

Locating abandoned mine shafts using a proton magnetometer

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Abstract: The location of abandoned mine shafts is very important, especially considering increasing urban development in old mining areas. Many old mine shafts are unstable and liable to collapse. The usual methods of finding these shafts, such as coring, are very slow. A study was made using a proton precession magnetometer, of the anomalies associated with some old shafts at Rothley Shield near Newcastle upon Tyne, England. Computer contouring was also carried out to develop the optimum field technique for shaft location using the magnetometer. Several shafts were then successfully located, but further work in an urban environment highlighted difficulties due to noise.

Abstrak: Kedudukan syaf lombong terbiar adalah penting, terutamanya memandangkan bertambahnya pembangunan bandar di bekas kawasan perlombongan. Kebanyakan syaf lombong lama adalah tidak stabil dan berkemungkinan untuk runtuh. Kaedah yang biasa digunakan untuk menentukan kewujudan syaf ini seperti menggali, adalah amat perlahan. Satu kajian telah dilakukan menggunakan magnetometer liukan proton dengan anomali bersangkutan dengan syaf lama di Rothley Shield berhampiran Newcastle upon Tyne, England. Pengkonturan komputer juga dijalankan untuk menentukan teknik di lapangan yang optimum untuk menentukan kedudukan syaf menggunakan magnetometer. Beberapa syaf telah berjaya ditemui, tetapi kerja lanjut dilakukan di kawasan persekitaran bandar menemui kesukaran akibat hingar.

INTRODUCTION

Since very early times it has been necessary to sink shafts into the ground, both for extraction of water, in the form of wells, and for the extraction of important ores and minerals, in the form of bell pits, vertical shafts and adits. Obviously most very early workings have long since disappeared through natural infill and erosion, although they are sometime detectable indirectly, and they do not now present a hazard. However, deep workings are still in existence, dating back two or three hundred years and sometime older, and it is these which create problems, particularly where new developments are being started on the site of old workings which are liable to collapse, with consequent damage to property and danger to life.

The problem arises from the fact that it was not until 1873 that all owners of mines were required to publish plans of their abandoned workings (Maxwell, 1976). The first step is to try and locate area in question. The National Coal Board is responsible for all published coal mine plans, which probably represent the majority of workings in England, and H.M. Mines Inspectorate for the abandonment plans of all other mines (Henshaw, 1980).

Examination of old records can sometimes be helpful, but often as in the case of old maps, can only serve to give approximate locations of shafts.

Aerial photography sometimes shows up the position of old workings, but it is usually no help in urban environments. Because of the difficulty in locating these old shafts and problems associated with them, other methods such as trial trenching and boring were used in potential sites. These methods, however, were often unsuccessful because of the practical problems associated with the location of for example, a shaft only 2 metre in diameter, the work requiring a grid of boreholes or trenches spaced only a metre apart and consequently being very slow and expensive.

For these reasons, geophysical techniques are increasing in importance, the usual exploration techniques such as seismic, gravity, resistivity and magnetic being the ones most commonly tried. However, seismic reflection and refraction methods are more useful for dealing with layered structures, such as lithological boundaries, and are not well suited to the detection of relatively narrow, roughly cylindrical shafts. Gravity measurements tend to be used in large scale exploration work, the slowness of operation of the equipment, and the complicated corrections to the data rather limiting the possibilities in this case. Both magnetic and electrical techniques have been successfully used in the past (e.g. Barker and Worthington, 1972; Molyneux, 1979), though the work has been confined to a relatively small number of shafts.

The aim of this project was then to examine a

number of known shafts in the field, using a proton precession magnetometer, both to see the variation in the anomalies associated with the shafts, and to decide on the best field techniques from the point of view of speed of operation and success in location. The experience gained from this initial survey was then used to attempt the exact location of a shaft whose position was known approximately. A further survey was also carried out in a more difficult urban environment. Contouring of the result was carried out using a commercial software.

THE GEOLOGY

The rocks are those of the Bernician division of the Lower Carbonaceous, and are cyclic sediments, thin limestones alternating with thicker beds of grit and sandstones, the sequence also containing thin beds of coal associated with shales. The glacial cover is thin, however, in the cuttings made for an open cast coal site about a kilometre to the north, around 5 metres of glacial till and boulder clay are exposed, although this may not continue to the area studied.

The shafts on the Rothley Shield site are of 'ancient date', indicating that they are probably pre 19th century. The shafts were sunk to the Rothley coal, one of the more northerly ones apparently reaching the coal at about 50 metres, but the seam was too thin to work, averaging only about 50 centimetres just to the south of the area. The largest pit appears to have been Rothley Shield Colliery, about 250 metres north west of Rothley Shield East, and is said to have reached the coal at about 40 metres (Henshaw, 1980).

THE SHAFTS

According to Maxwell (1976), the shape of the mine shafts and their mode of lining was dependent on local mining customs. In England for example, the shafts were circular, in Wales they are elliptical, and in both cases, where necessary, are lined with bricks or stones. In Scotland, the shafts were rectangular and lined with wood. Whether a shaft is lined or not depended on the state of the strata through which the shaft passed. Soft clay or crumbly rock would obviously need to be lined to prevent collapse of the shaft, and in very wet conditions, where the water table was very high, the shafts were sometimes lined with cast iron (Rathore, 1978). The presence of a brick or stone lining might affect the anomaly associated with a shaft. Cast iron linings are probably rare in most early shafts, but the presence of one could create a very substantial anomaly. The width of the shafts is said to vary between 2 to 5 metres depending on the use to

which the shaft was put, winding shafts would obviously have to be wider than shafts used purely for ventilation. A cross section of a typical shaft in the study area is shown in Figure 1.

CAUSES OF MAGNETIC ANOMALY OVER SHAFTS

A major cause of a magnetic anomaly in the case of a mine shaft is the change in the induced magnetisation around the shaft due to differences in magnetic susceptibility between the shaft infill and the surrounding material. A large anomaly would thus be caused when the shaft is in the form of void surrounded by material of relatively high susceptibility, such as shale.

Anomalies may also be caused by the presence of ferrous material in the infill, and of magnetic lining of the shaft, for example fired bricks which would have acquired thermal remanent magnetisation at the time of the firing (Tarling, 1983). Magnetic anomalies may also be due to the presence of other ferrous material near the shaft, such as buried pipes, steel fences, power lines, etc., and the remains of the building associated with the workings.

THE SURVEY

The survey was carried out in a system of 30 by 30 metre grid squares covering a number of shafts to the north of the road from Rothley Shield cottage (Fig. 2). The grid was set up parallel to the road for ease of surveying. Marking out of the traverses was done using non-metallic 30 metre tapes held down with wooden pegs. Different detector heights and traverse spacings were tried to find the optimum survey method. It was found that one person could cover a 30 by 30 metre grid on a 2 metre spacing in approximately 2½ hours, the work including moving the tapes between traverses, taking an average of three readings at each magnetometer station, and taking base station readings (for correction) at the beginning and end of each traverse. Other surveys were later carried out on noisy sites for examples near a fenced farm and a well developed area of Wallsend, a suburb of Newcastle (Fig. 2).

LOCATION OF SURVEYS

Rothley Shield site was chosen for the initial survey because it contains a large number of shafts within a small area. The area is about 30 km from the city of Newcastle (Fig. 2). It is an open country which is completely free from external magnetic disturbances such as power lines, wire fences, etc., which would mask the anomalies associated with

the shafts.

The exact position of shafts on the site can be seen from the ground as the backfill of most of them has subsided slightly, this meant that the exact position of the shaft could be compared to the magnetic profile without recourse to coring. Aerial photographs of the area were available, and were compared with various maps of the area. It was found out that maps were unreliable in locating the shafts.

RESULT OF SITE 1

The results of this survey after correction for diurnal variation are shown in Figure 3. A three dimensional display of the data is shown in Figure 4. The centre of the shaft, which is about 2 metre in diameter, lies just north of the largest positive region, and to the south of the largest negative region. As can be seen in all the displays, there is

an appreciable anomaly around the shaft which is much larger than any background variation. A magnetic profile across the shaft in a south-north direction with the detector at 160 cm height is shown in Figure 5.

A detector height of 160 cm was chosen because it was felt that near surface variation in susceptibility, and buried ferrous objects, would have less effect on the results. However, the size of the anomaly falls off with height approximately following an inverse square law, and surveys of other squares with the detector at this height were not successful in locating anomalies associated with the shafts.

Site 1 was then resurveyed with the detector height of 60 cm, and these results are shown in Figure 6. Again, these show the same result as the previous although the maxima and minima are much larger, so much so that the magnetometer became unstable directly over the shaft and the

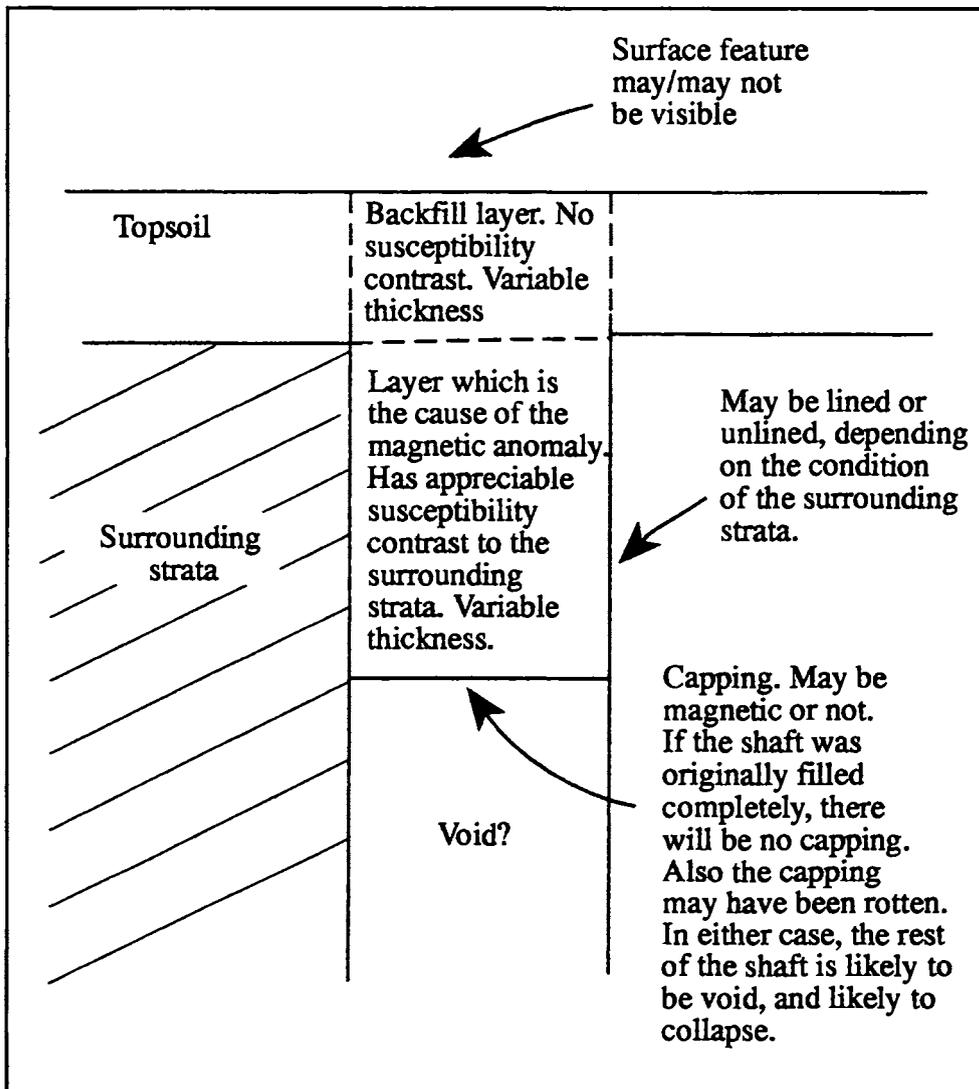


Figure 1. A cross section across a typical abandoned shaft.

override facility had to be used. The instability indicating the presence of ferrous material in the backfill causing a high magnetic gradient. This was proved to be the case when the shaft was augered.

RESULTS OF OTHER SITES

In site 3a the survey were carried out with 2 m grid. Result of traverse 8 (in NW-SE direction) with detector at three different heights (60, 110 and 160 cm) is shown in Figure 7. The anomaly is much less pronounced than on site 1, and would be

unnoticeable in a noisy site. The shaft produces an appreciable anomaly with the detector at 60 cm height. The shape of the anomaly cannot be directly compared to those of site 1 because the traverse is not in the south-north direction.

In sites 4 and 7, the surveys were carried out on a 3 m grid with the detector at 110 cm with north-south traverses across shafts 4 and 7 (Figs. 8 and 9). Shaft 4 produces an anomaly but it is not of the same type as over previous shafts, having a larger negative value flanked by smaller negatives to the north and south.

Shaft 7 does not stand out at all well, and in

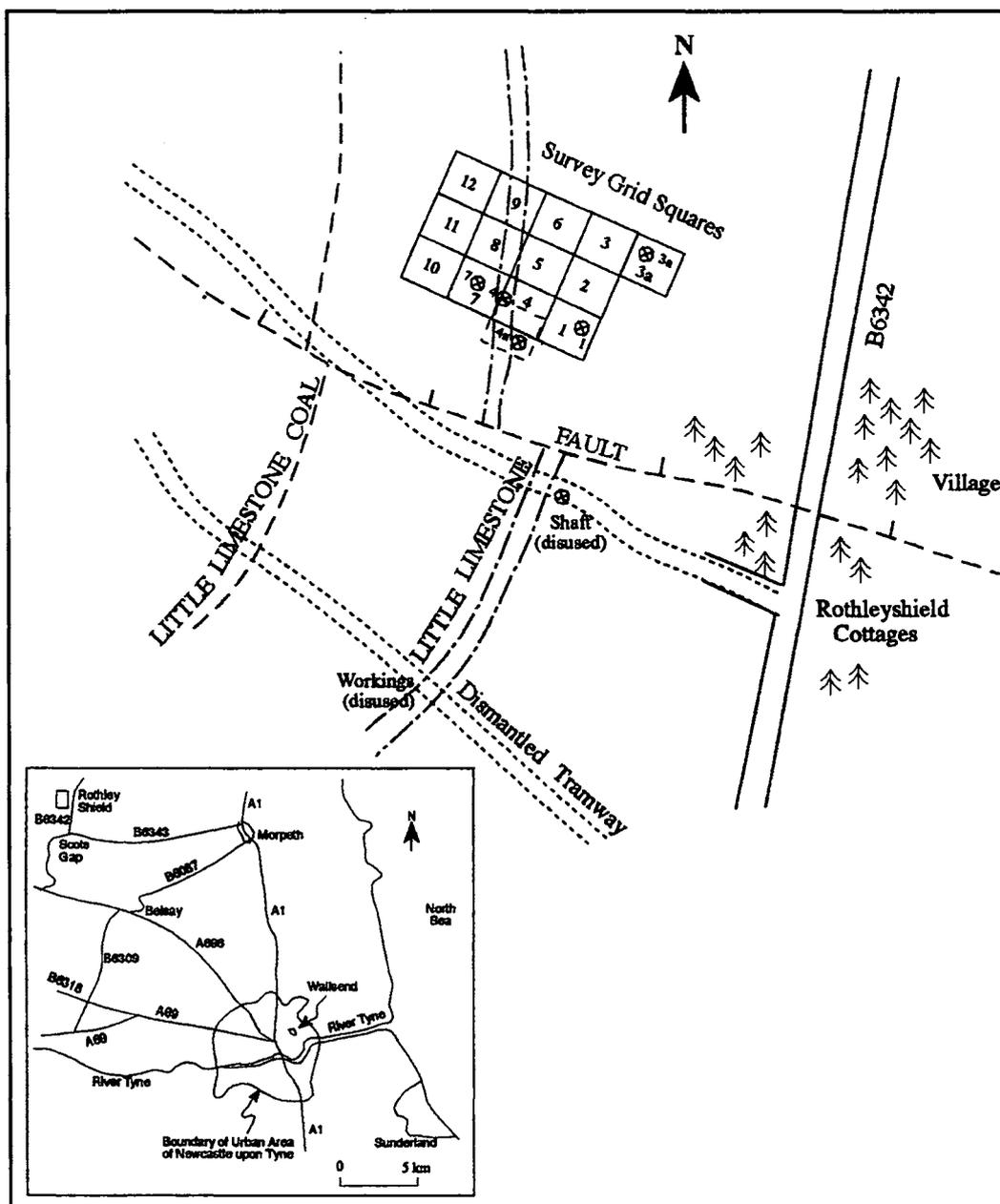


Figure 2. Rothley Shield area showing relationship of grid squares to geology and geography (inset the map of Newcastle area).

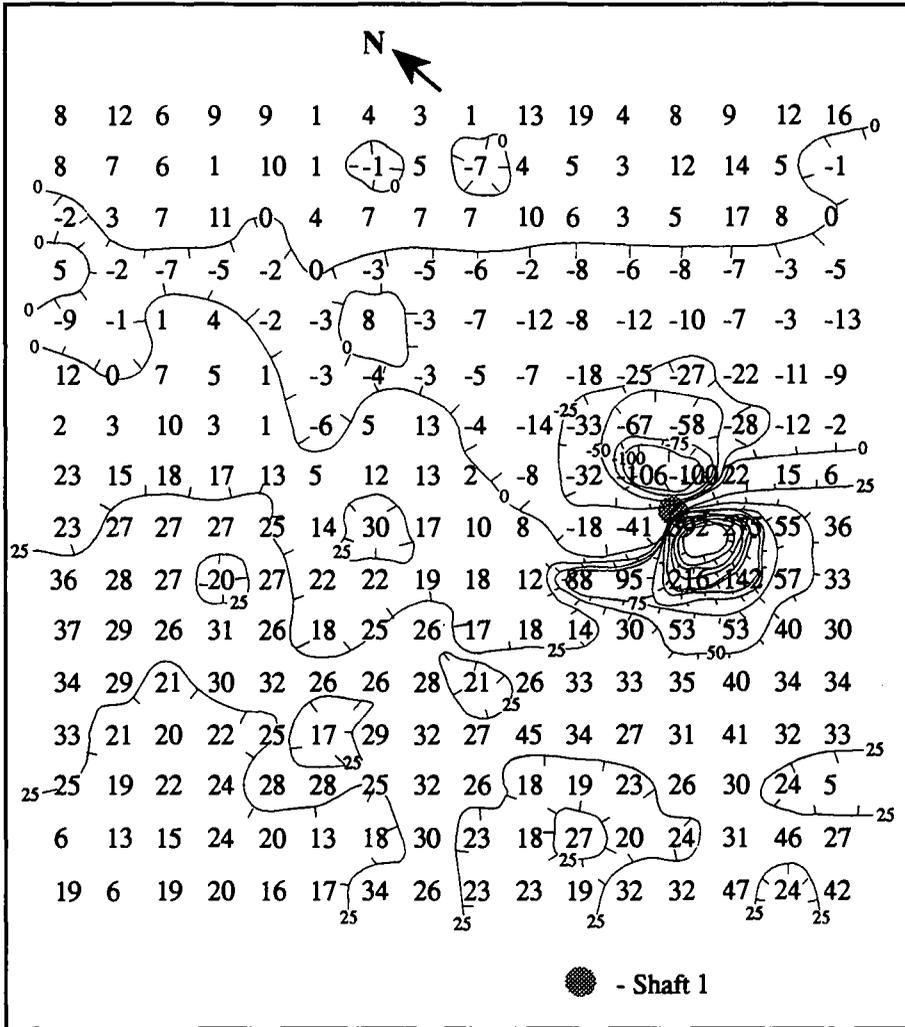


Figure 3. Magnetometer readings with detector at 160 cm height with 2 m grid in locating Shaft 1. Contour interval 25 gamma.

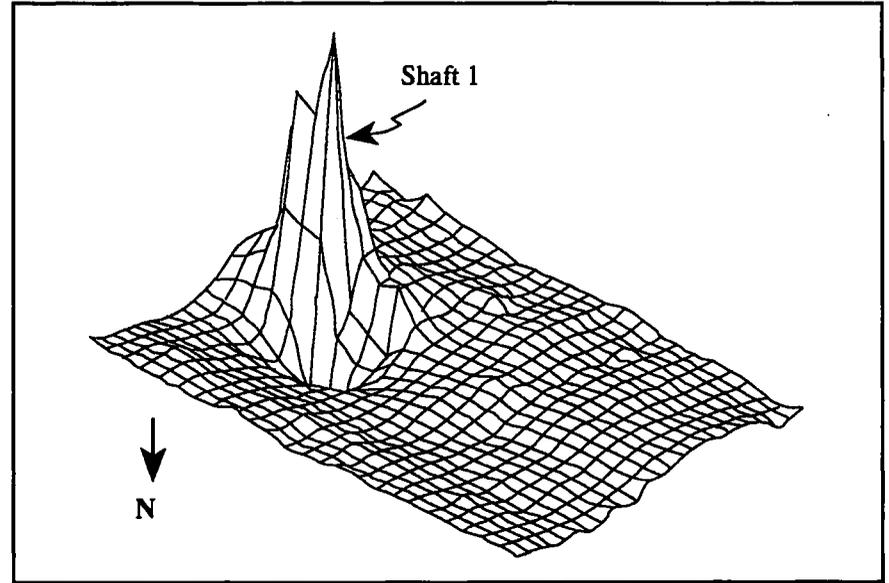


Figure 4. A three dimensional plot of anomalies showing the location of shaft 1 over a positive anomaly.

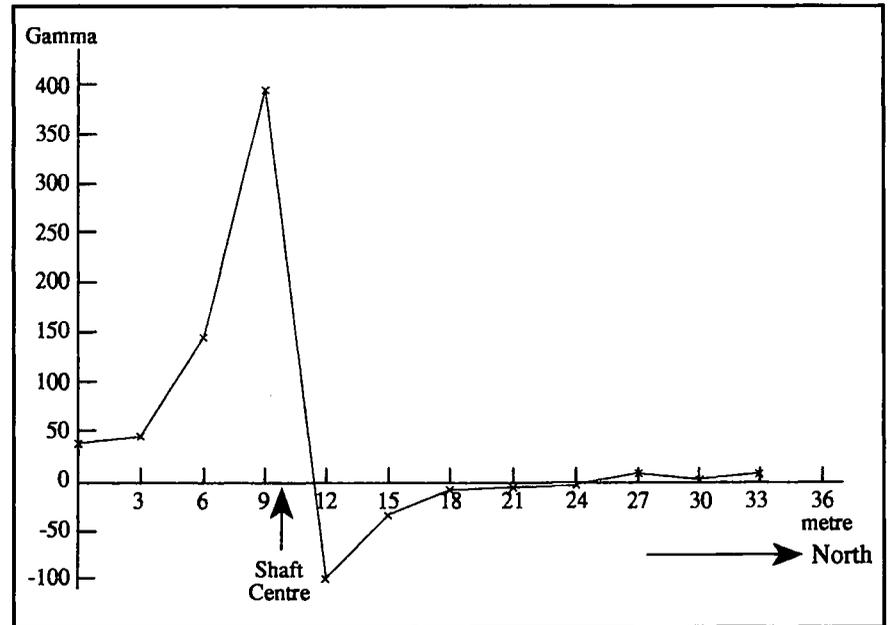


Figure 5. South-North traverse across a shaft with detector at 160 cm height.

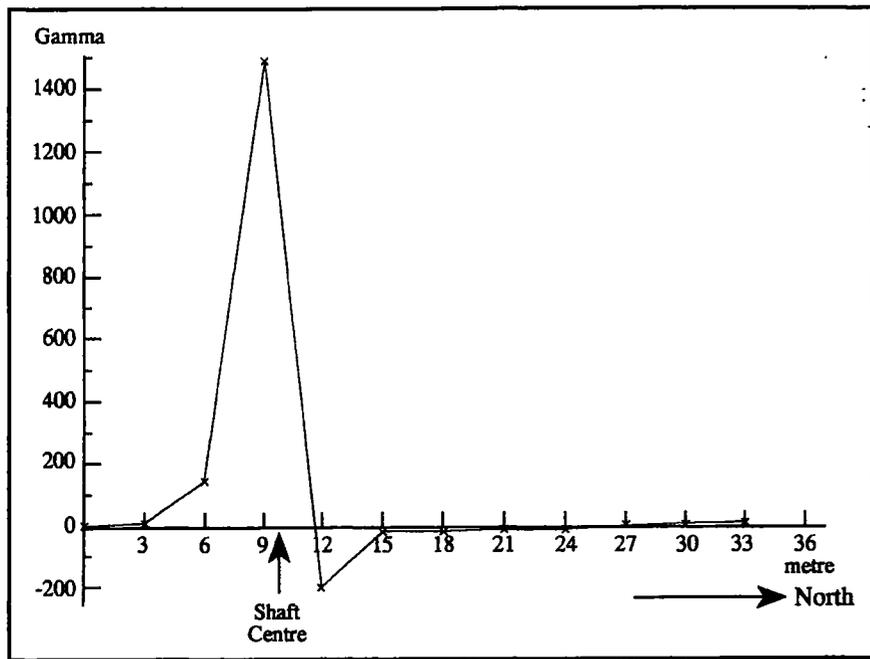


Figure 6. South-North traverse across a shaft with detector at 60 cm height.

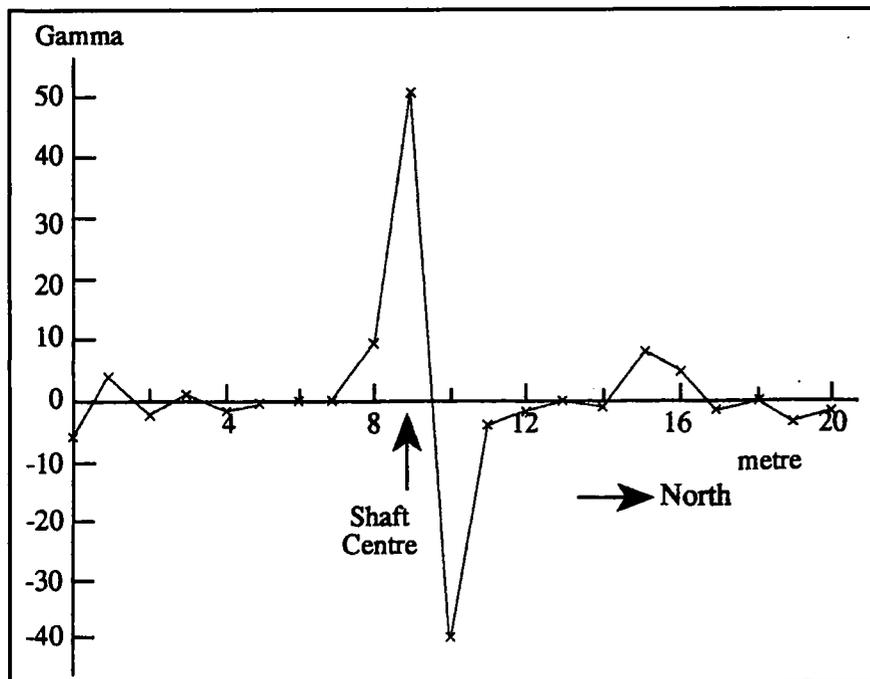


Figure 8. South-North traverse across shaft 4 with detector at 60 cm height.

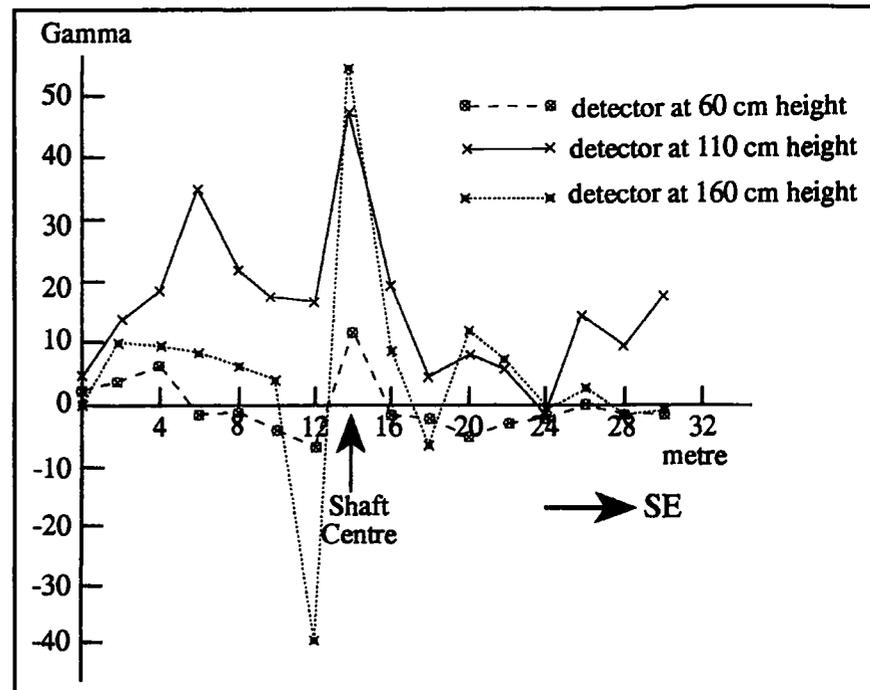


Figure 7. Traverse 8 (NW-SE direction) across a shaft with different detector heights.

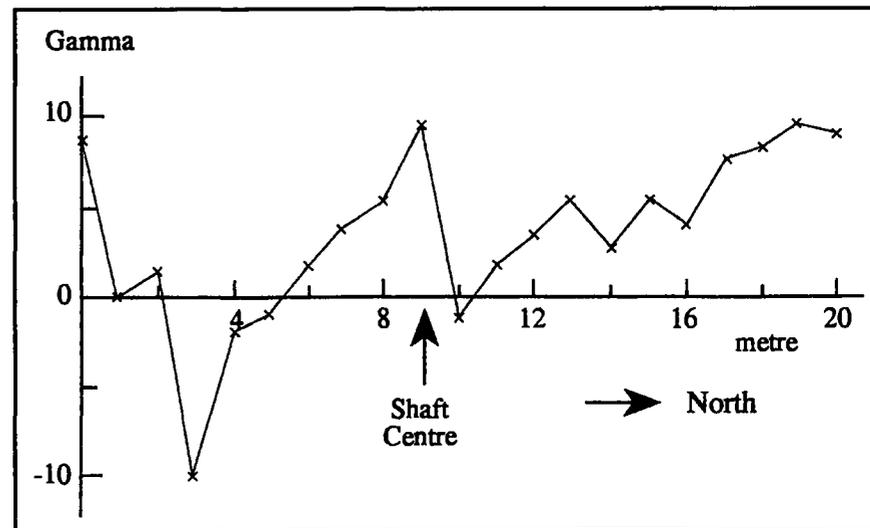


Figure 9. South-North traverse across shaft 7 with detector at 60 cm height.

both cases the shafts would be undetectable in a noisier environment. A stone wall (Fig. 10) running approximately east-west, to the northwest of the shaft produces a slight anomaly with general positive values to the south and negative values to the north. The wall was only partially buried so still visible, but a completely buried structure would obviously be troublesome for interpretation.

Other site surveyed was in site 4a. It was carried out on a 2 m grid pattern with the detector at 110 cm. Results are shown in Figures 11 and 12. There is the positive region to the south, and the negative region to the north of the shaft. The anomaly due to the shaft does not stand out above other anomalies as shown in the three dimensional display of Figure 13.

TEST OF METHOD

Using the experienced gained on at Rothley Shield, it was decided to attempt to find the exact location of a shaft which was no longer visible, but whose approximate position was known. The shaft was in the corner of the field. According to the farmer who owned the land, the shaft was unlined and around 2 metres in diameter, and had been filled by him some years previously using general farm waste, and the levelled and ploughed over. A wire fence ran along the edge of the field, and the road carried some heavy lorries travelling to a nearby quarry. It was felt that the situation was one which could be commonly encountered in practice, and although not in an urban environment, the site was magnetically noisy enough to provide a useful test.

A 20 by 20 metre square was centred at the approximate location of the buried shaft, with two sides of the square oriented north-south so that all traverses could be in this direction. Readings were taken with the detector at 60 cm above ground, at 2 metre intervals along traverse spaced 2 metre apart. It was planned that if this spacing fail to locate the shaft a 1½ metre space grid would be used.

Results of the survey are shown in Figures 14. The presence of shaft was shown by a pronounced positive anomaly in the south of the square, with negative to the north. The zero values in the southeast corner of the square were caused by instability of the magnetometer when within 2 metres of the wire fence. Further away than this the readings were stable. Instability was also found directly above the supposed site of the shaft, probably due metal in the fill causing high magnetic gradient. The peak value shown was the average of a number of readings taken using the override

facility, but as variation of up to 5,000 gammas were apparent, this value can only be regarded as approximate. Variations up to 10 gammas in the readings were apparent when heavy lorries were passing within 20 metres from the magnetometer, however, this problem was simply overcome by repeating the reading after the lorry had passed. The survey in this site was completed in less than 4 hours.

THE WALLSEND SITE

In order to test the possibilities of the method in an urban environment, it was decided to try and locate the position of an old engine-level, which was believed to be causing the subsidence of some buildings in Wallsend, a suburb of Newcastle. The engine level is shown on several maps of the area (Fig. 15), but it was visible on the ground. Its location could be defined within limits of 30 metres along a section of the stream edge, however, it was hoped to locate the level by the magnetic method.

The level was thought to be 1–2 metres in diameter, running nearly horizontally away from the stream. The stream bank, which consisted of boulder clay, ran very steeply uphill away from the stream, the best hope of locating the level appeared to be a traverse along the stream edge where the level would only be about one metre below the surface. The level dates back to the 19th century or earlier, and was used to carry water from the stream to an engine in Wallsend. It was probably constructed of brick, and an appreciable remanent component was thus felt likely to be present, as well as the contribution from the susceptibility contrast of a void in the boulder clay. The site was magnetically very noisy, as the stream was full of old metal parts and there was interference from nearby metal fences and brick and stone walls.

In order to get an idea of the type of anomaly likely to be encountered over a horizontal shaft, traverses were conducted across three adits, about a metre in diameter and buried at about a metre which connected to a small stream of Wallsend Burn nearby. These adits lay about 20 cm apart, and ran parallel in an approximately north-south direction, the same as that shown for the engine-level. The position of the trench containing the adits was easy to see as grass had not completely grown over the backfill.

Three traverses were conducted across the trench, in an east-west direction and with the detector at different heights. The results are shown in Figure 16 and show a pronounced positive anomaly centred on the adits, and flanked by negative values. A traverse across a horizontal

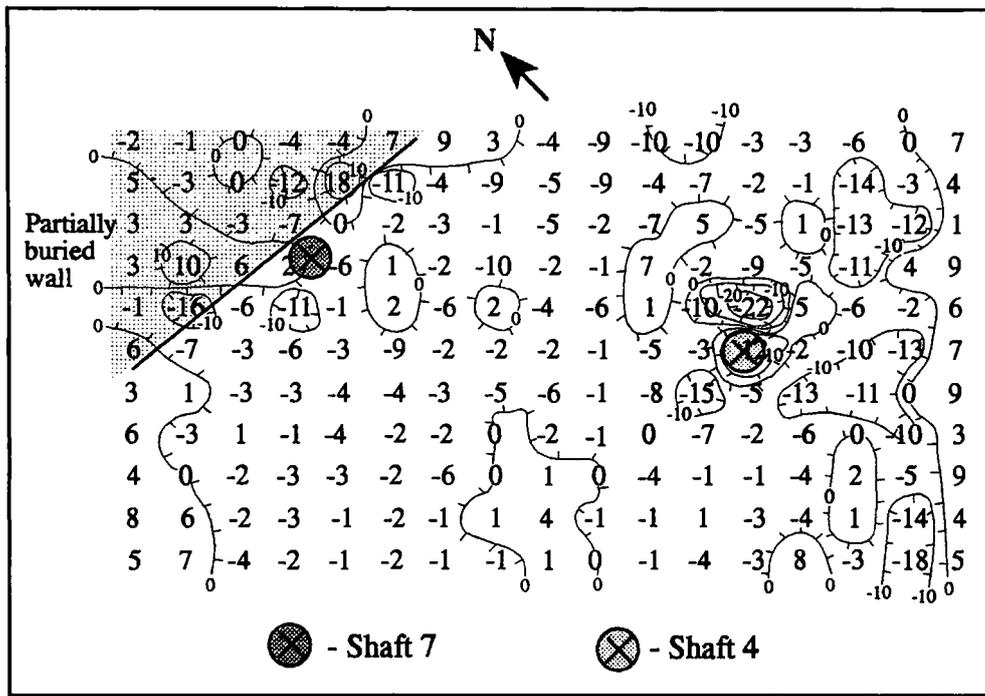


Figure 10. Magnetometer readings with detector at 110 cm height with 3 m grid in locating shafts 4 and 7. Contour interval 10 gamma.

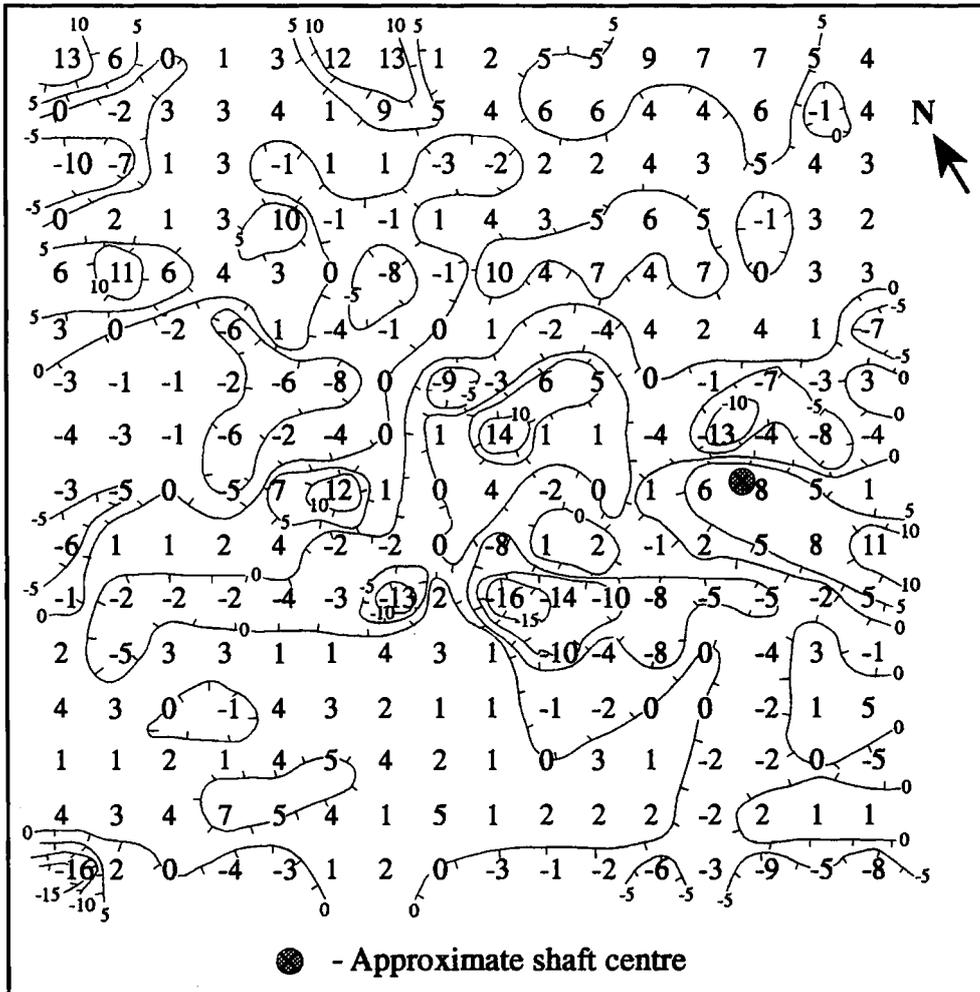


Figure 11. Magnetometer readings with detector at 110 cm height with 2 m grid in locating shaft 4a. Contour interval 5 gamma.

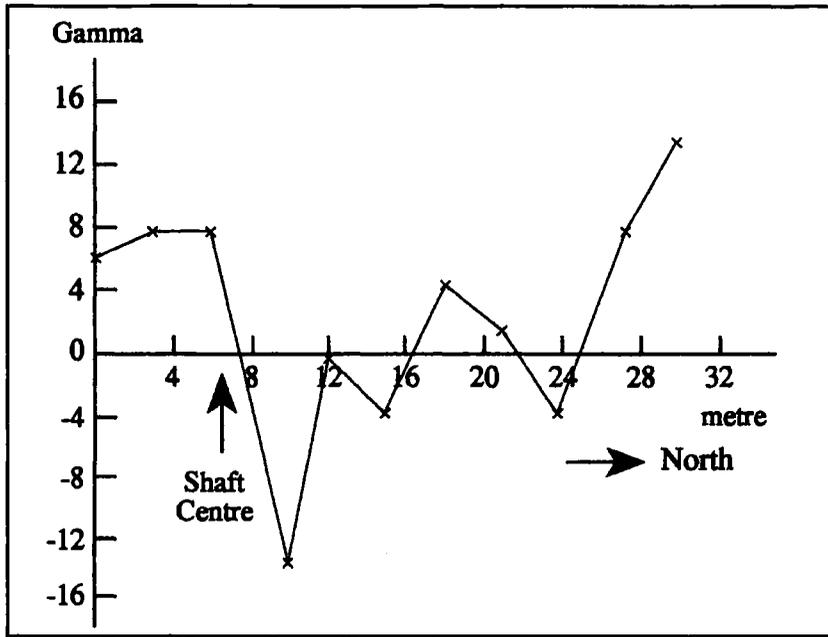


Figure 12. South-North traverse across shaft 4a with detector at 110 cm height.

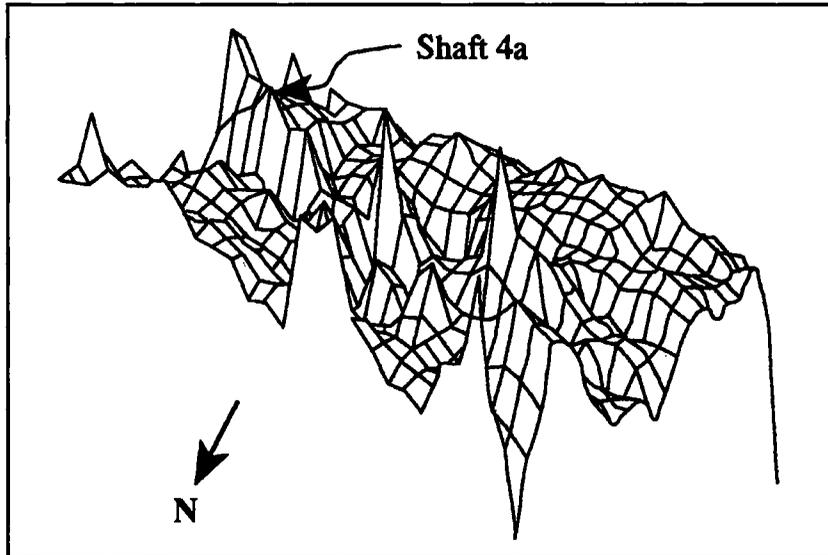


Figure 13. A three dimensional plot of anomalies in 4a square grid. It is a challenge to locate a shaft based on anomalies shown.

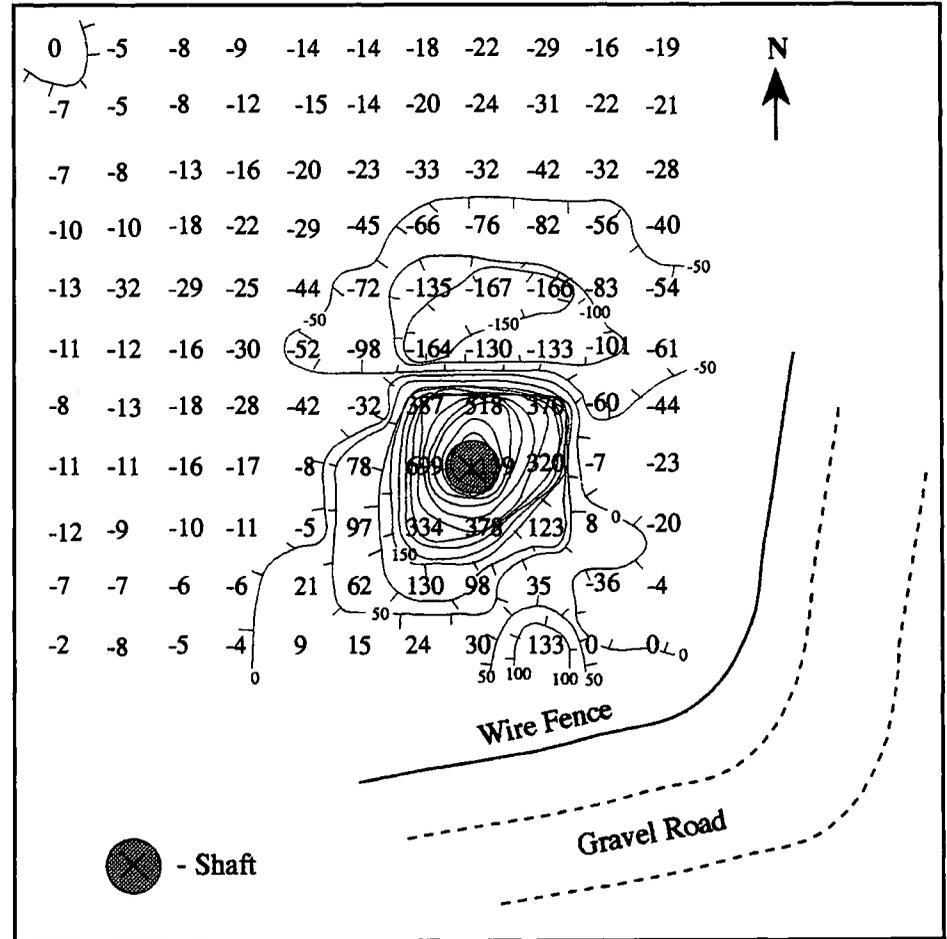


Figure 14. Magnetometer readings with detector at 60 cm height with 2 m grid. Contour interval 50 gamma.

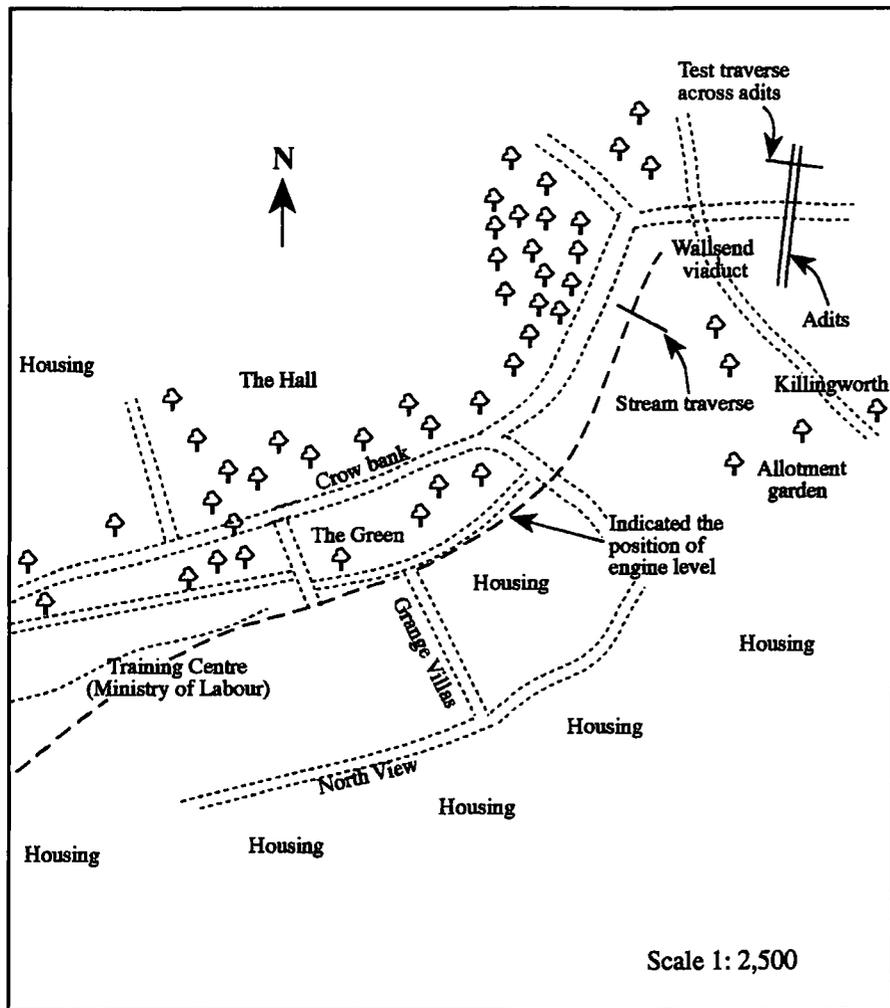


Figure 15. The map of the Wallsend site showing the positions of engine level, adits and traverses.

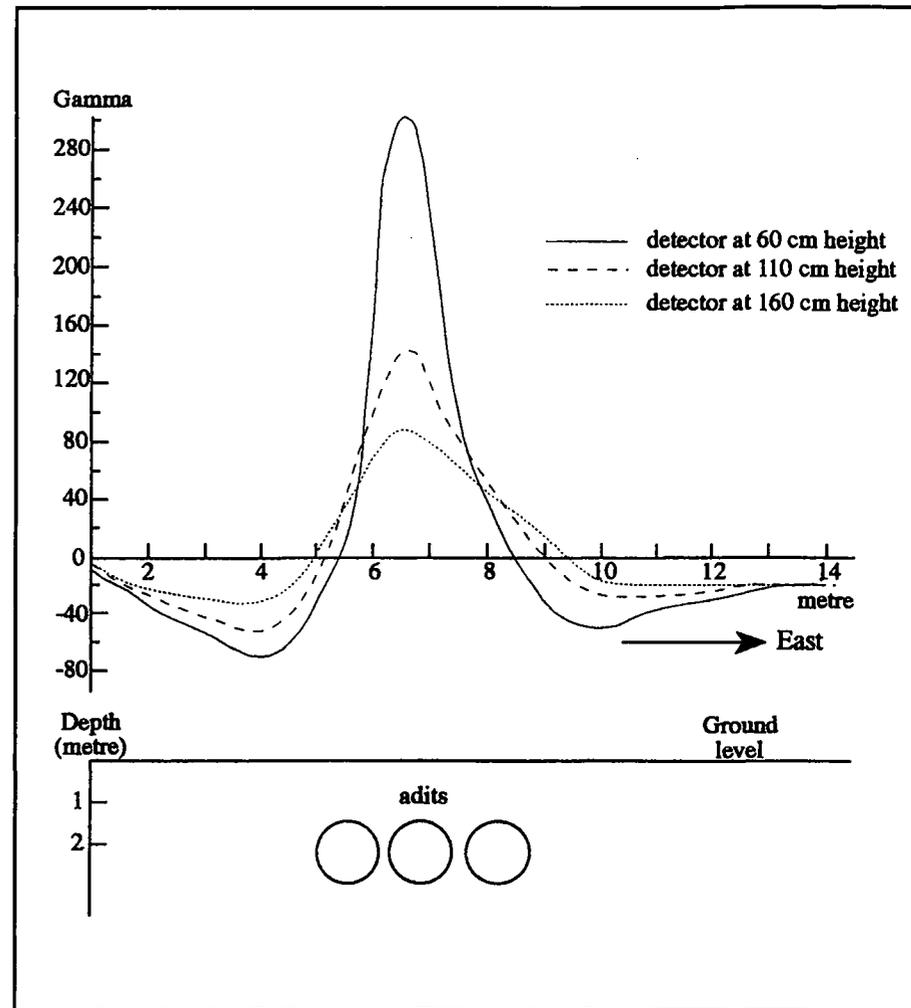


Figure 16. Traverses across horizontal adits with detector at 60, 110 and 160 cm heights in Wallsend site.

adit running east-west would produce an anomaly shape similar to that over a vertical shaft. The positive part of the anomaly is about the same width as the trench, and is quite large in magnitude, possibly due to steel reinforcing used in the concrete construction of the adits.

The stream traverse was likely to be much noisier than the above site, which had no metal fences or walls to disturb it, and it was decided to traverse the bank firstly with the detector at 60 cm, and then at 110 cm. The lower height, although more likely to detect the level, was also felt to be more prone to disturbances from the metal in the stream, but any anomaly appearing on both traverses was felt to be worth investigating.

The results of the traverses are shown in Figure 17. As expected anomalies with the detector at 60 cm is higher than those with the detector at 160 cm. Two anomalies stand out above the background variations. Anomaly 1 is quite broad, and high positive readings appear on two successive stations, whereas anomaly 2 is very narrow, the peak value appearing at only one station. Also the magnitude of anomaly 2 falls off sharply with an increase in detector height more so than anomaly 1 and is probably due to a very shallow ferrous object, whereas anomaly 1 is likely to be caused by more deeply buried object. Any flanking negative values are masked by noise, and this is likely to be a problem for interpretation in any site such as this.

Anomaly 1 when augered, unfortunately did not provide any positive results, as although the auger hit solid material about a metre deep, this may or may not have been the engine-level. However, if this was the correct position for the level, then the existence of a semi-circular stone built structure further up the bank may be explained, as the direction of the level would then take it underneath the structure. A traverse was conducted across this structure to see if it may have been an air shaft for the level. The results were inconclusive though, as the magnetometer was found to be unstable close to the stone walls. Later augering showed that the ground appeared to be solid underneath the structure although the locals believed that originally it was an air shaft.

The survey demonstrated the problems associated with magnetically noisy sites, in that anomalies may appear to be monopole in form, as the smaller flanking dipole part may be swamped by background noise. Small anomalies would probably be missed completely, and an anomaly of about 30 gammas is probably the minimum that would be detectable in this sort of situation.

DISCUSSIONS

All the shafts surveyed produced anomalies of the same general shape. In cases the maximum was positive. The size of the anomaly was very variable, however, ranging from few gammas to well over a thousand gammas, and the size of the anomaly does not appear to show the presence of shaft. The very large anomaly in site 1 was proved upon augering to have been caused by ferrous material in the backfill. Any large anomaly is likely to have been caused in this way. Sometimes the positive anomalies was not so prominent and it is a challenge to locate a shaft based only on the contour map and three dimensional plot as for an example shown in Figures 11 and 13.

Bricks may have been used for building associated with the mining operation, and it is probable that some contribution to the anomalies measured, came from remanent magnetisation in waste bricks thrown into the backfill. It is difficult to estimate the contribution of this remanent magnetisation in waste randomly thrown into the shafts. However, the direction of magnetisation of fired bricks used in the lining of a shaft would tend to be more ordered. The presence of brick lining may increase the size of the positive anomaly and decrease the negative value as suggested by Barker and Worthington (1972). Whether the anomaly is positive or negative will depend on whether the susceptibility contrast between the shaft and its surroundings is positive or negative, and the size of the anomaly also depends on the depth to which the shaft has been backfilled.

CONCLUSIONS

The Rothley site was magnetically very quiet, although fluctuations, probably due to variations in the topsoil susceptibility were apparent. These fluctuations, however were small in magnitude. The low detector height of 60 cm will be affected more by buried ferrous objects than a greater height, but the chance of detecting a shaft is very much better with a lower height.

The survey was successful in locating position of shafts and it was quick, and would have saved a lot of unnecessary coring. Even on noisy site, the anomaly would have been detectable. Variations in topsoil, susceptibility, and disturbances due to power lines, fences, buried metal and traffic will probably mask this minimum in many urban situations, especially where the anomaly is only a few gammas in magnitude, and anomalies may be completely missed, even with careful corrections

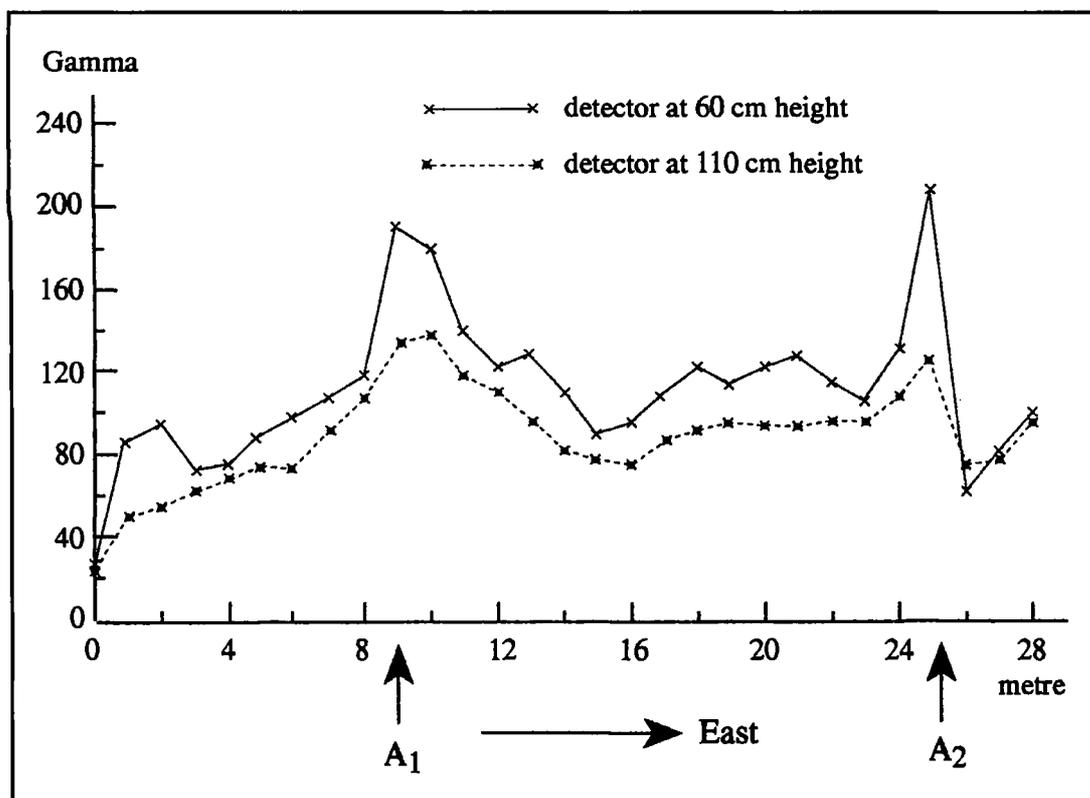


Figure 17. West-East traverses across a stream with detector at 60 and 110 cm heights in Wallsend site.

being made. Thus all anomalous areas may need to be investigated, although those with the characteristic shape are the most likely to yield positive results. Lack of anomaly does not necessarily mean the lack of shaft, so recourse may have to be made with other investigation techniques (e.g. resistivity and seismic refraction) in the event of a magnetic survey proving negative. The Wallsend survey did also show the possibilities of a magnetic survey for other buried objects such as sewers, etc.

Magnetic method appears to be capable of successfully locating abandoned shafts and adits, provided that adequate corrections are made to the results, and that the survey is conducted on a small grid pattern, preferably with the traverse aligned north-south, and with the detector height of less than a metre. The method is obviously going to be most successful in a quiet environment, but even in urban situations, especially where the site has not previously been developed, large anomalies may be encountered. The anomalies would still stand out above the noise, though interpretation is a bit difficult. Because of its speed, a magnetic survey is

probably worth considering, even in difficult conditions, for all situations where a shaft may be present, and the method appears to be more successful than other geophysical techniques for this type of problem.

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