While Britain has benefited from mined wealth for centuries, historical mining activity has left a hazardous legacy of unrecorded shafts. These are now being revealed using cutting-edge imaging techniques.

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Locating lost mineshafts

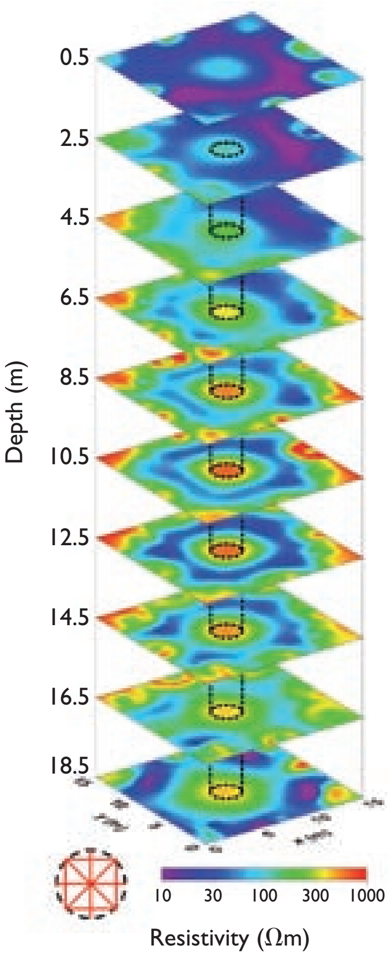
Mine workings associated with the extraction of coal, metalliferous ores and other economic minerals are ubiquitous across almost all inhabited areas of the world. Industrialised countries that have extensively exploited their energy and mineral resources are particularly affected by the legacy of mining. For example, in the UK there are likely to be more than 250 000 disused shafts associated with old workings. The history of mining extends over many centuries and consequently the locations of many workings and shafts are unknown or cannot be precisely fixed. Areas affected include many towns and cities, which grew up during the Industrial Revolution in close proximity to the sources of valuable materials such as coal and iron. Today, shafts may be found in any condition from open holes to those with well-engineered permanent caps, although most shafts have only a temporary capping.

Mineshafts pose a number of significant hazards, particularly when land containing them undergoes redevelopment. Many old shafts are in a dangerous condition and have been left open or treated using only cheap temporary measures. In such situations small disturbances of the ground can cause a collapse. Furthermore, gradual subsidence can occur due to the slow collapse of shafts or the progressive settling of infill material. Another hazard associated with old mineshafts is groundwater pollution. This may arise from the frequent practice in the past of tipping waste into open shafts, or from contamination caused by the mining operations themselves. Gases and vapours emanating from shafts can also present hazards to people and property. Explosion, asphyxiation, or the corrosion of foundations are all possible, depending on the type of gas involved. Consequently, it is important that we are able to detect shafts so that remedial measures can be taken.

Mineshaft detection

In the absence of accurate historical records, we must employ ground investigation techniques to detect mineshafts. Direct methods include drilling, trenching, and surface stripping. But these methods can often be expensive, impractical, and are not guaranteed to detect the presence of shafts. Even surface stripping can be unsuccessful if the top of the shaft is deeply buried.

A new approach to the problem is to use geophysical imaging techniques such as electrical resistivity tomography (ERT). The primary benefit of using geophysical imaging alongside more conventional direct methods is that it fills in the information 'gaps' between discrete intrusive sample points with



A 3D resistivity image of a mineshaft. The central resistive feature in the image corresponds closely to the actual location and geometry of the air-filled shaft (shown by the dashed lines).

A resistivity imaging survey in progress.

spatial and volumetric data. Geophysical survey techniques are also relatively rapid compared to many intrusive methods. They also employ lightweight equipment, which is an advantage when working on unstable ground. Some techniques that can be deployed at the surface are also minimally invasive. However, in the built environment, structures such as buildings, roads, and other services may prevent the use of surface-based techniques. In these situations, cross-borehole imaging can be a particularly valuable investigative tool.

3D resistivity imaging

ERT is now a well-established tool for site investigation, and is routinely applied to the detection and characterisation of engineered structures. This technique can detect the contrasts in resistivity that may exist between the shaft and bedrock material. If the shaft is filled with air, it will be revealed as electrically more resistant than the surrounding rock. If however, the cavity is flooded with water, it will normally be more conductive than the shaft walls. Even if shafts have been infilled, there will often be a contrast between the resistivity of the shaft and the bedrock due to differences in the packing and composition of the fill material.

We have recently developed 3D ERT for the detection of mineshafts through a research project led by the BGS. The work was commissioned by the UK Coal Authority (CA) as part of a wider research programme investigating the suitability of different geophysical techniques in detecting hidden mine entries. For this study, a number of 'built-environment' sites containing open and backfilled mineshafts were selected. The investigations were carried out in two phases. In the first phase, surface methods were used to identify electrical anomalies likely to be associated with mineshafts. These were intended as blind tests, so the surface at each site had been prepared by the CA to remove any trace of the shaft location. The second phase involved cross-borehole surveys. Boreholes were drilled around the shaft locations that had been deduced from the surface investigations, and confirmed by the CA. These surveys were intended to test a mode of deployment suitable for investigating ground beneath buildings or in confined spaces.

These studies demonstrate that both surface and cross-borehole 3D ERT are powerful tools for shaft detection and characterisation that can complement and enhance existing conventional site investigation strategies. The suitability of a particular mode of ERT deployment (whether it be surface or cross-borehole) should be determined on a site-by-site basis, and will be controlled mainly by the prevailing surface conditions. While these studies have focused on using ERT for imaging man-made structures, the technique is equally suited to detecting naturally occurring features such as sinkholes, dissolution pipes and caves.

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An abandoned mineshaft prior to capping.