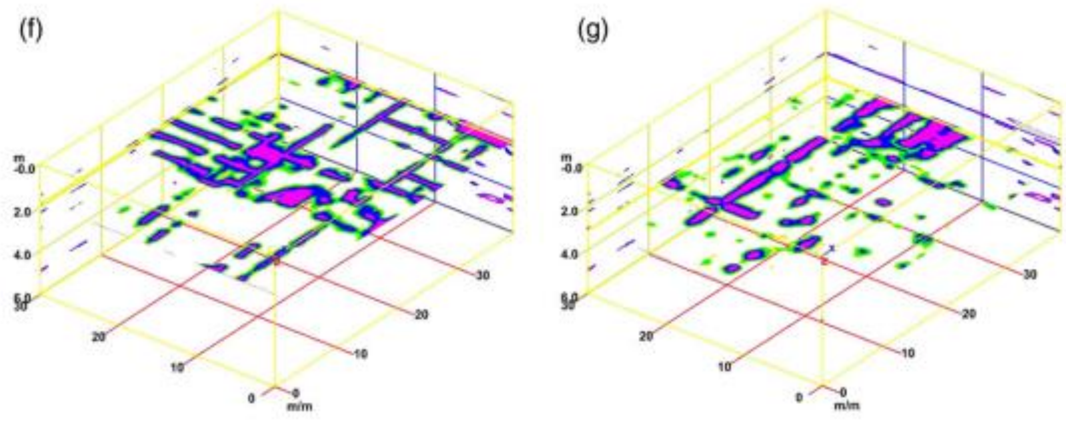
Ground Penetrating Radar

Principles and Applications



Dr. R. Jegankumar M.Sc., M.Tech., Ph.D.,
Professor and Head
Department of Geography
Bharathidasan University Tiruchirappalli

Ground Penetrating Radar

Historical Development

The history of ground penetrating radar started from the **discovery of electromagnetism** by Michael Faraday, mathematical formulation by James Clerk Maxwell, advances of radar sounding in air during second world war and later turning the air-borne radar to ground based radar during the post-war time.

1831 Michael Faraday presented a paper about the characteristics of **electromagnetism** to the Royal Institution in London. 1860s James Clerk Maxwell published four Maxwell's equations describing the physical rules of electromagnetic waves moving in free spaces. Heinrich Hertz proved the existence of electromagnetic waves.

1904 Christian Hülsmeyer filed the first patent on a radar application for measuring distant objects with radio waves, the basis of detecting aircrafts during second world war in the battlefields of Pacific Ocean and the English Channel in early 1940s. **1950 - 1960** The first real field trials of 1-10 MHz radio signals was used to detect the water table. Radar altimeter was converted to estimate ice sheet thickness in Greenland, in which the pre-cursor of the usage initially caused accidents of mis-reading altimeter height because the penetration of radio wave into the ice cap was not aware. These two events are regarded as the trigger of the real birth of GPR.

Ground Penetrating Radar

Historical Development

1960 - 1970 Ice sounding continued in research groups at The University of Wisconsin, USA and the Scott Polar Research Institute at Cambridge, UK. Non-ice uses in salt mines was also started by Unterberger and coal mines by Cook. The Apollo lunar science program started to study surface electrical properties (SEP) in the Moon in the Apollo 17 Mission. The Apollo program gathered a team of the future GPR innovators like, Annan, Olhoeft, Redman, England, Watts, Rossiter, Jiracek, and Phillips.

1970 - 1975 The dispersal of the scientists in Apollo team transferred the lunar research knowledge to few institutions such as the Geological Survey of Canada and US Geological Survey as well as universities, and commercial development of hardware by Annan, Davis and Morey, who produced the first commercial GPR products.

1975 - 1980 Many GPR developments started seriously worldwide, like Annan and Davis in Geological Survey of Canada, Olheoft in USGS, Arcone in Cold Regions Research and Engineering Laboratory, Unterberger at Texas A&M and BGRin Germany. Application areas include permafrost, ice sounding, bathymetry, soil moisture for agriculture, potash mine hazards, nuclear waste disposal site assessment, measurement of concrete properties, rock quality determination, hydrogeology and many others. The largest barrier to technological advancement was the availability of suitable instrumentation

Ground Penetrating Radar

Historical Development

1960 - 1970 Ice sounding continued in research groups at The University of Wisconsin, USA and the Scott Polar Research Institute at Cambridge, UK. Non-ice uses in salt mines was also started by Unterberger and coal mines by Cook. The Apollo lunar science program started to study surface electrical properties (SEP) in the Moon in the Apollo 17 Mission. The Apollo program gathered a team of the future GPR innovators like, Annan, Olhoeft, Redman, England, Watts, Rossiter, Jiracek, and Phillips.

1970 - 1975 The dispersal of the scientists in Apollo team transferred the lunar research knowledge to few institutions such as the Geological Survey of Canada and US Geological Survey as well as universities, and commercial development of hardware by Annan, Davis and Morey, who produced the first commercial GPR products.

1980 - 2000 Field trials and commercial surveys in many subsurface scientific and engineering applications were started, nurturing a continuous evolution of 3 technology and practical field solutions. A wide range of commercial products or prototypes become commercially available and the first international GPR conference was conducted in 1986 in Georgia, USA. American Society of Testing Materials (ASTM) published the first user guideline (D6432) of GPR for subsurface investigation.

Ground Penetrating Radar

Dielectric permittivity One of the three material properties in GPR survey. It describes the ability of a material to store electric energy by separating opposite polarity charges. It determines how the electric displacement, D, response to the an incident electric field, E, through $D=\varepsilon E$. The units of dielectric permittivity, ε, are farads/metre (F/m). Relative dielectric permittivity (previously called the dielectric constant) is the ratio of the permittivity of a material to that of free space, $8.854 \times 10-12$ F/m. For dielectric permittivity of a material greater than that of free space, it will be lossy and ε is represented as complex number in real and imaginary parts. Both parts are frequency-dependent typically described by the Cole-Cole (Cole and Cole, 1941) relaxation distribution model. Nearly all dielectric relaxation processes are the result of the presence of water or clay minerals (Olhoeft, 1998).

Magnetic permeability One of the three material properties in GPR survey. It describes the ability of a material to store magnetic energy induced by re-alignment of electron spin and motion. It determines how magnetized polarization in the magnetic induction, B, responses to a magnetic field H, through $B=\mu H$. The units of magnetic permeability, μ, are Henry/metre. Relative magnetic permeability is the ratio of the permeability of a material to that of free space, $4\pi \times 10-7$ H/m. It is commonly assumed that magnetic properties of material in GPR survey are the same as those of free space. Nearly all magnetic properties are due to presence of iron in a variety of mineralogical forms (Olhoeft, 1998)

Table 1 Approximate Electromagnetic Properties of Various Materials (ASTM D6432-11, 2011)

Material	Relative Permittivity ε'	Wave velocities (m/ns)	Conductivity (mS/m)
Air	1	0.3	0
Fresh water	81	0.033	0.10 – 30
Sea water	70	0.033	400
Sand (dry)	4-6	0.15-0.12	0.0001 – 1
Sand (saturated)	25	0.055	0.1 – 1
Silt (saturated)	10	0.095	1 – 10
Clay (saturated)	8-12	0.106-0.087	100 – 1000
Dry sandy coastal land	10	0.095	2
Fresh water ice	4	0.15	0.1 – 10
Permafrost	4-8	0.15-0.106	0.01 – 10
Granite (dry)	5	0.134	0.00001
Concrete	5-10	0.134-0.095	
Asphalt	3-5	0.173-0.134	
Sea ice	4-12	0.15-0.087	
PVC, epoxy, polyesters vinyls, rubber	3	0.173	

https://www6.polyu.edu.hk/lsgi/uusspec/up_load/general/NSTSID-UU-1.2GPR_draft_v1.1a.pdf

Ground **P**enetrating **R**adar

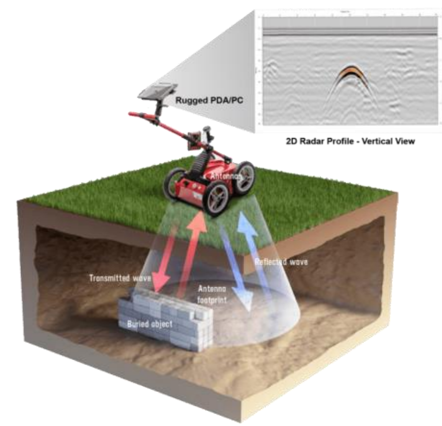
Facility @ Bharathidasan University

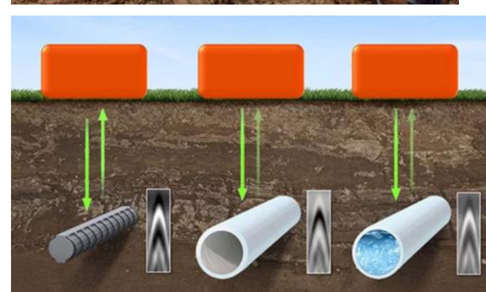
DST PURSE I

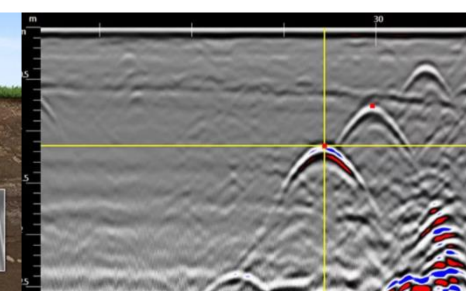
GPR's is used to identify and mark the position and depth of metallic and non-metallic objects; including utilities such as gas, communications and sewer lines as well as underground storage tanks and PVC pipes

SIR 30 Rugged, Multi-channel GPR Controller

The SIR 30 is the next-generation high-performance multi-channel radar control unit. This system can collect up to eight channels of data simultaneously with uncompromised performance, making it ideal for transportation infrastructure, large-scale utility, geology, and mining applications.







Ground Penetrating Radar Components (GPR)

Ground Penetrating Radar Technology Explained
This page is designed as a basic introduction to some of the key concepts of ground penetrating radar. Ground penetrating radar is also known as GPR, Geo-radar, and ground probing radar.
A GPR system is made up of three main components:
Control unit
Antenna
Power Supply
GSSI GPR equipment can be run with a variety of power supplies ranging from small rechargeable batteries to vehicle batteries and normal 110/220-volt. Connectors and adapters are available for each power source type. The unit in the photo above can run from a small internal rechargeable battery or external power.

Source: https://www.geophysical.com/whatisgpr

GPR Control Unit and Antenna

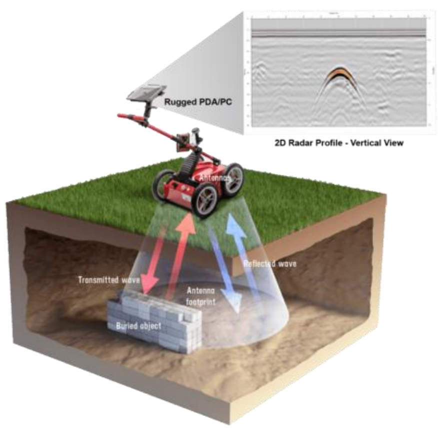
The control unit contains the electronics which trigger the pulse of radar energy that the antenna sends into the ground. It also has a built-in computer and hard disk/solid state memory to store data for examination after fieldwork. Some systems, such as the GSSI SIR 30, are controlled by an attached Windows laptop computer with pre-loaded control software. This system allows data processing and interpretation without having to download radar files into another computer.

The antenna receives the electrical pulse produced by the control unit, amplifies it and transmits it into the ground or other medium at a particular frequency. Antenna frequency is one major factor in depth penetration. The higher the frequency of the antenna, the shallower into the ground it will penetrate. A higher frequency antenna will also 'see' smaller targets. Antenna choice is one of the most important factors in survey design. The following table shows antenna frequency, approximate depth penetration and appropriate application.

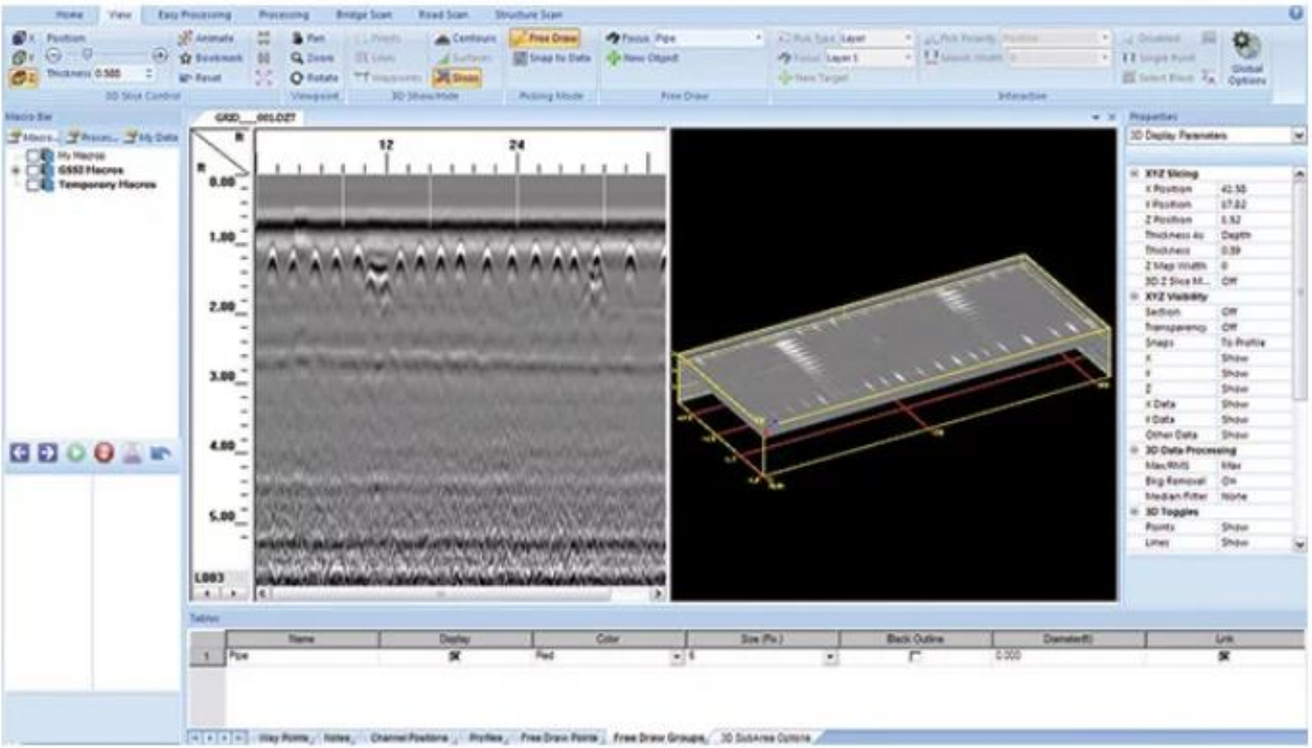
Source: https://www.geophysical.com/whatisgpr

The following table shows antenna frequency, approximate depth penetration and appropriate application:

APPROPRIATE APPLICATION	PRIMARY ANTENNA CHOICE	SECONDARY ANTENNA CHOICE	APPROXIMATE DEPTH RANGE
Structural Concrete, Roadways, Bridge Decks	2600 MHz	1600 MHz	0-0.3 m (0-1.0 ft)
Structural Concrete, Roadways, Bridge Decks	1600 MHz	1000 MHz	0-0.45 m (0-1.5 ft)
Structural Concrete, Roadways, Bridge Decks	1000 MHz	900 MHz	0-0.6 m (0-2.0 ft)
Concrete, Shallow Soils, Archaeology	900 MHz	400 MHz	0-1 m (0-3 ft)
Shallow Geology, Utilities, USTs, Archaeology	400 MHz	270 MHz	0-4 m (0-12 ft)
Geology, Environmental, Utility, Archaeology	270 MHz	200 MHz	0-5.5 m (0-18 ft)
Geology, Environmental, Utility, Archaeology	200 MHz	100 MHz	0-9 m (0-30 ft)
Geologic Profiling	100 MHz	MLF (16-80 MHz)	0-30 m (0-90 ft)
Geologic Profiling	MLF (16-80 MHz)	None	Greater than 30 m (90 ft)



Source: https://www.geophysical.com/whatisgpr



Data Processing

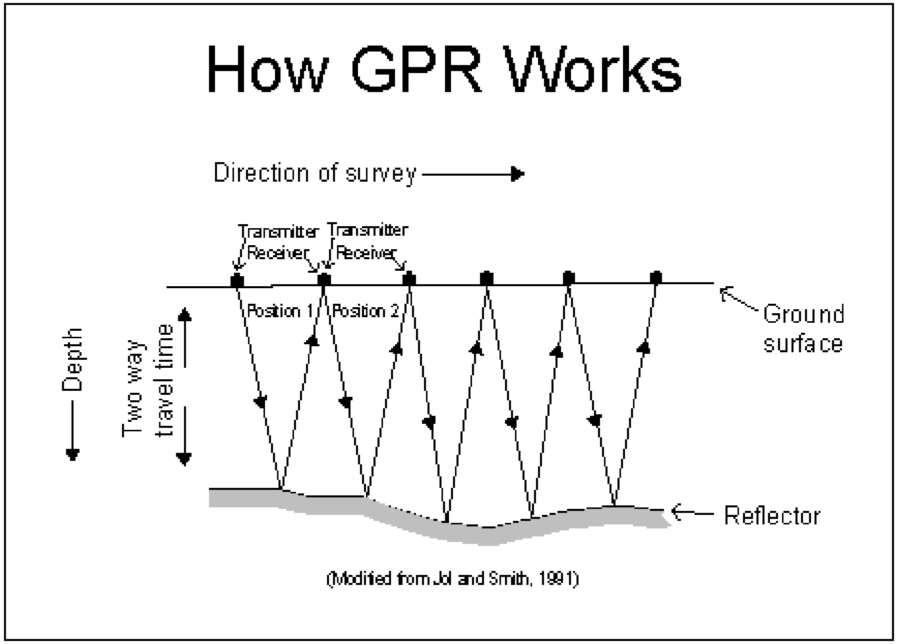
Data is collected in parallel transects and then placed together in the appropriate locations for computer processing in a specialized software program. The computer then produces a horizontal surface at a particular depth in the record. This is referred to as a depth slice, which allows operators to interpret a planview of the survey area.

Source: https://www.geophysical.com/whatisgpr

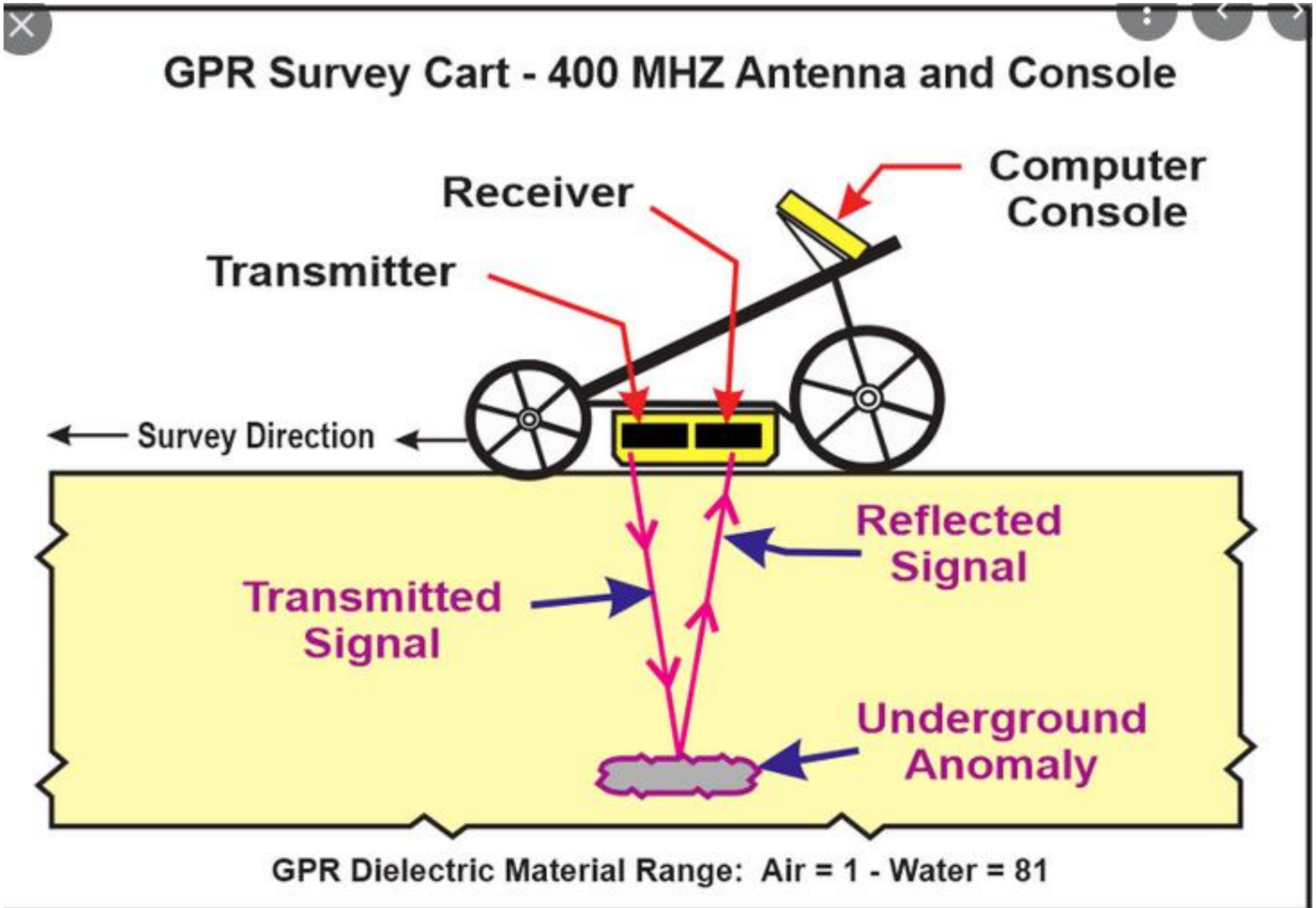
GPR Survey Methods

How GPR Works

GPR involves a step-like procedure of repetitive moves of both the transmitter and receiver at a constant spacing. The transmitter sends a short pulse of electromagnetic energy (approximately radio frequency) into the ground which is reflected by boundaries in the penetrated medium and received by the receiver antennae before the ensemble moves. The two-way travel time of this process is measured and translated into depth using the electromagnetic velocity in the penetrated medium gained from a specialized GPR survey performed at each site (common mid-point, Jol and Smith, 1991).



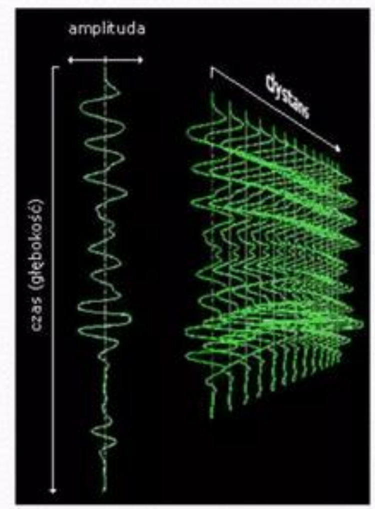
https://people.uwec.edu/jolhm/Past_Students/Wenell/ncdune/methods.htm



https://www.topographix.com/ground-penetrating-radar/

➢ Operating Frequency

- There is an **optimum choice of frequency of operation to achieve best performance** in terms of depth and ability to see details in the target structure. This choice is **between 1 and 5000 MHz.** Generally low frequencies are used for deep probing (>50 m) and high frequencies are used for shallow probing (<50 m).



- The initial frequency estimation formula:

$$f = \frac{150}{X\sqrt{K}}(MHz)$$

X-specify a desire spatial resolution

K - relative permittivity (dielectric constant) of most material

➢ **Resolution** (depend on Frequency)

- Low frequencies (a few MHz) give good depth penetration, but low resolution (more than 50 m).
- High frequencies (about a GHz) can resolve cm-sized objects, but penetrate only a meter or less in many materials (less than 50 m).
- In archaeology, resolution is generally more important than depth, so high frequencies are commonly used.
- In geologic survey, depth is generally more important than resolution, so low frequency are used to survey.

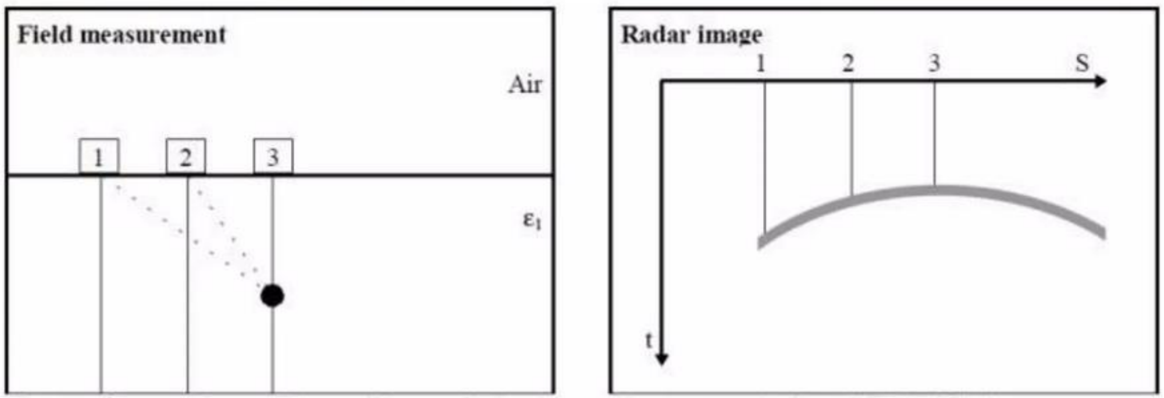
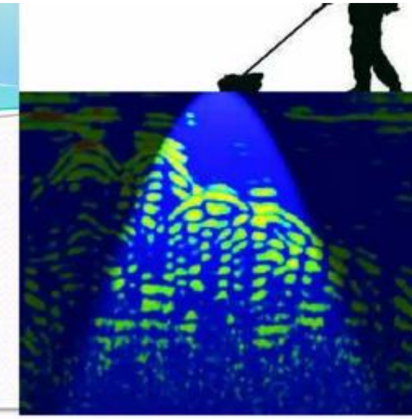


Figure 8 Generation of hyperbolas in radar images (after ERA 1996).

- The GPR image shows buried objects in a hyperbolic shape; the top of the hyperbola represents the exact location of buried object. It is a well known fact that GPR images are obtained by using a single radio-wave frequency
- Regular radar image interpreters decide the exact location and depth of targets depending on a direct distance measurement from the top of the hyperbola



How create Hyperbola ?

- Intensity of frequency
- Object distance from transmitter
- Angle/cone

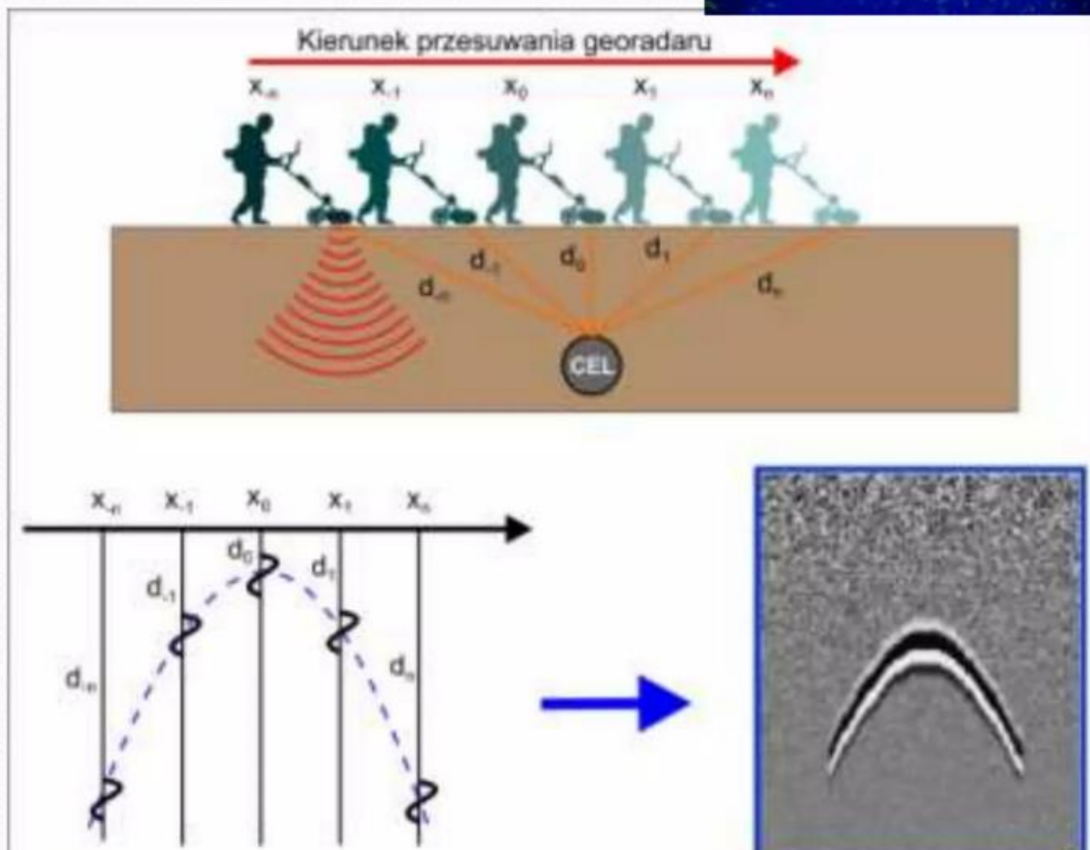
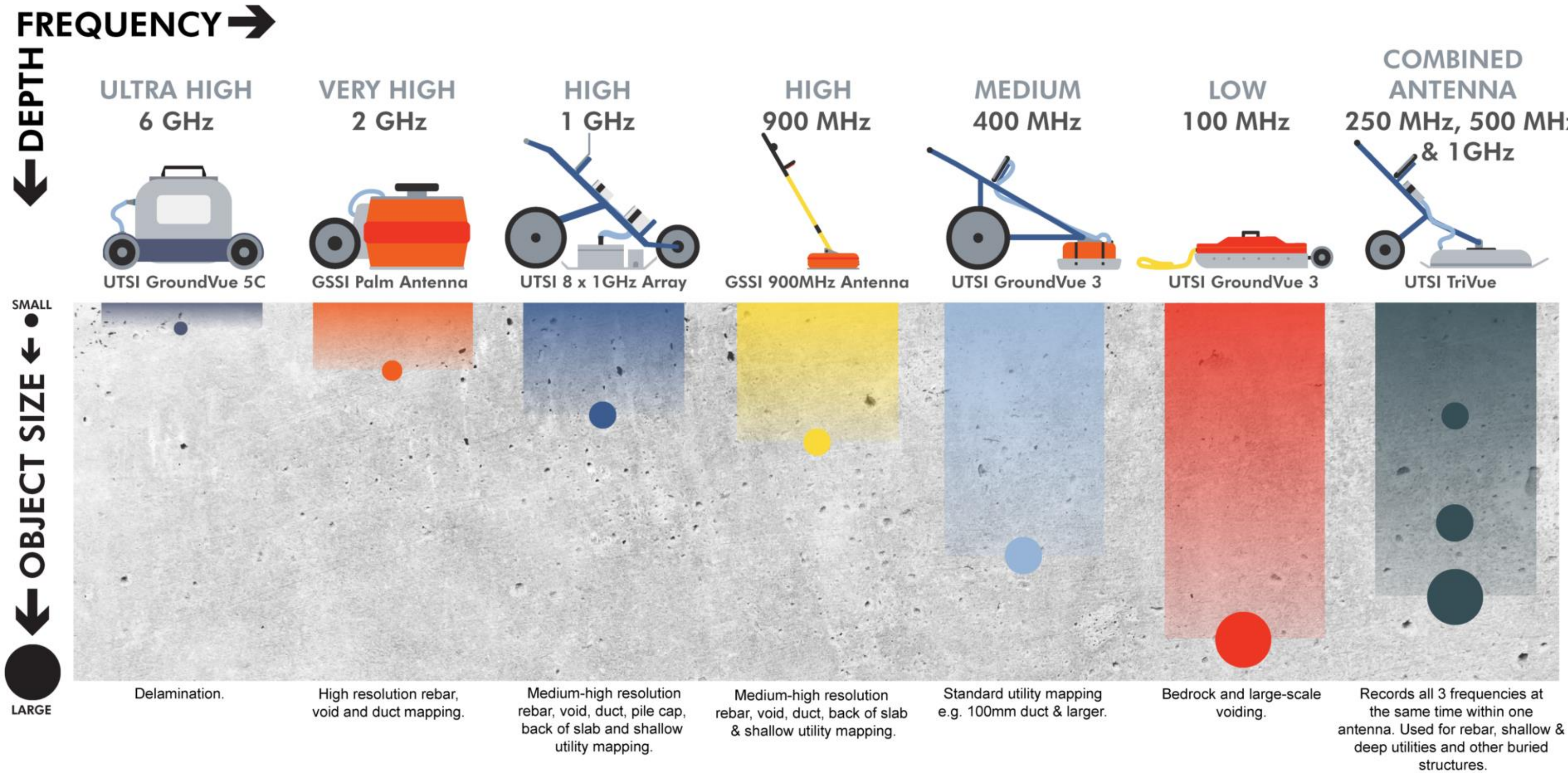


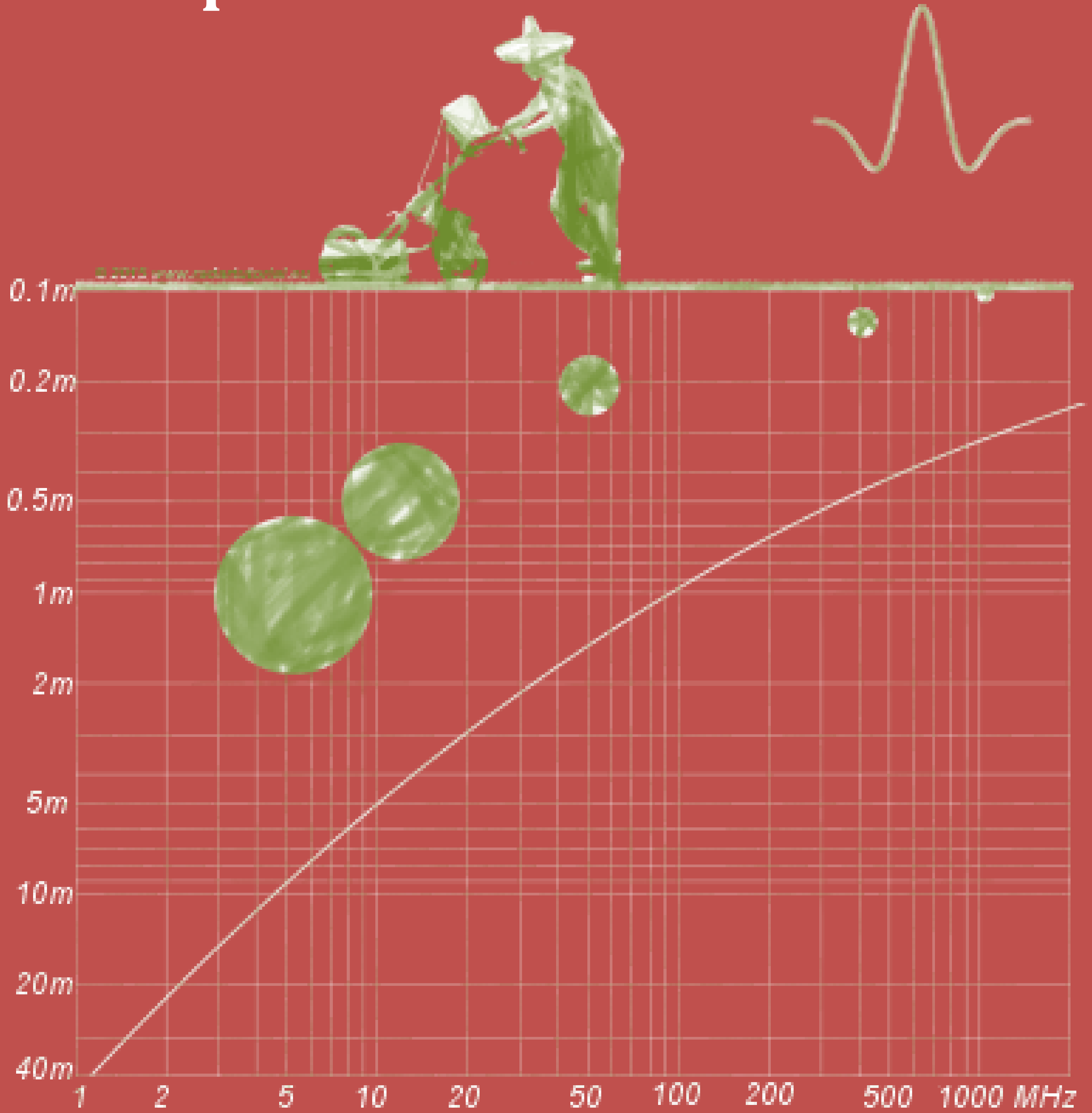
Table of relative dielectric permittivity (e_R), electrical conductivity (σ), and velocity.			
Material	**e_R**	**σ (mSeimens/m)**	**V avg (m/ns)**
Air	1	0	.3
Distilled water	**80**	**0.01**	0.033
Fresh water	80	0.5	0.033
Sea water	80	**3000**	**0.01**
Dry sand	**3**- 5	0.01	0.15
Saturated sand	20-30	0.1-1.0	0.06
Limestone	4-8	0.5-2.0	0.12
Shales	5-15	1-100	0.09
Silts	5-30	1-100	0.07
Clays	5-40	2- 1000	0.06
Granite	4-6	0.01-1.0	0.13
Dry salt	5-6	0.01-1.0	0.13
Ice	3-4	0.01	**0.16**

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

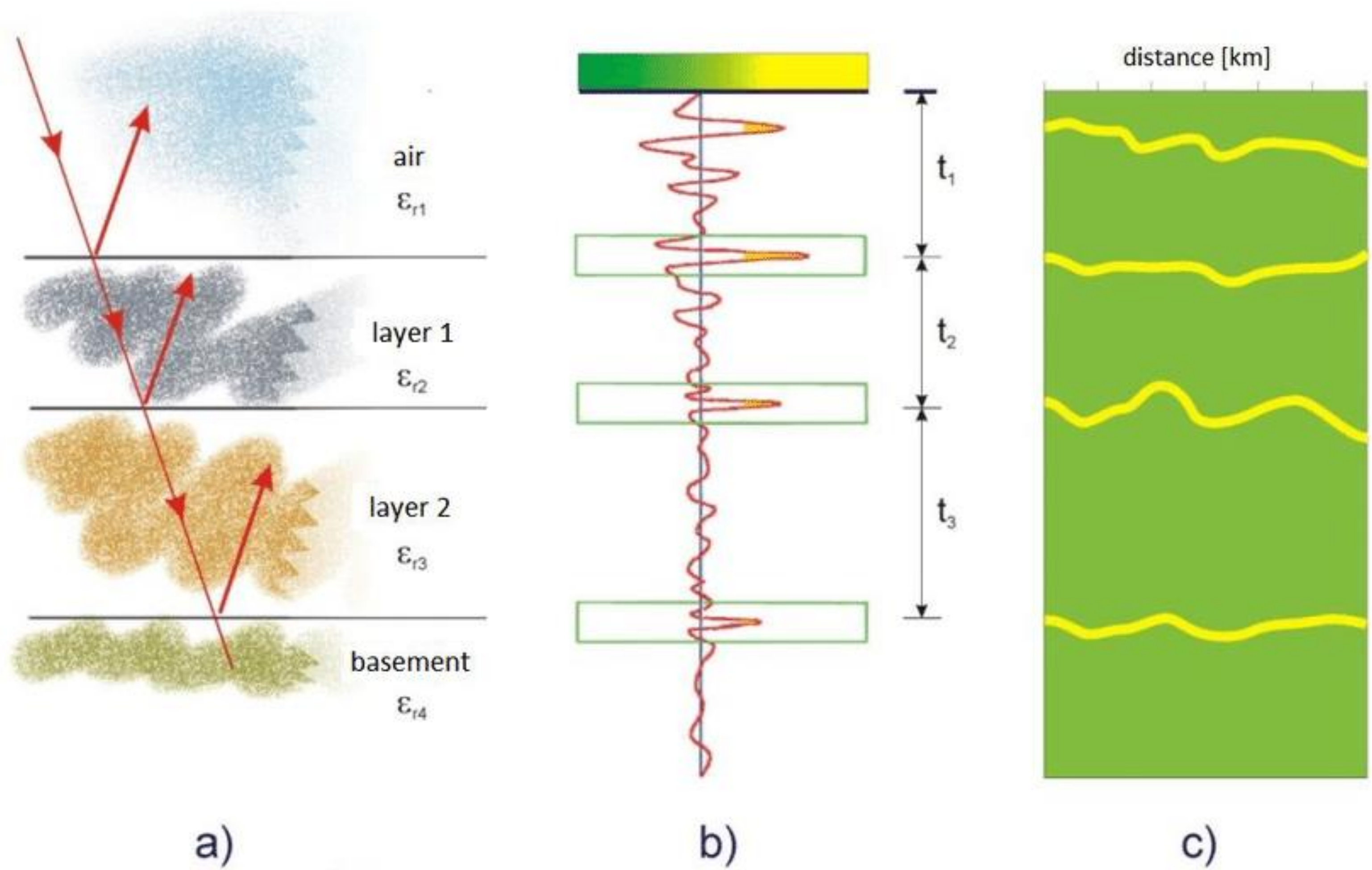


https://www.land-scope.com/designing-a-gpr-survey/

Depth of Penetration Vs Antennae Frequency

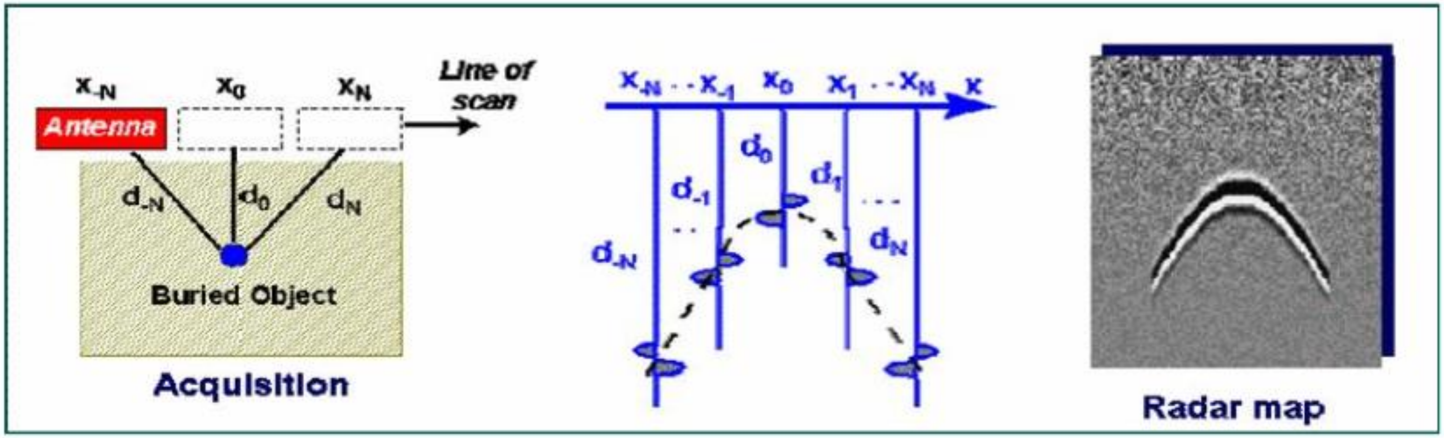


https://www.radartutorial.eu/02.basics/Ground%20penetrating%20radar.en.html



https://www.researchgate.net/figure/GPR-System-Signal-Recording-Principle-a-Simplified-Image-Depicting-Passage-of-the_fig1_288370556

Data Collection – Point Target

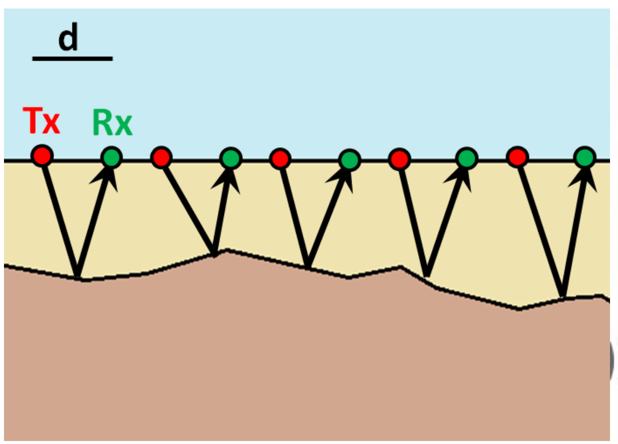


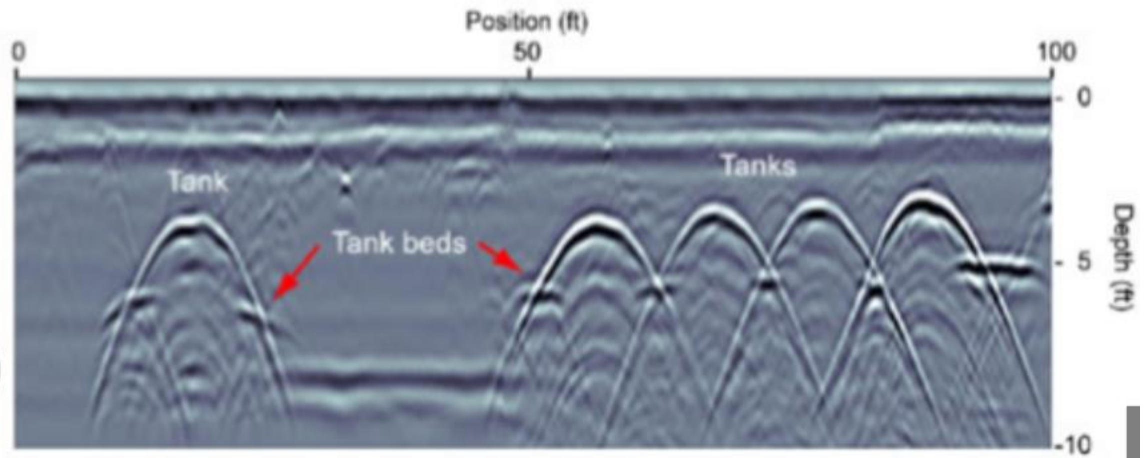
- A transmitter generates an electromagnetic wave.
- Energy reflected back by an underground target is captured by a receiving antenna that travels along the surface.
- The transmitter and receiver operate as a single unit.
- Data captured by the receiver is recorded for later processing & interpretation.

Common Offset Survey

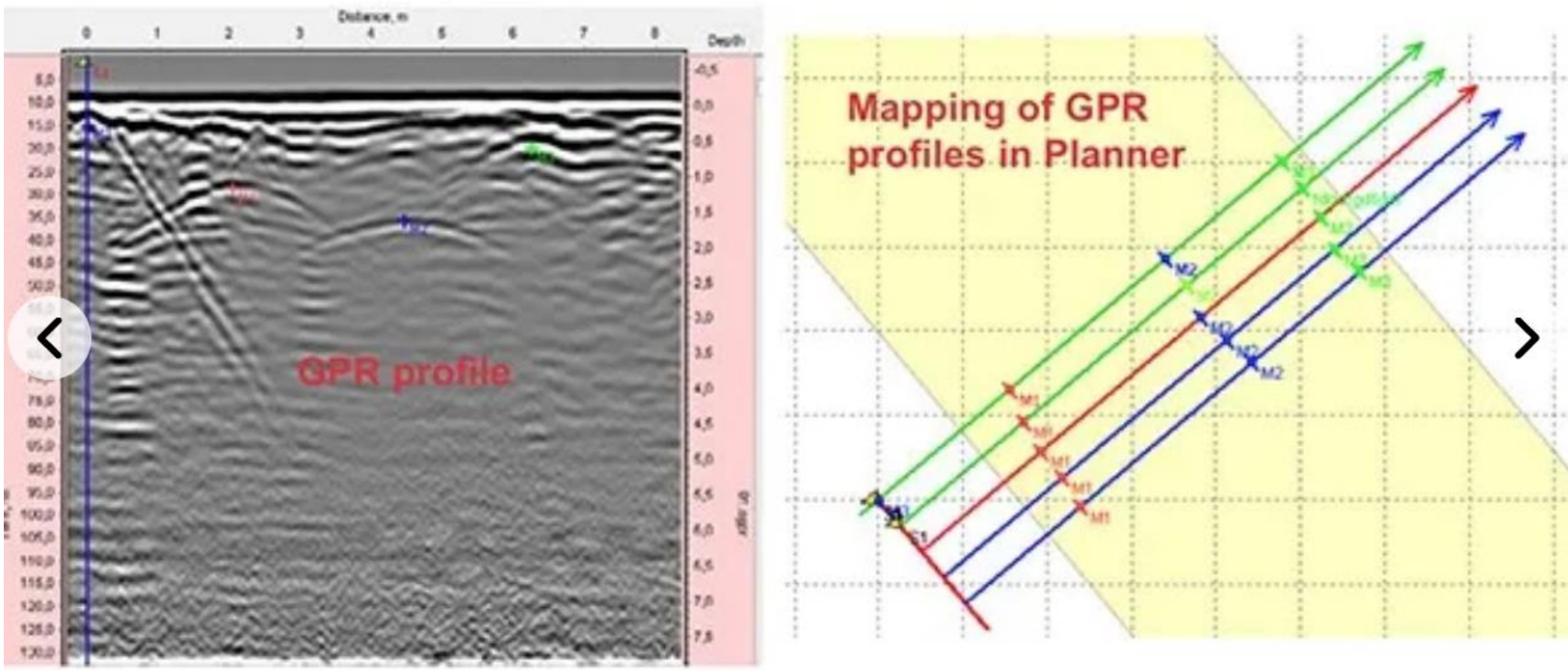
Common offset surveys are the most frequently used configuration for GPR surveys. In common offset survey, the distance between the transmitter and a single receiver is fixed. Data are collected each time the transmitter-receiver pair are moved to a new position. In some cases, the transmitter and receiver are placed at a zero-offset; otherwise known as a coincident source and receiver.

Common-offset surveys are effective for locating the depths of approximately horizontal interfaces. In addition, zero-offset surveys are very affective a locating pipes, tunnels and compact buried objects; as they generate hyperbolic signatures in radargram data. Examples of this can be seen below.



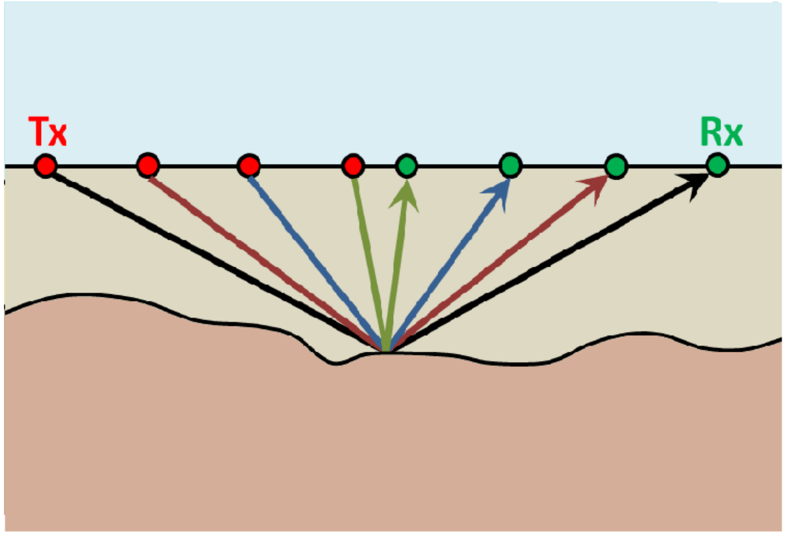


GPR Survey Plan



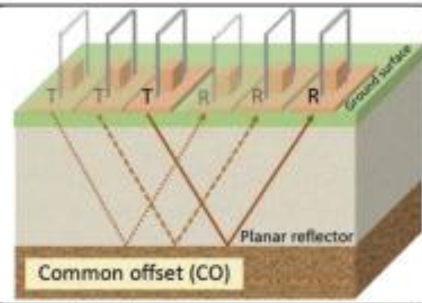
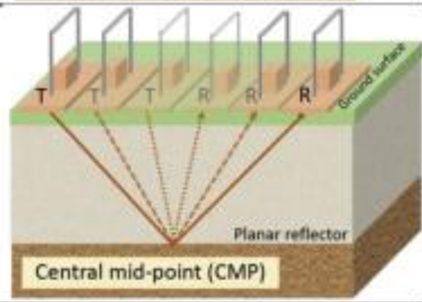
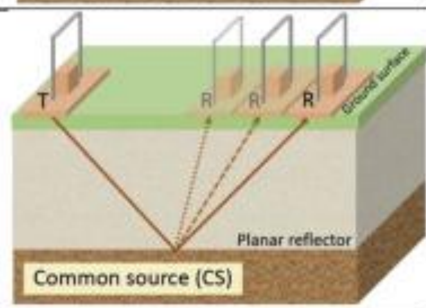
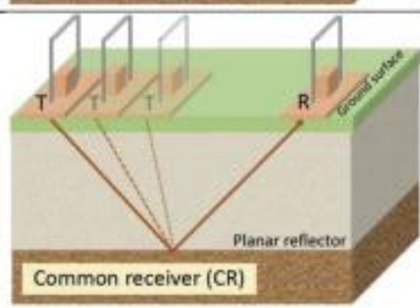
https://www.archiproducts.com/en/products/novatest/gpr-2d-3d-processing-software-with-data-export-module-in-dxf-synchro-gpr-3d-planner_416485

Common Midpoint Survey

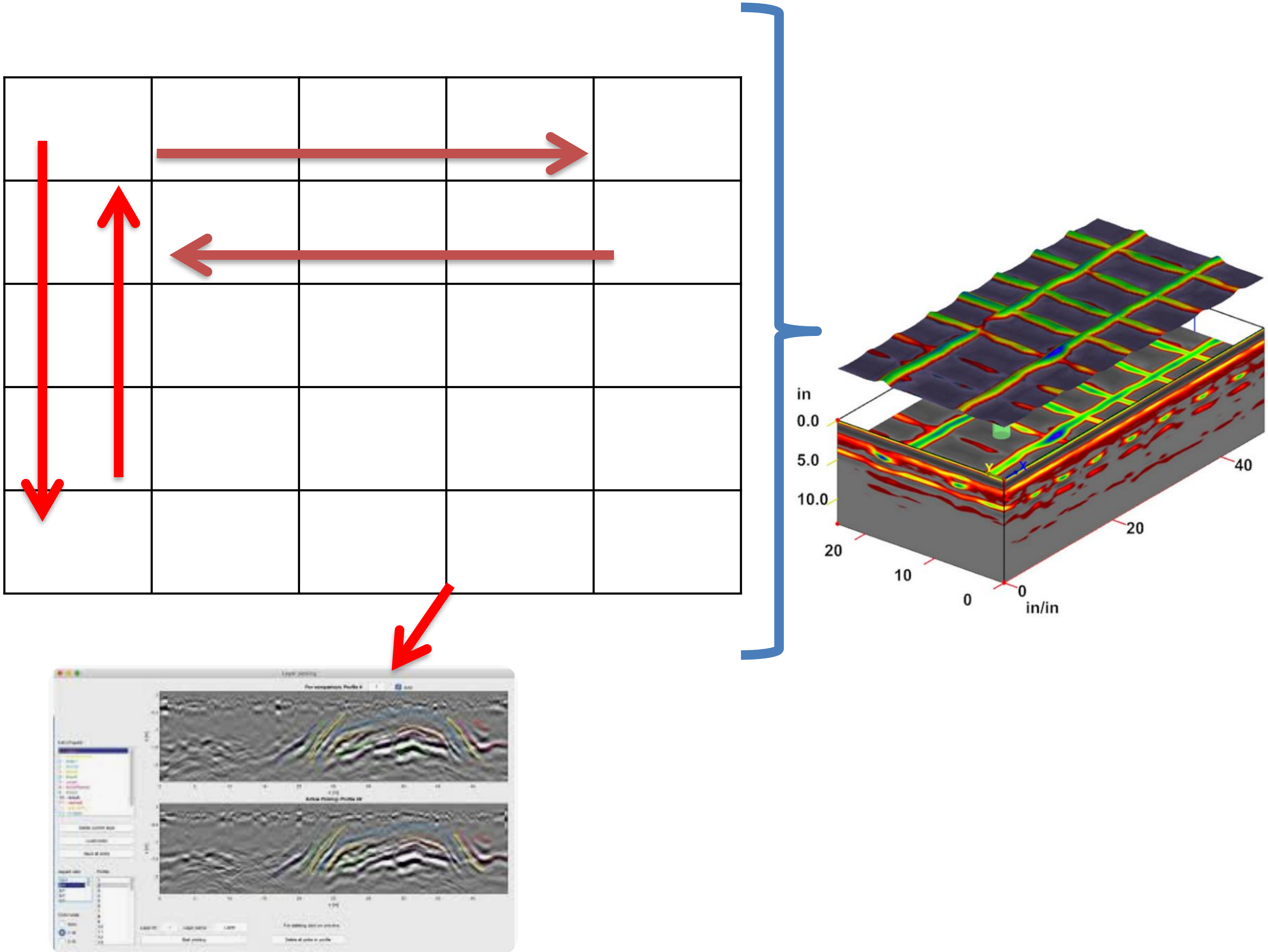


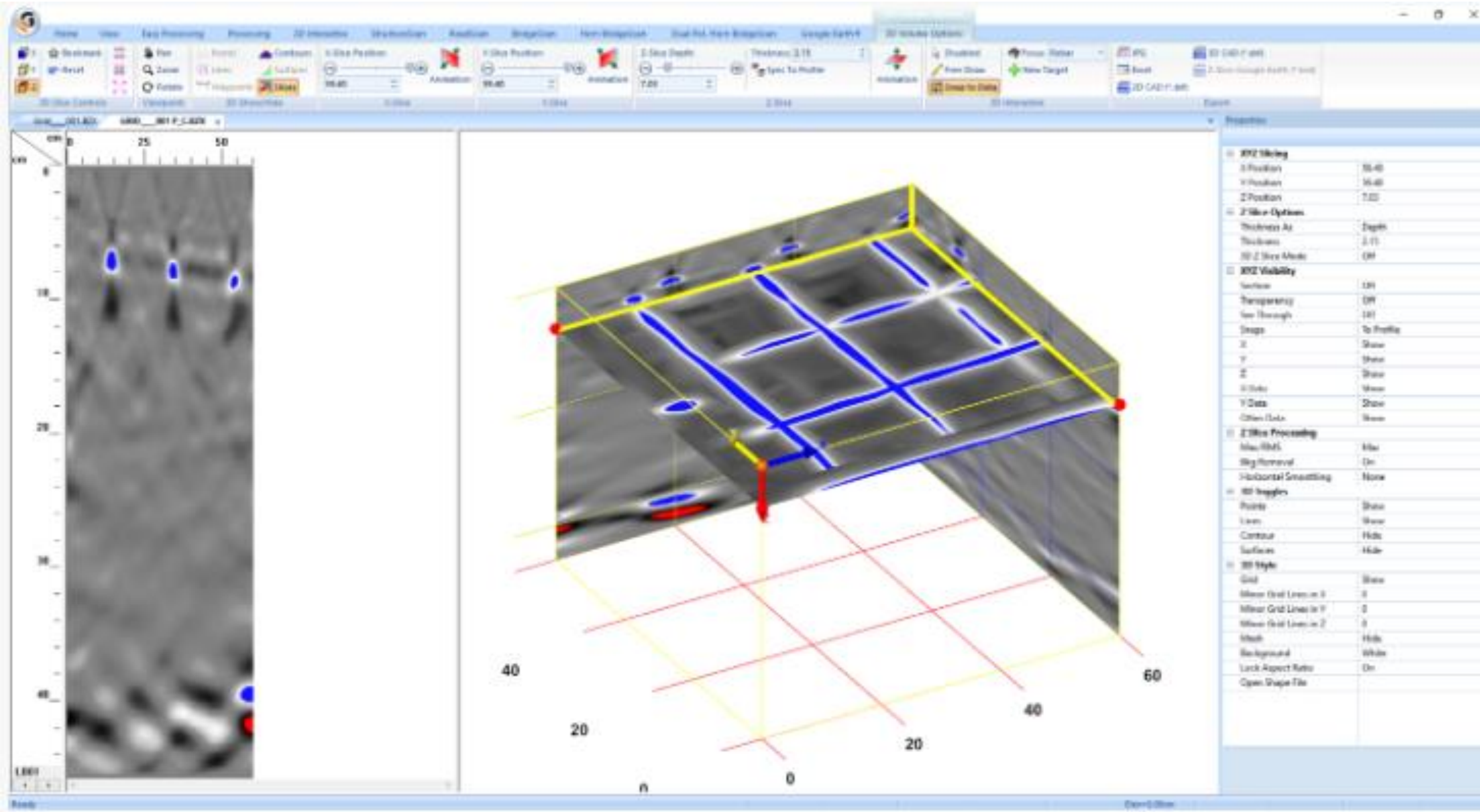
The distance between the transmitter and receiver are changed for every reading. However, the halfway point between the transmitter and the receiver is kept the same. As we will show, common midpoint surveys are useful for determining the top-layer velocity and thickness.

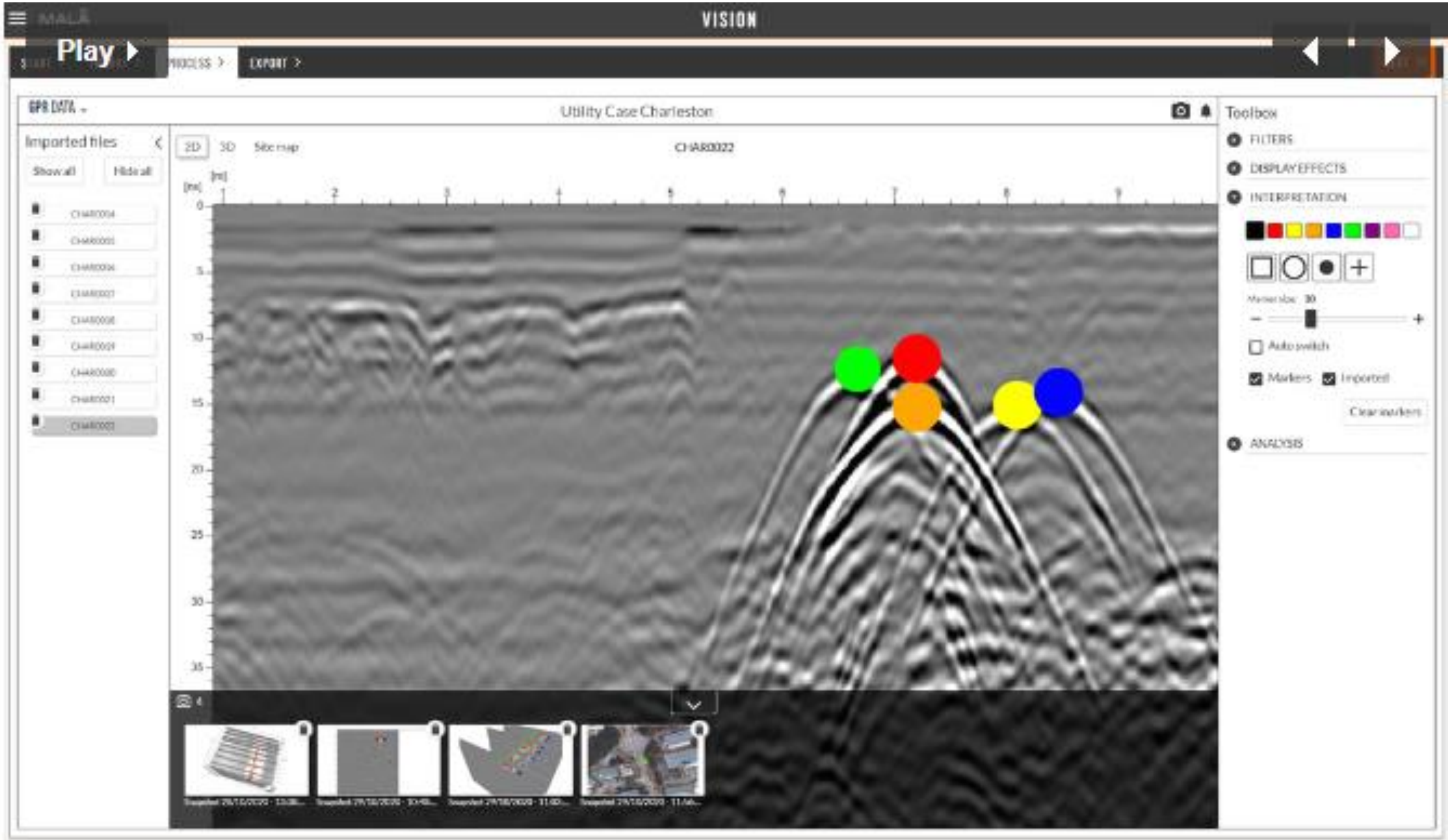
From the survey schematic, we see that if the interface is approximately flat, the point of reflection is the same for all readings. As a result, the signal from the reflected wave in the radargram should form a hyperbola.

Survey method	Survey diagram	Uses /advantages	Disadvantages
Common offset (CO)		Most common type. Relatively fast to conduct and able to move quickly across the terrain	Lower processing time.
Common mid-point (CM)		Test survey on arrival, calculation of velocity for conversion of Two Way Travel Time (TWT)	Lower processing time, allows more advanced signal analysis such as Amplitude Variation with Offset (AVO)
Common Source (CS)		Improved signal to noise ratio. Greater depth of penetration.	Increased processing time and higher survey cost.
Common Receiver (CR)		Improved signal to noise ratio. Greater depth of penetration.	Increased processing time and higher survey cost.

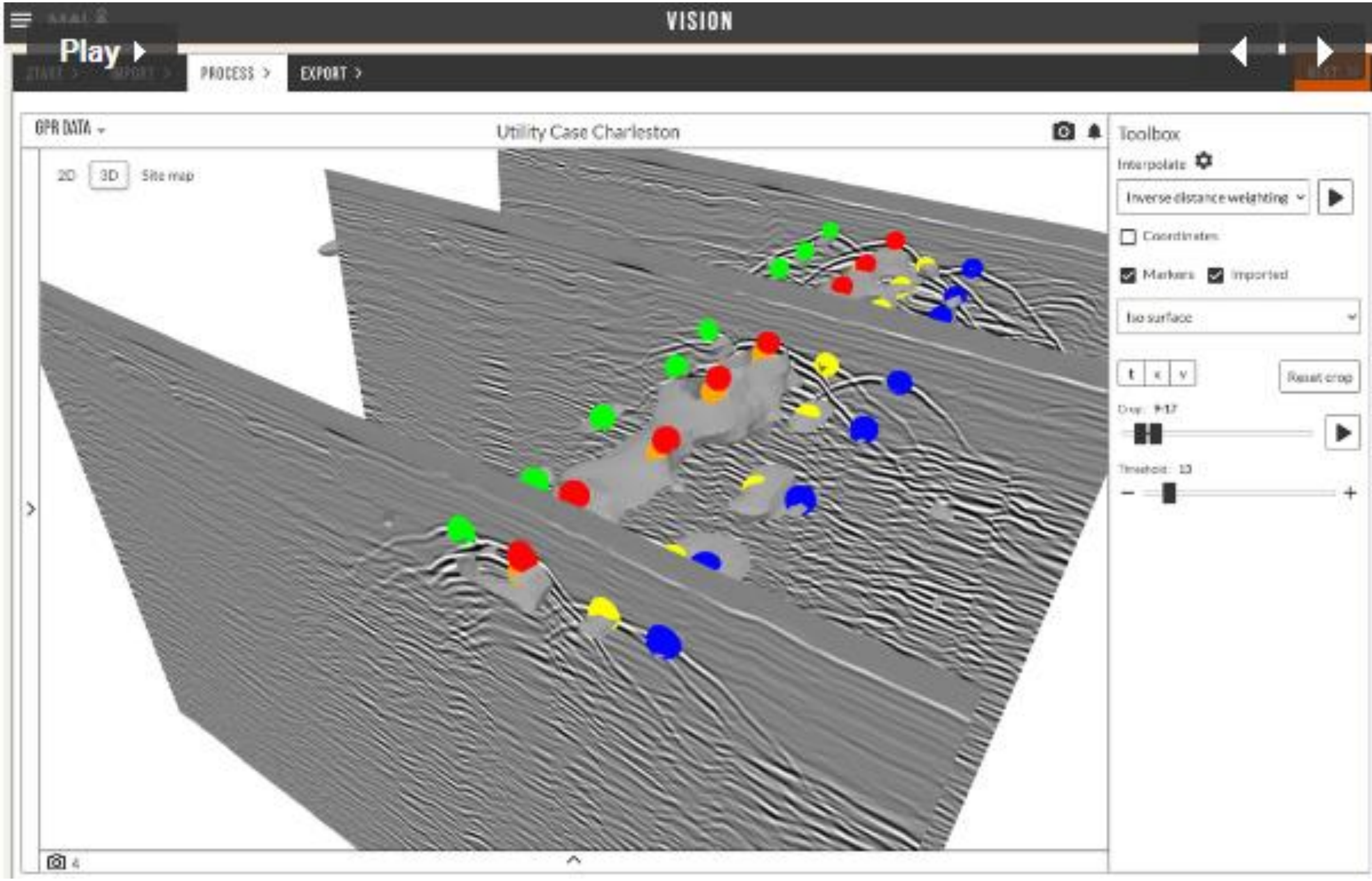
GPR 3D Survey

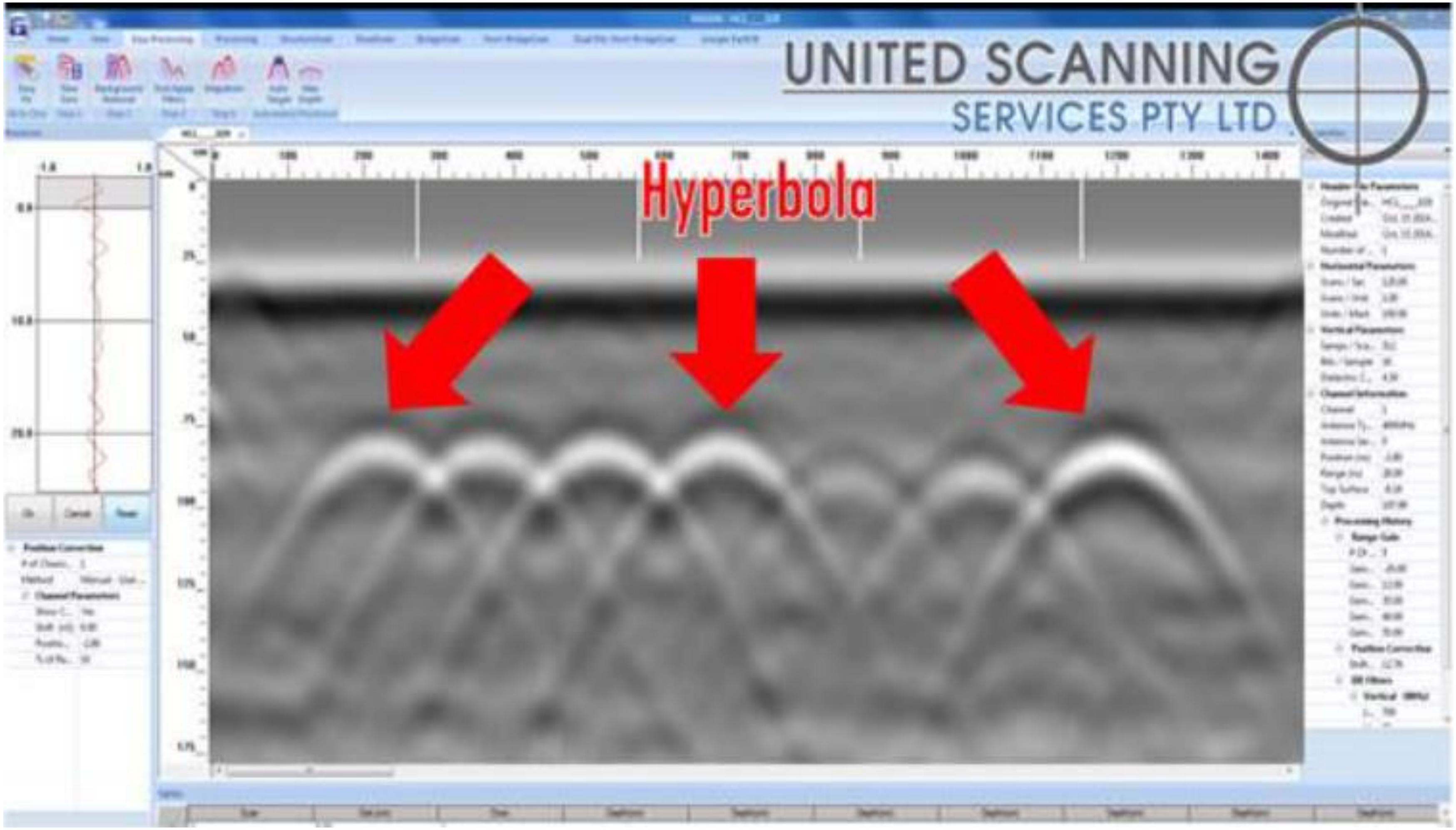


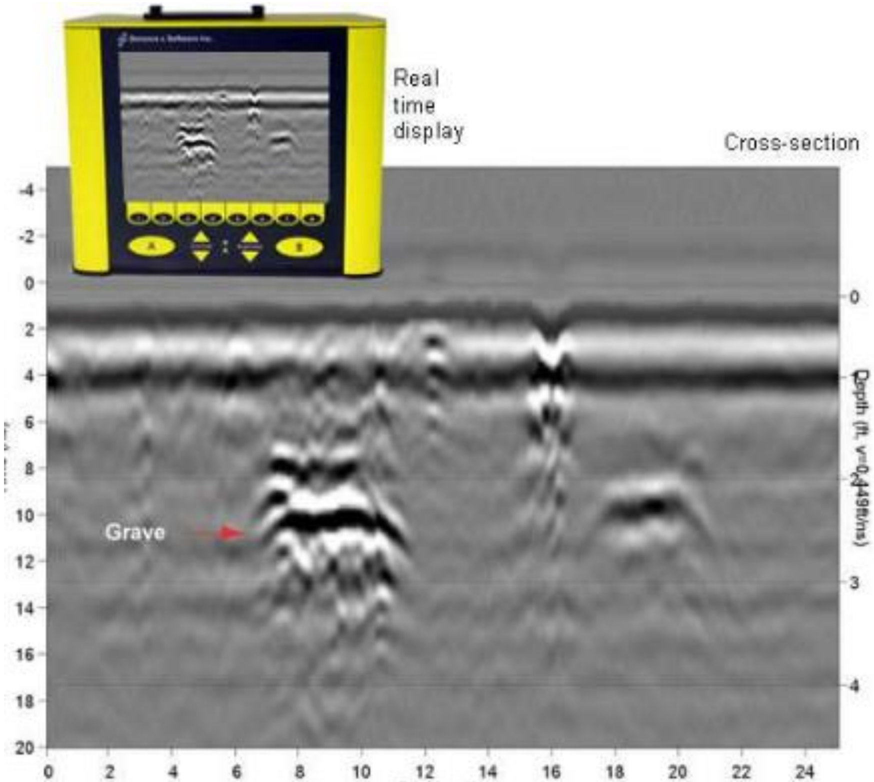

40
20
0
0
20
40
60

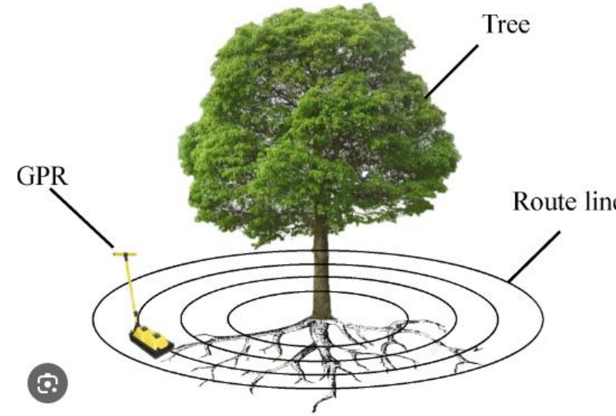


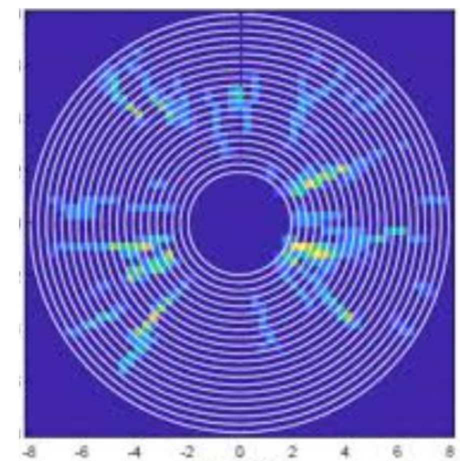
VISION
Play
PROCESS
EXPORT
GPR DATA
Utility Case Charleston
Toolbox
FILTERS
DISPLAY EFFECTS
INTERPRETATION
ANALYSIS
Imported files
Show all
Hide all
2D
3D
Site map
CHAR0022
Auto switch
Markers
Imported
Clear markers

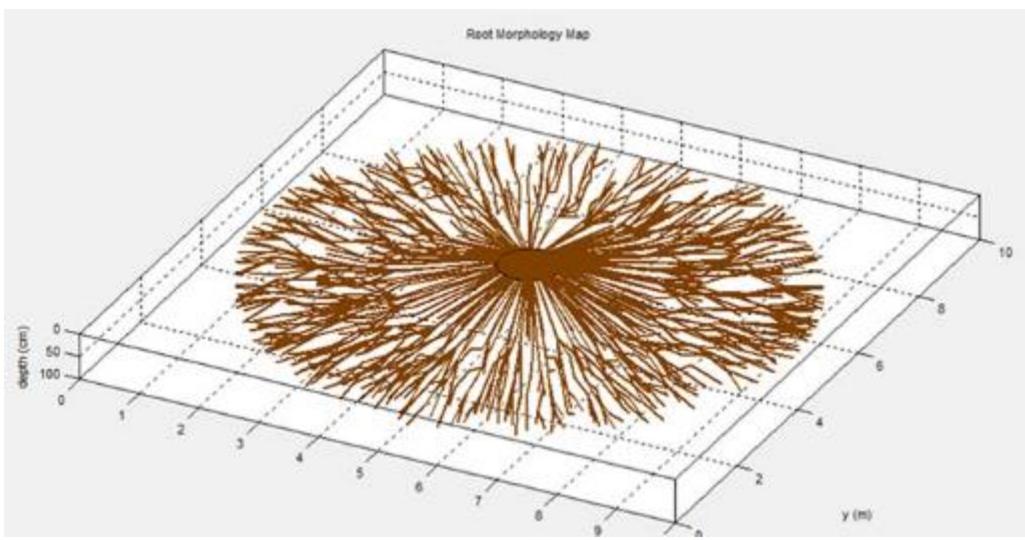

VISION
Play
PROCESS >
EXPORT >
GPR DATA
Utility Case Charleston
2D
3D
Site map
Toolbox
Interpolate
Inverse distance weighting
Coordinates
Markers
Imported
Iso surface
Reset crop

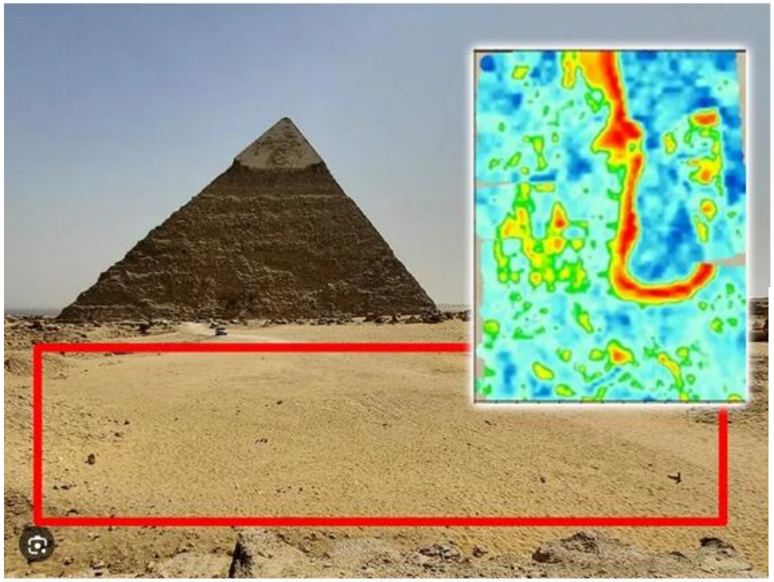

UNITED SCANNING
SERVICES PTY LTD
Hyperbola


Real time display
Cross-section
Grave


Tree
GPR
Route line

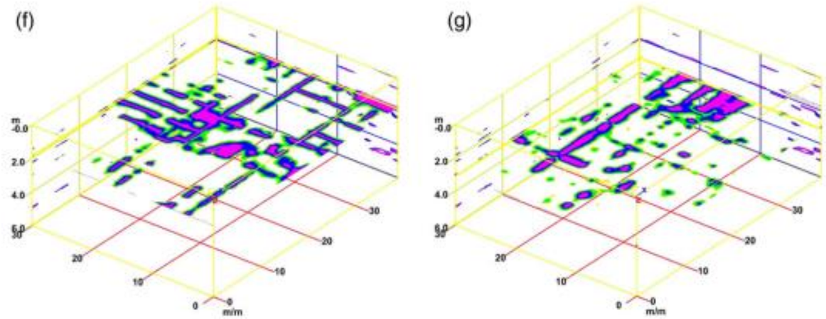



Root Morphology Map
depth (cm)
y (m)



Archaeologists identify buried L-shaped structure near Giza Pyramids | Archaeology News Online Magazine

Visit ›



JRE 5 Continued.

Thank You