Impacts of abandoned mine workings on aspects of urban development

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Synopsis

Man-made 'geohazards'—which can take the form of undermining, mine entrances, fault reactivation, mine-water rise, disposed wastes, derelict and contaminated land and subsurface civil engineering activities—are widely distributed in the United Kingdom, which has a history of mining activity dating back more than 3000 years. Many urban environments are located in regions where mining has occurred and abandonment has left a legacy of old workings and mine entries, many of which may still be uncharted and can be hazardous to development. The many aspects of mining and other human activity that give rise to potential geohazards are reviewed. Site investigation techniques appropriate to mining areas are discussed, with particular emphasis on rapid non-destructive (geophysical) survey methods. Geohazards that result from human activity can also have a considerable impact on urban areas when manifested after completion of a building or construction project. In an extreme case these hazards can result in both injuries to local residents and damage to property. More common, however, are a loss of property value and the creation of 'blight' when the presence of abandoned mine workings is identified. Some aspects of the current situation with regard to devaluation of properties as a result of the availability of information on abandoned mining activities are discussed.

In addition to the effect of natural geological processes, man has interfered with the ground by the extraction of minerals over the past 3000 or more years. Such activities have resulted in significant changes at the ground surface, including long-term subsidence over large areas and catastrophic failure at localized points where mine workings are close to the surface. Opencast mining of coal and other minerals has resulted in major changes to the topography and also in subsidence of the ground surface as overburden materials were replaced following removal of the mineral.

Quarrying is another human activity that has sometimes created large holes in the ground as man has extracted rocks both for building stones and to crush for aggregate. The excavation of cuttings and the construction of embankments for road and rail links are two major human activities that have modified the landscape in many parts of the world. Where both quarries and cuttings have fallen into disuse the empty space has been utilized for the disposal of waste material from a variety of sources and dumping of waste is now a major industry in the United Kingdom. Once the quarry or cutting has been completely infilled the ground is allowed to settle and consolidate so that it can be reused for the construction of housing and industrial and commercial buildings.

Unfortunately, many mining activities carried out in the past have been covered over and hidden by later development, such as the construction of housing estates, new factories, office blocks and roads. These hidden 'geohazards' often manifest themselves many years after completion of the construction projects, so that considerable damage and, at times, loss of human life can occur. Thus, knowledge of the location of geohazards left by past mining may be regarded as essential both for urban development and prior to purchase of a property.

In such areas the site investigation process falls into two parts. First is the desk study in which information held by a wide range of organizations (for example, local authorities, the Ordnance Survey, the Coal Authority, the British Geological Survey and the Environment Agency)[19] should be consulted to determine what is known about past mining activity. It can be difficult and time-consuming to find this information, even for professionals. However, the last few years have seen the development of digital information systems that can guide land- and property-owners and their advisors on the likelihood that mining (and other) hazards are present and also suggest where further advice may be obtained. The cost of such information may be quite low (tens of pounds to a few hundred). The information systems will usually distinguish sites with no hazard from those with a significant hazard and those with a possible hazard. Where a possible hazard has been identified recommendations as to whom to approach for further advice will usually be made. For home-buyers this may be all the information that they need to make a decision on whether or not to buy.

For larger purchases or developments a ground investigation probably will be required. In areas of abandoned mine workings conventional site investigation methods, such as drilling and trenching, are often inappropriate. For example, a search for a possible abandoned mine-shaft of 1- to 2-m diameter by the use of drilling or probing could take a long time and be excessively expensive. In such circumstances non-destructive methods, such as geophysical techniques, have proved effective and these are described briefly below.

Geohazards that arise from human activity

Although man has interacted with the ground for only a few thousand years, the effect can be highly visible and can have a significant effect on subsequent development. The main geohazards relate to: (1) what has been taken from the ground (by mining); (2) what has been put into the ground (waste disposal and pollution); and (3) changes that have been made to the ground (engineering).

Undermining

Undermining refers to the (often very old) extraction of mineral deposits (metalliferous minerals, stone, gypsum,

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limestone, chalk, coal, etc.) by underground workings. These workings can take the form of bell-shaped chambers (bell pits), near-horizontal excavations, in which the roof is supported by pillars of unworked mineral (pillar-and-stall workings), or stopes, which are steeply inclined passages that follow mineral veins with near-horizontal adits running off from the main passage. All such workings may have had the supporting pillars partly removed ('robbed') on completion of mining, so that partial collapse may have taken place, or they may have been partly backfilled with waste material. Supporting pillars may deteriorate with time, leading to eventual collapse. Most of the old bell pit and pillar-and-stall workings were quite shallow, at depths of less than about 50 m. Salt, too, has been extracted—both by the extraction of natural brines (wild brining) and by the pumping of water into the ground to dissolve the mineral followed by pumping of the brine to the surface (controlled solution mining).[5]

More modern coal mining has been carried out largely by the use of longwall methods, in which the area adjacent to the working face is supported to protect the miners. Once a long section of coal has been extracted the support is moved forward and the previously supported roof is allowed to collapse. This has led to subsidence at the ground surface and consequent associated damage to buildings and structures. This subsidence does not occur instantaneously, but is a process that involves, first, compression and then tension at the surface as the working face moves laterally.[6] Mining subsidence is usually considered to have ended within a few years of the cessation of mining.

Mine entrances

Access to mines was usually either via near-vertical shafts or along near-horizontal or inclined adits. These entrances may have been covered or capped on completion of mining or may have partly collapsed. In either case they may no longer be apparent. With time coverings or caps can deteriorate, leading to later collapse. Mine entrances are not easy to locate by direct methods, such as pitting or drilling. However, the use of electromagnetic and magnetic methods has proved successful in locating shafts, whose presence can then be confirmed by excavation.[17]

Fault reactivation

Geological faults, when located within an area where mining subsidence is taking place, are susceptible to reactivation.[9] This can result in disruption of the ground surface due to the formation of fault scarps, compression humps and ground fissures. These features are often referred to by subsidence engineers as 'steps' in the subsidence profile or 'break-lines' along the ground surface. Fault scarps may be up to 3 m in height where three or more seams have been extracted. The zone of ground deformation is usually limited to a few metres either side of the fault but can be more, depending on the geotechnical properties of any superficial deposits that may be present.

Mining-induced fault reactivation, during subsidence, can cause damage to civil engineering structures, residential property, industrial premises and transportation networks. Movement along faults can also damage underground services, such as gas and water mains, sewers and communication cables. Agricultural land can be disturbed by alteration of the gradient and flooding. Faults may also act as permeable conduits for groundwater and mine-water discharges. Furthermore, noxious and potentially explosive gases from mine working or waste disposal may discharge from geological fault outcrops (see later). Donnelly[10] has provided several examples of damage caused by fault reactivation in the east Midlands of England.

The likelihood of damage should a further phase of reactivation, mine-water discharge or mine-gas emission occur can be reduced by locating a building or structure a short distance from the fault outcrop position. If geological faults are suspected during development of land, they should be located accurately and avoided.

Mine-water rise

The complete closure of a coalfield and cessation of pumping may result in the regional recovery of groundwater levels and the flooding of abandoned mine workings. Should the mine waters reach the ground surface, discharges may occur, which can result in the pollution of surface water-courses and contamination of aquifer water supplies.[23,24]

Rising mine waters may penetrate geological faults and could contribute to a reduction in the shear strength of the fault through an increase in the pore-fluid pressure of the fault zones. This is able to counteract part of the normal stress acting across the fault and may result in reactivation in the absence of mining.[12] In addition, if rising mine waters reach currently unflooded, shallow, abandoned pillar-and-stall workings, pillar deterioration may result, with increased collapse of the old workings.

Faults may enhance the permeability of the rock mass between the mined seams and the ground surface, creating favourable conditions (pathways) for groundwater, mine-water and gas discharges into the surface environment. The rising water may cause subsidence by washing out clay or silt fines from granular materials. Aggressive waters may result in chemical attack on buried concrete structures and foundation piles. The gases may be explosive and/or noxious, potentially comprising methane (firedamp), carbon monoxide (whitedamp), hydrogen sulphide (stinkdamp), 'stythe' (also known as blackdamp, which is air depleted in oxygen and rich in carbon dioxide) and radon.

Waste-disposal sites

Waste comes in many forms: domestic, commercial, industrial, mining and radioactive and in the state of solid, sludge, liquid or gas; it can be non-hazardous or hazardous. Waste may undergo chemical alteration with time, degrading into harmful or harmless products. Waste can be disposed of on the ground surface, in disused surface excavations and underground, either in old workings or in engineered cavities. The waste may be dumped randomly, carefully placed or compacted (engineered). Waste-disposal sites present a significant hazard to building and construction when the contents and character of the waste at a site are not known, when leachates or gases leak from the site[22] or when the location of a site is not known. For example, destructive differential settlements have affected buildings built across the edge of completely infilled quarries or pits. Development responses to waste-disposal sites include avoidance of the site, re-engineering of the site, redisposal of the waste off site and containment and control with clean-up of any contamination to a 'fit-for-purpose' level. Guidance for construction on closed waste-disposal sites has been provided by the United Kingdom government[2] and by Leach and Goodger.[16]

Derelict and contaminated land

Derelict and contaminated land is usually a consequence of past industrialization and, often, urbanization. It is convenient to distinguish between derelict and contaminated land in terms of the former being despoiled by the presence of physical objects (basements, reinforcing, cables, drums, concrete, etc.), whereas the latter contains chemical substances (organic or inorganic) that, if present in sufficient quantities or concentrations, have the potential to cause direct or indirect harm to humans or the environment. Recently, the formal definition of contaminated land has been changed. Land can only be classified as contaminated if, as well as there being a source of contamination, there is also a receptor and a pathway between the source and the receptor. The receptor itself is also carefully defined in terms of humans, specified sites of environmental sensitivity and controlled waters (surface and ground). This is an interesting development that, in relation to potentially harmful chemicals in the ground, appears to move from the concept of identifying a *hazard* to one which involves identification of a *risk*.

The site investigation response to derelict land is no different from that applicable to a 'greenfield' site: volumes of ground (including man-made objects) that will affect the foundation design must be identified and their properties must be quantified. Contamination of land may, however, have no impact on the physical design of a foundation, yet may still affect the possible use of the building or structure. The site investigation must focus, therefore, on determination of the risk that any contamination poses to humans and the environment; to this end sources, pathways and receptors must be identified.[21]

Civil engineering activities

Civil engineering activities take place on the surface and below ground. In both situations hazards exist during construction, during operation and after the building or structure has been abandoned. Although there may be problems during construction on or close to the ground surface, in the United Kingdom the structure itself is rarely a hazard during its working life. After the end of its useful life a building may contribute to the problem of dereliction (see above). However, with structures at depth (tunnels and other underground spaces) problems of ground movement or even collapse may ensue. The collapse of the Heathrow railway tunnel and the explosion in the water transfer tunnel at Abbeystead, Lancashire, illustrate the problems that can occur. Ground movements associated with engineering and structures have been discussed at length in a number of publications.[4,13–15,7]

Geophysical methods for location of geohazards

Traditional ground investigation methods that make use of trial pits and boreholes can be expensive in areas of complex geology or where geohazards, such as mine-shafts, are suspected. In these circumstances a large number of pits and boreholes are required to achieve a sample density that is statistically valid to ensure that small but significant targets are located. A comprehensive programme of boreholes and trial pits is expensive and this has resulted in increased use of geophysical methods, which can provide additional information about the rock mass both vertically below the ground surface and laterally across the site.

The use of geophysical methods does not preclude the use of boreholes and trial pits since borehole logs provide direct geological information that can be used to calibrate the interpretation of the geophysical survey data across the construction site. The comparison of a geophysical interpretation with directly obtained geological data is known as 'ground-truthing.' This methodology enables the geophysical survey results to be extrapolated into areas where little or no ground truth information is available so that more confidence can be placed in the interpretation of the geophysical survey data.

It must be stressed that geophysical survey data on their own merely measure the vertical and lateral variation of the physical properties, such as electrical conductivity, magnetic, etc., of the geological materials at the site under consideration. These data can only be interpreted in the light of some knowledge of the likely ground conditions that will give rise to the data-set measured. In this respect there are two main approaches to carrying out a geophysical survey. The first is to measure a physical property, such as electrical conductivity, on a grid over the ground surface. Contouring of these data will locate anomalous zones, which may be associated with mine-shafts or adits. Further investigation of the anomalous areas is required, unless historical mining information exists that indicates the likely cause of the geophysical anomaly. The second approach is to measure a physical property along a detailed horizontal profile, such that details of the vertical variation of that property are determined. In this case the geophysicist attempts to produce a mathematical model of the geological structure, which will give rise to the measured geophysical data-set. Again, the accuracy of the model is largely dependent on the ground-truth information that is available either from historical sources or from boreholes and trial pits.

It is important to differentiate between these two approaches to geophysical surveying since the production of a simple, contoured geophysical map that identifies anomalous ground conditions is much quicker and less expensive than the more detailed survey that is needed to generate a model of both the vertical and lateral geological structure in three dimensions. The cost of obtaining a complete three-dimensional model of the geological structure or landfill distribution on a site can be four to five times greater than that of producing a simple, contoured geophysical map, and it is probable that lack of appreciation of this one factor has resulted in much of the bad press received in many areas where geophysical methods have been applied. As in all other fields, the final objective of a geophysical survey must be clearly specified so that it can be designed and costed appropriately to achieve the required objective.

In this application, where the requirement is to locate the position of buried mine-shafts and adits in a rapid and economic manner, only surveys of the first type are considered further here since rapid reconnaissance methods should be used in this application. Particular attention is paid to those methods which require no direct contact with the ground surface.

Magnetics

The magnetic method consists in the measurement of variations in the magnetic field of the earth caused by local differences in the magnetization of the subsurface rocks. The standard instrument in use remains the proton magnetometer and the major improvement to the instrumentation has been the addition of microprocessor control to record the data for downloading to a computer at suitable points in the survey. Modern instruments now include two magnetometers within the system so that measurements of the vertical magnetic gradient can be recorded.

Significant progress has been made in the mathematical modelling of magnetic data, particularly along profiles. It is common practice to produce two-dimensional geological models from the magnetic data, and this is often carried out in conjunction with the interpretation of gravity data along the same profile.

A magnetic survey is rapid and easy to carry out and a site can be surveyed with a close grid spacing (often 1 m) at low cost. The only correction required to the observed data is subtraction of the diurnal variation, which is usually recorded continuously throughout the survey period. This is not required if a magnetic gradiometer survey is carried out, since the gradient of the vertical magnetic field is measured by two magnetometer sensors separated by a fixed distance in the vertical plane, with simultaneous recording.

When a site has a long urban or industrial history it will invariably be littered with ferrous debris that may prevent location of the main magnetic anomaly. Some attention should be paid to the possible effects on the local magnetic field of magnetic objects carried by the operator. The method has particular application in the location of buried mine-shafts and adits.

Ground electrical conductivity

In the ground conductivity method a transmitter coil is energized with an alternating current and is placed on or above the ground surface. The time-varying electromagnetic field in the transmitter coil induces very small currents in the earth. These currents generate a secondary magnetic field, which is sensed together with the primary field by the receiver coil. The inter-coil spacing and operating frequency are chosen so that the ratio of the secondary to primary magnetic field is linearly proportional to the apparent ground conductivity. This ratio is measured and a direct reading of apparent ground conductivity is obtained. With a fixed separation of 4 m between the transmitter and receiver coils the depth of penetration is limited to less than 6 m, but the survey can be carried out rapidly and economically by a single operator.

It is important to realize that a ground conductivity survey does not supply the quantitative information on earth layering that can be obtained by resistivity sounding or seismic refraction surveys. However, as the technique is so cost-effective, it can be considered for the provision of non-quantitative data prior to drilling or to fill gaps between boreholes or resistivity soundings. The constant-separation equipment is particularly effective in the location of cavities or buried mine-shafts when used in conjunction with a magnetic survey. The measurements compare very closely with results obtained with conventional resistivity profiling and ground conductivity surveys should be carried out in preference to resistivity profiling where the depth of investigation required is appropriate for the method.

Ground-penetrating radar

Ground-penetrating radar has been introduced into site investigation over the past 20 years. The apparatus comprises a radar antenna that transmits electromagnetic energy in pulse form at frequencies between 25 MHz and 1 GHz. The pulses are partially reflected by the subsurface geological structures, picked up by a receiving antenna and plotted as a continuous two-way travel time record, which is displayed as a pseudo-geological record section. The vertical depth scale of this section can be calibrated from the measured two-way travel times of the reflected events either by use of the appropriate velocity values of electromagnetic pulses through the lithological units identified or by direct correlation with borehole logs.

The depth of penetration achieved by the radar pulse is a function of both its frequency and the conductivity of the ground. In the United Kingdom, where highly conductive clay materials tend to predominate in the near-surface, the maximum penetration is likely to be between 1 and 4 m, but useful penetration to greater depth can be achieved in more resistive geological environments. Ground-penetrating radar is not a reconnaissance method as defined above since it provides a radar cross-section of the geological strata beneath the ground surface rather than a contoured map identifying anomalous zones that may be associated with buried mine-shafts and adits. It is, however, a non-contacting geophysical method and can be used to locate hidden targets, although the cost of the survey may be significantly higher than that of a magnetic or electrical conductivity survey.

Gravity

The gravity method consists in measurement of variations in the gravity field of the earth caused by local differences in the density of the subsurface rocks. The technique is normally associated with large-scale regional geophysical surveys that investigate the geological structure to considerable depth. A more recent trend has been the use of microgravity surveys in the detection of natural cavities and mine-shafts, facilitated by the introduction of the La Coste Romberg Model D in the early 1970s, which enabled readings to be made down to 10 μgal.[18] This particular instrument is still the most widely used for engineering site investigation, although more modern meters with digital outputs have been developed.

Initially, gravity data were used to produce contoured maps to locate anomalous zones associated with a density reduction in the near-surface material resulting from the presence of a cavity. Significant developments in the mathematical modelling of gravity data enabled the geophysicist to produce two-dimensional geological models from data recorded along profile in the field.

The problem of equivalence remains a particular difficulty in the modelling of gravity data since the gravity profile can be modelled by a large number of possible geological solutions and additional information is required to constrain the model in some way. The gravity method is expensive because of the variety of corrections that have to be applied to the observed data. It may be the only geophysical method that is applicable in some instances in an urban environment, but in those instances significant terrain corrections might have to be made for local anomalies in built-up areas.

Thermal techniques

Despite the success of the geophysical techniques described thus far, a need remains for the development of further rapid, non-invasive, cost-effective techniques. Recent research has concluded that the ground immediately above mine entries may be warmer than its surroundings, so it is possible that mine-shafts may be located by thermal techniques.[11] Airborne infrared thermography is increasingly used in the survey of landfill sites and its application to the detection of mine-shafts is being researched. The technique produces an image of temperature variation over the ground surface. Ground investigations are necessary to calibrate temperature anomalies. Anomalies may be related to the release of mine gases, particularly through old mine-shafts.

The rate of fluctuation of barometric pressure has been found to be one of the major factors that influence the escape of mine gas into the atmosphere. The gases originate in rock formations and collect in discontinuities, pores and voids and in waste or stowed material in the mine, which act as a reservoir. If the barometric pressure falls gradually, the gases will be diluted adequately as they overflow into the ventilating currents. If the fall is rapid, however, and the ventilation poor, the volume of gas that escapes from the walls or waste in a short space of time may be sufficiently large to cause a dangerous fouling of the airways.

An increase of ground surface temperature above a mine-shaft is most likely to occur when there is a reduction in barometric pressure immediately after a prolonged period of high pressure. The high-pressure phase allows gas to accumulate in the mine workings. Mine-shafts may be envisaged as acting as intake and exhaust systems during periods of high and low pressure, respectively (Fig. 1).

Assessment of geophysical methods

All the geophysical methods described above require no contact with the ground surface for their operation. The most efficient approach to the location of anticipated geohazards

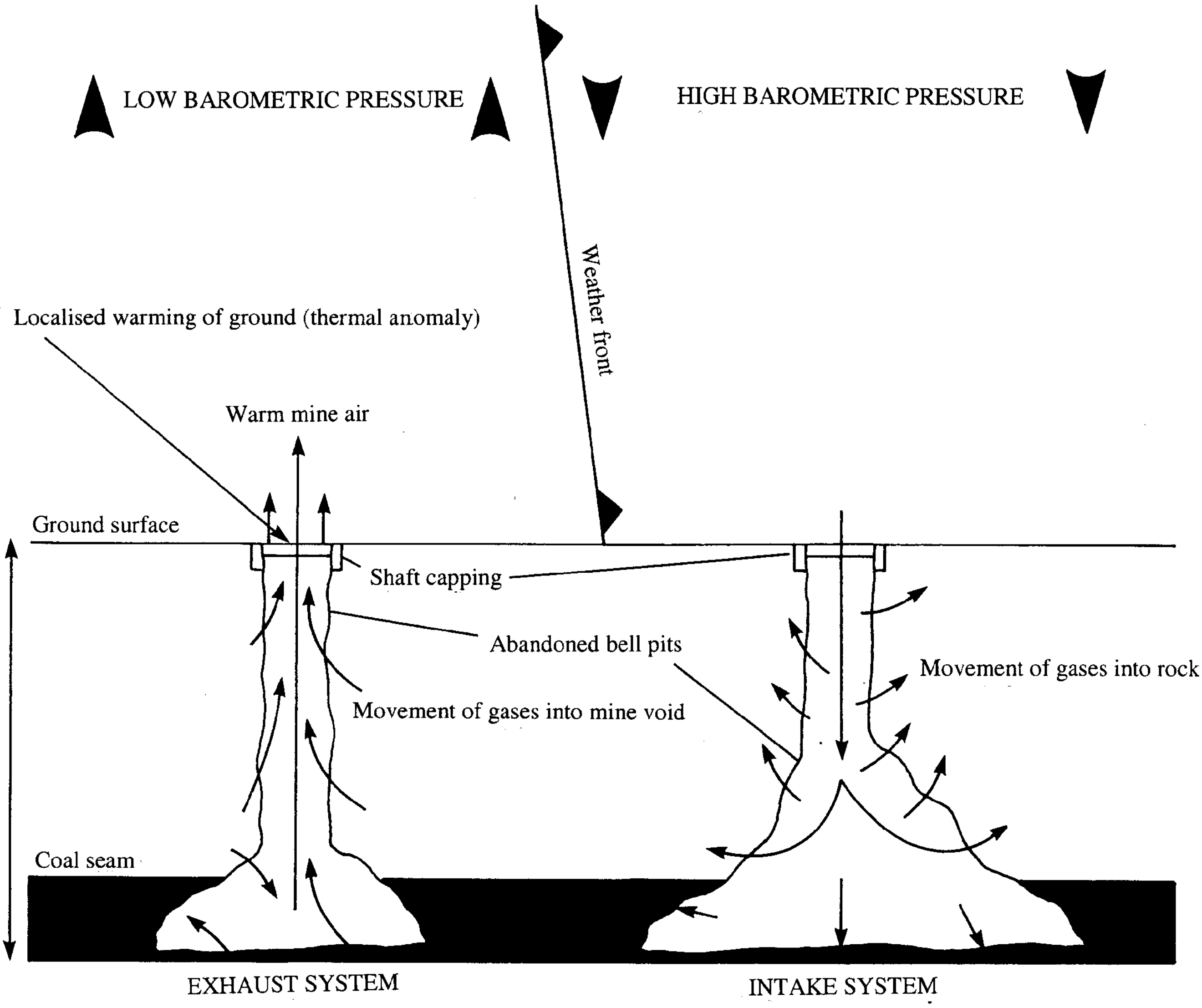

Fig. 1 Near-surface abandoned mine workings may act like an intake/exhaust system through which gases are driven by fluctuations in barometric pressure

on a site is a combination of the magnetic and ground conductivity methods used over the same survey grid. The magnetic method will respond to the presence of ferrous materials beneath the surface of the ground, whereas the ground conductivity method will respond to changes in the groundwater drainage pattern associated with the presence of, for example, sinkholes or infilled mine-shafts.

Ground-penetrating radar produces a radar section of the geological structure beneath the ground surface on a continuous basis. The depth of penetration of a radar pulse is largely a function of the conductivity of ground and it is common to carry out a ground conductivity survey of the area before going to the expense of a radar survey. If the ground conductivity is high, it is unlikely that the radar pulse will penetrate very far into the ground and a radar survey should not be proposed.

In an urban environment a gravity survey may be the only method that will work effectively because of the presence of electromagnetic noise and magnetic bodies. This method is, however, much less cost-effective than the magnetic or ground conductivity methods since the spot measurement of gravity takes about 10 min per station as opposed to 2 min per station in the other two methods.

The infrared thermography method is comparatively new and should only be used to assess large areas of ground, preferably from the air. It is likely to respond to the presence of buried mine-shafts only if the barometric pressure is low over the site. Infrared thermography is a highly specialized method with limited applicability to the location of mining-related hazards, but it can be used successfully on a regional basis in the correct weather conditions.

The five geophysical methods discussed here are listed in an order that reflects their ease of use and cost. A consultant geophysicist would always consider a combination of the magnetic and ground conductivity surveys as the first approach to the rapid reconnaissance of a construction site. Further information could be obtained if a ground-penetrating radar survey were judged applicable, and the three methods considered together would give an excellent appreciation of the ground conditions at a construction site.

It is difficult to make specific recommendations on the geophysical method to select for the location of hazardous ground conditions since this is largely controlled by the geology of the site and the state of the ground surface. A table listing the various methods and their likely areas of applicability has been published,[1] but this should only be taken as a general indication since a geophysical consultant should be asked to give guidance in most circumstances.

The cost of a geophysical survey depends on the specification of the survey recommended by the geophysical consultant. As a rule of thumb, each day spent in the field will require at least three in the office to interpret the data and prepare the report to the client. Approximate costs have been given in a recent report by the Construction Industry Research and Information Association and the Geological Society (Table 1).[3] These should be used for guidance only since, again, it is the site geology and ground conditions that control the time required to carry out the survey.

Table 1 Relative costs and output of land-based surface geophysical methods for location of mining hazards[3]

Method	Unit cost, £	Cost/day, £	Typical daily output
Magnetic (field/gradient)	0.5–1/station	500–1000	500–2000 stations
EM31* ground conductivity	0.5–1/station	600–1000	600–2000 stations
EM34* ground conductivity	2–5/station	600–1000	200–400 stations
Ground penetrating radar	140–1400/km	800–1400	0.5–10 km
Gravity	8–20/station	750–1200	50–100 stations

*EM31 and EM34: Geonics, Ltd., instruments with coil separations of 3.66 m and of 10, 20 or 40 m, respectively.

Financial and legal aspects of man-made geohazards in the urban environment

It is usual to think of the interaction of geohazards and people in terms of health, safety and the stability of buildings and structures. In the last twenty years or so property owners have also become concerned about the financial implications of the presence of geohazards. This manifests itself in two ways. First, the discovery of the existence of a geohazard close enough to a building to affect its stability or the health and safety of its occupants might reduce the financial value of the building. Second, many buildings are insured against the possible effects of geohazards on the structural integrity of the building. Identification of geohazards in an area might lead to an increase in the cost of insurance premiums or increased difficulty in obtaining insurance cover. In these ways the discovery of the geohazard creates what has come to be known as 'blight.'

From the point of view of abandoned mine workings 'blight' might occur, for example, when previously unknown shallow pillar-and-stall workings are discovered beneath an occupied area—perhaps after a collapse has occurred. Although the degree of hazard will not have changed (assuming that the conditions affecting stability have not significantly changed), the public perception of the hazard has changed through increased awareness. This increased awareness may lead to a loss of the value of properties when put up for sale. This, in turn, may lead to calls for the mine workings to be stabilized or for compensation to be paid. However, the viability of these demands depends on a legally responsible and financially viable entity being identified to bear the cost. For many coal workings the Coal Authority might be that entity, but for other types of workings there may be no legally responsible body. In these circumstances responsibility may ultimately fall on some combination of central government, local government, insurance companies and property owners.

Once a hazard has been identified further problems may arise for property owners. Again, these relate not to an increase in the degree of hazard but to an increase in awareness. First, the awareness of the presence of a hazard may alter planning policy. For example, permission to build extensions to buildings or new buildings may be refused. Second, insurance premiums may be increased. Since about 1990 information systems on the distribution of geohazards have been available to insurers in Britain.[8] Before this time, although losses from damage caused by geohazards were covered by many building insurance policies, premiums were determined irrespective of the degree of hazard. The system worked on the principle of 'social justice' (the misfortunes of the few are paid for by the many). However, as information on the distribution of the degree of hazard became available, there were increasing demands for premiums to be set on the basis of 'natural justice' (the premium should reflect the degree of hazard affecting the property to be insured). This meant that insurance premiums would be higher in areas of higher degree of hazard.

A further problem for property owners in areas were mine-shafts are known to be present relates to the process that is followed by solicitors when carrying out 'searches' (for information about a property, the land on which it is built and the surrounding area) on behalf of their clients.

Mine-shaft search zones

Abandoned mine-shafts in the vicinity of a property or structure represent potential hazards. A 'mine search' is frequently undertaken for property insurance and conveyancing purposes and identifies whether a mine-shaft is recorded in the vicinity of a property. If the presence of a mine-shaft is suspected, it is desirable that it be located as accurately as possible and its stability be assessed prior to possible treatment and stabilization.

It is necessary to define a safe limit around a mine-shaft, i.e. a distance from the shaft beyond which damage to a property will not occur in the event of shaft collapse. This is a difficult task since the stability of an individual shaft is controlled by the mining history of the area, the local geology and the environmental conditions. A 20-m zone of influence in the vicinity of an abandoned mine-shaft has been suggested by the Law Society and the Coal Authority. However, this has resulted in controversy since the definition of 'the vicinity' has been subjective and has not been based on research or scientific investigations.

Prior to 1989 there was no standard system whereby purchasers of property and their mortgage lenders could obtain information about historical and previous mining activities that might affect the property or an area of land. Individual solicitors acting for purchasers would write to the local offices of British Coal. The solicitors would decide what questions to ask and British Coal surveyors then provided appropriate responses. On the instruction of a solicitor British Coal surveyors, drawing as necessary on local knowledge, would make an assessment of whether they felt that a shaft, if it collapsed, could affect the stability of the property.

There was no formal definition of 'the vicinity' and the interpretation of its meaning by the various British Coal officers is disputed. The distance was varied according to the judgments made by the Area Surveyor. In some regions details were given for a search distance of 50 m or more,[20] but the most common interpretation among professional advisers was that a 5 m 'rule of thumb' was used from the boundary of the property. However, this is not confirmed by the Coal Authority.[20]

In 1991 the search form was revised to reflect the Coal Mining (Subsidence) Act (1991), which reformed the entitlement and procedures for recovery of compensation for coal-mining subsidence. The Coal Mining Sub-Committee of the Law Society in conjunction with the Royal Institution of Chartered Surveyors (RICS) and British Coal decided that it would be preferable, in the interests of consistency, if a more specific approach were taken towards replies for coal-mining searches. In December, 1991, the form was amended and 'in the vicinity of the property' was changed to the more precise question: 'Are there any shafts, adits or other entries to coal mine workings within 20 m of the boundary of the property recorded on plans in the possession of British Coal?' The 20-m zone around the property was apparently determined on the basis of advice from mining engineers and surveyors. The search form was further revised in 1994 as a consequence of the privatization of the coal industry and the establishment of the Coal Authority as the successor to British Coal. According to the Law Society, 'the absence of a standard approach in preparing the reply was clearly unsatisfactory and carried dangers that house buyers might be misled.' However, this non-systematic approach may also have led to different responses to the same degree of hazard from the presence of mine-shafts near different properties.

The increase in search radius to 20 m has resulted in a greater number of mine-shafts being revealed on searches made with the Coal Authority. People who bought property before 1991 and who were told that no mine-shafts were in 'the vicinity' of their property now find that a mining search has revealed the presence of a shaft. This is illustrated in Fig. 2, where an increase in the search distance from 5 to 20 m would have included an abandoned mine-shaft not previously considered to be a threat to adjacent buildings. When this shaft, in a northern British city, did collapse no building was damaged.

More recently, the situation seems to have changed again. On 12 January, 1997, an article appeared in *The Sunday Times* concerning renewal of a house building insurance. AA Insurance Services (AAIS), asked the client to 'confirm that no house within 150 m from a mine, has ever suffered from, or shows signs of, subsidence, flooding or a range of other hazards'. Landslides, coastal or river flooding, ground heave and, presumably, mine-shafts are included in the 'other hazards' category. The client was confused as to how this could be undertaken. The authors are concerned about the origin of this 150-m zone. Where does it come from? How does this relate to the 20-m coal-mine search zone? Was this figure based on any scientific findings, or is it purely arbitrary? Furthermore, according to the newspaper article, this recent question is the result of much discussion involving a panel of 23 insurance companies; ' ... some of the insurers actually wanted it to specify a radius of 200 m'!

Conclusions

The nature of man-made geohazards, particularly those related to abandoned mine workings in the urban environment, has been reviewed and the types of non-destructive geophysical methods available for the identification of hazards caused by abandoned mine workings have been described. In addition, the financial and other problems caused by 'blight' when the presence of abandoned mine workings becomes known have been discussed.

The collapse of mine-shafts and shallow pillar-and-stall workings is likely to remain of concern to the occupiers of former mining areas, although the situation may be exacerbated in some of the former coalfields if the potential problem of rising mine-water levels is not overcome. Rising mine water may also cause pollution of water-courses and increase the emission of mine gases.

Site investigations in old mining areas must make full use of existing data holdings that are also becoming more accessible to non-specialists, such as developers and householders. In addition, the full potential of geophysical methods of

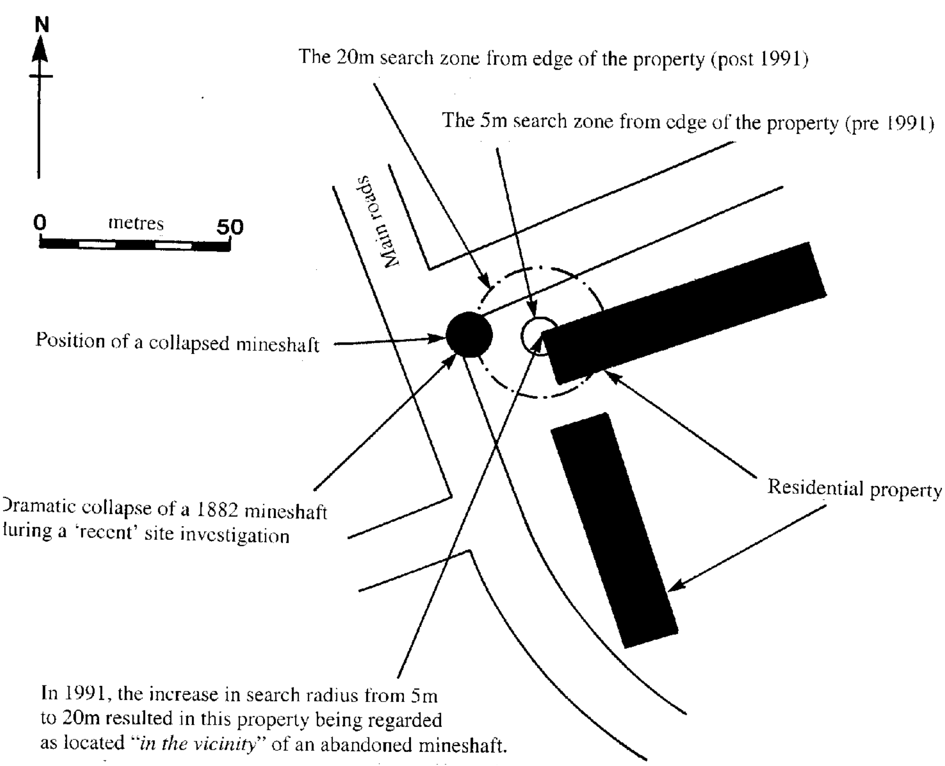

Fig. 2 Schematic diagram showing effect of altering search distance for coal-mining searches. With a distance of 5 m the mine-shaft would not have been have identified by searches around either of the two nearest buildings; with a distance of 20 m a search in relation to the nearest building would have included the shaft. When the shaft collapsed neither building was damaged

ground investigation should be realized as they are able to 'sample' much larger volumes of ground than such intrusive methods as boring, probing and pitting. New methods, such as thermal techniques, continue to be developed and it is likely that the resolution and accuracy of older geophysical methods will improve as equipment and interpretative software improve.

Traditional concerns about the safety of buildings and structures in old mining areas will remain, but there will also be increasing concerns about the problems brought about by 'blight'—loss of financial value caused by knowledge of the presence of a geohazard. A more scientific approach is needed to assess the degree of hazard properly—for example, in the case of old mine-shafts—and better communication of the nature of the hazard to the general public will help to avoid exaggeration of the problem.

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References

1. Anon. Engineering geophysics, report by the Geological Society Engineering Group Working Party. *Q. Jl Engng Geol.*, **21**, 1988, 207–71.
2. Anon. *Notes on the development and after-use of landfill sites*. Interdepartmental Committee on the Redevelopment of Contaminated Land. (London: HMSO for Department of the Environment, 1990). *Guidance Note* 17/78
3. Anon. Engineering geophysics, a report prepared by a Working Party jointly sponsored by the Engineering Group of the Geological Society and the Construction Industry Research and Information Association's Ground Engineering Core Programme Advisory Committee. Final review draft, 2000, 252 p.
4. Attewell P. B. and Taylor R. K. eds. *Ground movements and their effects on structures* (London: Surrey University Press, 1984).
5. Bell F. G. Salt and subsidence in Cheshire, England. *Engng Geol.*, **9**, 1975, 237–47.
6. Bell F. G. *et al.* A review of ground movements due to civil and mining engineering operations. In Bell F. G. *et al.* eds *Engineering geology of underground movements* (London: Geological Society, 1988), 3–32. *Engineering Geology Spec. Publ.* 5
7. Bell F. G. *et al.* eds. *Engineering geology of underground movements* (London: Geological Society, 1988), 453 p. *Engineering Geology Spec. Publ.* 5
8. Culshaw M. G. and Kelk B. A national geo-hazard information system for the United Kingdom insurance industry—the development of a commercial product in a geological survey environment. In Regional geological cartography and information systems. *Proc. 1st European Congress, Bologna, Italy, June 1994, vol. 1* (Bologna: Regione Emilia-Romagna–Servizio Cartografico e Geologico, 1996), 208–9.
9. Donnelly L. J. Predicting the reactivation of geological faults and rock mass discontinuities during mineral exploitation, mining subsidence and geotechnical engineering. Ph.D. thesis, University of Nottingham, 1994.
10. Donnelly L. J. Fault reactivation induced by mining in the east Midlands. *Mercian Geologist*, **15**, part 1, 2000, 29–36.
11. Donnelly L. J. and McCann D. M. The location of abandoned mine workings using thermal techniques. *Engng Geol.*, **57**, 2000, 39–52.
12. Donnelly L. J. *et al.* The legacy of abandoned mining in the urban environment in the United Kingdom. In Forde M. C. ed. *Proc. 5th International conference on polluted and marginal land, Brunel University, London, July 1998* (Edinburgh: Engineering Technics Press, 1998), 559–72.
13. Geddes J. D. ed. *Proc. 1st International Conference on large ground movements and structures, Cardiff* (London: Pentech Press, 1978).
14. Geddes J. D. ed. *Proc. 2nd International Conference on large ground movements and structures, Cardiff* (London: Pentech Press, 1981).
15. Geddes J. D. ed. *Proc. 3rd International Conference on large ground movements and structures, Cardiff* (London: Pentech Press, 1985).
16. Leach B. A. and Goodger H. K. *Building on derelict land* (London: Construction Industry Research and Information Association, 1991). *CIRIA Spec. Publ.* 76
17. McCann D. M., Jackson P. D. and Culshaw M. G. The use of geophysical surveying methods in the detection of natural cavities and mineshafts. *Q. Jl Engng Geol.*, **20**, 1987, 59–73.
18. Neumann R. Microgravity methods applied to the detection of cavities. In *Proc. Symposium on detection of subsurface cavities* (Vicksburg, Mississippi: Soils and Pavements Laboratory, United States Engineering, Waterways Experiment Station, 1977).
19. Perry J. and West G. *Sources of information for site investigations in Britain (Revision of TRL Report LR 403). Transport Research Laboratory Report* 192, 1996, 47 p.
20. Trade and Industry Committee, House of Commons. *Former mineshafts, seventh report* (London: HMSO, 1996).
21. Tucker P., Ferguson C. and Tzilivakis J. Integration of environmental assessment indicators into site assessment procedures. In Lerner D. N. and Walton N. R. G. eds *Contaminated land and groundwater: future directions* (London: Geological Society, 1998), 127–33. *Engineering Geology Spec. Publ.* no. 14.
22. Williams G. M. and Aitkenhead N. Lessons from Loscoe: the uncontrolled migration of landfill gas. *Q. Jl Engng Geol.*, **24**, 1991, 191–208.
23. Younger P. L. Possible environmental impact of the closure of two collieries in County Durham. *J. Instn Waste Environ. Management*, **7**, 1993, 521–31.
24. Younger P. L. Minewater pollution: the revenge of Old King Coal. *Geoscientist*, **4**, part 5, 1994, 6–7.

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