within that particular material. The depth readings in each case are taken by extracting cores from the survey site at predefined positions.



Known Layer or Layers…Caution

- Exact location of BH on GPR line. Use marker

- The most common problem with this method lies in the timing and placement of the boreholes and the markers. For this method to be accurate, it is essential that the **GPR survey is carried out in advance of the cores being extracted and that the location of the cores is accurately marked on the GPR data**. If the cores are extracted in advance of the GPR work, it is impossible to survey the location of the boreholes since the relevant materials are no longer in the same position.

Known Layer or Layers…Caution

Where cores have been extracted in advance of the GPR survey, it is common practice to compare the contents of the borehole with the GPR data collected from a nearby location. **Unfortunately this is only accurate if the subsurface layers lie at a constant depth across the survey area**. Even in built environments, this is far less likely than is sometimes assumed. Layers of asphalt and concrete frequently vary over relatively short distances, making the comparison inaccurate and the calibration invalid. In open countryside, where the stratigraphy has been laid down by natural forces and there is no requirement for leveling, it is frequently highly inaccurate. An inaccurate depth reading resulting in an inaccurately calculated transmission velocity will result in depth errors for the whole survey. **This is not inaccuracy on the part of the radar.**

Known Layer or Layers…Caution

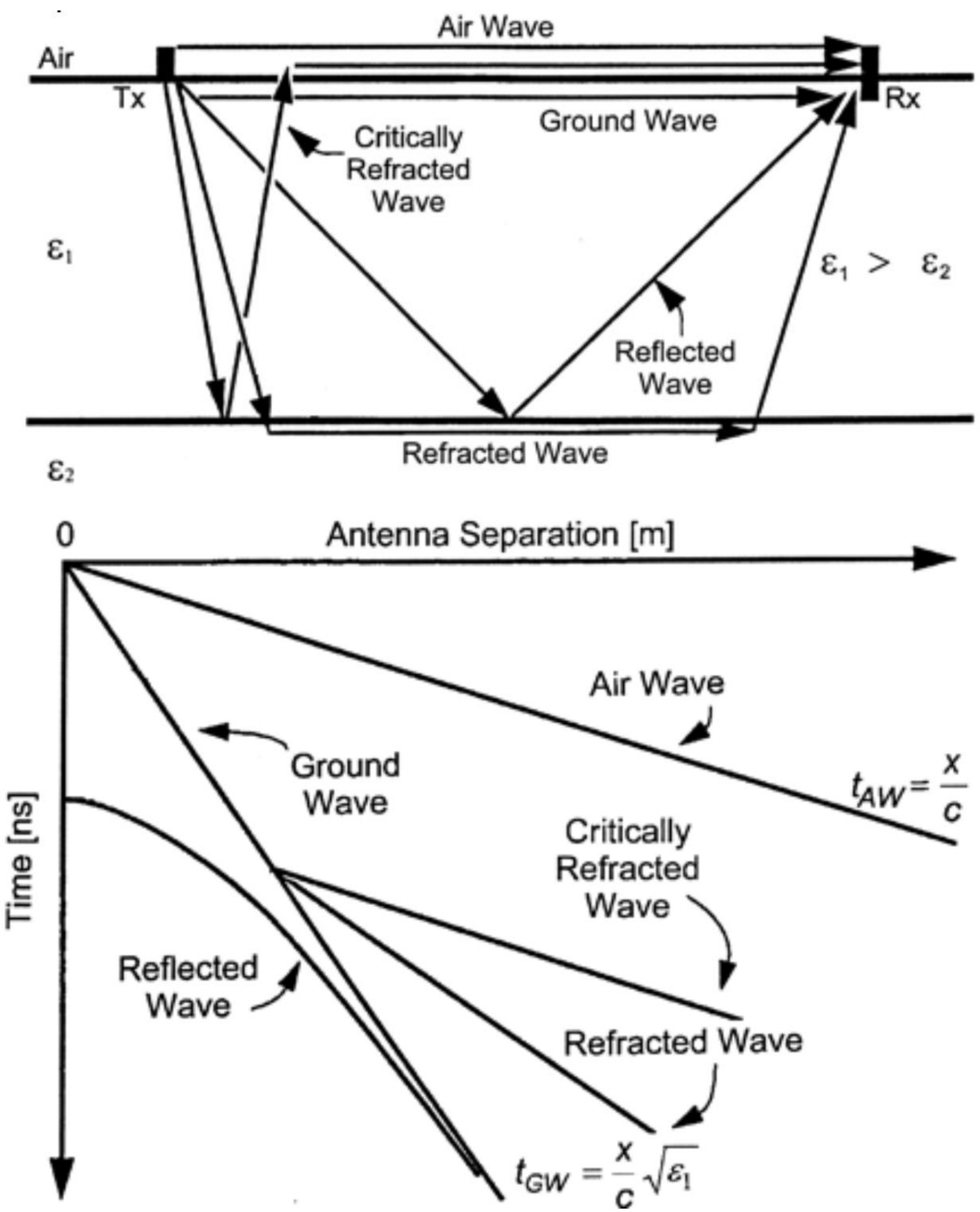
Unlike layers of construction materials, buried soils do not always correspond visually to their electromagnetic composition.

Object at Known Depth

This method relies on a specific target being already in place on the site to be investigated or on being able to place such a target accurately within the survey site environment.

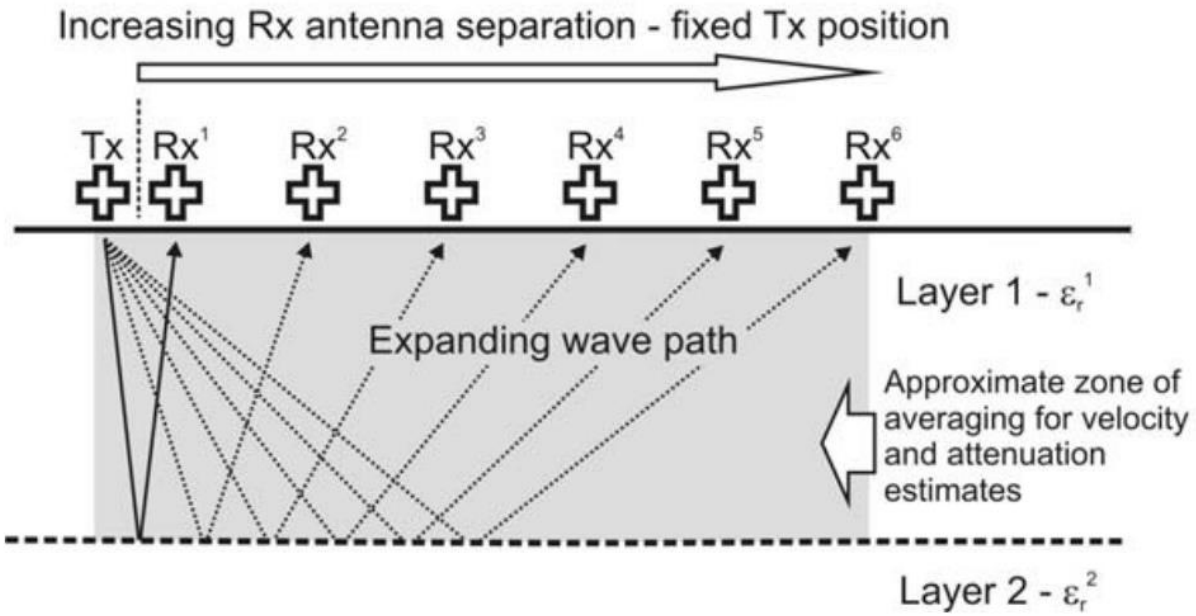
Change in moisture level can completely change the calibration and should be considered while using such data.

Wide Angle Reflection & Refraction (WARR) & CMP



Wide Angle Reflection & Refraction (WARR)

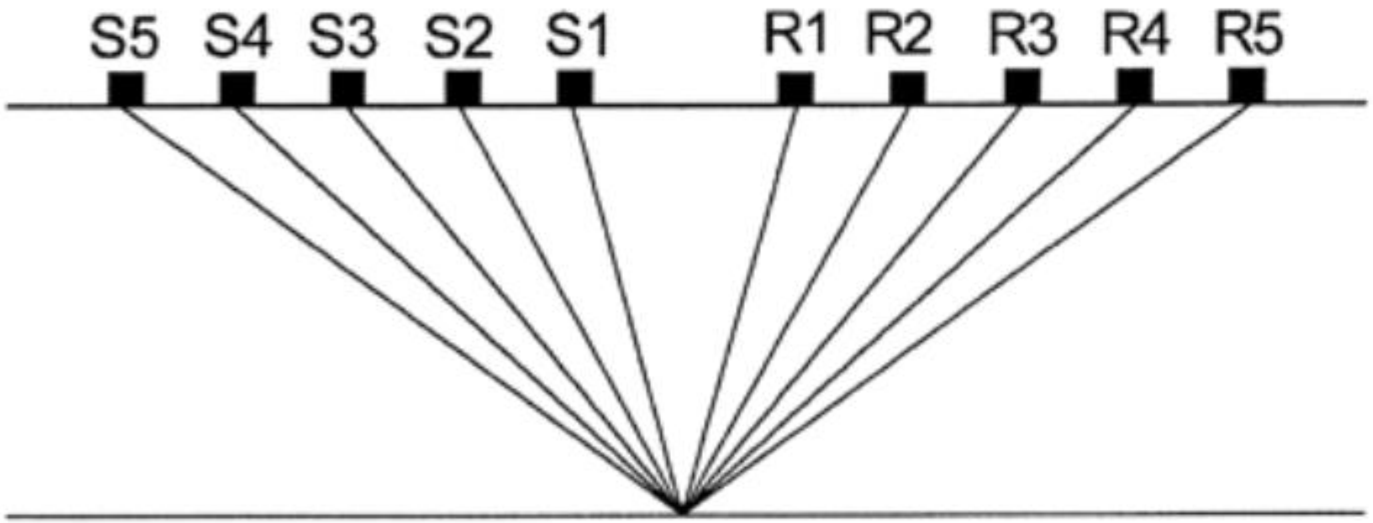
The object of the exercise is to compare the direct signal through the air from the transmitter to the receiver with that of a simultaneous signal through the ground. Since the velocity of the signal in air is known (the speed of light, or approximately 0.3 m/ns), it is possible to use a simple computer program to compare the two signals and, from the comparison, work out the velocity of the signal through the ground.



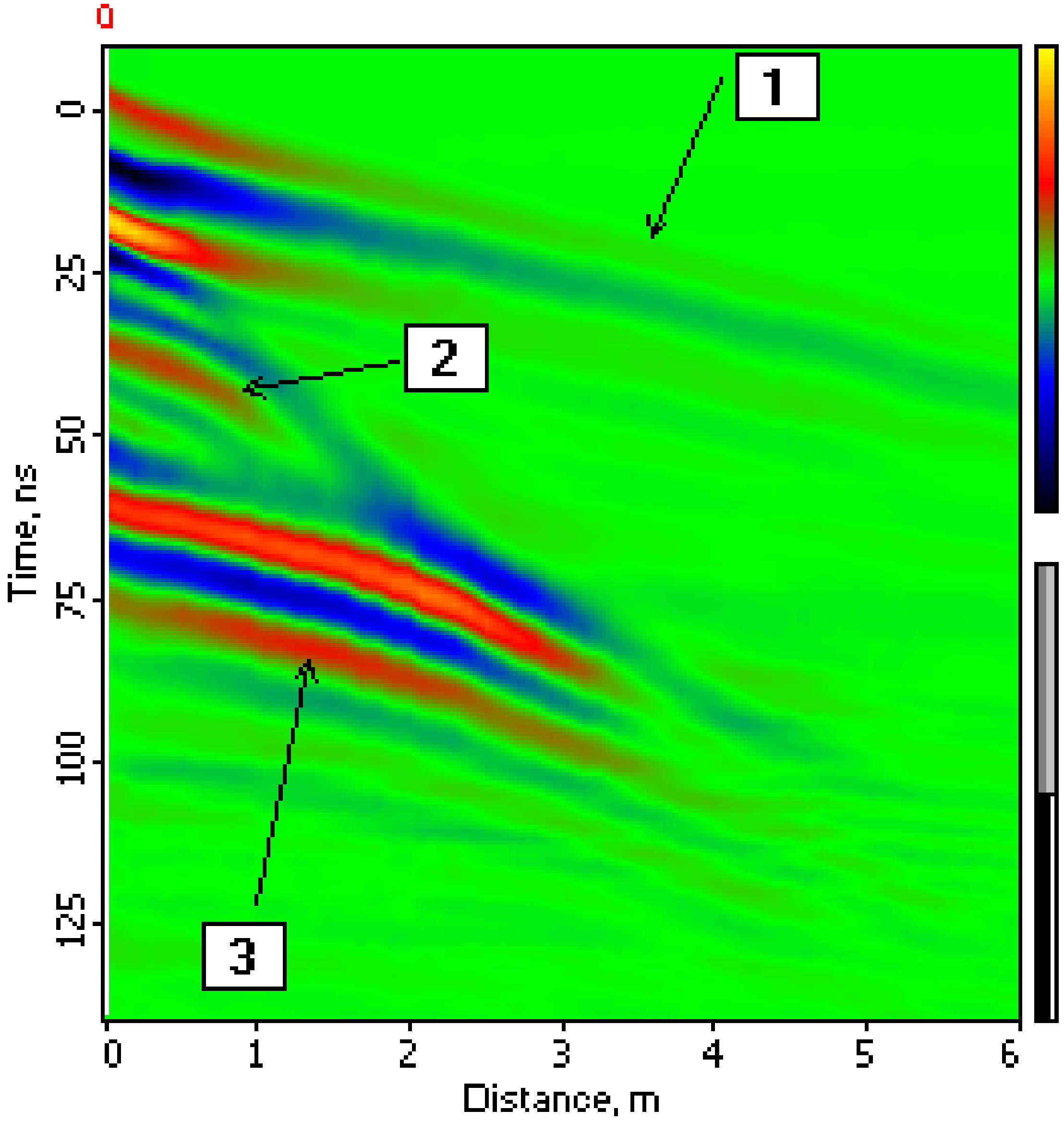
Wide Angle Reflection & Refraction (WARR)

One of the basic assumptions of this method is that the subsurface layer being surveyed should be flat or reasonably flat.

Common mid-point (CMP) reflection mode

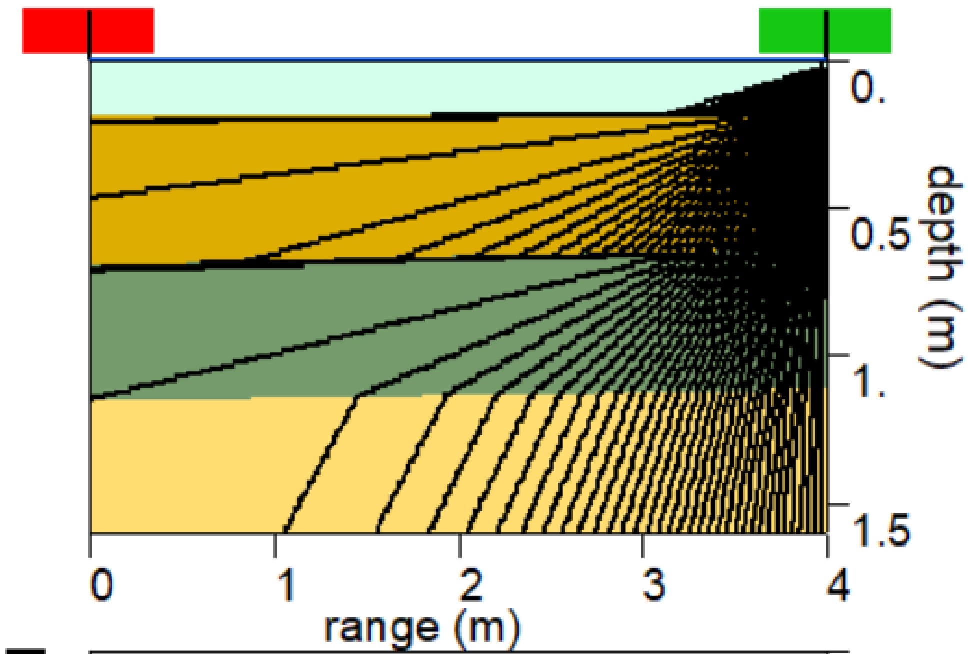


Common mid-point (CMP) reflection mode



1. Air wave path signal. Always appears as an inclined straight line.
2. Path of signal reflected from the first layer interface.
3. Path of signal refracted on the first layer interface and reflected from the second layer interface.

Rebar in concrete

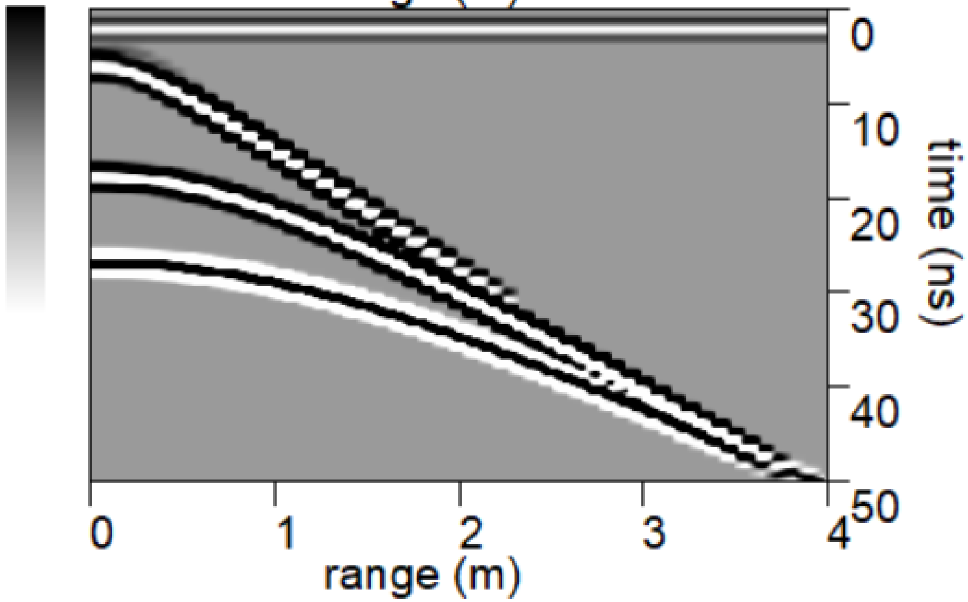


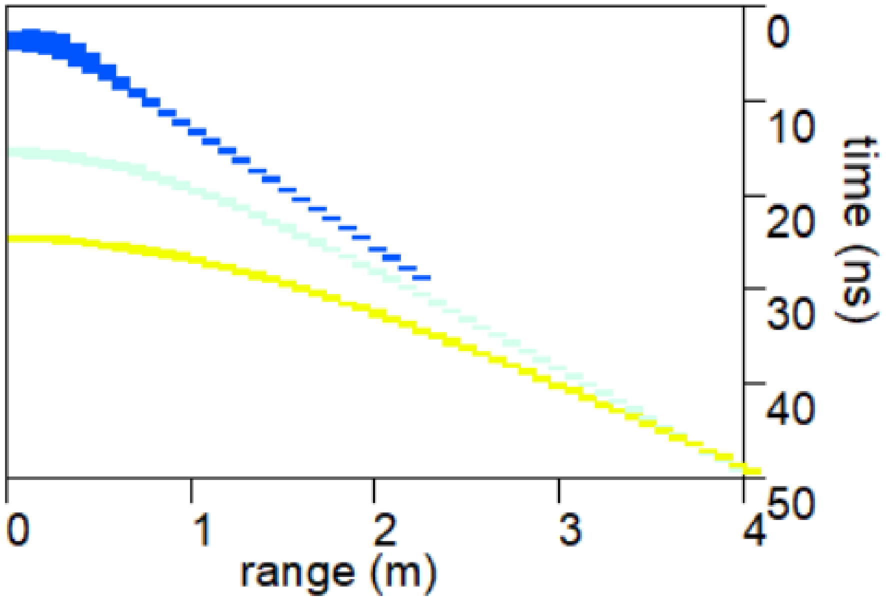
Material	Er	C.mho/m
air	1.	0.
soil-sandy-dry	15.	0.001
soil-clayey-dry	8.	0.0003
soil-clayey-wet	17.	0.05
silt-wet	12.	0.005

Simulation Parameters

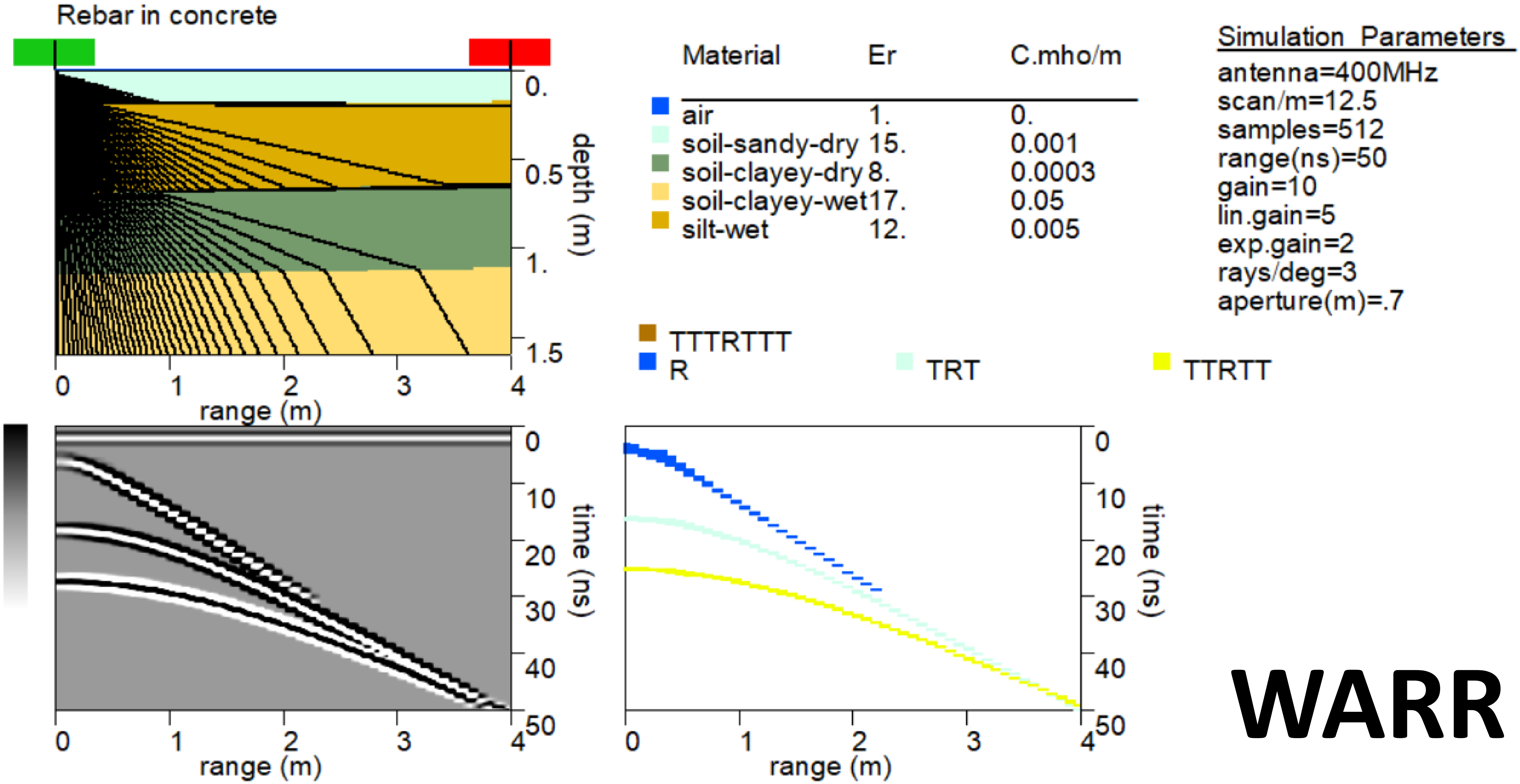
antenna=400MHz
scan/m=12.5
samples=512
range(ns)=50
gain=10
lin.gain=5
exp.gain=2
rays/deg=3
aperture(m)=.7

TTTRTTT
R
TRT
TTRTT

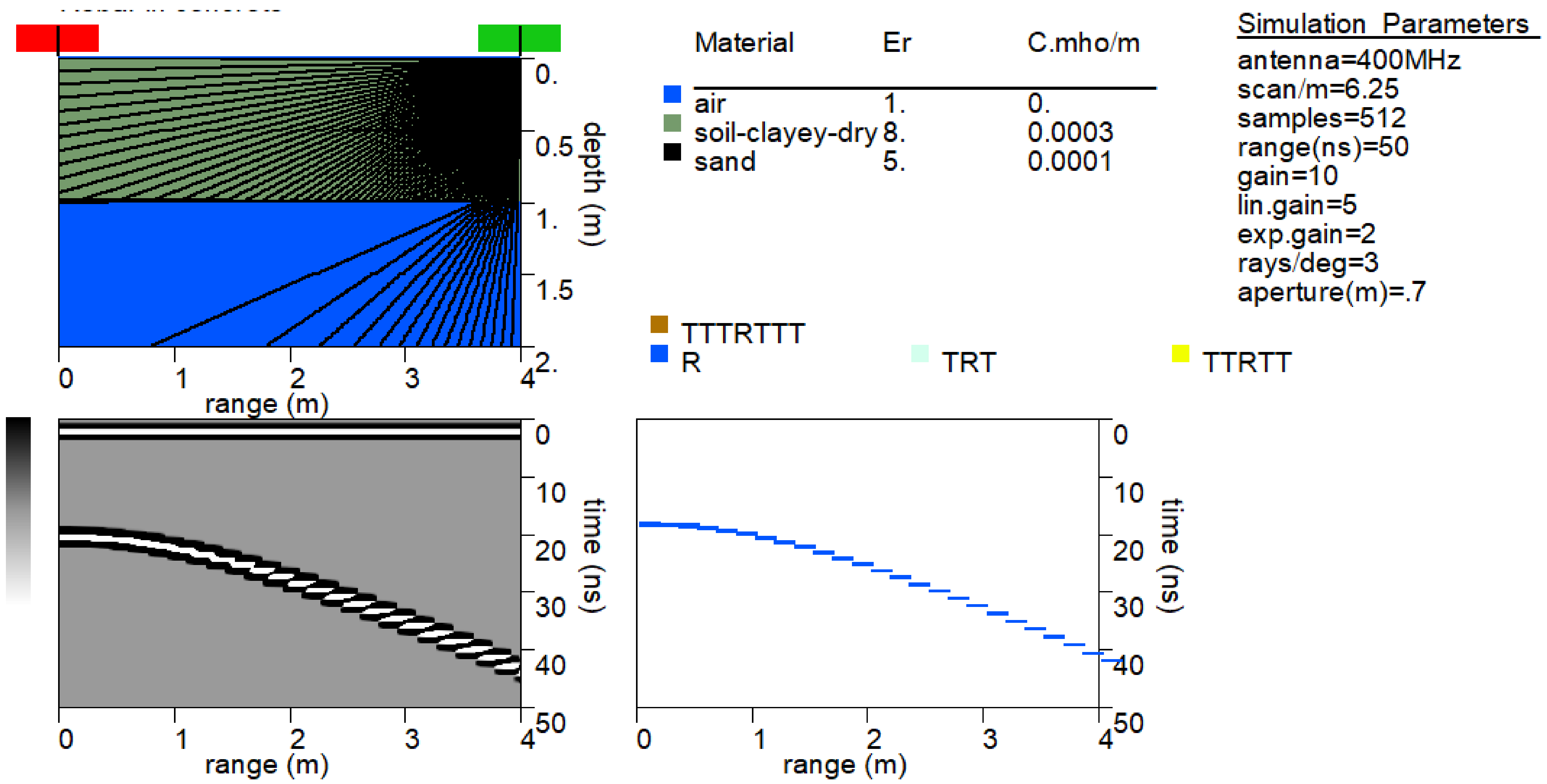




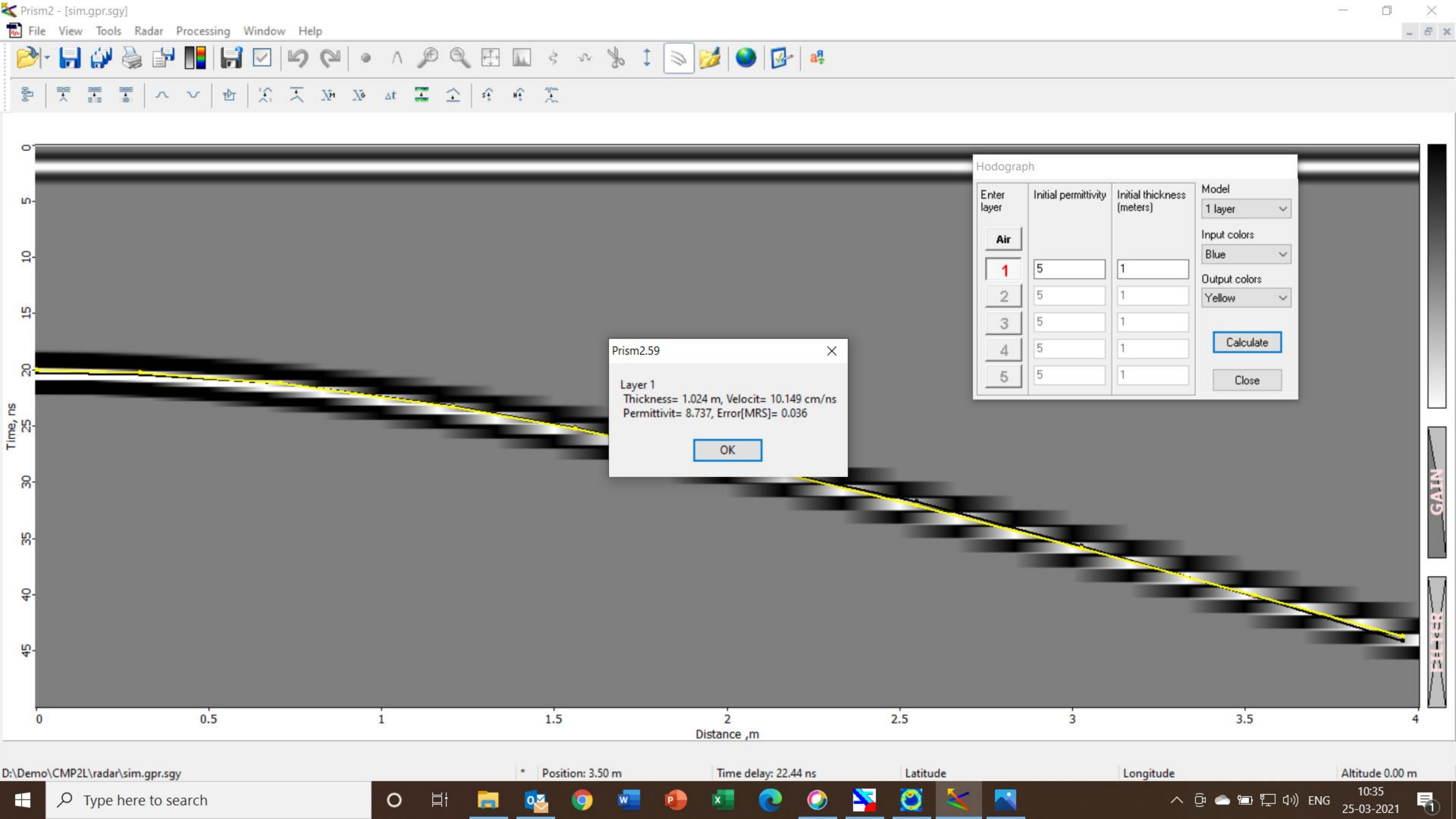
CMP


Rebar in concrete
0.
0.5
1.
1.5
depth (m)
0
1
2
3
4
range (m)
Material Er C.mho/m
air 1. 0.
soil-sandy-dry 15. 0.001
soil-clayey-dry 8. 0.0003
soil-clayey-wet 17. 0.05
silt-wet 12. 0.005
Simulation Parameters
antenna=400MHz
scan/m=12.5
samples=512
range(ns)=50
gain=10
lin.gain=5
exp.gain=2
rays/deg=3
aperture(m)=.7
TTTRTTT
R
TRT
TTRTT
0
10
20
30
40
50
time (ns)
range (m)

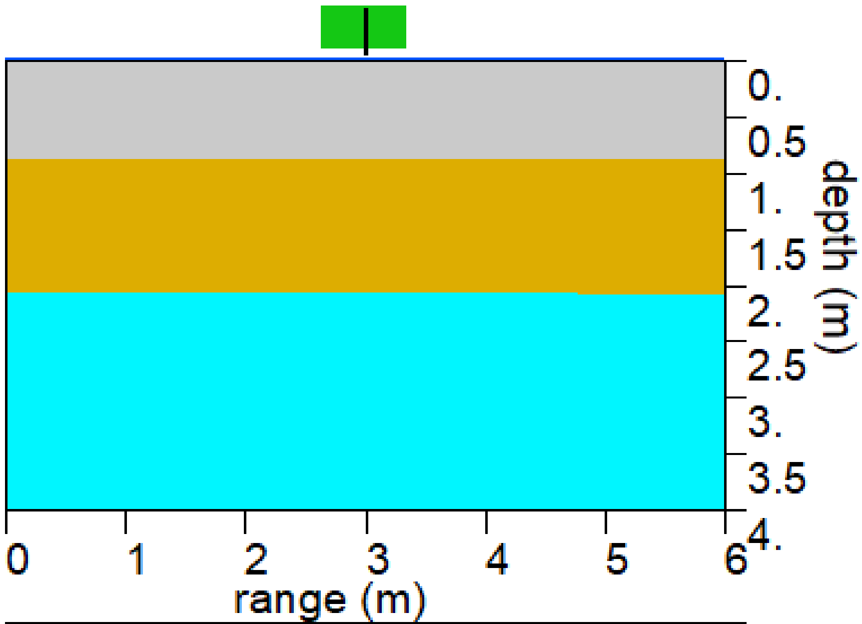
WARR



Material Er C.mho/m
air 1. 0.
soil-clayey-dry 8. 0.0003
sand 5. 0.0001
Simulation Parameters
antenna=400MHz
scan/m=6.25
samples=512
range(ns)=50
gain=10
lin.gain=5
exp.gain=2
rays/deg=3
aperture(m)=.7
TTTRTTT
R
TRT
TTRTT
depth (m)
range (m)
time (ns)
range (m)
time (ns)
range (m)


Prism2 - [sim.gpr.sgy]
File View Tools Radar Processing Window Help
Hodograph
Enter layer
Initial permittivity
Initial thickness (meters)
Model
1 layer
Input colors
Blue
Output colors
Yellow
Air
1 2 3 4 5
Calculate
Close
Prism2.59
Layer 1
Thickness= 1.024 m, Velocit= 10.149 cm/ns
Permittivit= 8.737, Error[MRS]= 0.036
OK
Time, ns
Distance ,m
GAIN
D:\Demo\CMP2L\radar\sim.gpr.sgy
Position: 3.50 m
Time delay: 22.44 ns
Latitude
Longitude
Altitude 0.00 m
Type here to search
ENG
10:35
25-03-2021

Rebar in concrete

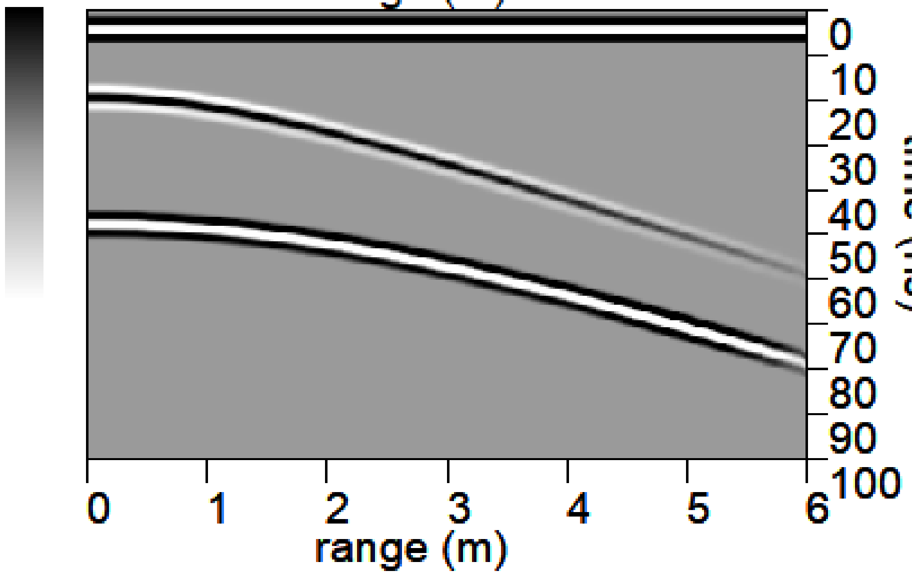


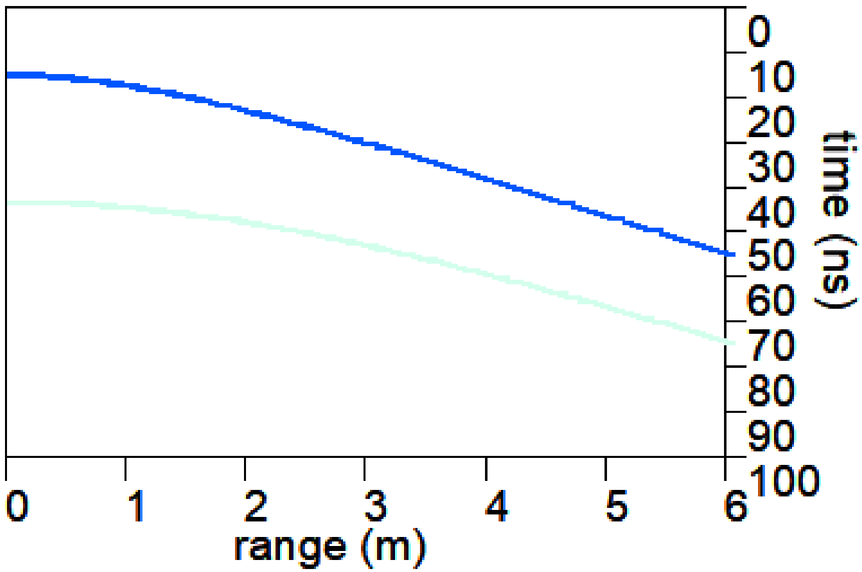
Material	Er	C.mho/m
air	1.	0.
silt-wet	12.	0.005
granite	5.	0.0005
concrete	7.	0.005

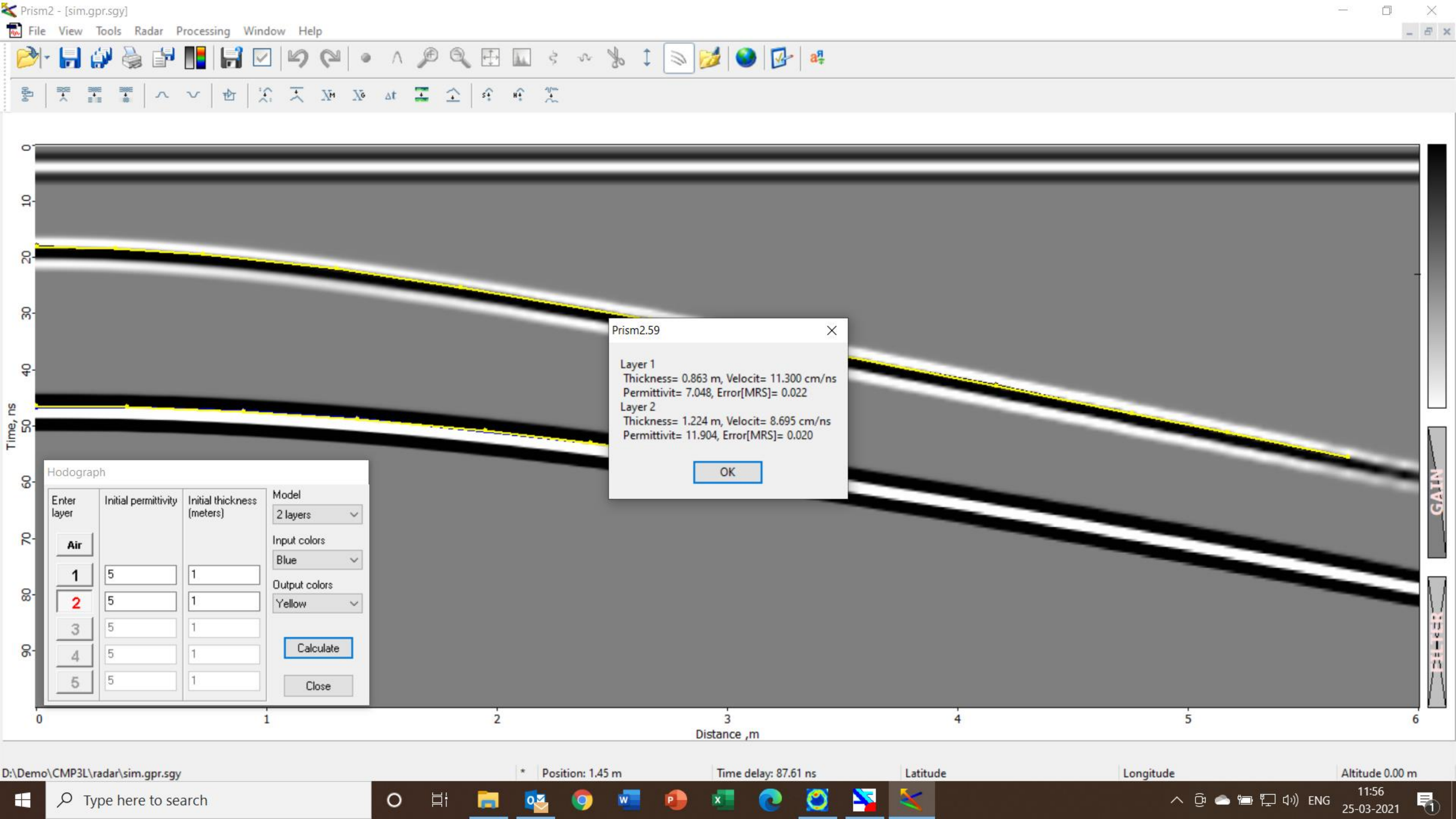
Simulation Parameters

antenna=400MHz
scan/m=16.67
samples=512
range(ns)=100
gain=10
lin.gain=5
exp.gain=2
rays/deg=3
aperture(m)=.7

TTTRTTT
R TRT TTRTT






Prism2 - [sim.gpr.sgy]
File View Tools Radar Processing Window Help
Time, ns
0
10
20
30
40
50
60
70
80
90
Prism2.59
Layer 1
Thickness= 0.863 m, Velocit= 11.300 cm/ns
Permittivit= 7.048, Error[MRS]= 0.022
Layer 2
Thickness= 1.224 m, Velocit= 8.695 cm/ns
Permittivit= 11.904, Error[MRS]= 0.020
OK
Hodograph
Enter layer
Initial permittivity
Initial thickness (meters)
Model
2 layers
Input colors
Blue
Output colors
Yellow
Air
1
2
3
4
5
Calculate
Close
GAIN
0
1
2
3
4
5
6
Distance ,m
D:\Demo\CMP3L\radar\sim.gpr.sgy
Position: 1.45 m
Time delay: 87.61 ns
Latitude
Longitude
Altitude 0.00 m
Type here to search
ENG
11:56
25-03-2021

A note of calibration

Regardless of which method of velocity calibration is used on a survey, **there should be a minimum of one calibration exercise on each site on each day**. This is because the velocity may change, particularly if there is a significant alteration in the weather, e.g., heavy rainfall. If weather conditions alter during the day, it is sensible to carry out another calibration exercise to ensure that changes in transmission velocity are picked up. It is also good practice to carry out more than one calibration exercise especially where there is any indication that one area may contain more moisture than another, for example.

Best Practices: Use Antenna Orientation

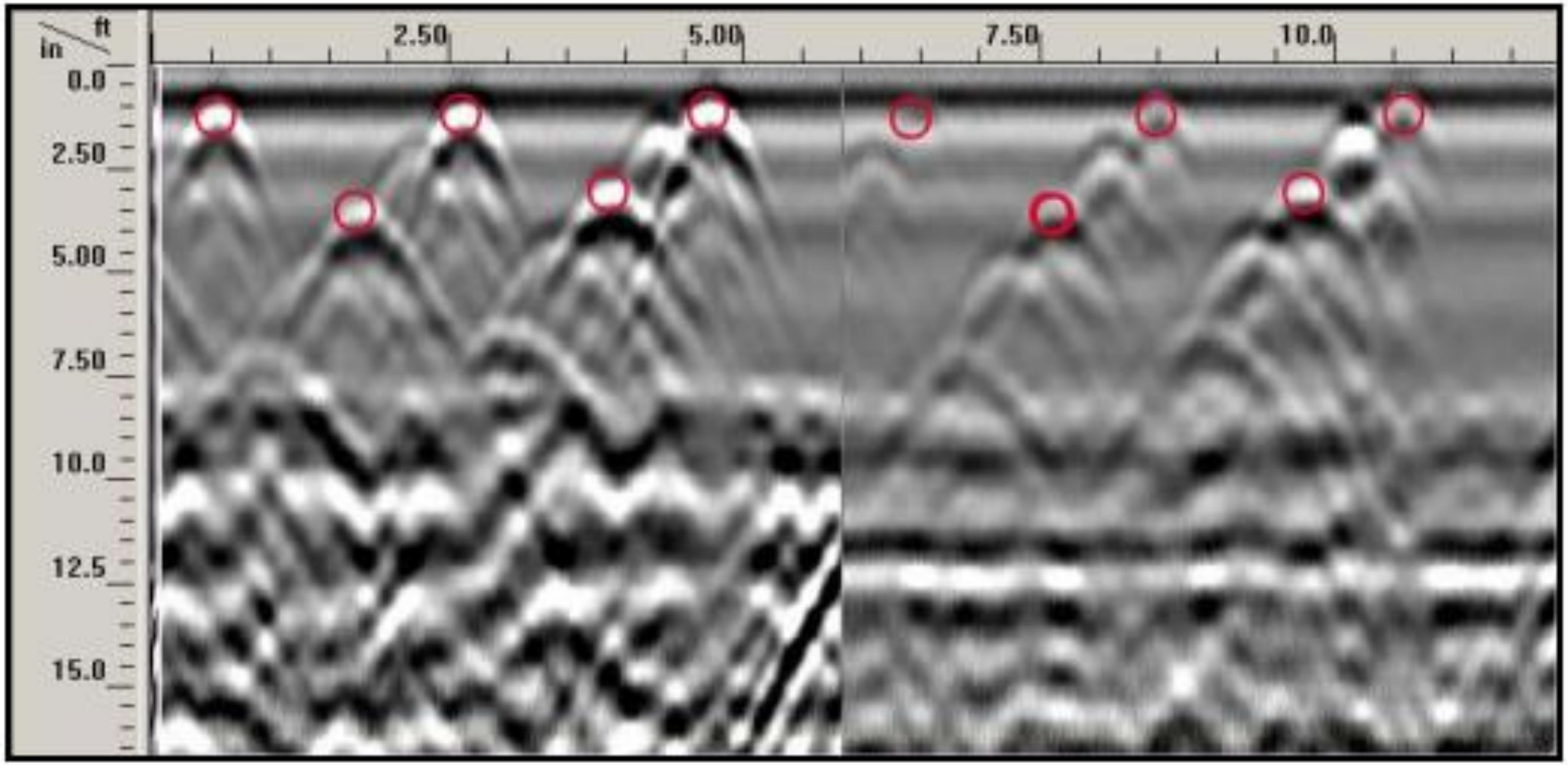


Figure 16: An elevated slab with parallel metal and PVC conduits. Left half of the profile - "standard" antenna position, right half – same survey line with antenna turned sideways. Red circles define metal targets, unmarked targets are PVC.

Benefit/Usage of dual polarization

Normal

Scanning direction

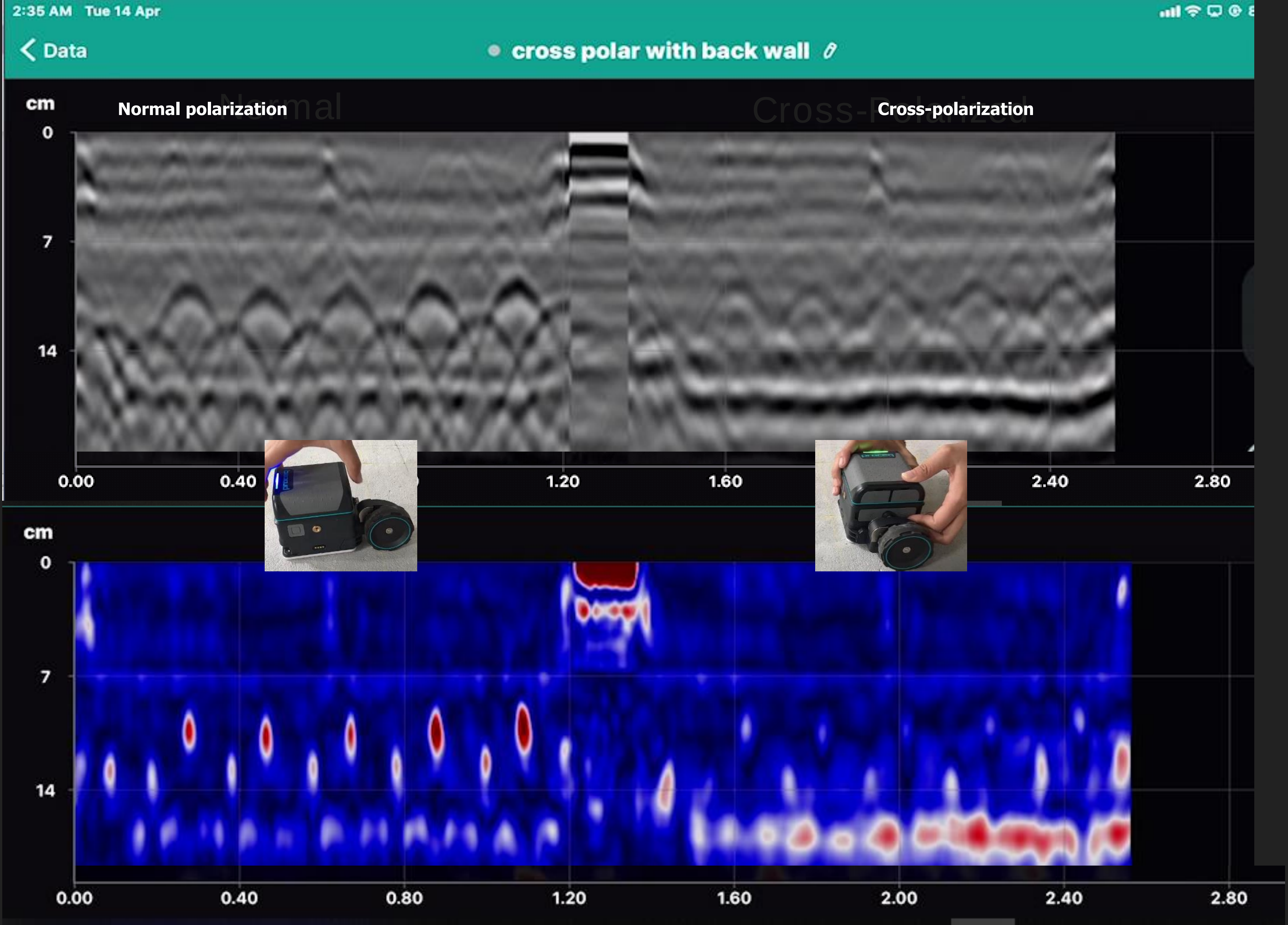
Cross-Polarized

- **Normal way of using GPR**:
  - Fits most cases
  - Highest resolution

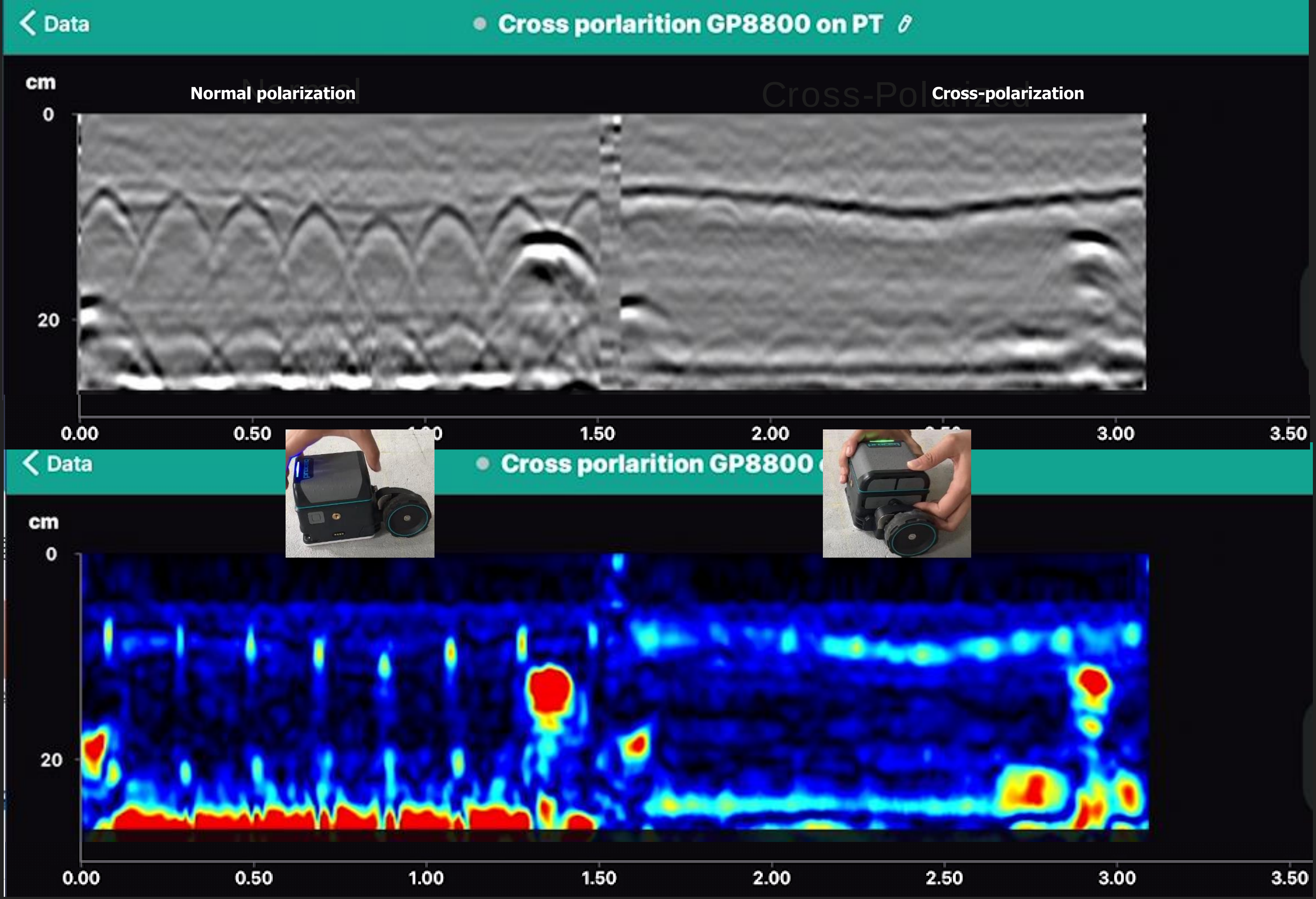
- Detecting object perpendicular to scanning direction
  - Rebar perpendicular

- Help to detect object/cables below a rebar net
  - Tendon cable parallel to scanning direction
  - Backwall
  - Verifying rebars along scanning direction

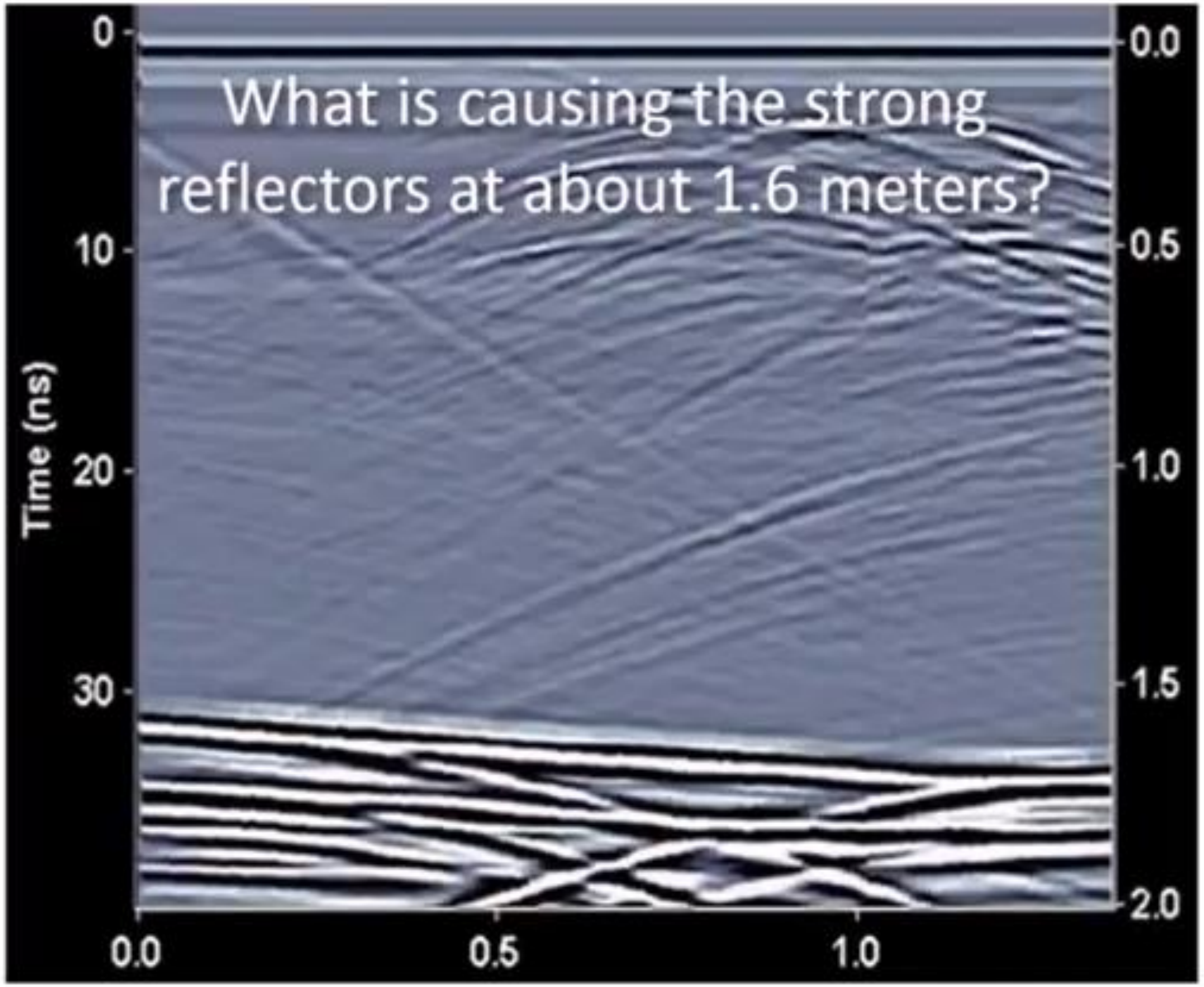
- Non-metallic object more highlighted



2:35 AM Tue 14 Apr
Data
cross polar with back wall
cm
Normal polarization
Cross-polarization
0
7
14
0.00
0.40
1.20
1.60
2.40
2.80
cm
0
7
14
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80


Data
Cross porlarition GP8800 on PT
cm
Normal polarization
Cross-polarization
0
20
0.00
0.50
1.50
2.00
3.00
3.50
Data
Cross porlarition GP8800
cm
0
20
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50

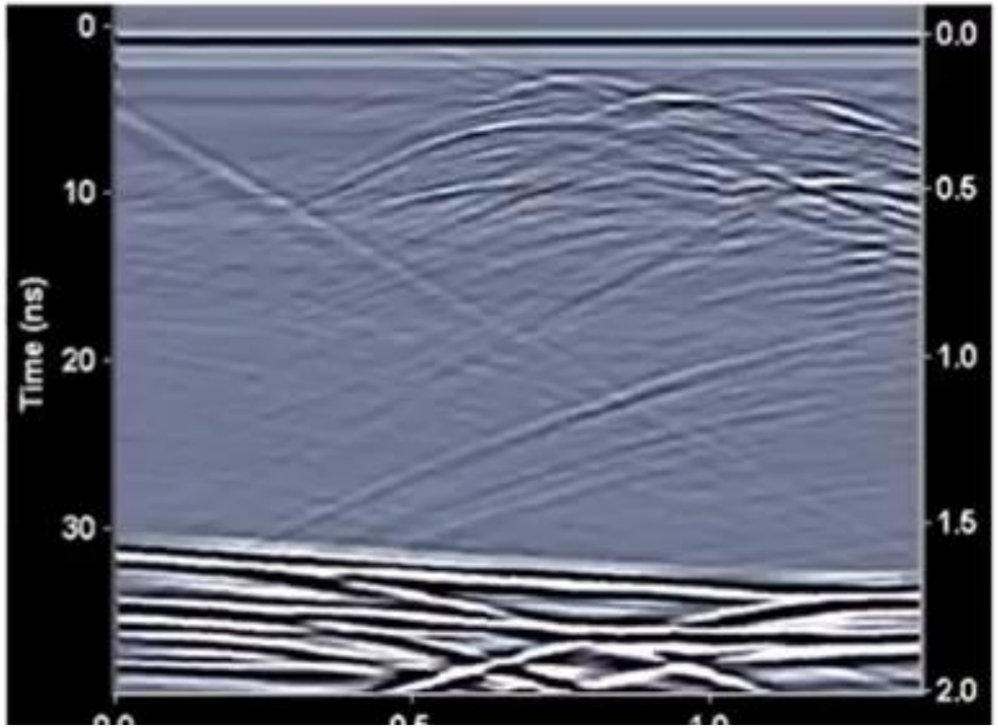
Best Practices: Keep Notes

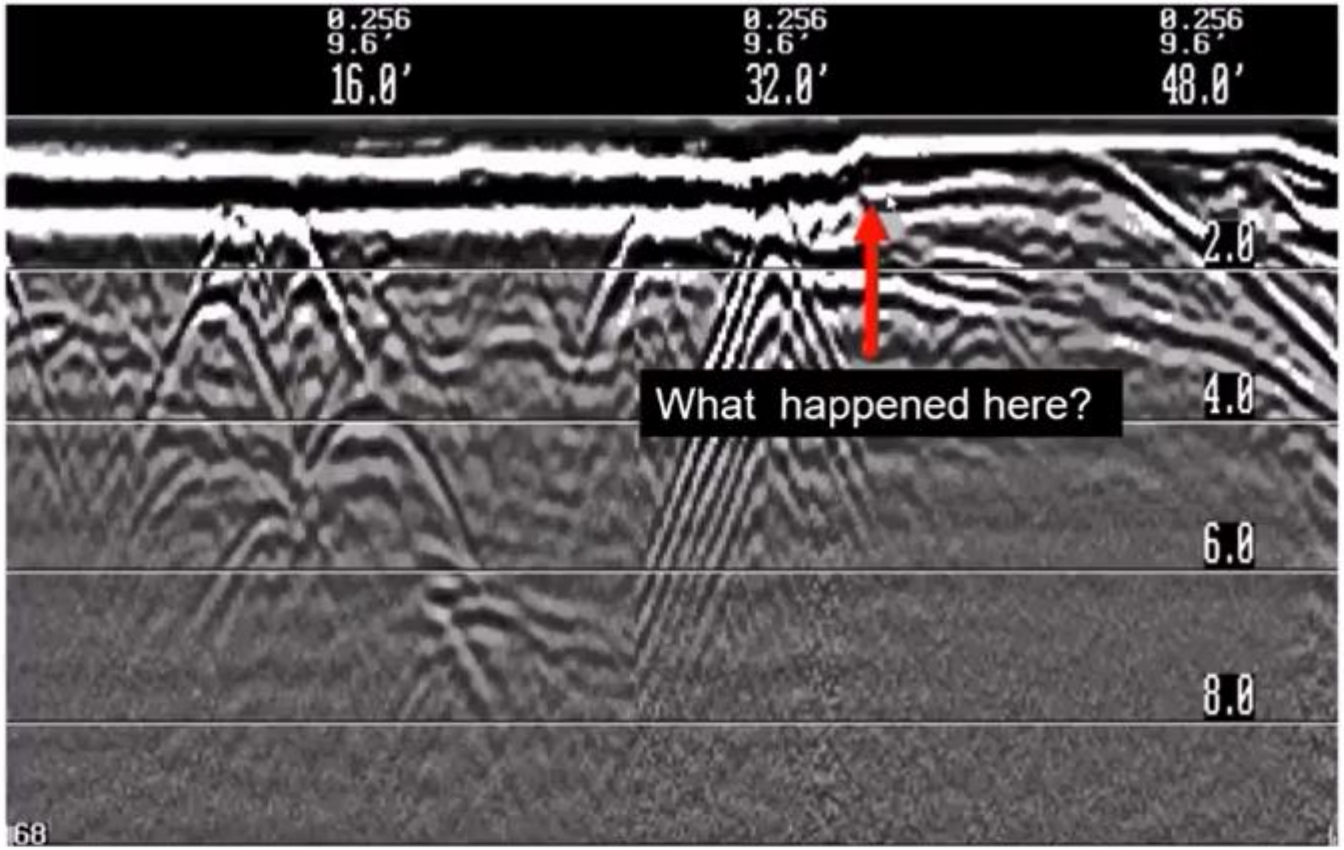


1) Bedrock
2) Cavity
3) RF Noise
4) None of the above

Can’t determine
Unless we have notes….

What is causing the strong reflectors at about 1.6 meters?



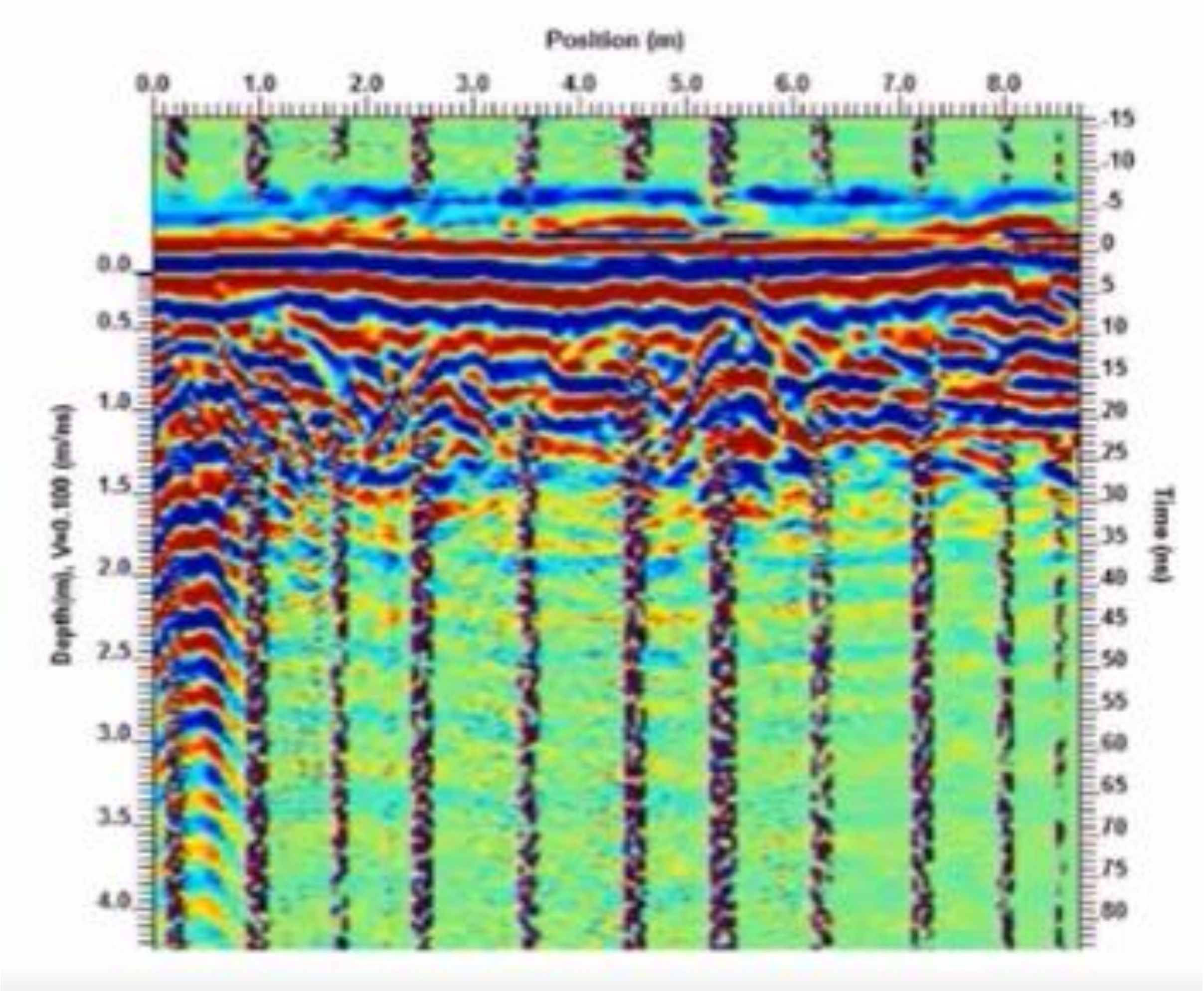


Sensors & Software

9:42 PM

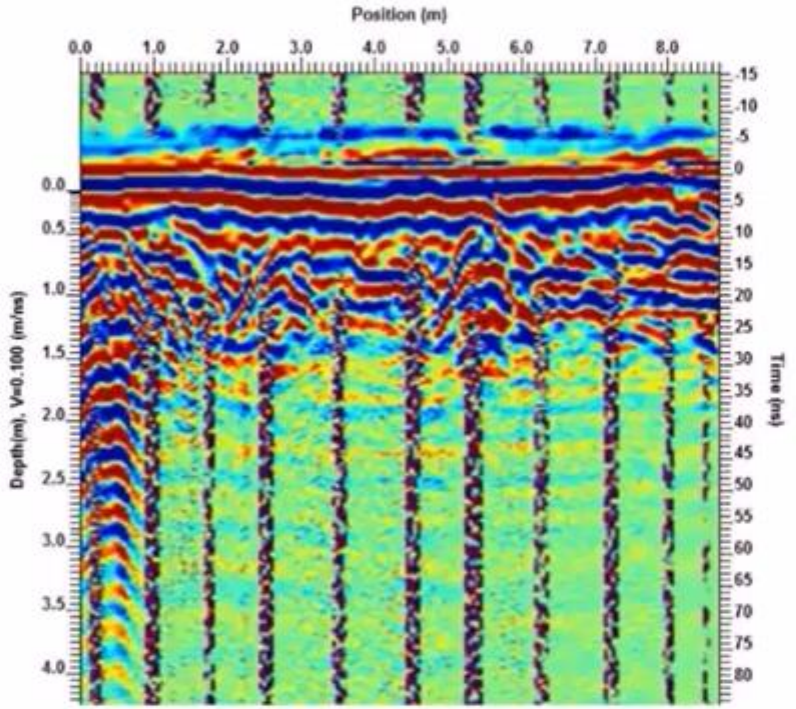
Sensors & Software

Look at the GPR record and comment on possible reason for vertical noise lines



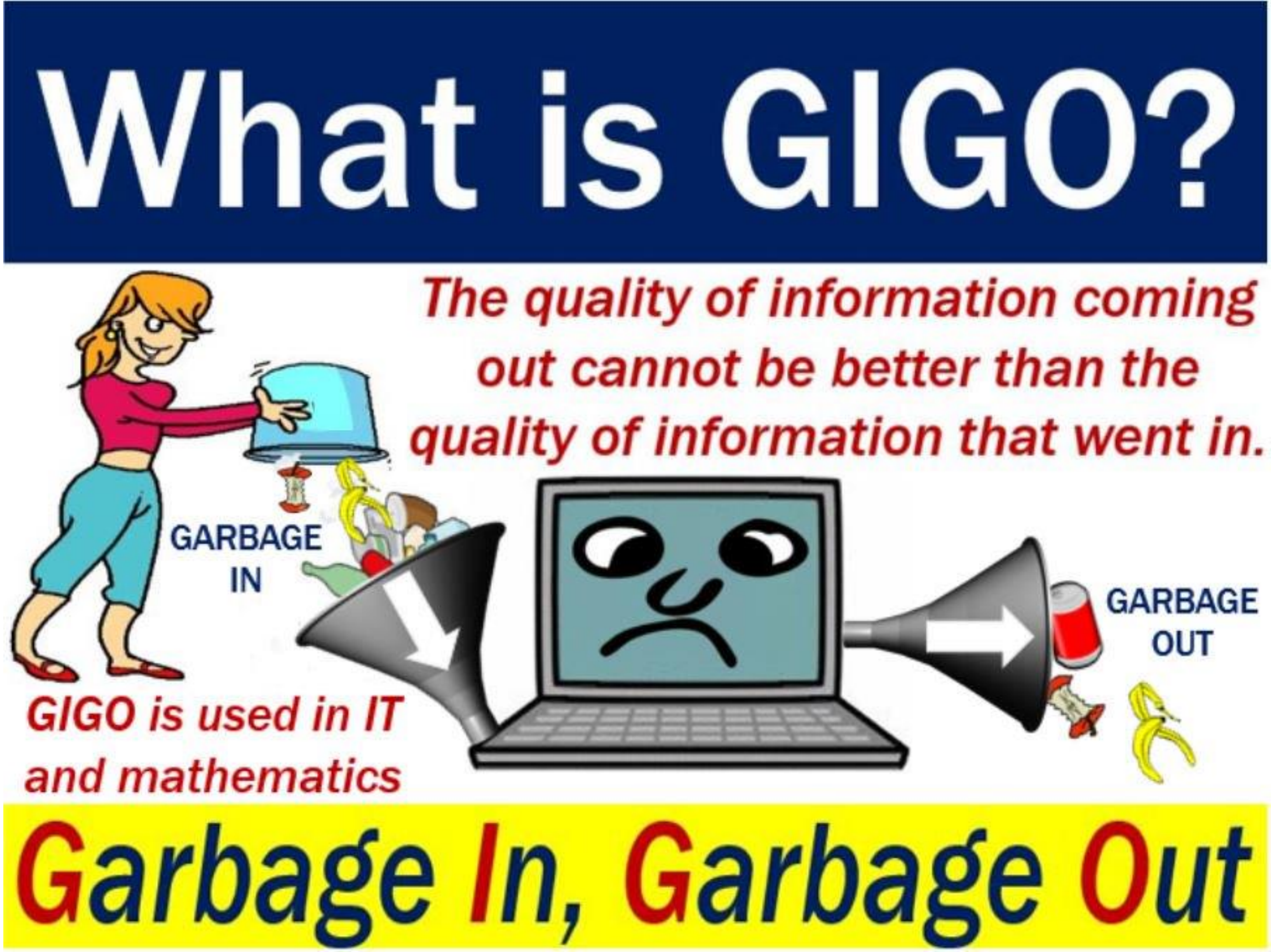
A. **External Radio Noise from a fixed tower**
B. **External Radio Noise from a rotating transmitter**
C. **Equipment malfunction.**
D. **Bad top surface**

External Radio Noise in GPR Data



Sensors & Software

Best Practices: Processing


What is GIGO?
The quality of information coming out cannot be better than the quality of information that went in.
GARBAGE IN
GARBAGE OUT
GIGO is used in IT and mathematics
Garbage In, Garbage Out

kiss

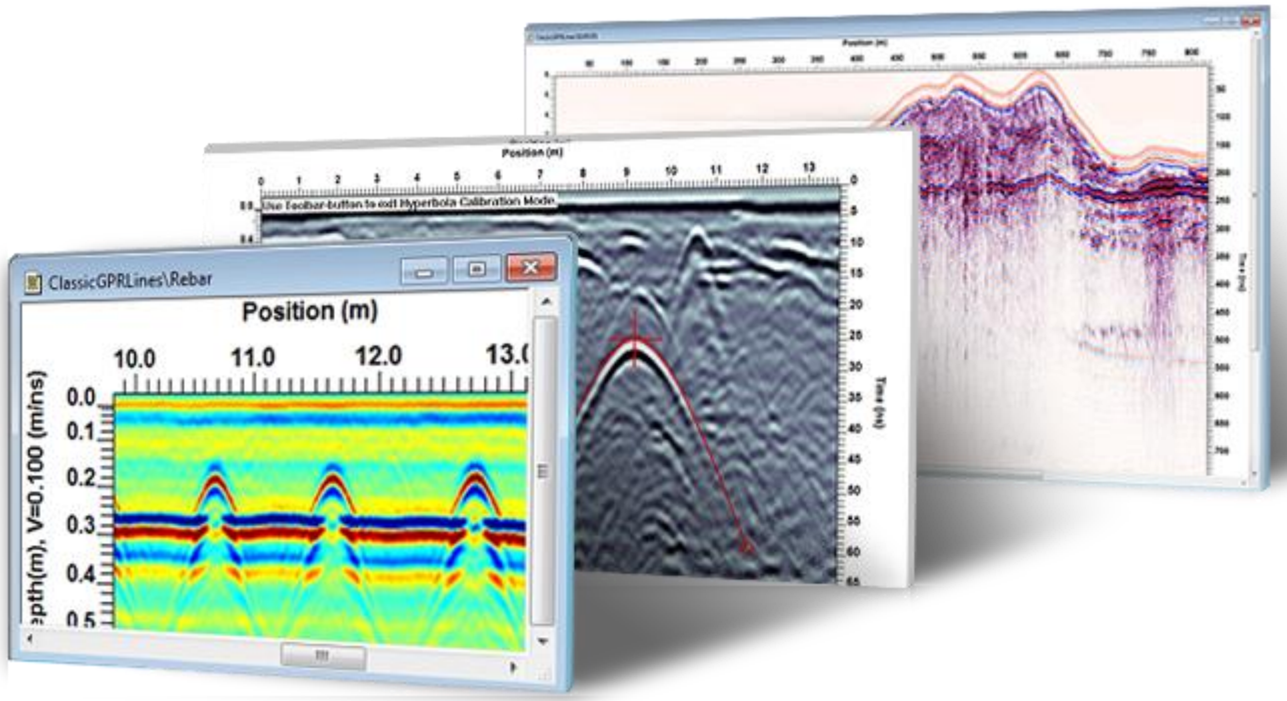
keep it simple & short

- 90% data needs only basic processing
- Ask yourself…….Why advanced processing
- Less time consuming to collect good data than to process

Keep it Real!

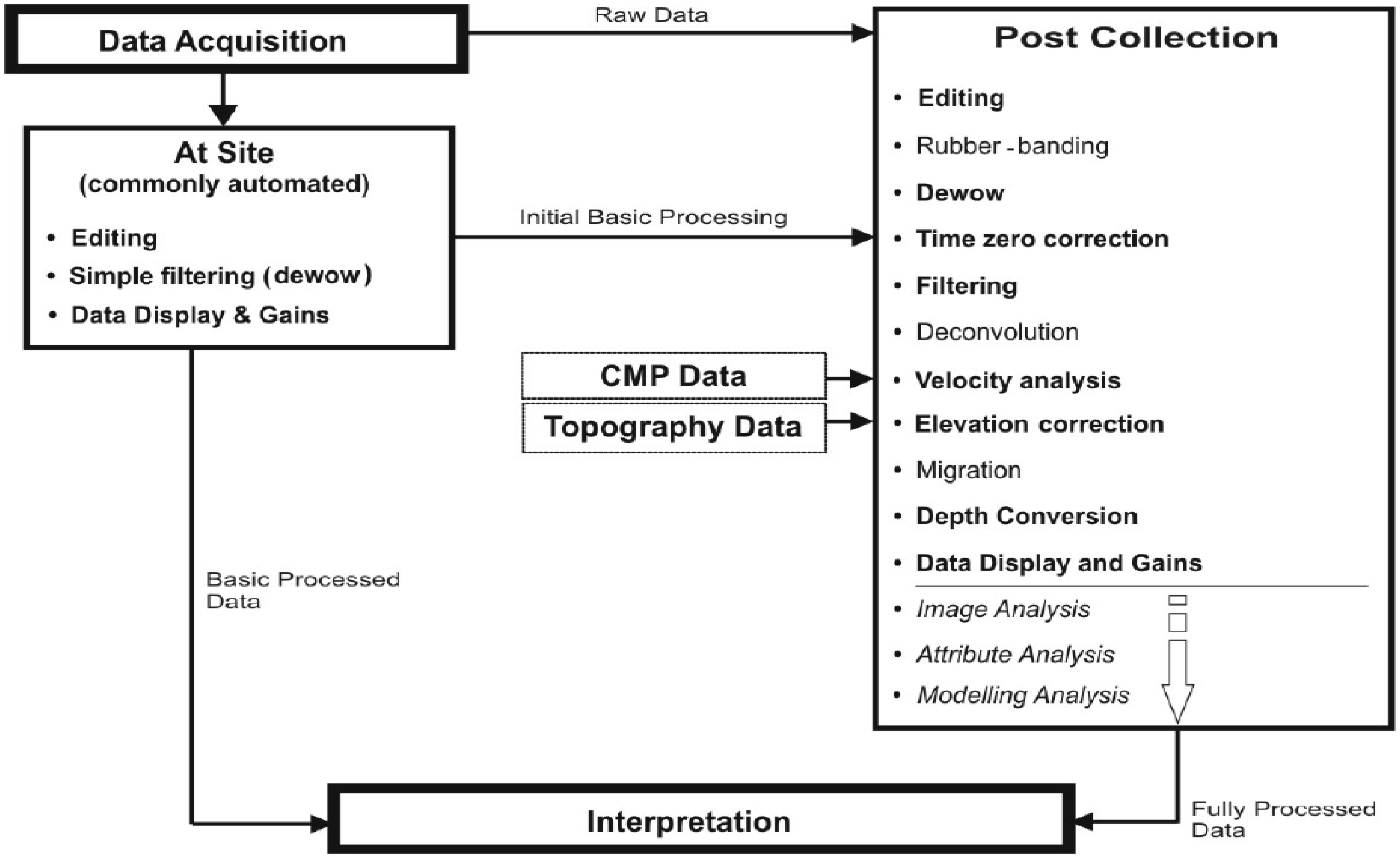
- If you can’t see it in raw data, is it really there?
- Resist temptation to over-process and create artefacts
- Interpretation counts…not the beauty

- Understand what you are doing…
- Data processing should enhance interpretation….not control it



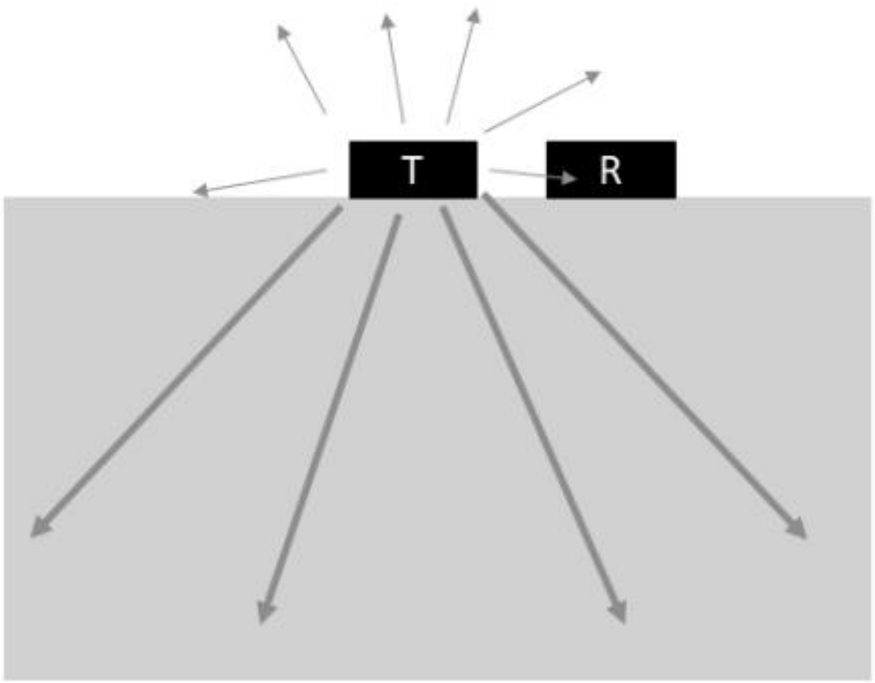
- Be systematic & Consistent
- Make a processing flow chart
- Same parameters for same dataset

Typical GPR data processing Flow : 2D bistatic common-offset reflection data

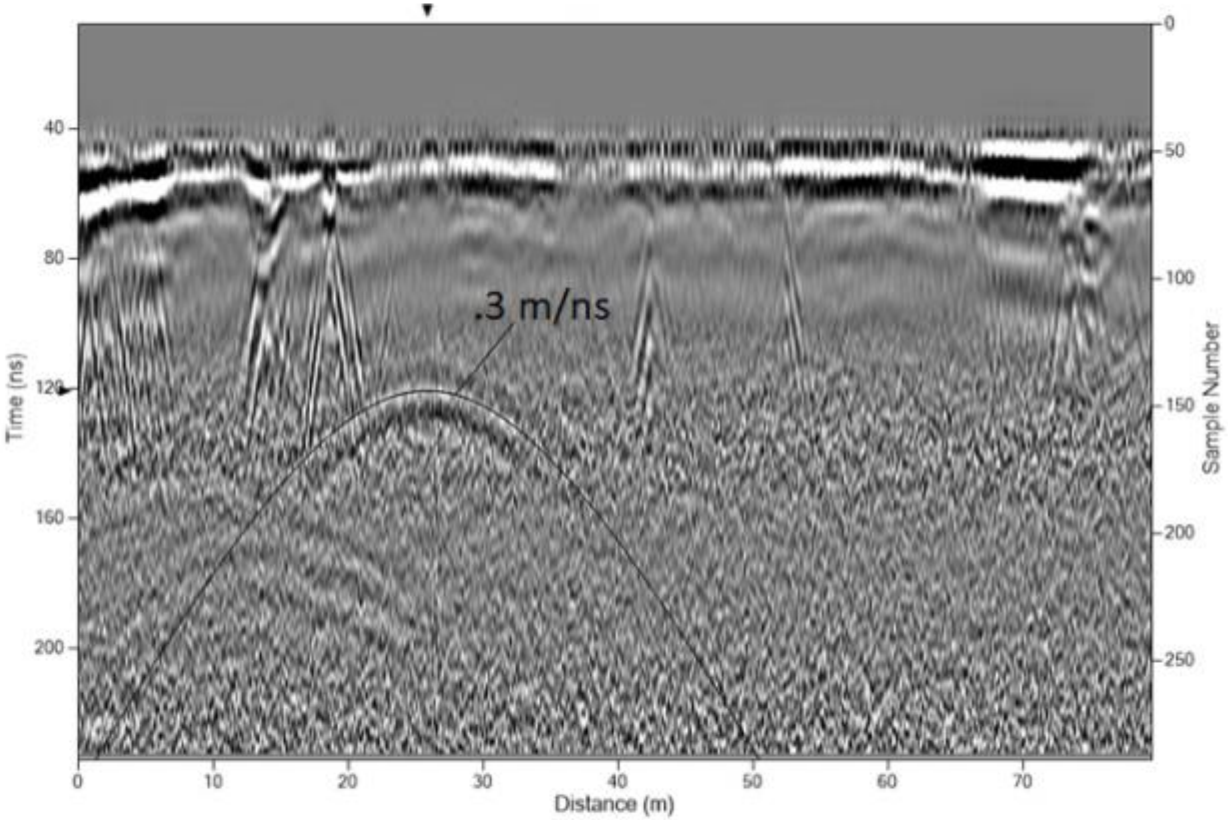


GPR Data Processing and Analysis Steps : Basic Descriptions

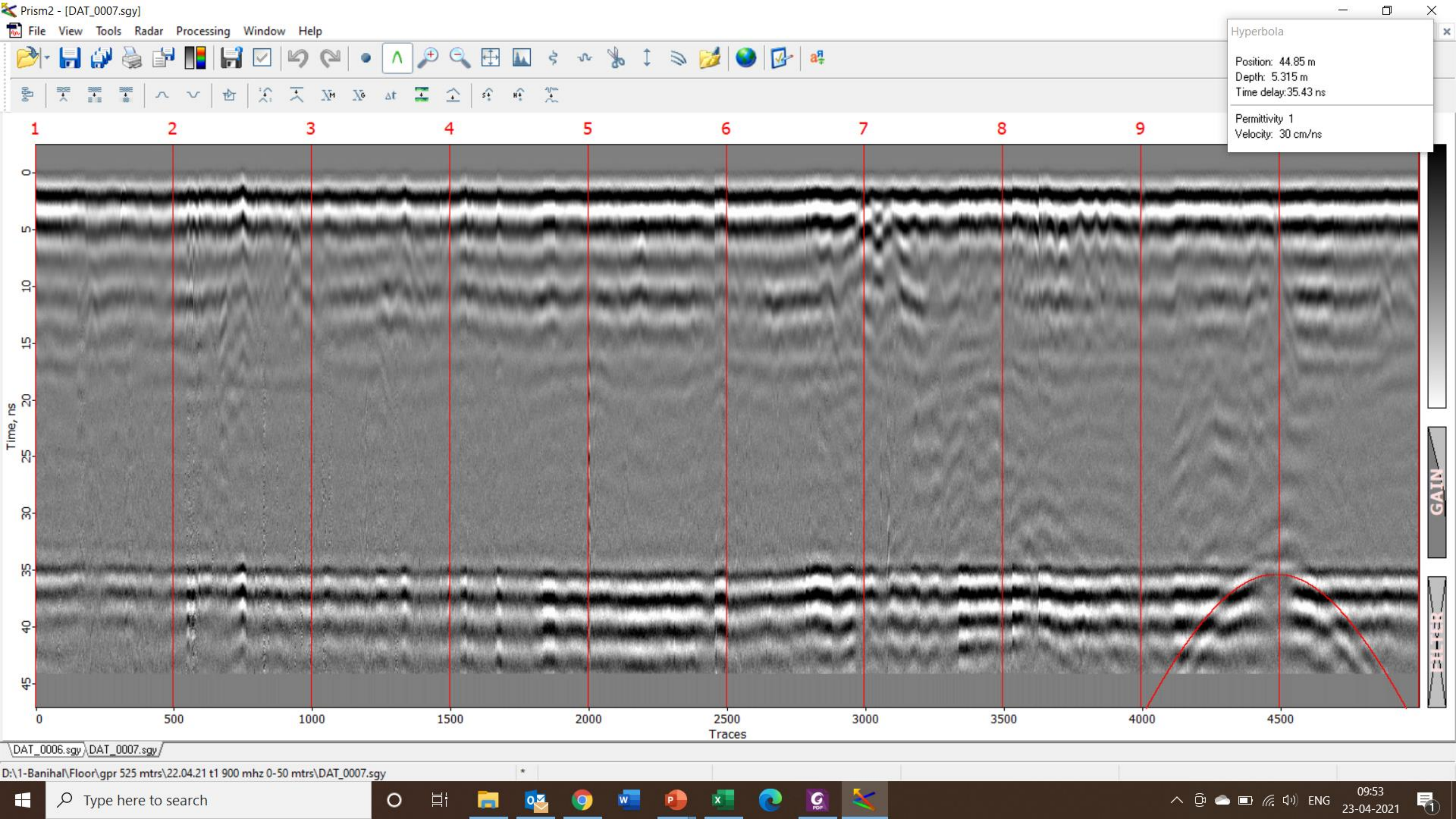
Air Waves



- **GPR signal does NOT only go into the ground. It goes in all directions from the transmitting antenna.**



.3 m/ns
Time (ns)
40
80
120
160
200
Sample Number
0
50
100
150
200
250
0
10
20
30
40
50
60
70
Distance (m)


Prism2 - [DAT_0007.sgy]
File View Tools Radar Processing Window Help
Hyperbola
Position: 44.85 m
Depth: 5.315 m
Time delay:35.43 ns
Permittivity 1
Velocity: 30 cm/ns
1 2 3 4 5 6 7 8 9
Time, ns
0 5 10 15 20 25 30 35 40 45
0 500 1000 1500 2000 2500 3000 3500 4000 4500
Traces
GAIN
DAT_0006.sgy DAT_0007.sgy
D:\1-Banihal\Floor\gpr 525 mtrs\22.04.21 t1 900 mhz 0-50 mtrs\DAT_0007.sgy
Type here to search
ENG
09:53
23-04-2021

Ground Penetrating Radar
With Special Focus on Importance of Simulation

Dr. Sanjay Rana
sanjay@parsan.biz
+91-9811168288