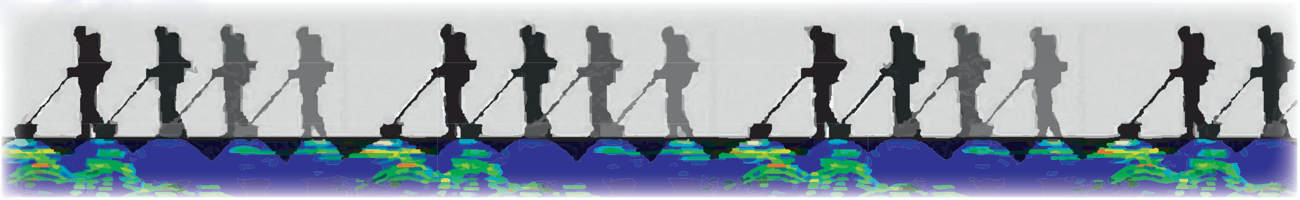
ORFEUS - Next Generation GPR Technology

Optimised Radar to Find Every Utility in the Street



Project Summary

1. ORFEUS Project Details

Contract number - 036856
Project acronym - ORFEUS
Project name - **O**ptimised **R**adar to **F**ind **E**very **U**tility in the **S**treet
Priority / Priority Component - Sixth Framework Programme
Priority [4], Global Change and Ecosystems

1.1 Strategic Objective

This project, co-funded by the European Commission's 6th Research and Development Framework Programme, addresses the requirement for technological tools for increasing the capacity of public and private utilities for the integrated management of buried infrastructure (area II.3.3). Specifically it fulfils the requirement for locating buried assets by means of new, reliable technology. Ground Penetrating Radar (GPR) is the only known non-invasive technique that can detect metallic and non-metallic buried objects, and this project will provide technical advances to significantly advance the state of the art performance.

1.2 Project logo

1.3 List of participants

OSYS Technology Ltd	United Kingdom
Ingegneria Dei Sistemi S.P.A.	Italy
GDF Suez	France
Tracto-Technik GmbH & Co.KG	Germany
UK Water Industry Research Ltd	United Kingdom
Eurogas-GERG	Belgium
Technische Universiteit Delft	Netherlands
Università Degli Studi di Firenze	Italy
Vysoke Uceni Technicke v Brne	Czech Republic

Total cost	€4,897,479
Commission funding	€2,697,814

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2. Project main goals

1 To provide a step change in the depth penetration and spatial resolution of GPR used for surveys carried out from the ground surface.
2 To produce a prototype, innovative, GPR-based real-time obstacle detection system for steerable bore-heads of Horizontal Directional Drilling (HDD) pipe and cable laying systems.
3 To increase knowledge of the electrical behaviour of the ground to enhance understanding of the sub-soil electrical environment and to provide information for scientifically based antenna design.

3. Key issues

Industrial societies have grown to be dependent upon services that are delivered by infrastructure buried in the ground, principally in roadways. The economic, environmental and safety implications of disruption to these services can be critical.

Traditionally, work on buried plant and equipment involves digging a trench, completing the work, and reinstating the filled hole. In recent years, the use of trenchless technology has significantly increased because of the economic benefits, particularly a reduction in the number and extent of excavations. Whichever method is used – trench or trenchless – there is a need to understand the nature of the underground environment that will be disturbed when planning new installations or when excavating to maintain existing infrastructure.

4. Technical approach

A. **Location and Mapping from the Surface**

An incremental development of conventional GPR technology cannot provide the step change in performance referred to in the Project Goals. ORFEUS will use new approaches in three key technical areas to :-

i. replace conventional pulse source and receiver technology with a high performance, cost effective, ultra-wide band Stepped Frequency Continuous Wave (SFCW) source and receiver;

ii. develop new techniques so that the sensor can adapt to the variations in ground characteristics found in Europe so that optimum performance is maintained in all conditions;

iii. design an innovative ultra wide-band antenna with characteristics that are independent of variable ground constituents, and that closely match the requirements of target detection.

Figure 1 Conventional surface radar

B. Obstacle Location and Avoidance via Bore-head Mounted Radar

The outcome of the second task must resolve several severe electromagnetic and mechanical problems in order to:-

i. provide durable antennas whose characteristics, in all types of ground conditions, are predictable, controlled and provide "look-ahead" and "look-sideways" capabilities;

ii. design ruggedised microwave sources and receivers that are able to survive the high g-force environment encountered in trenchless drilling equipment;

iii. develop new concepts for signal and data processing algorithms that will extract reliable information from the radar to help operators avoid obstacles in the drill path.

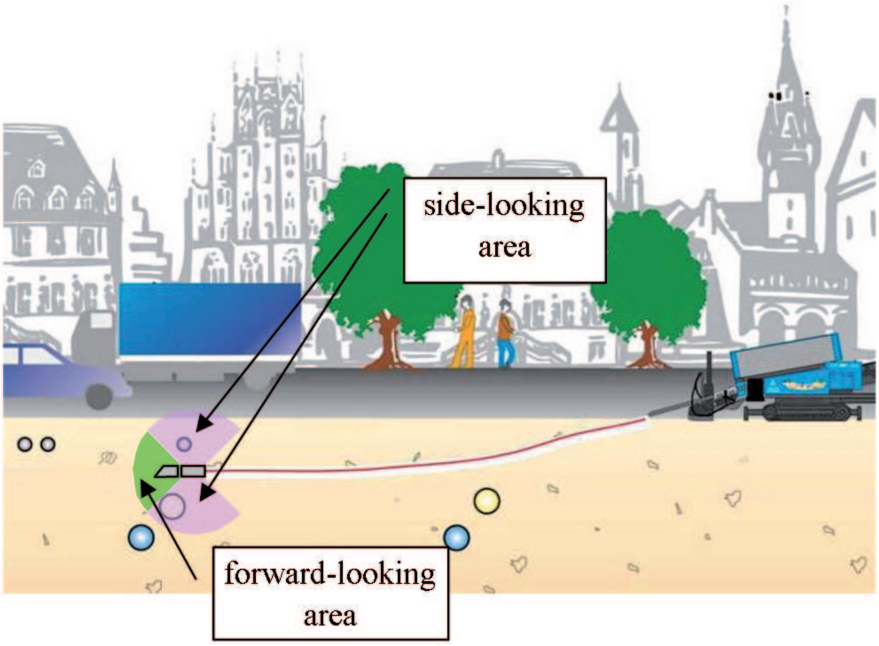


Figure 2– Bore-head Radar

The performance of both systems will be assessed though critical End-User tests in artificial and real-world (in-situ) test sites. In-situ tests will also provide information to allow the development of guidelines for the integration and use of GPR within Utilities' maintenance and replacement activities so that the best outcomes can be achieved.

C. Characterisation of Underground Environment

Knowledge of the dielectric properties of the ground is vital for both of the above tasks and ORFEUS will develop methods for reliable in-situ measurements of soil characteristics relevant to GPR. These measurements will also be used as an input for the other research activities to provide essential information on the fundamental limits of GPR detection and, as a result, guide equipment design decisions.

Expected achievements/impact

It is anticipated that the new technology will yield a step improvement in the key performance parameters of surface radar compared to current state of the art systems, principally with regard to detection depth and resolution of closely spaced buried pipes and cables. It will also provide a capability for obstacle avoidance that is not currently available for Horizontal Directional Drilling equipment.

The overall impact of the work will be to enhance the safety and efficiency of Utilities' maintenance and replacement activities. This will bring both environmental and economic benefits. In addition, there will also be a direct impact upon European citizens, who will benefit from a reduction in the disruption, noise and congestion caused by unnecessary street work activity.

6. Project results

6.1 Surface radar

The most critical system parameter for determining the detection performance of a GPR is its dynamic range defined as the ratio of the maximum received power it can handle to that of the minimum signal it can detect. Even the best pulse-based system, due to the wideband nature of the receiving process has a dynamic range which is unlikely to exceed 70 dB.

For this reason, ORFEUS sought to introduce Stepped Frequency Continuous Wave (SFCW) technology into GPR systems as an alternative to the present approach. A Stepped Frequency radar is similar to a Continuous Wave radar with the main exception being that the frequency can be changed in discrete, highly repeatable and stable, steps to cover the desired bandwidth. Following theoretical analysis, a novel UWB SFCW synthesiser was developed employing both DDS and PLL technology. A low noise heterodyne SFCW receiver was also developed with emphasis on the maximisation of its dynamic range.

Two dielectric embedded, resistively loaded shielded bow-tie antenna systems, were also designed specifically to be integrated with the ORFEUS Surface GPR. These antennas were highly innovative and were expected to be well matched in the entire ORFEUS ultra-wide operative band and to provide both high resolution and high signal penetration depth on most soils. Trials on the radar were conducted using this antenna and performance compared against a conventional, modified, production antenna.

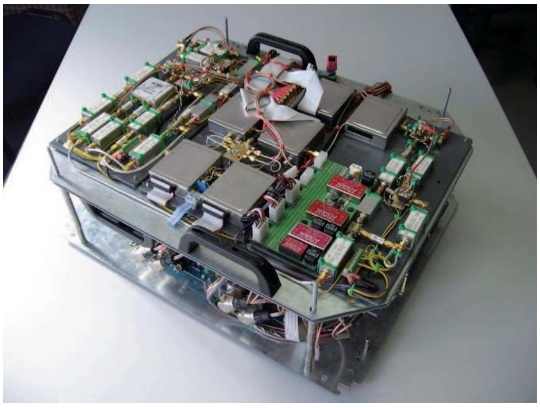
Trials of the radar system were carried out in 7 locations, carefully selected in collaboration with GPR end-users, to provide a realistic evaluation of ORFEUS detection performance in a wide range of typical operational contexts, with an emphasis on urban environments. Tests were carried out at a reference artificial test site operated by GDF Suez in San Denis, Paris, supplemented by further deployments in:

- Newcastle upon Tyne and Liverpool - UK
- Milan, Florence and Sardinia – Italy
- Villefranche - France

The spurious free dynamic range (SFDR) of the system was measured to be 85 dB, which yielded, approximately, a 30% improvement in detection depth with respect to a pulsed GPR system having the same spatial resolution. The ORFEUS radar produces detailed radar images, in difficult soil conditions, at depths exceeding 1.5m, thus fulfilling the main technological and scientific objectives (TSO).

Antenna characteristics limit the potential of the performance improvements that could be obtained from the SFCW system. Design issues have been identified that, if successfully addressed, would lead to a new high performance antenna that would provide an estimated 40% detection depth improvement over pulsed systems.

A further development of the novel ORFEUS-based Surface GPR product could, by the end of 2012, offer the GPR end-user community accurate mapping of utilities buried up to 2m depth, even in difficult soils.



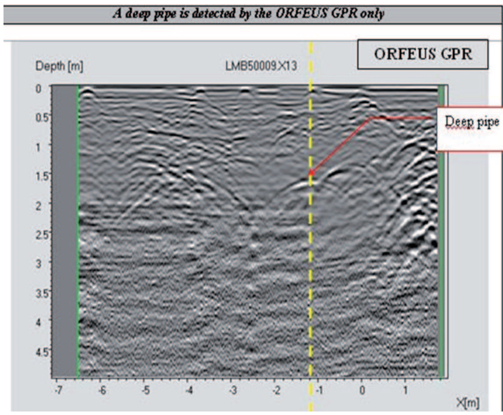


Figure 3 ORFEUS radar system electronics

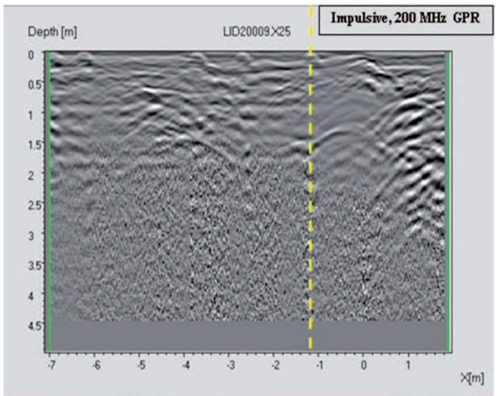


Figure 4 ORFEUS radar tests against pulse radar

Figure 5 ORFEUS versus pulse radar results

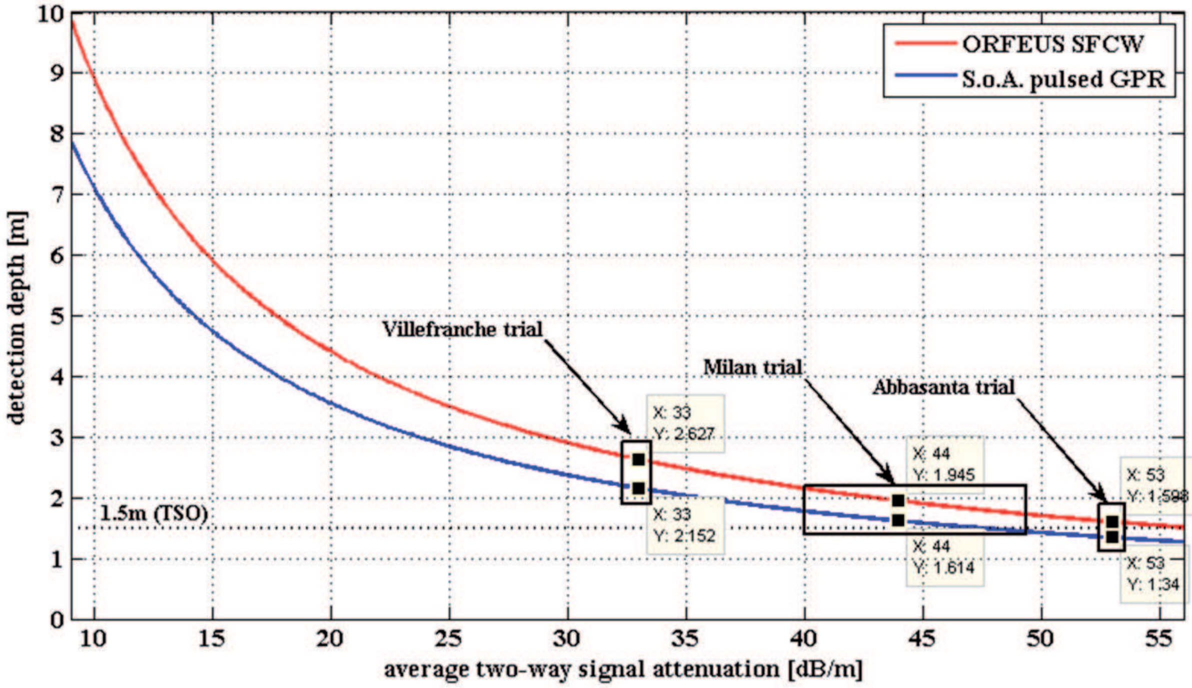


Figure 6 ORFEUS and pulsed GPR detection depths in different soils

6.2 Bore-head radar

During the project, a Bore-Head radar prototype was designed and manufactured by IDS and TT which was subjected to laboratory, test box and field trials carried out by IDS and TT. In addition, an evaluation of a proposed data communication system was carried out by OSYS and TT. A prototype bore-head radar system was produced that demonstrated:

1) The development of high performance radar antennas sufficiently compact be embedded in the drilling head

2) Shock absorbing mounting systems to enable the antennas to withstand the drill head vibration environment

3) The identification and use of new ceramic materials to produce electromagnetic windows sufficiently rugged to protect the antennas from the aggressive, high friction, soil environment

4) The demonstration of effective front and sideways looking detection capabilities

5) The demonstration of real-time data communications from the drill tip to the surface operator

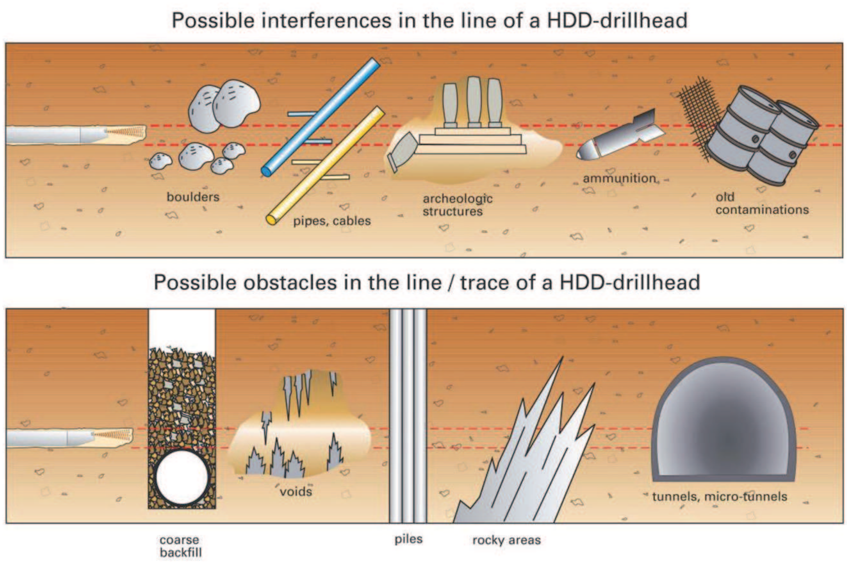


Figure 7 The HDD environment

From the results of the trials described above, and from additional theoretical work carried out by IDS, TT and OSYS, proposals are now made to:

- carry out further work for the rapid development of Bore-Head Radar system offering performance and operational benefits,
- identify issues to be addressed by a future programme of work that will lead to the availability, in the mid term, of a system offering enhanced performance and improved functionality.

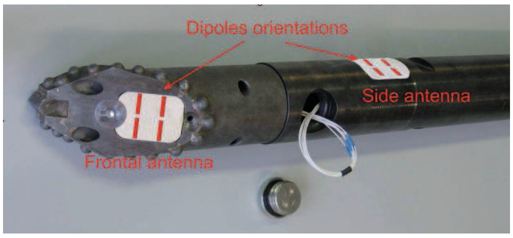


Figure 8 Bore-head radar sensors

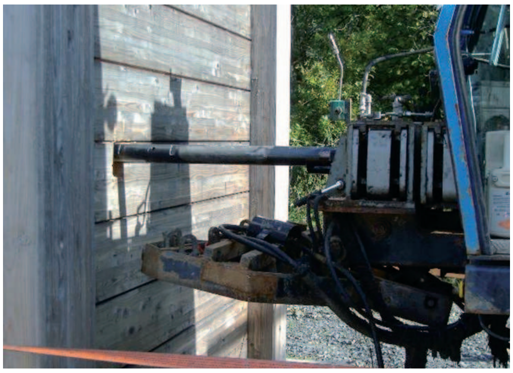
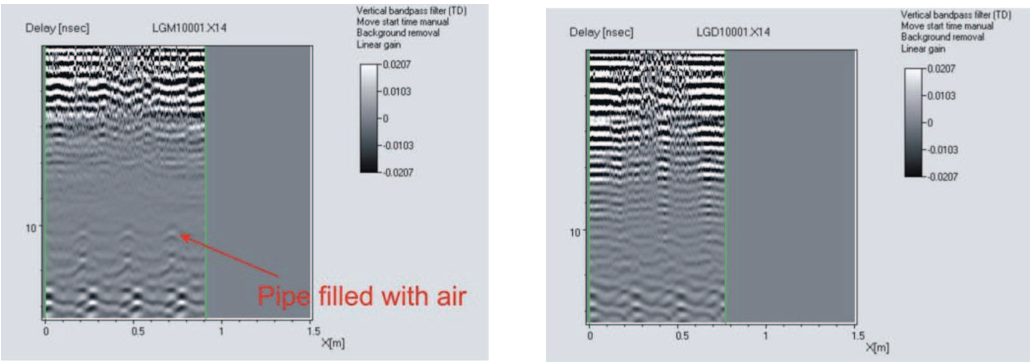


Figure 9 Bore-head radar pre-field trials

Figure 10 Bore-head radar on field trials



a) b)

Figure 11 Bore-head radar results

From the results of the field trial to evaluate existing equipment, two important issues have been identified as requiring further attention. These are data communication and robustness of the electronics

6.3 Soils measurements

Ground characteristics measurements had three objectives:

1. estimating the average vertical propagation velocity and the attenuation coefficient based on reflection data acquired in the field with commercially available GPR;
2. characterizing soil samples in terms of their complex electric permittivity in the laboratory for samples taken from surface to 1 metre depth;
3. determination of maximum detection depth of pipes and cables of different composition, located at various depths and in different types of soil.

To achieve these three goals work was carried out in two field sites and a constructed test site. Locations were chosen for difference in soil, in surface cover and control over the buried objects. Ground consisting of anthropogenic sand is characterized and sampled to the first metre of depth in two different seasons. Each of these samples is characterized by the complex permittivity in the frequency range of interest.

From the samples taken in the winter and in the summer, it was concluded that in the wet season water content does not increase with increasing depth, but water can be held up near the surface at high saturation levels, increasing the surface impedance considerably. This leads to reduced energy radiated into the ground resulting in decreased penetration and detection depth levels.

Figure 12 Anthropogenic layers

Figure 14 Measuring sub-surface velocity

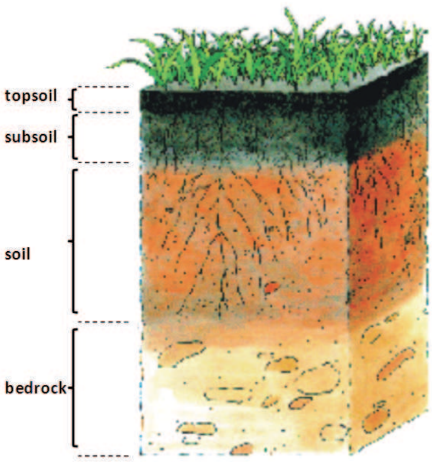


Figure 13 Typical profile of the ground.

Figure 15 Vertek SMR Probe

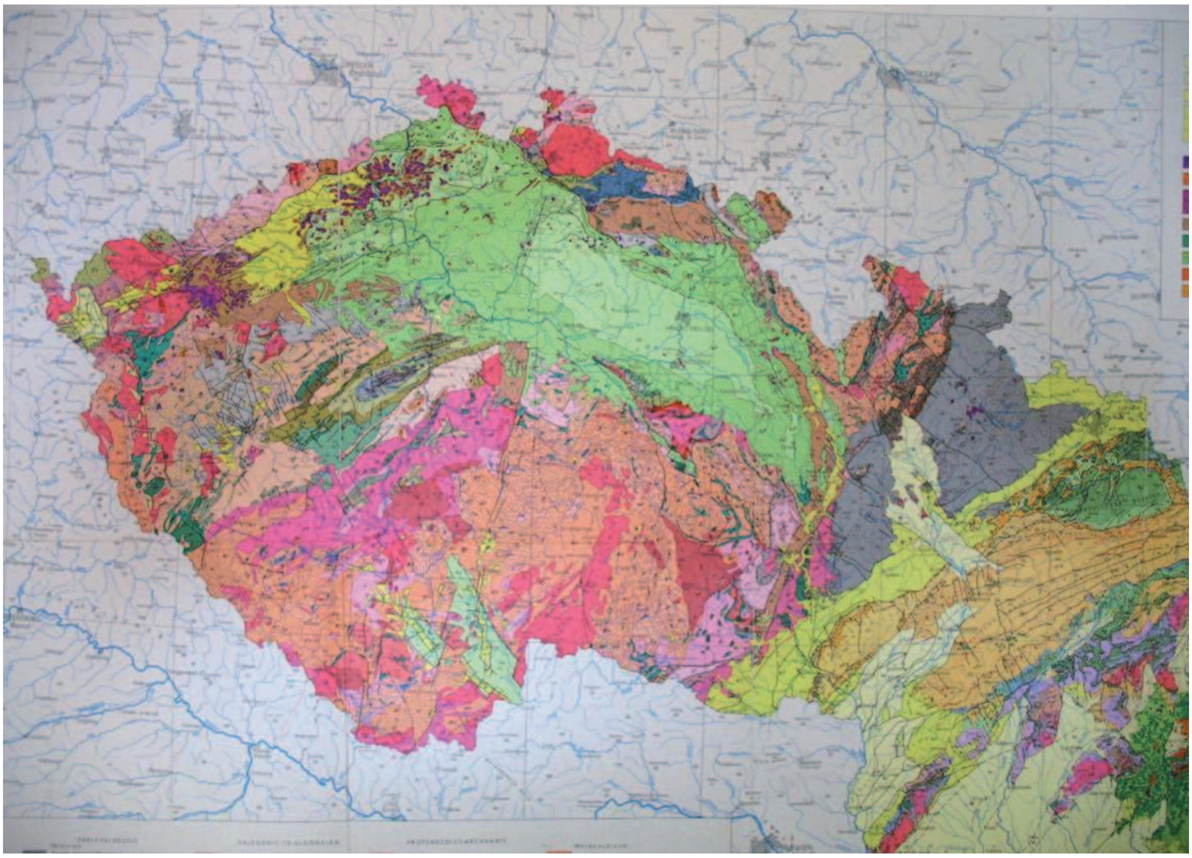


Figure 16 Part of overview geological map - Czech Republic - 1:1 000 000 Kodym, 1966

From the geotechnical characterisation, grain size distribution maps have been constructed from which hydraulic conductivity estimates are generated. Several soil types were simulated in the laboratory set up and their geo-mechanical strength was determined with a handheld penetration test device (DCP), but no clear connection between the obtained failure strength and the electric parameters could be given.

The landscape of EU countries is very variable, not only from the point of view of geomorphology and vegetation but also because of the quality of the ground. The various countries contain many types of rocks/ soils in different conditions of weathering, water saturation etc. Therefore a single map classifying the ground for GPR measurement in the detail needed for practical use would be extremely complex and difficult to interpret.

The cost effective solution achievable in reasonable time is to educate the workers in the measurement process. Workers who understand the measurement process will be able to adapt the parameters by, for example, delaying the measurement after heavy rain, and/or slightly changing the profile and/or optimising the setting of the GPR apparatus so that higher quality data for final analysis may be obtained.

The measurement results depend upon a complex methodology of measurement. Discipline is essential to avoid missing any important disturbing factors that may compromise the integrity of the whole process of measurement and analysis of the data. Those data may then become unreliable. Adhering strictly to the proposed methodology will increase the quality of final results of analysis.

7. User workshop programme

7.1 Paris 13th and 14th September 2007

Some 62 delegates enrolled for the event, from a wide range of countries and business interests. About two weeks before the event we placed a note on the web site advising would be delegates that the event was over subscribed due to venue capacity.

The conference day was mainly directed towards education, as the ORFEUS project work had yet to complete any major milestones. After an opening from our hosts, two user presentations give the view of agencies that perform GPR surveys for utilities. These gave an insight to weakness and strengths of current technology. A presentation on the technology of GPR explained how it worked. All these presentations are available on CD-ROM, and were also distributed to delegates.

Figure 17 Attendees at the Paris workshop

7.2 Birmingham 19th June 2008

39 delegates attended the event, which was co-located with GPR 2008 ayt Birmingham University.

Following user presentations from the City of Dublin, the presentations from the ORFEUS project team and an additional presentation from Enrico Boi of TST Engineering the workshop concluded with a feedback session managed by Andrew Thomas of Mapping the Underworld, and Jo Parker of Project Vista. The delegate feedback is recorded below. The workshop programme, and the presentations, as given on the day, were issued to delegates on CD-ROM .

Figure 18 The Birmingham workshop

7.3 Granada 28th May 2009

Co-located with IWAGPR conference, and attended by, approximately 70 delegates.

It was a half day programme of presentation and discussion. The series of ORFEUS workshops is intended to involve the user community in our research, development, and field testing, providing a valuable reality check for the project team, as well as sharing information back with the user community at large. It is part of our dissemination activity.

This workshop concentrates on technical issues, with five papers, followed by two sessions covering reporting on progress on the field trials, and maintaining a dialogue on other issues users have told us are important, such as quality, accuracy, and training/validation.

7.4 Pisa 26th November 2008

20 delegates attended the event at the Academia Palace hotel in Pisa.

This was a workshop and meeting orientated towards the GPR user community designed to involve users beyond the main project team – It was intended to appeal to users who need to be updated on issues of detailed performance of the new GPR being developed within ORFEUS and who have in an interest in the technology. It was also be a meeting for end users who wish to be involved in the ORFEUS test programme and who have offered test sites. It gave those users attending a direct input in to the extended test programme and planning of practical on-site GPR tests.

7.5 Southampton 24th February 2010

Co-located with the Mapping The Underworld project, managed by Birmingham University, and attended by 70 delegates. The event took place at the headquarters of the UK Ordinance Survey mapping agency.

This was the ORFEUS research project final public presentation, and will covered the original aims and the significant technical achievements of the project.

Figure 19 The ORFEUS project team in Southampton

8. Coordinator contact details

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