British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Alcan Lynemouth Smelter, geology and hydrogeology in the vicinity of the ash storage lagoons

Integrated Geoscience Surveys Northern Britain and Pollution, Waste Management and Extractive Industries Impacts Programmes

COMMISSIONED REPORT CR/02/055

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/02/055

Alcan Lynemouth Smelter, geology and hydrogeology in the vicinity of the ash storage lagoons

D J D Lawrence and B A Klinck.

Key words

Geology, hydrogeology, Landfill, Smelter

Bibliographical reference

LAWRENCE DJD AND KLINCK B A. 2002. Alcan Lynemouth Smelter, geology and hydrogeology in the vicinity of the ash storage Lagoons *British Geological Survey Commissioned Report*, CR/02/055 28pp.

Edinburgh: British Geological Survey 2002

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham and Edinburgh; see contact details below or shop online at www.thebgs.co.uk

The London Information Office maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

Keyworth, Nottingham NG12 5GG
☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.thebgs.co.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA
☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE
☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU
☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS
☎ 028-9066 6595 Fax 028-9066 2835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB
☎ 01491-838800 Fax 01491-692345

Parent Body

**Natural Environment Research Council, Polaris House,
North Star Avenue, Swindon, Wiltshire SN2 1EU**
☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Cover photograph: Looking northwest towards Alcan Power Station from Beacon Point. The sandstone in the foreground is the ‘Seaton Sandstone’, the rock that underlies the Landfill waste site. Joint fractures in the sandstone can be clearly seen.

Photograph B A Klinck 2002

Executive Summary

The British Geological Survey (BGS) was commissioned by Mr John Clarkson, Alcan Smelting and Power UK, to carry out a desk study of the geology and hydrogeology information of the area around the waste landfill site and ash storage lagoons at Alcan, Lynemouth. The desk study was supplemented by a site visit. A main concern was the possibility that the ash in the lagoons might be contaminated by contact with leachate from the hazardous materials disposed in the landfill. The BGS was asked to provide an independent report on the contamination risk and of the suitability of the ash lagoon test bores plus any existing and proposed groundwater monitoring wells at the Alcan Lynemouth site to detect such contamination.

An extensive search was made for previous site investigation reports. The information obtained, in particular the records of over 50 boreholes drilled in the study area since 1990, has been used to review the published geological interpretation and better understand the hydrogeological regime. In general the new information supports the existing solid geological interpretation, but enables improved understanding of the disposition of the superficial deposits including a glacial buried channel.

The site is over a minor Coal Measure aquifer, the North Seaton Sandstone, which is underlain by a mudrock aquiclude sequence. Groundwater flow in the sandstone, is dominantly fracture controlled and is to the east. The groundwater system is isolated from the flooded, abandoned mine workings beneath the site where the water level is at about 90 m below Ordnance Datum and slowly rising. Saline intrusion is evident in the aquifer, and the saline interface appears to cut across the axis of the buried glacial channel.

An unsaturated zone of sandstone hydraulically separates the landfill and the PFA lagoons from the water table in the North Seaton Sandstone aquifer. It is concluded that it is unlikely that the PFA will become contaminated from the landfill leachate via the groundwater pathway or through direct discharge of leachate through the retaining bunds.

The Coal Measure sandstone is overlain, but hydrogeologically unconfined by a glacial till sequence where the flow is probably predominantly vertical through fractures.

The landfill operates on the dilute and disperse principle and the limited hydrochemical data available indicates that the groundwater impact diminishes along a flow line from the landfill.

The existing series of operational monitoring wells is useful in providing information on water levels to help determine direction of groundwater flow and hydraulic gradient, and chemical data to help determine the extent of saline intrusion from the sea and the extent of dispersion of contaminants from the landfill. However the limited area covered by the wells gives rise to uncertainty in the interpretation. These uncertainties are discussed and possible avenues of investigation and action recommended in order to reduce them. The recommendations include:

- Increasing the range of parameters determined in the landfill monitoring wells to include major anions and cations as well as nitrate and ammonia.
- Implementing the five additional monitoring wells proposed by URS with specific suggestions for screening of the two proposed on the eastern perimeter of the site
- Including a new well, integrated into the monitoring network, at the south-west corner of lagoon 1
- Giving consideration to the complementary approach of building a numerical model for the site

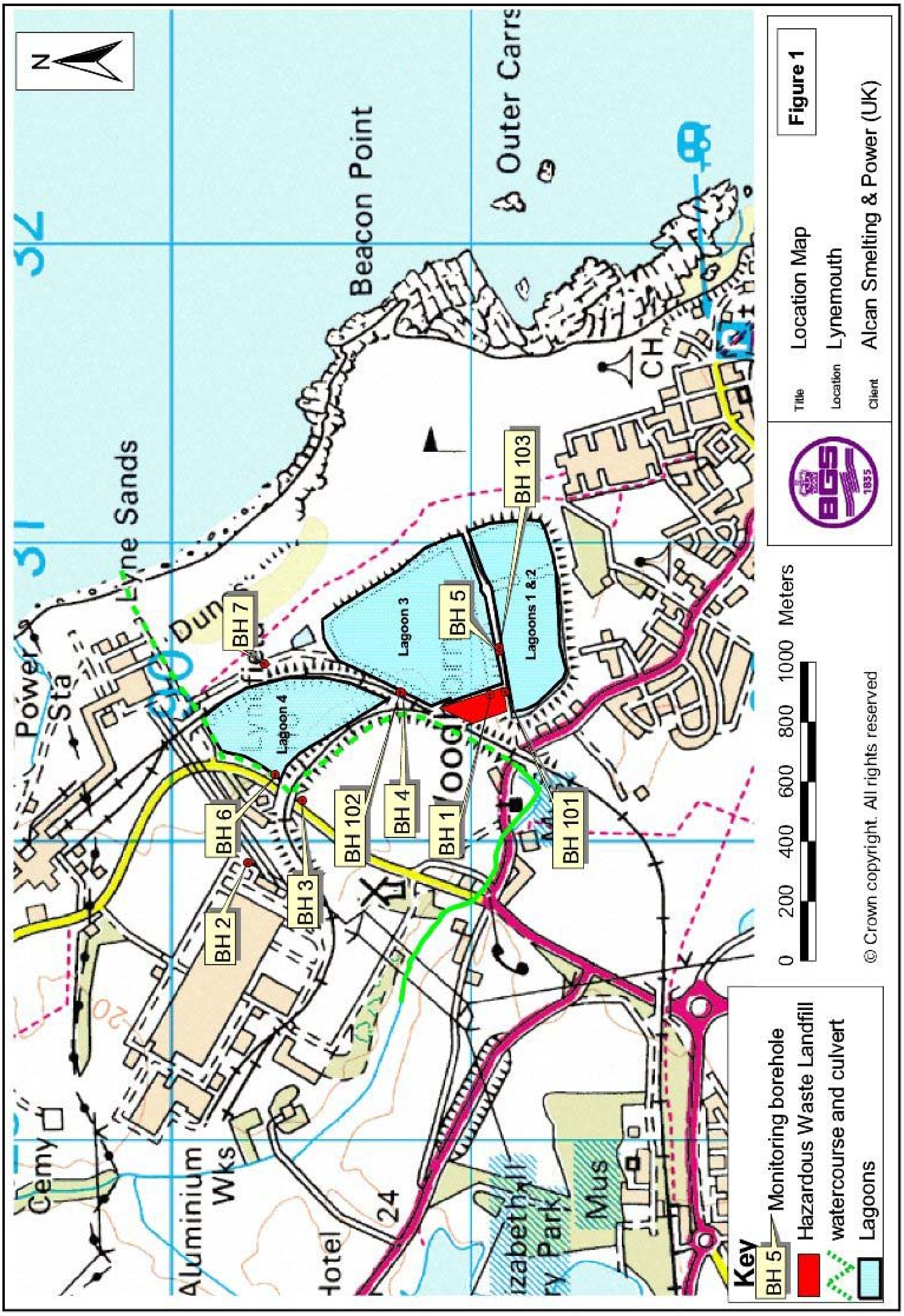
Acknowledgements

Miss Charlotte Vye incorporated the geological mapping and borehole data into a Geographic Information System to aid analysis and prepared a number of figures from the digital data. Mr David Granger, URS, Edinburgh supplied a significant amount of the data used to compile this report and his assistance is greatly appreciated. With the permission of Stuart Rolley of the Coal Authority, John Ottoway of IMC Consulting Engineers supplied the data used in constructing Figure 8. Professor Geoff Williams of the BGS has reviewed the report.

Contents

Figures

.



N
Lyne Sands
Power Sta
Beacon Point
Outer Carrs
Aluminium Wks
Cemy
Hotel
CH
Lagoon 4
Lagoon 3
Lagoons 1 &2
BH 1
BH 2
BH 3
BH 4
BH 5
BH 6
BH 7
BH 101
BH 102
BH 103
31
32
24
0 200 400 600 800 1000 Meters
Key
BH 5 Monitoring borehole
Hazardous Waste Landfill
watercourse and culvert
Lagoons
Title Location Map
Location Lynemouth
Client Alcan Smelting & Power (UK)
Figure 1

1 Introduction

In February 2002, the British Geological Survey (BGS) was commissioned by Mr John Clarkson, Alcan Smelting & Power UK (Alcan) to carry out a desk study. The study involved an appraisal of the current understanding of the geology and hydrogeology in the vicinity of the Alcan Hazardous Waste Landfill (the Landfill) and Ash Lagoons at the Alcan Lynemouth site (Figure 1).

This report describes the findings of the appraisal, supported by a two-day field visit to the site and surrounding area on 25 and 26 February 2002. The presentation of the results is based on Appendix H to the Environment Agency Internal Guidance on Regulation 15 (Environment Agency, 1999) of the waste Management Licensing Regulations, 1994. The documents examined are listed in the references and Appendices 1 and 2; those provided by Alcan and URS, Edinburgh, are referenced in the text under the numbers {R1} to {R16} (see Appendix 1).

1.1 BACKGROUND

Alcan operates an aluminium smelter and power station at Lynemouth, Northumberland (Figure 1). The pulverised fly ash waste (PFA) from the power station is currently stored in a series of ash lagoons. Waste materials from the smelter, including List I and List II substances, are disposed to the landfill that is currently operated under a Waste Disposal Licence issued by Northumberland County Council. The storage capacity of the lagoons is likely to be reached within the next one to two years and Alcan is proposing and applying for planning permission to build an Aardelite treatment plant on site in order to process the PFA directly from the power station. If the plant is built Alcan would, in due course, propose to extract the PFA from the existing lagoons and process it. A number of local residents have expressed concern about potential toxic materials being released locally if the ash is extracted from the lagoons. A main concern is the possibility that the ash might be contaminated by contact with leachate from the hazardous materials disposed in the landfill.

A gap analysis was undertaken by URS, Edinburgh in November 2001 in order to recommend steps to be taken to ensure that the landfill will comply with Regulation 15 of the Waste Management Licensing Regulations 1994 {R11}.

1.2 SCOPE OF WORK

BGS was commissioned to act as an impartial consultant and provide an opinion, in the form of a report, on the contamination risk. It was also required to assess the adequacy of groundwater monitoring. The report to comprise:

i). A summary of the solid and superficial geology within the environs of the lagoons and surrounding area of approximately 1.5 km^2.

ii). A summary of the hydrogeology including possible groundwater gradients, flow pathways and interaction with saline intrusion from the sea.

iii). An assessment and opinion on the location of the existing ash lagoon test bores plus any existing and proposed groundwater monitoring wells and their suitability to detect contaminant plumes from the nearby hazardous waste site.

2 Summary of geology within the study area

The following section provides a description of the geology within the study area. The description is based on the most recent 1:10 000-scale geological maps NZ28NE and NZ38NW and the geology and land-use-planning reports and accompanying 1:25 000 scale maps published in 1990 (Jackson and Lawrence, 1990; Lawrence and Jackson, 1990).

The geology of the area is subdivided into artificial (man-made) deposits, natural superficial (drift) deposits and solid (bedrock) strata. It is illustrated in Figures 2 to 4.

Information made available for this study, in particular the records of boreholes drilled since the publication of the maps (see Appendix 2), has been used to review the published geological interpretation. In general the new information supports the published solid geology, but enables improved understanding of the disposition of the superficial deposits including the glacial buried channel. Minor modification to the solid geology mapping is shown in figure 3.

2.1 SOLID GEOLOGY

Coal Measures rocks underlie and are obscured by superficial deposits throughout most of the study area, but the sandstone, which underlies much of the lagoon area, is exposed along the coast around Beacon Point. The distribution of the principal components of the Middle Coal Measures at outcrop and beneath the superficial deposits is presented in an extract of the published 1:25 000 scale geological map (Figure 2).

The Coal Measures comprises strata arranged in distinct cycles (cyclothems). Marine bands, which comprise fossiliferous, dark grey to black, carbonaceous, pyritic and sulphurous shales commonly mark the bases of the cyclothems. The marine bands are generally a few centimetres thick, but may attain thicknesses of 2-3 m. They can be recognised across large areas, and the presence of diagnostic fossil assemblages result in marine bands forming important marker horizons.

The marine bands commonly pass up through mudstone, siltstone and sandstone, showing both vertical and lateral gradations. The mudstones are typically dark grey silty, laminated or massive, locally with ironstone nodules. Siltstone is commonly medium grey, micaceous and thinly laminated or cross-laminated. Sandstone is typically pale grey, ochreous-weathered, very fine- to very coarse-grained, commonly planar or cross-bedded. Above the sandstone there is commonly a seat earth (seat clay or ganister) and a thin coal seam.

The Coal Measures succession beneath the study area and presented in Figure 4 is described below in ascending order of superposition.

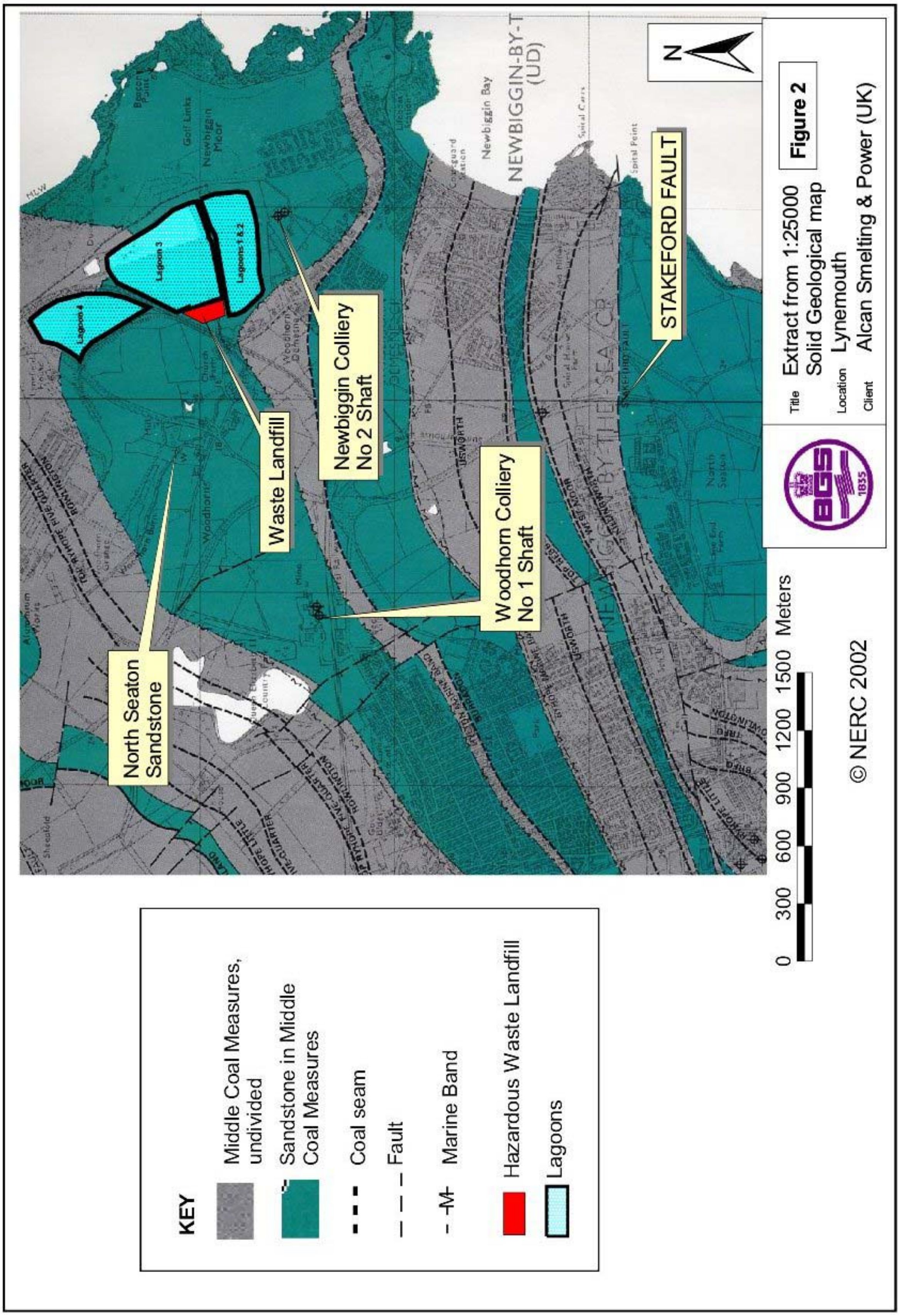


Figure 2 Extract from 1:25 000 scale solid geological map

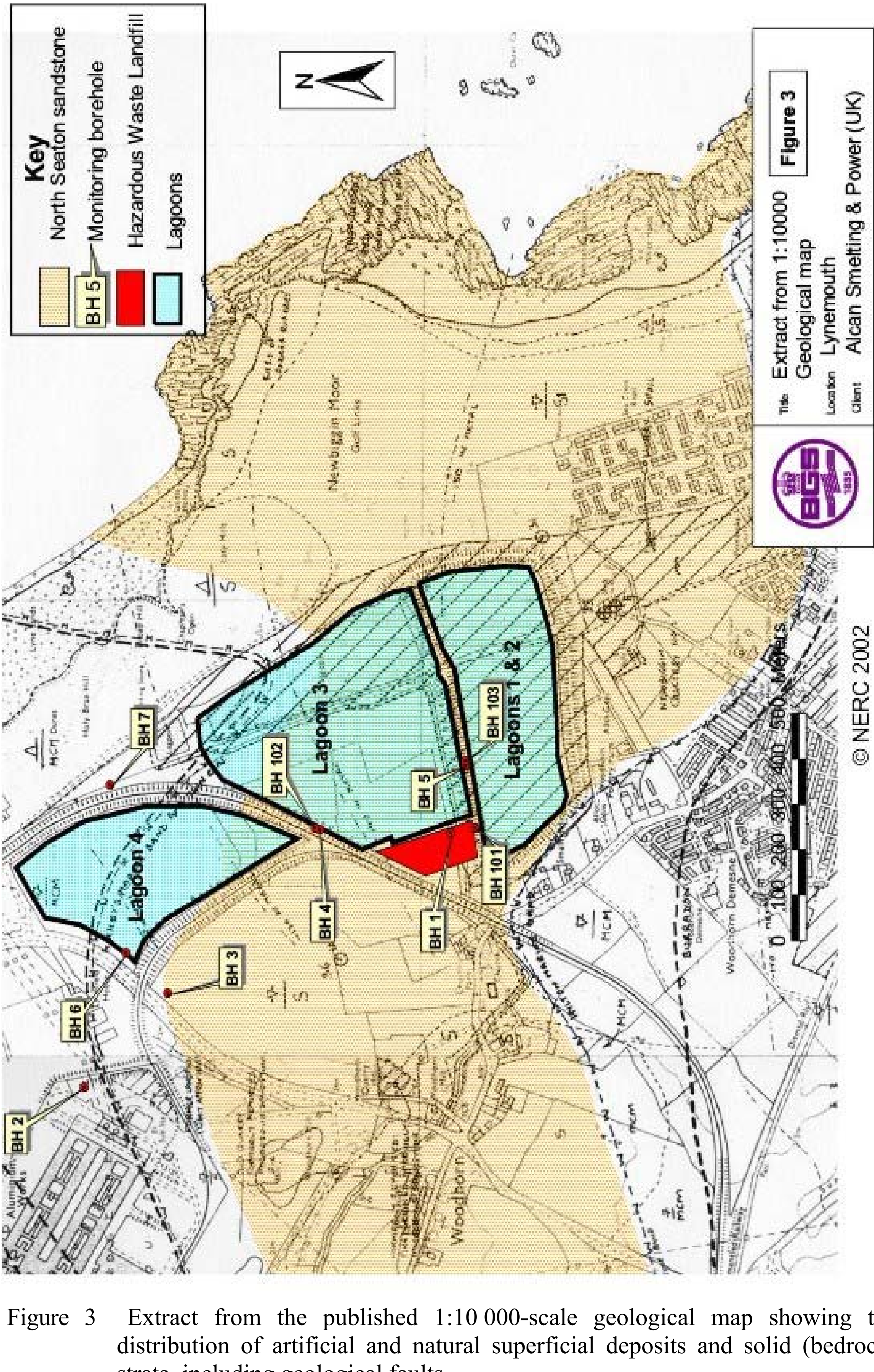


Figure 3 Extract from the published 1:10 000-scale geological map showing the distribution of artificial and natural superficial deposits and solid (bedrock) strata, including geological faults.

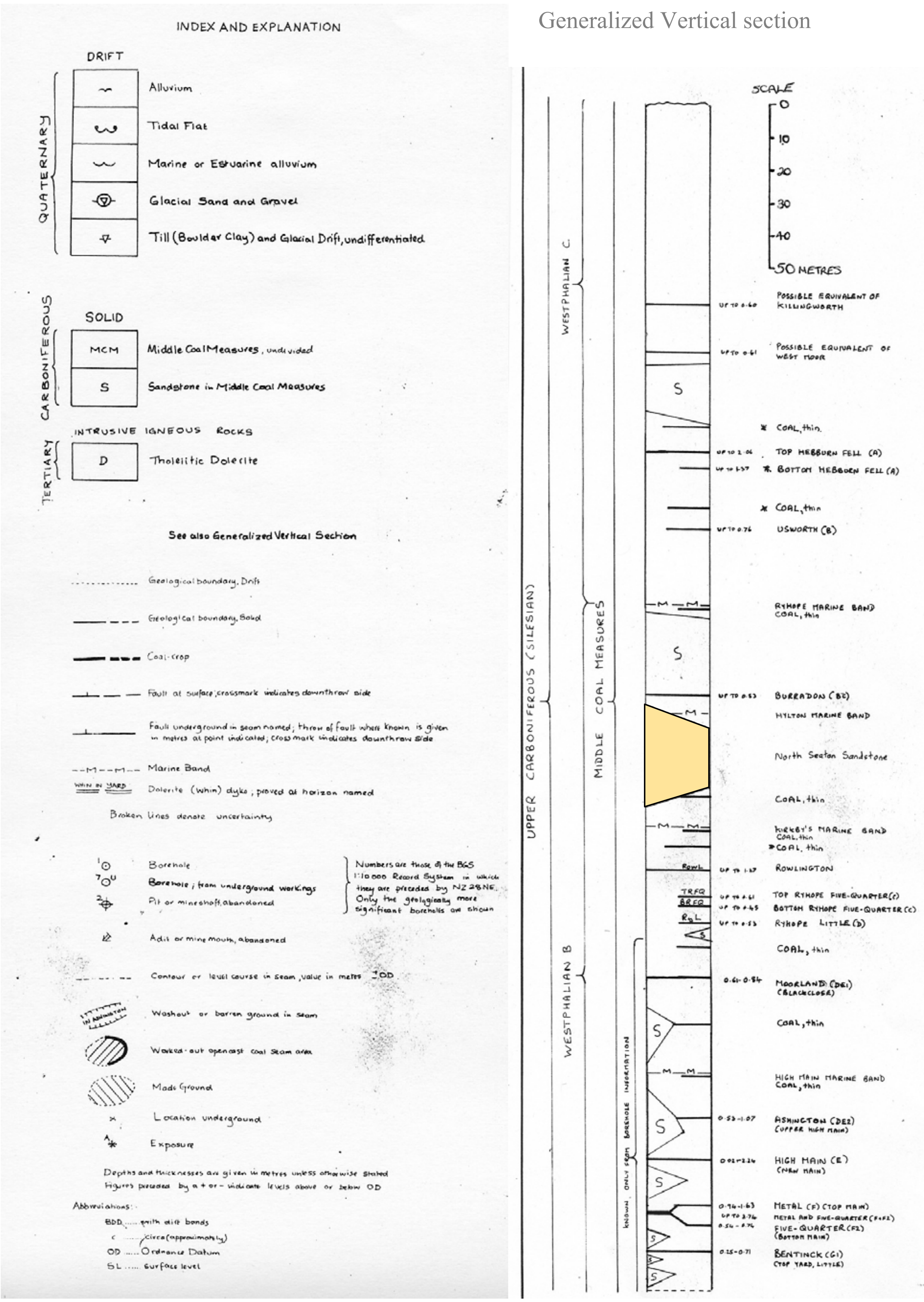


Figure 4: Key to figure 3 and Generalized Vertical Section, derived from the published 1:10 000 scale geological map NZ38NW

2.1.1 Kirkby's (Haughton) Marine Band and underlying strata

The Kirkby's Marine Band has been identified with certainty in only one borehole in the Morpeth-Bedlington-Ashington District. Its position is conjectural in the area of the study and is based on the presence of a thin coal that is commonly associated with it. The 10 cm coal at a depth of 13.50 metres in Borehole 93-2 {R7}, see Appendix 2, is considered to represent this thin coal.

2.1.2 Strata between the Kirkby's Marine Band and Ryhope Marine Band

The sequence between the Kirkby's Marine Band and Ryhope Marine Band ranges from 55 metres to 70 metres in thickness, predominantly comprising sandstone with a median mudstone, correlated with the Hylton (Sutton) Marine Band. A thin coal, the **Burradon coal**, commonly occurs in the interval between the Hylton and Ryhope Marine Bands

In the Ashington district to the west of the study area approximately 10 metres of mudstone and siltstone overlie the Kirkby's Marine Band at the base of the interval.

Borehole 93-3 {R7}, see Appendix 2, and a number of the boreholes and trial pits within the investigation for lagoon 4 {R4} record siltstone and mudstone assumed to be in the lower part of the sequence above the Kirkby's Marine Band. This is similar to the same part of the succession in the Ashington area to the west of the site. The resulting minor modification to geological map is illustrated in Figure 3.

The overlying sandstone, locally known as the North Seaton (or Woodhorn) Sandstone, is at rockhead beneath much of the study area, indicated in yellow in Figure 3. It is this sandstone which directly underlies the landfill. It is recorded in the 1979 feasibility report for the tip {R1}, that "sandstone was exposed over much of lagoon 3 during construction" and "During construction of lagoon 2 clay at the western end of the lagoon floor was in places excavated down to sandstone rockhead". It is also noted in that report that the upper part of the sandstone was weathered and that the "weathered sandstone is heavily fractured and probably highly permeable". The sandstone is exposed on the coast at Beacon Point where it was examined as part of the site visit, additional comments regarding this sandstone are included in the hydrogeology section below. In the quarry at Woodhorn village over 21 metres of brown, fine-grained, sparingly micaceous sandstone was worked for facing and grindstones.

The position of the Hylton Marine Band is speculatively assigned, as the mudstone has not yielded any correlative fauna in the Morpeth-Bedlington-Ashington district. Approximately 4 metres of mudstone and sandstone separate the marine band from the Burradon seam which has been extended into the area from exposures encountered during the site investigation for the new hospital at Ashington where it was 0.45 metres thick.

The sandstone between the Burradon coal and the Ryhope Marine Band is about 25 metres in thickness and is exposed on the coast at Newbiggin. Pebbly lenses and beds are common within the sandstone.

2.1.3 Strata above (Hylton) Marine Band

The sequence above the Hylton Marine bands consists predominantly of mudstone and siltstone with thin sandstones and a number of coals.

2.1.4 Geological Structure

The general dip of the rocks beneath the lagoons is to the southeast at about 1 in 25 (2^{o} to 3^{o}). No geological faults are shown within the study area, although faults of less than 3 metres throw (10 feet on old plans) are plentiful on the mine plans. The major fault in the district is the Stakeford Fault situated to the south of the study area (see Figure 2), which shows a maximum northerly downthrow of some 200 metres in the Yard (G) seam. Seam contours from mine plans of deeper coals worked immediately north of the Stakeford fault show a progressive increase in dip as the fault is approached.

2.2 SUPERFICIAL DEPOSITS

Superficial (drift) deposits underlie the majority of the study area (Figure 2). Both rockhead and the ground surface fall generally to the east. The main deposits mapped at the surface include Till (boulder clay), Alluvium and Artificial Deposits.

2.2.1 Artificial Deposits

Small areas of artificial deposits are recorded within the study (Figure 3). Spoil from Newbiggin Colliery was deposited along a north-south strip to the east of the colliery shafts and extended as far north as gridline northing 89. Colliery spoil would have been present under the eastern part of lagoon 2 and may possibly have extended as far as the south-eastern corner of lagoon 3. Artificial deposits also occur as embankments along the line of the railway, which extends from north-west to south-east across the site. The composition and thickness of these deposits is not recorded, but is believed to consist, at least in part, of colliery spoil.

2.2.2 Alluvium

A strip of alluvium was mapped northwards from Newbiggin to the area formerly known as 'Blue Holes', now largely covered by the eastern parts of lagoons 2 and 3 in the north, and colliery spoil to the south.

The composition of the alluvium is likely to be highly variable, varying from pebbly gravel to alluvial silt and clay and peat. Peat was proved in the sinking of the Newbiggin Colliery shafts (BGS borehole references NZ38NW/33 and NZ38NW/34.)

2.2.3 Till (boulder clay)

Till forms a largely featureless spread across the study area. The deposits are poorly exposed, but generally comprise unsorted pebbles and boulders of sandstone derived predominantly from the Coal Measures in a variably sandy, grey and brownish red, mottled clay matrix. Thin lenses and partings of sand and gravel and silt and clay are commonly found in the till.

A typical description of the Till from a borehole record is as follows: "stiff reddish brown sandy silty clay with some fine to coarse angular to subrounded gravel and occasional cobbles and boulders: occasional pockets of orange brown silty fine sand".

2.2.4 Laminated clay and silt

Distinct units of virtually stone-free finely laminated silt and clay, up to almost 1 m in thickness are recorded in boreholes beneath the lagoons, e.g. borehole 26640_7 {R4}, see Appendix 2. It is likely that such deposits are present where the superficial deposits are thickest.

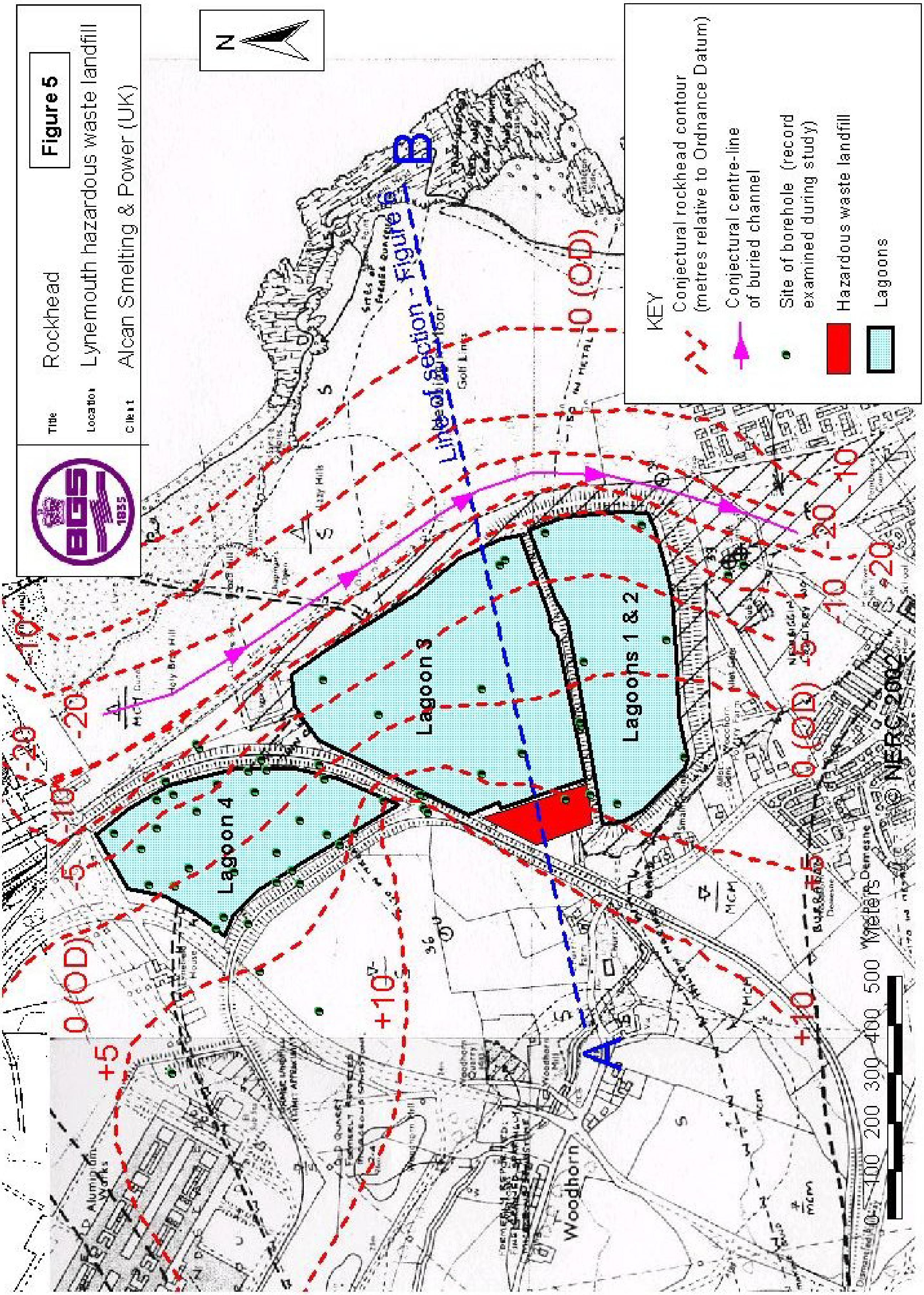


Figure 5 Rockhead elevation and location of borehole information

2.2.5 Drift thickness and rockhead surface

An approximately north-south trending buried channel filled with glacial deposits is known to be present near the eastern side of the lagoons. It is likely that the drift deposits attain a maximum thickness of over 20 metres within this channel. Boreholes drilled during the site investigation for the power station enable the position of the channel to be defined to the north of the study area. An examination of borehole records made available during this study has improved the definition of the western margin of the channel in relation to the lagoons (Figure 6). However, there is considerable uncertainty regarding the eastern limit of the channel and its maximum depth owing to the absence of boreholes. Thin till-covered, rock outcrops on the coast indicate that the edge of the channel must lie between there and the lagoons. Bore 92_2 {R5}, see Appendix 2, that terminated at either bedrock or a boulder obstruction only provides a minimum thickness of superficial deposits and an upper estimate for rockhead. The channel might be deeper at the eastern edge of the lagoons

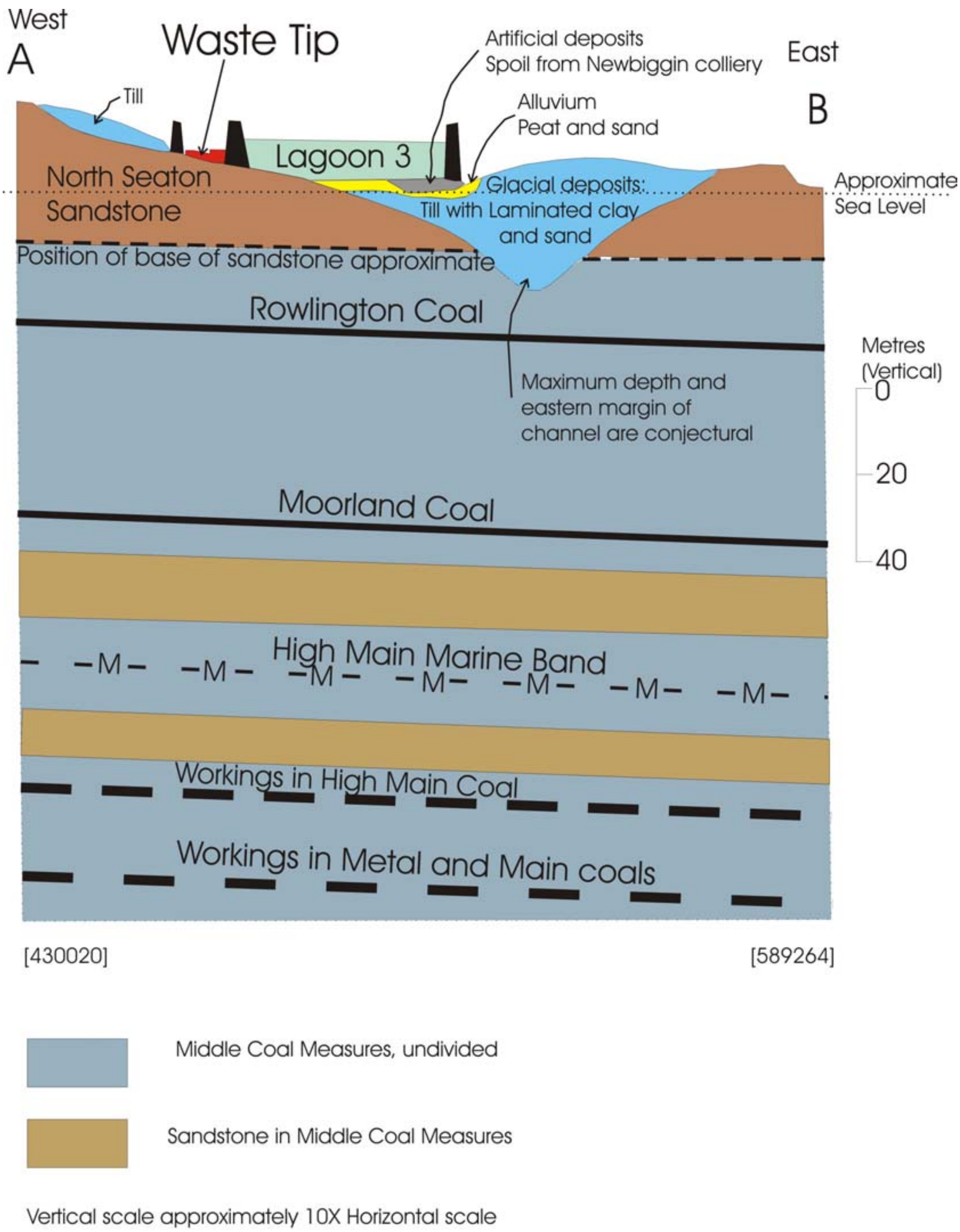


Figure 6 Diagrammatic cross section along line shown on Figure 5

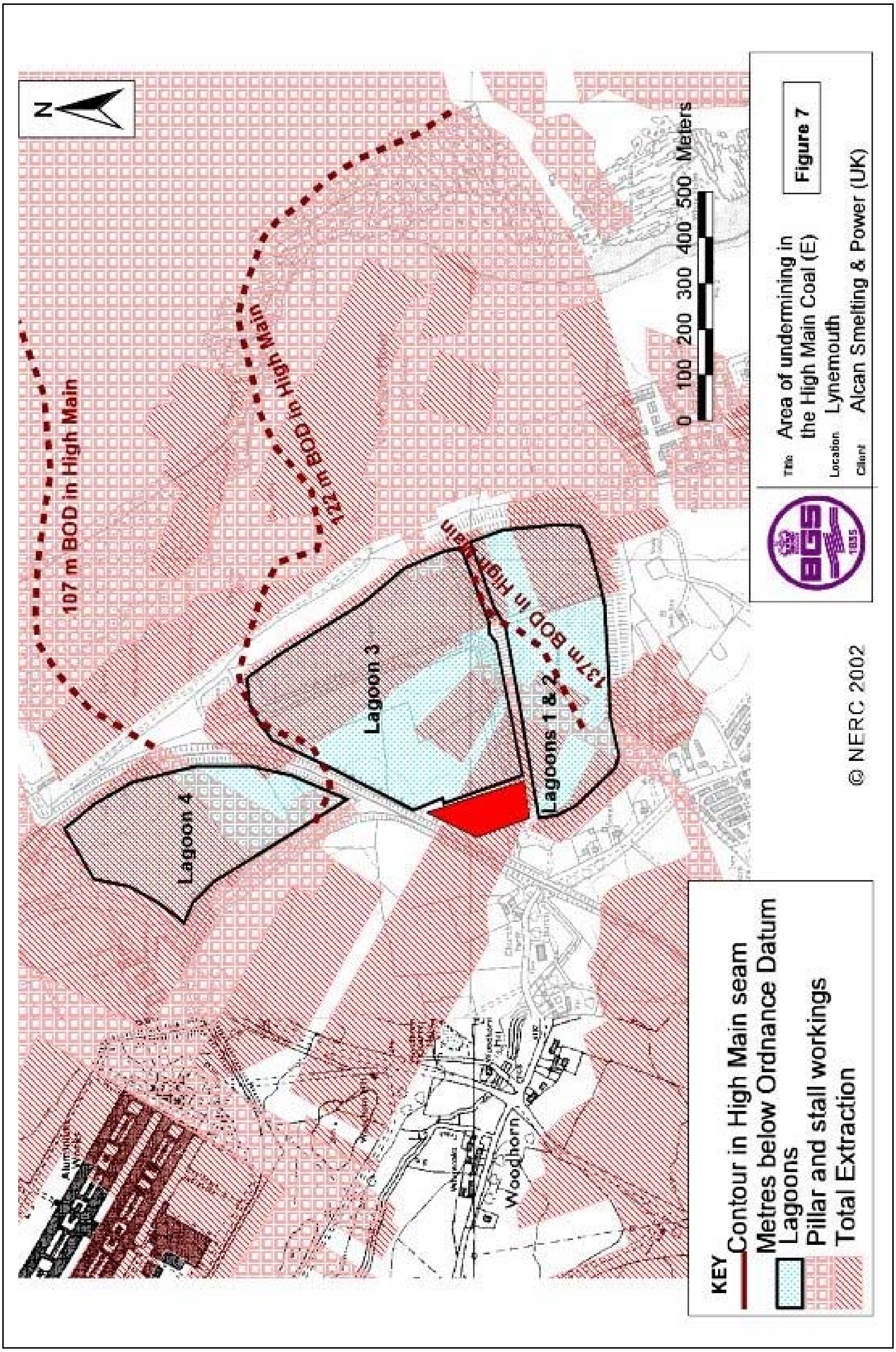


Figure 7 Area of undermining in the High Main Coal (E), including contours of level in seam

2.3 COAL MINING

The study area has been undermined in up to twelve seams of coal from the High Main (E) to the Bottom Plessey (M) at depths ranging from approximately 130 metres to 310 metres. Workings were by both pillar and stall and total extraction methods and ceased in 1976. Practically the whole of the study area has been undermined in one or more seams. The site area on the surface is within the zone of influence from these workings and the associated subsidence would be expected to have caused dislocation and fracturing of the overlying strata. However, it would generally be considered that ground movement from past coal workings will have ceased. It is, however, possible that further subsidence could occur as a result of the collapse of pillar and stall workings.

The position and level of workings in the High Main Coal (E) is illustrated in Figure 7,

Newbiggin Colliery No 1 and No 2 shafts are located to the south of lagoons 1 &2. The Coal Authority report of October 2001 {R12} records the following details of the shafts:

430588-002. This shaft was previously used as a pumping station. According to the Newbiggin Colliery Estates Community Association {R17} pumping ceased about nine years ago. The pump was removed and replaced with a methane drainage system.

430588-001. This shaft was filled and capped in December 1969.

3 Hydrogeology

Groundwater is monitored from a network of boreholes. Nine of the ten boreholes illustrated in Figure 1 are currently in use. In the most recent URS report {R16} BH2 was reported to be inaccessible and no information from it was available for this study. The existing operational monitoring wells are useful in that they provide information on water levels, to help determine direction of groundwater flow and hydraulic gradient, and chemical data to help determine the extent of saline intrusion from the sea and the extent of dispersion of contaminants from the landfill.

3.1 THE COAL MEASURES GROUP

At the Alcan site the North Seaton Sandstone generally forms an unconfined aquifer beneath the drift cover with confined conditions possibly occurring at the southern end of the site. The hydraulic gradient in the sandstone has been determined from subsets of three monitoring wells. This approach is necessary because we are considering the gradient of a water surface and not a linear feature. Water level and topographic data for the calculations was provided by URS. Using boreholes 1, 4, and 5 a gradient of 0.038 to the east with a vector of 98.2^{o} is calculated. For boreholes, 101, 102, and 103 adjacent to 1, 4 and 5 respectively, the calculated gradient is also 0.038 to the east (vector direction 093^{o}). Using the data from boreholes 3, 4, and 6 the gradient is 0.01 to the north-east, (vector direction 11.87^{o}), while a similar gradient is calculated using data from boreholes 3, 4, and 7 (0.013 to 19.74^{o}). Flow directions can only be generalised on the assumption that the water levels measured represent the same water surface and are not due to distinct flow systems. On this basis the flow direction from the waste tip is to the east, and in the vicinity of Lagoon 4 the flow direction is to the north-east.

An examination of the cliff section in the sandstone confirmed that vertical fracturing is pervasive and fracture flow is likely to dominate over matrix flow. This means that advective velocities will be well in excess of those calculated from Darcy's Law. However, site-specific hydraulic conductivity and porosity data for the sandstone is currently unavailable.

The Coal Measure Group is classified as a minor aquifer (Jones et al., 2000). The BGS Wellmaster database indicates that there are no potable abstractions in the area from the sandstone.

The underlying mudrock sequence is essentially an aquiclude and it is anticipated that horizontal flow will predominate over vertical flow in the sandstone under the prevailing hydraulic gradient.

The Stakeford Fault is known to be an effective barrier to mine water movement within the Coal Measures. North of the fault pumping from the Ellington and Lynemouth complex controls the mine water level. Groundwater level data has been obtained from the Coal Authority for the Newbiggin and Woodhorn shafts and are presented as a graph of water level against time in Figure 8.

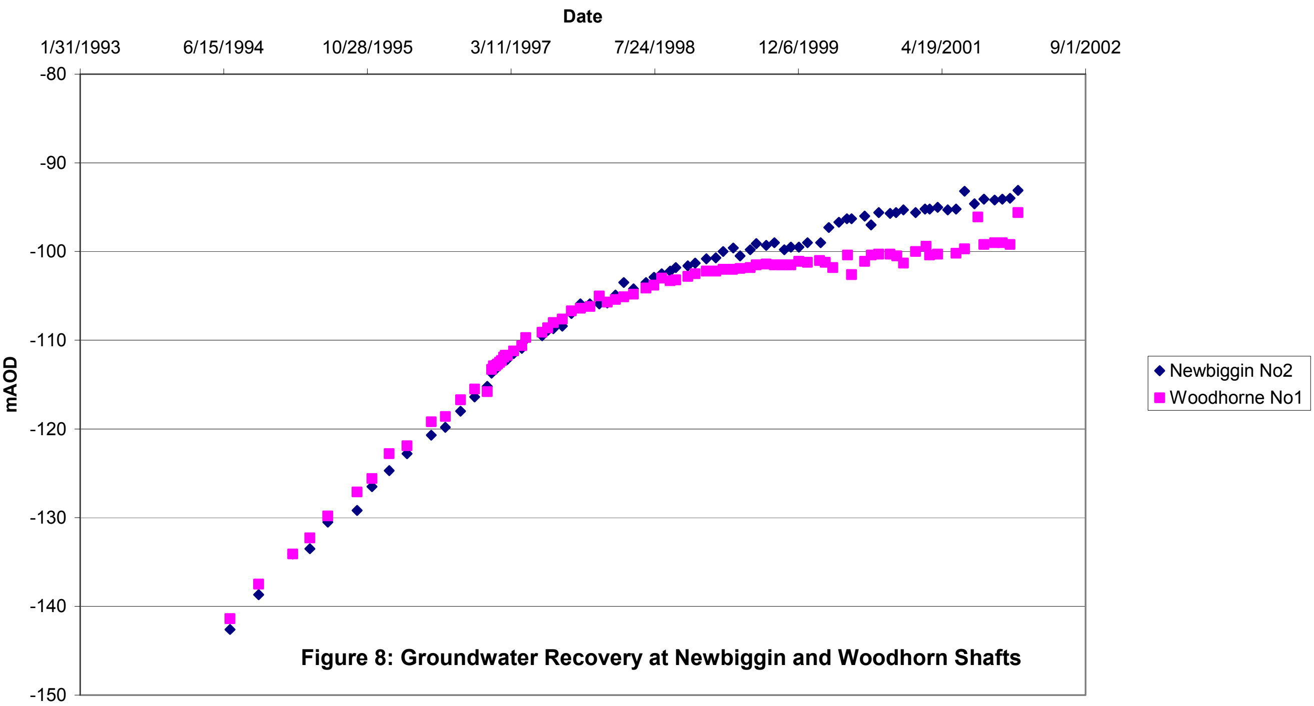


Figure 8: Groundwater Recovery at Newbiggin and Woodhorn Shafts

The data indicates that the abandoned coal workings are now completely flooded, but that the groundwater level is still some ninety metres below the surface. This data supports the view that the water table seen in the North Seaton Sandstone is perching on the underlying mudstone aquiclude and that there is no direct connection between the waste site and the underlying flooded mine workings.

According to URS {R16} the Coal Authority anticipates that groundwater levels will recover significantly after the closure of the Lynemouth Colliery. However, pumping will continue in order to allow for water treatment prior to its discharge. Thereafter the water levels will be permitted to rise and discharge will occur at the Newbiggin Shaft, which is the lowest point topographically in the coal field. To accommodate this discharge a culvert has been installed at approximately 10m depth in the shaft that runs east below Newbiggin Moor to outfall in the sea. The shaft-sinking log of the No. 2 pit held by the British Geological Survey, record number NZ38NW/33, indicates that the original ground level was 16.35 feet above OD (approximately 4.98 maOD). Using this information the depth of the discharge culvert in the shaft would be at about -5.01 maOD and roughly 11.96m below the base of the waste at the disposal site based on the borehole log for BH 1 (Borehole 93-1 {R7}, and Appendix 2). It seems unlikely therefore that rising groundwater levels caused by the flooding of the abandoned coal workings will impact on the waste tip.

It is noteworthy that early maps of the smelter site indicate the presence of springs prior to major development of the coalfield and reactivation is a possibility. However, this also depends on spring elevation relative to the Newbiggin Shaft.

The waste tip is situated directly onto the North Seaton Sandstone. According to early records the till cover was stripped back to bedrock to form the bunds around the tip. The log for BH1 shows the presence of about half a metre of till on the sandstone, suggesting that some pockets of this material still remain below the waste. The hydraulic head in the tip indicates that the base of the waste is now saturated with leachate. This phenomenon may be due to a number of causes and possible candidates are:

- groundwater mound formation due to increased infiltration through more permeable waste;
- locally increased infiltration and mounding due to disposal of liquid waste,
- and local leachate perching due to the formation of a lower permeability layer at the base of the waste due to winnowing down of fine material.

3.2 THE SUPERFICIAL DEPOSITS

As previously stated (Section 2.2.3) glacial till predominates over the site. The lithology is heterogeneous with silty clays dominating over sand and gravel. The cliff sections in the till indicate that vertical fracturing is common and this is reflected in the relatively high, falling head test, hydraulic conductivity values recorded, ranging from $4x10^{-6}$ to $3.9x10^{-5}$ m/s. Laboratory tests with remoulded material give values more typical of a till matrix ranging from 10^{-9} to 10^{-7} m/s (R4 and Foundation Engineering, Vol. 3, October 1978). This higher permeability property of fractured tills is well documented in the UK (Klinck 1997, Wealthall et al. 1997). It is anticipated that the dominant flow mechanism will be fracture flow in the tills with porous medium flow in the sandy partings and the sand gravel layer, which is often encountered at the till-sandstone interface. The range in hydraulic conductivity and compositional heterogeneity suggests that perched water tables will be a feature of the till sequence.

Other soil mechanical testing data is reported in a number of the reports. Moisture content ranges from 15 to 26% and specific gravity from 2.38 to 2.69 g/cm^3.

3.3 THE PFA

The PFA is discharged to the lagoons as slurry using a seawater carrier. The lagoons are inspected annually and were built to reservoir containment standards {R15}. When operational the hydraulic head is several metres above the base of the lagoons. A number of studies have been carried out to characterise the PFA {R8, R10, R14 and R15} through a comprehensive programme of drilling, trail pitting and testing. The PFA is generally described as dark grey clayey sandy silt {R8}, and hydraulic conductivity of recompacted laboratory samples ranges from $1.1x10^{-7}$ m/s to $9.5x10^{-7}$ m/s, very similar to the weathered till.

A risk assessment of the PFA conducted in October 2001 {R15} arrived at the following conclusions based on hydraulic considerations.

1. When operational the hydraulic head in the PFA lagoons is several metres above the base and surface of the waste tip. This essentially means that potential for flow is away from the lagoons and not into them from the waste tip.
2. When the lagoons are out of operation and drained then groundwater beneath the lagoons falls to a level approaching ordnance datum and any leakage from the lagoons would follow the normal hydraulic gradient away from the pot-lining tip.

In summary groundwater monitoring data in the vicinity of the lagoons indicates that the unconfined water table in the Coal Measure sandstone is below the base of the lagoons. There is no evidence of a hydraulic connection based on the available monitoring data. This supports the view that leachate migrating from the tip will not contaminate the PFA via the groundwater pathway.

3.4 HYDROCHEMISTRY

The main component of the waste in the disposal site is old refractory bricks and carbon, normally containing material from the electrolytic bath, e.g. fluorine rich cryolite, used as an electrolyte and a small amount of cyanide and PAHs. Some early chemical data {R7} is available for the waste pit sump and the groundwater monitoring boreholes BH1, BH3, BH4 and BH5. The sump is situated at the northern end of the waste pit and clearly shows the impact of leaching from the pot lining spoil and is characterised by high pH (10.85), total cyanide of 39ppm and the presence of ammoniacal nitrogen, a by-product of cyanide degradation. Very high concentrations of PAH (55288 ng/l) and fluoride (5305ppm) were also recorded. Clearly the available chemical data confirms that the waste is being leached to the groundwater and this is to be expected since the tip site is not lined and leachate is allowed to dilute and disperse. Boreholes BH1 and BH5 can be considered to lie on a groundwater flow line from the landfill and illustrate this dilution phenomenon. In BH1, at the edge of the pit, an impact is seen, cyanide is still detected, pH is still high and ammonia, and fluoride are present, although at lower concentrations than in the pit sump. At BH5 about 170m east of BH1 ammonia concentration is decreased by a factor of 10 to 2.57ppm, cyanide is just detectable and fluoride is below the detection limit. On the other hand chloride concentration in BH5 is at 20000ppm compared to 250ppm in the pit sump confirming that marine, saline intrusion is occurring into the aquifer on the eastern side of the site. More recent chemical data provided by URS {R16} is consistent with previous monitoring and lends support to the general conclusions drawn above.

Although the groundwater pathway can be eliminated as a source of contamination from the disposal site into the PFA lagoons, there remains the possibility of a direct pathway for leachate migration through the retaining bunds when the PFA lagoons are in the drained state. The presence of such a pathway is dependent on leachate levels in the waste and bund integrity. To assess this pathway a review of the data collected from a number of boreholes to characterise the PFA for use in the proposed Ardelite Plant has been examined. Data provided by Alcan presents the chemical analyses of a series of PFA samples collected down hole in exploratory boreholes into the waste as well as from trial pits. Some clear trends in the data are apparent:

- Moisture content increases with depth.
- Concentration of chloride, derived from the seawater carrier, increases with depth in most of the boreholes (for example ranging from 85ppm at 3m depth to 12000ppm at 9m depth in lagoon 3).
- Soluble fluoride concentration also increases with depth, the highest values being recorded in lagoon 1 and ranging from 4.1ppm to 10ppm over an interval of 6m.

This feature of increasing moisture content and increasing concentrations of chloride and fluoride with depth suggests that flushing of these contaminants downward is occurring. The most probable mechanism for this process is rainfall infiltration into the PFA. An earlier study by Exploration Associates {R8} also tested for cyanide in the PFA. Free cyanide analyses from 12 boreholes in lagoons 2,3 and 4 all produced results of <1ppm, the detection limit for the method.

Based on chemical considerations it is concluded that leachate is not entering the lagoons through the bunds in the vicinity of the boreholes tested since:

- cyanide was below detection in the samples analysed.
- Fluoride concentration, one of main contaminants from the waste tip, is within the normally accepted range for PFA of 0-200 ppm (UKQAA 2002).

3.5 FURTHER MONITORING WELLS RECOMMENDED BY URS

Further monitoring wells have been recommended by URS {R16} to comply with current guidance and to improve the understanding of the flow regime. These are briefly described here and their role in the monitoring network discussed:

- One borehole up hydraulic gradient of the landfill in the North Seaton Sandstone to provide background hydrochemical control of groundwater quality.
- A down gradient borehole on the eastern boundary of the landfill to confirm the hydraulic interpretation and to provide additional groundwater monitoring data.
- Two boreholes on the eastern perimeter of the site integrated into the monitoring network and to provide information on off-site contaminant migration. These boreholes will intersect the deposits in the glacial channel and should be screened in both the superficial drift deposits and the sandstone to determine the hydraulic interaction between the buried channel and the underlying sandstone.
- One borehole to the south of Lagoon 1 and 2 to provide further hydraulic information on flow direction and to assess the influence, if any, of the abandoned mine shafts on the flow field.

4 Conclusions

The main conclusions drawn from this desk study can be summarised as follows:

1. The site is over a minor Coal Measure aquifer in the North Seaton Sandstone that is underlain by a mudrock aquiclude sequence. Groundwater flow from the tip is to the east on a hydraulic gradient of 0.038 and flow is dominantly fracture controlled.
2. At the present time the groundwater system is isolated from the flooded, abandoned mine workings where the water level is at about -90 mAOD and rising slowly. A drainage culvert in the No. 2 shaft is topographically below the base of the waste tip and will discharge to the sea ruling out flooding of the waste site due to rising groundwater in the abandoned mine workings.
3. The Coal Measure sandstone is overlain, but generally hydrogeologically unconfined by a glacial till sequence in which the flow is probably predominantly vertical through fractures.
4. Water quality is poor and the groundwater is not potable. Saline intrusion is evident in the Sandstone aquifer, especially in boreholes BH101, BH103, BH4 and BH5 whereas boreholes BH3, BH6 and BH7 do not show a saline effect. The saline interface therefore seems to cut across the axis of the buried glacial channel. This argues against the channel being a hydraulic barrier to easterly flow. Another interpretation for the presence of chloride in the boreholes has been attributed, by URS {R16}, to infiltrating seawater from the ash lagoons. Seawater is used to slurry the PFA prior to its discharge to the lagoons. However, based on this interpretation one would also expect to see a saline effect in borehole BH7, down hydraulic gradient of lagoon 4, an effect that is not seen.
5. An unsaturated zone of sandstone hydraulically separates the PFA lagoons from the water table in the North Seaton Sandstone aquifer. It is unlikely that the PFA will become contaminated from the landfill leachate via the groundwater pathway since there is no hydraulic connection between the PFA and the water table beneath the lagoons. When operational the head in the lagoons is higher than the waste level in the pot lining tip and hence the potential for flow is away from the ash lagoons and not into them.
6. Chemical analyses of the PFA from the lagoons are consistent with the ranges normally found in UK PFA samples in general. There is no evidence of increased concentrations of cyanide or fluoride due to any direct discharge of leachate (through the bunds) from the waste disposal site in the boreholes and trial pits tested. The nearest borehole for which there is data was situated about 50m south of the waste tip {R15}. It should be pointed out that trial pits are generally excavated to less than three metres depth and that leachate levels in the pot-lining tip are lower down than this, so the probability of detecting leachate contamination by this means is very low. The evidence from chemical profiles in boreholes in the PFA strongly supports the view that downward leaching is occurring, probably due to rainfall infiltration.
7. The landfill operates on the dilute and disperse principle and the hydrochemical data available indicates that this is indeed the case with groundwater impact diminishing from BH1 to BH5 and from BH101 to BH103. Fluoride concentrations decrease due to dilution and cyanide concentration is decreasing probably due to degradation to ammonia and then to nitrate through ammonia oxidation.
8. The existing series of operational monitoring wells is useful in providing information on water levels to help determine direction of groundwater flow and hydraulic gradient, and chemical data to help determine the extent of saline intrusion from the sea and the extent of dispersion of contaminants from the landfill. However the limited area covered by the monitoring wells gives rise to uncertainty. The attenuation process uncertainty would be reduced to a large extent by increasing the range of parameters determined in the landfill monitoring wells.
9. It is believed that the locations of the five further monitoring wells proposed by URS {R16} should assist in understanding different aspects of the flow regime. However, in order to obtain a fuller understanding of the behaviour of the aquifer, in particular the role of the glacial channel on flow paths from the landfill, it is recommended that an additional monitoring well should be included at, or near, the south-west corner of lagoon 1.

5 Recommendations

Some uncertainty must be attached to the conceptual model put forward in the previous section concerning the behaviour of the aquifer and, to the attenuation processes taking place within it. In order to reduce this uncertainty a number of recommendations are proposed:

- Uncertainty associated with the hydraulic model is mainly centred on the role of the glacial channel on flow paths from the landfill. This could be investigated by including a new monitoring well at the south-west corner of lagoon 1 or possibly where the road into the landfill climbs the bund of lagoon 1. The borehole should be integrated into the monitoring network
- The five additional monitoring wells proposed by URS {R16} should be implemented. The two boreholes proposed on the eastern perimeter of the site should be screened in both the superficial drift deposits and the sandstone to determine the hydraulic interaction between the buried channel and the underlying sandstone. The expanded groundwater-monitoring network will also provide additional information on attenuation and dilution of contaminants away from the waste site. The data should be adequate enough to provide information to define the fate of cyanide and fluoride from the landfill and permit chemical modelling.
- The range of parameters determined in the landfill monitoring wells should be increased to include major anions and cations as well as nitrate and ammonia. This should help to reduce significantly the attenuation process uncertainty. The frequency of this extended suite of analyses should be determined by reference to current EA guidance, e.g. Waste Management Paper 4.
- Consideration should be given to the complementary approach of building a numerical model for the site. As a preliminary this would require hydraulic testing in the existing wells to establish hydraulic conductivity in the sandstone aquifer. A water balance estimate for the landfill would also be required to establish a source term and the recharge into the model. Such a model would offer the advantage of being able to predict future scenarios and could form part of a risk assessment submission for Regulation 15 compliance.
- In any future PFA exploitation scenario, systems should be in place to carry out rapid analyses of samples abstracted from the vicinity of the waste tip retaining bunds to test for the presence of leachate contaminants from the pot-lining tip. This would allow for rapid hazard mitigation and implementation of a risk management strategy should a leak be encountered.

Glossary

Alluvium Sediments deposited by rivers or streams during relatively recent geological time and deposited on the floodplain

Aquiclude A body of rock that is capable of slowly absorbing water but does not transmit it to yield significant quantities.

Aquifer A geological unit that is sufficiently transmissive to yield significant quantities of water.

Attenuation: the reduction in contaminant concentration due to physical, chemical or biological processes as it passes through a medium.

Clast Rock fragment

Dip The maximum angle of inclination of a bed of rock measured relative to the horizontal

Drift Unconsolidated sediments deposited during the Quaternary Period

Fault A fracture in rock along which relative movement has taken place

Fracture Flow Groundwater flow through fractures.

Groundwater Sub-surface water that occupies the saturated zone.

Hydraulic Conductivity The constant of proportionality in Darcy's Law. The ratio between the flow of water through a rock and the hydraulic gradient across it.

Hydraulic Gradient: The ratio between the difference in water level at two points on a flow line divided by the distance between those two points, or the rate in change of head per unit distance of flow. It is a dimensionless quantity.

Leachate The heavily mineralised solution formed by the percolation of rainfall and other surface waters through waste.

Lithology The physical description of a rock based on such characteristics as grain size and mineralogy.

Matrix Flow Groundwater flow through the interconnected porosity of a rock matrix.

Pathway The route taken by contaminants from the source to the receptor.

Permeability: the capacity of a porous rock to transmit water.

pH A measure of the activity of hydrogen ions in solution. In the field it is determined with an electrode; a $pH<7$ is acidic and a $pH>7$ is alkaline.

Porosity The percentage of the volume of a rock or soil occupied by void space.

Receptor Living beings or resources that may be exposed to and affected by contamination.

Recharge Rate The rate at which effective precipitation (rainfall) moves through the unsaturated zone to the water table.

Risk Assessment The process of estimating the risks of adverse health effects or environmental impacts due to exposure to a contaminant.

Source Term The quantity and concentration of a pollutant discharged at the pollution source.

Till Unsorted material deposited from an ice sheet (boulder clay)

Unsaturated Zone The zone between the surface and the water table in which the water pressure is less than atmospheric i.e. the zone is in suction.

References

The references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

BRITISH GEOLOGICAL SURVEY. 1990. Geological map NZ38NW. Solid and Drift. 1:10 000. (Keyworth: Nottingham British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1990. Geological map NZ29NE. Solid and Drift. 1:10 000. (Keyworth: Nottingham British Geological Survey.)

ENVIRONMENT AGENCY 1999 The EC Groundwater Directive (80/68/EEC) and theWaste Management Licensing Regulations, 1994. Internal Guidance on the Interpretation and Application of Regulation 15 of theWaste Management Licensing Regulations, 1994 (The Protection of Groundwater) with respect to Landfill

JONES, H K and others 2000. The physical properties of minor aquifers in England and Wales. *British Geological Survey Technical Report* WD/00/4; Environment Agency R&D Publication 68. 234pp.

JACKSON, I and LAWRENCE, D J D 1990 Geology and land-use planning: Morpeth-Bedlington-Ashington. Part 1: Land-use planning. *British Geological Survey Technical Report* WA/90/14

KLINCK, B.A. 1997 The Hydrogeological Characterisation of Superficial Clays: East Anglian Tills. *Environment Agency R&D Technical Report W28*

LAWRENCE, D J D and JACKSON, I. 1990 Geology and land-use planning: Morpeth-Bedlington-Ashington. Part 2: Geology. *British Geological Survey Technical Report* WA/90/19

UKQAA (United Kingdom Quality Ash Association) 2002 Technical Data Sheet 8. PFA and the environment.

WEALTHALL, G.P. and others 1997 The Hydrogeological Characterisation of Superficial Clays: The hydrogeology and hydrochemistry of glacial till and glacio-lacustrine sediments in Shropshire. *Environment Agency Project Record 455/03A/NW*

DISCLAIMER

Appendix 1 Sources of information provided by URS and ALCAN

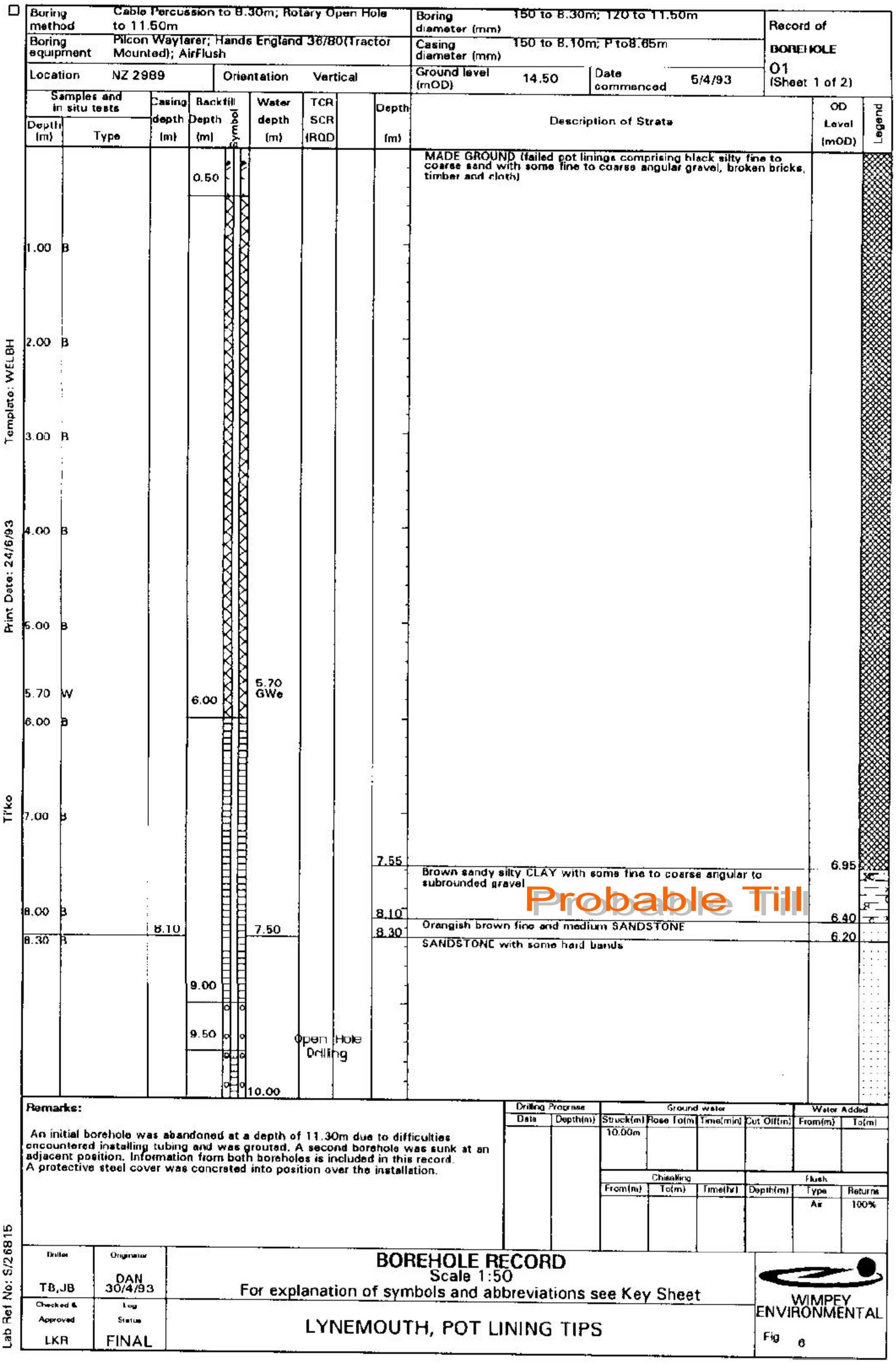
Ref	Description	Originator and Number	Year	Location	Boreholes	Comment
R1	Tip for failed potlinings. Feasibility report	EPD	1979	URS Edinburgh		Contains comments on formation of lagoon 2
R2	Appendix 1 and Appendix 3 (geology of the site) extracted from the report on tip for failed potlinings	EPD	1979	URS Edinburgh		5 A4 pages form Appendix to unknown document. Information has been extracted from R1
R3	As built A1 figure showing construction of tip for failed potlinings	A1/438/040	1980	URS Edinburgh		
R4	Bores for Lagoon area 4 - bores labelled "Lynemouth Power Station"	Wimpey (SU26640)	1992	Original from Lynemouth at BGS Edinburgh	11 boreholes **26640_1 to 26640_11**	Contained in SULI/7032
R5	Contamination survey at potlining tip (3 boreholes in lagoons 1, 2 and 3)	Wimpey Geotech (S/26651)	1992	URS Edinburgh	3 boreholes: **92_1 to 92_3**	Copies of borehole logs and sites, but no further info, in SULI/7032 (S26881)
R6	Analysis of Waters from Lynemouth: Ashington	Wimpey Environmental (SULZ/7416)	1994	Original from Lynemouth at BGS Edinburgh		Analysis of water samples (Appendix to SULI/7032)
R7	Lynemouth Pot Lining Tips Lynemouth Smelter	Wimpey Environmental SULI/7032 (S26881)	1994	Original from Lynemouth at BGS Edinburgh	5 boreholes: **93_1 to 93_5**	Report to assess the degree of contamination caused by leachate migrating from waste disposal facilities (two pot lining waste sites)

Ref	Description	Originator and Number	Year	Location	Boreholes	Comment
R8	PFA Removal Studies Ash Lagoons 2,3 and 4. Report on Ground Investigation	Exploration Associates (137101)	1997	Lynemouth	12 bores **97_1 to 97_12**	Several bores penetrate deposits beneath PFA
R9	installation of groundwater monitoring wells (BH101-BH103) at the Alcan Lynemouth facility	Dames & Moore (29633-013)	1998	Copy from URS at BGS Edinburgh	3 boreholes: **98_1 to 98_3**	Requirement for additional monitoring wells due to fall in groundwater elevation within 3 existing wells
R10	Boreholes - Ash Lagoons	SS Engineering, Darlington	1999	Lynemouth		Examined at Lynemouth. Bores all terminate within PFA. Show water levels at time of drilling.
R11	Lynemouth Hazardous Waste Landfill, Waste Management License 1994, Regulation 15 Hydrogeological Survey Gap Analysis for Alcan Smelting & Power UK	URS (29633-031)	2001	URS Edinburgh		
R12	report on working in the area commissioned by URS	Coal Authority	2001	URS Edinburgh		
R13	Results of chemical monitoring data carried out in vicinity of Ash Lagoons 2000-2001		2001	URS Edinburgh		
R14	the analysis of the ash from the boreholes in lagoons 1, 2 and 3	emailed to URS	2001			
R15	Ash recovery and Construction of Aardelite Plant. Risk assessment of Pulverised Fly Ash	Alcan Smelting and Power Uk	2001	Lynemouth		Chemical analyses of PFA
R16	Lynemouth Hazardous Waste Landfill, hydrogeological survey	URS (29633-031-788)	2002	URS Edinburgh		Regulation URS Edinburgh !5 assessment for Waste Management License
R17	Letter to Mr J Clarkson	William Harris	2002	Lynemouth		Photo of Newbiggin shaft

Appendix 2 Records of selected boreholes referred to in the text

Borehole 93_1, page 1

Brown sandy, silty clay unit with gravel from 7.55 to 8.10 indicates the presence of about half a metre of till on the sandstone, suggesting that some pockets of this material still remain below the waste.



Boring method	Cable Percussion to 8.30m; Rotary Open Hole to 11.50m	Boring diameter (mm)	150 to 8.30m; 120 to 11.50m
Boring equipment	Pilcon Wayfarer; Hands England 36/80(Tractor Mounted); AirFlush	Casing diameter (mm)	150 to 8.10m; P to8.65m
Location	NZ 2989, Orientation Vertical	Ground level (mOD)	14.50, Date commenced 5/4/93

Record of BOREHOLE 01 (Sheet 1 of 2)

Sample Depth (m)	Type	Casing depth (m)	Backfill Depth (m)	Water depth (m)	TCR SCR (RQD)	Depth (m)	Description of Strata	OD Level (mOD)
			0.50				MADE GROUND (failed pot linings comprising black silty fine to coarse sand with some fine to coarse angular gravel, broken bricks, timber and cloth)	
1.00	B							
2.00	B							
3.00	B							
4.00	B							
5.00	B							
5.70	W			5.70 GWe				
6.00	B		6.00					
7.00	B							
						7.55	Brown sandy silty CLAY with some fine to coarse angular to subrounded gravel	6.95
8.00	B					8.10	Orangish brown fine and medium SANDSTONE	6.40
8.30	B	8.10		7.50		8.30	SANDSTONE with some hard bands	6.20
			9.00					
			9.50		Open Hole Drilling			
				10.00				

Probable Till

Remarks:

An initial borehole was abandoned at a depth of 11.30m due to difficulties encountered installing tubing and was grouted. A second borehole was sunk at an adjacent position. Information from both boreholes is included in this record. A protective steel cover was concreted into position over the installation.

Ground water: Struck(m) 10.00m. Flush: Type Air, Returns 100%.

Driller: TB,JB. Originator: DAN 30/4/93. Checked & Approved: LKR. Log Status: FINAL.

BOREHOLE RECORD
Scale 1:50
For explanation of symbols and abbreviations see Key Sheet

LYNEMOUTH, POT LINING TIPS

WIMPEY ENVIRONMENTAL Fig 6

Template: WELBH Print Date: 24/6/93 T'ko Lab Ref No: S/26815

Borehole 93_2, page 1

Boring method	Cable Percussion to 9.80m; Rotary Open Hole to 17.90m	Boring diameter (mm)	150 to 9.80m; 120 to 17.90m
Boring equipment	Pilcon Wayfarer; Hands England 38/80(Tractor Mounted); AirFlush	Casing diameter (mm)	150 to 5.80m; P to9.80m
Location	NZ 3088	Orientation	Vertical
Ground level (mOD)	18.50	Date commenced	6/4/93

Record of BOREHOLE 02 (Sheet 1 of 2)

Template: WELBH Print Date: 24/6/93 Ti'ko

Samples and in situ tests

Depth (m)	Type
1.00	B
2.00	B
3.00	B
3.25	W
4.00	B
5.00	B
6.00	B
7.00	B
8.00	B
9.00	B
9.50	B
9.80	D

Casing depth (m): 5.80

Backfill depth (m): 0.50; 7.50

Water depth (m): 3.25 GWo; 5.20 GWo; DRY

Depth (m)	Description of Strata	OD Level (mOD)
	MADE GROUND (brown sandy silty clay with some fine to coarse angular gravel)	
0.80	MADE GROUND (failed pot linings comprising clayey in places silty fine to coarse sand with much fine to coarse angular gravel and broken bricks)	17.70
2.10	MADE GROUND (pulverised fuel ash with some fine to coarse gravel and cobbles)	16.40
3.80	MADE GROUND (failed pot linings comprising black clayey in places silty fine to coarse sand with much fine to coarse angular gravel, broken bricks and fragments of metal)	14.70
4.35	Stiff brown sandy silty CLAY with some fine to coarse angular to subrounded gravel and some fine and medium sand pockets. Becomes more sandy below 9.00m	14.15
9.15	Completely weathered grey SILTSTONE	9.35
9.70	Grey SILTSTONE	8.80
9.80	SILTSTONE	8.70

Remarks:

Small amounts of water were added to assist boring from ground level to 9.80m. A protective steel cover was concreted into position over the installation.

Drilling Progress Date	Drilling Progress Depth(m)
6/4	

Ground-water Struck(m)	Rose To(m)	Time(min)	Cut Off(m)	Water Added From(m)	Water Added To(m)
				0.00m	9.80m

Chiselling From(m)	Chiselling To(m)	Chiselling Time(hr)	Flush Depth(m)	Flush Type	Flush Returns
9.60m	9.80m	1.5h		Air	100%

Driller	Originator	
TB,JB	DAN 30/4/93	**BOREHOLE RECORD** Scale 1:50 For explanation of symbols and abbreviations see Key Sheet
Checked & Approved	Log Status	
LKR	FINAL	LYNEMOUTH, POT LINING TIPS

WIMPEY ENVIRONMENTAL

Fig 7

Lab Ref No: S/26815

Borehole 93_2, page 2 **The coal with base at a depth of 13.50 metres is believed to represent the coal commonly associated with the Kirkby's Marine Band**

Boring method	Cable Percussion to 9.80m; Rotary Open Hole to 17.90m	Boring diameter (mm)	150 to 9.80m; 120 to 17.90m		Record of BOREHOLE 02 (Sheet 2 of 2)
Boring equipment	Pilcon Wayfarer; Hands England 38/80(Tractor Mounted); AirFlush	Casing diameter (mm)	150 to 5.80m; P to9.80m		
Location	NZ 3088 Orientation Vertical	Ground level (mOD)	18.50	Date commenced 6/4/93	

Samples and in situ tests: Depth (m)	Type	Casing depth (m)	Backfill Depth (m)	Water depth (m)	TCR SCR (RQD)	Depth (m)	Description of Strata	OD Level (mOD)
			10.60				See previous sheet	
						12.40	SANDSTONE	6.10
						13.40	COAL	5.10
						13.50	MUDSTONE	5.00
							Possible position of Kirkby's Marine Band	
					Open Hole Drilling	14.00	SILTSTONE	4.50
			15.00					
						17.30	SANDSTONE with some siltstone bands	1.20
			17.90	DRY		17.90	END OF BOREHOLE	0.60

Remarks:

Drilling Progress: Date	Depth(m)	Ground water: Struck(m)	Rose To(m)	Time(min)	Cut Off(m)	Water Added: From(m)	To(m)

Chiselling: From(m)	To(m)	Time(hr)	Flush: Depth(m)	Type	Returns

Driller	Originator		
TB,JB	DAN 30/4/93	BOREHOLE RECORD Scale 1:50 For explanation of symbols and abbreviations see Key Sheet	WIMPEY ENVIRONMENTAL
Checked & Approved: LKR	Log Status: FINAL	LYNEMOUTH, POT LINING TIPS	Fig 7 Cont'd

Template: WELBH Print Date: 24/6/93 Titko Lab Ref No: S/26815

Borehole 93_3, page 1

Boring method	Rotary Open Hole	Boring diameter (mm)	140 to 6.15m; 120 to 13.15m
Boring equipment	Hands England 38/80(Tractor Mounted); Air Flush	Casing diameter (mm)	P to 6.15m
Location	NZ 3089	Orientation: Vertical	Ground level (mOD): 12.70
Date commenced	24/4/93	Record of BOREHOLE 03	(Sheet 1 of 2)

Casing depth (m)	Backfill Depth (m)	Depth (m)	Description of Strata	OD Level (mOD)
	0.50	0.20	TOPSOIL	12.50
		1.50	Orange brown sandy silty CLAY with occasional fine to coarse gravel	11.20
	4.15		Brown sandy silty CLAY with some fine to coarse gravel occasional cobbles and boulders	
6.15	6.65			
	7.15	7.10		5.60
			SILTSTONE with some mudstone bands	

TCR SCR (RQD): Open Hole Drilling

Remarks:

A protective steel cover was concreted into position over the installation.

Ground water Struck (m)	Rose To (m)	Time (min)	Cut Off (m)	Water Added From (m)	To (m)
10.40					

Chiselling From (m)	To (m)	Time (hr)	Flush Depth (m)	Type	Returns
				Air	100%

Driller	Originator		
JB	DAN 30/4/93	BOREHOLE RECORD Scale 1:50 For explanation of symbols and abbreviations see Key Sheet	WIMPEY ENVIRONMENTAL
Checked & Approved: LKR	Log Status: FINAL	LYNEMOUTH, POT LINING TIPS	Fig 8

Template: WELBH Print Date: 24/6/93 T'ko Lab Ref No: S/26815

Borehole 93_3, page 2

The two siltstone units at the base of the bore are believed to represent the lower part of the rock sequence above the Kirkby's Marine Band.

Boring method	Rotary Open Hole	Boring diameter (mm)	140 to 6.15m; 120 to 13.15m	Record of BOREHOLE 03 (Sheet 2 of 2)
Boring equipment	Hands England 30/80(Tractor Mounted); Air Flush	Casing diameter (mm)	P to 6.15m	
Location	NZ 3089 Orientation Vertical	Ground level (mOD)	12.70 Date commenced 24/4/93	

Samples and in situ tests Depth (m)	Type	Casing depth (m)	Backfill Depth (m)	Symbol	Water depth (m)	TCR SCR (RQD)		Depth (m)	Description of Strata	OD Level (mOD)	Legend
									See previous sheet		
					10.40 GWe			10.40	SANDSTONE	2.30	
						Open Hole Drilling		11.05	SILTSTONE	1.65	
			13.15					13.15	END OF BOREHOLE	-0.45	

Remarks:

Drilling Progress		Ground water				Water Added	
Date	Depth(m)	Struck(m)	Rose To(m)	Time(min)	Cut Off(m)	From(m)	To(m)

Chiselling			Flush		
From(m)	To(m)	Time(hr)	Depth(m)	Type	Returns

Driller JB	Originator DAN 30/4/93	**BOREHOLE RECORD** Scale 1:50 For explanation of symbols and abbreviations see Key Sheet	WIMPEY ENVIRONMENTAL
Checked & Approved LKR	Log Status FINAL	LYNEMOUTH, POT LINING TIPS	Fig 8 Cont'd

Template: WELBH Print Date: 24/6/93 Tiko Lab Ref No: S/26815

Borehole Record 26640_7 {R4}. Shows laminated clay and silt within glacial deposits in area of lagoon 4

Boring method: Cable Percussion	Boring diameter (mm): 200 to 7.60m		Record of BOREHOLE 7
Boring equipment: Pilcon Wayfarer	Casing diameter (mm): 200 to 6.00m		Sheet 1 of 1
Location: NZ 3089 Orientation: Vertical	Ground level (m OD): 4.55	Date commenced: 26/3/92	

Samples and in situ tests

Depth (m)	Type	Casing depth (m)	Water depth (m)
0.60	Db		
0.80	U(100)	-	
1.30	Dj		
1.60	Db		
1.80	GWs		1.80 GWe
1.90	U(100)	1.80	
2.40	Dj		
2.80	Db		
2.95	U(100)	2.90	
3.45	Dj		
3.80	Db		
4.10	U(100)	4.00	
4.60	Dj		
4.80	Db		
5.10	Db		
5.20	U(100)	5.10	
5.70	Dj		
6.50	Db		
6.85	U(100)s	6.00	DRY
7.00	S>50	6.00	DRY
7.00	Dj		

Strata

Date and Depth (m)	Description of Strata	O D Level (m O D)
26/3 0.15	TOPSOIL	4.40
1.85	Firm mottled orange brown grey and brown sandy silty CLAY with occasional fine to coarse angular to subrounded gravel	2.70
2.70	Stiff mottled brown and grey slightly sandy silty CLAY with some fine to coarse angular gravel	1.85
3.90	Very stiff brown with occasional grey mottles slightly sandy silty CLAY with some fine to coarse angular gravel	0.65
4.85	Brown sandy SILT with some brown silty clay laminations Laminated clay and silt	-0.30
6.25	Very stiff brown sandy silty CLAY with some fine to coarse angular to subrounded gravel	-1.70
6.95 27/3 7.05	Grey sandy silty CLAY with some fine to coarse angular to subrounded gravel and occasional cobbles	-2.50
7.60	Grey silty fine SANDSTONE	-3.05
	END OF BOREHOLE	

Remarks: Ground-water was encountered at a depth of 1.80m and the level rose by 0.35m in 20 minutes. Small amounts of water were added to assist drilling from 5.40m to 6.95m. The borehole was advanced by chiselling from 6.85m to 6.95m(1h) and 7.00m to 7.60m(4½h). A piezometer with a porous tip was installed at a depth of 2.00m. The borehole was backfilled as follows:- 7.60m to 2.50m:bentonite; 2.50m to 1.50m:sand; 1.50m to 1.00m:bentonite; 1.00m to ground level:concrete. A steel protective cover was concreted into place over the installation.

Originator 10/4/92	DAN	**BOREHOLE RECORD** Scale 1 : 50 For explanation of symbols and abbreviations see Key Sheet	WIMPEY GEOTECH
Checked & Approved 23/6/92	LKR	LYNEMOUTH POWER STATION	Fig. 8

124A (REV 9/90)

Ref No S/ 26640

Borehole 92_2, page 1

Boring method: Cable Percussion	Boring diameter mm: 200 to 13.90m; 150 to [illegible]	Casing diameter mm: 200 to [illegible]; 150 to [illegible]	Record of BOREHOLE 2
Boring equipment: Pilcon Wayfarer			Sheet 1 of 2
Location: [illegible]	Orientation: Vertical	Ground level m O.D.: [illegible]	Date commenced: [illegible]

Samples and in situ tests Depth m	Type	Casing depth m	Water depth m	Date and Depth m	Description of Strata	O.D. Level m O.D.
[illegible]	D				MADE GROUND (ash)	
2.00	D					
3.10	D					
				3.90		8.70
4.15	D				MADE GROUND (red ash and clay)	
5.00	D					
		5.30	DRY	5.30		
			DRY	7/4		
				5.90		6.70
6.00	D				MADE GROUND (brown sandy silty clay with some fine to coarse gravel and fragments of red ash)	
7.00	D					
8.10	D					
				8.60		4.00
8.80	D				MADE GROUND (red ash, coal and clay)	
9.90	D					

Remarks

Originator: DAN	**BOREHOLE RECORD** Scale 1 : 50 For explanation of symbols and abbreviations see Key Sheet	WIMPEY GEOTECH	
1/5/92			
Checked & Approved: WTG	LYNEMOUTH, POTLINING TIP	Fig. 2	
13/8/92			

REV 9.90

26651

Borehole 92_2, page 2 The borehole may have terminated in either a boulder within the drift sequence, or at solid rock, hence gives only a minimum depth for the buried channel at this point.

Record of BOREHOLE 2

Sheet 2 of 2

Sample depth (m)	Type	Casing depth (m)	Water depth (m)	Depth (m)	Description of Strata	O.D. Level (m OD)
11.00	Dj				See previous sheet	
12.00	Dj					
				12.65		-0.05
12.80	Dj				Greyish brown sandy silty CLAY with some fine to coarse gravel	
				13.60		-1.00
13.70	Dj				Greenish greyish brown sandy silty CLAY with some fine to coarse gravel and cobbles	
				14.10		-1.50
14.20	Dj				Dark brown sandy silty CLAY with some fine to coarse gravel	
14.60	Dj					
15.00	Dj					
15.55	Dj					
16.00	Dj					
16.50	Dj					
17.00	Dj					
				17.15		-4.55
17.30	Dj				Brown very sandy silty CLAY with some fine to coarse gravel	
17.80	Dj			17.60		-5.00
17.80	Dj	17.50		17.80	BEDROCK or BOULDER	-5.20
					END OF BOREHOLE	

Remarks Descriptions are based on Driller's log.
Small amounts of water were added to assist boring from 0.50m to 13.60m and may have masked the occurrence of ground-water.
The borehole was advanced by chiselling from 13.70m to 13.85m($^3/_4$h) and 17.60m to 17.80m(1h).
A piezometer with a porous pot was installed at a depth of 17.60m. The borehole was backfilled as follows :- 17.80m to 16.80m:sand; 16.80m to 16.30m:bentonite; 16.30m to 0.50m:bentonite/cement grout; 0.50m to ground level:concrete.
A protective steel cover was concreted into place over the installation.

Originator	DAN	**BOREHOLE RECORD** Scale 1 : 50 For explanation of symbols and abbreviations see Key Sheet — WIMPEY GEOTECH
1/5/92		
Checked & Approved	WTG	LYNEMOUTH, POTLINING TIP — Fig. 2 CONT'D
13/8/92		

(V 9.90)