COST Action TU1208

Civil Engineering Applications of Ground Penetrating Radar

This lecture is part of the TU1208 Education Pack

Overview of GPR applications

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Lecture Layout

I. Roads
II. Utilities
III. Concrete
IV. Other construction materials
V. Bridges
VI. Tunnels
VII. Railways
VIII. Modern buildings
IX. Archaeology and cultural heritage
X. Forensics
XI. Landmines and unexploded ordnance
XII. Rescuing of people buried under debris and avalanches
XIII. Through-the-wall

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Lecture Layout

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I. Roads

- GPR can be successfully used to measure road layer thicknesses, to find cavities and cracking under pavement, as well as other damages at deeper levels. GPR also allows to characterize the asphaltic materials used in the road and to estimate related properties such as water content and compaction.
- There are two different antennas configurations that can operate in road surveying: air-coupled (suspended 40-50 cm over the road surface) and ground-coupled antennas (suspended 5-10 cm over the surface). The air-coupled antennas allow operating at higher speeds, which is especially useful for highway inspections.
- The propagation velocity of the GPR signal in the road can be estimated by using different methods: the amplitude method (air-coupled antennas) or coring (air and ground-coupled antennas).

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I. Roads

- Air-coupled antennas, operating in a frequency range of 1-2 GHz, are commonly used for thickness measurements.
- The GPR system and the velocity of propagation of the signals are calibrated by using the amplitude method.

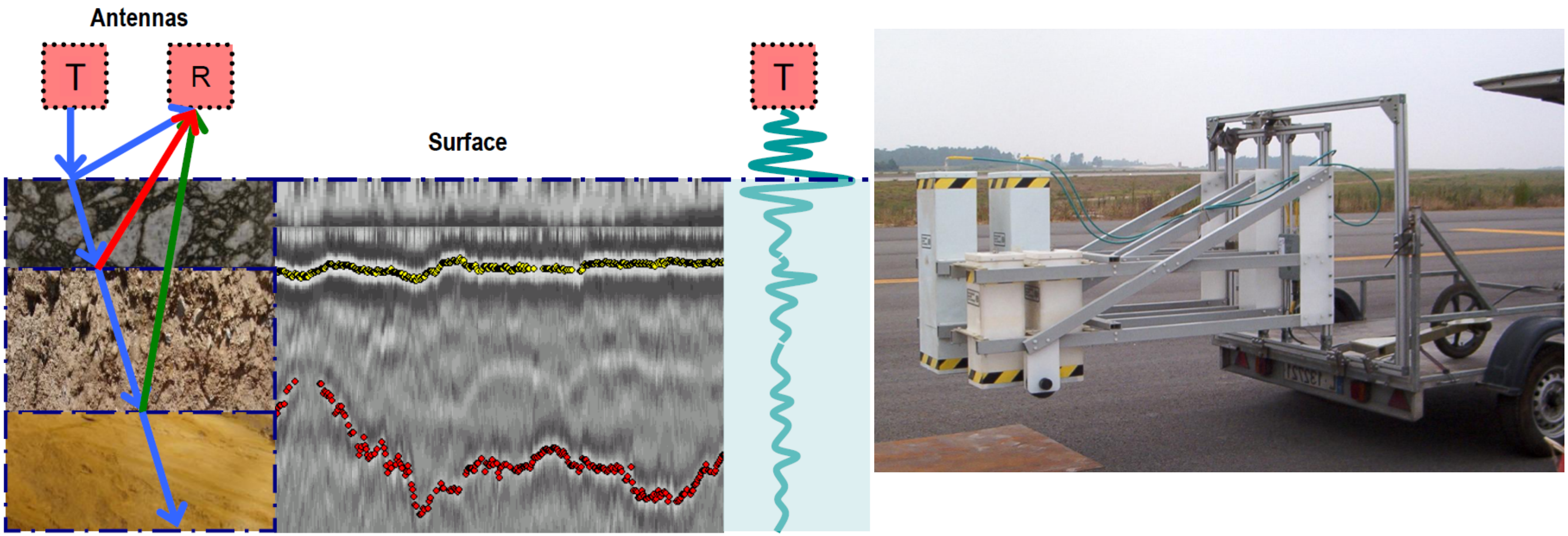

Fig. 1. Schematic representation of a road section and GPR thickness measurements (courtesy of National Laboratory for Civil Engineering (LNEC, Lisbon)).

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I. Roads

- For deeper investigations (such as cracking at the subgrade, lack of filling or presence of cavities, delamination in layering, etc.), ground-coupled antennas operating at lower frequencies are recommended, ranging from 1 GHz to 500 MHz.

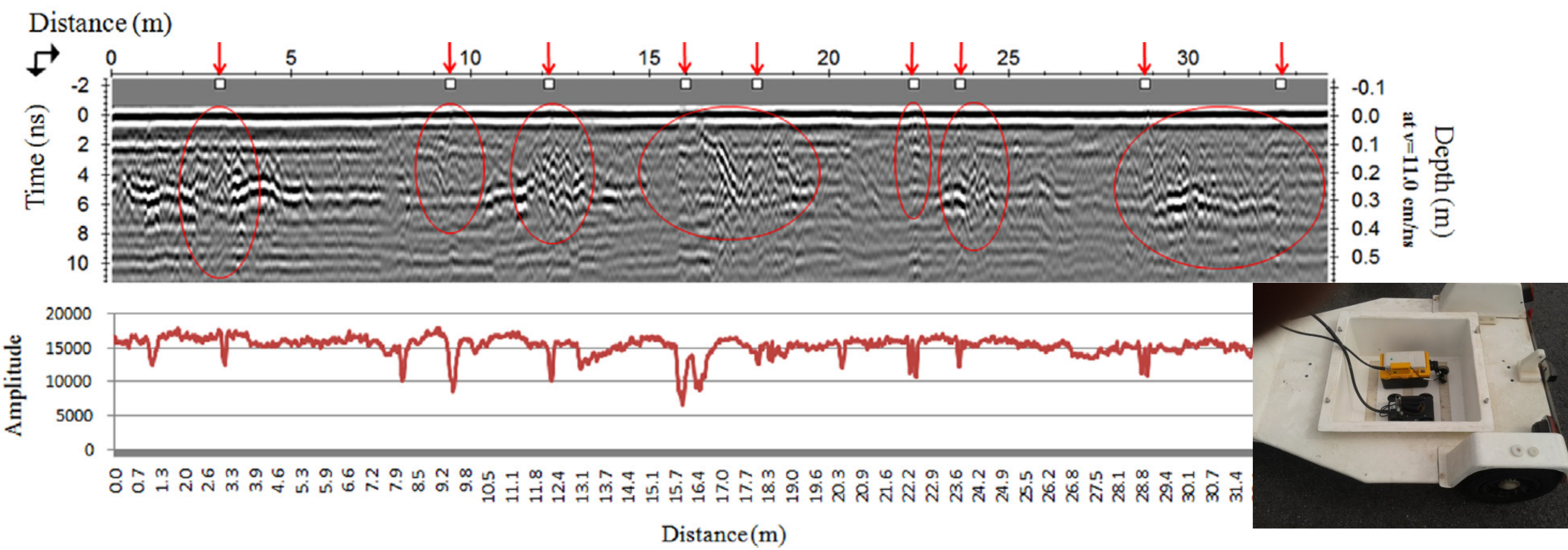

Fig. 2. 1-GHz data showing the presence of cracking in the subsurface (courtesy of Applied Geotechnologies Research Group (University of Vigo) [1]-[2]).

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II. Utilities

- Urban infrastructure and underground services require constant processes of operation and replacement for maintenance.
- Pipes are amongst the most important utilities in subsoil. There are pipe lines for telecommunications, electricity distribution, natural gas, clean and waste water distribution.
- GPR is capable to detect and locate pipe lines, sewers, drains, cables, wires, and other existing services. Their size, position, depth, and material composition can be estimated.
- Ground-coupled antennas are commonly used in utility surveys. High resolution frequencies of 1000–800 MHz are appropriate to obtain information about targets in the shallower subsoil, whereas frequencies from 500 to 250 MHz can yield information from the deeper subsoil.

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II. Utilities

- Figure 3 shows that the higher frequency of 1 GHz is able to detect shallower pipes (n. 1), whereas the 500-MHz profile shows a deeper pipe (n. 4).

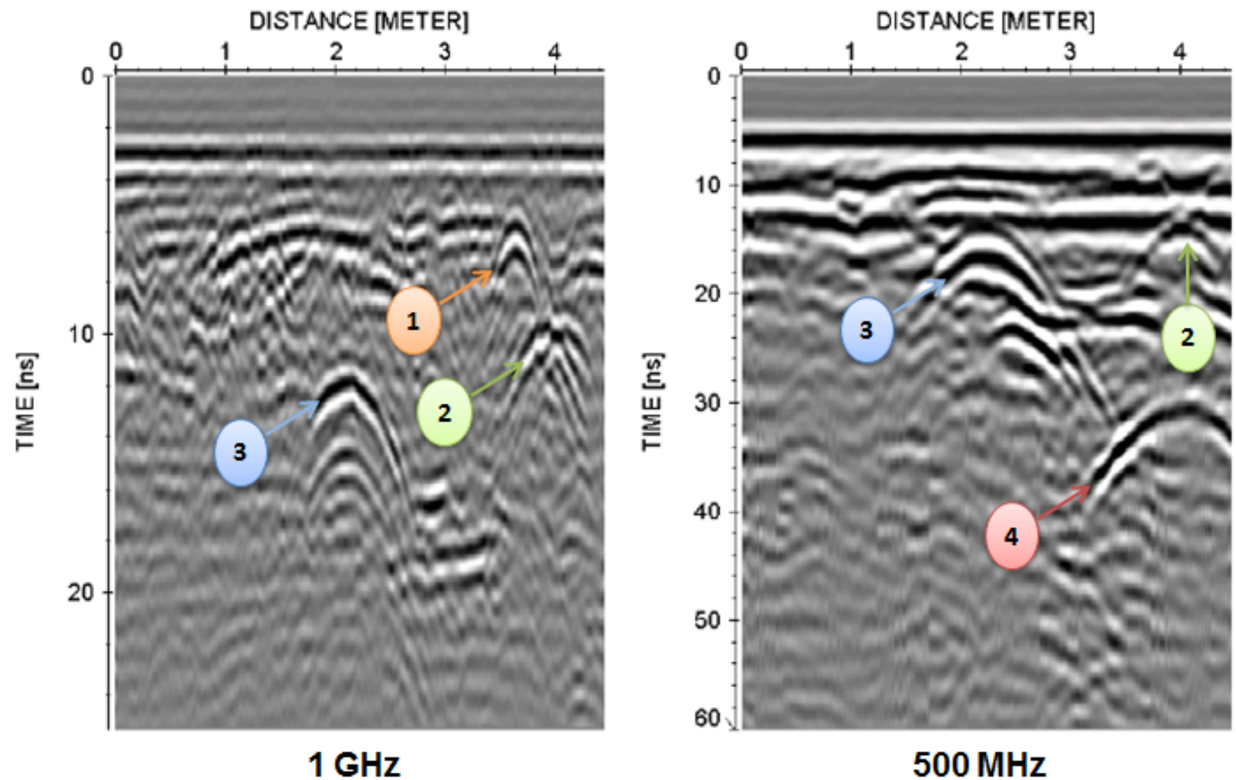

Fig. 3. Comparison of 1-GHz and 500-MHz data to detect pipes [3].

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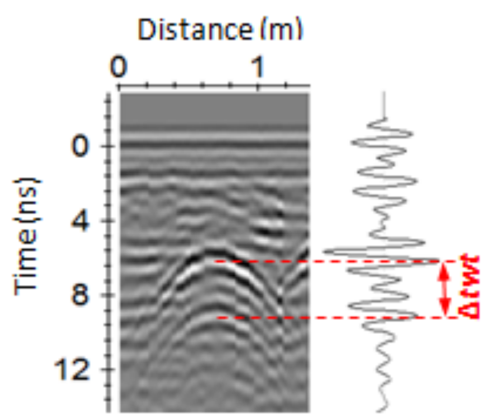
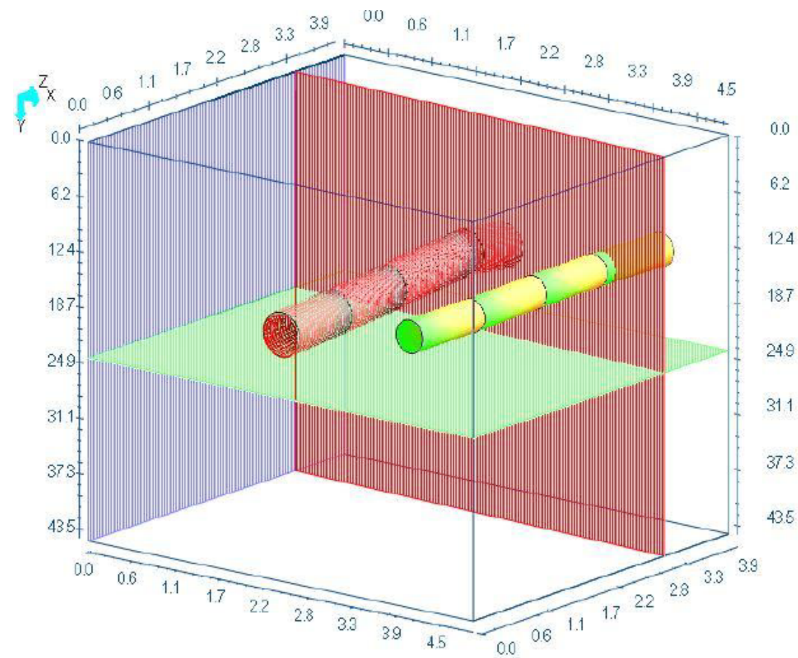
II. Utilities

- The pipe diameter can be determined by considering the travel-time distance (Δtwt) from the reflections generated at the top and bottom of the pipe, and by exploiting information about the velocity of propagation in the pipe (air/water).
- Antenna arrays easily generate 3D data, which allow the visualization of a whole piping network.

Fig. 4. Determination of pipe diameter (left) and 3D reconstruction of a (simple) piping network (right).



$$d = v\frac{\Delta twt}{2}$$



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III. Concrete

- GPR is a suitable method for the inspection of concrete structures, such as bridge decks and retaining walls.
- The GPR diagnosis of concrete structures includes: estimation of thicknesses, location of reinforcing bars and metallic ducts, estimation of bar size and configuration, location of voids, estimation of water and chloride content, investigation of the effects of water (moisture and corrosion), as well as of the concrete quality (e.g. porosity) and delamination or cracking.
- Both air-coupled and ground-coupled antennas are recommended, depending on the application: air-coupled antennas can be used to inspect bridge decks while ground-coupled antennas are preferable to assess retaining walls.
- The most commonly used frequencies are from 800 MHz to 2 GHz.

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III. Concrete

- The radargram in Fig. 5 shows the corrosion of reinforcing bars produced by high chloride content. The GPR measurements were done along a line perpendicular to bar axes, to ensure maximum reflection and strong hyperbolic signatures. The GPR signal is partially lost in the zone affected by corrosion, where the hyperbolic reflections are not well-defined.

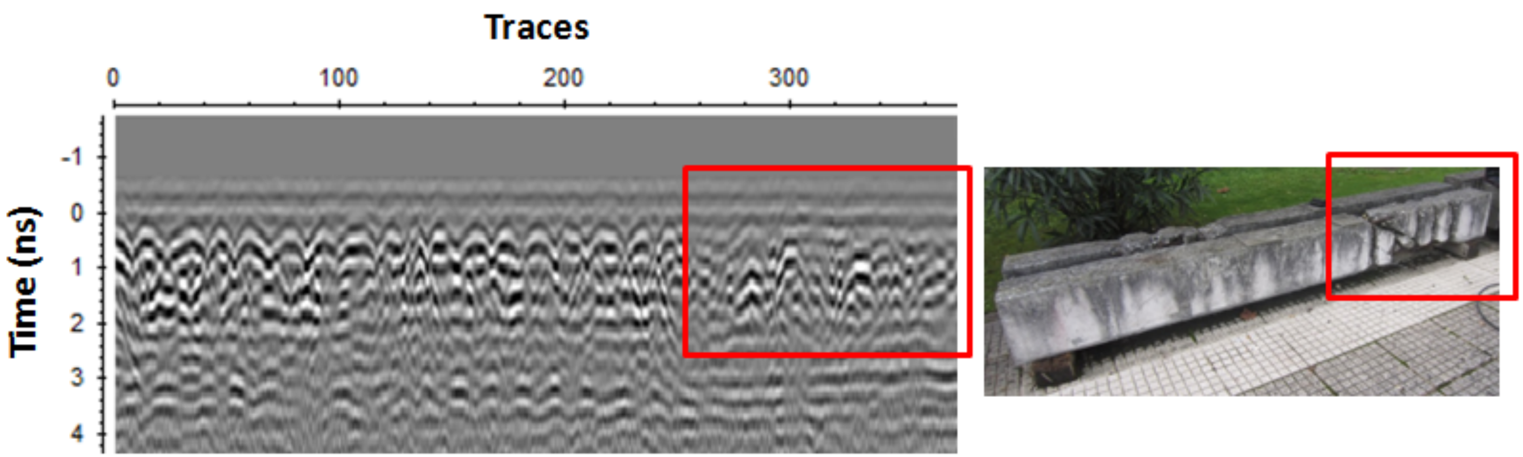

Fig. 5. 2.3-GHz data showing corrosion of the reinforcing bars due to the presence of high chloride content (zone into the red square) (courtesy of Applied Geotechnologies Research Group (University of Vigo) [1]-[2]).

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IV. Other construction materials

- Other construction materials that can be assessed with GPR include: masonry/stone, brick and wood.
- In masonry, both stone and brick, GPR can be used to detect internal hollows, cracking and fissures.
- In wood, GPR can be used to evaluate the water content and detect wood warms or fungi due to moisture. It is also possible to assess the wood quality by detecting internal faults such as knots.
- There are some published works focusing on the measurement of the wood permittivity, as an indicator of the material composition and its quality.
- High frequencies from 1 to 2 GHz are the most commonly used, with ground-coupled antennas.

V. Bridges

- GPR has been widely used to assess both concrete and masonry bridges. Depending on the building material, the obtained information is different.
- In concrete bridges, the GPR diagnosis includes: estimation of pavement thicknesses; estimation of position and size of reinforcing bars, metallic ducts, and voids; estimation of water and chloride content, and concrete porosity; investigation of the effects of water, moisture and corrosion, such as delamination or cracking, etc.
- In masonry bridges, the GPR diagnosis includes: estimation of thicknesses in stonework (e.g. solid piers), investigation of the effects of water and moisture, lack of ashlar or joints, location of cavities or cracking, etc.

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V. Bridges

- GPR is also useful to assess bridge foundations.
- Both air-coupled and ground-coupled antennas are recommended, depending on the application: air-coupled antennas can be used to inspect the pavement structure, whereas ground-coupled antennas are preferable to assess foundations. Based on the penetration requirements, the frequency range can vary from 250 MHz to 2 GHz.
- To visualize the rebar configuration in concrete and metallic ducts network, arrays of antennas can be used, to easily generate 3D data and obtain horizontal slices at fixed depths.

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V. Bridges

- Fig. 6a presents the identification of a water accumulation at the top of a bridge arch, coinciding with the stone-infill interface.
- Fig. 6b illustrates the effectiveness of the GPR technique to obtain information about the homogeneity and stratification of the infill, as well as to estimate arches thicknesses.

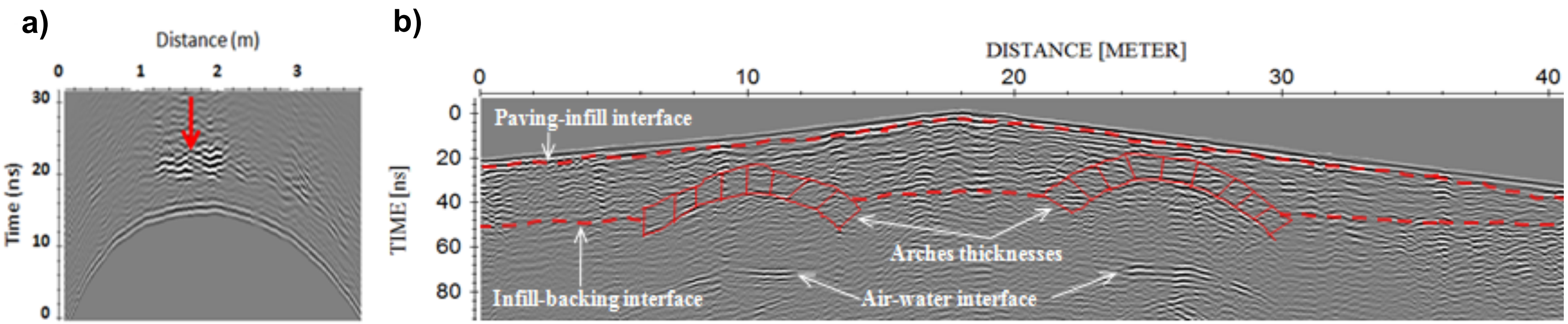

Fig. 6. Evaluation of masonry bridges: (a) 1 GHz data showing an accumulation of water and (b) 500 MHz data showing the identification of paving, infill and arches thicknesses (courtesy of Applied Geotechnologies Research Group (University of Vigo) [4].

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VI. Tunnels

- GPR is a valuable method for tunnel inspection. The technique has successful results in lining thickness estimation and can also identify defects in lining (e.g. voids).
- The GPR method is also useful for rebar detection and location, estimation of rebar size, and investigation of rebar corrosion. Additionally, GPR gives information about variations in water content and other aspects, such as the presence of other reinforcement elements embedded in lining.
- Lining thickness estimation is typically performed by using single ground-coupled antennas in the frequency range of 1-2 GHz. When a deeper analysis is required, for example to detect defects at the contact with the massive rock, frequencies from 400 MHz to 1 GHz can provide useful information.

VI. Tunnels

- Fig. 7a illustrates the presence of internal metal elements, or trusses, used for tunnelling reinforcement.

- Fig. 7b shows the existence of an air gap between the concrete lining and massive rock interface.

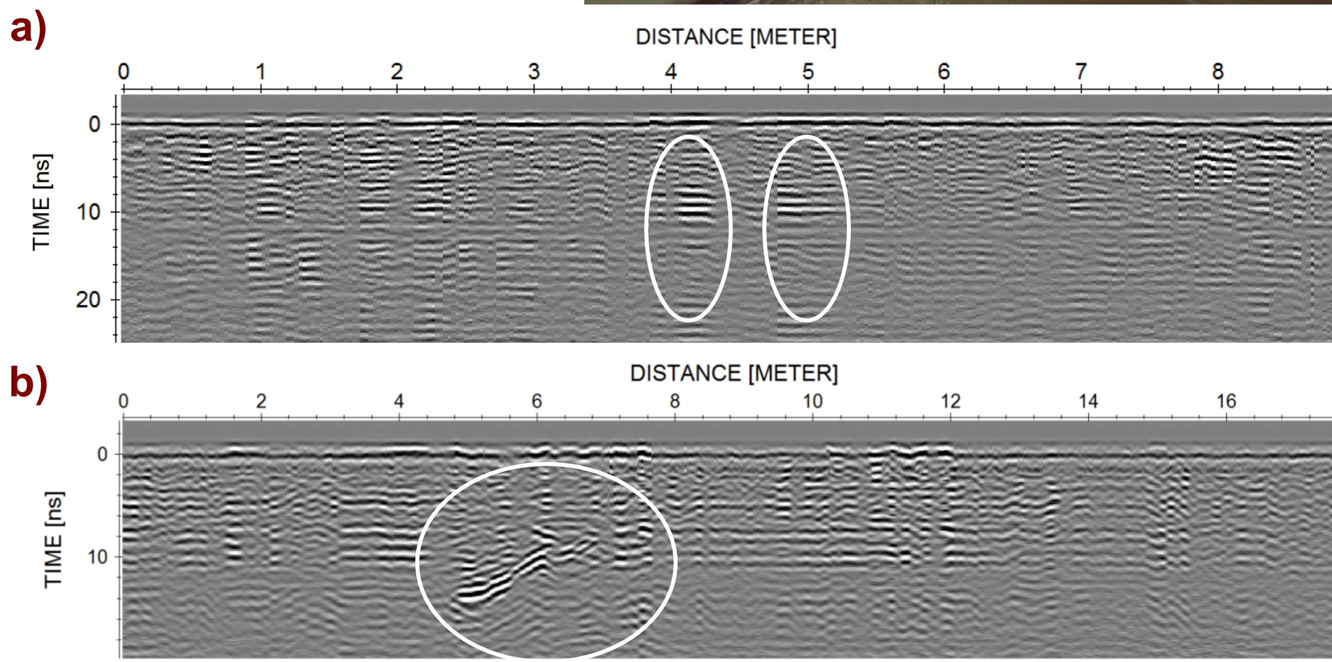

Fig. 7. 1 GHz data showing the reflections produced by internal metal trussers and a lining cavity (courtesy of Applied Geotechnologies Research Group (University of Vigo) [5]).

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VII. Railways

- GPR can be used for railways assessment, in particular for layer thickness measurement, detection of changes of the track geometry, estimation of the fouling level of ballast, water content estimation, as well as detection of other track defects and assessment of layer characteristics, mainly at infrastructure level.
- Two different antennas configurations can be mounted on a standard wagon or locomotive: air-coupled (suspended at 40-50 cm above the surface) and ground-coupled antennas (suspended at 5-10 cm above the surface).

Fig. 8. GPR antennas: air-coupled (right) and ground-coupled (left) configurations.

VII. Railways

- For ballast and sub-ballast layers, usually high frequency air-coupled antennas are used (1-2 GHz), which allow operating at higher speeds. High resolution data showing the boundaries between layers can be obtained.
- Ground-coupled antennas with lower frequencies (500 MHz – 1 GHz) allow to reach deeper layers. They are also useful when strong scattering occurs if high-frequency antennas are employed.

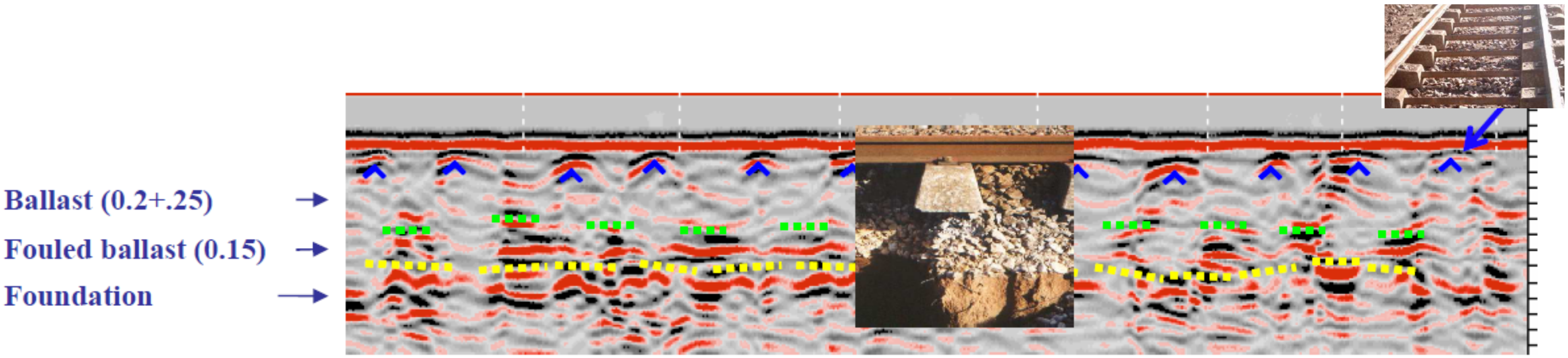

Fig. 9. 900 MHz data showing the different layers of an old railway substructure (courtesy of National Laboratory for Civil Engineering (LNEC, Lisbon)).

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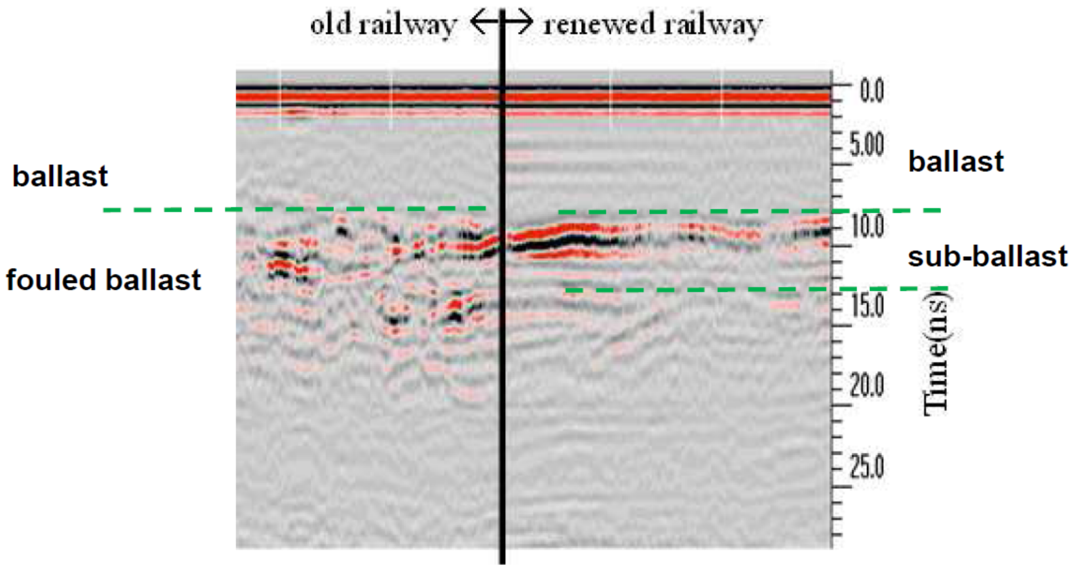
VII. Railways

- Fouled ballast:



- More scattered
- Interfaces not visible

- Higher definition
- Interfaces well revealed

Fig. 10. Transition between old and renewed zones (courtesy of National Laboratory for Civil Engineering (LNEC, Lisbon)).

- Track defects:

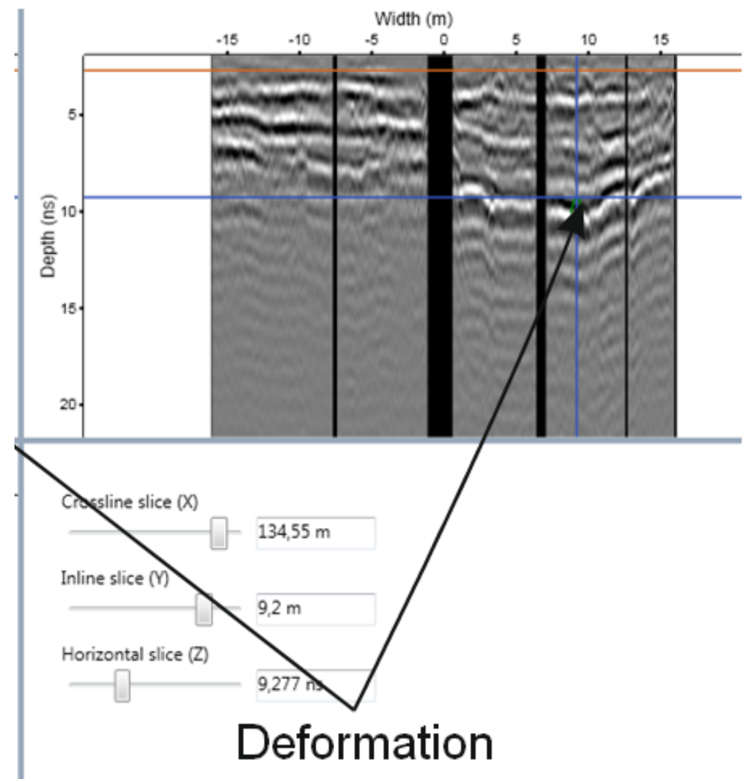


Fig. 11. GPR data showing deformation of the sub-base (courtesy of Geofísica Aplicada Consultores S.L.) [6].

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VIII. Modern buildings

- GPR can be used to detect damages in building walls and floors/ ceilings made of concrete, stone, brick and wood, to assess building foundations and to locate electricity cables, water pipes, as well as thermal floors pipelines.
- For concrete structures, GPR is useful to detect rebar or beams under enclosures. It can be also employed to detect steel corrosion as a consequence of dampness.
- For wooden structures, GPR can be used to detect wooden beams or wood supports, deterioration of timber elements by dampness, wood warms and fungi due to moisture.
- In masonry and brick structures, GPR can detect damages such as internal cracks, fissures and unfilled joints, as well as moist areas.

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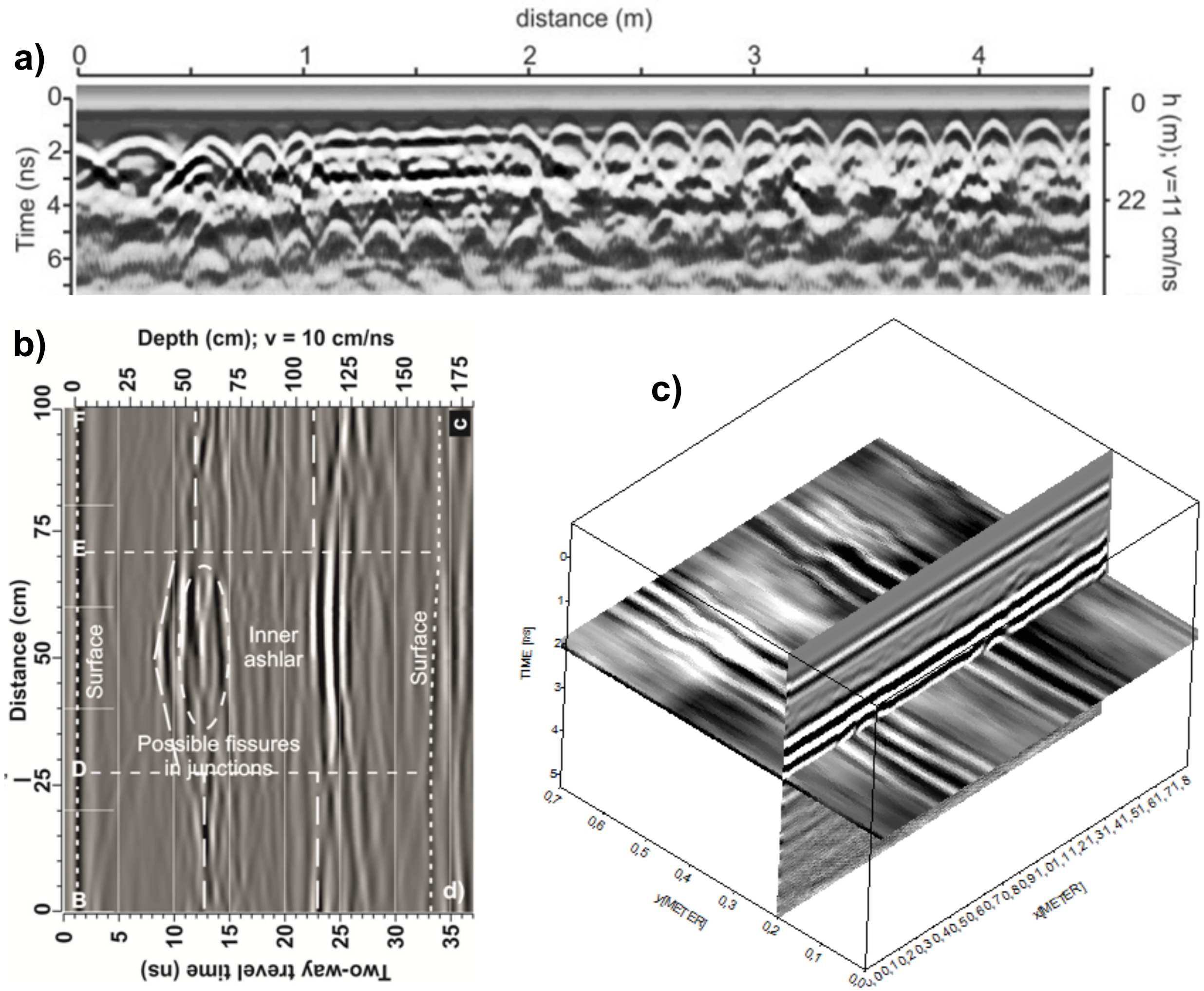
VIII. Modern buildings

- Ground-coupled single antennas with higher frequencies (800 MHz – 2.3 GHz) are recommended.

Fig. 12. (a) 2.3 GHz data showing the hyperbolas due to rebar in concrete, (b) 1.5 GHz data detecting internal fissures in a stone column and (c) 2.3 GHz data illustrating heating pipelines (courtesy of Polytechnic University of Catalonia & Applied Geotechnologies Research Group (University of Vigo) [7]).



IX. Archaeology and cultural heritage

- GPR is very often used for high-resolution imaging of archaeological areas and other cultural-heritage diagnostics.
- The use of 3D imaging techniques and processing allows to obtain realistic images of archaeological areas and reconstruction of buried remains.
- For large survey areas, the use of multi-channel systems has represented a new evolution in archaeological prospection.
- Archaeological prospection also includes indoor investigations (e.g. underground crypts, galleries), in limited areas. In such cases, the use of single ground-coupled antennas is necessary and several closely-spaced profile lines have to be acquired for 3D visualization.
- The most recommended frequencies are from 200 to 500 MHz.

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IX. Archaeology and cultural heritage

- Case study: Empuries Archaeological Site (Spain) with remains of Greek and Roman settlements.
- A massive array containing 15 dipoles in a parallel broadside configuration was used with a spacing of 12 x 6 cm and operating frequency of 200 MHz.
- An RTK GPS was attached to the system for track positioning.
- 1ha was covered in less than 2 hours.

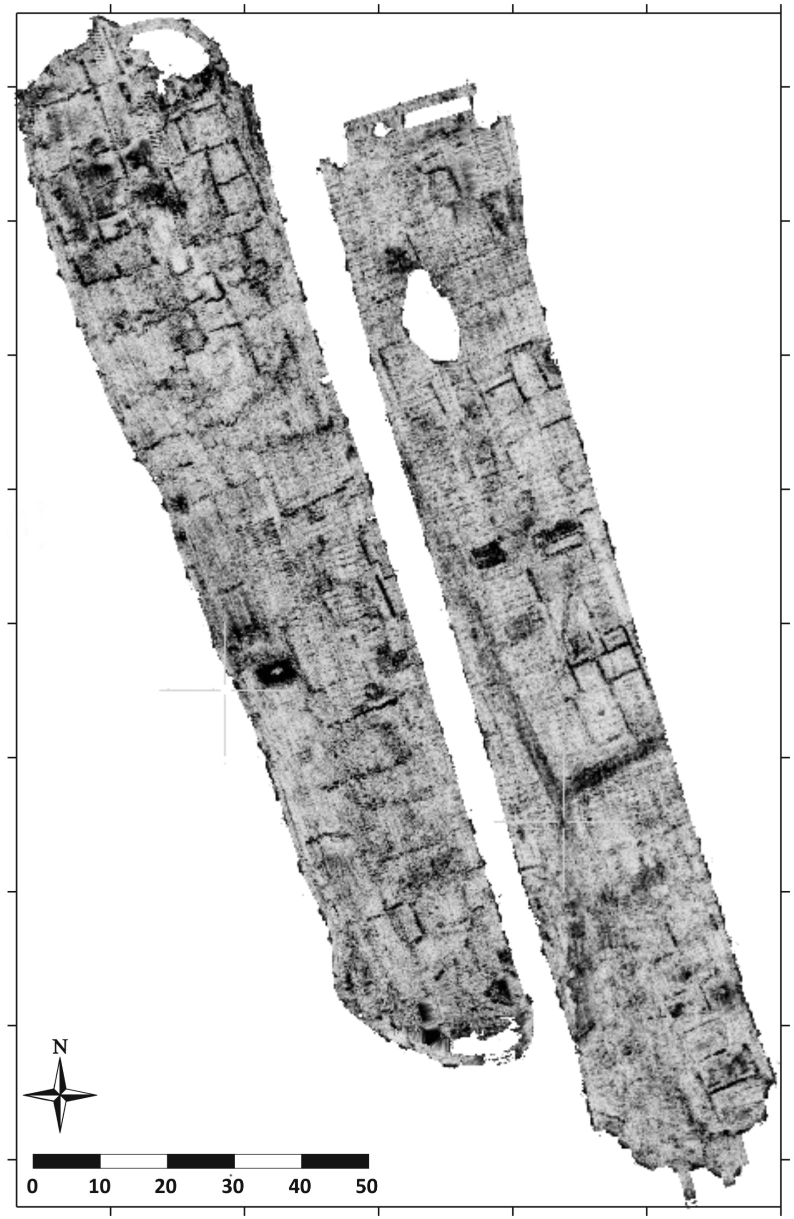

Fig. 13. 200 MHz 3D data produced (courtesy of Geostudi Astier, SOT Prospection & MAC (Archaeological Museum of Catalonia) [8]).

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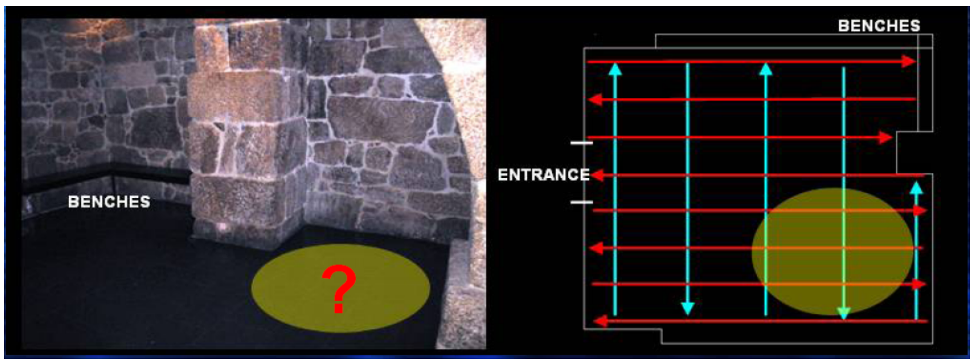
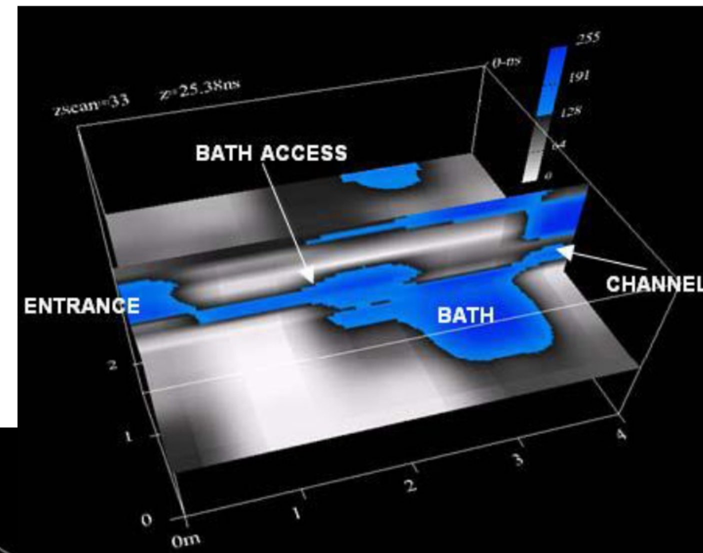
IX. Archaeology and cultural heritage

- Case study: a Jewish ritual bath in Ribadavia (Spain). A 3D survey was accomplished with a 500 MHz antenna and space intervals of 1 m and 0.5 m in longitudinal and transverse directions.





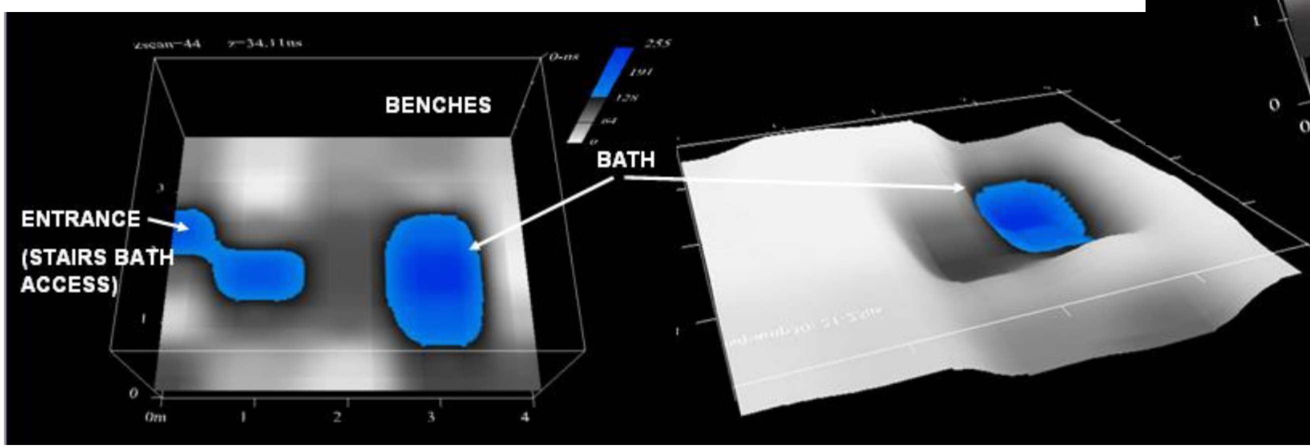


Fig. 14. 500 MHz 3D data produced (courtesy of Applied Geotechnologies Research Group (University of Vigo) [9]).

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IX. Archaeology and cultural heritage

- The protection and management of cultural heritage includes also historical buildings (e.g. churches: floors and walls, columns, moisture damage, etc.) and bridges.
- For the investigation of columns and moisture damage, single ground-coupled antennas and high frequencies are recommended (1-2 GHz); for large structures (e.g. bridges), lower frequencies are preferable (200-500 MHz).

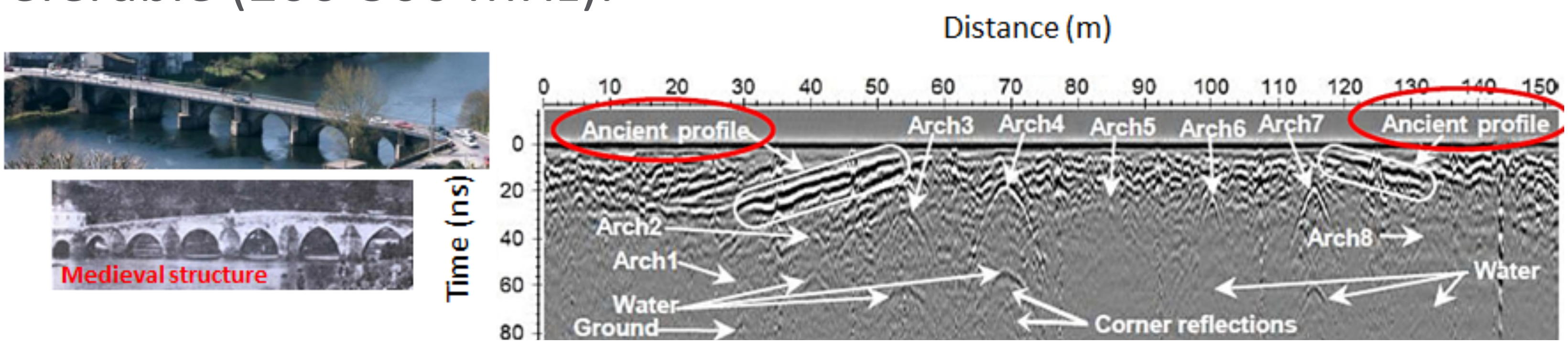

Fig. 15. 500-MHz data showing the existence of an ancient double slope profile of the bridge and the presence of different building materials (granitic or slate vaults) – note the attenuation of GPR signal due to slate materials (courtesy of Applied Geotechnologies Research Group (University of Vigo) [4]).

IX. Archaeology and cultural heritage

- Fig. 16 shows supporting structures in a floor room of an ancient building. GPR provides a well-defined image of the concrete beams and bars, vaults, bricks, and wooden coffered ceiling.

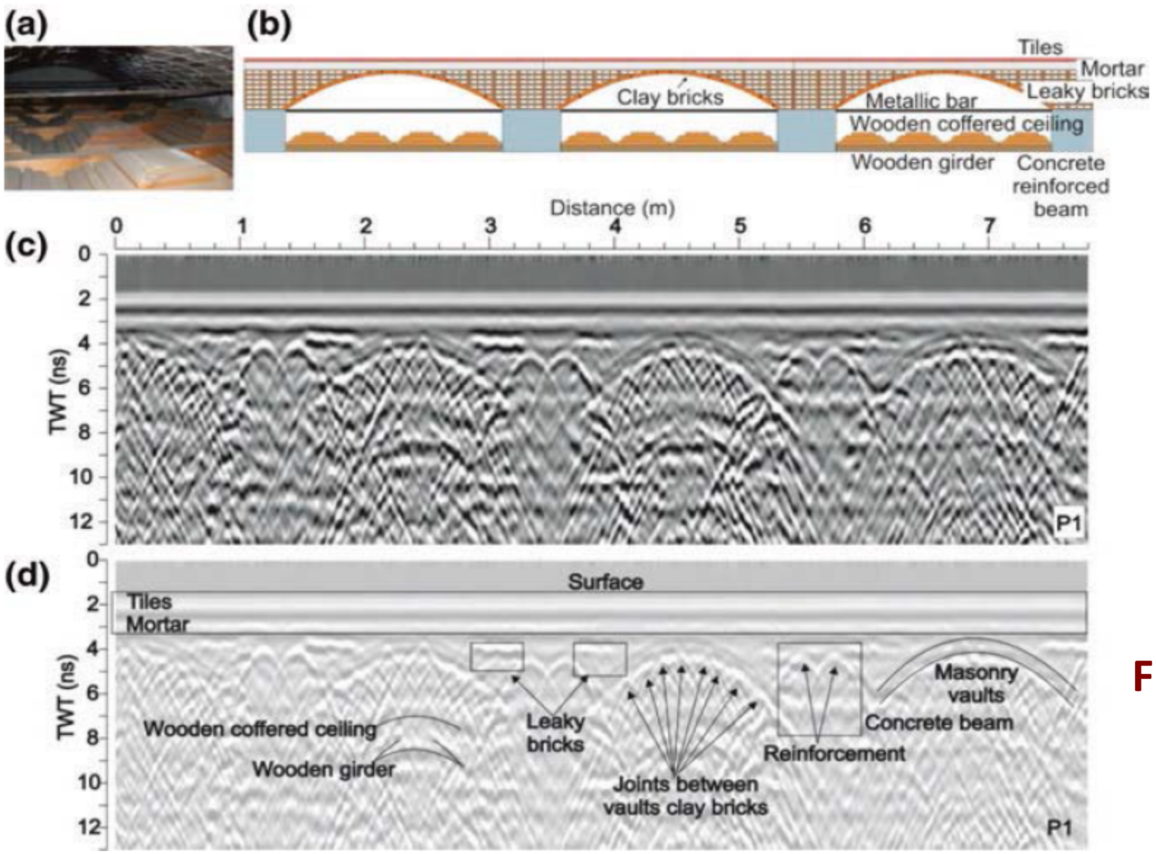

Fig. 16. 1.5-GHz data (courtesy of Polytechnic University of Catalonia [7]).

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IX. Archaeology and cultural heritage

- Finally, other historical elements that can be assessed by GPR are: mosaics (e.g. detection of delamination, monitoring of mosaic grouting and location of hidden heterogeneities), bas-reliefs (e.g. mapping cracks and lack of pieces), frescoes (e.g. mapping detachment and moisture), statues (e.g. identification of internal fractures and cavities, location of metal bars and joints), and ancient pottery (location of ceramic and pottery fragments).
- For such applications, a higher resolution is required. Thus, single ground-coupled antennas with central frequencies ranging from 1 to 2 GHz are most commonly used.

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X. Forensics

- GPR can detect buried bodies and graves. Some authors have demonstrated that GPR is not optimal to detect bodies if there is an advanced state of decomposition, over 18 months. Commonly, the detection of graves is possible by a disruption of the soil horizon or by discerning the grave walls, which guarantees the location even when no response is obtained from the body.

- GPR is a non-intrusive technique preserving the scene while saving time-consuming digging efforts as smaller areas are identified for further testing.

- The literature suggests frequencies from 400 to 500 MHz.

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X. Forensics

- The survey orientation may also affect detection. A body can be better detected when surveying in perpendicular direction, which results in a hyperbolic reflection instead of a flat reflection.

- Existence of GPR systems with antenna arrays can be used for fast prospection of large areas.

- In complex environments (with ground topographical variations and covered by trees, bushes, stumps, tufts of grass, rocks and stones, cracks and fissures in ground, as well as puddles of water) it is recommended to avoid 3D images and examine only 2D profiles.

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X. Forensics

- Fig. 17 presents an example of application, in which an experimental grave was simulated by using a pig carcass.
- The GPR data show a grave wall at the beginning of the radargram, with a hyperbolic anomaly at 22 ns in depth. A clear hyperbolic reflection from the pig carcass can be identified from 0.7 to 1.8 m.

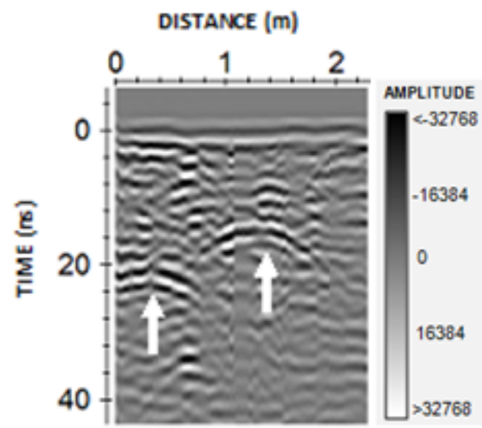

Fig. 17. 500-MHz data (courtesy of Applied Geotechnologies Research Group (University of Vigo) [10]).

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XI. Landmines and unexploded ordnance

- The GPR technique is a promising and safe method to assist in landmine clearance and unexploded ordnance removal.
- GPR has the ability to detect either metallic or non-metallic landmines, as long as the electromagnetic contrast between the ground and target is strong enough.
- Signal processing tools are being developed to achieve automated detection.
- For a proper analysis of the GPR signal and accurate detection, it is important to avoid the following conditions in the area under test: presence of small metal fragments, shrapnel, spent bullet and cartridge cases, ground topographical variations, puddles of water, tufts of grass, rocks and stones, animal borrows, cracks and fissures in the ground.

XI. Landmines and unexploded ordnance

- The scientific community has concluded that high frequencies around 1-2 GHz are the most appropriate to produce detailled data for landmine detection. For unexploded ordnance, at deeper depths, lower frequencies can be used (800-500 MHz).
- Vehicle-based systems have been developed that use arrays of antennas and generate 3D data, which are then processed to provide a rolling map of detections. Some examples are: HUDEM (Belgium), HSTAMIDS (USA), SALMANDER (France), etc.
- Several attempts have been made to detect minefields from airborne platforms. In Unmanned Airborne Vehicles (UAV), the sensor technology most commonly used is lightweight and ultra wideband (UWB) Synthetic Aperture Radar (SAR).

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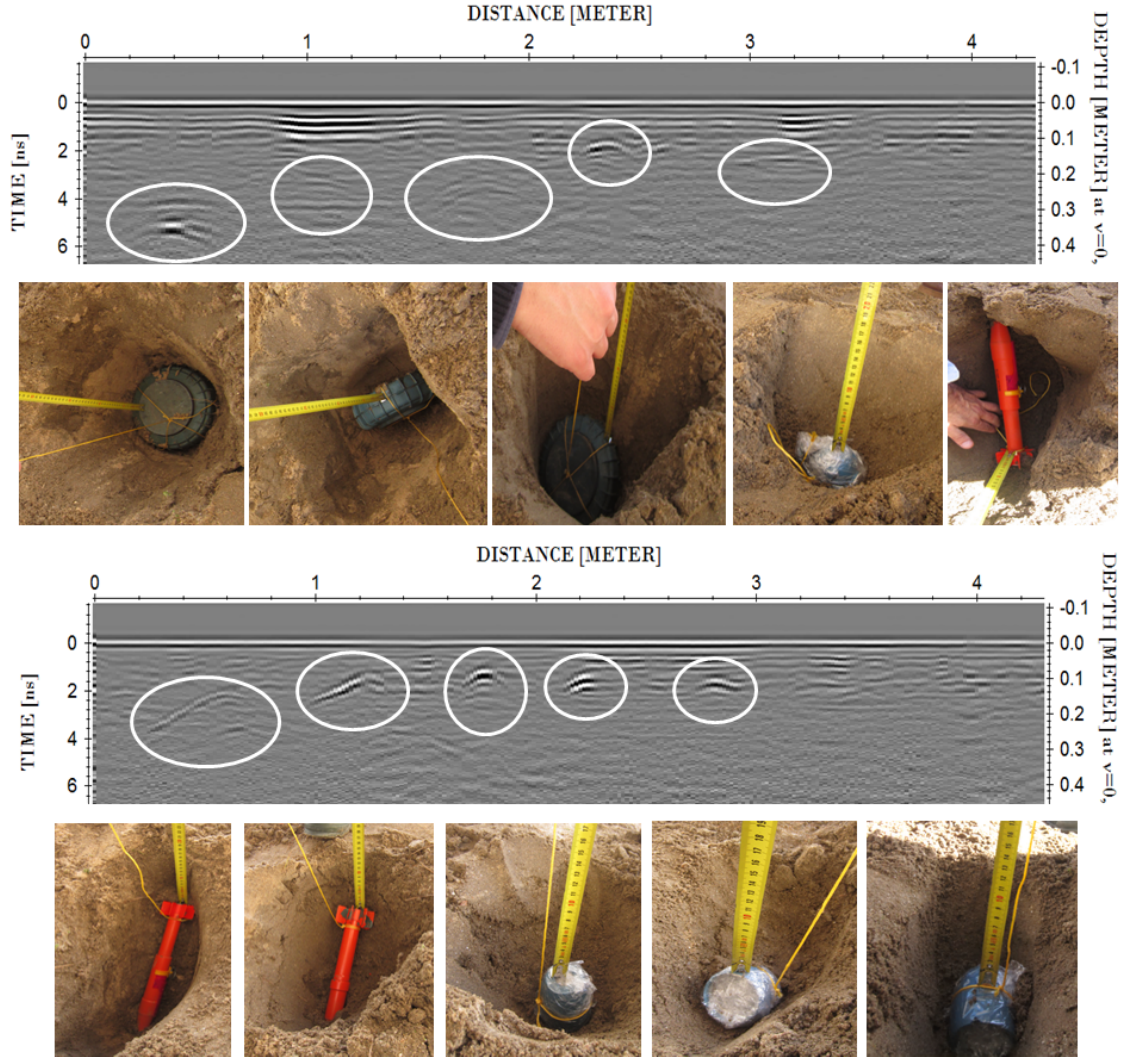
XI. Landmines and unexploded ordnance

- Fig. 18 presents an example, in which an experimental scenario was simulated, with anti-personnel and anti-tank mines, projectiles and granades.



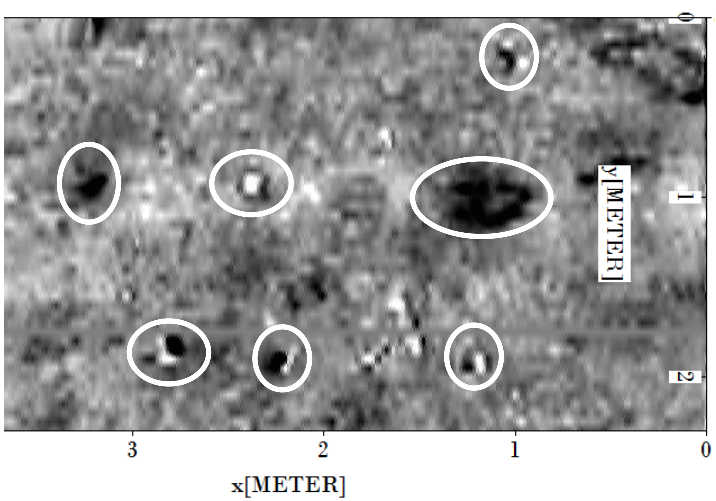


Fig. 18. 2D (right) and 3D (left) 2.3 GHz data (courtesy of Spanish Defense University Center [10]).

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XII. Rescuing of people buried under debris and avalanches

- Other applications of GPR are focused on searching and rescuing trapped people in disaster areas (earthquakes, avalanches, etc.).
- Searching for victims under avalanches is commonly carried out by using GPR systems operating in a frequency range from 400 MHz to lower frequencies. Buried bodies can be identified as a perturbation of the backscattered signal.
- The GPR location of victims under rubble is possible by detecting breathing movement and heartbeat. The detection of vital signs is commonly carried out by using continuous-wave (CW) microwave transceivers and more recently by using UWB radar systems at GHz frequencies.

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XII. Rescuing of people buried under debris and avalanches

- The most important issue in rescue missions is to detect buried victims who are still alive, hence timing is crucial. Therefore, array systems are recommended, when the area is accessible.
- To reach inaccessible or dangerous areas, rescue radar systems were designed to operate on UAV. In this cases, single antennas are used because of the weight limitation.

XIII. Through-the-wall

- Through-the-wall imaging (TWI) concerns detection and localization of people behind walls by using electromagnetic waves. TWI is demanded in surveillance applications, in addition to law enforcements and military operations.
- The detection can be possible by detecting moving objects or vital signs (breathing or heartbeat).
- TWI is commonly carried out by using continuous-wave (CW) and pulse radar. Doppler procedures and UWB frequency-modulated continuous wave are considered for TWI.
- High-range resolution requires use of UWB pulse radar, while high cross range resolution requires a very long aperture. Operating frequencies vary from 100 MHz to 4 GHz.

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XIV. Karsts and other natural cavities

- GPR can be used to detect karsts and other natural cavities, and to estimate their size and depth.
- High penetration of the GPR signal is required. Thus, central frequencies range from 50 MHz to 250 MHz.
- Single antennas are preferably used due to the roughness of the terrain.
- The survey orientation may affect the detection. A cavity could be better detected when surveying in perpendicular direction, which results in a hyperbolic reflection instead of a flat reflection.

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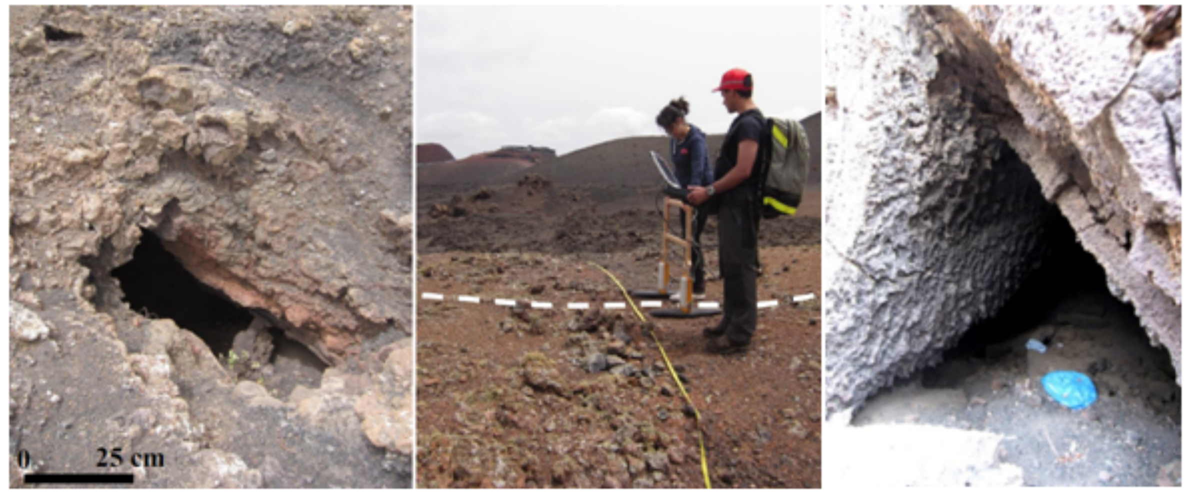
XIV. Karsts and other natural cavities

- Figure 19 shows an example of application for the detection of lava tubes in the volcanic area of the Timanfaya National Park (Canary Islands, Spain).

- The data produced have revealed the occurrence of 4 lava tubes (A-D).



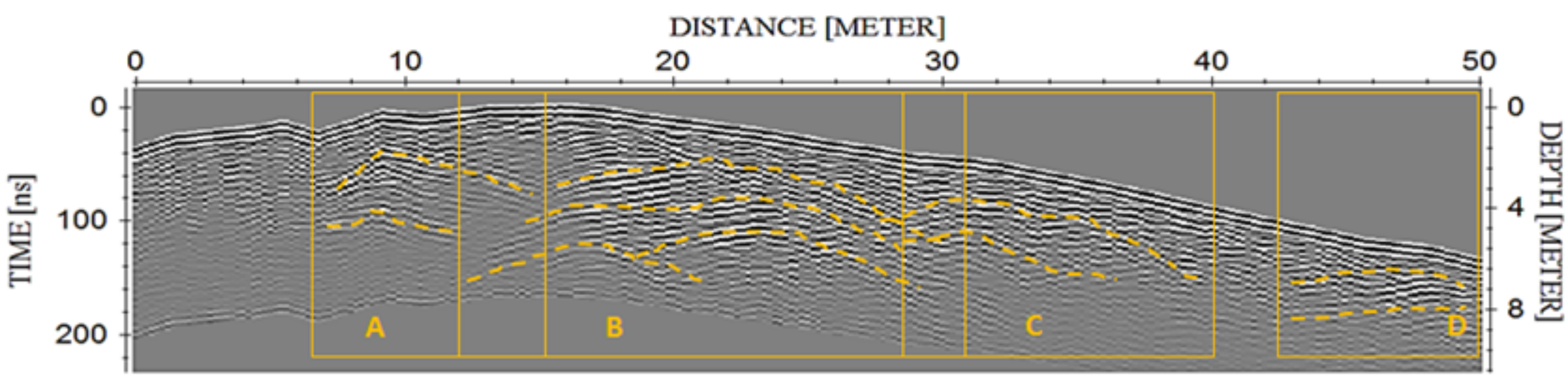


Fig. 19. 200-MHz data (courtesy of Spanish Superior Council for Scientific Research).

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XV. Glaciers

- GPR is widely applied for the study of glacial and frozen materials, including aspects such as: englacial water indicating the thermal regime of glacier ice or permafrost, drainage channels, layers of deposition, englacial debris, fracturing of frozen, glacier bed, etc.
- This type of studies requires high penetration of the GPR signal. Thus, central frequencies ranging from 50 MHz to 200 MHz are most commonly used.
- Single antennas, with a robust configuration, are preferable to avoid possible rolling caused by the extreme topographic and snowy surface conditions.

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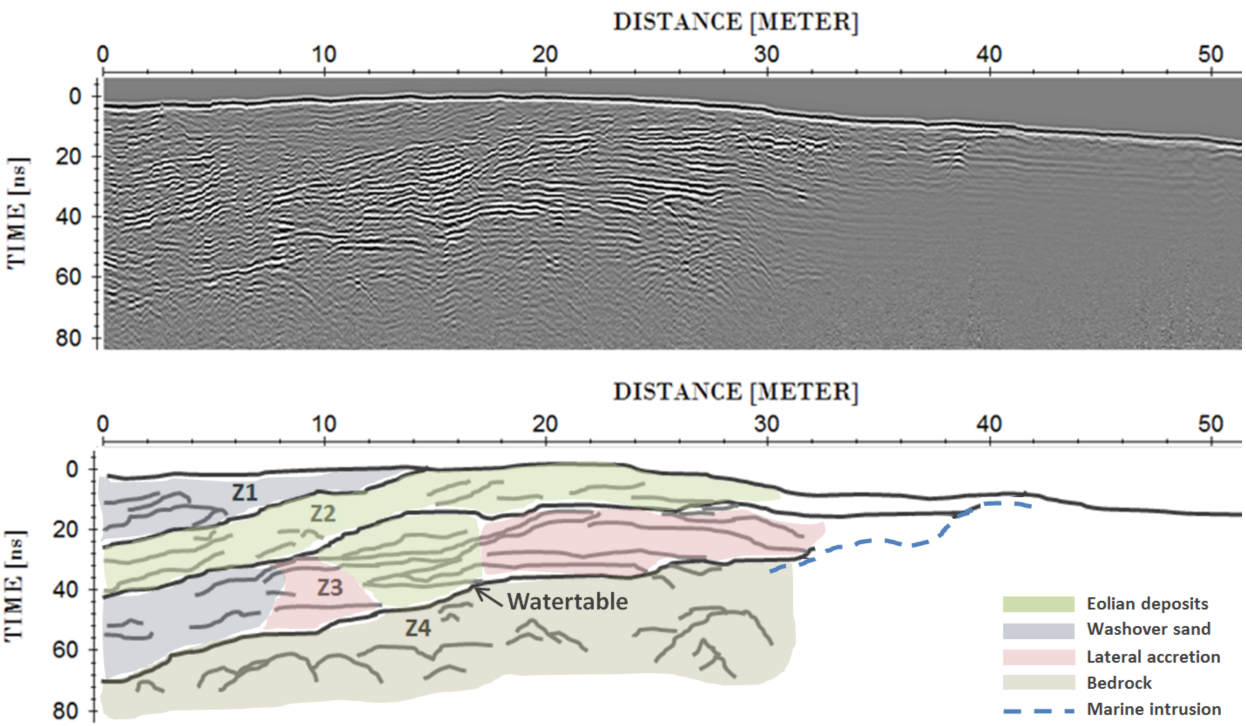
XVI. Sand environments

- In dry sand sedimentary environments, GPR has demonstrated its capability to locate both watertable and brine/fresh water interfaces. Moreover, GPR allows the distinction and characterization of different deposits in dune and coastal systems, as well as the investigation of sediment dynamics.
- These types of studies require high penetration of the GPR signal. Thus, central frequencies ranging from 50 MHz to 500 MHz are most commonly used.
- Single antennas, with a robust configuration, are preferable to avoid possible rolling because of the topographic conditions of the terrain.

XVI. Sand environments

- Fig. 20 shows the interpretation of a transverse GPR profile acquired on a beach. Different interfaces were detected by analyzing the reflection patterns and interpreted as: washover sand, eolian deposits, watertable and bedrock.



	RADAR FACIES	INTERPRETATION
	Tangential and concave downward	Washover sand
	Bounding surface	Eolian deposits
	Continuous very high amplitude	Watertable
	Parallel	Vertical aggradation (washover sheet), lateral accretion (inlet closure)
	Hyperbolic	Bedrock
	Reflection free	Signal attenuation by saturated salt water

Fig. 20. 500-MHz data (courtesy of Applied Geotechnologies Research Group (University of Vigo).

XVII. Water environments

- GPR can be used to detect the existence and level of water in the subsoil.
- GPR is also useful to survey freshwater environments (such as lakes and reservoirs) giving information about the column of water while differentiating layers of lacustrine deposits and rock formations in subsurface.
- High penetration of the GPR signal is required, particularly when travelling through freshwater media. Thus, central frequencies ranging from 50 MHz to 250 MHz are most commonly used.
- Single antennas are preferably used due to the complexity of the survey.

XVII. Water environments

- Figure 21 shows an example of application for the study of a lake, which is an abandoned kaolin mine. It was possible to interpret layers of lacustrine deposits and vegetation on the lake bed, as well as kaolin rock formations.

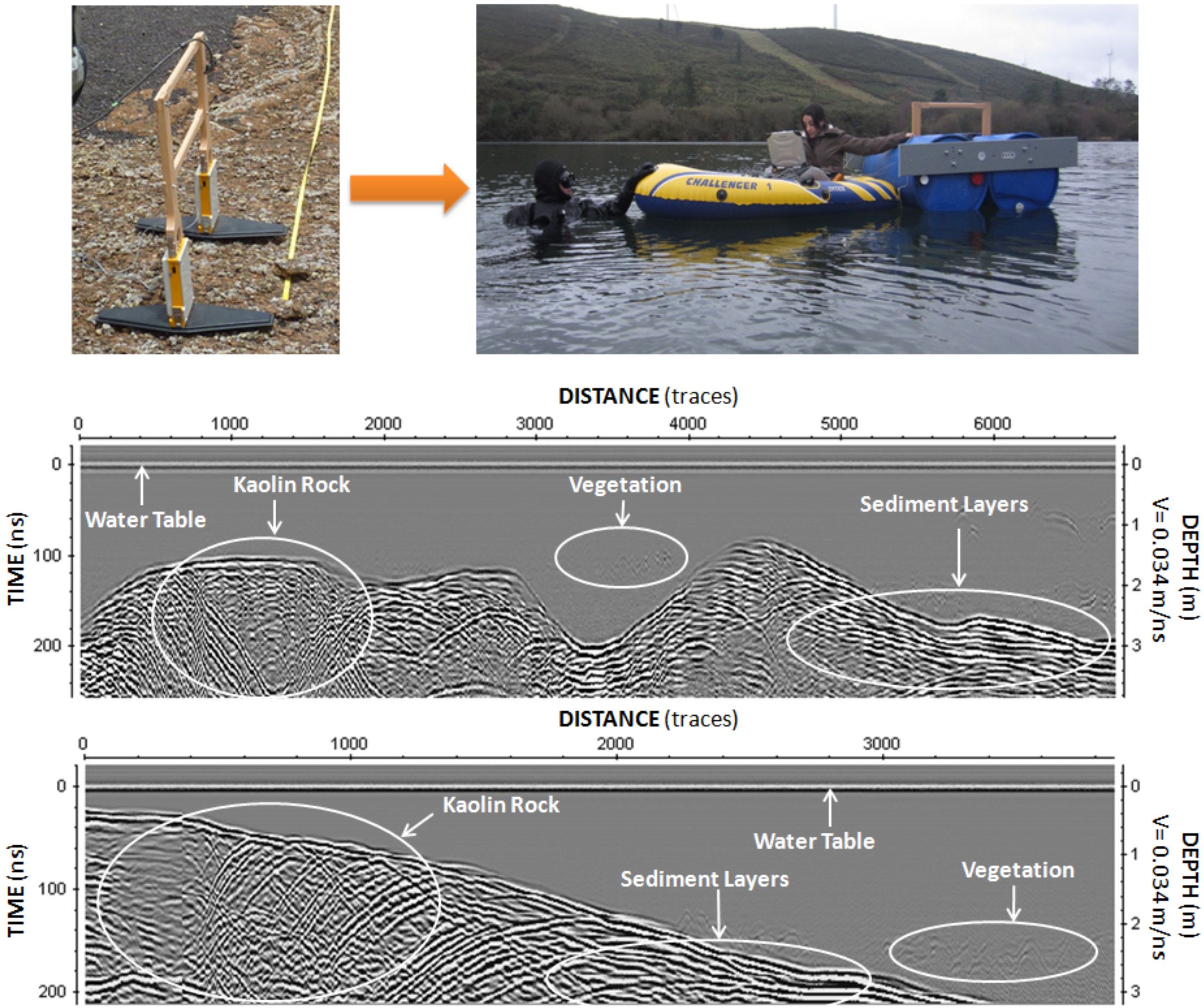


Fig. 21. 200-MHz data (courtesy of Applied Geotechnologies Research Group (University of Vigo)).

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XVIII. Agriculture

- GPR has demonstrated its capabilities to provide optimal growing conditions. Firstly, the method can be used to analyze the soil structure and land consolidation, estimate physical soil properties such as clay content or salinity, soil bulk density and texture, as well as detect subsurface horizons and determine thickness and depths of organic soils.
- It is also possible to estimate the volume content of moisture in the soil and the water movements, in addition to the investigation of the water table depth.
- GPR is useful to map areas with high potential for subsurface offsite movement of agrochemicals and pollutants.

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XVIII. Agriculture

- Other aspects that can be assessed are the biomass production and particularly the spatial distribution of plant roots and their diameters.
- With respect to the methodologies used for data acquisition, single ground-coupled antennas are most commonly employed for agricultural sensing.
- The frequencies of operation depend on the feature under investigation and vary from 100 MHz (e.g. water table depth) to 1 GHz (e.g. root biomass and diameters).

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XIX. Polluted soils and contaminated water

- GPR can be used to delimit polluted soils (detection of hydrocarbons and other organic wastes). GPR is also useful to detect contaminant plumes (e.g. hydrocarbon products) in water.
- High penetration of the GPR signal is required when travelling through wet soils or even freshwater media. In such cases, frequencies ranging from 50 MHz to 250 MHz are advised. In the case of sand, the penetration of GPR signal is higher and central frequencies from 500 MHz to 800 MHz provide good results.
- Single antennas are preferable used because surveys usually are carried out in sandy environments, on soils with a high content of stones and roots, or water surfaces.

XIX. Polluted soils and contaminated water

- Figure 22 shows an example of application to detect and delimit buried layers of fuel in the Carnota Beach (A Coruña, Spain) after the sinking of the Prestige Tanker, in November 2002.

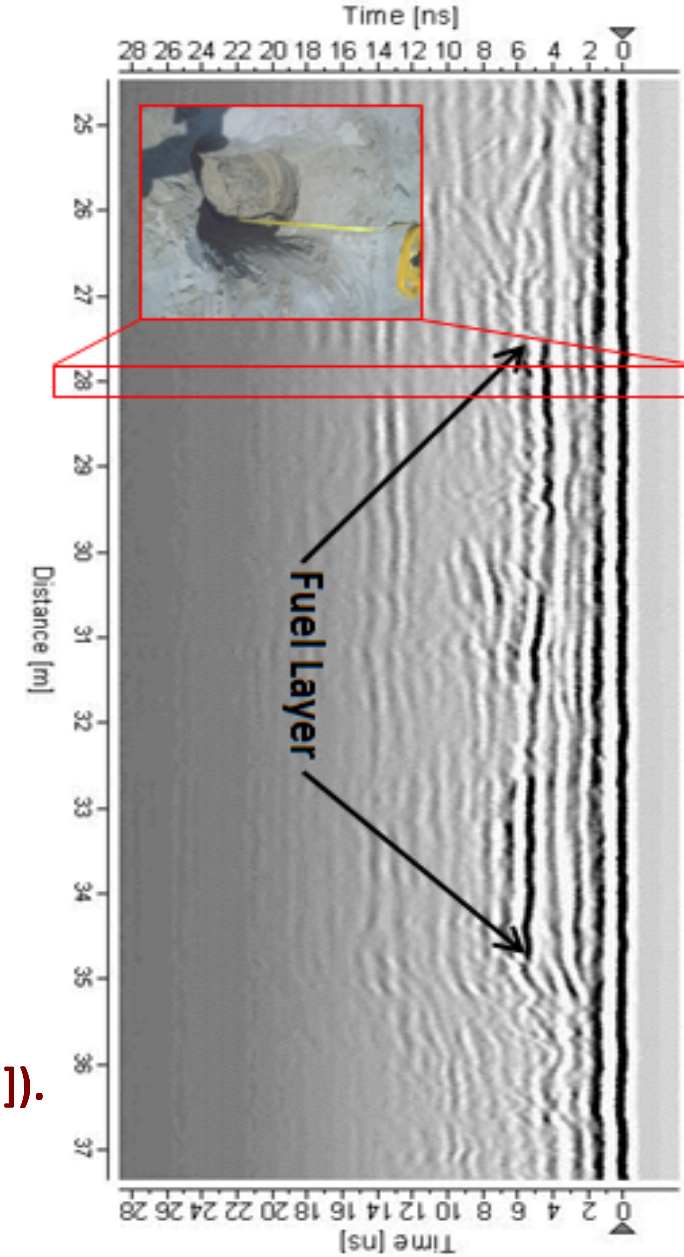

Fig. 22. 800 MHz data (courtesy of Applied Geotechnologies Research Group (University of Vigo) [11]).

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XX. Water management structures

- Some research works deal with the application of GPR for the evaluation of water management structures such as dams, water-retaining walls and dykes, as well as other installations of irrigation and drainage, water mains and sewerage.
- GPR allows the identification of different aspects affecting water management structures such as: detecting and localizing sandstone layers and banks in the subsoil below the structure that are potential routes of flow of water, detecting the presence of voids or fractured zones embedded in the structure or in its foundation soil, waterproof layer fractures and detachment that provoke water infiltration and moisture in the structure, reinforcing elements and problems of corrosion, and lack of fill material.

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XX. Water management structures

- With respect to water-supplies, GPR is able to: map the location and depth of drainage and irrigation systems, as well as water mains and sewerage. Installation defects (e.g. leakage) can be detected.
- Ground-coupled antennas are used. High resolution frequencies of 800 MHz – 2 GHz are appropriate to obtain information about the shallower subsoil (e.g. fractures and detachment), whereas frequencies from 100 to 500 MHz provide information from the deeper subsoil (foundation soil).
- To map water-supplies installations, the use of arrays of antennas (3D data) improves the understanding and visualization of the piping network.

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XX. Water management structures

- Figure 23 shows an example of application for the internal evaluation of a masonry dyke in a port area. Damages in superficial paving were observed such as block displacement, subsidence and sinking.
- The zones marked by (white) circles correspond to the possible anomalous areas due to cracking or lack of filling, which are interpreted from the scattering observed in such locations.

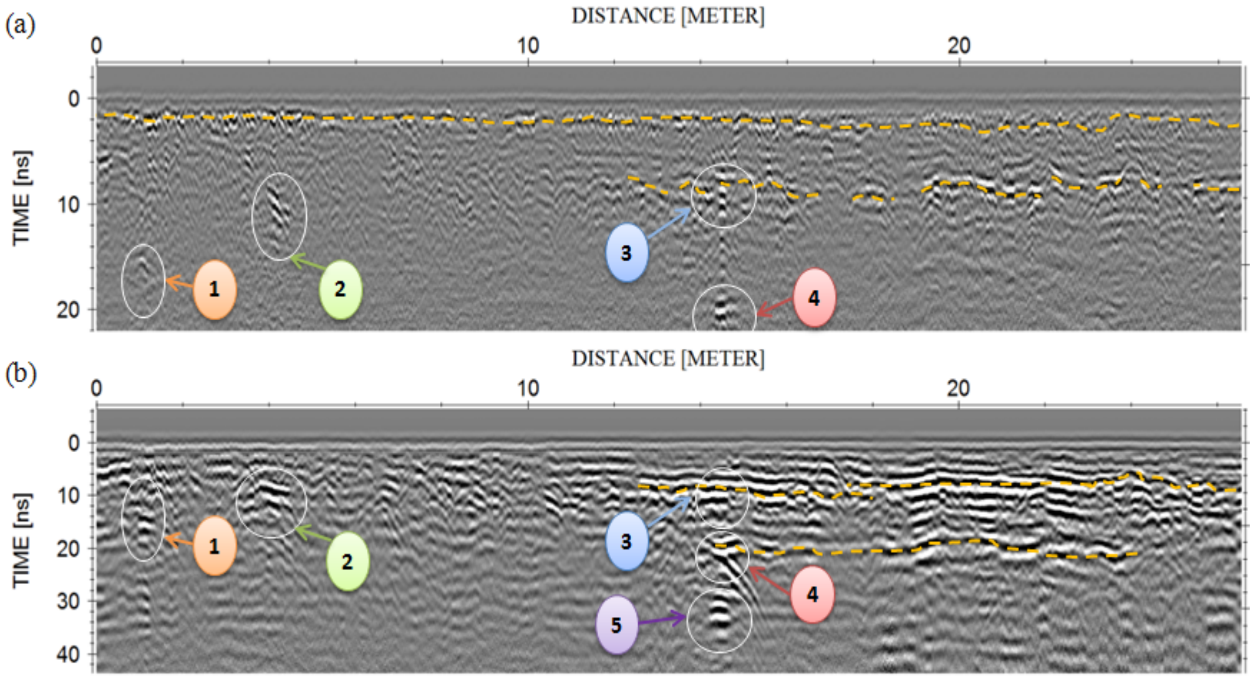

Fig. 23. (a) 800 MHz data and (b) 500 MHz data (courtesy of Applied Geotechnologies Research Group (University of Vigo) [1]).

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XXI. Tree trunks and roots

- The GPR technique has also forestry applications. The method can evaluate the properties of trees and timber as well as obtain information about the health of trees (water content, damages or diseases such as knots).
- Single antennas in a frequency range of 1-2 GHz are moved along the trunk with a metallic sheet on the opposite surface of the trunk.
- GPR is also useful to map tree root systems. It is possible to estimate the depth and diameter of the roots, which allows to estimate the root biomass.
- To map root systems, 3D full-resolution imaging is recommended by using arrays of antennas in a frequency range of 400–600 MHz.

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XXI. Tree trunks and roots

- Fig. 24 shows two weak internal reflections in the trunk that could be associated to inner discontinuities between the bark and the internal trunk. These reflections are most likely due to differences in te water content between these two parts of the tree.
- Fig. 24 also presents the detection of knots in timber.

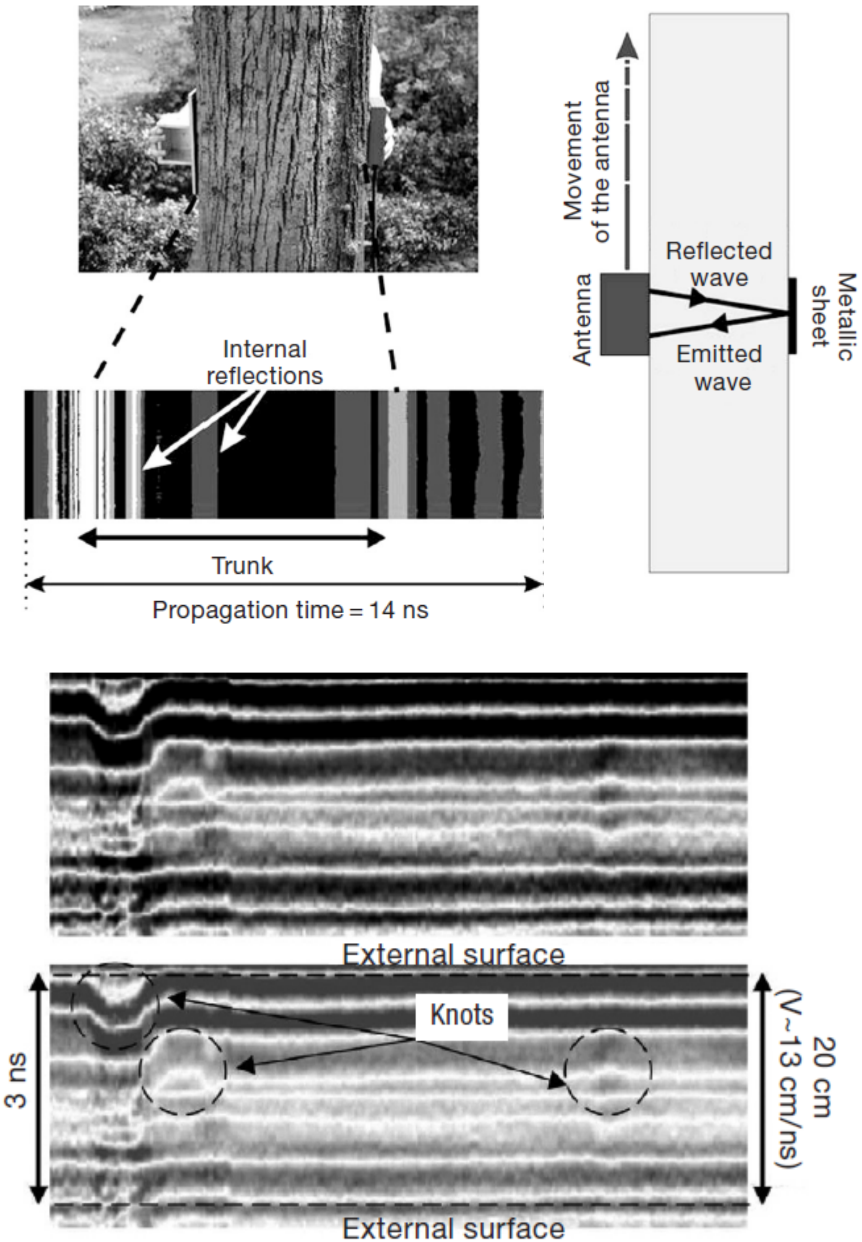

Fig. 24. 1 GHz data (courtesy of Applied Geotechnologies Research Group (University of Vigo) & Polytechnic University of Catalonia).

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XXI. Tree trunks and roots

- Fig. 25 shows a 3D distribution of a tree roots system in a survey area of 20 x 12.5 m with parallel GPR lines spaced by 5 cm.

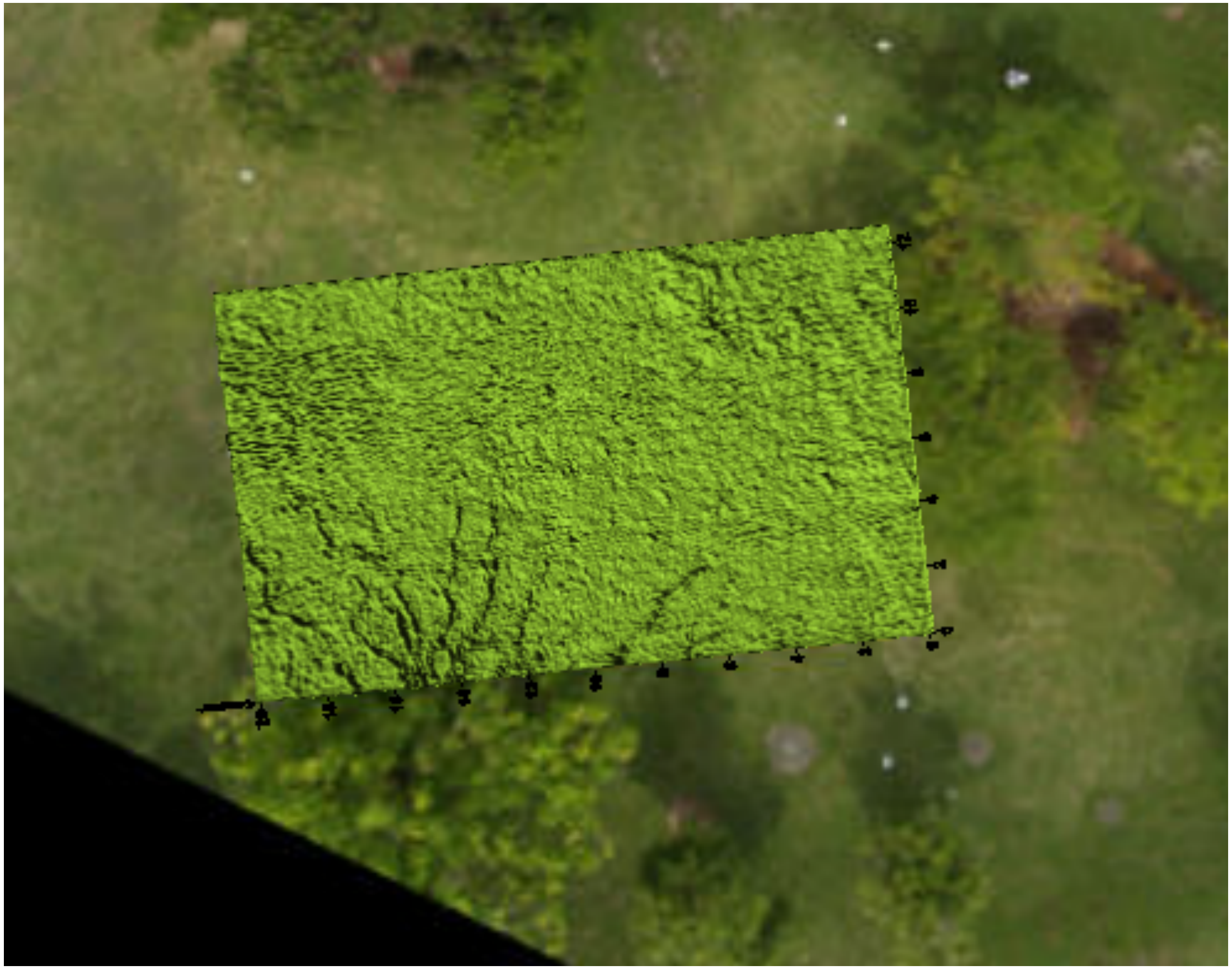

Fig. 25. 500 MHz data (courtesy of University of Miami & Applied Geotechnologies Research Group (University of Vigo)).

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XXII. Planetary exploration

- GPR can be used for mapping subsurface stratigraphy through rover platforms for planetary exploration (Mars, the Moon, etc.), as well as to characterize the GPR signature of likely planetary materials.
- The GPR technique can be also useful to locate and assess water deposits on planets.
- The use of GPR on planetary exploration rovers was proposed several times for Martian exploration by NASA.
- RIMFAX (Radar Imager for Mars subsurFAce eXperiment) is an ultra wideband GPR designed to fly on the 2020 rover, with a frequency range from 150 to 1200 MHz that allows for a penetrating depth greater than 10 m.

References

[1] "Applications of the GPR method for road inspection," (book chapter in "Non-Destructive Techniques for the Evaluation of Structures and Infrastructure", B. Riveiro & M. Solla Eds., 2016, CRC Press, Taylor & Francis Group, Book Series: "Structures and Infrastructures", ISBN: e-book 978-1-315-68515-1, hardcover 978-1-138-02810-4).

This book chapter presents a compilation of works regarding the use of GPR for road inspection. Different survey types, aiming at studying different road properties, are presented. All chapters on the GPR technique included in the book were prepared by Members of the COST Action TU1208.

References

[2] "Applications of GPR in association with other non-destructive testing methods in surveying of transport infrastructures," (book chapter in "Civil Engineering Applications of Ground Penetrating Radar"), A. Benedetto & L. Pajewski Eds., 8 April 2015, Springer, Book Series: "Springer Transactions in Civil and Environmental Engineering", ISBN: e-book 978-3-319- 04813-0, hardcover 978-3-319-04812-3; doi: 10.1007/978-3-319-04813-0.

This book chapter deals with the use of GPR and other non-destructive testing (NDT) methods in the evaluation of transport infrastructures. Investigations in roads and pavements, concrete and masonry structures, as well as tunnel testing, are mentioned. The book is an outcome of the COST Action TU1208.

References

[3] "Ground Penetrating Radar: fundamentals, methodologies and applications in structures and infrastructure," (book chapter in "Non-Destructive Techniques for the Evaluation of Structures and Infrastructure"), B. Riveiro & M. Solla Eds., 2016, CRC Press, Taylor & Francis Group, Book Series: "Structures and Infrastructures", ISBN: e-book 978-1-315-68515-1, hardcover 978-1-138-02810-4.

A short history of GPR and the main GPR applications are described in this chapter. The basic principles of the technique are also introduced, as well as the theory and fundamentals that govern the propagation of the GPR waves in media, the various possible operating modes for data acquisition, and some difficulties in data interpretation. All chapters on the GPR technique included in the book were prepared by Members of the COST Action TU1208.

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[4] "Non-destructive techniques applied to ancient masonry bridges assessment: structural diagnosis and geometric modelling," (book chapter in "Non-Destructive Techniques for the Evaluation of Structures and Infrastructure"), B. Riveiro & M. Solla Eds., 2016, CRC Press, Taylor & Francis Group, Book Series: "Structures and Infrastructures", ISBN: e-book 978-1-315-68515-1, hardcover 978-1-138-02810-4.

This book chapter presents the joint use of visual techniques (photogrammetry and laser scanning), infrared thermography and GPR for the evaluation of masonry arch bridges. Cases studies combining the three techniques are included. All chapters on the GPR technique included in the book were prepared by Members of the COST Action TU1208.

References

[5] "Non-destructive testing of tunnels: application of LiDAR and GPR technologies," (book chapter in "Non-Destructive Techniques for the Evaluation of Structures and Infrastructure"), B. Riveiro & M. Solla Eds., 2016, CRC Press, Taylor & Francis Group, Book Series: "Structures and Infrastructures", ISBN: e-book 978-1-315-68515-1, hardcover 978-1-138-02810-4.

This book chapter presents the application of GPR and LiDAR technologies for routine inspections in tunneling. Different case studies for underground tunneling prospection and quality detection are included. All chapters on the GPR technique included in the book were prepared by Members of the COST Action TU1208.

References

[6] "The use of geophysics for the condition assessment of railway infrastructure," (book chapter in "Non-Destructive Techniques for the Evaluation of Structures and Infrastructure"), B. Riveiro & M. Solla Eds., 2016, CRC Press, Taylor & Francis Group, Book Series: "Structures and Infrastructures", ISBN: e-book 978-1-315-68515-1, hardcover 978-1-138-02810-4.

This book chapter presents a brief overview of geophysical tools that can be used for railway inspection. The main areas of use of each tool are addressed, with special emphasis on the GPR method, which can be used for several tasks including: thickness measurements, detection of changes on track geometry, fouling level of ballast, etc. All chapters on the GPR technique included in the book were prepared by Members of the COST Action TU1208.

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References

[7] “Inspection Procedures for Effective GPR Surveying of Buildings,” (book chapter in “Civil Engineering Applications of Ground Penetrating Radar”), A. Benedetto & L. Pajewski Eds., 8 April 2015, Springer, Book Series: “Springer Transactions in Civil and Environmental Engineering”, ISBN: e-book 978-3-319-04813-0, hardcover 978-3-319-04812-3; doi: 10.1007/978-3-319-04813-0.

This book chapter deals with the use of GPR for the surveying of buildings. The book is an outcome of the COST Action TU1208.

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[8] "An evolution on GPR surveys of large archaeological sites," (book chapter in "Looking to the future, caring for the past. Preventive archaeology in theory and in practice"), F. Boschi Ed., 2016, Bononia University Press, ISBN: 978-88-6923-173-5.

This book chapter focuses on the recent evolution from single-channel to advanced multi-channel data collection that allows to obtain full-resolution images of large sites. Three different projects, where GPR was used to prospect archaeological areas, are described.

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References

[9] "GPR surveys in archaeology and additional interpretational methods," (book chapter in "Looking to the future, caring for the past. Preventive archaeology in theory in practice"), F. Boschi Ed., 2016, Bononia University Press, ISBN: 978-88-6923-173-5.

This chapter presents different case studies where GPR was used for archaeological investigations and cultural heritage diagnostics. Different indoor surveys are included, as well as the evaluation of historical monuments. It illustrates how visualization enhancements and 3D imaging techniques are important for a better comprehension and interpretation of GPR data.

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References

[10] "Applications of GPR for Humanitarian Assistance and Security" (book chapter in "Civil Engineering Applications of Ground Penetrating Radar"), A. Benedetto & L. Pajewski Eds., 8 April 2015, Springer, Book Series: "Springer Transactions in Civil and Environmental Engineering", ISBN: e-book 978-3-319- 04813-0, hardcover 978-3-319-04812-3; doi: 10.1007/978-3-319-04813-0.

This book chapter presents the use of the GPR technique for humanitarian assistance and security. The fields of application include: the detection of mine and unexploded ordnances, the location of underground spaces, the location of human remains or living victims in disaster areas. The book is an outcome of the COST Action TU1208.

References

[11] "The prestige oil spill," (Chapter book in "Ground Penetrating Radar"), D.J. Daniels Ed., 2004, Institution of Electrical Engineers, ISBN: 978-0-863-41360-5.

This chapter work presents a case study where ùthe GPR method was used in inland areas and beaches of the coast of Galicia (Spain) affected by oil spill after the sinking of the Prestige Tanker, in November 2002.

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Author

Dr. Mercedes Solla (merchisolla@cud.uvigo.es) is an Associate Professor in the Defense University Center (Spanish Naval Academy) and a researcher in the Applied Geotechnologies research group at the University of Vigo. She is an active member of the COST Action TU1208 and the Vice-Leader of Working Group 4, dealing with the applications of Ground Penetrating Radar (GPR) outside from the civil engineering area and with the combined use of GPR with complementary non-destructive testing approaches.

Mercedes' research interests include GPR methodology and its applications, as well as the development of electromagnetic modelling approaches for an advanced interpretation of GPR data. She is the editor of a book on non-destructive testing and the author(co-author of more than 10 book chapters, more than 35 journal papers, and more than 80 papers in conference proceedings. For more info on Mercedes' scientific activity, please visit this website: https://www.researchgate.net/profile/Mercedes_Solla_Carracelas

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