Thermal Infrared survey of mineshafts at Pewfall, St. Helens

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Abstract: Abandoned mineshafts are ground disturbances that have very localised effects on the morphology, physical, chemical, drainage and moisture properties of the surface geological materials and thus thermo-physical properties. Hence, localised differences in the temperature of the ground surface about a mineshaft occur that can be detected by thermal infrared (IR) surveys. Using a handheld thermal infrared imaging camera pixel-averaged measurements of temperature were taken at 2m intervals over a 50m by 50m grid at the former colliery of Pewfall, St. Helens. Measurements were contoured to provide a temperature image of the ground within the grid surrounding a mineshaft whose exact position was unknown. The week before the survey was characterised by very clear, sunny days with freezing temperatures in the evening. Prior to and during the survey air temperature, ground temperature at 0.1m, ground temperature at 1.0m and barometric pressures were logged (every 30 minutes) at various locations at the site. Effects on potential ground heating of wind exposure and sun-trapping caused differences in measured air temperatures of up to 5°C. Diurnal fluctuations are readily observed on ground temperature measurements at 0.1m depth, but measurements at 1m depth only show an overall temperature reduction of 0.5°C due to longer term mean air temperature changes. IR measurements indicated differences in temperature that correlated well with different ground conditions such as areas of long, tufty grass, very wet ground with standing water and ice, made ground with coarse gravel and brick rubble and very disturbed ground that was either tamped, highly vehicle rutted or highly cut up. A thermal anomaly of about 6m^2 above a known mineshaft was characterised by increased temperatures of between 0.5 to 1°C in comparison to the adjacent ground surface. The anomalous ground contained traces of methane gas and the total O_2 + CO_2 content only comprised the CO_2 component indicating oxidation of methane.

Résumé: Des puits de mine abandonnés sont des perturbations de terrain qui ont des effets très localisés sur les propriétés (en termes de morphologie, physique, chimie, drainage et humidité) des matériaux géologiques de surface, et de la sorte sur les propriétés thermophysiques. Ainsi, il y a des différences localisées de la température de la surface du sol au niveau d'un puits de mine, différences qui peuvent être détectées par des levés du type infrarouge (IR) thermique. À l'aide d'une caméra portable à imagerie infrarouge thermique, des mesures à moyenne en pixels ont été prises tous les 2 m sur un réseau de 50 m sur 50 m dans l'ancienne mine de charbon de Pewfall, St. Helens. Les mesures ont été profilées pour procurer une image de la température du sol au niveau du réseau entourant un puits de mine dont la position exacte était inconnue. La semaine qui a précédé le levé a été caractérisée par de très belles journées ensoleillées avec des températures glaciales le soir. Avant le levé ainsi qu'au cours du levé, la température de l'air, la température du sol à 0,1 m, la température du sol à 1,0 m et les pressions barométriques ont été enregistrées (toutes les 30 minutes) en divers endroits du site. Les effets de l'exposition au vent et de la rétention du soleil sur le réchauffement potentiel du sol ont entraîné des différences au niveau des températures mesurées de l'air pouvant aller jusqu'à 5°C. Des variations diurnes sont facilement observées sur les mesures de la température du sol à une profondeur de 0,1 m, mais les mesures à une profondeur de 1 m ne montrent qu'une réduction générale des températures de 0,5°C en raison des changements moyens des températures de l'air au plus long terme. Les mesures IR ont indiqué des différences de température qui correspondent bien aux différentes conditions du sol telles que les zones ayant de longues touffes d'herbe, un sol très humide ayant de l'eau et de la glace y stagnant, un remblai constitué de gros gravier et de moellons de briques et un sol très remanié ayant été tassé, hautement défoncé par le passage de véhicules ou hautement découvert. Une anomalie thermique d'environ 6 m^2 au-dessus d'un puits de mine connu a été caractérisée par des températures supérieures de 0,5 à 1°C par rapport à la surface du sol adjacent. Ce sol anomal contenait des traces de gaz méthane et la teneur totale en O_2 + CO_2 n'a compris que du CO_2, ceci indiquant une oxydation du méthane.

Keywords: abandoned mines, case studies, coal mines, geological hazards, soil gases, thermal methods

EFFECT OF MINING RELATED GROUND DISTURBANCES ON THERMAL PROPERTIES

Localised disturbances about mineshafts

Abandoned mineshafts are air, water or debris-filled voids that are commonly capped to some degree. Air and solid rock have different thermal properties and hence a temperature difference can be expected to occur between the two. Generally, mineshafts are cooler than their surroundings for much of the year, but in winter, at certain times of the diurnal cycle, mineshafts will be warmer than the enclosing ground, particularly during freezing conditions. Dependant on the effectiveness of the mineshaft capping a thermal anomaly may be produced at the earth's surface. Anomalously high temperatures have been observed to cause melting of frost over capped mineshafts and measurements indicate that anomalies can average 2-3°C under ideal conditions, (Donnelly & McCann 2000 and Donnelly & Meldrum 1997). Gases are associated with some mineshafts and can exert an influence on the strength of the thermal anomalies through possible exothermic reactions as they reach the surface. There is a tendency for gases to build up during periods of high pressure and to be released on a drop in atmospheric pressure, (Carter & Durst 1955 and Durst 1956).

Where abandoned mineshafts are open and have an obvious surface expression, the most likely cause of the thermal anomaly is the temperature contrast between the shaft-filling air and the surrounding ground. Where shafts have a less obvious surface expression, there is likely to be infill material between the shaft opening and the ground surface, or even an engineered capping. The thermal anomalies over such shafts may relate to the temperature contrast between ground disturbances and materials associated with the shaft and the surrounding ground. Ground disturbances can be due to excavation of a shaft or related actives of hauling, crushing, bagging and sorting, and transportation. Buildings and water pumping works would also disturb the ground and provide potentially anomalous surface areas. These ground disturbances have very localised effects on the physical, chemical, drainage and moisture properties of the surface geological materials. All of these properties have a direct and significant control on the diurnal heating and cooling cycles of the ground and on its ability to radiate heat energy.

Soil density changes are caused by shaft excavations, compaction by heavy trafficking about the shaft, mixing of surface soils with deeper derived rock spoil and looser shaft infilling materials. Shafts and associated ground fractures can either drain surface waters or provide spring sources for rising mine-waters, (McCann *et al.* 1987 and Jackson *et al.* 1987). Thus, localised disturbances to water-flow, drainage and material density will create secondary moisture content changes in the vicinity of a mineshaft. Changes in soil chemistry are caused by the mixing of surface soils with the mining spoils, and also by shaft infilling with materials, sometimes borrowed from sources outside of the local area. Soil chemistry, density, drainage and moisture content changes affect the localised distribution of the flora, and thus the heat radiation pattern about mineshafts.

The diurnal heating-cooling cycle of materials and their thermal inertia

Thermal inertia is the resistance of a material to temperature change, indicated by the time dependent variations in temperature during a full heating/cooling cycle (a 24-hour day for Earth). It is defined as:

$$P = (K.c.\rho)^{1/2} = c.\rho (k)^{1/2} \qquad 1$$

Where K is the thermal conductivity ($W.m^{-1}.K^{-1}$), c is the specific heat capacity ($J.kg^{-1}.K^{-1}$), ρ is the bulk density ($Mg.m^{-3}$) and k is the thermal diffusivity ($m^2.s^{-1}$). The thermal diffusivity governs the rate of temperature change within a material; it is a measure of a substance's ability to transfer heat in and out of that portion that received solar heating during the day and cooling at night. The specific heat capacity is a measure of a material's capacity to store heat energy. It governs the amount of heat energy that must be exchanged to cause a temperature change in the material. As components of thermal inertia, thermal capacity and diffusivity control the heat transfer rate across a boundary between two materials. e.g., air / soil. Because materials with high thermal inertia possess a strong inertial resistance to temperature fluctuations at a surface boundary, they show less temperature variation per heating / cooling cycle than those with lower thermal inertia, as shown in Figure 1.

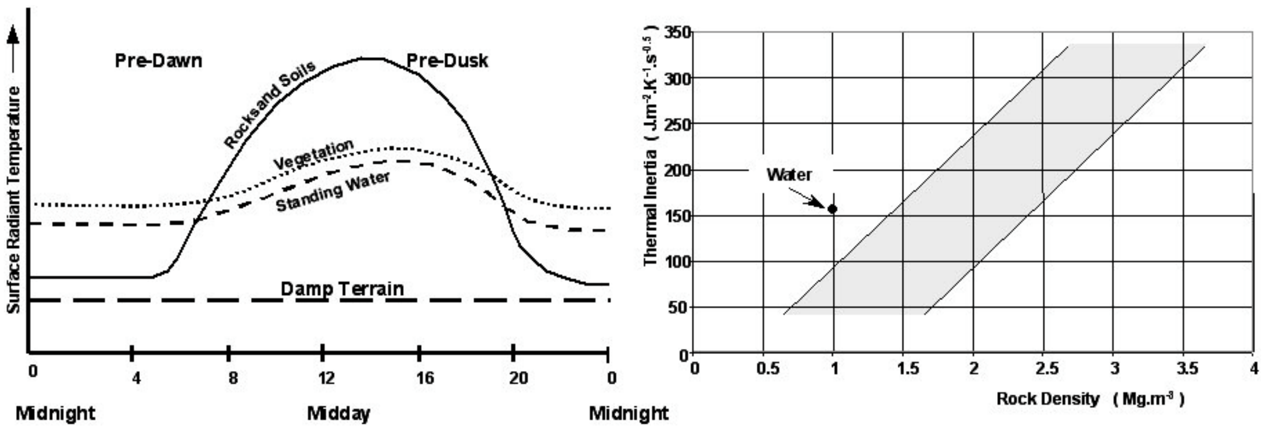

Figure **1**. General diurnal heating cycle and thermal inertia properties of rocks and soils, (after Sabins 1978).

Sabins (1978) showed that a generalised relationship could be established to predict thermal inertia as its dependent variable with density as the independent variable, as shown in Figure 1. In the dry state, soils have lower densities than rocks and thus lower thermal inertia, and low-density, high-porosity rocks will have lower thermal inertias than and high-density, low-porosity rocks. Coal can have an extremely low density, for example the Cinderhill Main Coal Seam in Nottinghamshire was described as being approximately 1 m thick of bands of bright and dull coal, whose specific gravities varied from 1.34 to 1.48. Very approximately, the thermal inertia reduces by 1% for each 1% increase in the coal proportion mixed into a typical sand-clay soil. Ager *et al* (2002) estimated coal proportions within the soil at Chilwell Dam Farm in Nottinghamshire resulted in a 30% reduction in the thermal inertia of coal-darkened ground disturbances.

The thermal inertia of water is similar to that of a medium density rock or soil, (Figure 1), but water bodies appear cooler on pre-dusk images and warmer on pre-dawn images. This is because convection currents maintain a relatively uniform temperature at the surface of a water body (Sabins 1978). Convection does not occur in rocks and soils, thus heat from solar flux is concentrated near their surfaces, causing a higher surface temperature during the daytime. At night the heat from rocks and soils is radiated to the atmosphere and is not replenished by convection currents, causing a lower surface temperature. Thus, water bodies have very different diurnal temperature cycles to rocks and soils, as shown in Figure 1. Damp ground is cooler than dry ground on both pre-dawn and pre-dusk images, due to the cooling effect as absorbed water is evaporated. Damp areas adjacent to water bodies, areas where the natural water table is just below the surface and rain-damp areas are all relatively cool on pre-dawn and pre-dusk images, (Sabins 1978 and Lillesand & Keifer 1987). Abandoned mineshafts can have a significant effect on the localised surface and groundwater pathways. Gunn *et al.* (2002) observed open and backfilled shafts with water at the surface on Baildon Moor, West Yorkshire, Engalnd, that were at altitudes 10 m to 20 m below the summits of local sandstone hills. In one case rising mine waters escaped from an open shaft, providing a spring line that flooded the surrounding ground. This area of ground had a mottled appearance on a remotely acquired thermal image caused by patchy areas of damp ground and surface water. The backfilled shafts had up to 6 m diameter pools of standing water over their central areas that caused relatively warm anomalies on pre-dawn thermal images. Even when water freezes as was the case during the Pewfall surveys described below, the latency of freezing serves to inhibit further temperature reductions of the water saturated ground.

The mixing with mining spoils with the topsoil adds further minerals and changes its overall chemistry. Coal Measures sequences are often very rich in carbonaceous materials like coal and black shales, and sulphide rich minerals like iron pyrites, (Waters *et al.* 1996). Oxidation of methane gases in the soil at the near-surface is an exothermic reaction, thus generating heat. The by-products of methane oxidisation, carbon dioxide and the positive hydrogen cation are both readily soluble in water. Often rising mine waters are acidic due to these dissolved compounds, again affecting the chemistry of the topsoils that it saturates. Soil chemistry, density and moisture variations associated with mining related ground disturbances can often be accompanied by vegetation changes. Green deciduous vegetation is relatively warm on pre-dawn images. Transpiration of water vapour lowers leaf temperature and causes a relatively cool appearance on pre-dusk images, (Sabins 1978). However, the relatively high pre-dawn and the relatively low pre-dusk temperatures of conifers are due to the composite emissivity of the needle clusters approaching that of a black body. Dry vegetation, such as crop stubble in agricultural areas, is relatively warm on pre-dawn images, in contrast to bare soil, which is relatively cool. Dry vegetation can insulate the ground, retain heat and causes the relatively warm pre-dawn image. However, long grasses, whether alive or dry and dead, can appear relatively cool on pre-dawn images due to the cold air around the blades of grass, particularly when the grass has frosted up. Thus, the varied vegetation distribution about mining disturbed ground is likely to contribute towards a localised thermal anomaly.

THE COAL AUTHORITY RESEARCH SITE AT PEWFALL, WIGAN

Site location and geology

The survey area was located on the former site of the Pewfall Colliery, which is roughly mid-way between St. Helens and Wigan in south Lancashire, north-west England. Since the cessation of mining the site has been returned to agriculture, but some fenced off mineshafts remain in neighbouring fields. Bedrock geology consists of the Lower Coal Measures Formation, the Middle Coal Measures Formation and the Ravenshead Rock with a regional dip of 30° to the south-east. The site is cut by a normal fault that is downthrown to the south-west, with a dip of 70° and strikes to the south-east (Figure 2a). The bedrock geology is overlain by glacial till to an unknown thickness but possible up to 10m thick. Two 50m x 50m survey grids were established and denoted Site B, which was on a gentle, south-west facing slope, and, Site C, which was in a shallow trough that widened and whose axis also dipped to the south-west, (Figure 2). The north-eastern half of Site B is covered by the remnants of an old spoil heap (denoted as made ground in Figure 2b). The x-axis of Grid B was orientated approximately east-south-east (E 23° S). The origin of the grid was located at British National Grid co-ordinates 355120.95E, 398376.82N. The elevation range across the grid was 2.4m. The x-axis of Grid C was orientated approximately west to east, but dipped to the south-east by 3°. The origin of the grid was located at British National Grid co-ordinates 355208.89E, 398346.88N. The elevation range across the grid was 3m.

Condition of the ground surface during the surveys

The nature and condition of the ground surface over both grids was very variable and in Grid B included areas of:

- long grass, within which very long tufty grass could occur
- very disturbed ground – highly turfted up; very wet ground with standing water and ice (the survey was carried out in winter)
- very disturbed ground – highly vehicle rutted
- disturbed ground – tamped
- temporary road surfaces

Looking across Grid B, long grass generally covered the area beyond y = 35m below which it occurred as small islands, (Figure 2b); a major zone of vehicle rutting occurred from x = 20m around y = 20m to 28m; a temporary road was mainly bounded within x = 12m and y = 10m, also around x = 13m was a mound of earth moved when laying the road; standing water / ice occurred as islands over the Coal Measures sub-crop; other areas comprised wet, flat, dark brown ground.

In Grid C, the nature and the condition of the ground surface included areas of:

- long grass, within which very long tufty grass could occur
- very short and sometimes very patchy grass
- flat dry brown soil with coarse gravel brick/stone rubble and occasional very short patchy grass (and very occasional caterpillar tracks)
- very disturbed ground – highly turfted up; very wet ground with standing water and ice
- very disturbed ground – highly vehicle rutted

Looking across Grid C, long grass generally covered the area below y = 13m and beyond x = 44m, (Figure 2b); generally long grass gave way to very short grass up to y = 20m and below x = 15m; vehicle rutting was confined to a small zone near y = 50m; an island of wet, disturbed and turfed up ground roughly 20m in the x-dimension by 25m in the y-dimension was centred about x=32m, y=36m; standing water / ice occurred over a 5m wide island in the trough along a section of x = 40m from y=15m to 32m, over the Coal Measures sub-crop; other areas comprised dry, flat ground with coarse brick and stone gravel sized rubble.

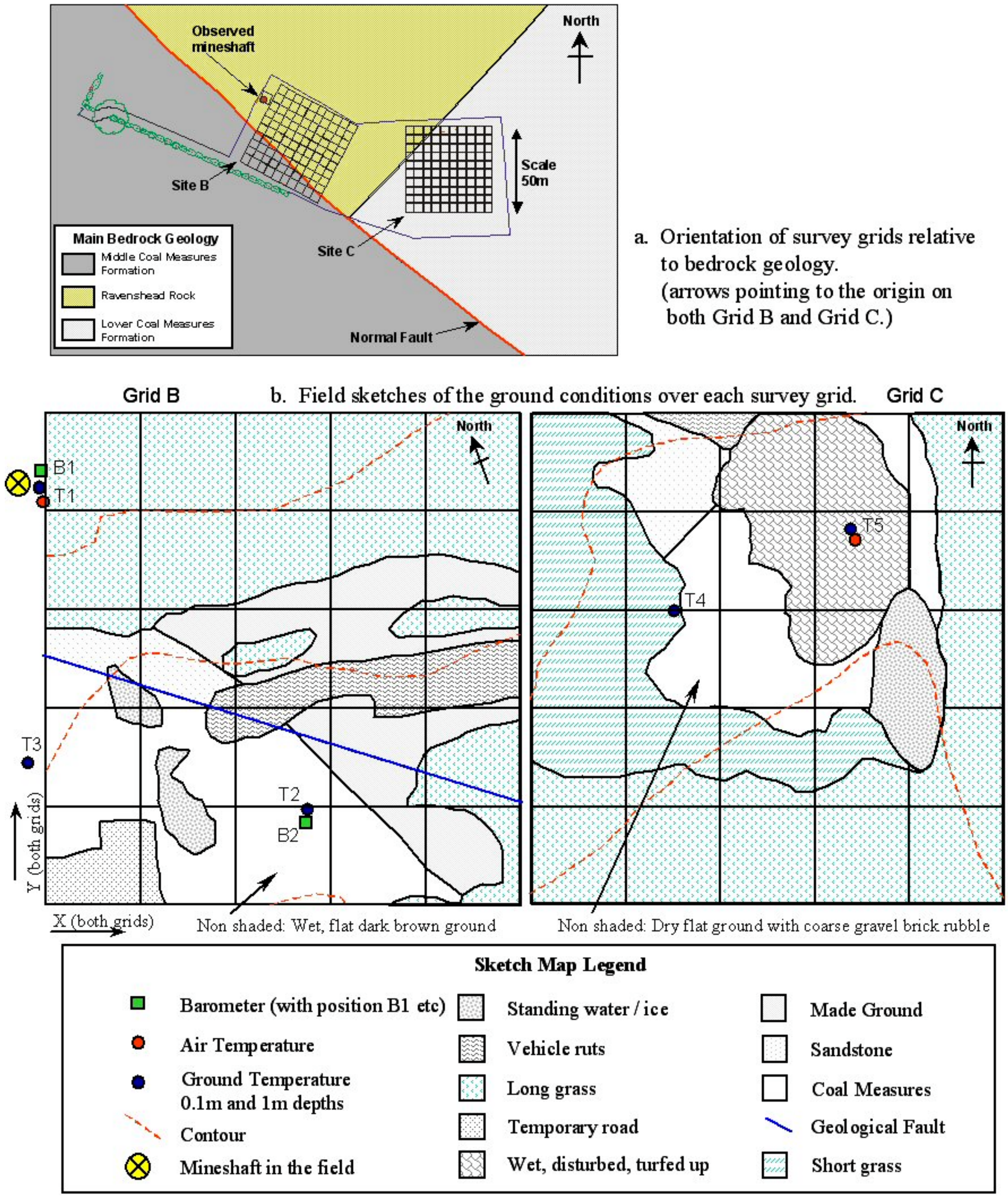

Figure 2. Geology, orientation and ground conditions of the Coal Authority research site at Pewfall, St. Helens.

The thermal survey was undertaken as part of a larger programme of field trials that tested a number of geophysical surface techniques over what were designated a "green field" site, covering Grid B, and a "brown field" site, covering Grid C, (Busby et al. 2004a; Busby et al. 2004b). The locations of the original mineshafts were already known, but were re-capped with wooden cappings and the ground surface was restored to a condition and topographic profile that would have existed had there been no mine entries. However, the considerable works to reinstate the ground led to the ground conditions described above. Of these two hidden mineshafts, one was known to be open, and therefore air or water filled whilst the other was backfilled. Since the region is a former mining district the ground adjacent to both shafts may also contain variable fill materials, adverse superficial deposits and buried structures. The locations of the mine entries were not known at the start of the survey and hence the trials were 'blind'.

THERMAL MONITORING AND SURVEYING OF THE GROUND

Conditions prior to survey

The survey over Grid B was undertaken from 01.15 to 06.30 on the 25th February 2004. The survey over Grid C was undertaken from 01.00 to 05.20 on the 26th February 2004. Generally, the winter of 2003 – 2004 had been fairly mild and in the weeks leading up to the surveys and there were several rainy spells. However, the week before the surveys was characterised by very clear, sunny days with freezing temperatures in the evening. There was only one spell of rain within this week, which occurred from 04.00 to 10.00 on the 24th February 2004. Barometric pressure was recorded to decrease during both surveys although the Grid B survey was undertaken during a hiatus in the pressure change (see below).

Air temperature and pressure monitoring

Air temperature, ground temperature at 0.1m, ground temperature at 1.0m and barometric pressures were logged (every 30 minutes) at various locations at the site, as shown in Figure 2b. Meteorological data from the nearest Met Office station at Manchester were also recorded in the month up to and during the thermal surveys. The air temperature sensors logged in still air at 0.75m above the ground surface shielded from solar radiation from above and due to ground reflections. The barometer was protected from the weather and the ground sensors were mounted on banding tape and inserted into augered holes that were back-filled after insertion. The air temperature location on the Grid B site (T1 in Figure 2b) was on the secluded, SW side (sun-trap) of the capped mineshaft near to position 0, 43(m) on the grid. The air temperature location on the Grid C site (T5 in Figure 2b) was in an exposed open field. The Grid C air temperature compared very well with the Met. Office data from Manchester, but the effects of solar heating on the localised sun-trapped air next to the boundary fence and bushes of the capped mineshaft can be seen as heightened temperatures of up to 5^{o}C, as shown in Figure 3. Both Pewfall sensors indicate sub-zero air temperatures during the surveys. Also, note the rapid increase in air temperature at around 7.45am on the 25th and 26th Feb as the site is exposed to direct sunlight. On the morning of the 24th a local rain front inhibited this effect, which led to the inhibition of ground warming in the shaded areas of Grid B (discussed below).

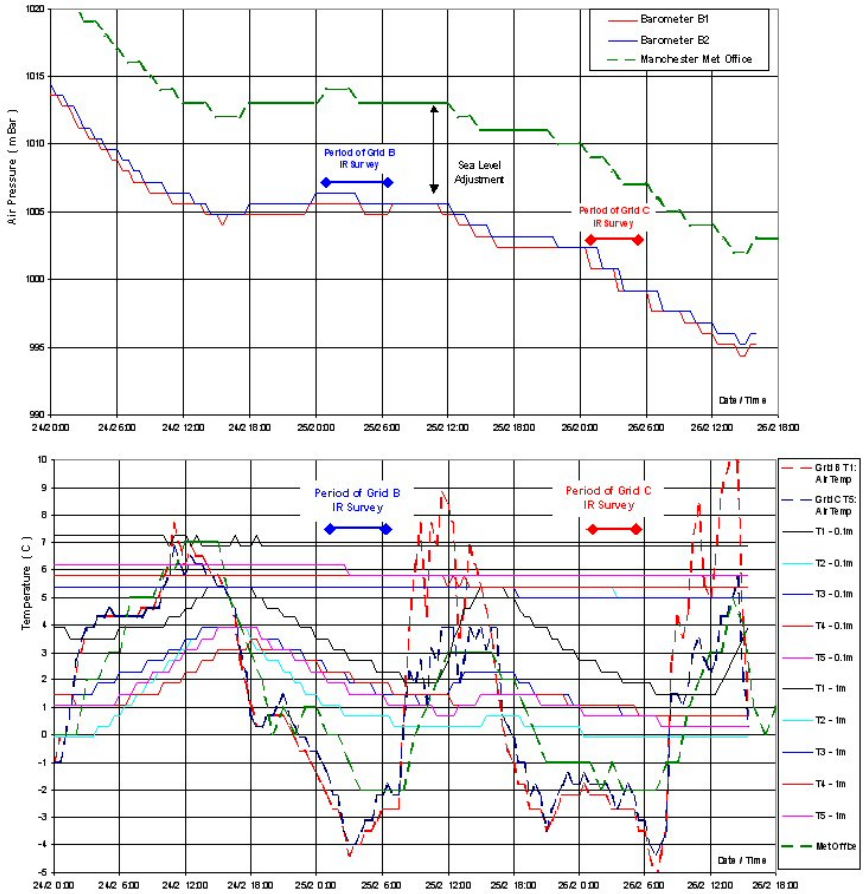

Figure 3. Air temperature and pressure and ground temperature logs before and during infra-red surveys.

Barometric pressure sensors were located on Grid B next to the capped mineshaft near to position 0, 43 (B1 in Figure 2b) and also at position 28, 9.5 (B2 in Figure 2b). Both pressure logs compare very favourably with the Met. Office data from Manchester where the Manchester data are adjusted to sea-level. The Grid B thermal IR survey was undertaken during a small decrease in barometric pressure on a general trend that showed a fall of nearly 25mb in three days. This survey was undertaken just after a half-day hiatus, which was after a one-day fall of around 10mb, where the pressure fell by 1mb over the duration of the survey. The Grid C thermal IR survey was undertaken during a decrease in barometric pressure of 7mb in a half-day after a 6-hour hiatus, where the pressure fell by 3mb over the duration of the survey.

Ground temperatures monitoring at 0.1m and 1m

Ground temperatures at 0.1m and 1.0m depths were logged (every 30 minutes) at various locations at the site, (logs shown in Figure 3). The attitude of the location to the sun and the overall ground conditions are significant factors in controlling ground temperature fluctuations at the 0.1m depth. The highest ground temperature at 0.1m was found in the sun-trap zone near the fenced mineshaft (T1), where the night and day temperatures were respectively at least 0.75°C and 1.5°C greater than other locations. This location also shows the greatest fluctuation from the peak daytime to the minimum night-time temperature. Protection from wind and good solar irradiation at this location are the main causes of the greater peak daytime temperature. Relatively low thermal inertia of the localised soil is possibly the cause of it having the greatest reduction in temperature during the nighttime. The lowest ground temperatures at 0.1m were within the area that had standing water and was in partial shade during the installation, (T2 in Figure 2b). Note how the latent heat of freezing inhibits the ground temperature at this depth from reducing below 0°C, and how the combined effect of latency, shade and low daytime air temperatures contribute to inhibit the daytime ground temperature rise during the 25th Feb.

At 1m depth all sensors indicate gradual reduction in temperature in response to a gradual cooling in the mean air temperature due to a cold front from Scandinavia moving south over the UK. No diurnal cycle is observed at this depth and all sensors show an overall reduction in temperature of about 0.5°C. Again, the highest ground temperatures at 1.0 m were found in the sun-trap zone near the fenced mineshaft (location T1) where the temperatures were about 1°C greater than other locations. The lowest ground temperatures at 1.0m were within the area that was in partial shade during the installation (location T2) and also at location T3 situated on a low S-SE facing slope near position 0, 14 on Grid B. (Note that these over plot one another).

Thermal Infra-red gridded surveys

Equipment and methods

A FLIR TERMCAM PM 675 was used for the survey. This has a minimum focal distance of 0.3m, a spatial resolution of 1.3mradians and a typical sensitivity of 0.1°C at 30°C. Measurements were taken over a 50m by 50m grid of points at every 2m in both x and y directions (i.e. 26x26=676 points per grid). At each measuring point within the grid the camera was held directly above the ground at head height such that an area of approximately 1m^2 could be imaged. The temperature attributed to the measurement point was the average of all the pixel values within the image (320x240). Thus, an overall averaged value of the ground was measured that was insensitive to the small-scale changes associated with footprints, grassy tufts, tyre ruts and so on. These values are presented as a contoured image covering the whole 50m by 50m grid for either the B or the C site. Control points were established for both girds where a series of repeat readings were taken throughout the duration of each survey. These repeat readings formed a baseline of temperature-time variation, which was used to correct the gridded surveys for background temperature drift. The control point for Grid B was at position x = 50m, y = 50m on the grid and the position for Grid C was at x = 0m, y = 0m on the grid. The gridded images presented below are corrected for background temperature drift.

Thermal infra-red image for Grid B

The thermal IR emitted from the ground over Grid B is shown in Figure 4. The line work overlay delineates the key surface and underlying geological features over the grid. The temperature scale of Figure 4a is set to show all ground temperature readings and provide a whole image. Thereafter, the scale is set within a series of bands in order to highlight several features within the whole image. The confirmed position of a 3m diameter brick-lined, air-filled mineshaft is denoted by the circular target with a diagonal cross at 28, 14m. Observing the whole image over the temperature range –8°C to –2°C in Figure 4a, the coldest part of the grid is centred around a target at x = 2m, y = 38m next to the capped mineshaft just off the grid. This coincides with an area of long, tufty grass, which is localised and could be associated with ground disturbances related to the present shaft, e.g. different soil cover? Note that cold air pockets trapped within the frosted grasses also contribute to this cold measurement and thus the anomaly is not wholly due to the ground temperature. Other cold targets within the long grassy area include an oval from x = 16m to x = 26m, y = 32m to y = 36m and also an oval from x = 24m to x = 34m, y = 38m to y = 42m, again which could be related to ground variability and its effect upon vegetation. The warmest part of the grid covers a zone up to y = 6m from x = 22m to x = 48m. This coincides with the root systems of two trees that provide the shade for the area about T2. Respiration within the root networks provides additional heat to the ground in this zone. Other evidence of respiration is provided by soil gas samples from this zone that show much reduced oxygen and increased carbon dioxide levels, (as shown in Figure 7). Other warm targets are generally related to standing water / ice, e.g. the target at x=14m, y=10m.

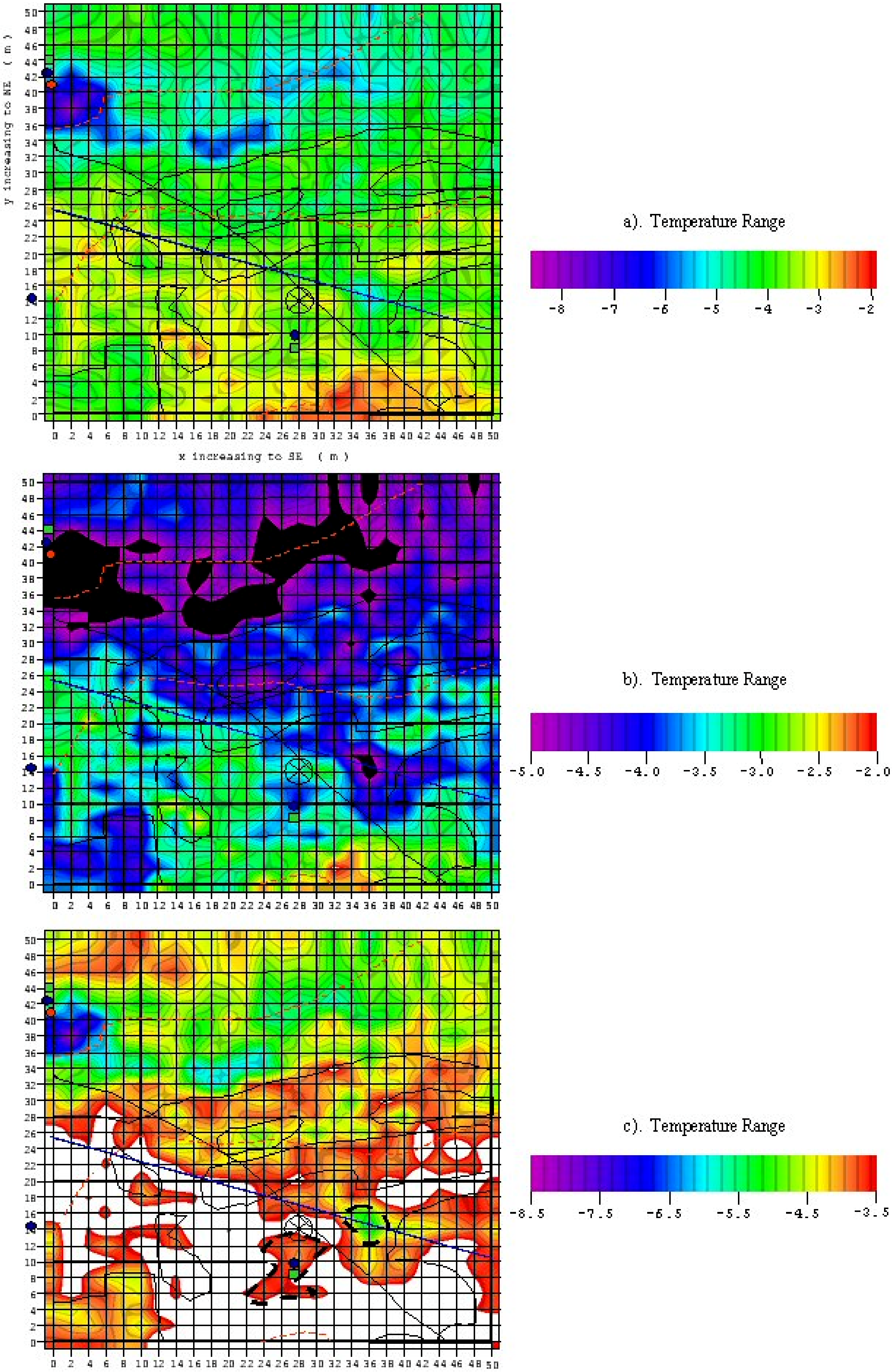

Figure 4. Contoured 2m infra-red temperature image of Grid B.

Displaying the image from -5°C to -2°C (Figure 4b) removes the very cold targets and provides increased differentiation between other, subtler ground features.The faulted boundary between the Sandstone and Coal Measures formations and /or the limit of the made ground is highlighted by the colour change around -3.7°C. The temporary road is also highlighted as relatively cold ground. The root zone and the water/ice zones are highlighted as relatively warm ground. Within the relatively warm ground W-SW of the made ground, a cold target of note is centred at x=28m, y=10m, where possibly targets at x=12m, y=18m and x=13m, y=13m are of lesser importance due to their limited size. Again, these targets are considered to be related to ground variability, significantly not within the area of made ground.

Displaying the image from –8.5°C to –3.5°C (Figure 4c) removes the very warm targets and provides increased differentiation between the relatively cold ground features. The faulted boundary between the sandstone and mudstone formations and /or the limit of the made ground is again highlighted. The long grassy areas within the grid are further highlighted as relatively cold ground. Another relatively cold target within the made ground is centred at x=36m, y=15m, which is ringed with a dashed black line. This may be related to variability within the made ground or other mining related disturbance. The cold target centred at x=28m, y=10m within the relatively warm ground W-SW of the made ground is again ringed. This too is of a size that is relevant to a mining related disturbance like a shaft. These two anomalies were identified as areas for further investigation, for example by pitting. Observations of the ground surface at the target centred at x=36m, y=15m indicated the presence of a small patch of brick rubble, thus providing circumstantial evidence of mining disturbances. Observations of the ground surface at the target centred at x=28m, y=10m indicated evidence of disturbance in the form of tamped flat ground which was related to the reinstating of the cover after installation of the temporary wooden capping.

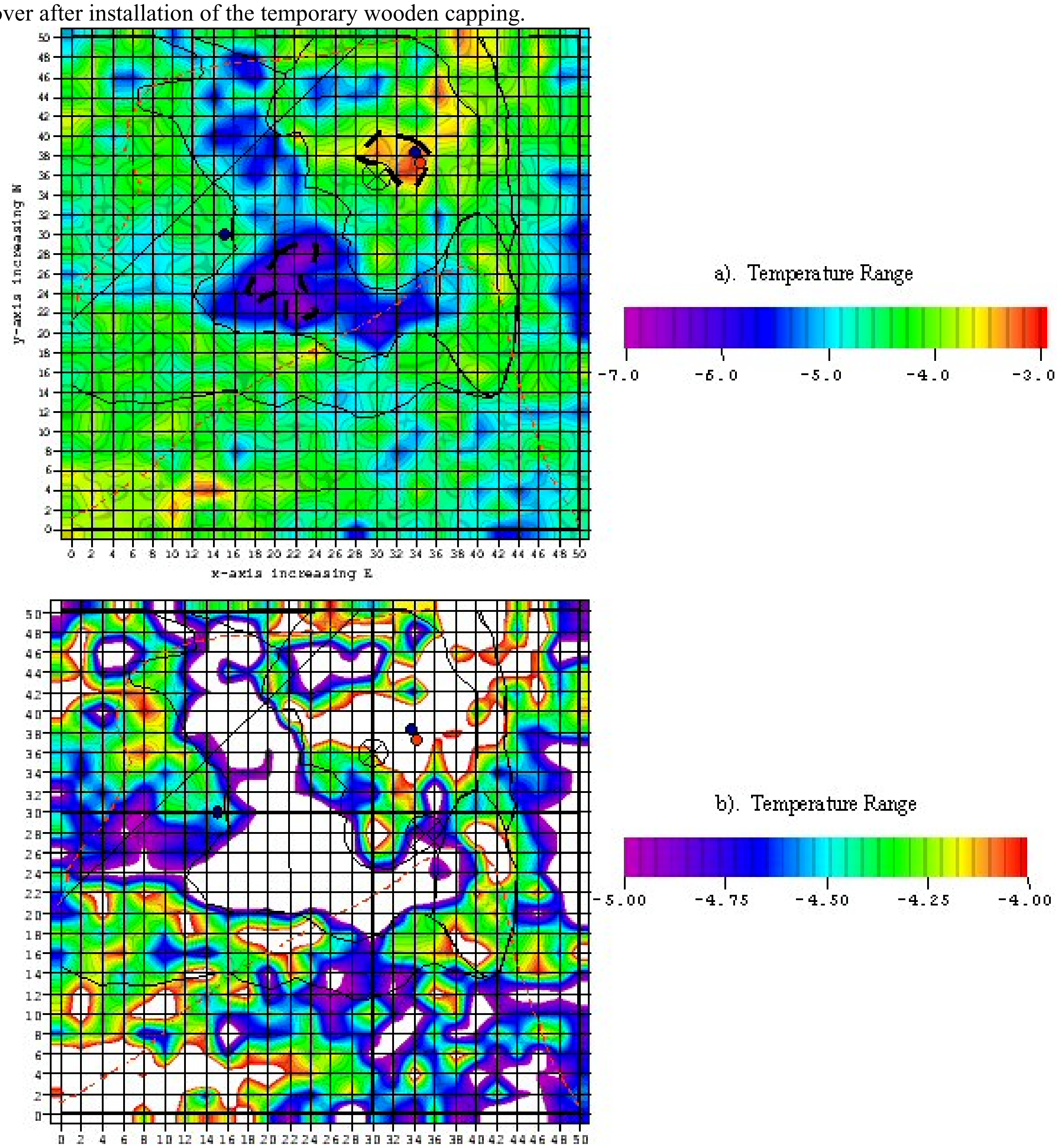

Figure 5. Contoured 2m infra-red temperature image of Grid C.

Thermal infra-red image for Grid C

The thermal IR emitted from the ground over Grid C is shown in Figure 5. The line work overlay delineates the key surface and underlying geological features over the grid. The confirmed position of a 3m diameter brick-lined, back-filled mineshaft is denoted by the circular target with a diagonal cross at 28, 14m. The temperature scale of Figure 5a is set to show all ground temperature readings and provide a whole image. Thereafter, the scale of Figure 5b is set mainly to remove the warmest and coolest features. However, displaying the image from –5°C to –4°C (Figure 5b) removes the very warm and very cold targets but only highlights the grassy cover over the grid.

Observing the whole image over the temperature range –7°C to –3°C in Figure 4a indicates that the temperature range between the warmest (-3°C) and coolest (-7°C) areas of Grid C was within the range for Grid B (-2°C to –8°C). One might have expected lower temperatures at Grid C due to a lower minimum air temperature and lower ground temperature measurements compared to conditions during the Grid B survey. The coldest parts of the grid coincide with the dry, flat ground containing coarse brick rubble. In fact, the amount of brick rubble was sufficient to give this area of ground a brown-red colour. This ground appeared to be of low moisture content and very well draining and the low temperatures are suspected to be due to heat losses caused by evaporation. A large cold target centred approximately at x=21m, y=25m has been highlighted for possible further investigation, but it is suspected that the anomaly is due to the large amount of brick rubble in the ground, for example consistent with buildings located here formerly. Another notable cold target is centred along x=50m from y=20m to y=36m. This is within the zone of long grass, within which there are areas of very long, dry wispy grass that had frosted up where pockets of cold air may have been trapped. It is possible that this cold zone is related to variability to the underlying ground, which may comprise made-ground associated with former railway works that were understood to have once occupied the site. The cold target within the wet, disturbed and turfted up ground coincides with a small island of brick rubble seen by the person in Figure 6. Warm targets of note include an oval zone roughly 5m by 4m centred at x=32m, y=37m, and also lesser targets at x=36m, y=44m, x=38m, y=50m and x=13m, y=4m. It was noted that the first three targets occur in grass-free areas, whereas the target at x=13m, y=4m occurred within the zone of long grass. The target at x=38m, y=50m coincided with standing water and ice that was observed during the survey, and it is suspected that the target at x=36m, y=44m was also associated with ice.

Figure 6. View of Grid C from the SE to the NW corners.

Soil gas sampling and analysis

Soil gas sampling across the largest anomaly at x=32m, y=37m on Grid C indicated the presence of very minor amounts of methane and complete deficiency of oxygen in the ground that is compatible with methane oxidation. Figure 7a shows a profile of analyses of gas samples taken along x = 32m across the warm target at y=37m. Exothermic oxidation of methane would provide additional heat into the ground and this is very compelling evidence for the presence of a mineshaft in the zone highlighted. The profile along x = 34m on Grid B indicates the consumption of O_2 and the generation of CO_2 within the warm area associated with many tree roots, (Figure 7b). CO_2 reduces and the O_2 increases and begins to approach normal atmospheric levels moving from the warm, root zone to the colder ground with increase in the y-station value. Note also, the reduced total component in the root zone which is suspected to be due to the production of plant cells taking some of the carbon and oxygen out of the gaseous phase. Two profiles on Grid B along x=0m and x=16m indicate the consumption of O_2 and the generation of CO_2 coincident with the boundary of the made ground. This is considered to be due to organisms metabolising the carbon from the made ground that has been mapped and identified in pits as burnt colliery shale. It is unclear to the authors as to why this phenomenon only occurs at the boundary.

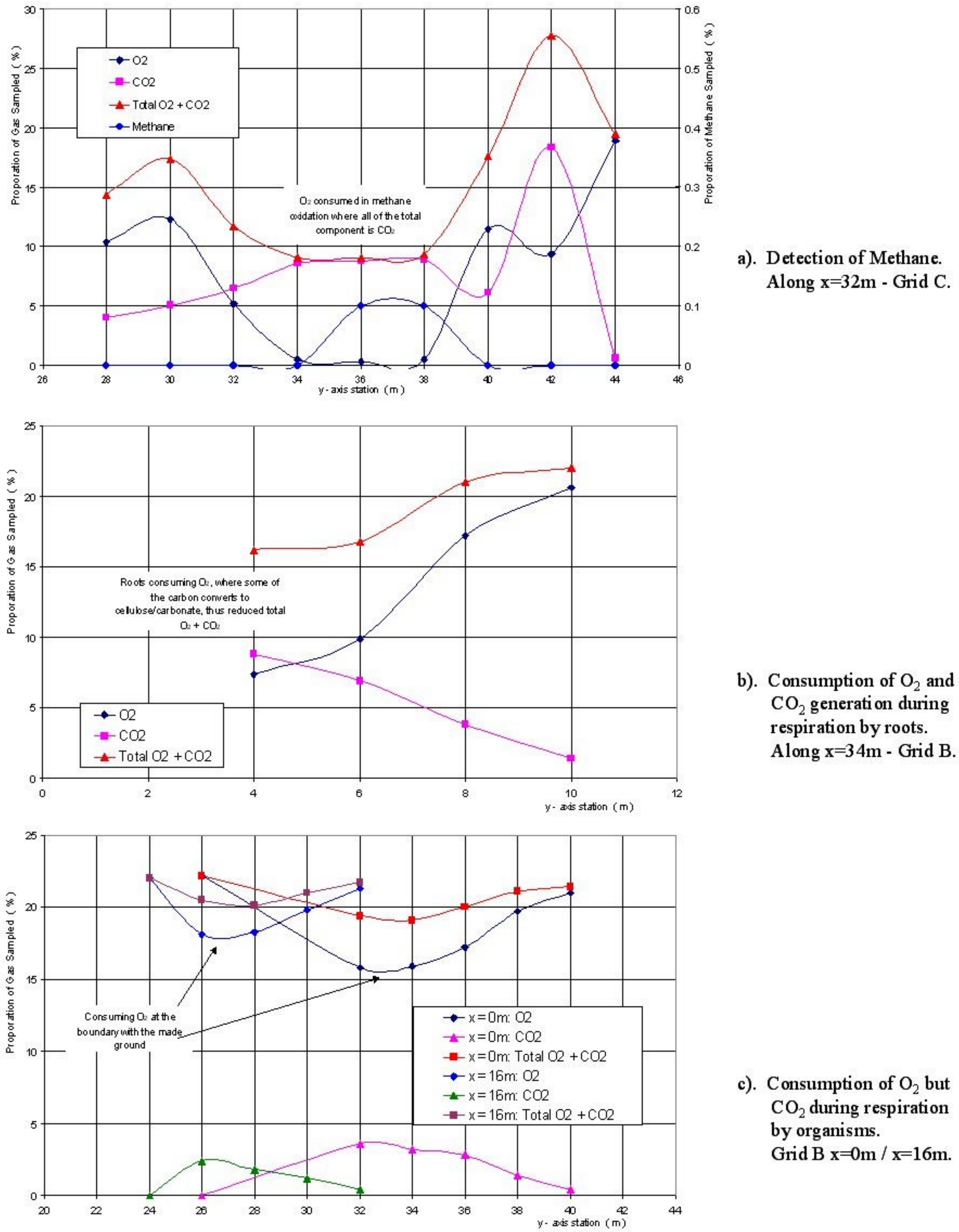

Figure 7. Soil gas sampling and analysis from Grids B and C.

DISCUSSION

Anomalies in thermal IR images are known to have been associated with mineshafts. These are either directly related to an air-filled shaft but more often are related to the ground disturbances and materials associated with the shaft. Ground disturbances include effects due to density changes caused by soil mixing, moisture content changes caused by the presence of a shaft and also chemistry and related vegetation changes.

Thermal IR surveys were undertaken at the Pewfall site over two 50x50m grids with a measurement interval of 2m. Air temperature and pressure, and ground temperatures were also logged at some locations over each grid prior to and during the survey periods. Generally, the weather conditions were considered to be extremely favourable for thermal IR surveys of the ground, which included very low air temperatures and falling barometric pressure.

The ground surface conditions over each grid were very variable and could be seen to significantly affect the survey data. For example, derelict ground comprising well-draining brick rubble produced relatively cold zones on images and standing water / ice produced relatively warm zones on images.

Capped mineshafts were present at the site and localised ground disturbances related to a capped mineshaft just beyond the perimeter of grid B resulted in a very cold target. Other evidence of mining related ground disturbances included tamped ground and dereliction in the form of brick rubble. Two targets on Grid B were highlighted for further investigation, for example by pitting and were approximately centred at x=28m, y=10m and x=36m and y=15m. Also, two targets were highlighted on Grid C for further investigation, where only one of these was immediately associated with evidence of dereliction. The second target was within a zone of disturbed ground where gas samples provide evidence of methane oxidation. These targets were approximately centred at x=21m, y=25m (brick rubble dereliction) and x=32m, y=37m (methane oxidation).

The position of the Grid C shaft was shown to be associated with methane in the ground, but unfortunately the association of methane with the Grid B shaft was not tested. This raises the issue of was there methane present in the Grid B shaft and if so could it escape into the soil covering the shaft? The temporary cappings to both shafts were different but neither was gas tight, thus methane if present near surface would have been allowed to escape from both shafts into the soil. Both the B and C shafts are connected at depth (approximately 30m to 35m) to a sough that drains water towards St. Helens. It is suspected that any methane detected in the near surface soils was probably generated near the surface, for example sourced from coal spoils backfilling the Grid C shaft. Also, it is possible that this methane is of biogenic origin and not due to release during a fall in barometric pressure. Any methane generated within the Grid B shaft would have oxidised by mixing with the air within the shaft itself and not within the near-surface soil, thus any warm thermal anomaly would have been masked by near-surface effects. Changes in ground temperature measurements are consistent with the near-surface significantly affecting IR radiation from the earth. These indicated far greater sensitivity to diurnal heating and cooling and far greater temperature variability at 0.1m depth than at 1m depth where the temperature changed more gradually with longer duration weather systems. Indeed, the key message from this paper is that surface and very near surface materials, processes and conditions significantly affect the thermal IR radiation measured using field devices. These factors have to be accounted for when interpreting thermal IR images for the presence of unmapped mineshafts.

This paper is published with the permission of the Executive Director of the British Geological Survey (NERC). The authors gratefully acknowledge the financial support of The Coal Authority (Contract Ref: CA 18/C1251). Finally, the authors thank Mr. Bob Heaton for provision of services during the site surveys.

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