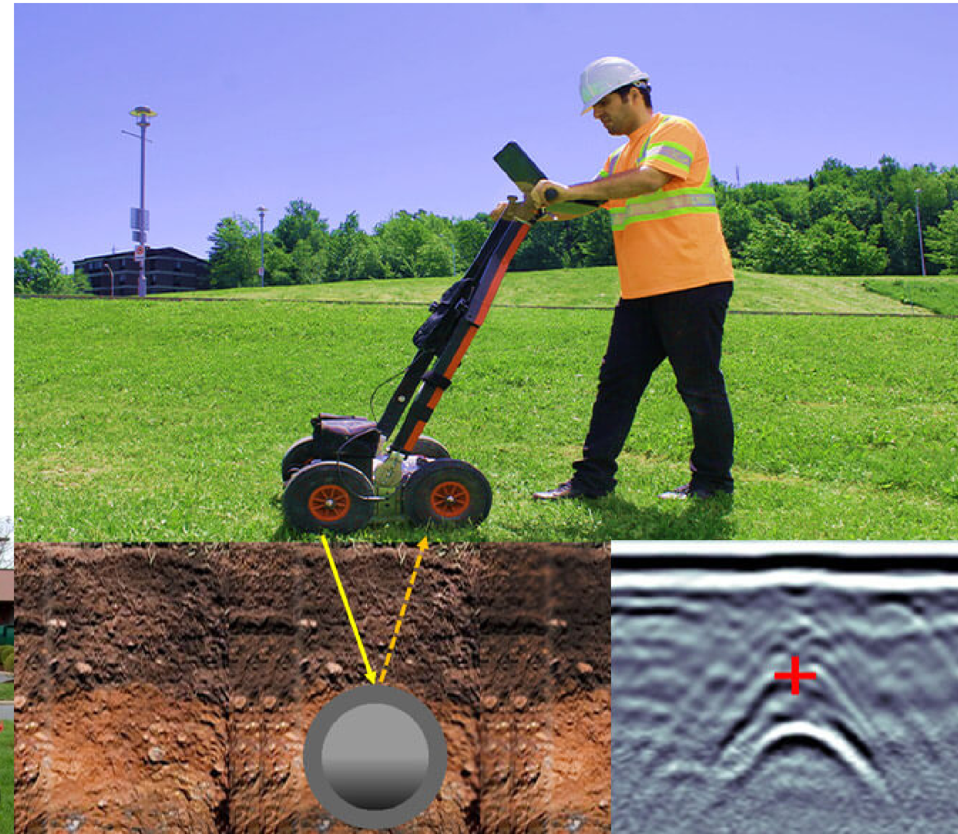
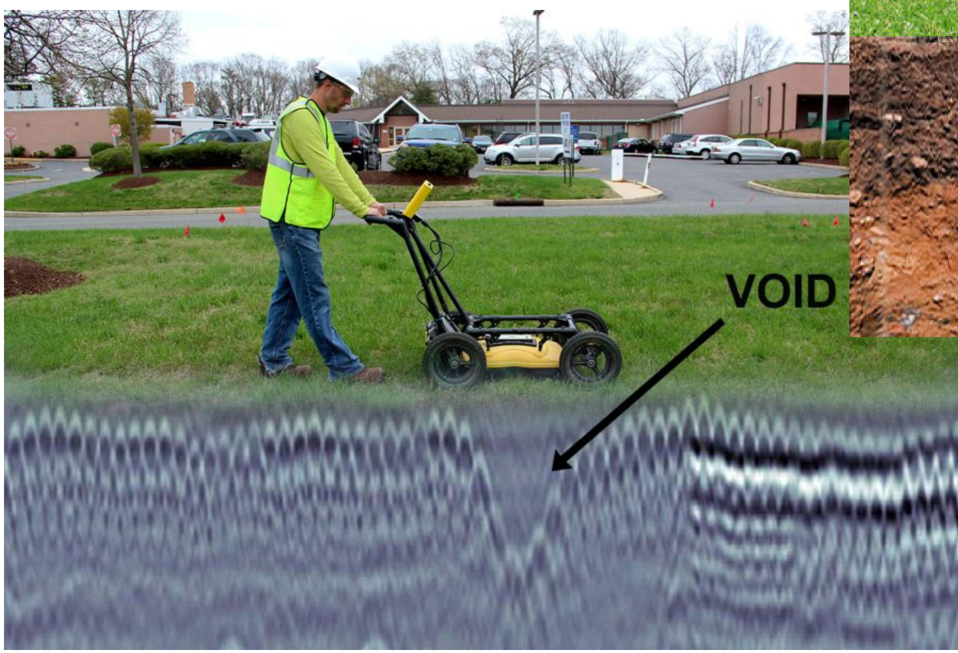
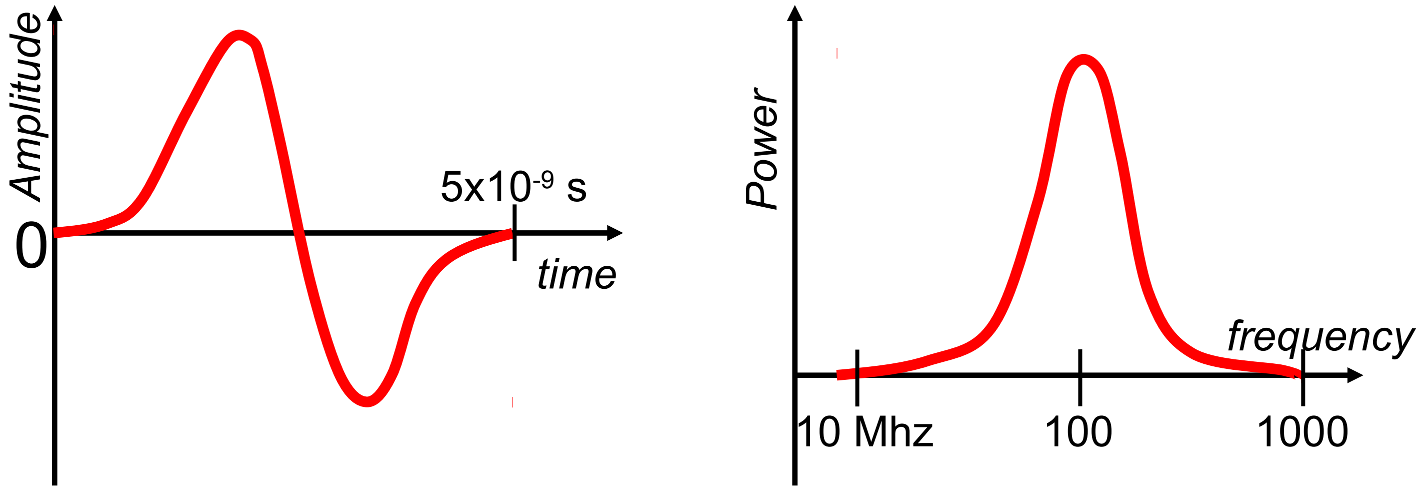
Ground Penetrating Radar





Ground Penetrating Radar

- ***Radar*** ⇒ electromagnetic waves (light) at radio frequencies (50 to 1000 MHz)
- Requires motion of source/receiver – Doppler Effect
- Requires a source and receiver (***dipole antennae*** for both)
- Source transmits a single pulse:



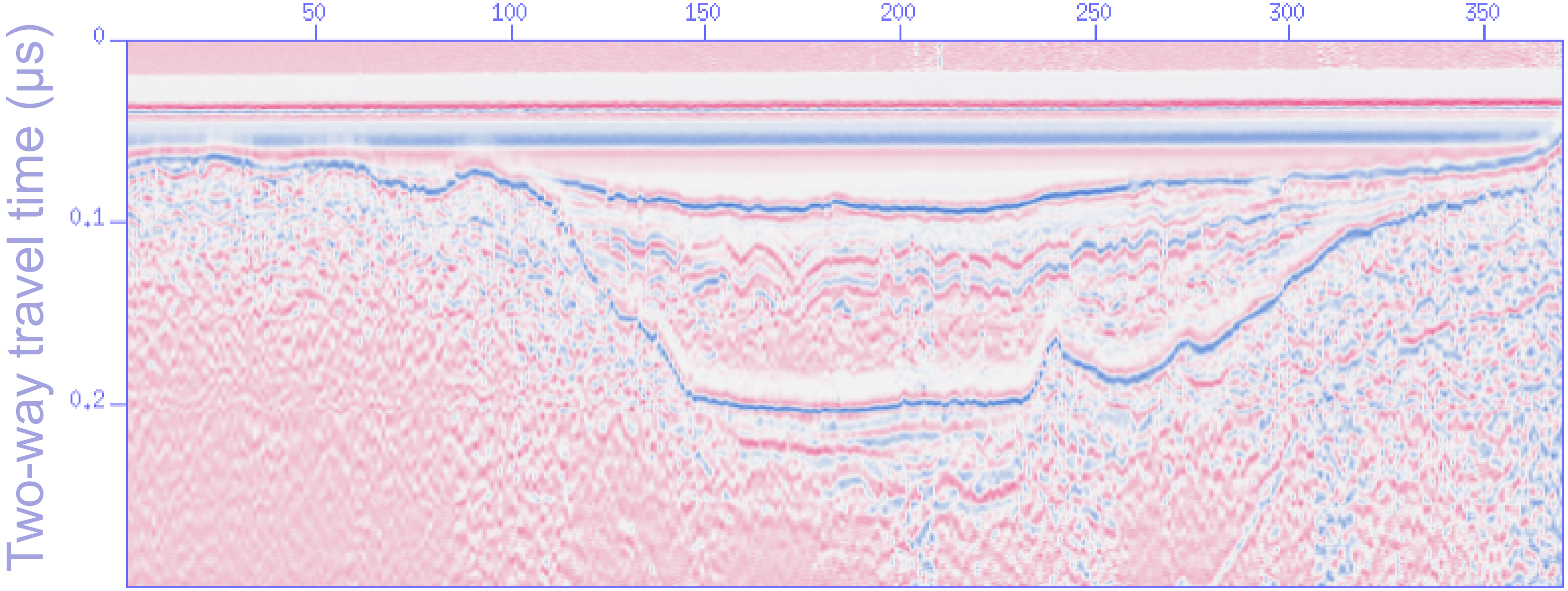
but can transmit and receive millions of pulses per second!

- Governed by physics of the wave equation (somewhat like seismic methods: $V = f\lambda$!)

Ground Penetrating Radar

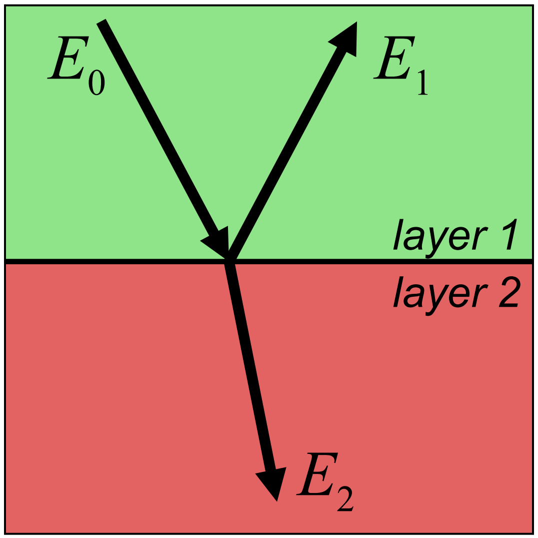
- GPR carts rely on the motion of the antenna to generate a continuous radar record of traverse distance vs. depth in the earth.
- GPR data is ordinarily recorded on video card and displayed on an LCD screen for immediate analysis.
- The successful interpretation of GPR records is an art as well as a science requiring considerable operator experience for good results.
- GPR’s are also known as “impulse radars” because the transmitted pulse is very short and is ordinarily generated by the transient voltage pulse generated from an overloaded avalanche transistor.
- The frequency used is a compromise. One desires to use the lowest possible frequency because low frequencies give reasonably high penetration depths into the earth. But a sufficiently high frequency must be selected so that the radar wavelength is short, allowing detection and resolution of small objects such as pipes.
- GPR surveys should be performed in the dry season if at all possible

- Display is very similar to seismic: Amplitude (voltage) versus time on a "trace". Source-receiver is usually near zero-offset (but ***can*** use NMO profiling, CMP gathers)



- High frequency ⇒ requires high sampling rate, very precise electronics.
- Lots more source/receiver obs ⇒ denser spatial sampling
- Higher frequency ⇒ <u>***higher resolution***</u>
- High attenuation ⇒ <u>***very shallow***</u> (< a few 10s of m)

Like seismic, waves are reflected & transmitted at interfaces with differing impedance properties:



- ***Snell's law*** applies.
- Amplitude dependence is different (simpler) because there is only one type of wave.
- ***Reflection*** R & ***Transmission*** T ***coefficients*** are identical to seismic (for 90° angle of incidence):

$$\frac{E_1}{E_0} \equiv R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad \frac{E_2}{E_0} \equiv T = \frac{2Z_1}{Z_2 + Z_1}$$

where Z_i is the ***electromagnetic impedance*** in layer i.

Recall for seismic: ***Acoustic Impedance*** $Z_i = \rho_i V_i$

For ***Electromagnetic Impedance***,

$$Z = \frac{\omega\mu}{\varepsilon_r(\omega)} = \frac{\omega\mu}{\sqrt{\omega^2\varepsilon\mu + i\,\frac{\omega\mu}{\rho}}} = \sqrt{\frac{\omega\mu}{\varepsilon\omega + i\sigma}} = \frac{1}{\sqrt{\frac{\varepsilon}{\mu} + i\,\frac{\sigma}{\omega\mu}}}$$

where: ω = frequency
ε = dielectric permittivity
μ = relative magnetic permeability
ρ = electrical resistivity
σ = $1/\rho$ = electrical conductivity
ε_r is called the dielectric constant (or “relative permittivity”): a complex variable.

All (except frequency ω) are physical properties of the medium, so like impedance & velocity in seismic studies, these contain information about the targeted volume!

Most modern radar sections are converted from two-way travel-time to depth using an assumed value for velocity… Important to note that:

$$V = \frac{c}{\sqrt{\varepsilon_r\mu}}$$

Soil and Rock Properties:

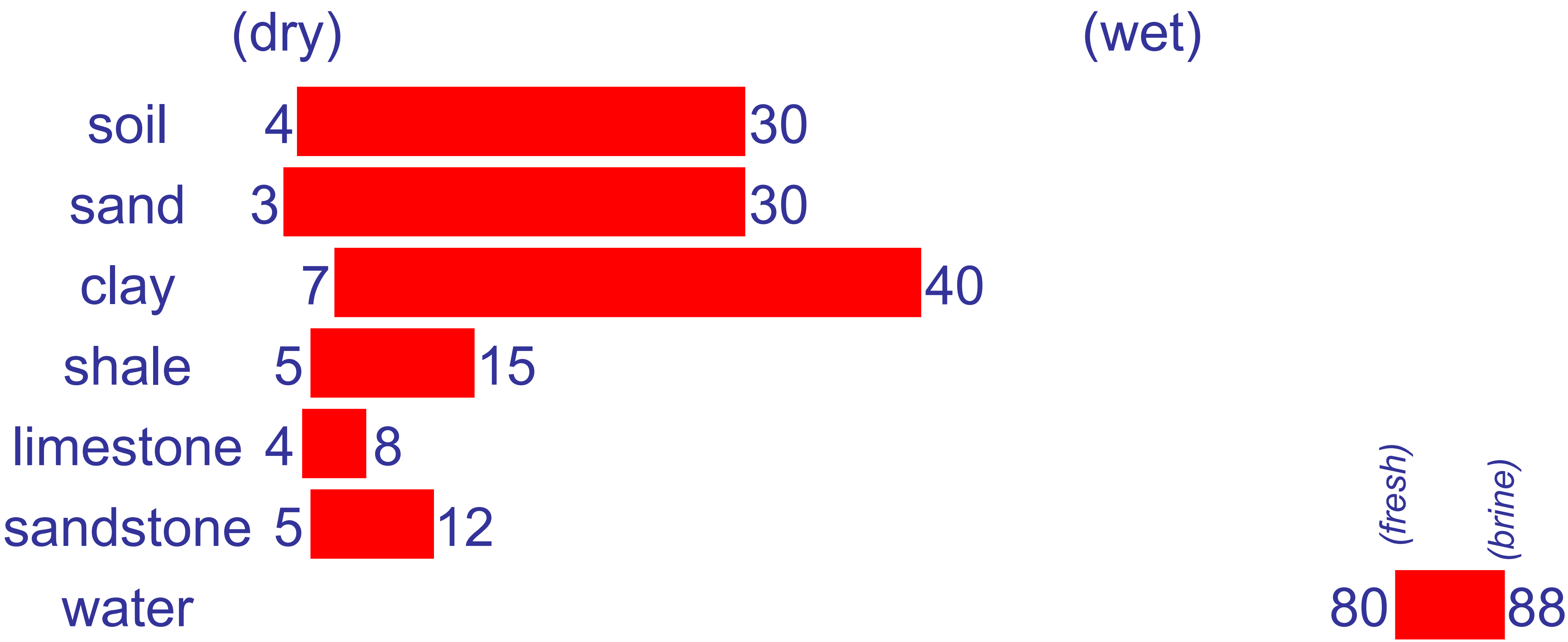
Relative Magnetic Permeability

$\mu \sim$ 1 for most rocks; (defined as: $\frac{\text{magnetic flux density}}{\text{magnetic field intensity}}$)

1.05 for hematite

5 for magnetite

Dielectric Constant ε_r (= relative permittivity) (real part):



For most applications (i.e., near-surface)

$\mu_1 \approx \mu_2 \approx 1$; σ (10^{-4}–10^{-1}) « $\varepsilon\omega$ (10^{6}–10^{10}!), and hence

$$Z = \sqrt{\frac{\omega\mu}{\varepsilon\omega + i\sigma}} \approx \frac{1}{\sqrt{\varepsilon}} \quad R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad \Rightarrow \quad R \approx \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \approx \frac{V_2 - V_1}{V_2 + V_1}$$

(i.e., we are imaging velocity variations corresponding to changes in dielectric permittivity!)

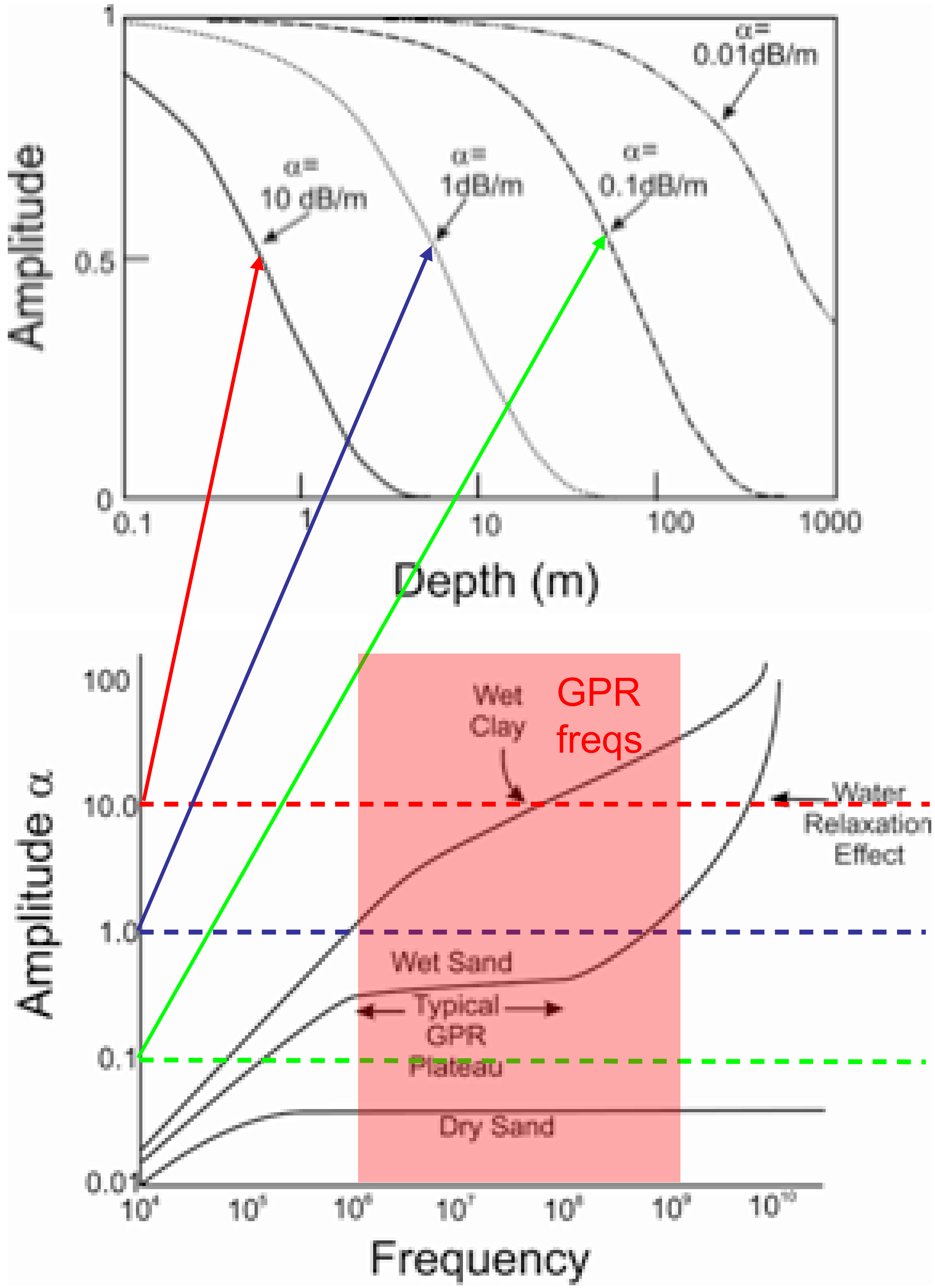
For the water table, $R \sim 0.1$

Recall seismic waves attenuate as $A = A_0 e^{-\frac{\pi f r}{QV}}$ where Q is quality factor;

Radar waves attenuate similarly as $I = I_0 e^{-\alpha r}$; where

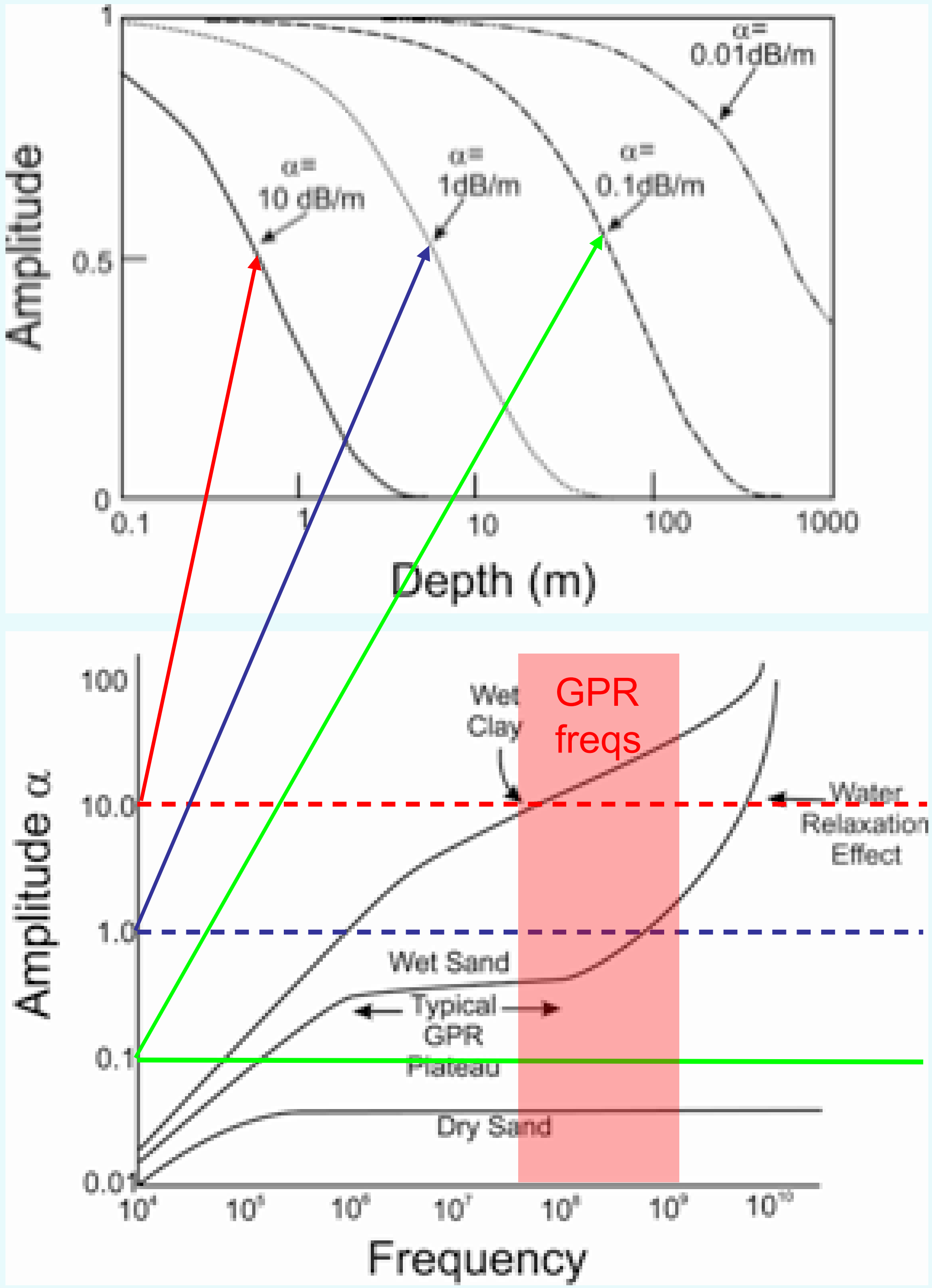
$$\alpha = \omega \sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{\frac{\sigma^2}{\varepsilon^2\omega^2} + 1} - 1\right)} \approx \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$$

Attenuation is ***extremely*** high for shale, silt, clay, and briny water (which is why GPR rarely penetrates > 10 m!).

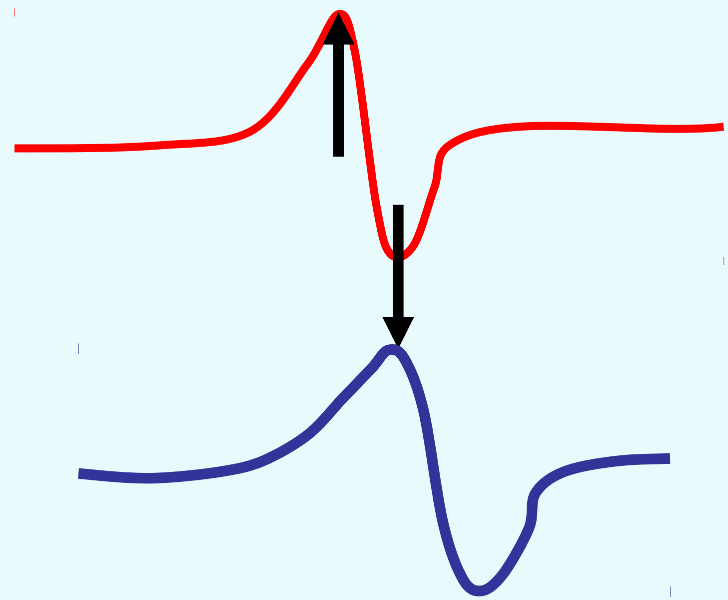


Skin depth, or depth of penetration, is $\sim 1/\alpha$. Hence main applications are in archaeology, environmental, engineering site investigation…

Also used for cavity detection and other very near-surface applications

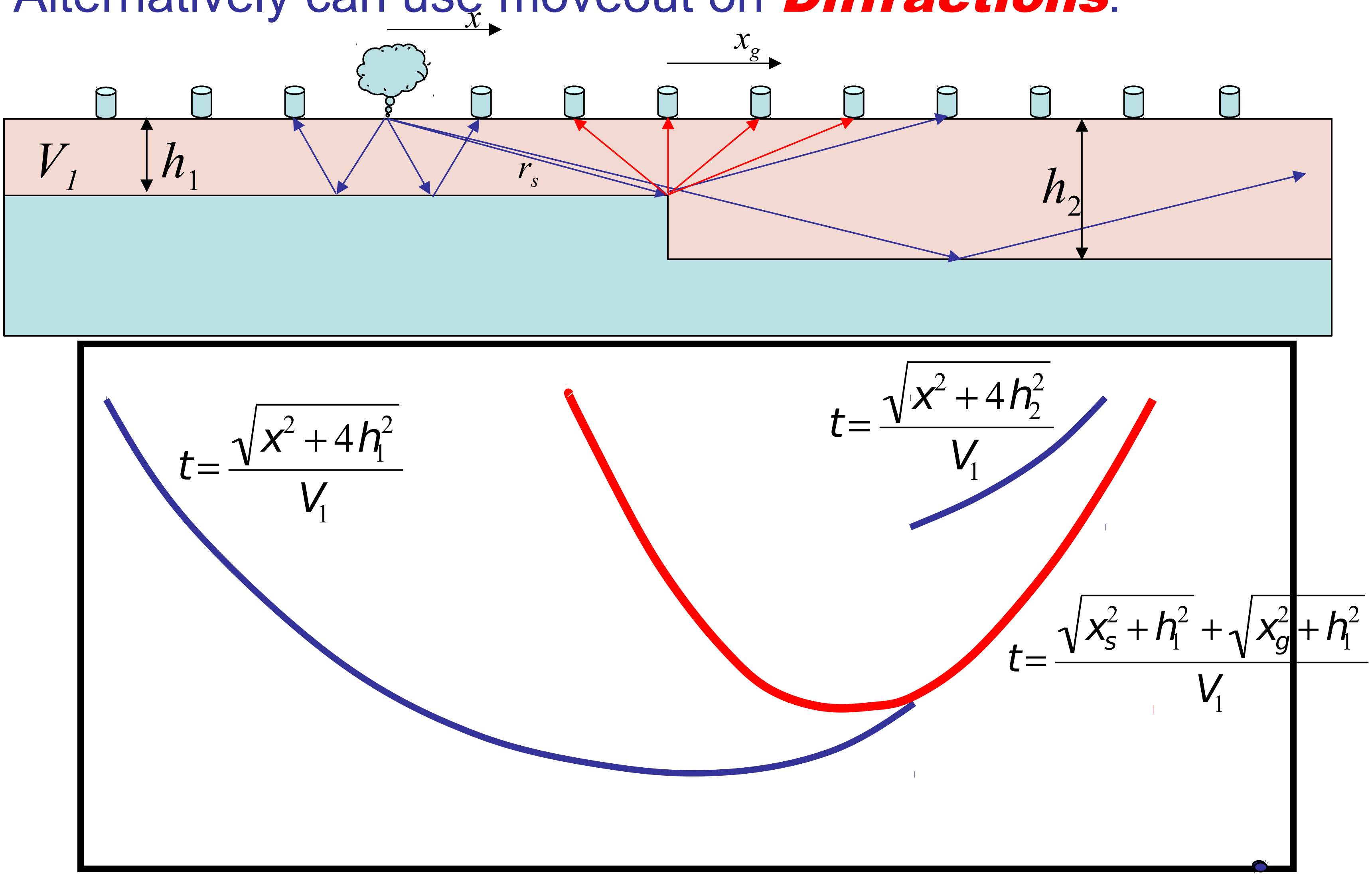


Frequency-dependence of the attenuation results in ***dispersion***: High frequencies attenuate more rapidly; pulse appears to “broaden” and the phase is delayed:



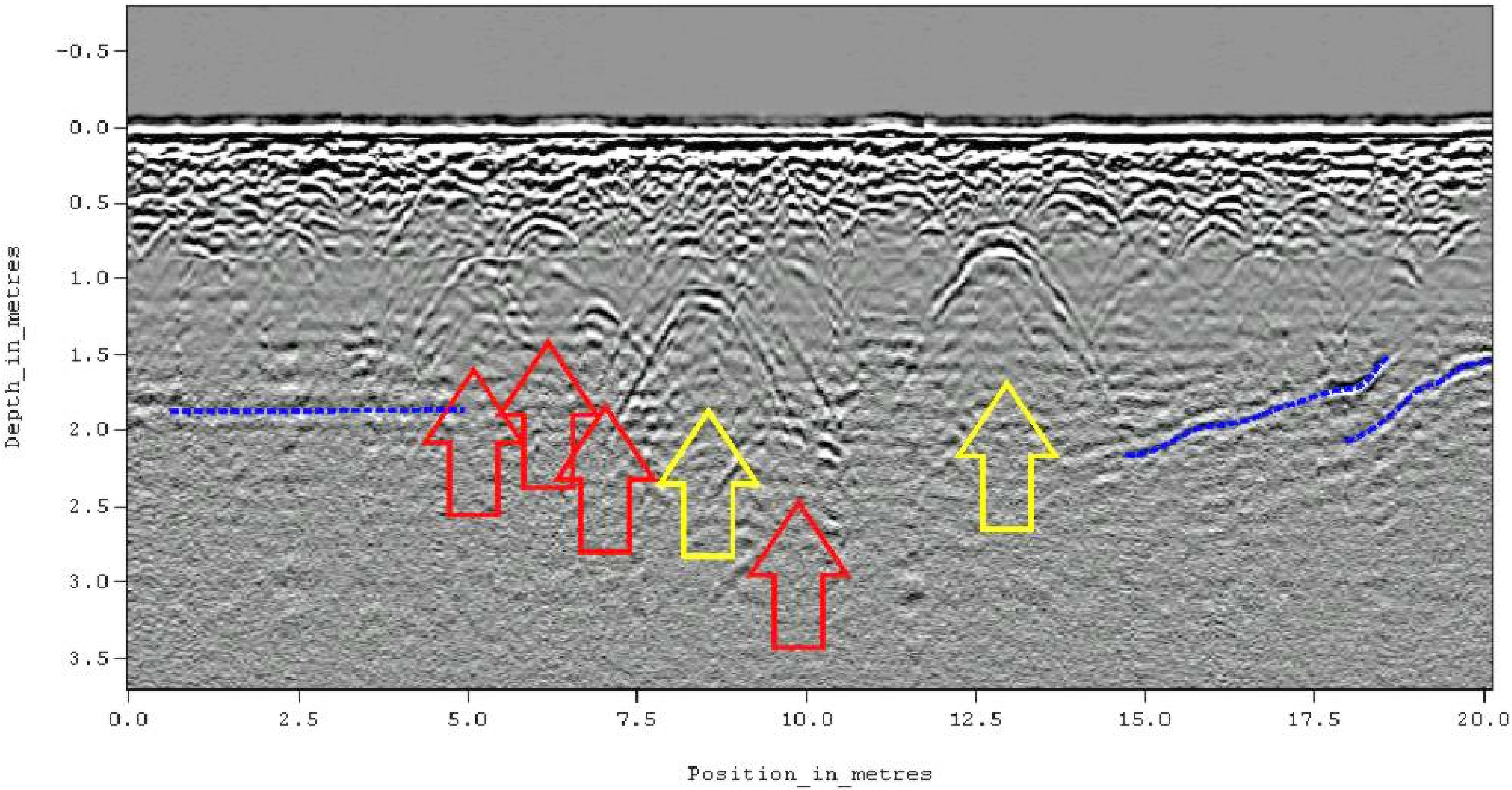
This yields a lower velocity (because part of V is imaginary!).

Alternatively can use moveout on ***Diffractions***:

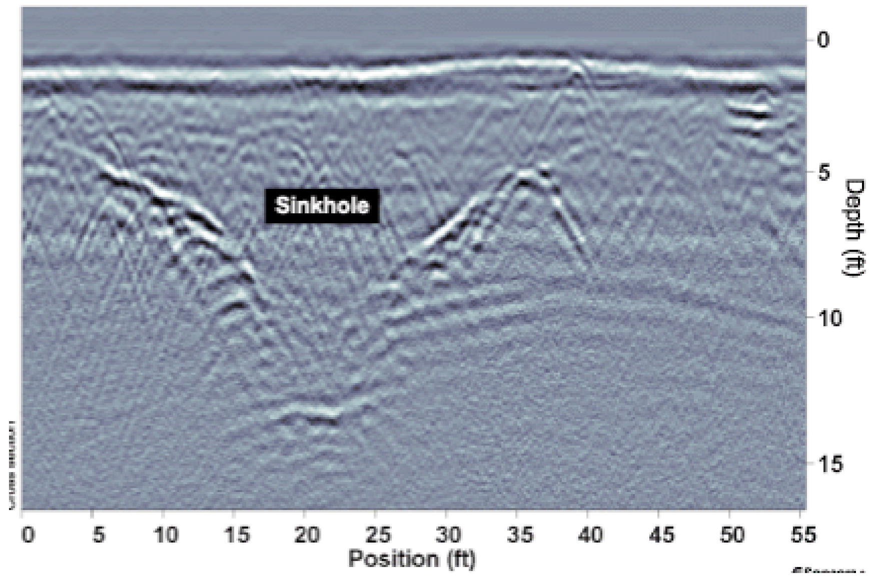


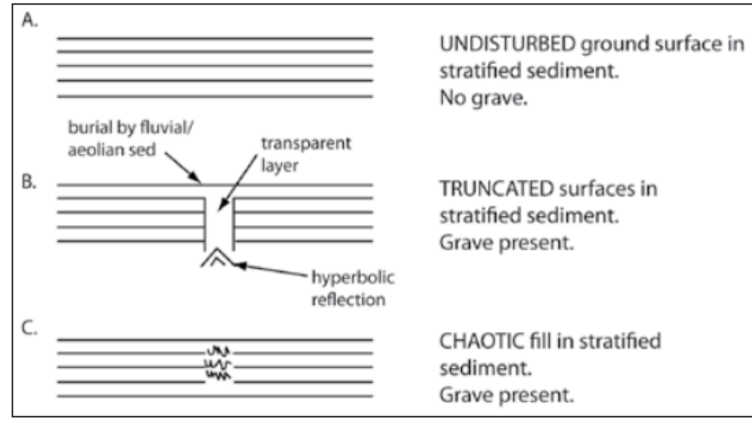
The equations are the same as they were for seismic, but since GPR is (usually) zero offset, $x_s = x_g$! Thus $t = \frac{2\sqrt{x^2 + h_1^2}}{V_1}$

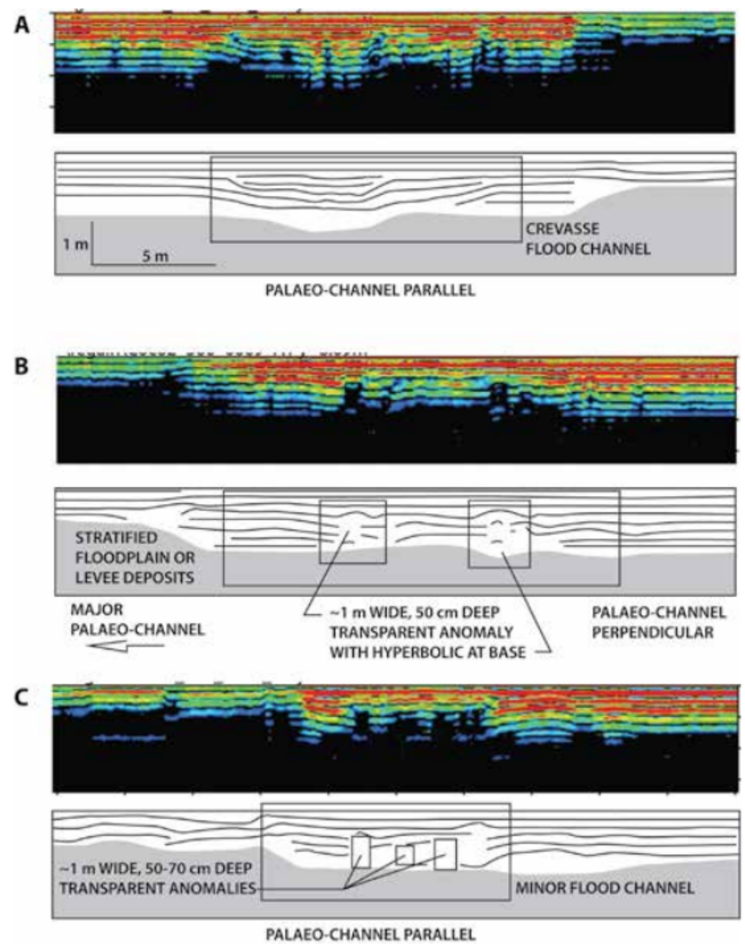
"Black-box" processing is simplistic so see some of the same features observed in low-level (brute stack) seismic processing:



(From a very old cemetery in Alabama…)


Sinkhole
0
5
10
15
Depth (ft)
0 5 10 15 20 25 30 35 40 45 50 55
Position (ft)


A.
UNDISTURBED ground surface in stratified sediment.
No grave.
burial by fluvial/ aeolian sed
transparent layer
B.
TRUNCATED surfaces in stratified sediment.
Grave present.
hyperbolic reflection
C.
CHAOTIC fill in stratified sediment.
Grave present.


A
1 m
5 m
CREVASSE FLOOD CHANNEL
PALAEO-CHANNEL PARALLEL
B
STRATIFIED FLOODPLAIN OR LEVEE DEPOSITS
MAJOR PALAEO-CHANNEL
~1 m WIDE, 50 cm DEEP TRANSPARENT ANOMALY WITH HYPERBOLIC AT BASE
PALAEO-CHANNEL PERPENDICULAR
C
~1 m WIDE, 50-70 cm DEEP TRANSPARENT ANOMALIES
MINOR FLOOD CHANNEL
PALAEO-CHANNEL PARALLEL