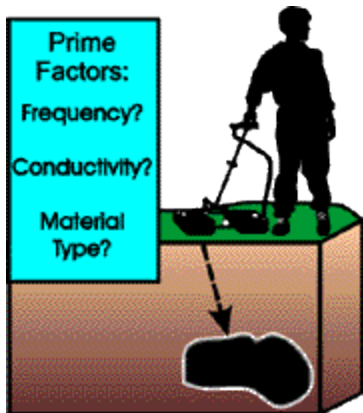


# How Deep Can GPR See?



"How deep can You see?" is the most common question asked of ground penetrating radar (GPR) vendors. While the physics is well known, most people new to GPR do not realize that there are fundamental physical limitations.

Many people think GPR penetration is limited by instrumentation. This is true to some extent, but exploration depth is primarily governed by the material itself and no amount of instrumentation improvement will overcome the fundamental physical limits.

## What Controls Penetration?

Radio waves do not penetrate far through soils, rocks and most man-made materials such as concrete. The loss of radio reception or cell phone connection while driving a car through a tunnel or into an underground parking garage attests to this.

The fact that GPR works at all depends upon very sensitive measuring systems being used and specialized circumstances. Radio waves decrease exponentially and soon become undetectable in energy absorbing materials, depicted in Figure 1.

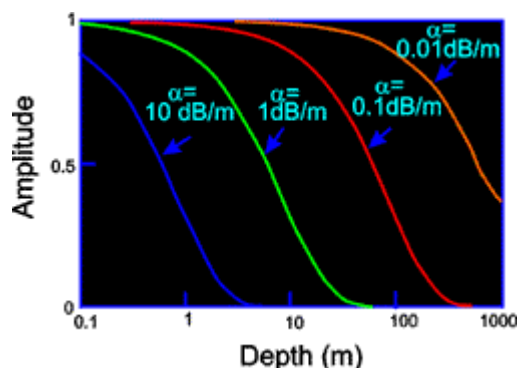


Figure 1: GPR signals decay exponentially in soil and rock.

The exponential attenuation coefficient,  $\alpha$ , is primarily determined by the ability of the material to conduct electrical currents. In simple uniform materials this is usually the dominant factor; thus a measurement of electrical conductivity (or resistivity) determines attenuation.

In most materials energy is also lost to scattering from material variability and to water being present. Water has two effects; first, water contains ions which contribute to bulk conductivity. Second, the water molecule absorbs electromagnetic energy at high frequencies typically above 1000 MHz (exactly the same mechanism that accounts for why microwave ovens work).

Attenuation increases with frequency as depicted in Figure 2. In environments which are amenable to GPR sounding there is usually a plateau in the attenuation versus frequency curve which defines the "GPR window".

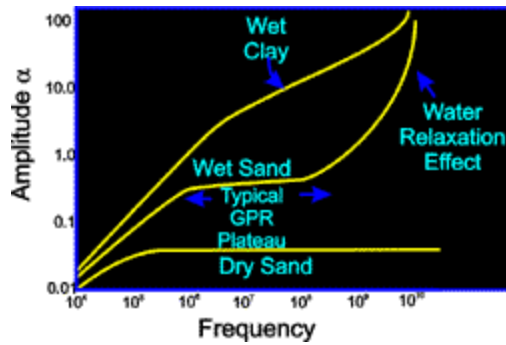


Figure 2: Attenuation varies with excitation frequency and material. This family of graphs depicts general trends. At low frequencies (<1 MHz) attenuation is primarily controlled by DC conductivity. At high frequencies (> 1000 MHz) water is a strong energy absorber.

## Can I Decrease Frequency To Improve Penetration?

Lowering frequency improves depth of exploration because attenuation primarily increases with frequency. As frequency decreases, however, two other fundamental aspects of the GPR measurement come into play.

First, reducing frequency results in a loss of resolution. Second, if frequency is too low, electromagnetic fields no longer travel as waves but diffuse which is the realm of inductive EM or eddy current measurements.

## Why Can't I Just Increase My Transmitter Power?

One can increase exploration depth by increasing the transmitter power. Unfortunately, power must increase exponentially in order to increase depth of exploration.

Figure 3 shows the relative power necessary to probe to a given depth for the attenuations depicted in Figure 1. One can readily see increases in exploration depth require large power sources.

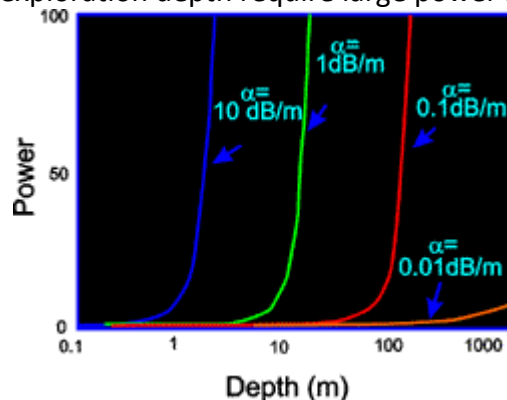


Figure 3: When attenuation limits exploration depth, power must increase exponentially with depth.

In addition to practical constraints, governments regulate the level of radio emissions that can be generated. If the GPR transmitter signals become too large, they may interfere with other instruments, TVs, radios, and cell phones. (Unfortunately, these same ubiquitous devices are usually the limiting sources of noise for GPR receivers!)

# Can I Predict Exploration Depth?

Yes, provided the material to be probed is known electrically, many numerical calculation programs are available. The simplest way to get estimates of exploration depth is to use the radar range equation (RRE) analysis. Software to carry out these calculations is available and there are numerous papers on the subject. The basic concepts are depicted in Figure 4.

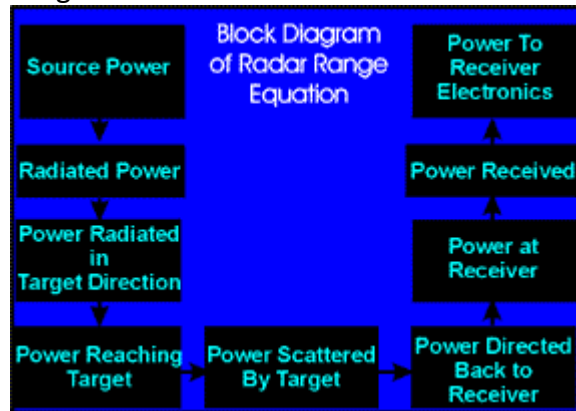


Figure 4: Radar range, shown here in flowchart form, determines energy distribution and provides a means of estimating exploration depth.

RRE analysis is very powerful for parametric studies and sensitivity analyses.

## Radar Range is Too Complicated!

Many users say RRE is too complicated for routine use. If you don't like to get into detailed calculations, we suggest using the following simpler rule-of-thumb for estimating exploration depth

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

where  $\sigma$  is conductivity in mS/m. While not as reliable as the RRE, this helpful rule is quite useful in many geologic settings.

An even simpler approach is to use a table or chart of exploration depths attained in common materials. An example chart for common materials encountered with GPR is shown in Figure 5.

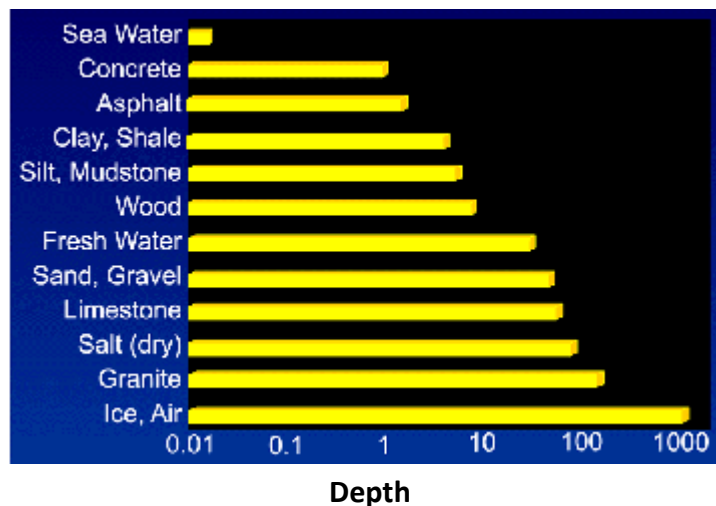


Figure 5: Chart of exploration depths in common materials. These data are based on "best case" observations. As Figure 9 demonstrates, material alone is not a true measure of exploration depth.

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Figures 6, 7 and 8 show examples which range from deep to shallow exploration. Material type can be seen to control exploration depth. Unfortunately, exploration can not always be predicted by knowing only the material in the survey area.

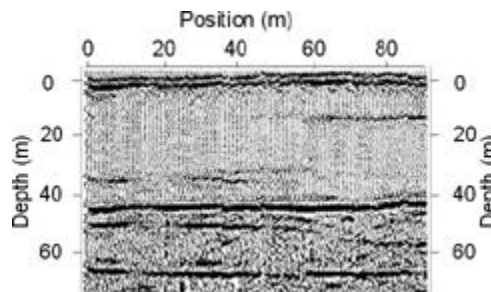


Figure 6: Data from a massive granite - reflections are fractures.

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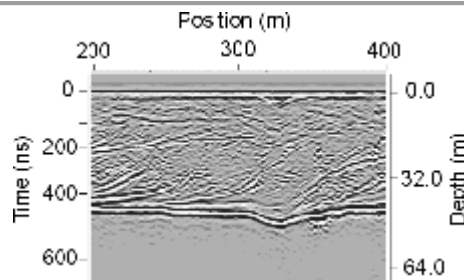


Figure 7: Data showing bedding in wet sand deposits.

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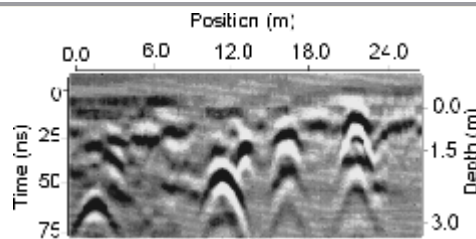


Figure 8: Data shows response of barrels in wet, silty clay.

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Figure 9 shows a section where the geology is basically uniform but the depth of exploration is highly variable. In this case pore water conductivity is varying while the geologic material is invariant! In this case, knowing conductivity provides a better measure of exploration depth than knowing the material.

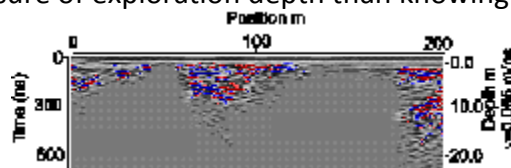


Figure 9: GPR section from sand setting. Depth of exploration is determined by pore water conductivity-not the sand material. Contaminates leaching from a landfill cause variable conductivity (and exploration depth) with position.