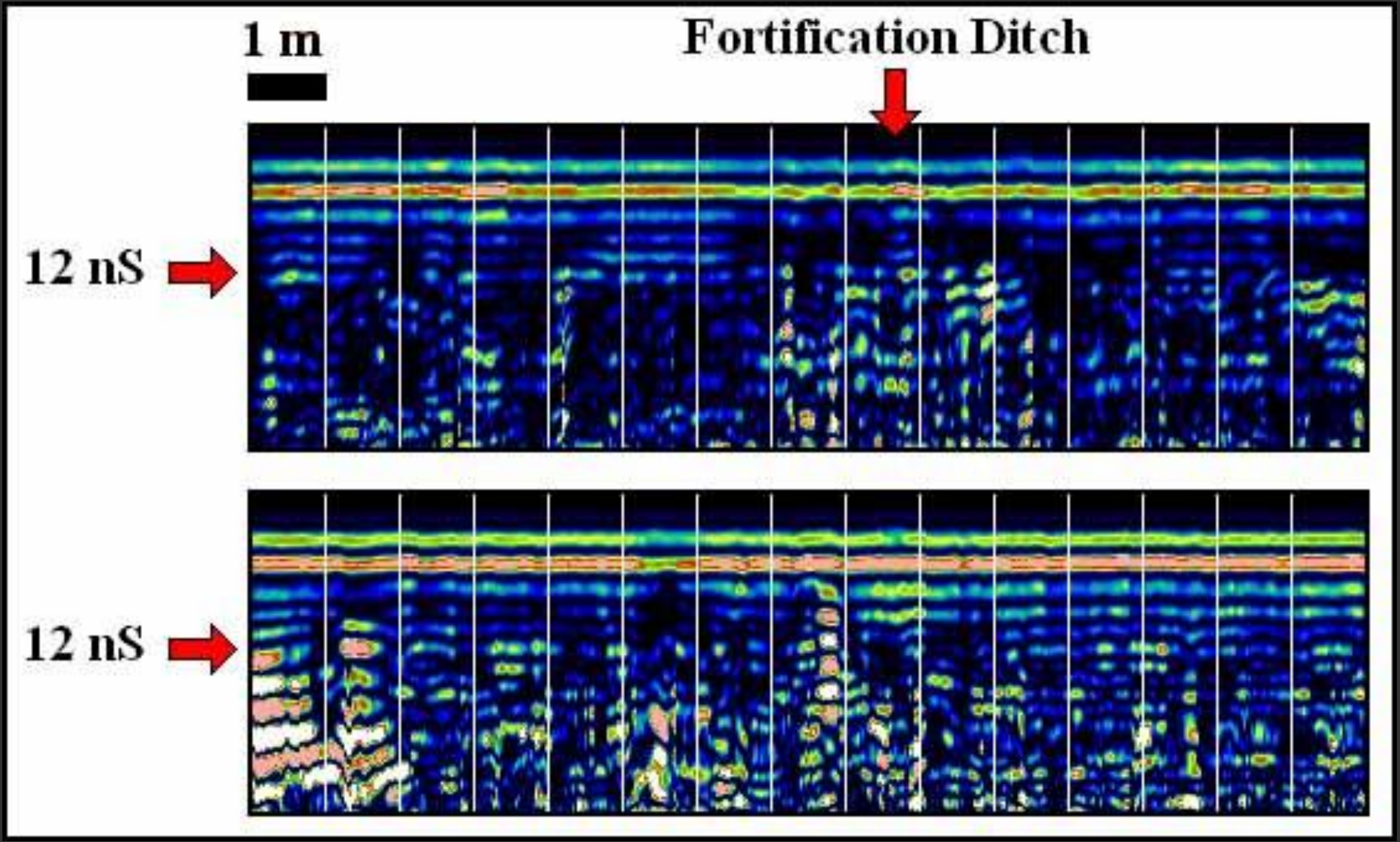
GROUND PENETRATING RADAR (GEORADAR)

Abdullah M. Alamri

- Ground penetrating radar (georadar) uses short pulses of ultra high frequency (UHF) radio to create an echogram of the subsurface.

- It has several similarities to seismic reflection, although the wave transmission is more complex and the results more dependent on the survey conditions.



Example of a GPR echogram. The colours show the amplitude of the reflection. (12 nS is around 1m to 3m depth).

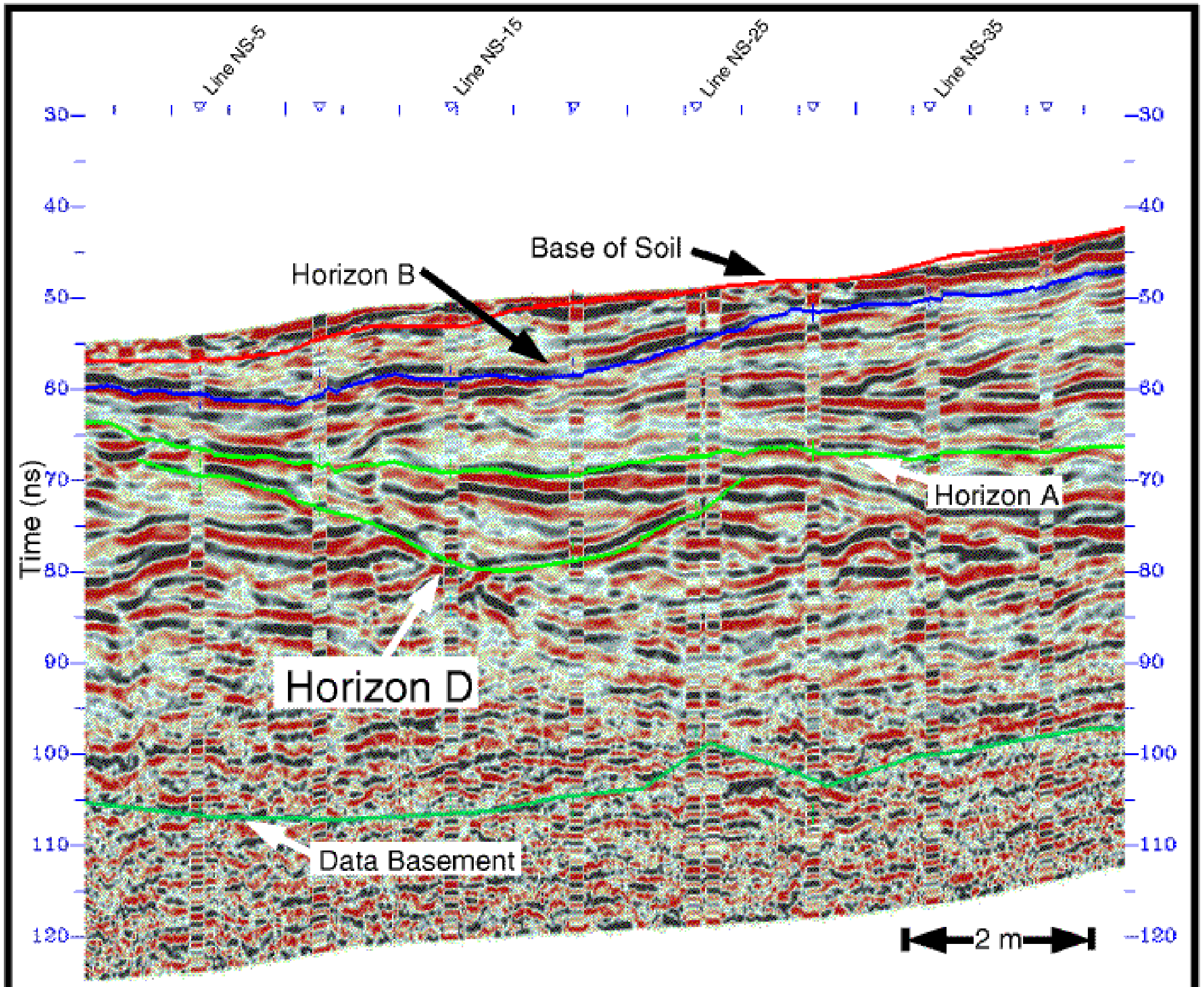
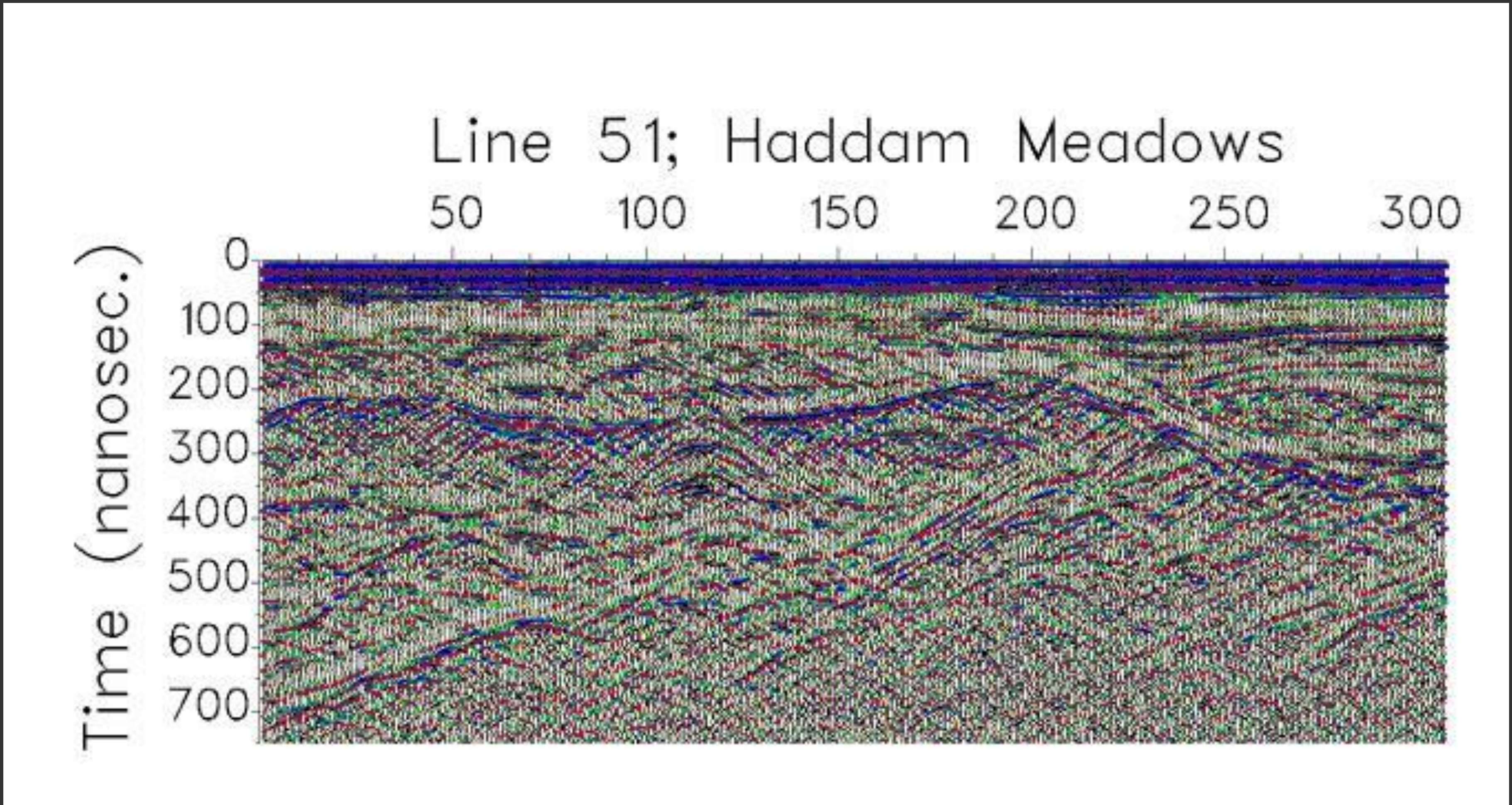


Figure 16B. Line EW-80

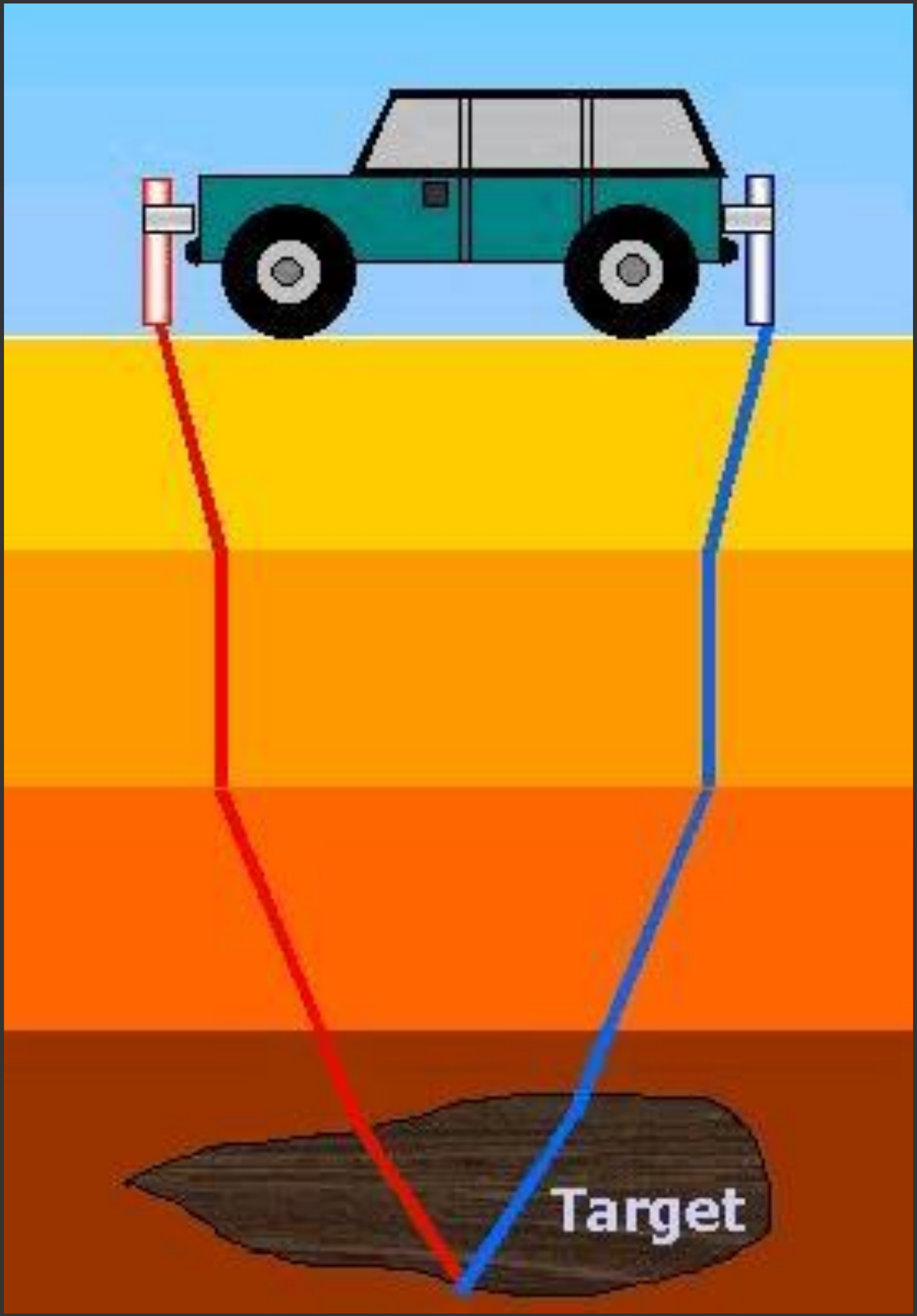
An interpreted 'geological' echogram.
The depth is around 5m.



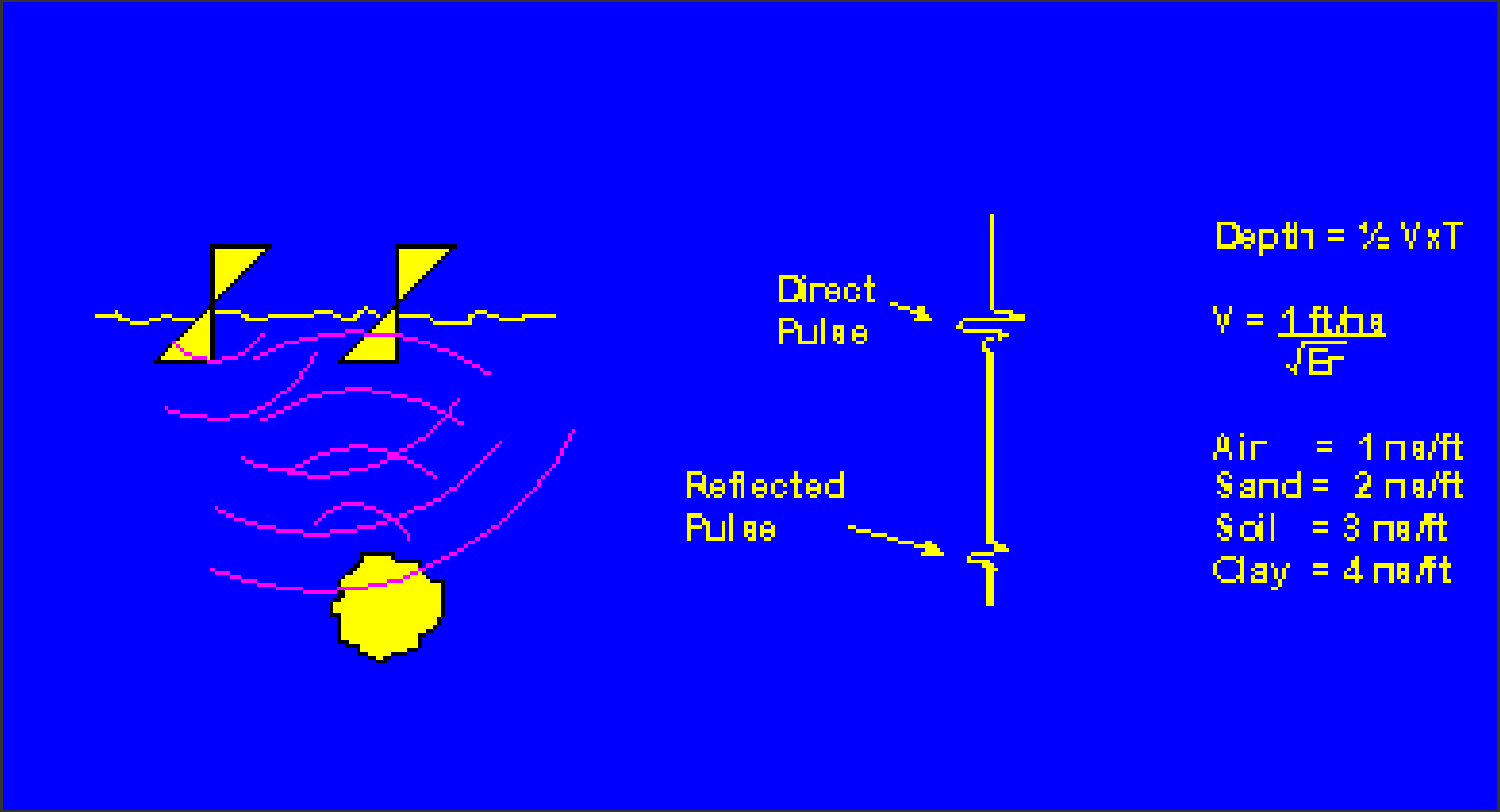
A deeper geological echogram. This is unusually deep (around 30m)

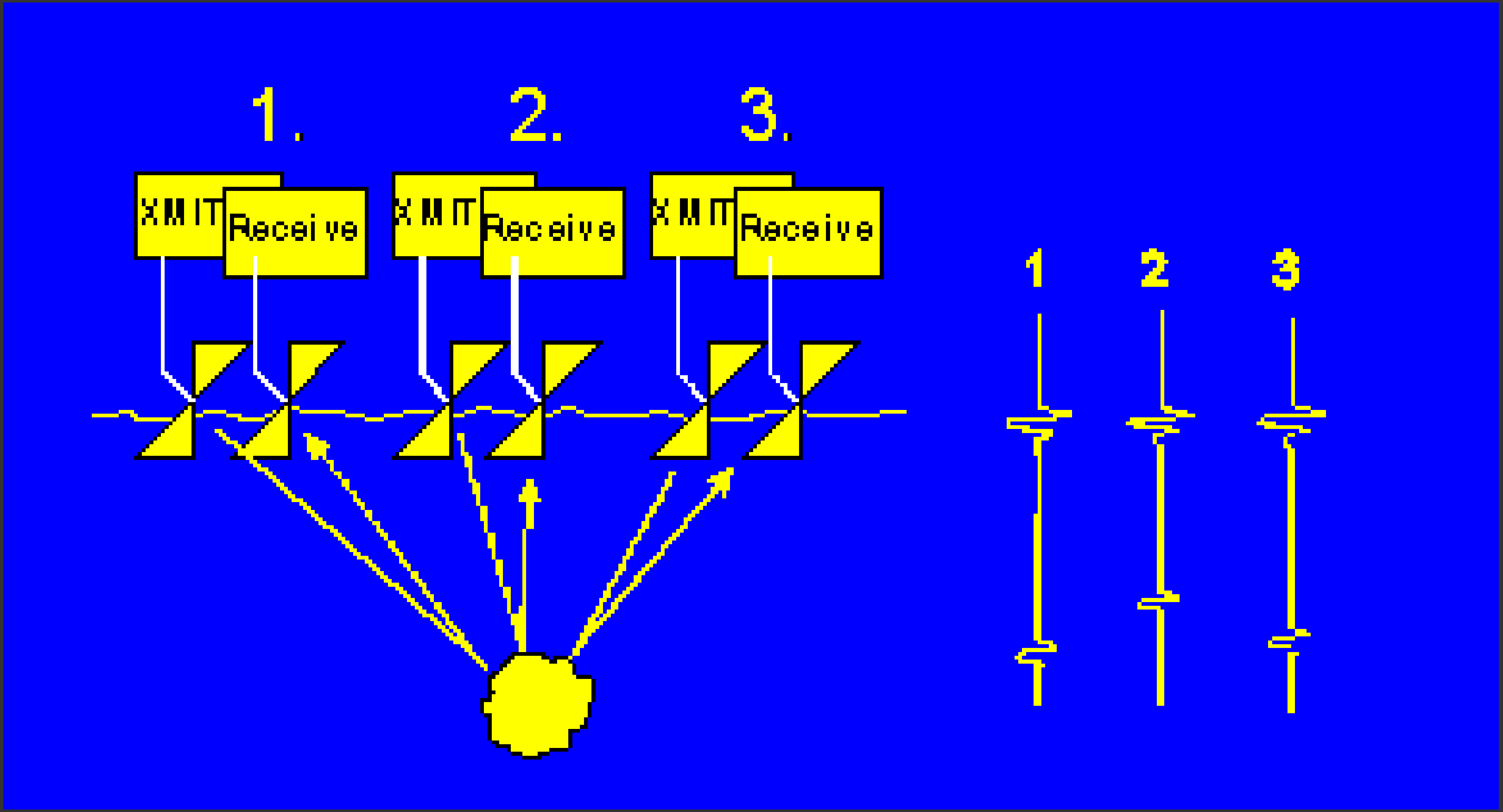
- The advantages of GPR lie in its speed, convenience and potential detail. It has many applications in geology, engineering SI, archaeology, to name some.

- GPR has several limitations. The most serious is the effect of soil conditions on the transmission of the electromagnetic pulse - this can render quantitative intepretation very difficult or impossible.

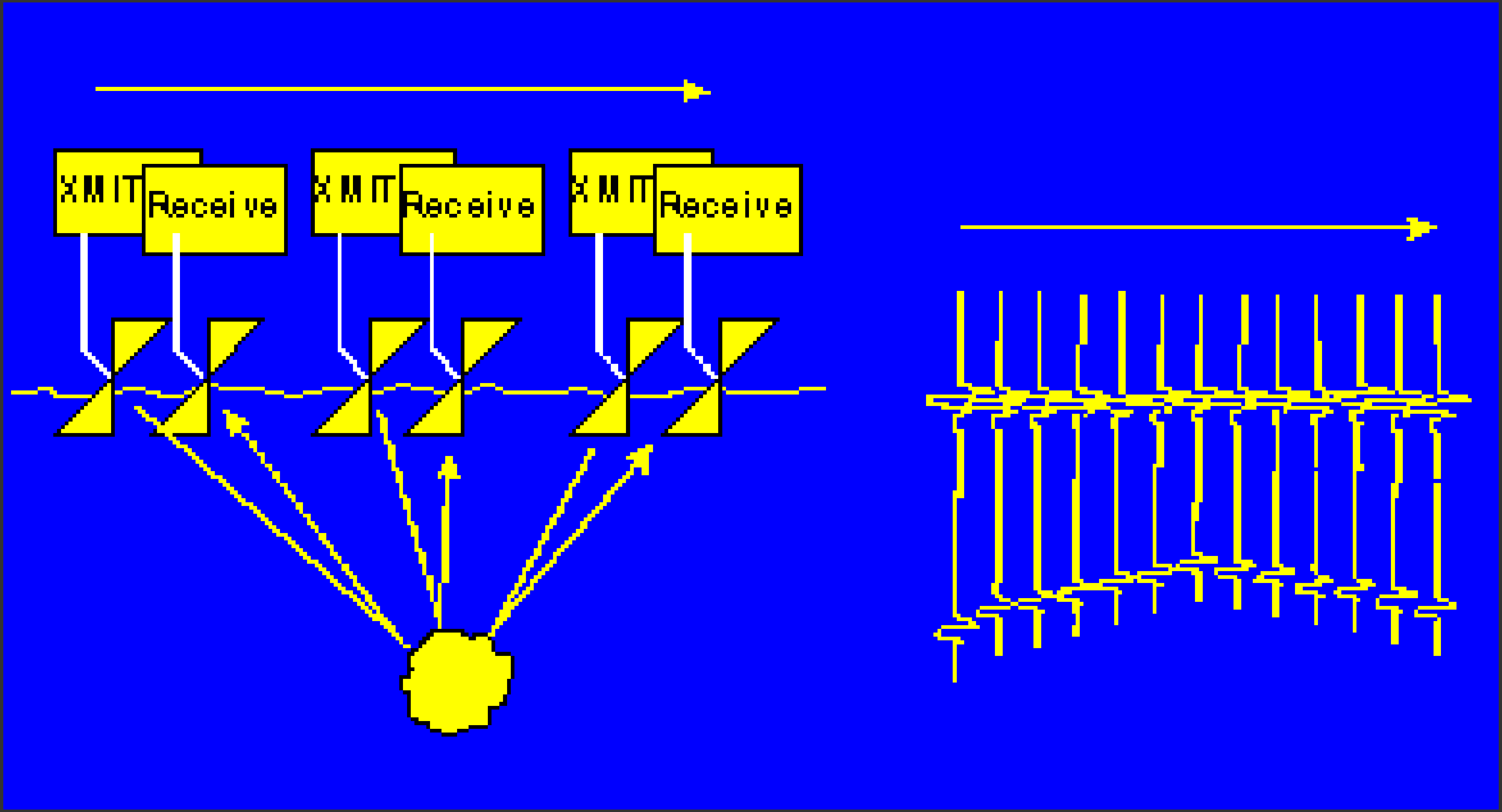

Target

- GPR uses the reflections from a short pulse to build an image of the subsurface.
- The basic principle is identical to that of the seismic reflection method, except that:
  - The energy is provided by a UHT pulse of around 200 MHz.
  - The velocity is around 100,000 metres/mS or 0.1m/nS (about 100,000 times faster than a seismic wave)
  - TWT is measured in 10s - 100s of nanoseconds
  - Reflectors are defined by a contrast in their **AC electrical impedance**, essentially a change in their **dielectric constant**
  - Penetration depth is usually limited to a few metres


Direct
Pulse
Reflected
Pulse
Depth = ½ V x T
V = 1 ft/ns / √Er
Air = 1 ns/ft
Sand = 2 ns/ft
Soil = 3 ns/ft
Clay = 4 ns/ft


1.
2.
3.
XMIT
Receive
XMIT
Receive
XMIT
Receive
1
2
3

- Discrete objects give rise to hyperbolic reflections in the same way as in reflection seismics.
- The image of a linear objects (eg a pipe) depends on its direction relative to the survey line.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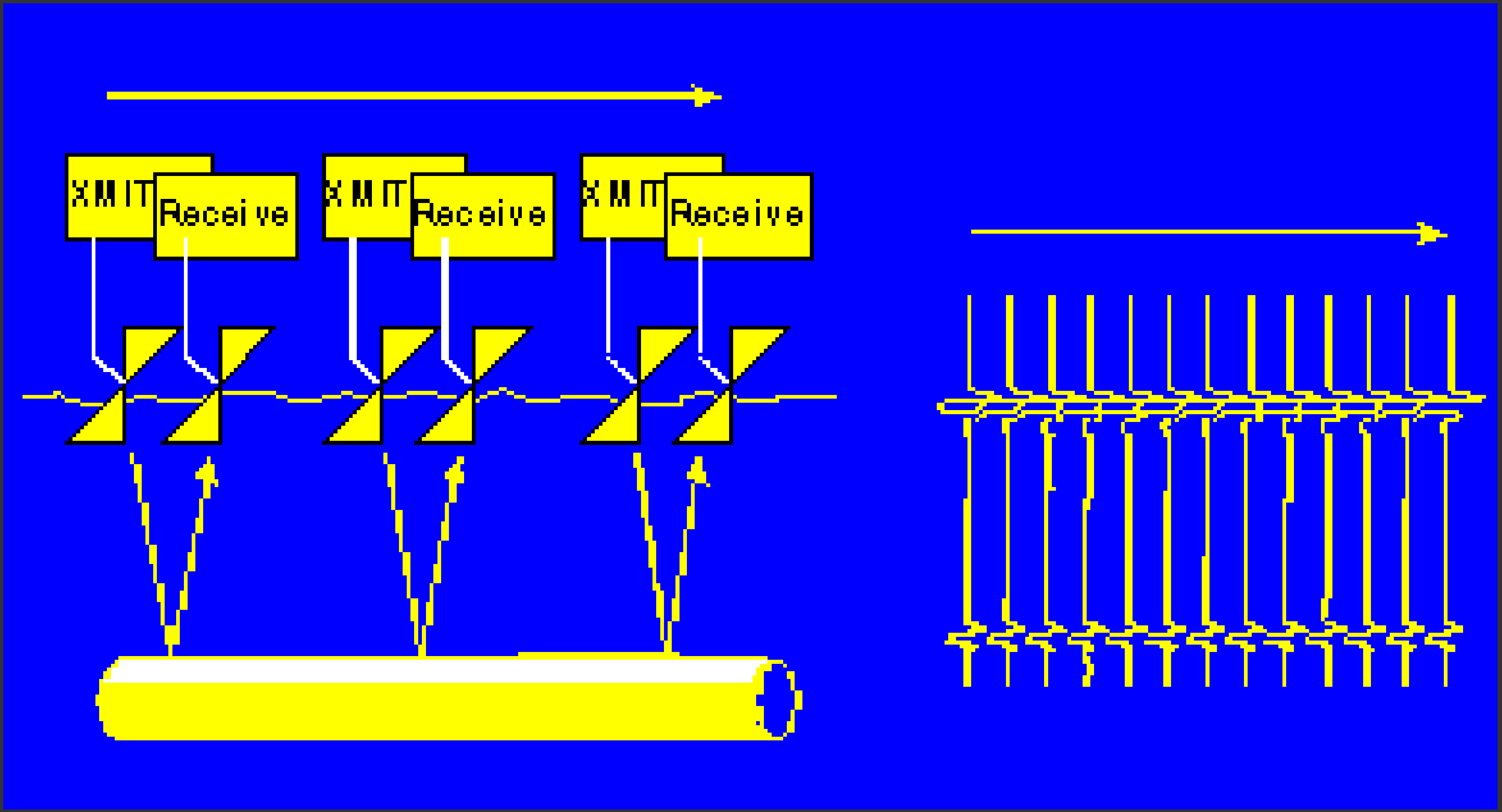

XMIT
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Receive
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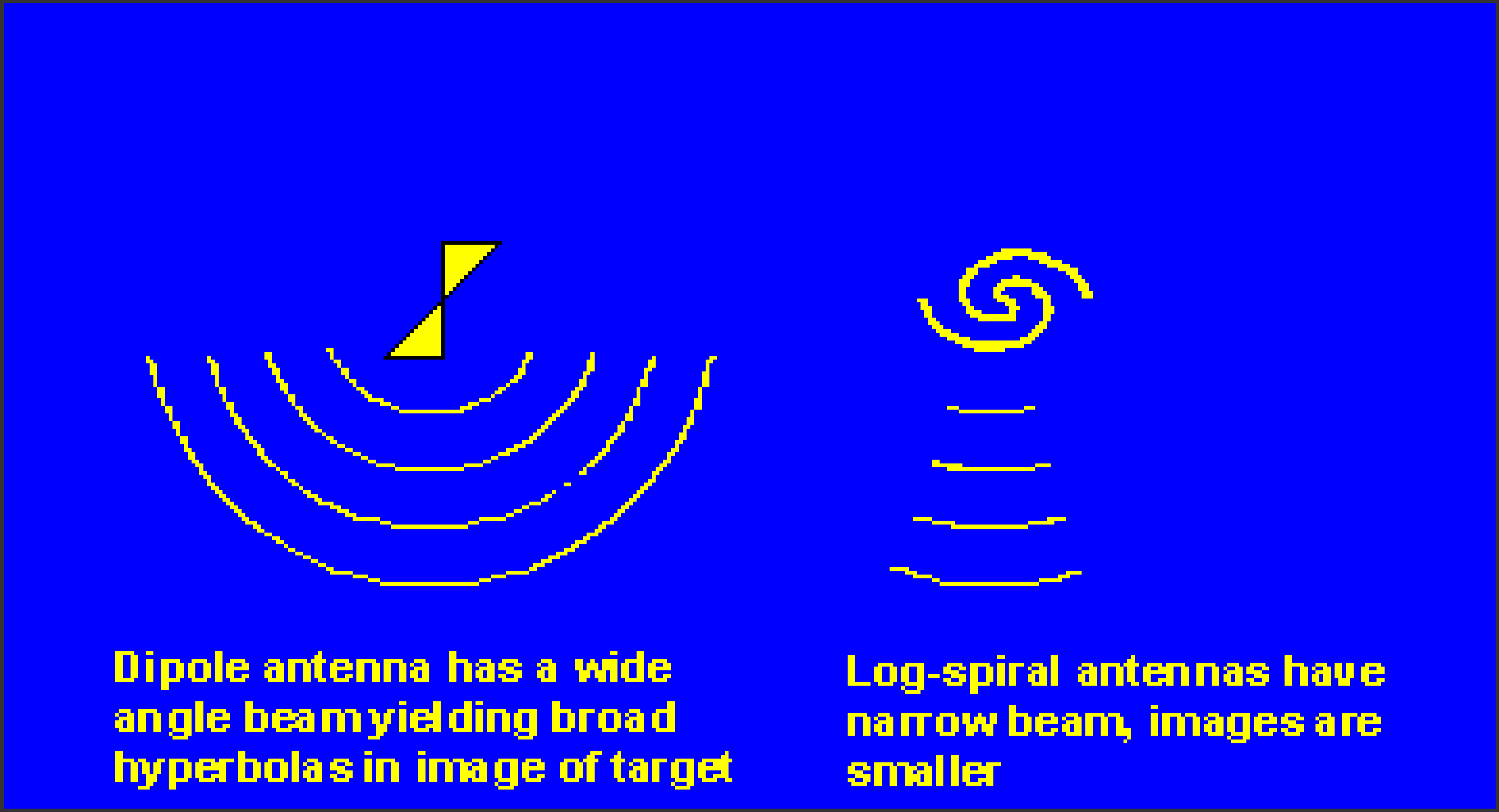
Receive

- Unlike seismic sources, GPR sources can be focussed using different antenna designs.

- The success of a GPR survey can be very dependent on the choice of antenna.

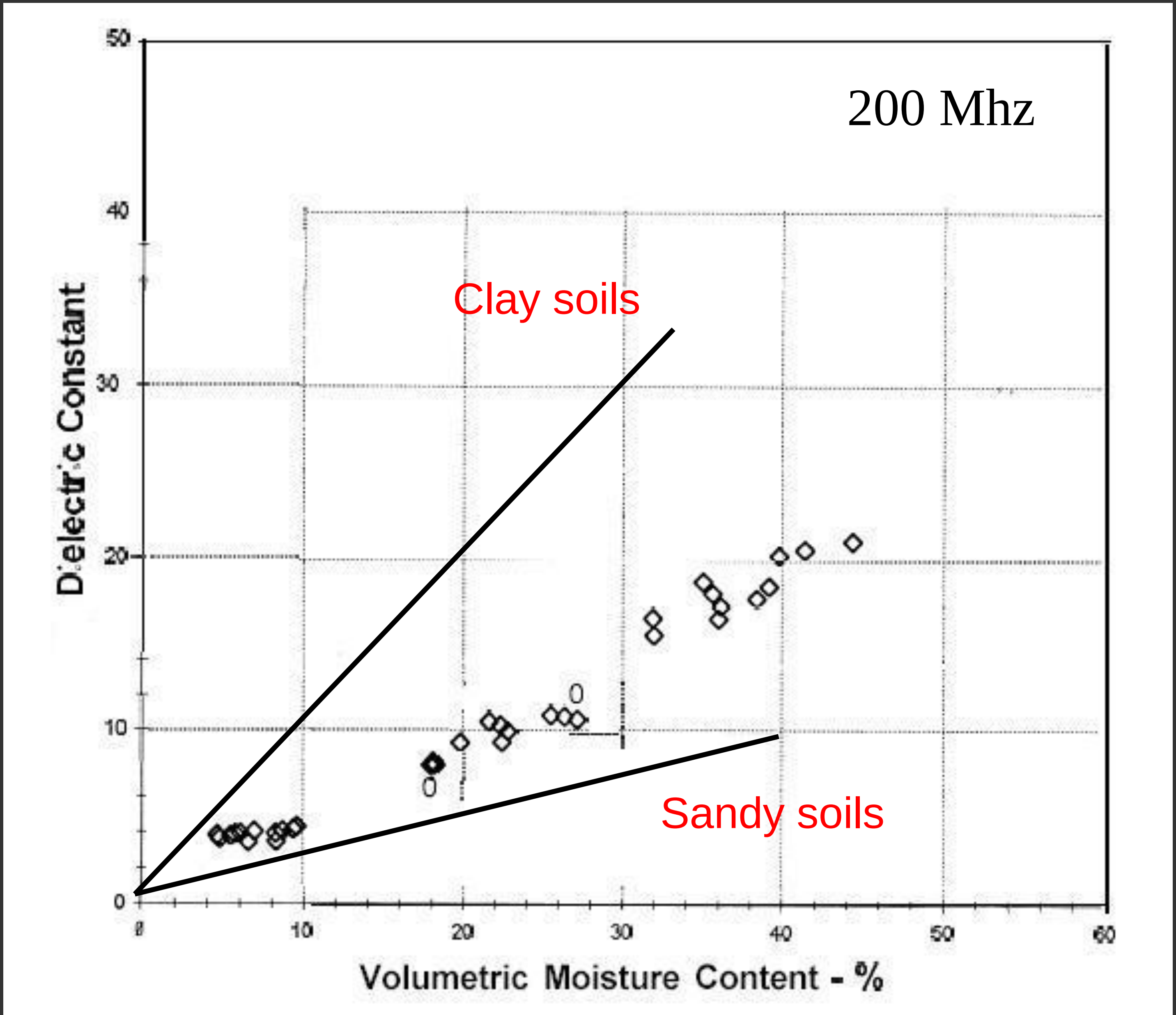


Dipole antenna has a wide angle beam yielding broad hyperbolas in image of target
Log-spiral antennas have narrow beam, images are smaller

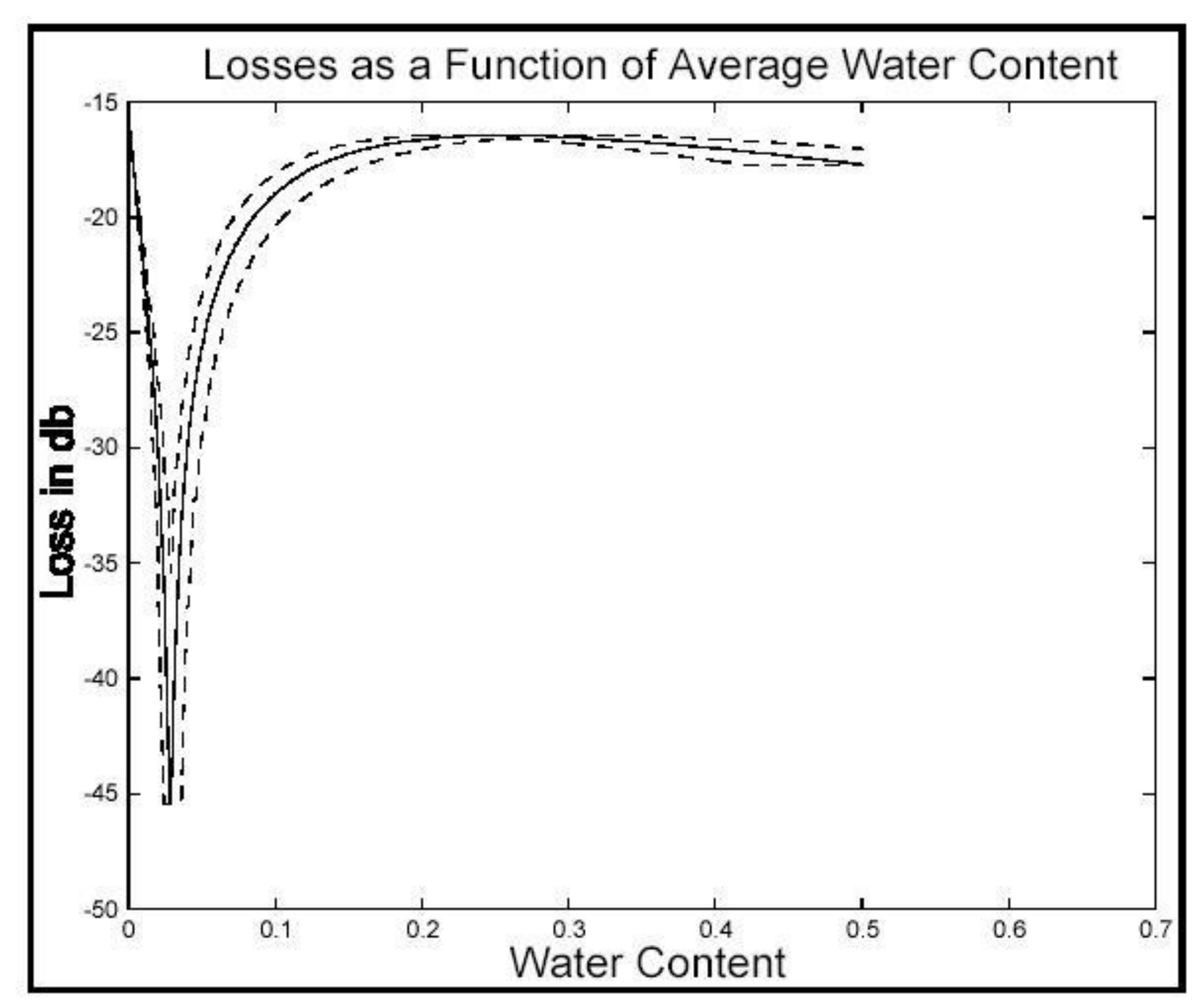
- The velocity of electromagnetic propagation in a material is equal to the speed of light (c) in a vacuum, reduced by a factor controlled by the dielectric constant (ε_r) of the material.

$$velocity = v = \frac{\omega}{\beta} \approx \frac{c}{\sqrt{\varepsilon_r}}$$

- The dielectric constant of soil is not a simple property. It is controlled by:
  - The pore volume and geometry (porosity and permeability)
  - The bulk water content and how it is distributed
  - The composition of the soil particles
  - The presence of salts in the pore water
  - The presence of organic liquids in the pore space
- A saline, saturated clay can have a dielectric constant perhaps four times greater than a dry sand.
- The EM velocity will thus be half that of the sand.


200 Mhz
Clay soils
Sandy soils
Dielectric Constant
Volumetric Moisture Content - %
0
10
20
30
40
50
60

- In a similar way, the absorption of the EM signal is very dependent on these factors. Thus in a clay soil there can be a considerable signal loss and thus a reduction in the depth of penetration.
- This loss is not uniform but is concentrated at particular values of the water content due to optimal absorption in certain particle packings.



Losses as a Function of Average Water Content
-15
-20
-25
-30
-35
-40
-45
-50
Loss in db
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Water Content

- Thus accurate depth interpretation can be very difficult in some soils.
- Problems arise especially if the water content is variable, if the clay content is variable or if there are big changes in either between layers.
- Problems also arise in saline soils, which limits the use of georadar in coastal situations.

- Georadar surveys are non-contacting profile surveys, in which the instrument is traversed along the desired line.
- The output is shown immediately on the display and is recorded either digitally or on paper, after internal processing.
- The equipment is light and portable, designed for a single operator. GPR surveys are thus relatively cheap.

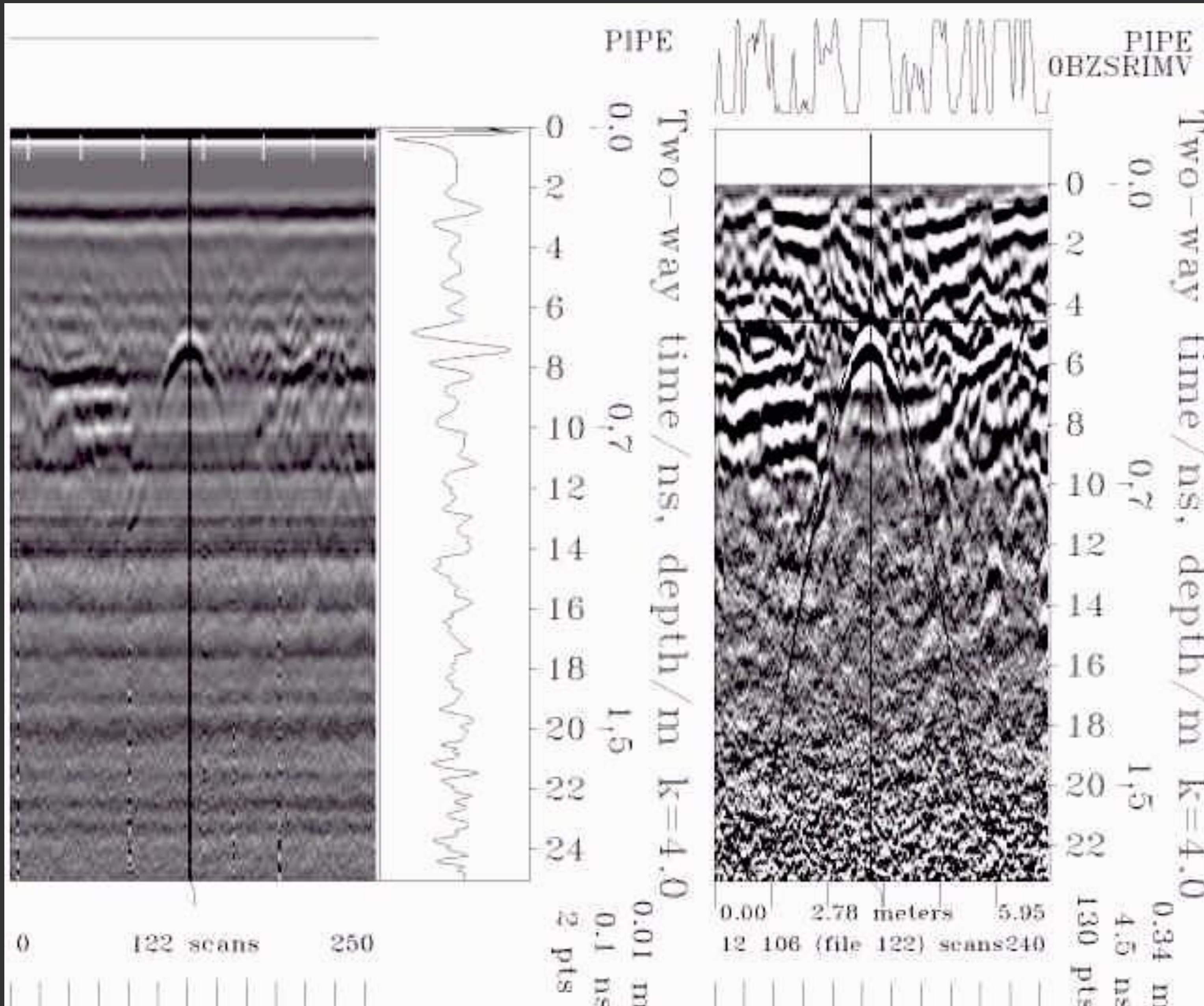
- The instrument size is determined by the antenna. This in turn is controlled by the required frequency.
- The most common 200 Mhz sets use antennae about 0.5m long, aligned perpendicular to the profile. These typically penetrate to 5m - 10m.
- Other frequencies in use include 50 MHz and 900 MHz, the latter being an adaption of a materials testing instrument.

- As in all geophysical surveys, it is essential to provide ground truth.
- The relatively shallow depth of a GPR survey makes this a simple if laborious task.

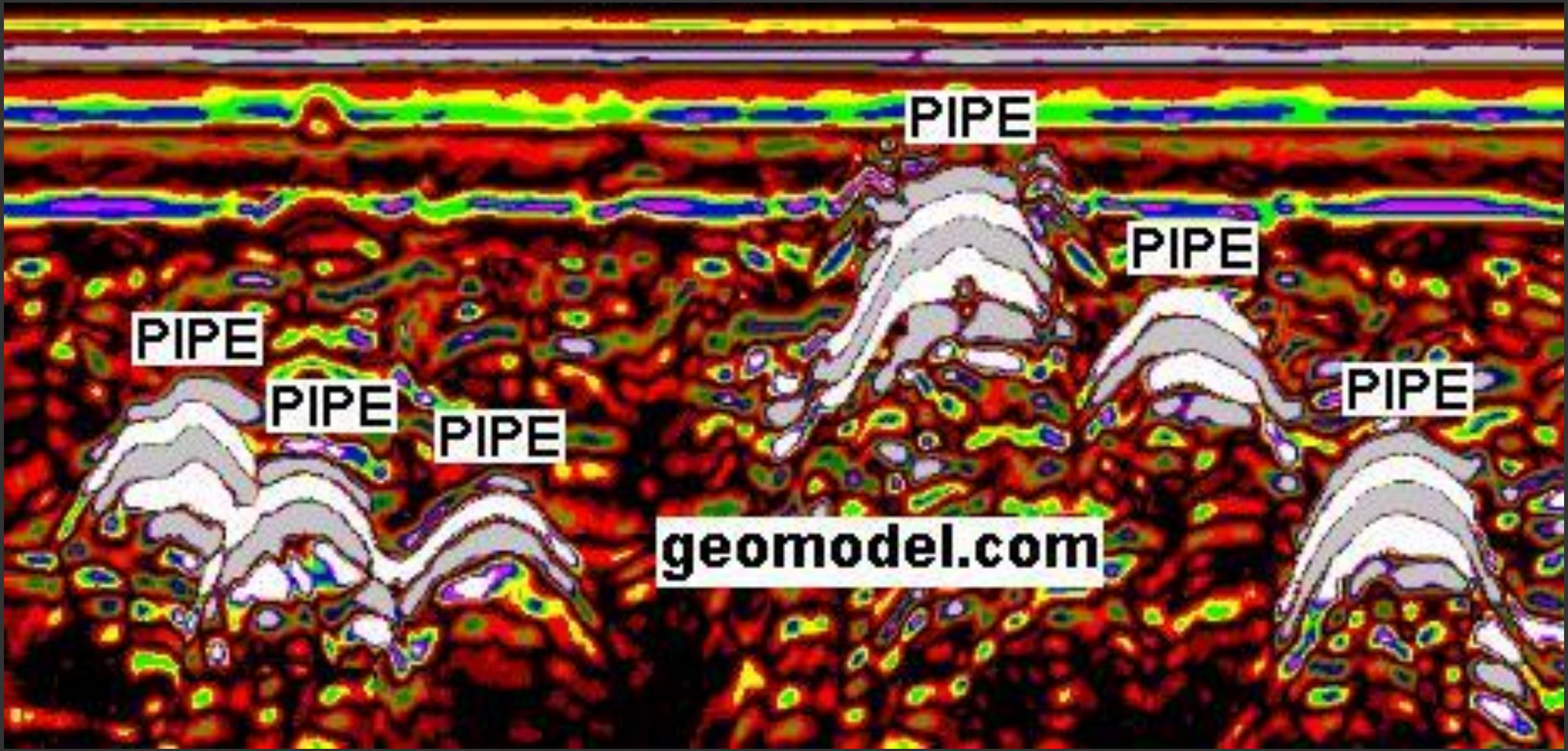
- Georadar results are normally interpreted visually and any features or anomalies are investigated by excavation.

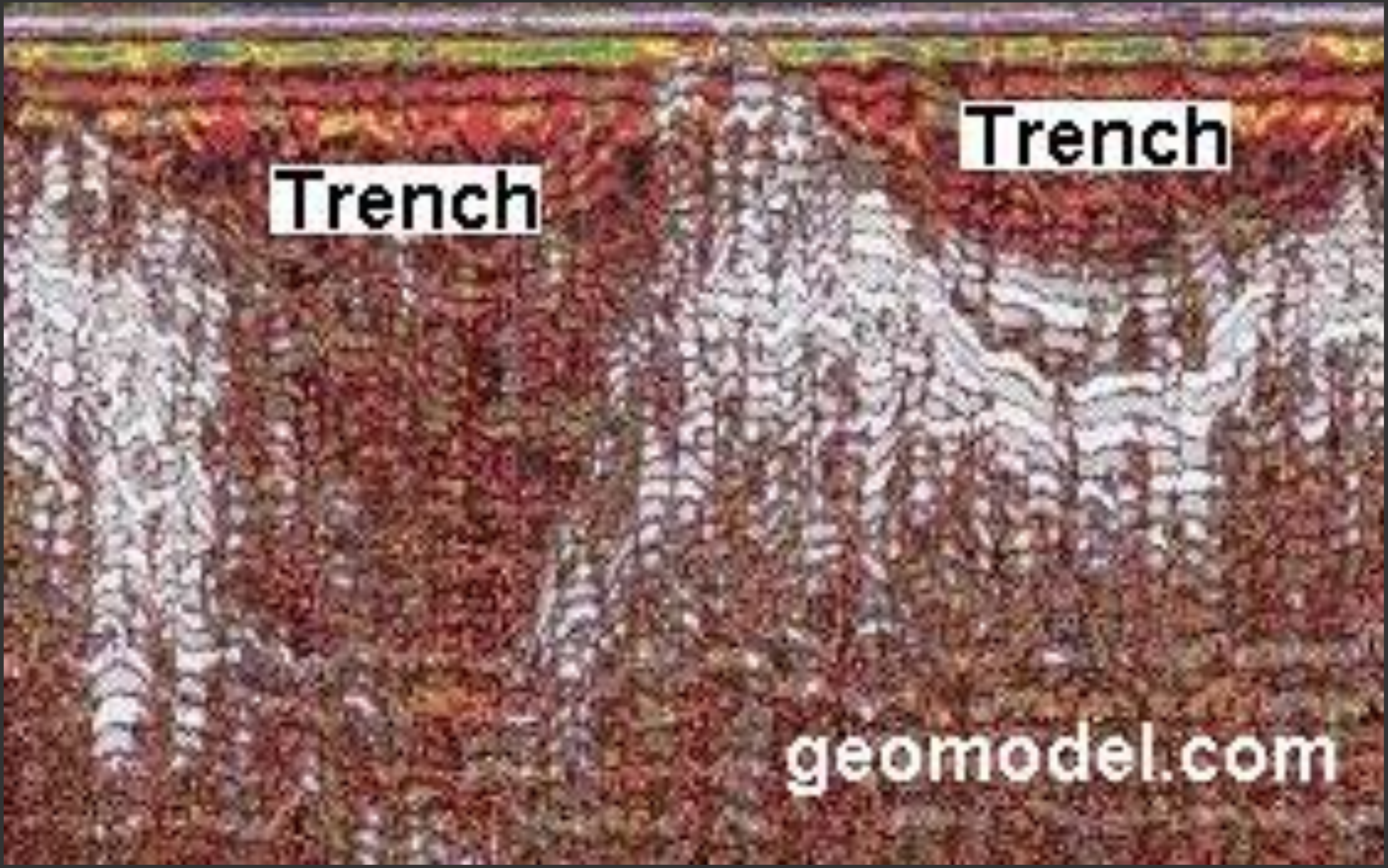
- Detailed depth predictions can be made in principle but in practice the uncertainty in the propagation velocity makes this difficult.

- It is nessary to process the results. This proceeds in three stages:
  - A large set of signals is added (stacked) to reduce noise. The large number is made possible by the very rapid pulse repetition rate of a GPR instrument (typically >100,000/sec)
  - The resulting image is enhanced to emphasise contrasts and edges
  - Multiples are removed if possible.
  - The amplitude of the reflection is colour coded to emphasise the stronger reflectors (not always done).


PIPE
PIPE
0BZSRIMV
Two-way time/ns, depth/m k=4.0
0 122 scans 250
0.01 m
0.1 ns
2 pts
0.00 2.78 meters 5.95
12 106 (file 122) scans240
0.34 m
4.5 ns
130 pts

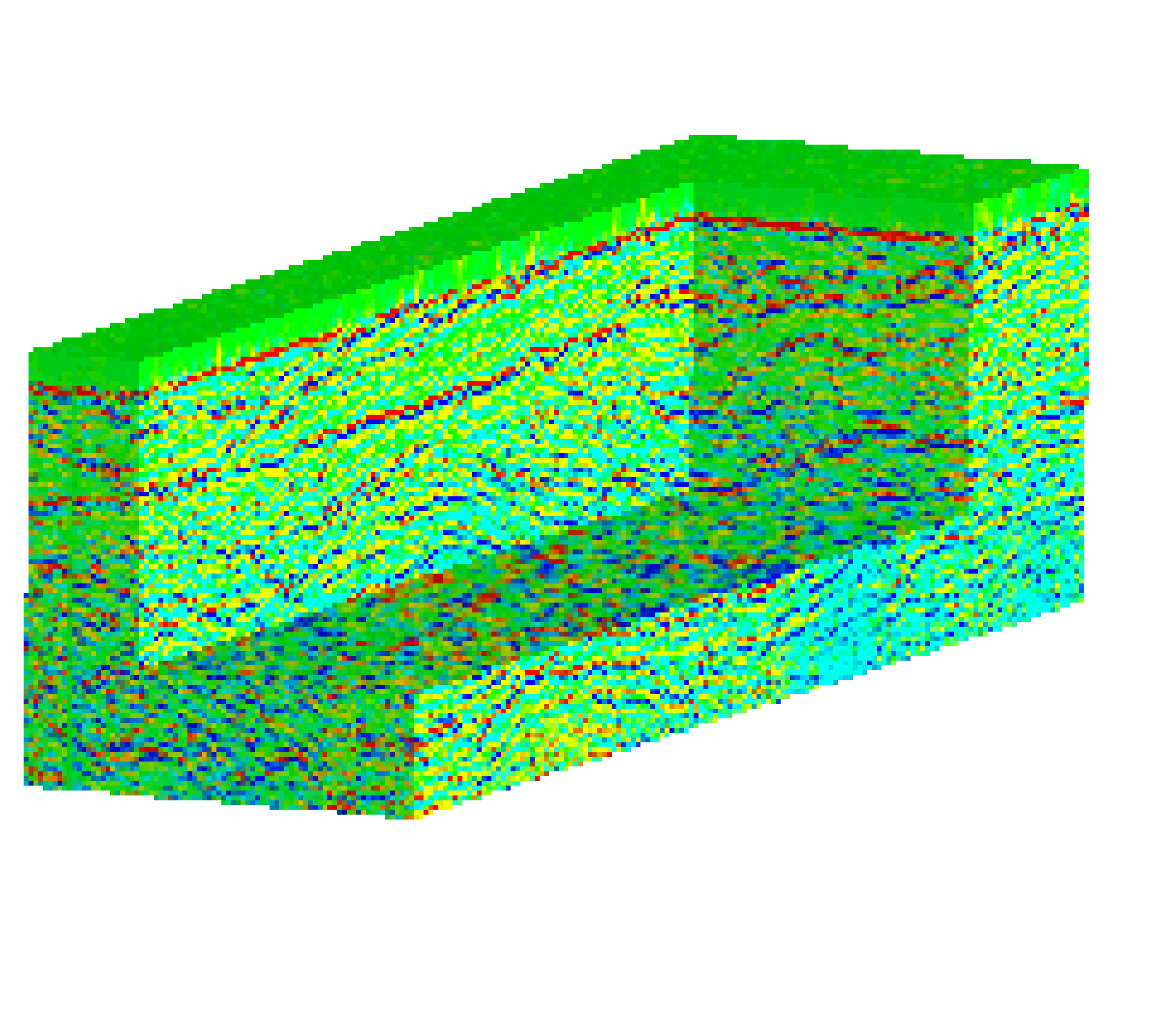
- Interpretation then proceeds visually, with the operator making allowance for the presence of multiples, hyperbolic reflectors etc.
- It is possible to define radar facies in the same way as seismic facies. This gives some indication of lithology.
- However, due to the ease of excavation, this approach is less critical than in seismic surveying.


PIPE
PIPE
PIPE
PIPE
PIPE
PIPE
geomodel.com

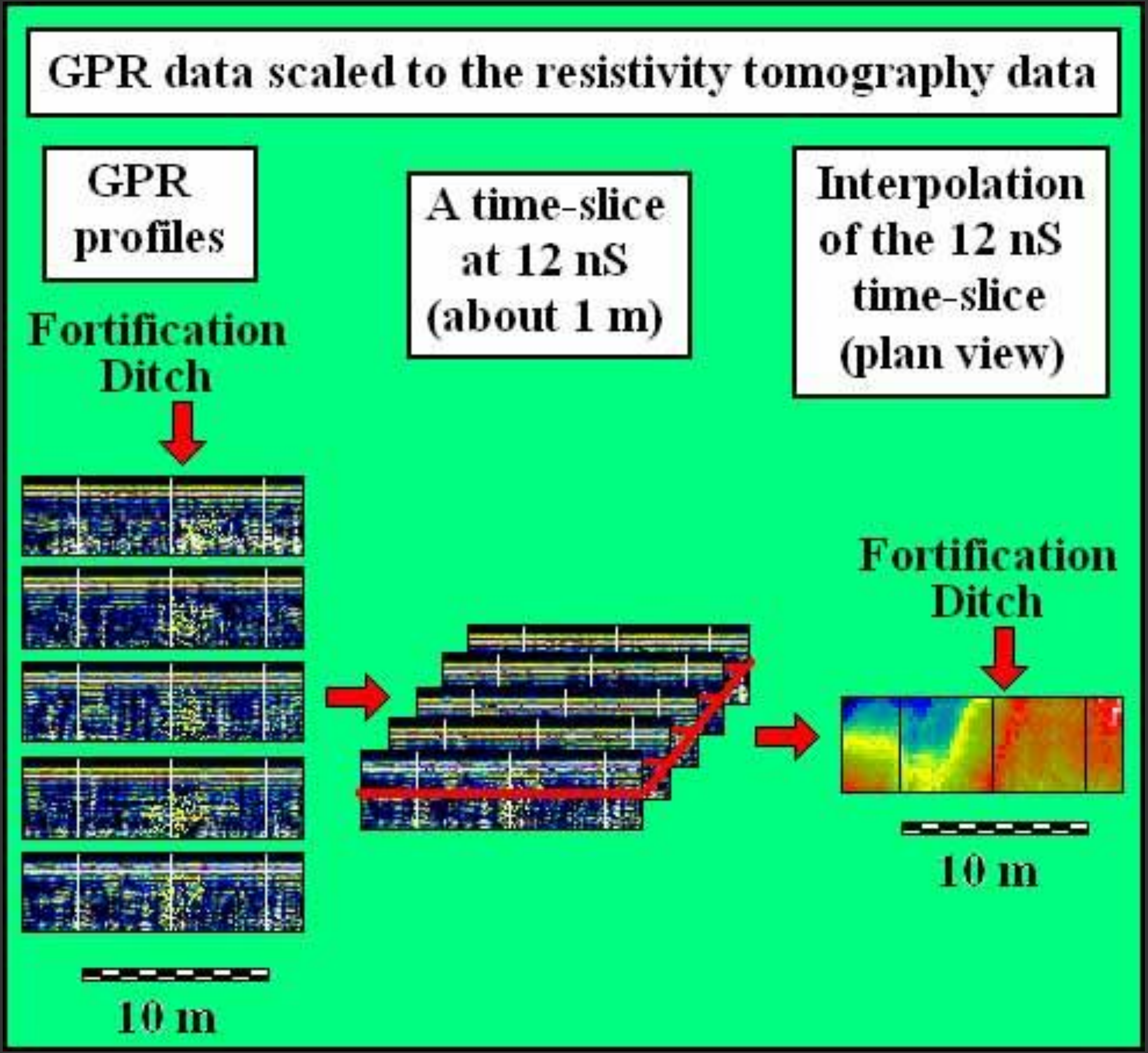

Trench
Trench
geomodel.com

Infilled fissure beneath soil cover

- More complex processing enables the stacks to be integrated into a three dimensional model of the ground.
- Individual layers can be extracted by time-slicing the model and the results displayed separately to produce a plan view of a particular level.

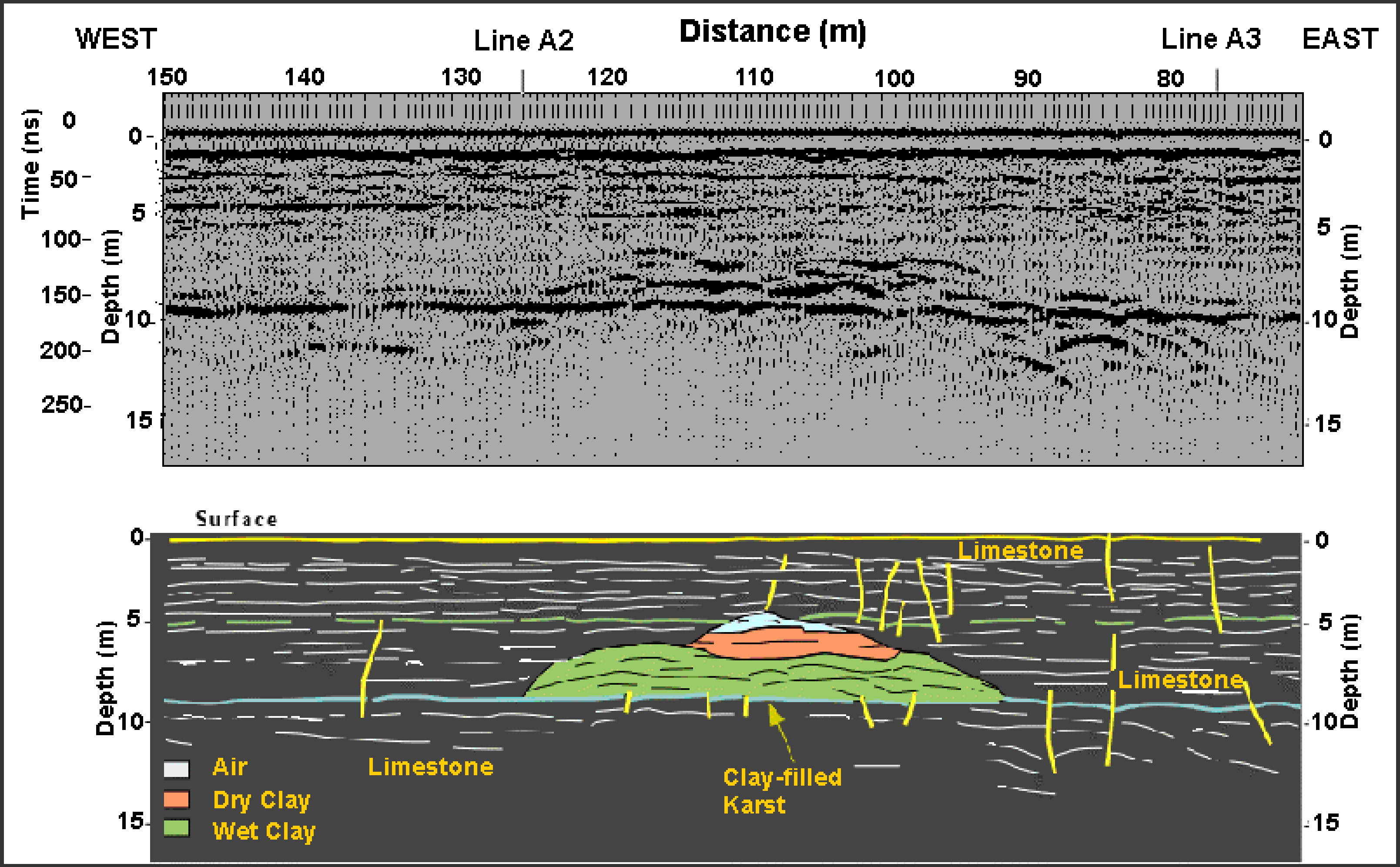


3D cube of data from S.Maine. 200 MHz, 40 * 35 * 10 m


GPR data scaled to the resistivity tomography data
GPR profiles
A time-slice at 12 nS (about 1 m)
Interpolation of the 12 nS time-slice (plan view)
Fortification Ditch
10 m
Fortification Ditch
10 m

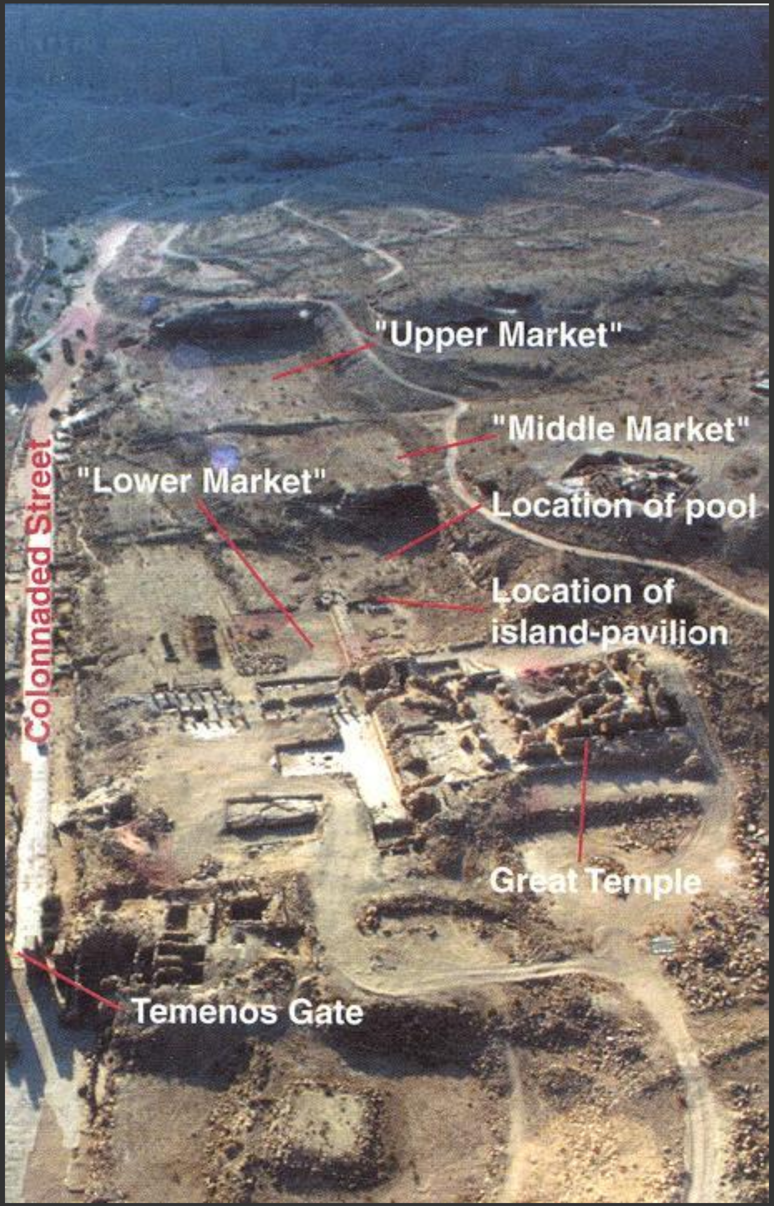
- The following examples show the range of problems to which GPR can be applied.

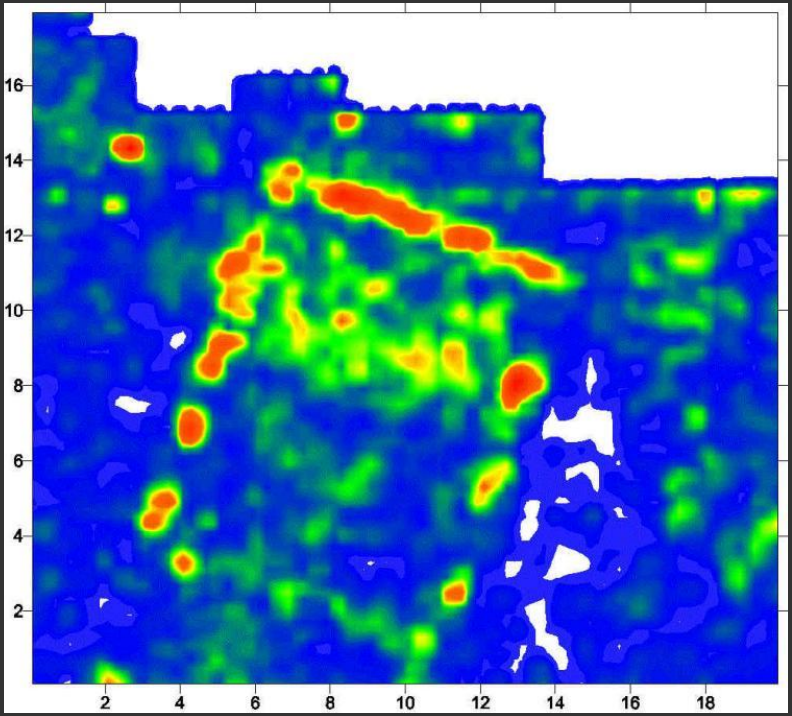
1. Conventional engineering survey to determine the presence of hazardous subsurface features, in this case solution sink holes in limestone.



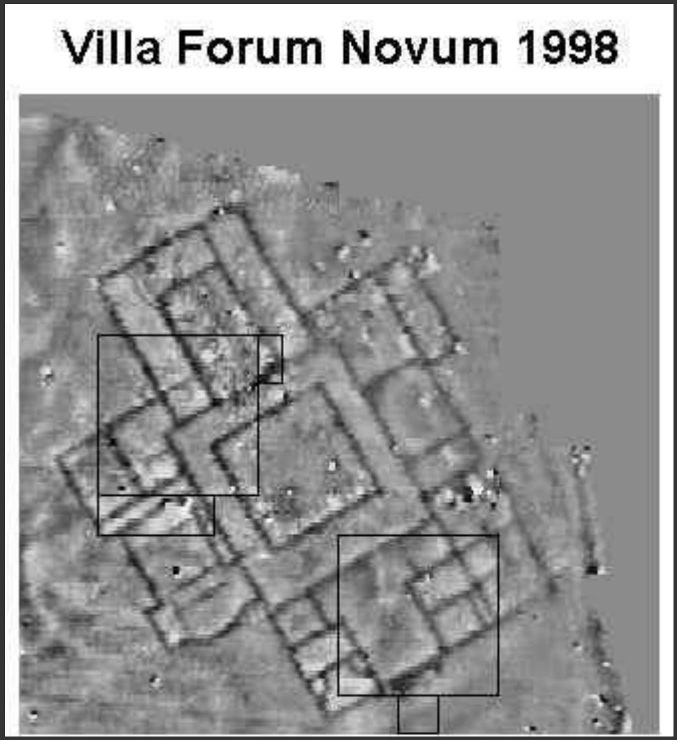
WEST
Line A2
Distance (m)
Line A3
EAST
150
140
130
120
110
100
90
80
Time (ns)
0
50
100
150
200
250
Depth (m)
0
5
10
15
Surface
Limestone
Limestone
Limestone
Air
Dry Clay
Wet Clay
Clay-filled
Karst

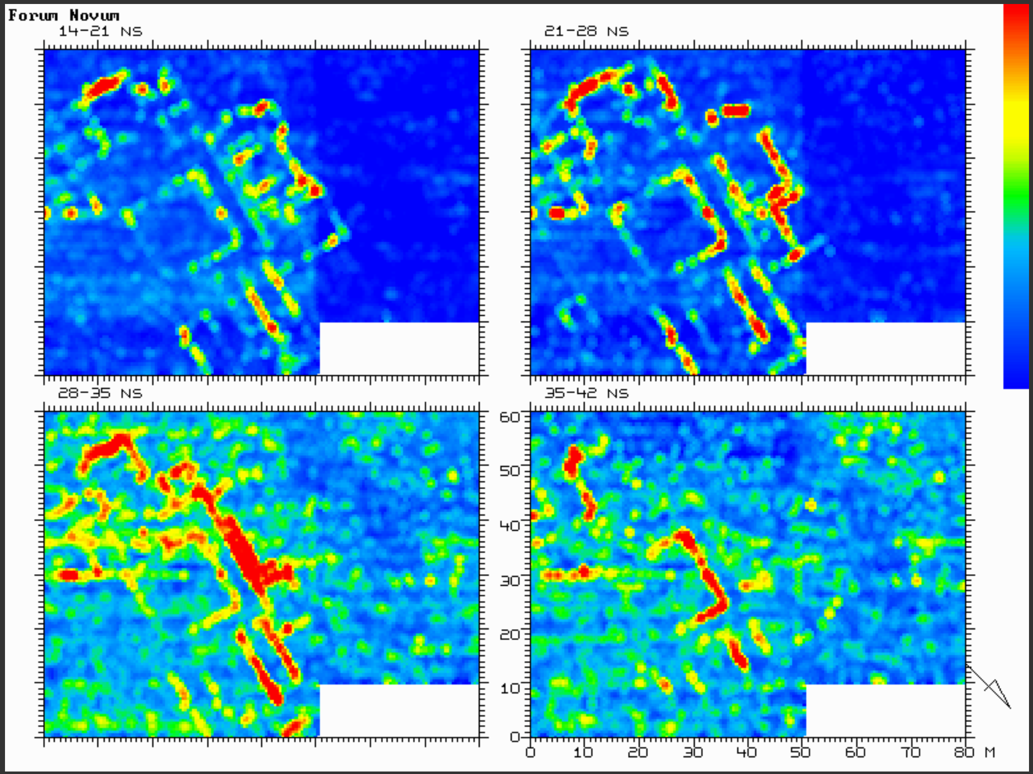
2. To determine the position and layout of shallow archaeological features, usually either walls or infilled excavations such as foundations or ditches.





Lower Market project
Petra, Jordan (Denver Univ)

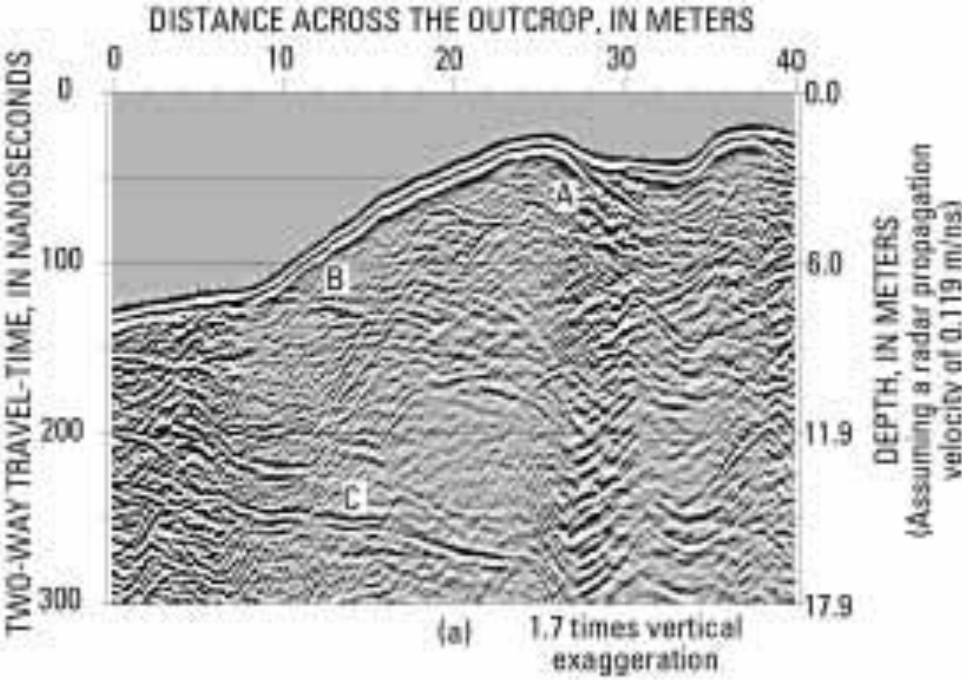




Forum Novum project
Sabine Hills, Rome
University of Birmingham

3. The presence and spacing of fissures in bedrock as part of a hydrogeological resource survey. This is a relatively difficult task.

   The detection of the groundwater surface itself is usually quite easy.

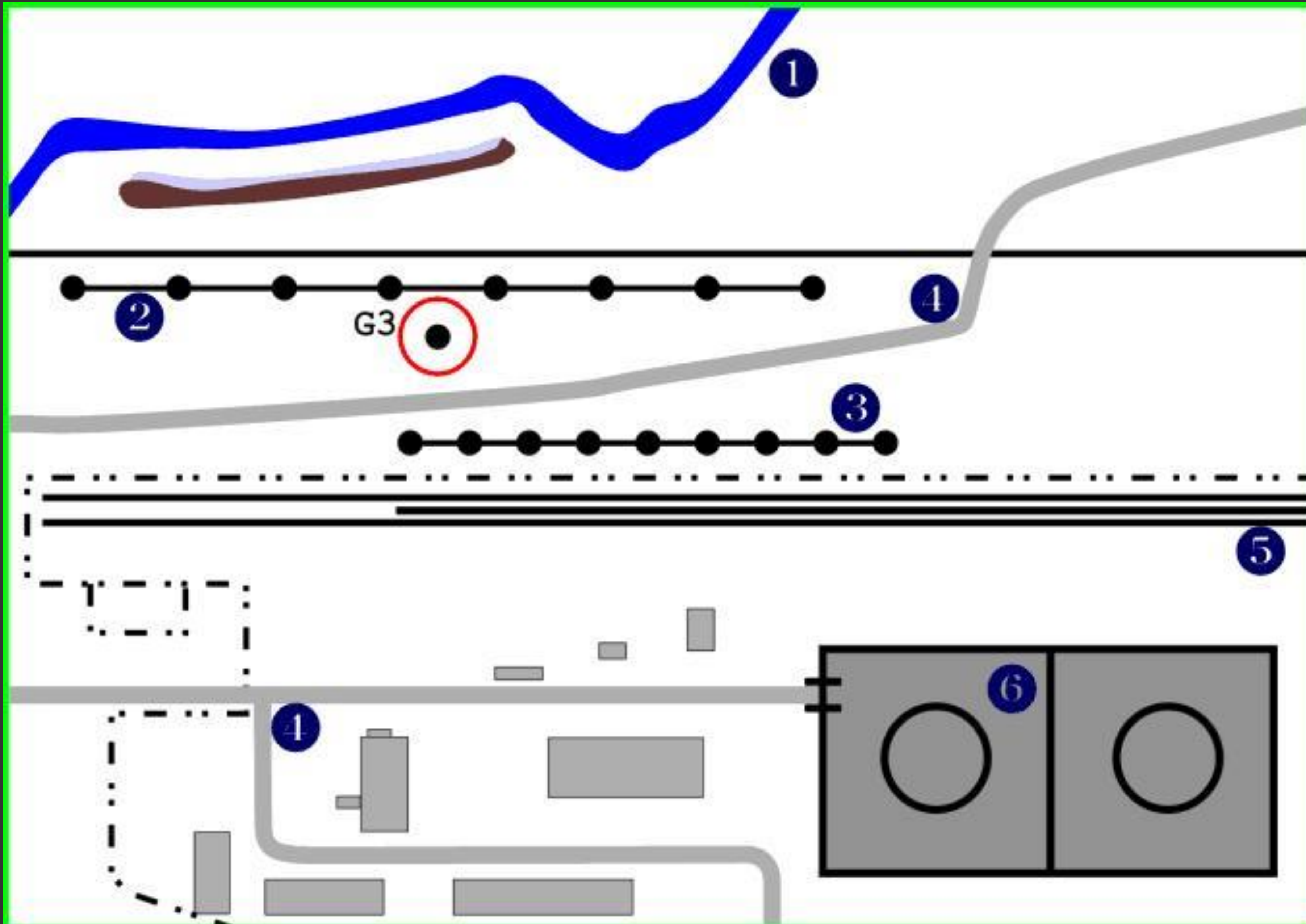


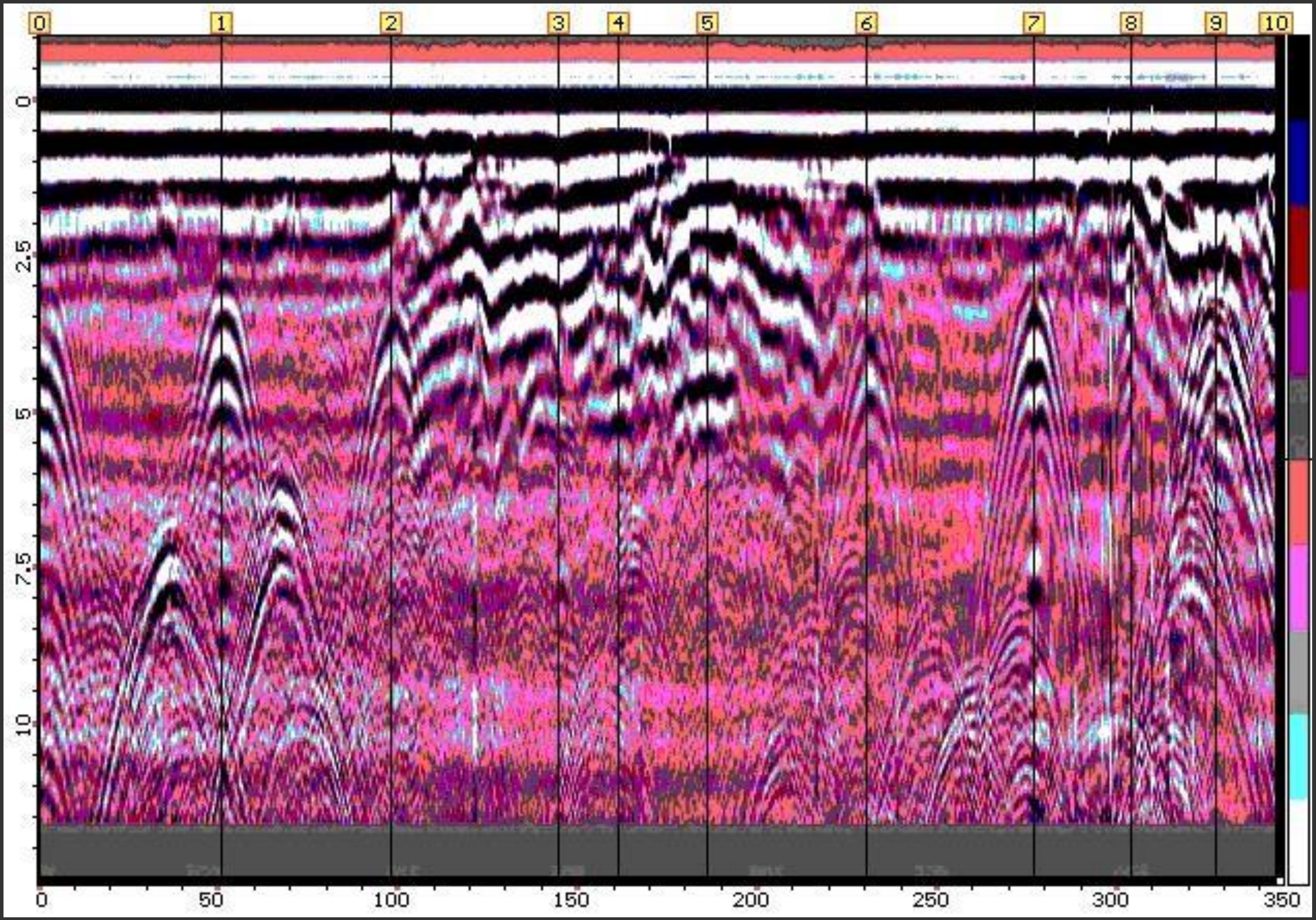
(a)

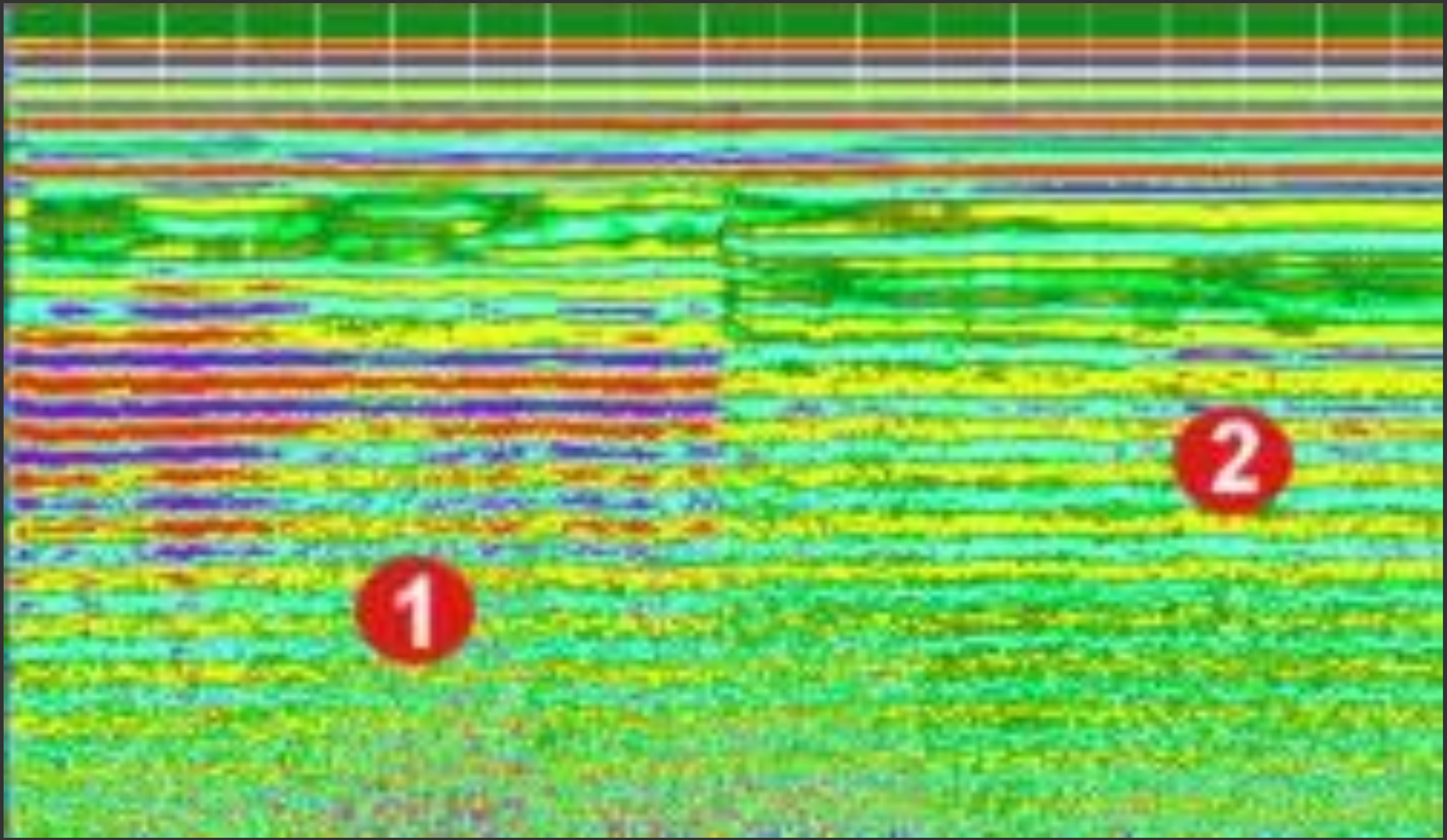
(b)

Figure 6. (A) Processed and topographically corrected GPR field record (200 MHz) collected at the center median of the I-93 outcrop. Reflections interpreted from the GPR data are annotated on the record and labeled A through C.
(B) Photograph of the section of the outcrop surveyed with GPR. Fractures A and B interpreted from the GPR records, which correlate with fractures observed in the outcrop, are annotated in the photograph. Fracture C is not observed in the outcrop because it projects below land surface.

4. The detection of hydrocarbon pollution within particular soil horizons, using the dielectric difference between oil and water.


1
2
G3
4
3
5
6
4


0
1
2
3
4
5
6
7
8
9
10
0
2.5
5
7.5
10
0
50
100
150
200
250
300
350


1
2