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Investigation of Geological Hazards & Mining Risks, Gallowgate, Newcastle-upon-Tyne

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Abstract: Gallowgate is an industrialised site located in the centre of Newcastle upon Tyne, UK, adjacent to St. James's Park football stadium. The site is currently being considered for major redevelopment with the current master plan envisaging a mixture of uses including a hotel, student accommodation, residential and office blocks, generally 9 to 14 storeys but with one of these reaching some 165m high, making this the tallest structure in Newcastle. Past land use at this site complex consisted of at least several hundreds of years of shallow underground mining and a variety of industrial, commercial and residential developments; many have long since been demolished. Mining records are incomplete and the precise position, extent, and conditions of mine shafts and mine workings are not known. Documentary evidence is unreliable and contradictory. The risks associated with past mining were assessed, these included the collapse of near-surface shallow workings (bell pits, shafts, room and pillar workings), residual mining subsidence, fault reactivation, acid mine drainage, mine gas emissions and spontaneous combustion. An assessment of the past industrial land use history and current land use enabled an estimation of the potential geological and mining hazards. A number of tunnels are present at the site, at a shallow depth, forming part of the existing underground Metro transport system and the brewery. These were envisaged to have implications on the site investigation, development and construction. The objective of this paper is to demonstrate the value of undertaking a desk study to determine hazards, risks and liabilities associated with the geology and past mining. This desk study is envisaged to significantly reduce the likelihood of 'unstable' or 'unforeseeable' ground conditions prior to the development of complex engineered structures in this prestigious, high-profile inner city site. It will demonstrate that by properly incorporating geological investigations the technical and financial risks to major developments may be substantially reduced.

Résumé: Gallowgate est un emplacement industriel, situé â coté du stade St. James's Park au centre de la ville de Newcastle-upon-Tyne au Royaume Uni. Actuellement, un grand réaménagement de ce terrain est à l'étude. Les propositions importantes qui ont été avancées comprennent le construction d'un hotel, bureaux et residences pour le public et pour les étudiants. La plupart des nouveaux batiments auront entre neuf et quatorze étages, mais l'un des bâtiments serait 165m de haut. S'il est construit, ce bâtiment serait le plus haut structure à Newcastle. Auparavant, l'utilisation du terrain composait d'exploitation peu profonde, qui a durée au moins pour plusieurs siècles. Ainsi que cette utilisation, il y avait un variété d'ensembles industriel, commercial et de logements, beaucoup desquels ont été demolis. Les comptes-rendus de l'exploitation sont incomplet et les positions exactaments, les ampleurs et les conditions des mines sont inconnus. Les preuves écrites de l'exploitation sont douteuse et contradictoire. Les risques se sont associés à l'exploitation passée ont été évalués. L'effondrement des travaux peu profonds proches de la surface (puits et puits de cloche, travaux de pièce et pilier), de l'affaissement d'extraction résiduel, de la réactivation de défaut, du drainage acide de mine, des émissions de gaz de mine et de la combustion spontanée était inclus parmis les risques. Une évaluation de l'histoire industrielle passée d'utilisation de la terre et de l'utilisation de la terre courante a permis une éstimation des risques minières et géologiques. Plusieurs tunnels se sont produits à l'emplacement, à une profondeur faible, faisant partie du système souterrain existant de transport de Metro et de la brasserie. En plus des tunnels souterrains de transport ont été proposés à une profondeur relativement faible sous cet emplacement. Ceux-ci ont été envisagés pour avoir des implications graves sur la recherche, le développement et la construction d'emplacement. Les objectifs de cet article sont de démontrer la valeur d'entreprendre une étude de bureau pour déterminer les risques et les responsabilités liées à la géologie et l'exploitation passé. Il est à souhaiter que cet article réduira sensiblement la probabilité des conditions au sol 'instables 'ou 'imprévues', avant le commencement de la construction des structures complexes dans cet emplacement prestigieux et de haut-profil. Il est clair qu'en incorporant correctement des investigations géologiques les risques techniques et financiers aux développements principaux peuvent être réduit sensiblement.

Keywords: Engineering geology, geological hazards, geotechnical engineering, remediation, mining geology, urban geoscience.

INTRODUCTION

Gallowgate is an industrialised site located in the centre of Newcastle upon Tyne, to the south-west of St. James's Park football stadium. The site comprises typical inner city industrial land use including a variety of buildings, accommodation, an electrical substation, and factories. The site is currently being considered for major redevelopment and rehabilitation. The current master plan envisages a mixture of uses including a hotel, student accommodation, residential and office blocks, generally 9 to 14 storeys but with one of these reaching some 165m high, making this the tallest structure in Newcastle (Figure 1).

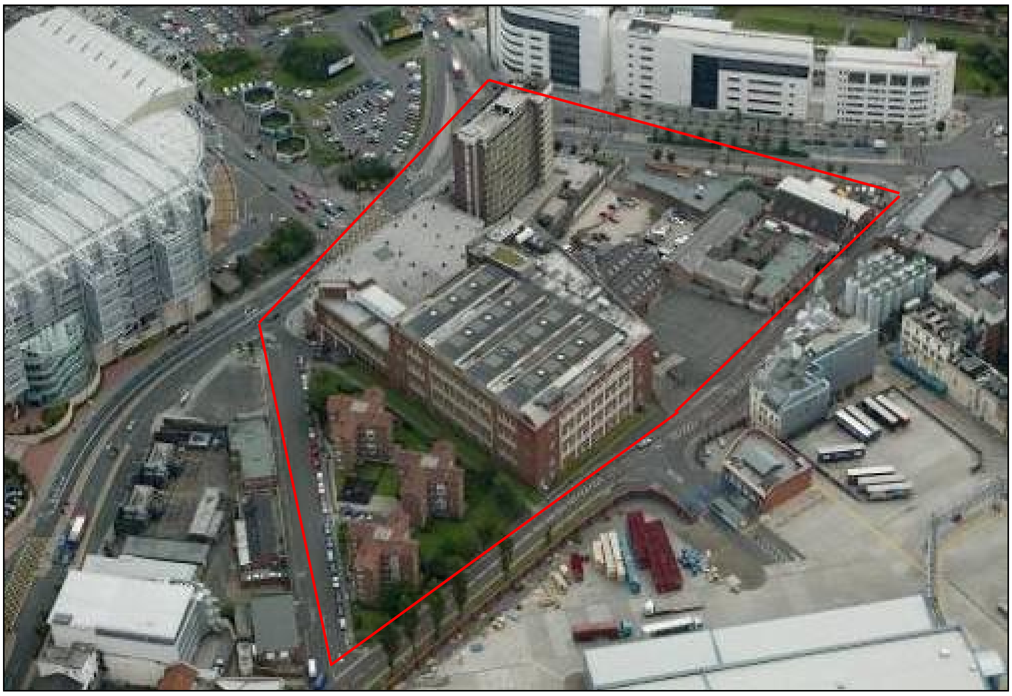

Figure1. Gallowgate redevelopment site, Newcastle upon Tyne (outline of site is shown in red).

SOURCES OF DATA AND INFORMATION

The acquisition and interpretation of archive data, information and documents, forms the first part of any desk study. For this particular investigation information was obtained from a variety of sources which included, the British Geological Survey, the National Geological Data Centre (NGDC), the Ordnance Survey, Landmark (Envirocheck), the Coal Authority, Durham Mining Museum, Scottish Mining Museum, Northumberland Records Office, Newcastle University, the Environment Agency and Newcastle City Council.

Desk study

The redevelopment site is underlain by coal bearing rocks of Upper Carboniferous (Westphalian) age and these have a long complex mining history. The hazards and liabilities associated with past mining need to be assessed and investigated to minimise physical, technical and financial risks to the development. This first phase of this investigation was to conduct a desk study. A desk study seeks to make a close approximation of the geological and mining conditions at the site and to produce a conceptual geological 'model'. The accuracy and precision of this model should evolve as the project proceeds from the desk study phase, through to site investigation, design and construction. The desk study therefore provides a starting point from which the hazards and liabilities at the site will become apparent. The desk study also enables the Client to foresee potential issues and concerns so that he/she may be better placed to manage the financial resources which may be required to reduce geological and mining risks (such as the stabilisation and treatment on mine entries and shallow mine workings) (Fookes 1997).

Archive records, geological maps and abandoned mine plans

Archive data and published information is not always complete, accurate and reliable. But it gives a general appreciation of the site conditions, geology, past mining and historical land use. Coal has been extracted in Britain over a period spanning several centuries, but it was not until 1850 that the 'Inspection of Coal Mines in Great Britain Act' made the preparation of mine plans a statutory obligation (Donnelly *et al.,* 1998). This Act also established an Inspectorate of Mines. This legislation required mine owners to prepare accurate plans for the mine inspector, twice a year, on a scale of no less than 2 chains to 1 inch. In 1855, a strengthening of the act required the mine owner to give the inspectorate at least two months notice of any intention to commence, recommence, discontinue or abandon mining. This practice was undertaken until 1887 and was not totally reliable, with some surveys only undertaken at the time of inspection, resulting in a lack of data. In addition, there was still no legislation that required abandonment plans to be compiled. In 1872, the introduction of the Coal Mines Regulation Act required accurate abandonment plans to be submitted with the Secretary of State within 3 months of mine closure. It was not until 1896 that surface features were included in any detail. Not until 1911 did the act require mine owners to maintain accurate plans of a specified scale, and revise them every three months. Plans had to show the position of mine workings in relation to surface features, these included mine shafts and geological faults. In 1927 a government committee concluded that plans made prior to 1887 should not be regarded as indicating the actual position of workings, but must be treated as evidence that old workings exist in the neighbourhood. Therefore, even when former mine workings have been recorded, their precise locations can not be determined accurately in all situations. It is often not known whether the shafts have been capped to reduce the risk of collapse or how effective the capping has been.

In other instances, mineshafts are marked on plans, but do not actually exist, or their positions have been purposely mislocated (this may be a result of bogus mining activities during the 18th century in Great Britain, for instance to avoid payment of taxes). Following the nationalisation of the British coal mining industry in 1947, coal mining records and mine abandonment plans were passed to the National Coal Board (later the British Coal Corporation). In 1994, following the privatisation of the coal industry and the establishment of the Coal Authority, all mining records relating to coal became lodged with the Coal Authority. This excludes metalliferous mine records (such as iron, lead, copper, zinc, and gold) and industrial minerals (such as limestone and sandstone) for which there are no national repositories of data and information.

GEOLOGY

Geological maps and borehole records provide a general appreciation of the stratigraphy at Gallowgate which consists of made ground and infilled ground, overlying superficial deposits and Coal Measures sequences. An assessment and interpretation of geological maps enables the type, thickness, engineering properties and possible geological and mining hazards to be estimated (British Geological Survey 1992, 1976).

Made ground and infilled ground

Made ground includes any materials placed by man on the natural ground surface. Infilled ground is materials which have been placed in excavations. Natural ground is not exposed on the site, or in its immediate vicinity, due to urbanisation, industrialisation including the presence of buildings, residential property, roads and other structures. Geological and ordnance survey maps (dating back to at least 1862) indicate that made ground, or fill, may be present over the majority of the site.

Geotechnical significance of made ground and infilled ground

It is possible that thick reinforced concrete foundations exist on parts of the site; and are likely to require mechanical breaking prior to any ground investigation. The made ground across the site is likely to be highly variable in composition, geotechnical properties and thickness (commonly 1 to 2m, but over 20m is possible). The materials may include variable amounts of chemical, industrial and mining waste, domestic refuse, construction material, hardcore (bricks and concrete), other rubble and bulk fill derived from the bedrock. The possibility exists that the material may include a very wide range of inorganic, organic, inert, reactive, combustible, harmless, radioactive and toxic substances. In the worst case, these materials may have been tipped without regard to compaction, containment or their potential to interact with each other and the environment. There may be no record of what materials were deposited and when. The geotechnical properties of tipped material will vary with time as the material alters due to decay, decomposition and chemical breakdown. Not all made ground will present problems since most modern engineering fills are compacted according to highways and other engineering guidelines. However, some of the fill and made ground was deposited in the past, when environmental and engineering specifications were not so highly regarded and do not reach current standards of engineering practice. Unless the type, extent and material nature of the made ground and fill are known to a high degree of certainty, all parts of the site should be considered as suspect, due to the extreme variability in composition and compaction. The made ground should be considered as potentially hazardous to health or harmful to the environment or structures. Old foundations will need to be removed due to the possibility of creep, collapse, differential settlement and the presence of voids (basements, cellars, tunnels, service ducts) which may be only partly filled with rubble and often remain as a complete void (British Standards BS5930:1999; BRE Digest 275, 1983; Institute of Civil Engineers, 1993).

Superficial deposits

The dominant natural superficial deposits are likely to be glacial tills, deposited during the last ice age and reworked during subsequent periglacial conditions, some 10,000 to 7000 years ago. The type, distribution and depth of till are not known, although rock head contours on the geological map indicate that the thickness is probably in the order of about 10 m. Other superficial deposits which could be present include alluvium, lenses of laminated silts and clay, loess of aeolin (wind blown) origin, lacustrine (lake) deposits, fluvio-glacial sands, solifluction deposits and organic matter (rootlets or peat). Due to the processes by which they were deposited the superficial deposits may comprise a mixture of variable lithologies consisting of cohesive and non cohesive soils.

Geotechnical significance of superficial deposits

Due to weathering, glacial till within 1 to 2 m of the ground surface may be fissured with a desiccated zone and soft layers which gradually become stiffer with depth. Clays within the till may be of variable plasticity. Compressibility is usually low but consolidation settlement may be high in softer till adjacent to water-bearing sands and silt horizons. The geotechnical properties of the superficial deposits may vary and include highly variable clays, water bearing sands and gravels (perched water tables). Some of the deposits may be susceptible to shrink-swell, compression or running conditions. Large, strong, boulders within the till (erratics) may also present drilling and ground engineering problems. In some instances voids may also be present in the till, on the lee-side of boulders (caused by ice flow). The shear strengths will be variable in the superficial deposits and alluvium may be compressible. High moisture contents should be anticipated within some of the superficial deposits. The presence of head deposits can not be discounted.

Head deposits may be poorly sorted, poorly consolidated deposits derived from bedrock and other superficial deposits, by the slow, downslope movement of saturated materials due to creep on slopes and past periglacial freeze-thaw processes. These are highly variable in composition and commonly comprise a soft to firm, silty clay or clayey silt of low to intermediate plasticity, with scattered cobbles and pebbles. These may be of high compressibility, have variable rates of consolidation settlement and low shear strengths. These may be prone to slipping on gentle slopes and in cuttings. Head deposits must be accurately located and their extent determined. They rarely exceed 1 to 2 m in thickness.

Alluvium may occur, representing former river or stream channels (possibly to the east of the site). These are extremely variable in composition, ranging from very soft to soft, to firm, sandy, silty clays and silts of low to intermediate plasticity. Peat and rootlets may be present interbedded within the alluvium.

Peat may occur as irregular patches of fibrous or amorphous material, or as persistent layers and lenses of organic clays and silts within alluvium. Organic soils and peat generally cause soft ground conditions and possess low densities, high moisture contents and low strengths. Differential and total settlement may be a problem. Settlement may also take place without external loading due to changes in groundwater conditions, lowering the water table or drainage.

Rockhead

The rockhead is probably about 20 m below existing ground level, it may be inclined or horizontal, will vary throughout the site, and may drop suddenly in places. It is possible that the rock head surface is uneven, and may represent a post-glacial erosion surface leading to the possibility of buried channels, infilled with glacial till. It is likely that the bedrock is moderately to highly weathered and fractured and may contain widened and clay filled joints.

Bedrock

The solid strata beneath the site are of Upper Carboniferous, (Westphalian B) Middle Coal Measures age. These were deposited, in cyclic sequences (cyclothems), some 320 million years ago in subsiding deltaic, marine and fluvial environments. The strata typically comprise alternating sequences of sandstone, siltstone, mudstone, seatearth, fireclay, ganister, claystones, ironstone, limestone horizons and coal (Table 1).

Geotechnical significance of bedrock

The geotechnical behaviour the coal measures is highly variable depending upon the physical and chemical properties of the rocks. These will range from very strong sandstones to weak soils. Mudrocks (a collective term for non carbonate, fine-grained siliciclastic rocks); include siltstones, mudstones, claystones and shales. These are generally weak and have a tendency to become weathered when exposed at ground surface, in mine workings, or due to the removal of overburden. Hard siliceous sandstones exist in the Coal Measures sequences. These are very resistant to weathering and mechanical breakdown. However, the occurrence of joint sets can severely reduce the strength of these sandstones, since joints represent structural flaws within the otherwise intact rock and provide convenient sites for weathering and erosion; including ground water and mine water percolation. At least three coal seams subcrop at rockhead beneath the site. From north to south these are the High Main Seam, the Metal Seam and the Five-Quarter Seam; it is possible that they have been mined at some stage in the past, although there are no records of any mining activity.

Structure

The strata at the site dip towards the south east. The amount of dip is not known, but is probably low not exceeding about 5 to 10^0. Geological faults are shown on the British Geological Survey's published maps to occur within the development site, trending approximately east to west, consistent with the regional tectonic trend. However, mapped fault positions can not be taken as evidence that this is the only faulting to occur. Small scale faulting, folding and flexuring is also a possibility and the strata are likely to contain at least two sets of major joints. Other discontinuities which can be expected include fracture patterns parallel to the direction of regional faulting, bedding planes and fissures at rock head induced by mining subsidence, weathering and erosion.

Hydrogeology & hydrology

No water courses exist within the vicinity of the site, but the possibility that streams have been culverted can not be dismissed. The depth of the water table is not currently known. Flow is likely to predominate via shallow abandoned mine workings, rock mass discontinuities such as joints, faults, bedding planes and mining subsidence induced fissures; within the carboniferous strata. The quality of the ground water is not currently known, but may be ferruginous and ochrous, due to interaction with pyrite in coal. Mudrocks may have a slight to moderate permeability but this will vary from place to place throughout the site. Groundwaters in Coal Measure rocks may have a sufficiently high sulphate concentration to require special measures to avoid the attack on concrete foundations.

Gas and leachates

The main naturally occurring gas hazards are associated with methane, carbon dioxide, hydrogen sulphide, carbon monoxide and radon. These gases are generated by certain rock formations and may accumulate in buildings and engineering works such as tunnels and cellars. Gases and leachates may be generated from man-made deposits on site or in the vicinity. At least one landfill site is located in proximity of the site. Some leachates may be toxic or harmful to humans, animals and plants. Leachate plumes and gases may migrate in response to changes in groundwater and mine water flow or fluctuations in barometric pressure. Gases can also be dissolved under pressure in groundwater and may be released as the pressure drops as water emerges at the ground surface from an underground source. Gases may migrate to the surface along discontinuities (joints, faults and bedding) in permeable sandstones. Gases released into the air, may accumulate in basements, foundations and tunnels, in dangerous quantities unless they are sufficiently vented. Identification of the source and likely pathways for gases and leachates will be required to determine the extent, if any, of possible hazards. Treatment of a site prior to its development is often less expensive than resolving a problem after development is complete (CIRIA 1993).

Landslides

Given the low relief at the site landslides and natural slopes failures are not envisaged to represent a risk, although cuttings and excavated slopes may need stabilisation (see section below) (Department of the Environment 1996a, 1996b).

Table 1. General stratigraphy at North Elswick Colliery, showing the main coal seams (source, British Geological Survey and Durham Mining Museum).

Period	Group	Strata Type & Seam Name	Approximate Depth (mbgl)	Approximate Thickness (m)
Upper Carboniferous (Silesian)	Westphalian ‘B’ Middle Coal Measures (MCM)	Made ground	3.00	3.00
		Glacial till	7.30	4.50 (up to 20m)
		High Main Seam	9.15	1.35
		Top Main	17.99	1.15
		Bottom Main	26.20	0.30
		Un-named	28.70	0.06
		Yard	37.40	0.35
		Un-named	43.20	0.06
		Un-named	48.20	0.10
		Un-named	57.60	0.10
		Maudlin	62.80	0.78
		Brass Thill	102.00	0.40
		Hutton	111.63	1.40
		Un-named	155.55	0.03
		Un-named	156.77	0.08
		Beaumont (or Harvey)	172.00	1.32
		Un-named	174.80	0.10
		Hodge	176.90	0.48
		Tilley	186.00	0.70
		Un-named	209.00	0.43
		Three Quarter	224.00	0.70
		Un-named	231.00	0.30
		Brockwell	236.00	0.80

MINING

Mining in the Newcastle upon Tyne region dates back several centuries, possibly since Roman times. This record is incomplete but past mining has left a legacy of relics and liabilities which are potentially hazardous when developing an area of ground. Although there is little documentary evidence of mining before the 19th Century, these assumptions are consistent with observations and evidence from similar sites through urbanised parts of the Durham and Northumberland coalfields, where the mining of coal and other minerals played a key role in the development and industrialisation of major towns and cities.

Drift mines and bell pits

Coal was probably originally extracted in the Gallowgate area from small open pits, where the seams outcropped beneath the cover of drift, followed by the sinking of horizontal or gently inclined drift mines. These were likely to have been small, not exceeding a few tens of metres in length with size determined by ventilation and drainage. By the thirteenth century the drift mining had given way to the bell pit method of working, originally used for the extraction of fireclay and bedded ironstone, coal, and ganisters; and continued until about the 18th Century. The shafts of bell pits rarely exceed 12 m in depth and their diameter is usually less than 1.5 m. Bell pits tended to concentrate along coal and mineral outcrops, or where there was only a thin superficial cover and were closely spaced. Mining was carried out until roof supports became impossible or flooding or high gas concentrations occurred, at which time the pit was abandoned and another shaft sunk nearby. It was easier to sink a new shaft than to maintain underground roadways.

Some bell pits were partially or completely filled and capped, others were not. The types of fill material and shaft caps varied considerably. It is impossible to predict, with any degree of accuracy, if and when collapse may occur and the amount of void space associated with bell pits.

Room and pillar mines (partial extraction)

Where coal seams occurred greater than about 7m below ground surface, bell pit mining was replaced by headings that radiated into the coal seam for short distances around the shaft. The pillars of coal between the headings generally represented the only type of support to the overlying strata. The layout of a mine was unplanned and simply evolved as a series of interconnected headings. Hence, the support pillars were irregular in shape and size and varied throughout the mining regions in Britain. Due to the scarcity of timber, increased demand for coal in the sixteenth century led to the development of the room and pillar method of extraction. Underground workings were shallow and not extensive, for example, they rarely penetrated more than 40 m from the shaft. Indeed, when such limits were reached, it was usually less costly to abandon a pit and sink another shaft nearby. Workings extending 200 m from the shaft were exceptional even at the end of the seventeenth century, the shaft itself usually being less than 60 m deep. In very early mining the remnant pillars and voids (also referred to as stalls, rooms, bords) usually differed in size and arrangement, but with time mining became more systematic and pillars of more or less uniform shape were formed by driving intersecting roadways in the seam. Several variations of the pillar and stall method were devised. Square-work appears to have been the favoured method of extraction at Gallowgate, whereas in other parts of Newcastle ribs of coal were generally left to support the roof rather than pillars. The pillar support method used in the 19th century workings was designed for long-term stability to protect the ground surface or to minimize damage to the roof.

Longwall mining (total extraction)

The longwall method of mining was first developed in the 20th Century. The majority of the coal mined in Britain in the twentieth century and at present, although much reduced in amount, is by panel working, which is a development of the longwall system suited to mechanized extraction techniques. This method of mining involves the total extraction of a series of panels of coal that are separated by pillars whose width is small compared to overburden thickness. The coal is exposed at a face 30 to 200 m in length between two parallel roadways. The roof is supported temporarily at the working face, and in and near the roadways. After the coal has been won and loaded the face supports are advanced leaving the rock in the areas where coal has been removed to collapse. Subsidence at the surface more or less follows the advance of the working face and may be regarded as immediate. The mine abandonment plans and mining archive data does not provide any evidence that longwall mining was practiced at Gallowgate (National Coal Board 1975; Whittaker & Reddish 1989).

Collapse of shallow mine workings

The progressive deterioration of old, shallow workings can result in a collapse lag after abandonment meaning the timing of the collapse can not be accurately forecast. The mechanisms of collapse are complex, but well understood. These may involve a yield in the roof of the mine between supports or the collapse of the mine as a direct result of the failure of the supports (Littlejohn 1979; Piggott and Enyon 1978). In room and pillar workings, the failure of the roof is the most common cause of collapse. This is most likely at the intersection of roadways, where weaker roof strata exist, or due to the presence of geological faults. Mine workings which are located at depths in excess of approximately 10 m are not usually affected by enhanced loads induced by surface developments, buildings or vibrations from heavy traffic. In some instances yielding of large numbers of pillars can bring about shallow broad subsidence over large areas. This may be caused by the relatively strong coal pillars punching into the roof and floor of relatively weaker mudstones and seatearths, respectively. However, where strong sandstones form the roof these may span for several decades, behaving as beams, before eventually failures occur, often dramatically, resulting in collapse. It is generally accepted that shallow abandoned mine workings are susceptible to collapse. Research and past experience in similar geological and mining conditions does allow some general assessment of the likelihood of any collapses causing subsidence of the ground surface or the generation of ‘crown holes’. It may also be possible to make a reasonable assessment of the magnitude of any movements at the ground surface. Following the collapse of mine workings the available void space may become blocked, (or ‘choked’) by the overlying strata which fall into the space, this is known as ‘bulking’. Different rocks have different ‘bulking factors.’ In general, voids migrating from a depth of approximately 30 to 35 m below rock head are unlikely to reach the ground surface, due to bulking or the presence of a strong, thick sandstone horizon. Other prediction techniques use a combined rock and overburden thickness of 10 times the extraction thickness depending on the local geological conditions. These ‘rules-of-thumb’ are consistent with other recent investigations in the field of mining stability investigations (Healey & Head 1984).

Mining history

Elswick Colliery was the main deep mine in the area, located on the northern side of the River Tyne, approximately 3 km WNW of Newcastle city centre. The mine was opened some time before 1828 and worked until its closure during the early 1940s. The mine produced fireclay (household and manufacturing) and steam coal. The maximum number of employees at the mine reached 666 in the period 1914 to 1923. Elswick Colliery consisted of a number of pits including North Elswick Colliery, South Elswick Colliery, Mill Pit and Wortley/Enginer Pit. Of these mines, North Elswick Colliery was the closest to the Gallowgate site, approximately 100 m to the west. The colliery has since been demolished and the site redeveloped. A mining report was obtained from the Coal Authority and an inspection of mining records, abandonment plans and archive data was carried out. Although some mining records were available for the site, these were incomplete and do not provide a full and accurate account of past mining beneath and in the immediate vicinity of the site. The site is under the likely influence on the surface from workings in four seams of coal at 80 m to 230 m deep. The Three Quarters Seam has been worked beneath the vast majority of the site by semi-mechanised room and pillar workings. According to the mine shaft sections and mine plans dating from approximately 1940, the Three Quarters Seam occurs at a depth of 225 m and the Brockwell Seam was intersected at a depth of about 235 m. The distance between the Brockwell and Three Quarters Seam is reported to be just 11.8 m. The Three Quarter Seam shows extensive faulting, trending northwest to southeast, with unknown throws, beneath the north-western part of the site. Mine plans showing roadways from North Elswick Colliery, in the Beaumont Seam, occur below the northern part of the site at an estimated depth of 172 m. These appear to be exploratory roadways without the development of room and pillar workings. It is not known if this reflects inaccurate mine recordings or the reluctance to extract the coal resources beneath the site, in this seam, due to faulting or other geological reasons. The Brockwell Seam is at a depth of approximately 236 m, beneath the northern and southern part of the site. Again, semi mechanised room and pillar mining methods were used. The pillars were relatively large, compared to the narrow roadways; they were rectangular in plan with a regular geometry. This preferred method of extraction was probably a deliberate attempt to reduce the possible effects of subsidence in what is likely to have been a densely populated industrialised urban area. This is consistent with subsidence limitation methods deployed in other parts of the country where coal seams existed below heavily populated and urban areas. Some mine plans show the room and pillar extraction of seams in the vicinity of but not directly beneath the site. These include, for instance, the Bensham and Low Main seams. There is the possibility that these abandonment plans are not complete and the workings may well have extended beneath the site. One mine plan shows exploratory roadways and room and pillar workings at the northern part of the site. The seam name, depth, extraction thickness and dates of these workings can not be established from the mine plan and no further records are available from the Coal Authority; but it may be the Low Main Seam (also known as the Hutton Seam). Due to their depth, the above mentioned seams are not likely to represent a problem for the development of Gallowgate site. It is the unknown shallow workings which are of concern and present potential instability problems (Table 2).

Table 2. Recorded seams extracted (according to information supplied by Durham Mining Museum, the Coal Authority, Scottish Mining Museum and Northumberland Records Office); this information may be incomplete.

Name of Seam	Estimated Years Worked (incomplete)	Approximate thickness (m)	Possible Mining Method	Colliery	Estimated depth (mBGL)
High Main	Not known (historical)	Not known	Bell pit or room and pillar	Not known	Surface to 40 m
Metal	Not known (historical)	Not known	Bell pit or room and pillar	Not known	Surface to 40 m
Five Quarter	Not known (historical)	Not known	Bell pit or room and pillar	Not known	Surface to 40 m
Un-named (may be Low Main)	Not Known	Not known	Semi-mechanised, room and pillar	North Elswick Colliery	130
Beaumont (also known as Harvey)	1914 t0 1940	0.83 to 1.32	Semi-mechanised, room and pillar	North Elswick Colliery	172
Three Quarter	1914 to 1940	0.3 to 0.7	Semi-mechanised, room and pillar	North Elswick Colliery	224
Brockwell	1914 to 1940	0.8 to 1.27	Semi-mechanised, room and pillar	North Elswick Colliery	236

MINING HAZARDS

Abandoned mine entries (shafts and adits) and shallow mine workings

Within the site, or 20m of the site boundary, there is one mine entry recorded on mine plans. The approximate position of this is beneath an existing structure in the south-eastern part of the site. There are no records of what steps, if any, have been taken to treat the shaft. A search of collieries and pits within 5 miles (8 km) from Elswick Colliery provided a list of approximately 183 mines. The presence of shallow workings may also be inferred from the subcrop positions of three seams (the Metal, Five-Quarters and Main seams). Although there is an incomplete record of mine workings, the presence of workable minerals in close proximity to the ground surface introduces a reasonable chance that workings exists within the rest of the site, and in particular in close proximity to the subcrop positions of the coal seams. In this respect, zones of instability may be anticipated around mine entries and invasive investigations are required prior to any proposed redevelopment (Figure 2). The anticipated location of the mine shaft will require confirmation by physical investigations to determine the precise location of the shaft, its present condition and dimensions. Decisions can then be made on what, if any, stabilisation and treatment methods may be necessary. There is no evidence of historical opencast mining or quarrying at or within the vicinity of this site. However, it is possible that small scale surface excavations took place in the past, for coal and other mineral resources. These may have been backfilled and may be inferred by the presence of an uneven rockhead surface.

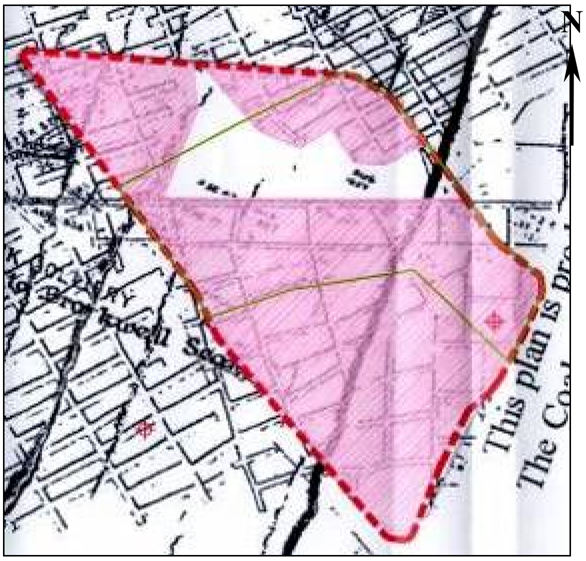

Fig 2. Extent of recorded workings in the Brockwell seam, located approximately 236 mBGL. The site's boundary is shown in red dots, the coal mine workings are shown in red shade. One recorded mine shaft, and room and pillar workings are recorded on the site. (source of original mine plans: The Coal Authority).

Fault reactivation

In any region where mining subsidence has occurred, faults, fissures and major joints may become reactivated. The result is a step, scarp, compression hump or fissure at the ground surface up to a metre or so in height, a few metres in width, and up to several hundreds of metres in length. The consequences may be moderate to severe damage to foundations, buildings, houses, structures, underground services (including sewers, water, gas and other pipelines and cables) and damage to agricultural land through disruption of drainage and alteration of the gradient. Reactivated faults and fissures may be difficult to observe along the ground surface, particularly in urban areas, or may be obscured by bridging soil cover or made ground. At least two hundred case examples of fault reactivation have been documented in other parts of Britain in similar geological and mining conditions. The absence of any records of fault reactivation cannot be taken as evidence that the faults have remained stable throughout the mining history of the site. Field evidence for faulting, particularly in areas covered with thick drift or in the built environment, may not always be apparent. Geological maps and mine plans may not always record the precise locations, dip, width, displacement and other characteristics of faulted ground. This makes the conjecture of geological structure in areas of less well known geology difficult. The absence of geological faults, on British Geological Survey published maps does therefore not imply faults do not exist. Fault zones comprising shattered rock, complex joint sets and clay-rich gouge may give rise to severe excessive differential settlements and present problems of low bearing capacity. The treatment and stabilisation of faulted ground may be necessary and a site investigation should aim to delineate the location of faults as accurately as possible prior to the placing of foundations. Faults may also increase the permeability of the ground and provide the site for the discharge of groundwaters, mine waters and mine gases. (Donnelly 1994a, 2000a, 2000b; Donnelly & Reddish 1994; Donnelly & Melton 1995; Donnelly & Rees 2001; Donnelly *et al.,* 1993, 2000a, 2000b, 2002).

Mine water rebound

The abandonment and complete closure of British coalfields, and the cessation of groundwater pumping, may result in the rebound of mine water levels and the flooding of abandoned workings. The subsequent rebound of water levels will continue until equilibrium is reached. In the Durham coalfield for instance, at least 300 years of pumping had de-watered the strata up to depths of 150 m below ground level and rebound is now taking place. Modelling studies of the Durham Coalfield indicate that if pumping were to cease completely mine water would rebound to ground level in 15 to 20 years in the southern part of the coalfield, increasing to about 40 years in the northern part. Similar types of data may exist for the Newcastle Coalfield. Rising mine waters may cause residual subsidence, fault reactivation, reduce the stability of slopes and cuttings and may potentially influence the geotechnical properties, and therefore behaviour, of the ground (Younger 1993; Younger & Bradley 1994). If the rising water level intersects surface water courses, uncontrolled mine water discharges will result. Due to solution of pyrite oxidation products, which is commonly highly ferruginous with low pH values, 'acid mine waters' may flow into surface watercourses and aquifers. These may become polluted with extensive precipitation of ochrous ferric hydroxide on the ground surface. The current levels of mine water and the status of mine water rise below Newcastle are not known and further monitoring and prediction data is required to consider any potential future effects of mine water and ground water levels. Given the site is located at an elevated part of Newcastle, it would be expected that any mine water discharges may occur at much lower topographical levels. The prediction and forecasting of mine water rebound is difficult to determine, but is likely to continue within the design life of the proposed development. Ground water monitoring from boreholes is currently being undertaken in the northeast of England, by some universities and consultants.

Mine gas

During periods of low barometric pressure, or forced by rising mine waters, mine gases can migrate from the rock mass and mine workings to the ground surface (Donnelly & McCann 2000). Mine gases may be explosive (methane), toxic (carbon monoxide and hydrogen sulphide) or asphyixiant (stythe gas or blackdamp; which is oxygen depleted air). Since 1945, there have been over 70 recorded incidents of gas emissions at the surface from abandoned mine workings in Britain. Over two-thirds of these were of methane, the remainder mainly blackdamp (which has been a particular problem in the Durham Coalfield). Permeable rock formations, faults, joints, fractures (enhanced by mining subsidence), shafts, adits, wells, boreholes and man-made cuttings and excavations, all act as gas migration pathways. Mine gas emission may be a significant issue during the digging of foundations or where structures have cellars and other confined spaces. The influence of gas emission on the geotechnical properties of the ground is minimal and probably negligible (Robinson 2000; Purdue & Armstrong 2000).

Mining-induced seismicity

In recent years seismicity (small earthquakes), or tremors, have been reported by local residents in the northeast of England (and in particular to the south around Ryhope, in County Durham). Seismometer networks have been installed to monitor these small earthquakes. The source of these tremors could not be determined. These may be related to mine water rebound, the collapse of pillars in shallow workings, fault reactivation or the falling of relatively small blocks of rock within the walls of underground fissures which have become dilated. Sensitive engineered structures in the region may need to consider ground acceleration and ground motion associated with seismcity, although the risk of any future events are considered to be negligible to low, in most cases. It is worth noting that larger earthquakes originating from other parts of the country are known to have affected the Durham and Northumberland area. These include for example the Carlisle earthquake on 26 December 1979 (4.7 ML), the Kirkby Stephen earthquake on 9 August 1970 (4.1 ML), the Lleyn Peninsula earthquake on 19 July 1984 (5.4 ML) and the Bishop's Castle earthquake on 2 April 1990 (5.1 ML). Of the approximately 400 recorded earthquakes each year in Britain during the 1990s, the average number attributed to coalfield events was approximately 25%. It is now (2005), on average, approximately 9% (it was 17% in 1999; 8% in 2000; 3% in 2001; 5% in 2002, and 11% in 2003) (Donnelly 2002; Al-saigh & Kusznir 1981).

Spontaneous Combustion

The oxidation of coal and carbonaceous soils when exposed to air can lead to its spontaneous combustion. This is a common cause of fires in coal mines, colliery spoil and mining waste. Some coals ignite more easily than others; for example, high rank coals are less prone to spontaneous combustion than low rank coals. Another factor which may aid spontaneous combustion is the surface area of the coal exposed to air; the larger the area exposed, the greater the opportunity for oxidation. If the moisture content of a coal seam rises, then this tends to lead to the liberation of heat and subsequently to spontaneous combustion. Any increase in ground temperature facilitates the likelihood of spontaneous combustion occurring. Fires may result in subsidence, and in noxious and poisonous gas emissions which are hazardous to health. The risk of spontaneous combustion at the Gallowgate site is low but steps should be taken to consider the duration and exposure of old mine workings to the atmosphere and the proportion of coal, carbon and other combustible materials within fill, made ground, and superficial deposits. The products of spontaneous combustion are often known as 'red shale'. This is a red-brown to orange, weak to strong, fissile, angular deposit. Any occurrences of these deposits on the ground surface, in boreholes and trail pits need to be recorded and sampled and considerations given as to the location and migration of any 'burning lobes' in the ground. However, this is not thought to be considered likely at the site (Bell & Donnelly 2002).

PAST LAND USE

The industrial land use history of the site has been determined from an inspection of past topographic and Ordnance Survey published maps. This has enabled an estimation of potential contamination concerns, which will provide information for the specifically designed contamination testing survey during the site investigation (Environment Agency 2002).

Archaeology

Hadrian's Wall and other sites of historical and archaeological interest, or of national heritage value, are relatively close to the site and therefore a detailed archaeological survey is recommended as part of an environmental impact assessment.

Unexploded ordnance (UXO) and unexploded bombs (UXB)

Thousands of bombs fell on urban parts of Britain, including Newcastle, during World War II. It is estimated that 10% of bombs did not explode or were rendered safe. These may present a danger during site investigation or construction even though the actual risk of an explosion is small. Such incidents occur about once a month and are most frequent in urbanised and industrialised parts of Britain. If a UXO or UXB is uncovered, or suspected, all site works should stop immediately and the Police and the appropriate specialists should then be informed.

REDUCING THE RISK DUE TO PAST MINING

The acquisition, analysis and interpretation of publically available data and information enabled a conceptual appreciation of the geology, a prediction of the engineering properties of the rock and soil likely to be encountered and an estimate of the hazards from past mining at the Gallowgate site. There is however, insufficient information to enable the actual levels of risk and liabilities from past mining to be quantified, or for the geology to be sufficiently characterised for the purposes of engineering design. To satisfy building regulations and minimise client risk, a properly procured, supervised and interpreted ground investigation is recommended to fully characterise the ground conditions and mining liabilities. A ground investigation should be undertaken in accordance with industry standards, approved practices, working party reports, technical papers and guidance documents (these include for example, Healy & Head 1984; BS5930:1999; BS1377:1991; Institute of Civil Engineers 1993; Department of the Environment 1976, 1993; National Coal Board 1982; Bell 1986, 1988a, 1988b, 1992; Bell *at al.,* 1989; Price 1971; Price *et al.,* 1969; McCann *et al.,* 1999; Culshaw *et al.,* 2000 and others). The ground investigation should also incorporate current best practice for the assessment of land contamination and risks to human and environmental receptors. Ground investigations are likely to consist of a combination of conventional invasive methods, including trial pitting, the drilling of boreholes and associated monitoring, sampling, insitu and laboratory testing. A phased trial pitting and drilling approach, on a regular grid pattern, provides the most cost-effective way to investigate the geology and mining hazards, although concentrations of boreholes will be needed at mine entries, or areas where shallow mine workings are suspected. Trial pit investigations, to about 4 or 5 m below ground level, are useful to determine the soil profiles and the quality and surface expression of rock head. It is likely that the trial pits will be carried out simultaneously with the drilling. The first stage of investigation will be the boring of a series of shell and auger boreholes, with associated geotechnical and geoenvironmental sampling and testing. These may then be continued by a combination of rotary coring and rotary percussion drilling to a minimum depth of at least 30 m below rock head, to investigate the underlying strata, to accurately determine the stratigraphy, the presence of unrecorded coal seams (and other mineral resources of a workable thickness) and to determine the affects of mining subsidence and any ground movements. It may be necessary to investigate some of the boreholes by use of one or more borehole logging techniques. These may be used to provide a series of profiles down the borehole, each profile giving different geophysical and geotechnical parameters. These may include for example calliper logs, gamma logs and sonic logs.

If the mine shaft or other shallow workings can not be reached by conventional drilling and trial pit methods, or additional information is required, the use of alternative methods to investigate the ground conditions such as geophysical techniques (including ground penetrating radar, electrical resistivity, electromagnetic, magnetic, microgravity, and seismic) may be considered. Where mine entries are located beneath the foundations of existing structures, the use of cross-hole geophysical methods may also be necessary (McCann *et al.,* 1997; Reynolds 1997) even though these depend on geophysical 'noise' which may limit the use of some geophysical methods in urban areas.

The short, intermediate and long term monitoring of boreholes may be necessary to provide information on ground water fluctuations (using piezometers), mine water levels and mine gas emissions. Information and data provided from the ground investigation, laboratory testing and field monitoring will require analysis to determine the levels of risks and liabilities from past mining and to provide a range of geotechnical parameters for the design of foundations. The treatment and stabilisation of the shaft or any shallow mine workings may be required prior to construction.

CONCLUSIONS

Gallowgate is a major industrial site located in the centre of Newcastle upon Tyne in north-east England. Extensive redevelopment of the site has been planned to provide a combination of inner city industrial land uses. The area is covered entirely by made ground, which overlies glacial till and rocks of Upper Carboniferous (Westphalian) Coal Measures age. A desk study has been undertaken based on the compilation, analysis and interpretation of publically available archive data and information (including geological maps, mining records and old topographic maps). This study has revealed complex geology, an extensive mining history and has drawn attention to a number of mining hazards and liabilities. At least four seams may have been extracted by semi-mechanised room and pillar mining operations, over periods spanning at least one hundred years. Unrecorded coal seams and other minerals may have also been mined, at a shallow depth, from bell pits and room and pillar workings. At least one recorded mine shaft is known to occur on the site and the possibility of other mine entries can not be ruled out at this stage. The client, consultants and other project collaborators are now aware of the possible hazards and a plan may be devised to determine their risks and any stabilization and remediation measures. This may be undertaken by a properly designed ground investigation. Information obtained in the desk study phase may underpin a ground investigation. This in turn, will enable the mining liabilities to be accurately assessed and provide information on ground conditions to enable the design of engineered foundations. Sources of contamination may also be identified as part of this investigation as well as possible pathways and receptors located. The desk study ensures that unforeseen ground conditions are minimised and improves the financial management of projects.

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