Practical Geophysical Methods of Cave Detection

*Geophysical methods of cave detection have, to date, reaped few positive results in finding new caves. As **Atanas Rusev** and **Tanya Slavova** report, however, this isn't inevitable. Here they describe cave detection, using ground-penetrating radar, magnetometry, gravimetry and infrared imaging, and illustrate the techniques with case studies showing the discovery of new caves and entrances.*

A lot has been written about geophysics for cave detection and, although it has confirmed the presence of known caves, little success has been reported in finding new caves, the existence of which were then confirmed by human exploration. Indeed, Mike Bedford (2012) discussed this problem in an article with the controversial title *Why Earth Resistivity Surveying Doesn't Work*. Although this referred to just one geophysical method, limited success has been reported with other techniques.

Here we present several geophysical methods and equipment we have used in the last decade to find new cave entrances, and promising cave areas which prompted digging. On some occasions, we've succeeded in finding new caves, which were then explored. We describe a practical approach that will be especially beneficial from the point of view of cavers and cave diggers, and illustrate the benefits on offer by referring to some case studies.

Ground-Penetrating Radar

Overview

Ground-Penetrating Radar (GPR) is a geophysical, nondestructive method that uses electromagnetic pulses and detects the reflected signals from subsurface structures. GPR is probably the best standalone equipment for cavers to find new shallow caves.

For the last 10 years, the main GPR equipment we've used has been from MALÅ GPRs – especially the MALÅ X3M and the MALÅ GroundExplorer systems. We have used them with 160MHz, 250MHz, 450MHz and 800MHz shielded antennas, and have succeeded in scanning and penetrating to a depth of 25m in different limestone strata. Lower frequencies allow deeper penetration of the signal but with lower resolution of the data. Penetrable cave galleries, in that respect, are rather large objects and detected successfully even on the maximum depth setting. The GPR equipment is expensive (€30,000+) and self-made GPRs are not an option, because they are not at all reliable.

Workflow

First, we investigate large areas in prospective zones for new caves with 160/250MHz antennas with a depth penetration down to 15m. When we spot anomalies, we collect data at a higher density and gather all the data needed to allow further 2D and 3D interpretation of underground cavities. After analyzing all the data, we make a decision about any further potential to penetrate the ground and find, in the data, the shortest or easiest way into the unknown cave.

Quite often we just need to dig a few metres of dirt or solid rock, but we have always found what we suspected, because of the integrity of the GPR method.

Practical use of GPR for cavers is enormous because, in real time, you can detect underground karst features, precise distance to the object, its shape, etc. The method is very fast, direct and reliable.

Case Studies

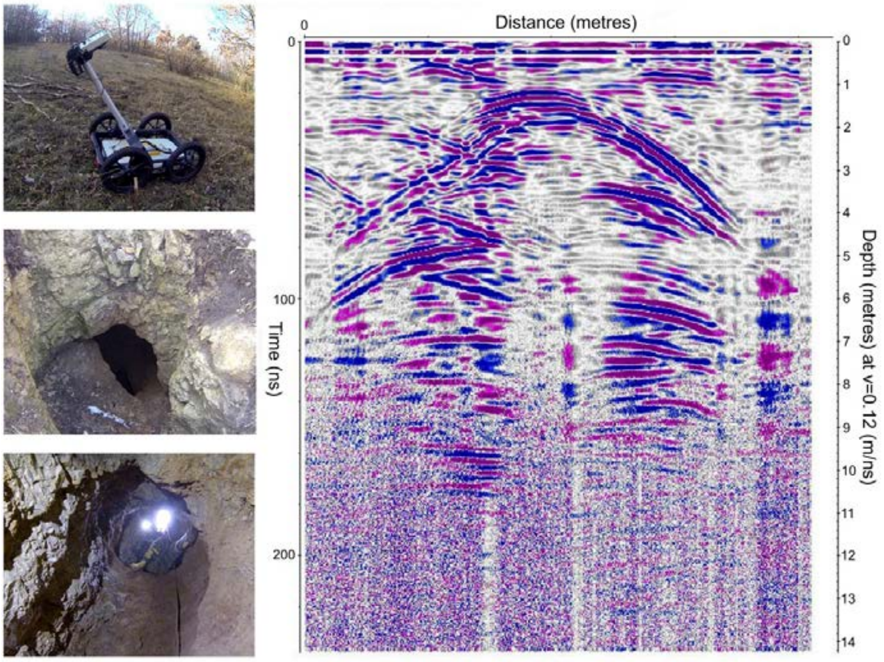
Here we present two case studies of GPR investigations for finding new caves.

On 15th June 2013, with the help of GPR, we found a new cave, now named Sunlivcite 2, which we entered after just a few minutes of digging from the surface. See the middle figure on the next page.

On 1st November 2014 we discovered a cavity in one GPR profile of a wide investigation campaign in a very likely area of the Bosnek Karst Area in Bulgaria. After 2m digging in solid rock, we found the top of a huge vertical pitch with a strong airflow. We suspect this to be a new entrance, named Chakula, to unknown parts of the biggest

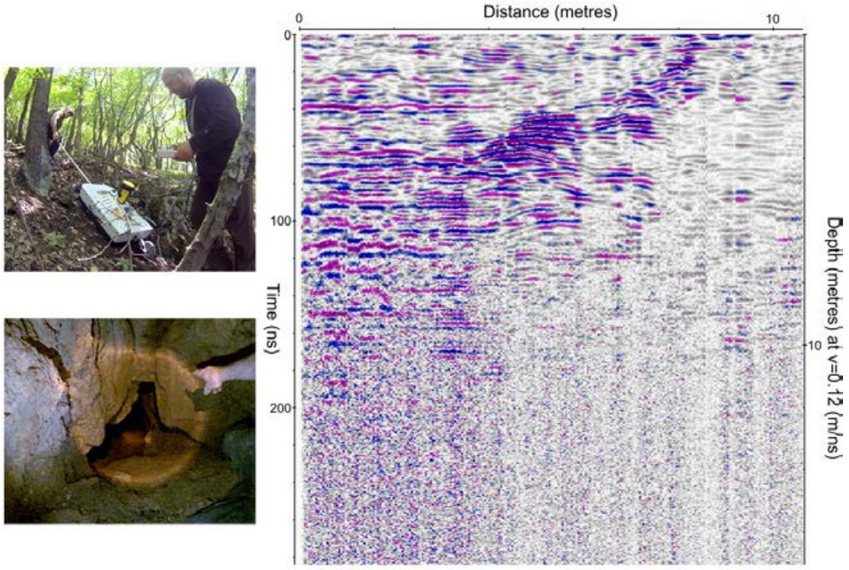
Typical GPR Configuration with 250MHz Shielded Antenna

GEM GSM-19 Magnetometer (Gradiometer) in Action



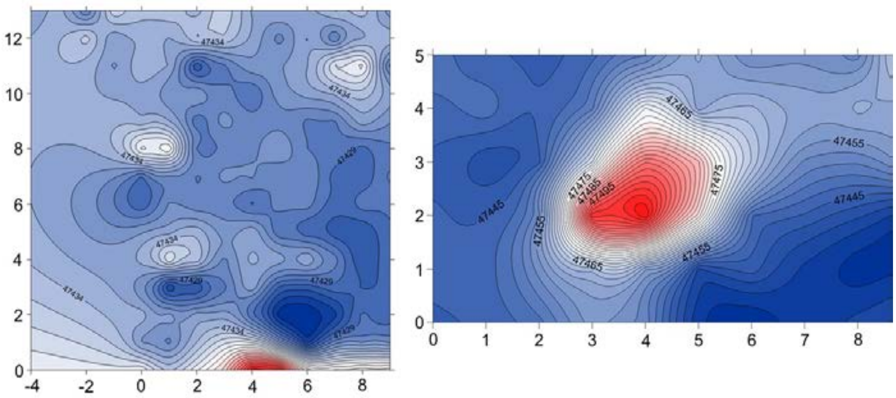
New Chakula Entrance Discovered using GPR

Left: Location before, after dig, and inside.
Right: In the GPR profile radargram, the hyperbolas clearly show an underground cavity.



New Sunlivcite 2 Cave Found with GPR

Left: Location before, and inside. Right: GPR profile radargram: the best place to dig is clearly visible.



Left: Typical dipoles that outline the underground gallery in Pepeliankata Cave (near to surface, 1-5m), Right: Roby's new cave entrance.

cave system in Bulgaria that we have been exploring for the last 30 years. The figure at the top of this page represents a vertical slice through the earth with discontinuities appearing as hyperbolas.

Magnetometer

Overview

Magnetometry is a technique for the very precise measurement and mapping of patterns of magnetism in the soil.

We have used the GEM GSM-19 (Overhauser) magnetometer. It has a sensitivity of 0.022nT @ 1Hz, a resolution of 0.01nT, and an absolute accuracy of ±0.1nT. The basic configuration cost is about €12,000. We tried several other basic and cheap magnetometers in the past without any success.

Many factors influence magnetism, and investigations and measurements have to be performed very carefully. The main factors for effective cave detection are present, however, namely the different susceptibility of limestone and air. These anomalies can result in magnetic dipoles with positive and negative poles. This is clearly visible in the graphic result, the magnetic dipoles appearing like bar magnet field lines (see figure below left).

Workflow

We always make a small grid (maximum 20m × 20m) to get data relatively quickly, because otherwise we have to use additional equipment for corrections. Also, the additional GNSS module ('walking gradiometer') is a plus. The main requirement is to carry out the survey in a 'clear' environment (i.e. no metal or electrical influences around). Further processing of the results is necessary to get the graphical picture.

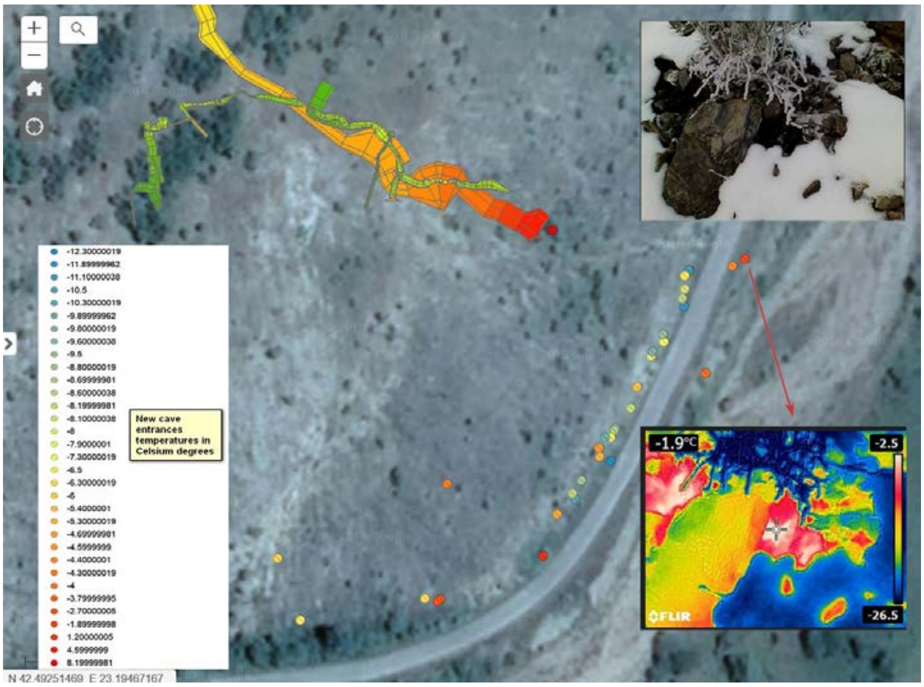
Case Studies

We have used this method with success to detect caves located near the surface. Here we present results from a magnetic survey of the known Pepeliankata Cave, for reference, because of its large volume close to the surface, and Roby's new cave entrance (in the Duhlata Cave area), that was later explored. See figure left.

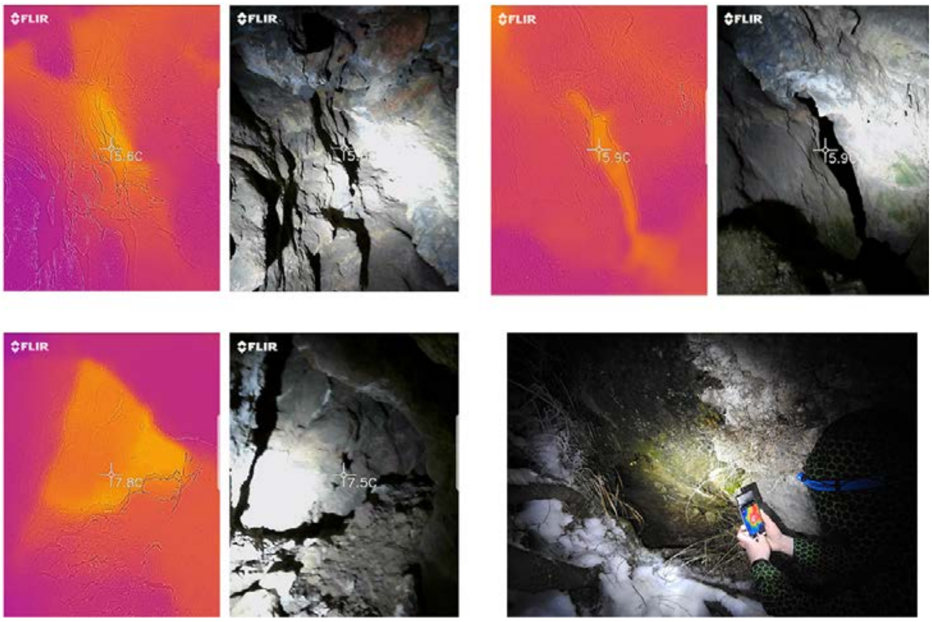
Thermal Imaging

Overview

Infrared cameras have been used widely to detect new cave entrances. Better still, if the proper atmospheric conditions (temperature, wind, etc.) are deliberately chosen, it is possible to detect shallow cave voids that don't have an entrance to the surface



IR detection of 32 new cave entrances near Pepeliankata Cave
Higher measured entrance temperatures are nearer to new cave.



Infrared Imaging Results

Top left and right: 'Invisible' crack into collapse in Christmas entrance.
Bottom left: Second place in collapse.
Bottom right: In front of the new cave entrance called The Clay Wind

In the past we used a Raytheon Palm IR-250-D infrared camera, but now we mainly use the FLIR E5 and FLIR ONE (or PRO). The latter is probably the best option for quality/price/usability – it costs about €230 or €500 for the PRO model. We also use DJI Inspire drones, equipped with a Zenmuse XT.

Workflow

For best results during a surface investigation, we choose very cold weather – a temperature of -25°C or less – with no wind, and no clouds. The best time, from our experience, is very early in the morning (rocks accumulate a lot of heat in daytime), before sunrise, and with just a thin snow/ice (spring time) cover. It is also possible to choose the opposite – in very hot days +35°C or more – with a proper temperature gradient of 20° or more.

Near the surface, but underground, we use thermal cameras to determine the appropriate place to dig, to find new entrances or new cave passages. This is mainly used in collapses or places where we cannot determine the exact source of the airflow (on specially chosen cold days, because the rock layer in the first 10-15m of depth has to be colder than the inside cave temperature).

We collect all possible data from the infrared camera, including exact coordinates of locations with an accurate GNSS receiver. This allows the results to be recorded in a GIS, and thereby allows the results to be checked with GPR, on warmer days, before digging.

Case Studies

An IR investigation was carried out using a FLIR E5 to search for new, lower floors of Pepeliankata Cave, close to the Duhlata Cave System. We suspect a huge part of Duhlata cave is still not discovered. This includes a possible underground river, located in the suspected unknown lower floors of Pepeliankata Cave. The outside temperature was -27°C and that morning we found 32 possible new entrances, which were further analyzed with GPR. Some of the entrances were dug, but still we have not managed to enter them.

The other exercise is a thermal investigation of a large collapse that we found after digging 8m from the surface in the new Christmas cave entrance, located by following hot airflow detection. This thermal study showed us the right place to continue with the dig, a technique that we started using in 2018 and is first reported here.

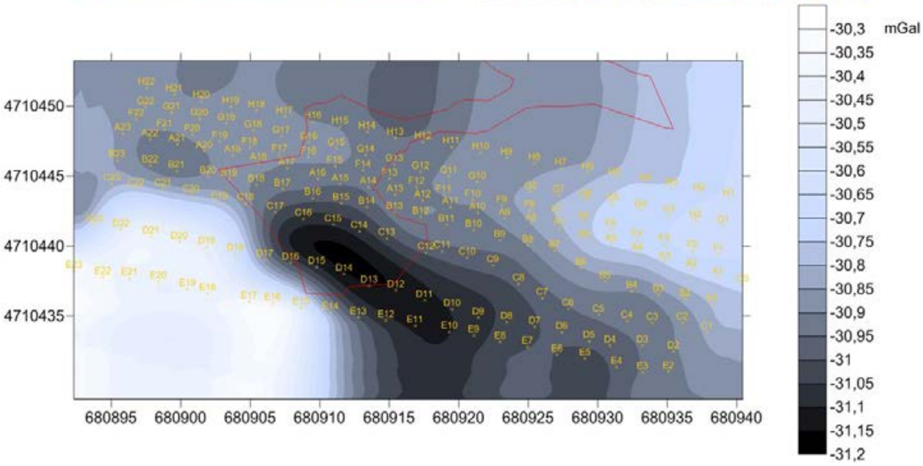
Gravimetry

Overview

Gravimetry is another geophysical method that is very suitable for cave detection. It is sensitive to differences in density – the higher the density contrast between a feature and its surrounding environment the greater effectiveness of the method. Therefore it is more suitable for dry caves than those filled with water. The size, and especially the depth of a cave, also matters – smaller and deeper features are hard to detect.

Major advantages of this method are the portable instrumentation, the possibility of one-man operation, and its silent and non-intrusive performance. However, an essential difference between this and some other methods is that the results are not available in real-time because the data requires additional post-processing.

For our investigations, we have available a LaCoste & Romberg model G gravimeter. It has a sensitivity of 0.04mGal which is not perfect for cave detection, but it is enough for our particular needs.



Gravimetric Cave Detection

Top left: The entrance of the cave, and part of the slope where the grid was laid. Top right: Using the gravimetric equipment. Bottom: The cave outline is shown in red. The darkest area is over the cave entrance – the shallowest part of the cave; low gravity values indicate possible cavities.

Workflow and Case Study

We staked out a grid of 23 × 8 points, spaced roughly 2m apart from each other. The array was placed over a known cave – named Zhivata Voda – to study the effectiveness of the method and also to improve it over an extended area.

The results seemed reliable, but it was pretty hard to make our measurements in such a harsh environment – the average time spent on each point was 10 minutes, but it often required even longer.

In total, it took weeks to complete our work on this grid.

This investigation was used for calibrating the method for that specific area to make another investigation nearby to detect cavities and to find the origin of the unique pulse spring Zhivata Voda.

We now know that if we are to use gravimetry for cave detection, we need a more recent gravimeter, in terms of speed of work, analysis and quality of measurements.

Other Methods

In addition to the methods discussed here, we also use several other techniques. Included here are Electrical Resistivity Tomography (ERT), air flow (hunting hot/cold air currents) and dowsing. Remote methods have also been used, including satellite/SAR/thermal/multispectral imaging, and data collection using drones, followed by various forms of analysis such as orthophoto, thermal imaging, and LiDAR (for example in Yucatán, Mexico).

GIS and Multi-sensor Cave Detection

We include all data collected in advanced GIS (Geographic Information System) software, which is also available as a mobile application for field speleological explorations. This way, an explorer can analyze all the data, even in the field, or collect new data in real-time. These data are automatically and immediately available to all members of the exploration party with the help of the GIS server and mobile technology.

In this article we've described the use of particular geophysical methods used in isolation for finding new caves and entrances. However, using several methods and combining the results in a GIS is an extremely valuable technique for exploration in speleology.

We plan to discuss this multi-sensor approach to cave detection in a forthcoming article.

Reference

Bedford, Mike (2012) *Why Earth Resistivity Surveying Doesn't Work*, CREGJ **78**, pp. 6-9.

Atanas Rusev

Atanas has been a caver and mountaineer since 1984, with a passion for exploring new caves which started in 1987 with the discovery of the Edelweiss cave system. In 1990 he founded Club Extreme in Bulgaria, and the very same year, they made a major cave discovery in Vreloto Cave.

He is a cave digger and explorer of many new big caves in Bulgaria. Atanas has been involved in 3D cave mapping, and has actively used GIS technology in exploring karst areas. Since 2007 he has used GPR for detecting new caves. He is the GIS Manager of the Bulgarian Geoinformation Company and now uses magnetometers, infrared cameras, remote methods etc. for finding new caves. He has created and supports mobile GIS applications for several cave areas in Bulgaria and for underwater caves in Yucatan, Mexico, since 2015.

Tanya Slavova

Tanya Slavova is a geodetic engineer who graduated from the University of Architecture, Civil Engineering and Geodesy in Bulgaria in 2011. The beginning of her caving experience dates back to the same year and led her to a PhD in detection of underground cavities by gravimetry.

Starting with interests in physical geodesy, GIS and GNSS, over the years her research has extended into geophysics, geo-archaeology, remote sensing, etc. This project was rewarded by the Karoll Financial Group under their PhD Fellowship Program in 2014. After a successful defence in 2016, Tanya Slavova is currently an Assistant Professor at the University of Mining and Geology in Sofia. Her caving interests are related to surface detection and 3D modelling. Her experience includes cave systems in Bulgaria.