Efficient geological investigations using low frequency GPR

Jaana Gustafsson of Mala Geoscience looks at ways that geological investigations have been made simpler by using specialized equipment.

Geological knowledge from deep structures is most often needed when planning groundwater resources or out-takes of raw material for construction. In this case the use of low frequency radar systems can be both cost-effective and efficient way to obtain more knowledge of the subsurface conditions. By using a bi-static one-unit in-line antenna of 50 MHz these types of investigations have been made noticeably easier and can be handled by one operator, which cuts the costs. Several examples are given here of different types of geological investigations, down to a depth of approximately 20 m.

Introduction

The need for fast, cost-effective, and reliable ground investigation techniques reflect the increased need of raw materials in the form of freshwater or construction material (gravel, sand, etc.). GPR (Ground Penetrating Radar) measurements have been used for a long time to investigate the ground conditions for soil stratigraphy mapping, detection of cavities, bedrock surface mapping, peat thickness mapping, lake and riverbed sediment mapping, goundwater resources contamination mapping, etc. (Sutinen et al., 1992; van Overmeeren, 1998; Beres et al., 1999; Chamberlain, 2000; Slater et al.; Ezzy et al., 2003, among others), and have often provided adequate and reliable results.

A typical groundwater or geological survey is carried out with a lower frequency GPR system in the frequency range of 10 to 50 MHz, maybe up to 100 MHz, giving relatively detailed information down to soil depths of 10-50 m in non-conductive environments. The system at hand, however, most often demands at least two operators to carry out the field measurements, due to sensitive fibre cables and quite long antenna elements which make the use more complicated than needed. Today there are also systems made to be one man operated for non-cleared terrain. This type of system offers an easy and efficient radar investigation, which can cost-effectively complement the point wise geotechnical investigations used when mapping ground conditions.

This paper discusses how such a system works and gives several examples where the GPR provided information in groundwater and geological investigations.

Method

When mapping geological structures, low frequency GPR systems are needed to reach a satisfying depth penetration. Low frequency antennas (in the range of 10 to 50 MHz) mean long antenna elements (up to 2 m) of unshielded types. This again demands quite an effort during fieldwork.

The fieldwork with two separate unshielded antenna elements can be carried out in several different ways (Fig. 1) (Aaltonen, 2003). Most common is the use of bi-static antennas to measure the radar profiles in broadside configuration where the transmitter and receiver dipole antennas are held perpendicular to the measurement line with a fixed distance in between them, in a so called co-polarized manner (Guy et al., 1999; Lehmann et al., 2000; Radzevicius et al., 2000; Van Gestel & Stoffa, 2001 etc.). If the radar antennas are used in this normal configuration, quite wide paths have to be prepared in the investigation area and at least two people have to be involved in the data collection.

To increase the measurement capacity, make fieldwork easier, and only be dependent on one single operator, a new antenna was developed during 2003 (Aaltonen, 2003) in an in-line parallel configuration (See Fig. 1), a so called RT antenna (for Rough Terrain).

As the antenna configuration affects the results of the radar measurements, discussion and tests were carried out to see the differences between traditional broadside and the in-line configuration used in the RT (Aaltonen, 2003).

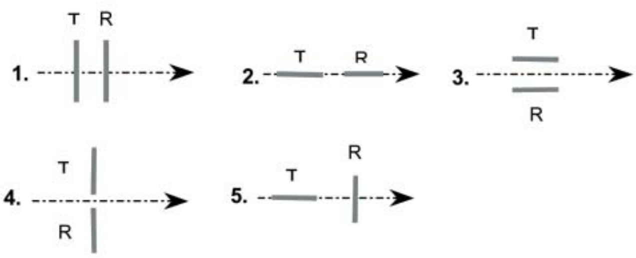

Figure 1 *Example of antenna configurations (T: transmitter and R: receiver). 1: Broadside perpendicular. 2:In-line (end-fire) parallel. 3: Broadside parallel. 4: In-line (end-fire) perpendicular. 5: Cross-polarized.*

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For the in-line configuration, the polarization as well as the antenna radiation pattern makes close range detection somewhat more difficult. However, when mapping layers and other non-polarizing targets, especially deeper ones, there is little difference between the two configurations. The differences are shown in the pictures below, both the mapping of an object and the mapping of layers (See Fig. 2).

Moreover, the use of an in-line configuration also affects the subsurface beam shape. A simplified beam pattern shows a broader footprint in the broadside antenna direction than in the end-fire direction. This means that a traditional broadside perpendicular investigation can be considered more of a cross-section of the subsurface while broadside parallel and in-line parallel will also gain information from the sides. (Aaltonen, 2003)

In Fig. 3, different ways of using the RT antenna system is shown. As the RT antenna is built in one piece, it is very straightforward to carry out field investigations even in rough terrain. Clearings of measurement lines are most often unnecessary: where the operator can walk, the antenna will follow. The antenna can of course also be attached behind a vehicle or boat, depending on the investigation type.

The RT antenna has a central frequency of 50 MHz, with a resolution of approximately 0.5 m and with a depth range of 5 to 25 m in suitable conditions. In field work the distance and the position is managed with a hip chain encoder. The position can of course also be governed by a GPS, connected directly to a GPR system. However, it should be remembered that the measuring point of the RT antenna is in-between the two antenna electronic units.

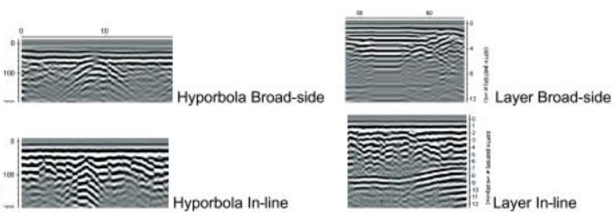

Figure 2 *Comparison between broadside and in-line configurations (Aaltonen, 2003).*

Figure 3 *Different applications of the RT antenna. When measuring on water the RT antenna is placed within a plastic tube.*

Results

The following results have all been measured with the RAMAC RT antenna and RAMAC CUII control unit, showing applications of different kinds.

The first example is from a lake investigation, where the aim was to map the bottom topography of the lake, and also to see if there was any sediment present on top of the firm bottom. In the radargrams in Fig. 4, the bottom topography is seen most clearly, together with singles objects (seen as so called hyperbolas, some of them marked with arrows). Also, underneath the bottom, several underlying layers can be identified, representing in parts the bedrock and in parts a firmer till.

In this investigation the GPR was triggered by time and the positioning logged with a DGPS system, giving a position for each measured trace along the way the boat was driven. This track and the resulting picture of the bottom topography are seen in Fig. 5.

In the following example the RT antenna was used to map a thin soil layer (in all parts less than 5 m) of till material on top of the bedrock (bedrock level marked with a green line below in Fig. 6). Interesting to note also that the investigation resulted in mapping of larger fracture zones within the bedrock, represented by the two red/orange lines below in Fig. 6.

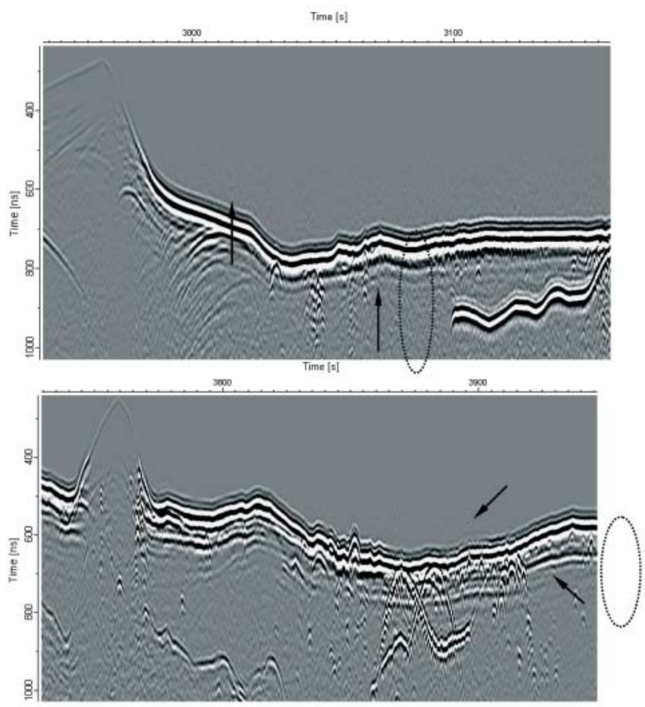

Figure 4 *Example from a lake investigation. Note that the x-scale is given in time (s). The arrows point out some single larger objects, most likely larger stones/ boulders. The marked areas show accumulations of stones. Measurement settings were: samples: 1000, sampling frequency: 508, time window: 1970, trace interval: 0.3 s.*

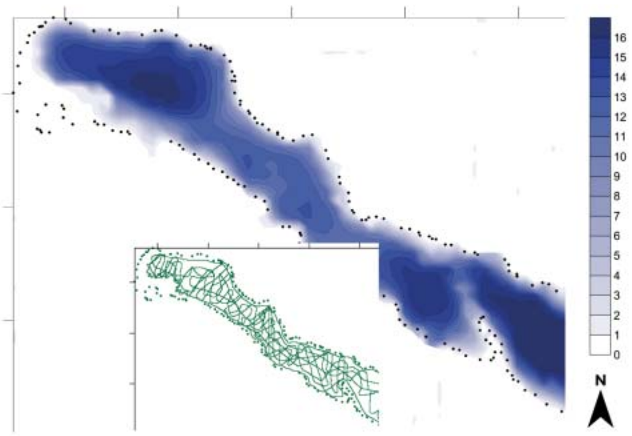

Figure 5 *Example of a result from GPR lake investigation, aiming at mapping the bottom topography and the sediment thickness. The colour scale gives the depth to the bottom in metres. The small picture represents the GPR track travelled by boat.*

The bedrock level was quite easy to map, even though the till was of a clay type. This most likely depends on the fact that the overburden was relatively thin, as clay most often decreases the energy of the radar wave quite extensively. An example of this effect is shown in Fig. 7.

The RT antenna is also quite suitable to map groundwater levels in non-conductive areas. The example below is from a sandy area (quite graded sand with some separate boulders), where the groundwater is clearly seen as a slowly dipping surface at approximately 14 m depth. See Fig. 8.

The last example is from the geological mapping of an esker area, where the structure of the ground is quite nicely illustrated by GPR measurements (Fig. 9). See for example the depression marked with an arrow. However, in these areas, with an extensive amount of boulders, the different layer can be hard to distinguish, due to the fact that the hyperbola pattern (with several hyperbola 'legs' interacting) complicates the picture to interpret. Groundwater level is in some parts indicated, while the

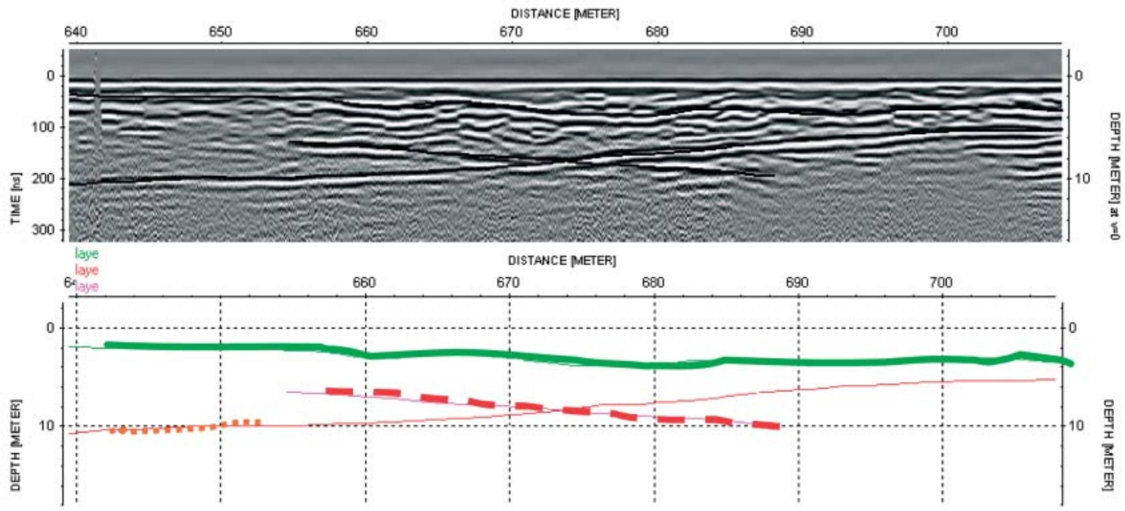

Figure 6 *Example of an investigation where the aim was to map the overburden, but as a result also the fractures within the bedrock could be seen. The green line represent till bedrock surface and the two red lines fractures. Measurement settings: samples: 408, sampling frequency: 702, time window: 581, trace interval: 10 cm.*

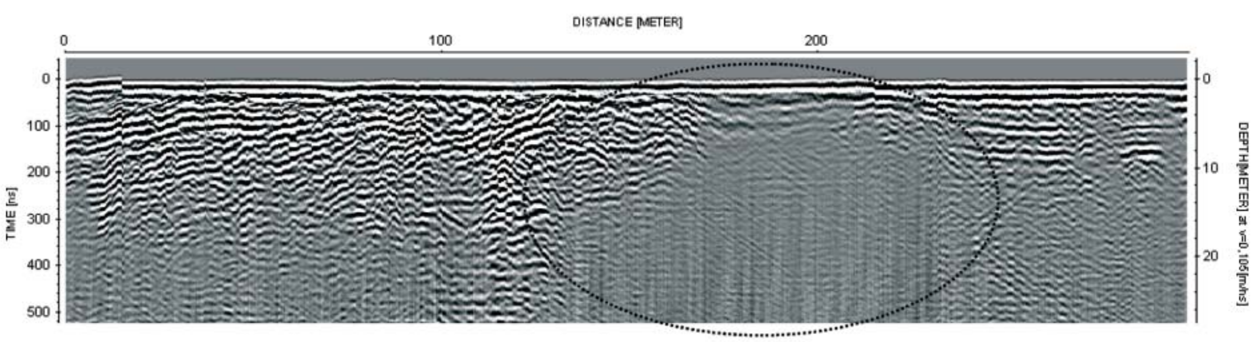

Figure 7 *Example of how a conductive ground, in this case clay, affects the resulting radargram. From 150 m to approximately 220 m, the depth penetration is quite limited due to measurements on a ground containing clay.*

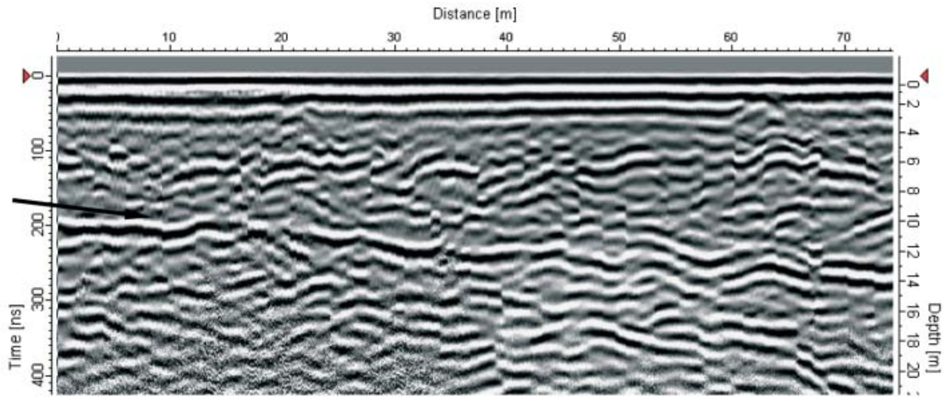

Figure 8 *Investigation of the groundwater level in a sandy area. The groundwater surface is marked with an arrow.*

bedrock surface cannot be seen, most probably because it is found below 20 m depth. The mapping of bedrock can also be more complicated in areas with hard packed till material, as this type of surface most often gives the same signature in a radargram as the bedrock surface itself.

Conclusions

The GPR investigations with a low frequency system have proved to be useful for a number of different purposes; geological mapping on ground and lakes, structure mapping of bedrock, groundwater investigations, etc. The filed investigations can be carried out, quite quickly, most often also in non-cleared terrain.

The operator should however be aware of the limitations with the GPR technique, especially in inductive environments. Low frequency GPR systems have unshielded antennas, which can create unwanted noise to occur in the data due to the fact that the antenna emits electromagnetic waves in any direction and also receives them from any direction. The noise is most often in the form of so-called air-reflexes, and can easily recognized by the shape of reflections.

As discussed, the system presented here is quite sufficient for performing mapping stratigraphy and superior in terms of efficiency in fieldwork, especially in non-cleared forest areas compared to traditional broadside systems. Moreover, the RT Antenna is always on ground, which gives a very good coupling of the EM energy into the ground. One drawback of having a one-piece antenna is the fact that no CMP measurements can be carried out to define the correct velocity, and by that depth, of the ground investigated.

In Table 1 some management aspects are being compared between two system types, the more common broadside and the newer in-line. Observe that by using traditional separate unshielded antennas, in-line measurements can of course be done. In comparison these are almost as fast as the new in-line system, but still need two operators in the field.

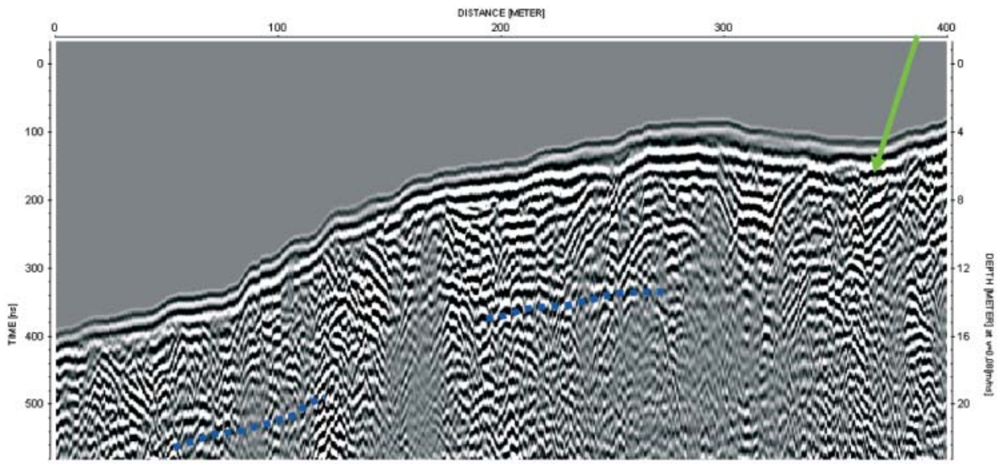

Figure 9 *Mapping of an esker area with the RT antenna. The groundwater level is detected only in parts, but some soil structure (green arrow) is clearly seen. Measurement settings: samples: 320, sampling frequency: 570, time window: 560, trace interval: 15 cm.*

Table 1 *User comparison between traditional antennas and one-man operated in-line system. (Aaltonen, 2003).*

	Traditional broadside		*One-man operated in-line*	
	Forest	*On track*	*Forest*	*On track*
Ground coupling	Above ground	Above ground	On ground	On ground
Time / m	Very slow walking speed	Slow walking speed	Walking speed or Slow walking speed	Walking speed or vehicle mounted
Cleared lines	Needed	-	Not needed	-
Operators	2	2	1	1
Resistance to dirt etc	Sensitive cables and connectors		Rugged and durable	

In terms of fieldwork efficiency, it can be stated that the RT antenna in forest can be managed at walking speed or slow walking speed, and on track, at walking speed or vehicle mounted, giving a time-effective system and by that also cost-effective. The RT antenna is also simple to freight, as all parts (including control unit and computer) can be stored in an ordinary suitcase and the weight is less than 14 kg.

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