EASTGATE GEOTHERMAL EXPLORATION BOREHOLE

FINAL REPORT

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CONTENTS

SUMMARY

List of abbreviations and terms used

AOD	-	Above Ordinance Datum, a defined measure of altitude
BGS	-	British Geological Survey
Ca	-	calcium
Cambokeels	-	a mine near the Eastgate borehole site, now disused
EA	-	Environment Agency
g	-	grammes
K	-	potassium
KW	-	kilowatts
l/s	-	litres per second
m	-	metres
m^3/h	-	cubic metres per hour
MW	-	megawatts
mg/l	-	millgrammes per litre
Na	-	sodium
Slitt Vein	-	a mineral formation in the North Pennines
TDS	-	Total Dissolved Solids

SUMMARY

The Eastgate geothermal exploration borehole was drilled between August and December 2004 in order to establish the presence of a geothermal energy resource capable of supplying heat to the redeveloped Lafarge cement works site.

The borehole was drilled to a depth of 995 metres using “open hole” techniques, and encountered 271.5 metres of Recent and Lower Carboniferous rock followed by 723 metres of granite. The hole was intentionally located to run down the edge of the Slitt Vein, and mineralization observed in the drilling cuttings suggests that the hole did indeed follow the Slitt Vein structure to a depth of at least 720 metres.

Post-drilling logging of the hole showed a temperature of 46.2°C at 995 metres, some 10 – 15°C higher than the UK average for this depth, confirming the elevated temperature gradient predicted for the site. The observed linear gradient suggests that at 1800 metres, for example, a temperature of 75 – 80°C would be attained. Geochemical analysis of cuttings samples has also confirmed the heat production potential of the underlying granite as being consistent with that previously measured in the area.

Of particular importance is the presence of natural groundwater in the hole that could allow heat energy to be readily extracted. Significant volumes of water were encountered during drilling, including a major feeder of warm (26°C) saline water at a depth of 410 metres. Deeper water sources have also been identified further down the hole. Logging and limited test-pumping after drilling completion showed that the current borehole is capable of producing at least 50 m^3/hour of water at 27°C, and the high degree of fracturing observed in the Slitt Vein suggests that deeper sources of hotter water are also likely to be available. The nature of the hydrogeology at Eastgate can thus be summarised as a fractured vein structure providing a groundwater pathway, surrounded by heat-producing granite. This is a type of geothermal resource never previously described in the UK or elsewhere.

The water currently available from the borehole has potential uses on a redeveloped cement works site. The temperature, volume and salinity may suit a “hot springs” development, or use as ground-sourced heat for buildings. Further drilling to greater depths, preferably via a second borehole, would be likely to access a higher temperature resource with a wider range of potential uses. To confirm the feasibility of using the current borehole, the following next steps are recommended:

- Confirm the sustainable water flow by more extensive test-pumping.
- Temporarily seal off the current 410 metre feeder to establish the temperature and volume of warmer water sources further down the hole.
- Establish the suitability of the water for bathing.
- Identify a route for water disposal after use.

In summary, the borehole has established the presence of a unique geothermal resource at the Eastgate site with the potential to make a significant contribution to the sustainable redevelopment of the Lafarge site.

1. INTRODUCTION

This report summarises the final results of the Eastgate geothermal borehole, which was drilled on the Lafarge Eastgate site during August to December 2004. It has been jointly written by PB Power (Project Managers) and the University of Newcastle (Technical Advisers). This report updates the interim report published in December 2004.

The project was funded by the Weardale Taskforce, made up of One North East, Durham County Council, Wear Valley District Council and Lafarge Cement. The University of Newcastle also made contributions in kind to the project.

The report is divided into five sections, including this introduction.

- Section 2 provides a record of the borehole operation and the final borehole profile.
- Section 3 reports on the project costs.
- Section 4 summarises the scientific findings in terms of geology, hydrogeology and geothermal resources.
- Section 5 discusses the options and next steps for exploiting the geothermal resource.

2. BOREHOLE RECORD

2.1 Completed borehole

The borehole was completed on 2nd December 2004 at a depth of 995 metres. Drilling was halted 5 metres short of the original target depth of 1000 metres to prevent possible equipment loss in the hole. The drilling contractor was Foraco S.A.S. of Lunel, France. The borehole was constructed in 3 phases:

i. From surface to 93 metres, cased and cemented with a final internal diameter of $13^3/_8$ inches. The first 20 metres from the surface is further surrounded by a 20 inch casing, which was used to stabilise the surrounding ground during the initial stages of drilling through weak drift deposits and karstified limestones.

ii. From 93 to 403 metres, cased and cemented with a final internal diameter of $9^5/_8$ inches.

iii. From 403 to 995 metres, without casing and with a diameter of $8^1/_2$ inches.

Following borehole logging, Foraco reported the final water level in the hole as 14.3 metres below ground level.

Note that all depths given in this report are measured from the drilling table, which was 0.95 metres above the surface of the drilling compound.

2.2 Site condition

The hole has been capped with a double-locked plate and the keys retained by Lafarge. The concrete pit surrounding the well-head has been covered with a steel plate and temporarily buried flush with the surrounding surface, to deter vandalism.

The precise national grid coordinates of the borehole (measured to the centre of the cover plate) are 393890.932 E, 538200.147 N, 250.867 AOD.

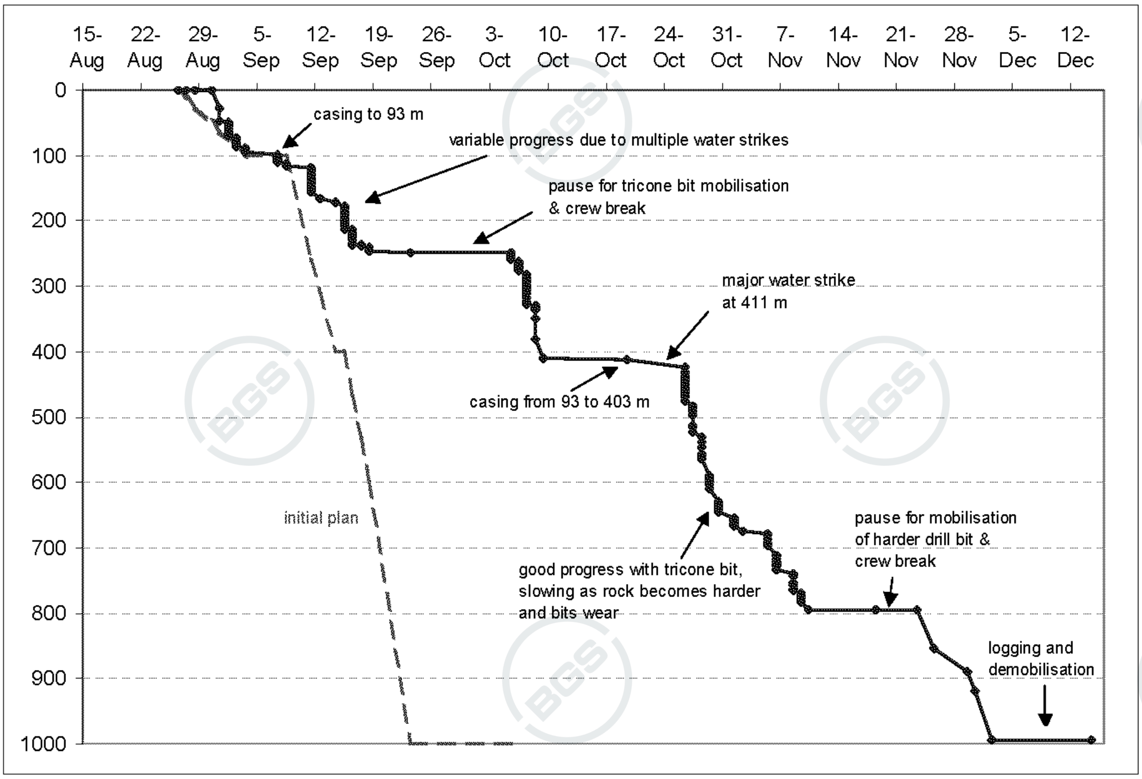
The drilling site has been cleared. With the agreement of Lafarge and the tenant farmer, the drilling compound and access road have been left in place to allow future access to the hole. Lafarge have agreed to carry out any future landscaping of the drilling compound if required.

2.3 Drilling progress

The significant water volumes encountered during drilling resulted in slower progress than originally planned. The progress of the drilling programme is illustrated in Figure 2.1 below which shows the rate of progress and significant events that occurred.

Daily drilling logs are provided in Foraco's completion report of December 2004.

Figure 2.1: Progress of Eastgate borehole



2.4 Permits and consents

The drilling was carried out with consent from the Environment Agency (EA) under the Water Resources Act 1991 (consent number CON 24/1/002) and with planning permission from Wear Valley District Council (ref 3/2004/0568).

2.5 Health, Safety and Environmental

There were no accidents or other health & safety incidents during the drilling works. No polluting discharges of lubricants, oil or other materials occurred.

During drilling, the following waste disposal took place with prior consent from the Environment Agency:

- 218 m^3 of water and 40 tonnes of rock chippings to the Lafarge quarry.
- 690 m^3 of water to a soakaway pit next to the drilling compound.

4. SCIENTIFIC FINDINGS

4.1 Geology

The sequence of rocks encountered during drilling is of considerable geological significance, as this is only the second borehole ever to penetrate the Weardale Granite, an important batholith which is nowhere exposed at surface. As the following account demonstrates, the sequence encountered in the Eastgate Borehole closely resembles that encountered in the Rookhope Borehole drilled in 1962-3 (Dunham et al., 1965[1]), which first proved the existence of the Weardale Granite.

Given the primary purpose of the borehole, and associated constraints of cost and available time, the borehole was drilled by "open hole" methods (as opposed to continuous coring), and the geological interpretation is therefore based on:

(i) Samples of drill cuttings flushed from the hole, together with groundwater, using compressed air. Cutting samples were taken at 1 m intervals down to 615 m, and 5 m intervals thereafter. Field examination of these led to compilation of a cuttings log that records the rock types and hydrothermal minerals present (see Appendix C).

(ii) Driller's records of zones of fractured ground (evident from changes in drilling speeds and tool movements) and water ingress (evidenced in changes in borehole water levels and air pressures needed to flush the borehole).

(iii) Lithological interpretation of geophysical logs collected after completion of drilling. Rock identification / level confirmation was especially aided by reference to natural gamma, resistivity and density traces, with some interpretations of fracture zones also being supported by references to fluid conductivity and temperature logs.

Cuttings were logged by Dr F. W. Smith of FWS Consultants, Spennymoor, who also interpreted the drillers records and selected 'picks' from the geophysical logs. Most of the following account is derived *verbatim* from Dr Smith's summary of the geology encountered by the borehole. Particular incidents during drilling were noted by Dr Sorcha Diskin of Foraco, and were discussed with Dr Smith and Professors Younger and Manning of the University of Newcastle during the course of drilling.

The Eastgate Borehole penetrated 271.5 m of Recent and Lower Carboniferous cover rocks then nearly 723 m of basement granite. Superficial deposits of Recent and Quaternary age were encountered down to rockhead at about 4 m (all depths in this section are below drilling table, which was at 251.81 m AOD), and consisted mostly of sand, gravel and boulders. The borehole was open-holed to 10 m without casing, so that there was considerable cross contamination of rock cuttings with caved drift material over that interval.

The Scar Limestone was present from rockhead to about 12 m, and is believed to be karstic (i.e. to have caves within it, which from the initial site investigation were found to be mud

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[1] Dunham, K. C., Dunham, A. C., Hodge, B. L. and Johnson, G. A. L., 1965, Granite beneath Visean sediments with mineralization at Rookhope, northern Pennines. Quarterly Journal of the Geological Society of London, **121**: 383 - 417.

filled). This was followed by the 'Alternating Beds', a sequence of thinly bedded limestones, mudstones and sandstones. The Tynebottom Limestone was recognised between 39.5 - 51.5 m. As with the other horizons below the Scar Limestone, this formation was found to be heavily mineralised (predominantly in the form of quartz veinlets); it was also the source of a significant increase in groundwater influx to the borehole.

The Jew Limestone was encountered between 76 and 83 m, again showing signs of mineralisation. Immediately beneath it was a mineral vein, from 83 to 87 m, of coarse green fluorite, interpreted as a branch of the Slitt Vein.

The top of the Great Whin Sill was encountered at 92 m, and continued to 158.5 m. The Sill was extensively carbonated and altered to “white whin”, a type of alteration often found close to mineral veins.

Rocks beneath the Great Whin Sill were heavily veined by quartz down to about 175.5 m. Beneath this the sequence was essentially devoid of mineralization for almost fifty metres, and the Smiddy, Upper and Lower Peghorn, and Birkdale Limestones were easily recognised. The Robinson Limestone (223.5 - 234.5 m) was fractured and heavily replaced by quartz and calcite, a form of mineralization which continued into the Melmerby Scar Limestone (239.5 - 249.5 m).

Beneath the Melmerby Scar Limestone, the Orton Group and Basement Beds occupied the depth interval 249.5 - 272.5 m. Mainly sandstones with occasional thin limestones, these rocks were cut by veinlets of mineralisation.

The granite surface at 272.5 m below table (271.5 m below surface) was marked by the occurrence of cuttings of a sticky white clay, presumed to be kaolinitic, over an interval of 0.5m. The first few metres of granite were relatively soft, then becoming harder and more coherent. The granite resembles the cored material from the Rookhope Borehole. It is fairly uniformly coarse grained (2 - 6 mm), consisting of feldspars, quartz, muscovite and biotite. Down to approximately 400 metres, the granite has a greenish hue, likely due to hydrothermal alteration of the feldspars. Below this depth the granite was white in colour.

Mineralisation was found throughout the granite, usually as quartz veinlets with sporadic occurrences of pyrite, chalcopyrite or galena. An open fracture was intersected at 410 m, and provided a strong influx of warm (26^{o}C) saline water.

Cuttings from 415 to 615 m were uniform, with sparse indications of mineralisation. Below 615 m cuttings were taken at intervals of 5m. Fluorite mineralisation was intersected between 620 and 650 m (recognized in waste cuttings, rather than in the samples collected at 5m intervals). Minor quartz-pyrite veinlets were encountered at 655.5 m, associated with sticky white clay (presumably kaolinite). White quartz veins were encountered at 690 m and 720-721 m.

More complex mineralisation was encountered below 720 m in the form of three fine-grained quartz veins with pyrite and hematite (740-742 m, 888.5 m, 912-913.5 m).

Comparing the depths at which different marker horizons have been encountered in other boreholes and at outcrop, it appears that the pre-Carboniferous surface was very flat (8 m or so relief between Rookhope and Eastgate). This observation means that future boreholes can be planned with greater confidence using existing deep borehole data.

In summary, typical Weardale mineralisation was found down to about 720 m, with more complex mineralisation beneath that depth. These observations suggest that the borehole followed the Slitt Vein structure down to 720 m. Below this depth it may have died out, or have deviated too far from the borehole azimuth to be recognised.

In addition to the description of cuttings provided by Dr Smith, phytoclast reflectance (a measure of ancient temperature conditions, deduced from plant-derived matter within the rock)[2] was determined on cuttings from the sedimentary sequence by Dr J. M. Jones, who previously carried out a similar study on material from the Rookhope core. Very similar results were obtained, with reflectance values immediately above the granite of approximately 4, corresponding to an ancient maximum temperature of the order of 130°C. The similarity between the Rookhope and the Eastgate boreholes suggests that the heat flow regime in this part of Weardale is very uniform (and has been for millions of years).

4.2 Geochemistry of the Weardale Granite: implications for heat production

Limited geochemical analysis of selected samples from the granite were made in order to evaluate its heat production potential, which is governed by the concentrations of certain naturally radioactive chemical elements. The data are also useful from a wider geological perspective, as indicators of the degree of uniformity of the rock. Sixteen samples of cuttings were selected at approximately 50 m intervals, and submitted to the Department of Geology at the University of Leicester for analysis of major and trace elements using X-ray fluorescence. The analytical results are given in full in Appendix D.

Given their origin as flushed cuttings from a borehole being drilled in conditions which were aggressive towards the drilling equipment, it is prudent to expect some adulteration of the samples by metals derived from the drilling bit, rods and other downhole equipment. By and large, few indications of such adulteration were evident. The most prominent example indicating a clear case of adulteration is the 650 m sample (Figure 4.1), which displays exceptionally high concentrations of tungsten, molybdenum and chromium (metals associated with hardened tools), as well as high levels of iron. While the results for the 650 m sample must be used with care, such adulteration appears not to have affected concentrations of other important elements in this or any other sample.

Downhole homogeneity is readily assessed from data for sodium (expressed as Na_2O), potassium (K_2O) and calcium (CaO). These elements are most easily affected by surface weathering or alteration adjacent to mineral veins. Figure 4.2 shows their distribution downhole, and shows that the granite at 400 m and shallower depths has low K_2O and Na_2O contents, and elevated CaO compared with the values reported for samples from depths

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[2] The more familiar term “vitrinite reflectance” is not used here, simply because it is not possible at high reflectance values to distinguish vitrinite from other coal macerals.

greater than 400 m. The reduction in alkalis may reflect weathering of the surface of the granite before it was covered by the overlying sediments. The high calcium contents may be associated with weathering, or be caused by hydrothermal mineralisation associated with the Slitt Vein.

Figure 4.1. Distribution downhole of chromium, molybdenum and tungsten.

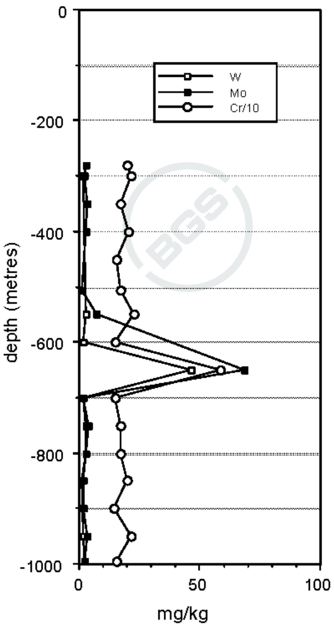
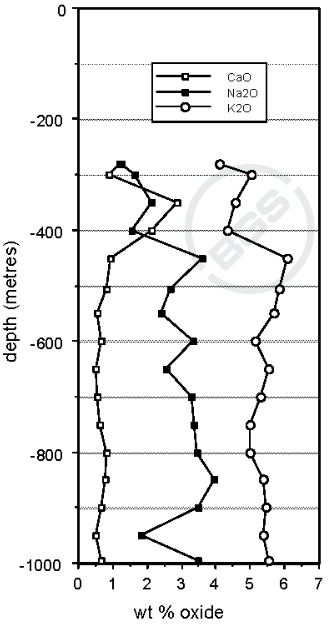


Figure 4.2. Distribution within the granite of calcium, sodium and potassium.



The heat production capacity of the granite can be calculated from the chemical analysis (Downing and Gray, 1986[3]), using the equation (Webb, pers.comm.[4]):

$$A = 0.1326\rho * (0.718U + 0.193Th + 0.262K)$$

Where:
A = heat production in $\mu W/m^3$
ρ = density in g/cm^3
U = uranium content in mg/kg
Th = thorium content in mg/kg
K = potassium content in element, %.

The density of analysed cuttings was determined by measuring the displacement of 100 ml of water by 100 g of cuttings, agitating ultrasonically to remove occluded air.

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[3] Downing, R. A. and Gray, D. A. (editors), 1986, Geothermal energy - the potential in the United Kingdom. British Geological Survey. HMSO, London. 187pp.
[4] Webb, P. C. (Open University) personal communication to David Manning, September 1987.

Figure 4.3 shows downhole variations in the calculated heat production capability of the granite at Eastgate. In general, heat production rises to consistent values below 400 m. This is consistent with the general suggestion that it is unreasonable to estimate heat production values from near surface outcrops of granites, as they may be affected by weathering to depths of as much as 150 m.

Figure 4.3. Variation with depth in calculated heat production

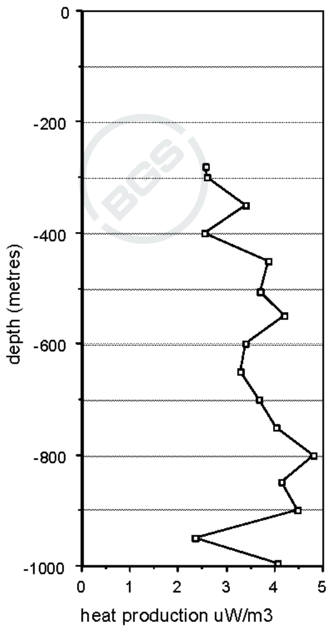

Figure 4.4. Variation of granite silica content with depth

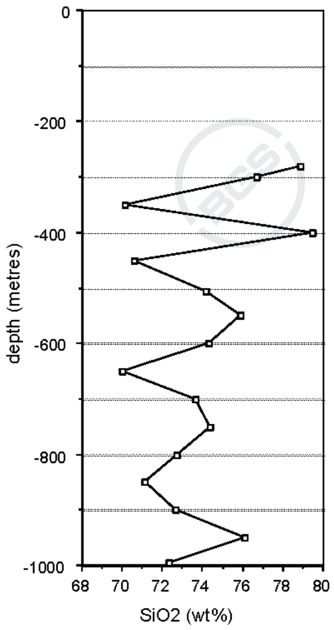

Figure 4.4 shows the distribution of silica with depth, which shows most variability at 400 m and shallower depths, consistent with evidence from logs showing that this part of the granite has been altered. The low value for heat production at 950 m may be associated with the high silica content, and may reflect mineral veining observed in cuttings from around this depth.

Overall, the geochemical data from the granite yield the following results:

1. The heat production value for unaltered granite is estimated to be 3.97 μW/m^3, excluding samples at depths of 400 m and shallower, and excluding the 950 m sample. These values are slightly higher than that reported by Downing and Gray (1986)[3] for the Weardale Granite (3.7 μW/m^3).

2. Heat production appears to increase with depth, overall, with local perturbances due to the occurrence of veins of quartz etc. that are unlikely to affect the bulk heat production capacity.

No attempt has been made to measure the thermal conductivity of the granite from the Eastgate borehole. It is not possible to do this accurately using cuttings. Instead, values of thermal conductivity taken from the Rookhope core can be used at Eastgate. This has been taken as 2.94 W/mK (Downing and Gray, 1986)[3].

An estimate of heat flow can be made using the bottom hole temperature (46°C), the annual average ground surface temperature (8°C) and: (a) a weighted mean of all rock types encountered in the hole and using the entire sequence, or (b) for the granite alone. Both give similar results (81 mW/m^2). This figure is lower than that obtained by the British Geological Survey (Downing and Gray, 1986)[3] for the Weardale Granite at Rookhope (92 mW/m^2). It is sensitive to the determination of surface temperature, decreasing by approximately 2 mW/m^2 for an increase of 1°C in the measured surface temperature.

In summary, the thermal properties for granite from the Eastgate borehole are:

Average heat production	3.97 μW/m^3
Thermal conductivity	2.94 W/mK
Surface heat flow at Eastgate	81 mW/m^2 (cf. 92 mW/m^2; Downing and Gray, 1986)[3].

These heat production capacity and heat flow data allow a comparison to be made with previous work carried out in the 1980s with the intention of recovering geothermal energy using a 'hot dry rock' (HDR) approach, in which cool water is pumped down one borehole into a fractured granite and warm water is recovered from a second borehole tens of metres away. On the basis of the data obtained in this study, the Weardale Granite has heat production values similar to those of the Cornish granites (although heat flow values are lower), and so in principle would be compatible with HDR developments. This possibility is strengthened in view of the technological changes that have been made since the 1980s. In particular, the use of a single borehole with a double pipe (cool water pumped down the outer pipe and warm water recovered up a central plastic pipe) is being explored in Aachen, Germany, at the present time[5]. It is not known at this stage whether or not this technology will succeed, but (importantly) the amount of energy that can be recovered from a dry hole of this type is a fraction of the amount that can be recovered by the extraction of warm water, because of the difficulty of transferring heat from a rock to a circulating water system. Eastgate, like Southampton, has the advantage that warm water has been found to occur naturally at depth, and so no man-made heat transfer system is needed down-hole.

4.3 Water strikes and hydrogeological conditions

Significant water strikes encountered during the sinking of the borehole are recorded in Appendix C. The borehole experienced unusually high rates of groundwater ingress from the Carboniferous sequence; for instance, at times whilst proceeding through the Carboniferous strata, the water yield of this one borehole exceeded the entire former dewatering rates of a number of local mines. It is not credible to claim that every geological unit in the Carboniferous is locally anomalous in its native properties; the only logical conclusion is that

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[5] www.superc.rwth-aachen.de

the high water yields reflect the high permeability of fractures associated with the Slitt Vein structure. In practical terms these heavy water yields made hammer drilling inefficient, prompting the contractor to switch to using a tri-cone roller.

Casing was installed twice to eliminate shallow-sourced groundwaters from the borehole (for details of casing depths and diameters see Section 2). The first casing effectively sealed the hole off from all water feeders associated with the limestones above the Whin Sill, working on the supposition that the Sill itself is rarely a prolific aquifer. However, not just one but <u>two</u> major water feeders were subsequently hit within the Whin Sill, bringing the borehole water yield back to levels found in the overlying sedimentary strata (~ 60 m^3/h).

Once the borehole had proceeded some 130 m into the granite, it was felt likely that installation of the second casing would eliminate all shallow feeders once and for all. Given the generally low permeability of granite, subsequent feeders would be expected to be minimal unless it was subject to unusually intense fracturing. Sure enough, after the second casing had been grouted in the borehole water yield dropped to zero. For seven metres, this state of affairs continued. However, at around 410 m below ground, the drill stem pressure gauge suddenly jumped to 23 bar, and then the drill bit suddenly dropped by 0.5 m. At this point the pressure gauge went off scale (> 30 bar), and water surged into the hole, rapidly rising to within 10m of the ground surface. It is clear that a major open fissure had been encountered at 410m below ground. The electrical conductivity of this water greatly exceeded that of the waters previously encountered in the Carboniferous, and it was also warm to the touch (around 26°C). Air-lifting at rates of up to 60m^3/h (maximum capacity of the equipment) failed to lower the water level by more than a metre, indicating a transmissivity in excess of 1700m^2/d – certainly a record for granite in the UK, though no doubt reflecting the extraordinary permeability of fractures associated with the Slitt Vein. Other fractures were hit at depths below ground of 436 m, 464 m, 492 – 496 m, 654 m, 720 – 721 m, 739.5 m, and 813 - 814.5 m. Although these fracture intersections were not accompanied by dramatic events such as occurred at 410 m, and the quantities of water which they introduced to the borehole were difficult to discern given that the 410 m feeder had already exceeded the air-lift capacity of the rig, the gradual increase in the temperature of the water arriving at the well head (> 27°C towards the end of drilling) indicated that a significant amount of warmer deeper water was now mixing with the 410 m feeder water.

After the end of drilling, geophysical logs for fluid temperature, conductivity and flow rate (by impeller) were run twice: first through the static water column, and then with a 100 mm electric submersible pump stimulating the borehole water column by pumping from just below the water surface at a rate of around 1.4 m^3/h. Comparison of the two suites of logs indicates significant water feeders associated with fractures at approximately 730 m and 756 m depth[6]. While none of these were as prolific as the 410m feeder, their occurrence bolsters confidence in the existence of permeable fractures at depths approaching those which would be proposed for a long-term production borehole.

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[6] Other feeders were also indicated by the geophysical logs at 420, 434, 447, 485, 497, 527, 540, 557, 670, and 686 m.

4.4 Groundwater quality

The electrical conductivity and pH of water from the borehole were measured continuously at the cuttings separator. Water samples were taken initially every 10-20 metres. Below 300 m water samples were taken approximately every 50 m. Cations were determined using atomic adsorption spectroscopy, alkalinity by titration, ammonium using Kjeldahl digestion and anions by ion chromatography. Water samples up to and including 86.5 m were acidified before filtration; this meant that dissolved suspended solids were reported in the chemical analysis, giving misleading results that over-estimated dissolved cations (high positive charge balances; all data are given in Appendix E). From 135 - 995 m samples were filtered prior to acidification, and gave charge balances predominantly less than ±5%.

Very high levels of electrical conductivity were observed on site, and much lower (and less scattered) electrical conductivities were observed for samples analysed in the laboratory. Figures 4.5 and 4.6 compare measured conductivities with total cation and anion concentrations expressed as milliequivalents per litre, which ideally give a straight-line plot with a slope of 100. This is observed for the laboratory measurements (bearing in mind that this relationship breaks down for highly saline solutions such as those encountered at depth), and shows that the field conductivity measurements are over-estimates.

Figure 4.5. Comparison of field conductivity measurements with total cations and anions in solution (meq/l)

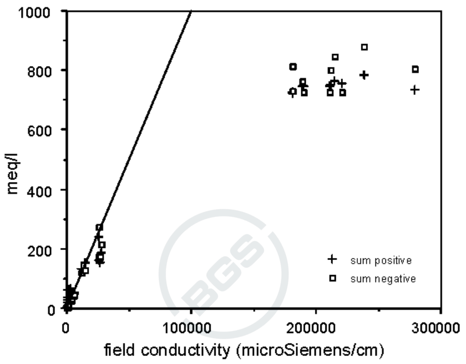
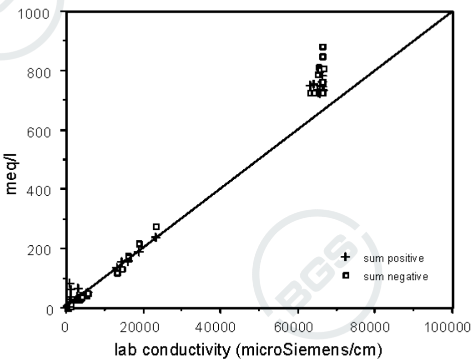


Figure 4.6. Comparison of laboratory conductivity measurements with total cations and anions in solution (meq/l)



Variation in conductivity and temperature with depth, for the samples taken for analysis, is shown in Figures 4.7 and 4.8. Values rise until approximately 400m, at which point there is a sharp increase in both temperature and conductivity. This corresponds to the point at which the hole intersected a large open fracture. At greater depths, both temperature and conductivity change very little.

Individual chemical species show contrasting behaviour with depth. The major cations (Na, K, Mg, Ca) and chloride increase in the same way as conductivity. Figures 4.9 - 4.12 show observed changes in selected ions with depth. Observed pH also decreases, from 7.6 - 8.1

Figure 4.7. Variation of water temperature with depth in samples taken for analysis

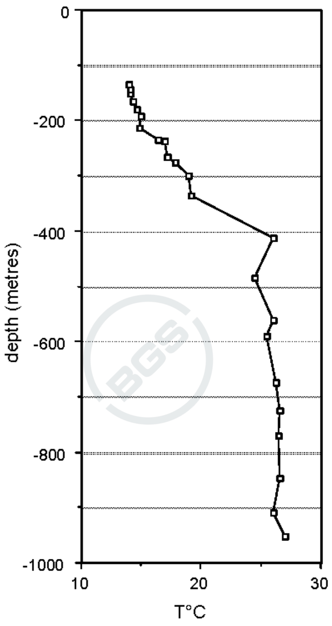


Figure 4.8. Comparison of electrical conductivity observed on site and on samples taken for analysis

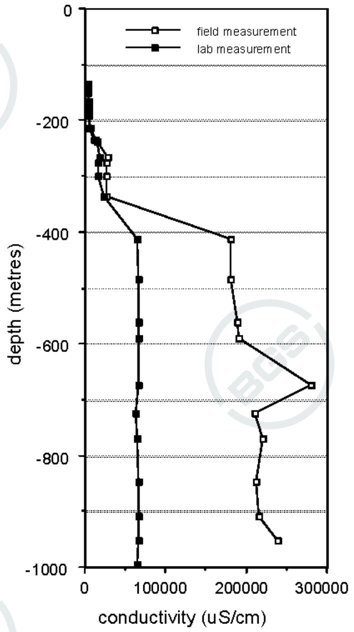


Figure 4.9. Variation with depth in observed water pH for samples taken for analysis

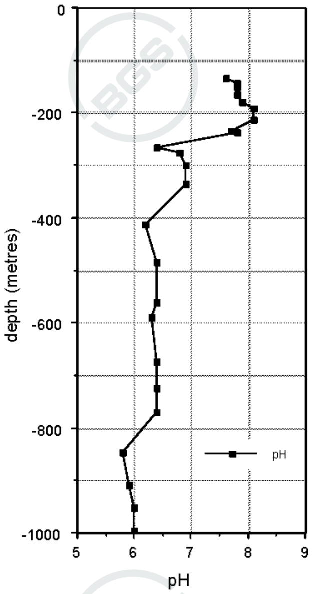
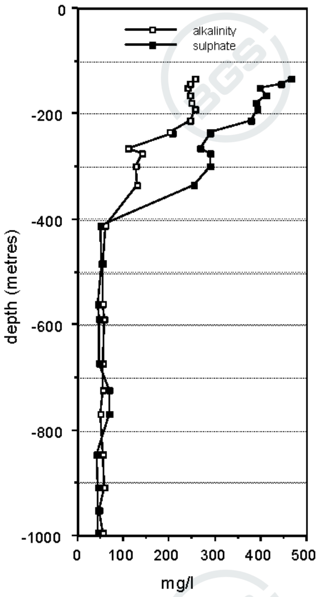


Figure 4.10. Variation with depth in alkalinity (mg/l $CaCO_3$) and sulphate



to 5.8 - 6.0, probably reflecting the absence of bicarbonate buffering at depth: alkalinity (expressed as mg/l $CaCO_3$) decreases with depth to very low values, as does dissolved sulphate. Figure 4.11 shows that calcium, sodium and chloride increase gradually downhole, with a sudden increase once the 410 m feeder had been accessed; similar patterns are observed for lithium and strontium (Figure 4.12).

The constancy of the chemical composition of the water below 400 m reflects a combination of two possible causes:

- The water column within the hole is well mixed as a consequence of the drilling operation.

- The contribution of water from the fissure at 410 m is sufficiently strong to dominate water chemistry during drilling.

There is no evidence from the water chemistry of any substantial flow of more saline (i.e. deeper sourced) or less saline (i.e. derived from nearer the surface) water into the hole at depths greater than 410 m.

Figure 4.11. Variations with depth in calcium, sodium and chloride (mg/l)

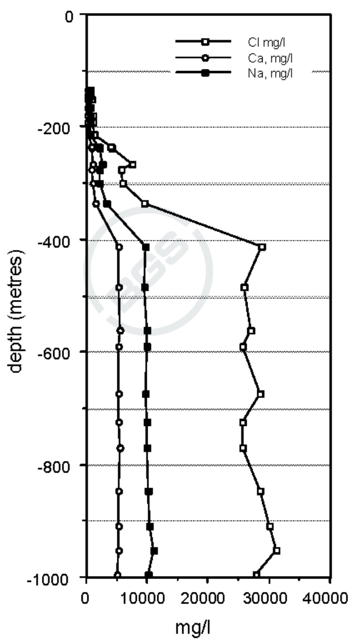
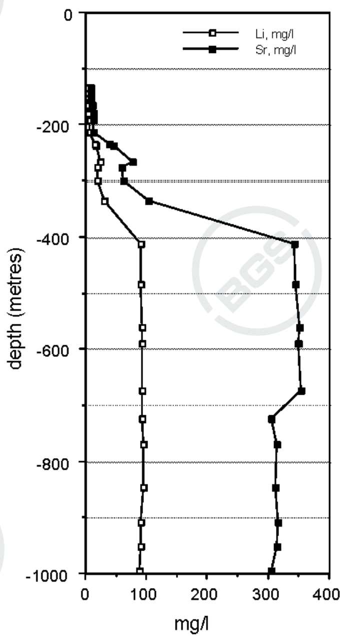


Figure 4.12. Variations with depth in lithium and strontium (mg/l)



Water compositions clearly show evidence of mixing between shallow components and a single deep brine, with minimum salinity of 27700 mg/l chloride, 10030 mg/l sodium and 5320 mg/l calcium. The composition of this brine is summarised in Table 4.1, where it is compared with water recovered from the nearby Cambokeels mine when it was operational (Manning and Strutt, 1990[7]). There is little doubt that, more than 15 years after the brine was sampled in the mine, the Eastgate borehole has intersected the same water system where it is deeper, more saline and warmer.

Importantly, the Eastgate borehole water is about 25% more saline than seawater, but less than half (36%) the salinity of the water currently produced at the Southampton geothermal plant. The Eastgate water contains amounts of transition metals that are below detection (but may be present in suspended solids generated during drilling).

Using the chemical data given in Table 4.1, temperatures at which the water may have equilibrated can be estimated (Table 4.2[8]). The quartz geothermometer gives a temperature of 38°C (which is below the observed bottom-hole temperature of 46°C), whereas the alkali geothermometers give more credible temperatures from 146 - 191 °C. These temperatures agree very closely with those calculated by Manning and Strutt (1990[8]). What this means is that it is quite likely that the water has lost silica by precipitation of quartz close to the surface and possibly in the recent geological past (quartz precipitation is abundant within fractures in the Slitt Vein). The alkali geothermometers suggest that the water picked up its dissolved solids at depths of 3-4 km (assuming a geothermal gradient of 40°C/km). This is evidence to suggest that the water in the borehole forms part of a deep circulation system, which appears still to be active given the similarity of the water to that encountered at Cambokeels between 15 and 20 years ago.

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[7] Manning, D. A. C. and Strutt, D. W. 1990 Metallogenetic significance of a North Pennine springwater. Mineralogical Magazine 54, 629-636.

[8] Truesdell, A. H. 1984 Chemical geothermometers for geothermal exploration. In: Fluid-mineral equilibria in hydrothermal systems (Henley, R. W., Truesdell, A. H. and Barton, P. B. eds.) Reviews in Economic Geology 1, 31-44 (Society of Economic Geologists).

Table 4.1. Water compositions for samples taken from the Eastgate borehole (mean of 10 samples below 400 m), compared with analyses reported for water from Cambokeels mine (Manning and Strutt, 1990)[7], from the Southampton geothermal project (Downing and Gray, 1986)[3], and for seawater.

Parameter	Units	Eastgate deep brine	Cambokeels mine water 1988	Southampton geothermal water	Seawater
Temperature	°C	26.1	16	76	
Electrical conductivity	µS/cm	65591			
Discharge	m^3/day	1600		1700	
pH		6.2		6	
Alkalinity	mg/l	55		62	
Sodium	mg/l	10028	7345	41300	10760
Potassium	mg/l	660	340	705	399
Magnesium	mg/l	73.8	121	752	1294
Calcium	mg/l	5323	5236	4240	412
Ammonium	mg/l	11.2		36	
Iron	mg/l	<0.1		4.1	
Manganese	mg/l	<0.1		1.26	
Zinc	mg/l	<0.1			
Copper	mg/l	<0.1			
Lead	mg/l	<0.2			
Lithium	mg/l	92.4	70.5	31	
Strontium	mg/l	328		134	7.9
Barium	mg/l	12.9		0.52	
Silica (SiO2)	mg/l	9.6		32.1	
Chloride	mg/l	27692	24600	75900	19350
Sulphate	mg/l	50.1		1230	2712
Nitrate	mg/l	<5			
Bromide	mg/l	146		91	67
TDS	mg/l	44482	37713	124440	35000
		10 samples			

Table 4.2. Temperatures derived from borehole water compositions using chemical geothermometers (explained in Truesdell, 1984)[8]

Geothermometer	Temperature (°C)	
	Eastgate	**Cambokeels**
Quartz	38	43
NaK (Fournier)	184	169
NaK (Truesdell)	146	129
NaKCa	191	159

4.5 Geothermal potential

It was the geophysical logging of the settled water column in the borehole, three days after the end of drilling, which gave the best indication of the magnitude of the geothermal resource potentially developable in this vicinity. The bottom hole temperature at 995 m was 46.2°C. To put this value in perspective, at UK sites with only average geothermal potential, one would have predicted a bottom hole temperature in the range 30 – 35°C. The elevated bottom hole temperature is the clearest credential of the magnitude of the heat resource at this site. As the geothermal gradient is likely to continue on the same linear trend as logged from 411 m to 995 m, the implication of the measured bottom-hole temperature at 995 m is that a borehole sunk to a typical "production" depth of about 1800 m would be expected to return a bottom-hole temperature in the range 75 – 80°C.

Having already established (Section 4.2) that the heat production capacity of the Weardale Granite at Eastgate is similar to that previously calculated from Rookhope Borehole granite cores, the key issues relate to the availability of natural groundwater to act as a transmission fluid for heat produced in the granite at various distances from the borehole. The extraordinary transmissivity of the major fracture at around 410 m below ground level provides unequivocal evidence of the association of highly permeable fractures with the Slitt Vein structure. While the deeper fractures were not quite so permeable, the indications from geophysical logging (Section 4.3) are that they are still significant water-bearing structures. The occurrence of significant permeable fractures at depth means that, in contrast to the usual assumption that similar UK granites are (at best) HDR prospects (Downing and Gray 1986)[3], the fracturing associated with the Slitt Vein renders the system sufficiently well-endowed with native groundwater (itself displaying a chemistry which betrays high temperature origins; Section 4.4) that the need to artificially introduce water to the geological environment is highly unlikely ever to be needed at this site. Instead of an HDR prospect, therefore, the Eastgate resource may be classified as a "low-enthalpy hydrogeothermal resource hosted in vein-bearing granites". This is a category of geothermal resource never previously described in the UK (cf. Downing and Gray 1986[3]; R A Downing, *personal communication*, 2004), nor elsewhere for that matter.

To develop these considerations further, Table 4.3 compares aspects of the Eastgate Exploration Borehole with a "traditional" low-enthalpy aquifer resource (the Southampton system, operating since 1986) and the planned Aachen system (borehole completed at 2500m on 22 November 2004). The Southampton geothermal system is a far better analogue for Eastgate than Aachen, given that the amount of water that may be produced from Eastgate is very similar. The Eastgate water has the advantage that it is much less saline than the Southampton water (44500 mg/l TDS compared with 124440 mg/l TDS at Southampton).

Table 4.3. Comparison of aspects of the Eastgate Exploration Borehole with the existing production facility at Southampton and the planned system at Aachen.

	Eastgate (existing borehole only)	**Southampton**	**Aachen (expected)**
Temp (°C)	27 (bulk, mixed water in late stages of drilling) 46 (bottom hole temperature)	76 (water)	70 (water) 85 (rock)
Depth (km)	1	2	2.5
Yield (m^3/day)	> 1600	860 (originally 2330 in 1987)	injected
Salinity (mg/l)	44500	124500	Nil
Heat output (MW_{th})	~ 0.75	2	0.45

Given the findings from the Eastgate exploration borehole, it is reasonable to predict that a further borehole sunk to 1800 m could provide a resource similar in magnitude to that at Southampton. However, because the Southampton borehole was drilled to intersect a more-or-less horizontal aquifer unit at the target depth, a production borehole at Eastgate would need to intersect fractures associated with the Slitt Vein at the target depth. From the experience of drilling this exploration borehole, it is unlikely that a depth of 1800 m could be reached without intersecting a number of shallower fractures carrying cooler water. Allowance for a further casing run close to the total depth would therefore be needed, so that shallower feeders could be cased-off. This would be both the most significant engineering challenge and the most significant risk element in proceeding to full production operations at Eastgate. However, further analysis of fracture frequency data from the geophysical logs should allow some quantification of the risks prior to final commitments being made.

5. TECHNOLOGY OPTIONS

The borehole has proven the existence of a hydrogeothermal resource at the Lafarge site, as described in Section 4. At this stage, there are two options for the exploitation of this resource as part of a redevelopment of the site. These are discussed below.

5.1 Option A – use existing borehole

"Warm water, low volume"

The existing borehole could supply warm water for use on site. This water would then require disposal, probably after treatment. This may limit the volume of water than can be used.

The composition, temperature and flow could suit use for a "hot springs" development, where low volumes of warm saline water are typically used. The geothermal water resource from the existing borehole could potentially supply bathing pool(s) with a total volume of several hundred cubic metres. This is described further in Appendix A. Depending on confirmation of the commercial viability of a hot springs development, this may be the most valuable use of the existing borehole.

The existing resource could also be used for space heating in new buildings in "ground-source heat" mode (by means of pipes embedded in a floor slab). This would be feasible using the water at the present temperature of 27°C. Such a use would be likely to require integration with the biomass-fuelled heating system being discussed for the site.

The feasibility of Option A will depend on the following uncertainties being satisfactorily resolved:

- Available warm water flow

  The water available from the current borehole is at 27°C. This temperature is typical of swimming pools, although at the cooler end of the temperature range used for spas and hot springs. If warmer water were required, it would be possible (with further funding) to temporarily seal off the 411 m feeder using inflatable packers, to allow direct testing of the temperature and volume of warmer water from deeper sources.

- Composition

  Further work will be necessary to determine the suitability for bathing purposes of the waters already encountered (including any pre-treatment that might be needed to remove specific cations, such as barium), and to evaluate treatment requirements prior to disposal.

- Water disposal

  A route for water disposal needs to be established. The salinity of the water is such that any disposal into the river during dry periods would need to be at low levels to allow sufficient dilution. Acceptable dilution levels would need to be agreed with the EA as part of the discharge consenting process. If treatment of the water prior to disposal is required (as seems likely) technologies to do this need to be identified.

- Sustainable abstraction rate

  Pumping of water from the borehole will require an abstraction licence from the EA. Test pumping data will be required to support any licence application, and to demonstrate the sustainable rate of water extraction (although indications from the air-lift test at the end of pumping shows that a large quantity of water (>1600 m^3/d) is available).

All equipment used will need to have appropriate corrosion resistance to handle the salinity of the water.

5.2 Option B - deepen existing borehole or drill further production borehole

"Hot water, high volume"

Greater volumes of water, at higher (and therefore more useful) temperatures could be made available by deepening the existing borehole or drilling a further production borehole. The second of these would be preferable, as it would allow the existing exploration borehole to be used for re-injection of water, removing disposal as a limitation on usable water volume. Any second borehole should be designed to be drilled to a greater depth, thus accessing a higher temperature resource. For example, the geothermal gradient predicts a temperature of 70°C at 1525 m depth, which would allow a wide range of space heating uses (e.g. as used in the Southampton district heating system).

The key uncertainties with this option are:

- Water sources at greater depth

  There is no guarantee that more water will be found at greater depths. Results to date, however, suggest that significant water sources exist at many levels in and around the Slitt Vein structure, so that it would be reasonable to expect to find fairly prolific sources of hot water at greater depth.

- Water re-injection

  Injection of water into boreholes is always more difficult than pumping it out, mainly because of the limited scope for raising head before the well overflows. A reasonable amount of head-room exists in the exploration borehole, but some testing of the capacity of the hole to receive water will be needed. It should be noted that, although the current head-room of 14 m might impose a limitation on the achievable rates of injection, it ought to be possible to significantly increase available head-room by feeding water to the re-injection well via a storage tank located some distance uphill from the existing wellhead, which would need to be pressure-sealed.

5.3 A hybrid approach

Options A and B are not mutually exclusive. Option A could be used as a first stage while Option B is developed. Both options could eventually run in series, with hot water first supplying building heat, then being used in the hot springs before re-injection back into the ground.

5.4 Resource location

The existing borehole has been drilled at the western extremity of Lafarge's landholding in order to intersect the Slitt Vein, which has now been proven as the conduit for water flows in the Weardale granite. The successful result of this borehole means that any future holes are likely to be drilled in the same area. The geothermal water resource is therefore located approximately 1 km from the main works site where it would be used. It would be possible to locate a second borehole a little closer to the cement works site by siting it to the southeast of the exploration borehole site along the strike of the Slitt Vein. The gains in proximity, however, would be outweighed by losses in ease of site access on the hillslopes to the south of the minor road. Appendix B provides a map indicating the locations involved.

Pipeline transfer of geothermal fluids is widely employed elsewhere (see Section 5.6), often over considerable distances. Pipes may be insulated or uninsulated, depending on the cost of insulation versus the savings through reduced heat loss. Above ground or buried pipes may be used, the latter being more expensive to install and maintain but having lower visual impact, some inherent insulation and a reduced risk of damage. The type of pipeline used for the Eastgate project will need to be determined as part of the detailed system design. It should be noted that the pipeline will need to cross the river Wear – there may be an opportunity to use any new crossings in the overall site redevelopment to carry the geothermal pipeline.

Temperature loss during transfer is not likely to be significant for this project. Assuming 50m^3/h of water at 27°C pumped over 1000 m, the temperature drop from a buried, insulated pipe will be less than 0.5°C[9].

5.5 Energy balances

The heat extracted using either option depends on the use to which the water is put, as well as on the volume and temperature available from the borehole(s). For Option A, useful heat extracted is likely to be a few hundred kilowatts (kW), while for Option B several megawatts (MW) could be available.

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[9] Using method of Rafferty, Chapter 10 of "Geothermal Direct Use Engineering & Design Guidelines", from http://geoheat.oit.edu/pdf/pdfindex.htm

Both options will require the use of electrical power to pump water out of the borehole. The power required depends on the water volume pumped and the head lift against which pumping would need to be sustained. Neither of these values can be absolutely confirmed at present, but using an example for Option A of 50 m^3/h of water pumped from a depth of 50 metres (a pessimistic assumption, given the current standing water level in the borehole), the power needed would only be of the order of 10 kilowatts.

Electrical energy will also be required to pump the water from the borehole to its use on the works site. Assuming 50 m^3/h pumped over a distance of 1000 metres, the energy requirement will be of a similar order of magnitude to that required to pump the water from the borehole.

This is significantly less than the useful heat output i.e. the project would have a positive balance of energy output to energy input. Electrical power for pumping could be readily supplied by the renewable electricity projects proposed elsewhere on the Lafarge site.

5.6 Comparison with the Southampton experience

As Section 4.5 and Table 4.3 made clear, the existing geothermal energy exploitation system in Southampton, although rather different in geological setting, has a number similarities to the possible full-scale use envisaged for Eastgate. As an aid to option selection in the Eastgate case, therefore, it is apposite to consider a number of similarities and contrasts between the two cases.

Since 1987 the Southampton geothermal production well has provided some 2 MW of heat capacity. It was the first element of what is now a multi-source combined heat and power (CHP) operation, providing some 26 MW in the western half of Southampton city centre. The first consumers to be attached to this system were the (large, draughty and palatial) 19th Century civic centre buildings, plus educational premises belonging to the Southampton Institute. Between them, these building consumed the entire 2 MW of heat provided in the form of hot water, which is used both for conventional wet radiator systems and for feeding hot water tanks. ***In the Eastgate case*** it would make more sense to use underfloor heating systems, which are far more efficient than wet radiators, and additional building insulation to the highest modern standards (as dictated by building regulations).

The Southampton production well has a minimum internal diameter of 250 mm, and a rest water level some 150 m below ground level. Given these characteristics, a deep well turbine pump has to be used to extract the required 10 l/s (the flow was originally 27 l/s for the same drawdown in 1987). The high lift and the high salinity of the water (see Table 4.3) have led to frequent problems with pump performance; given the depth of installation and the type of pump, maintenance is relatively expensive. ***In the Eastgate case*** the current rest water level is only 14 m below ground, and although a decline (in line with Theisian theory) would be expected were the borehole pumped at typical production rates, lifts in excess of a few tens of metres are unlikely. This means that a cheaper, more readily repairable electric submersible pump could be used, rendering considerable savings in maintenance costs compared to the Southampton case.

The saline groundwater pumped from the Southampton borehole has an ambient temperature of around 74°C, which is lowered to about 50 – 55°C on passing through a titanium plate heat-exchanger. The spent saline water is discharged to the sea. The clean 'town water' into which the heat is transferred leaves the heat exchanger at about 70°C; it is then passed through an absorption heat pump which raises its temperature to a little in excess of 80°C, which is the guaranteed delivery temperature to consumers. The use of an absorption pump has the advantage that the same plant can also be used to drive the district chilling system. The Southampton system currently has 19 km of heating mains and around 9 km of chilling mains. Heat losses in the heating mains (which are constructed using state-of-the-art insulated pipes with leakage detection implants) amount to only 0.2°C per km. ***In the Eastgate case***, although a raw water temperature as high as 78°C should be achievable without drilling beyond the depth of the Southampton borehole, the operating temperature to customers for heating purposes could be as low as 50°C (for underfloor heating systems in new buildings), which implies that the rejection temperature for the brine at Southampton retains residual value given suitable target premises. Discharge of saline water is more of an issue here than in Southampton, as previously discussed. District chilling may not be in such great demand here as in Southampton either, but should not be dismissed out of hand. Distances for transmission of hot water are not so great in this case as in Southampton.

Overall, Eastgate offers as many advantages as disadvantages when compared with the Southampton system, which is greatly encouraging in relation to future developments.

5.7 Next steps

At this stage, we consider that the immediate next steps are those required to confirm the feasibility of Option A, namely:

- Conduct a pumping test both with and without the 410 metre feeder, to establish the sustainable pumping rate and temperature.
- Establish bathing suitability and disposal options from the detailed water composition.
- Identify technology options for water treatment.

APPENDIX A – SIZE ESTIMATE FOR A HOT SPRINGS DEVELOPMENT SUPPLIED BY THE EXISTING BOREHOLE

The size of any bathing pools supplied by the existing borehole (under Option A) will be determined by the volume and temperature of water available. The calculation below is an example, based on the following assumptions

- A flow of 50 m^3/h at 27°C is sustainable (reasonable given observations to date).
- The pool(s) operate a flow-through process, with "used" water continually removed and replaced with fresh water from the borehole i.e. there is no recirculation of water.

A certain turnover of water is required for hygiene reasons. If a complete change of water is required every 7.5 hours[10], a flow of 50 m^3/h could supply pool(s) with a total volume of 375m^3. This represents, for example, a single pool of 25 m x 10 m x 1.5 m.

The water flow through the pool(s) will also need to be sufficient to maintain pool temperature. Assuming the pool walls are well insulated, the major heat loss will be from the surface. Heat loss from a pool surface can be estimated from

$$Q = U\ A\ \Delta t_1 \qquad \text{(equation 1)}$$

where Q = heat loss, kJ/h

U = surface heat transfer coefficient, estimated as 214 kJ/(h m^2 °C) [10]

A = pool surface area, m^2

Δt_1 = (pool temperature – ambient temperature), °C

Taking a pool surface of 250 m^2 and an ambient temperature of 10°C, heat loss is

$$Q = 214 \times 250 \times (27 - 10) = 909{,}500 \text{ kJ/h} = 253 \text{ kW}$$

This is the heat that new water will need to add to the pool, which is also defined by

$$Q_{in} = m\ c\ \Delta t_2 \qquad \text{(equation 2)}$$

where Q_{in} = heat lost by new water, kW

m = mass flow of new water, kg/s

c = heat capacity of water, approx. 4.2 kJ/(kg.°C)

Δt_2 = (inlet temperature – outlet temperature), °C

With Q_{in} equal to 253 kW and a mass flow of 14 kg/s (equivalent to 50 m^3/h), equation 2 gives Δt_2 = 4°C and an outlet temperature of 23°C.

The actual pool temperature will therefore be in the range 23 - 27 °C. Temperature loss could be reduced by enclosing some or all of the pool area.

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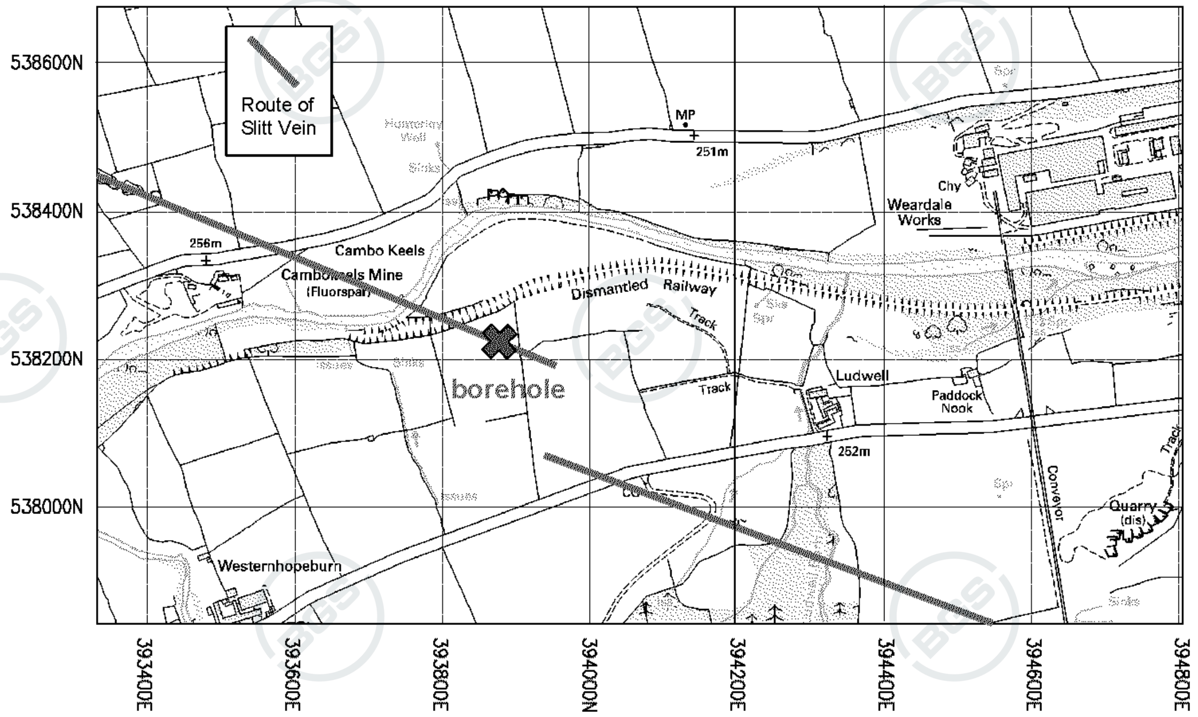
[10] Lund, J.W., "Balneological Use of Thermal Waters", Geo-Heat Center, Oregon, USA, http://geoheat.oit.edu/

APPENDIX B – BOREHOLE LOCATION RELATIVE TO WORKS SITE

Figure B1: location of borehole relative to works site



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APPENDIX C – FULL BOREHOLE LOG RECORDS (CUTTINGS LOG; RECORDS OF FRACTURE ZONES AND WATER STRIKES)

C1. Cuttings log

This section provides the full text of the cuttings log for the borehole. Abbreviations used in the descriptions are as follows:

ang	**angular**
bk	**black**
bn	**brown**
chl	**chlorite**
cpt	**chalcopyrite**
dk	**dark**
dol	**dolerite**
f	**fine**
fc	**fireclay**
fgr	**fine grained**
frag	**fragment**
gy	**grey**
incl	**including**
lst	**limestone**
mic	**micaceous (i.e. noticeable mica)**
ms	**mudstone**
nmic	**non-micaceous (i.e. no mica observed)**
occ	**occasional**
py	**pyrite**
Q	**quartz**
rndd	**rounded (cuttings/cavings)**
se	**seatearth**
ss	**sandstone**
tr	**trace**
vn	**vein**
vnlts	**veinlets**
xtal	**crystals**
xtalline	**crystalline**

Table C1: Cuttings log

SITE:	**EASTGATE GEOTHERMAL BOREHOLE**		
CONTRACTOR:	**Foraco SAS**	**DATE STARTED:**	**26 August 2004**
LOGGED BY:	**F W Smith (FWSC Ltd)**	**DATE ENDED:**	**December 2004**
TABLE HEIGHT:	**0.94 m above ground level (251.81 m AOD)**		
CO-ORDINATES:	**393 890.93E 538 200.15N**	**GROUND LEVEL:**	**250.87 m AOD**
SAMPLE DEPTH (METRES BELOW TABLE)	**CUTTINGS LOG**		**KEY STRATA**
-	Driller reported superficial deposits and broken ground to 4 m		Drift to ca. 4 m
4	Hole caving. 60% ss. wh. fgr. nmic. ang; 40% lst. gy. mostly rounded; very muddy		
5	Hole caving. 40% ss. wh. fgr. nmic. ang; 40% lst. gy. ang; 20% lst. gy. Rounded		
6	Hole caving. 40% lst. gy. ang; 30-40% ss. wh. nmic. ang; 20% lst, gy. rounded; single frag. lst. with py. vnlts		
7	Hole caving. as above. 40% lst; 40% ss; 20% lst. rndd		
8	Hole caving. 50% ss. wh. + bn. fgr. nmic; 30% lst. gy. ang; 20% lst. gy. Rndd		
9	Hole caving. 60% lst. gy; 40% ss. wh.+bn. fgr. nmic; very clayey		
10	Good returns. 80% lst. pgy; 20% ss. fgr. bn		
11	70% lst. gy; 30% ss. wh. fgr; Tr. silicified sh. w. py		
12	70% lst. (30% gy; 40% dk gy.); 30% caved ss; Tr. xtalline. Q with flecks ankerite; very clayey		Base Scar Limestone 12 m
13	30% lst; 30% ss. wh; 40% cavings; Tr. dkgy. ms; Tr xtalline Q		
14	Good returns. 60% ss. wh. fgr. nmic; 30% lst. gy; 10% ms		
15	70% ss. wh. fgr. nmic; 20% ms; 10% lst. gy; single tr. py		
16	70% ss. wh. fgr. nmic; 20% ms; 10% lst. gy		
17	95% ss. wh. fgr. nmic; 5% ms. and lst; Tr. chalcedonic Q		
18	60% lst., gy; 30% ss. bn. + wh. fgr; 5% ms; very clayey; 2% Q with trs. py. - could include cavings or washout?		
19	60% pgy. fc. ms. roots; 30-40% lst; 10% ss. wh. fgr		
20	50% pgy. fc. ms. roots; 30% ss. wh. fgr; 20% lst. dkgy. Tr. calc. vnlts		
21	80% lst. pgy. fgr. partly silicified; 20% pgy. fc. ms. Tr. Q occ. assoc. with py		
22	80% ms. dkgy. silicified; 20% ms. dkgy; Q vnlts; Tr. py		
23	95% ms. gy; 2-3% ss. dkgy. fgr; 2-3% Q vnlts; py. spotting in ms		

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
24	75-80% lst. Dkgy; 10% ms. Dkgy; 10-15% Q finely xtalline, probably as vnlts; py. Spotting in ms; possible coal trace – floated off from cuttings	Cockleshell Limestone ca. 23.5 to 24.5 m
25	30% pgy. Fc. Ms. Roots; 20% ms. Gy; 45% silicified dkgy. Ms. Spotted with py; 5% Q (finely xtalline) and chalcedony	
26	70% ms. Gy. Some roots; 30% ss. Dkgy. Fgr. Nmic; 1% Q white; rare Tr. Py	
27	95% ms. Dkgy. Slightly shaly; Tr. Q + py vnlts	
28	90% ss. F. to med. Gr. Gy to dkgy and very micaceous; 10% Q vnlts; occ. Pieces py up to 8 mm	
29	50% ss. Gy. Fgr. Nmic; 50% ms. Dkgy. Shaly; Tr. Q vnlts	
30	90-95% ms. Dkgy, shaly, carbonaceous; 5% ss. Gy. Fgr; 2-3% Q vnlts	
31	70% ms. Dkgy. Shaly w. occ. Py. Spotting and xtals; 25% ss. Gy to pale gy., fgr; 5% Q white vnlts. Containing py. Traces; NB. Some acid reaction from fine material, possible lst traces	Single Post (?) horizon at 31 m
32	80% ss. Wh. F. to med. Gr. Slightly mic; 20% ms. Dkgy. Shaly; rare Tr. Q; rare Tr. Py	
33	70-75% ss. Wh. Fgr. Slightly mic; 25% ss. Dkgy. Fgr. With Q vnlts. + py; Tr Q wh; Tr. Py; say 2-3% Q in total	
34	Typical grey beds. 60% ss. Gy. Shaly, mic; 40% ms. Silty, shaly, mic; 1% Q + py	
35	75% ss. Gy. Shaly, mic; 20% ms. Silty, shaly, mic; 5-10% Q vnlts with py. Trs	
36	85% sh. Gy. Mic. Sandy with siltstone laminae; 10-15% Q as vnlts. And replacement, trs. Calcite, some vuggy siderite (xtal. Terminations)	
37	95% ms. Dkgy. Shaly, slightly mic; 5% ss. Shaly, dkgy. Mic; up to 1% Q as vnlts and replacement; Tr. Py	
38	98% ms. Dkgy. Shaly; ca. 1% Q as vnlts and replacement; Tr. Py	
39	90% ms. Dkgy; 2-3% py; Tr. Q vnlts	
40	60% lst. Gy; 20% ms. Dkgy; 10-15% Q; 4-5% py	Top Tynebottom Limestone at ca. 39.5 m
41	90% dkgy. Silicified fgr. Rock (no acid reaction); 5% Q vnlts. And gy. Replacement; Tr. Py; Tr. Calc	
42	70% lst. Gy. (strong acid reaction); 10% ms. Dkgy; 20% Q vnlts; Tr. Py; single frag. Ankerite	
43	50% lst. Gy. Silicified; 10-20% ms. Dkgy; 30-40% Q vnlt and replacement incl. trs. Py; Tr. Sparry calc	(replaced and veined by quartz throughout)

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
44	75% Q wh. + clear vn. And gy. Replacement, some xtal terminations/vughs; 5% ankerite; 20% totally silicified rock, dkgy, mostly lst or sh, tr. Fgr. Ss; Tr. Py	
45	60% Q mostly gy replacement w. occ. Vnlts. Ankerite; 40% pale + dkgy. Totally silicified rock indeterminate; very rare py trs	
46	60% dkgy. Silicified lst. (occ. Weak acid reaction); 40% Q mostly gy. Replacement with some wh. Vnlt. Q; occ. Trs. Py contained in Q with some later py. Vnlts. Cross-cutting Q	
47	70% Q mixture gy replacement variety w. massive wh. Q and clear vuggy Q; 30% dkgy. Silicified rock – looks like dk. Mst; up to 2 or 3% ankerite; occ. Fgr. Py. Trs. Driller reported strong influx of water at 47 m below table	
48	60% Q (as 47 m); 40% mixture ss. Wh. Fgr. Nmic. And ms. Gy. Shaly	
49	60% Q, mostly gy. Replacement, some white vn. Q, tr. Clear vuggy Q; 30% dkgy. Silicified rock; (10% dk. Ms. Caving); some py . Tr. Ankerite; weak acid reaction but mostly from vn. Carb. – the gy. Rock is unreactive	
50	70% dkgy. Silicified rock, veined and replaced by Q. + py. And spotted with py; resembles fgr. Lst. But no acid reaction; 30% Q gy. Replacement and chalcedony; minor wh. Vn. Q including py; tr calcite	
51	80% gy. Silicified lst; 20% Q mostly vnlt, some gy replacement; trs. Calcite and ankerite NB: Some lumps (up to 5 cm) of silicified/Q veined limestone flushed from Tynebottom section and continued to appear as cavings later	Base Tynebottom Limestone at ca. 51.5 m
52	95% ms. Dkgy, with occ. Py. (max. 1%)	
53	80% ms. Dkgy; 20% py; tr. Q	
54	80% silicified dkgy. Ms. And black ms. And possibly lst. (but no acid reaction); 20% Q vnlt incl. py. And ankerite; Trs. Py	
55	95% Q massive wh. And glassy vein material; tr. Py; a few cuttings of fireclay + dk. Ms	
56	95% black silicified rock, fgr. Resembles ms; 5% Q mixed gy. Replacement and wh. Vnlt. With associated ankerite; Trs. Py. And py spots in silic. Rock	
57	70% Q mostly wh. And clear vein and vug varieties; 30% ss. Wh. Fgr. Veined and replaced by Q; 10% dkgy ms; trs. Py	
58	60-70% ss. Wh. Fgr. Veined and replaced by Q; 30-40% Q. wh; tr. Py	
59	80-85% ms. Dkgy; 10-20% Q mostly wh. Vnlts., occ. Gry replacement; tr. Py	
60	90% lst. Dkgy. Fgr; 5-10% Q vnlts	
61	80% lst. Silicified, gy. Fgr; 20% Q vnlts. With occ. Ankerite	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
62	80% ms. Dkgy. Silicified, with little diagenetic nodules and occ. Q vnlts; 10% ms. Pale gy. Sandy; tr. Lst; tr. Py	
63	75% ss. Gy. Fgr. Nmic. Silicified/replaced in parts; 15-20% Q vnlts and replacement, associated w. py. And ankerite; 5% py; 5% cavings	
64	70% ms. Silicified, dkgy; 20% py; 10% Q vnlts; tr. Ankerite	
65	80% Q gy. Replacement variety (and remnants of silicified wh. Ss?); 10% Q wh. Vnlts; 10% cavings of lumpy silicified rock; no pyrite	
66	50% ss. Wh. Silicified; 40% Q grey replacement and wh. Vnlt. Varieties; 10% cavings (lumpy mineralised rock – mostly silicified limestone); tr. Py. (probably caved)	
67	95% Q mixed gy. Replacement and wh. Vein variety; tr. Silicified wh. Ss; 5% cavings; no py	
68	As 67 m	
69	80% Q. wh. + gy; 20% ss. Wh. Silicified; trs. Py	
70	80% Q mostly wh. Vein Q; 20% ss. Silicified, wh. Fgr.; tr. Py; tr. Ankerite	
71	80% Q mostly wh. Vein Q; 20% black silicified rock resembles ms; tr. Py; tr. Brown carbonate	
72	60% black silicified rock, weakly bedded, probably ms; 40% Q vnlts. W. to pg. And carbonate; ? tr blende	
73	80% ms. Dkgy. Silicified, slightly shaly; 20% Q vnlts. W. prominent blende	
74	As 73 m	
75	95% ms. Dkgy. Shaly; 5-10% Q vnlts. W. trs. Blende	
76	40% ms. Dkgy. Shaly; 40% lst. Pale gy. 20% Q vnlts w. py. + blende; trs. Ankerite	Top of Jew Limestone at 76 m
77	60% lst. Black, crinoidal; 30% Q vnlts. W. occ. Ankerite; 10% rocky cavings	
78	70% lst. (50% gy, 20% black and silicified); 30% Q wh. Vnlts; tr. Py	
79	80% lst. (60% gy, 20% black silicified); 20% Q wh. Vnlts; tr. Py. Replacing lst	
80	As 79 m; Q vnlts. Up to 10 mm wide, with clear xtals. Some vuggy Q w. xtal terminations	
81	95% lst dkgy, shelly traces; 5% Q + py vnlts or gy. Replacement Q; fine (0.5 mm) py. Flecks throughout the lst	
82	95% lst. Gy. Bioclastic; 5% Q vnlts; occ. Py. Flecks (0.5 mm max.) in lstn; tr. Black shale - ?cavings	
83	70% lst. Pale grey to white; crystalline, intensely silicified and replaced with Q; 30% Q vnlts	Base Jew Limestone at ca. 83 m

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
84	VEIN 65% fluorite, glassy, white/colourless verging to pale green; 30% Q xtalline, white and colourless, occ. Small terminations; 1-2% calcite with vuggy nailhead spar; tr. Galena; tr. Py; tr. Ms. (?cavings)	Fluorspar vein 83 to 87 m
85	VEIN 95% fluorite, glassy, mostly very pale green with minor very pale purple – probably massive vein infill, no visible xtal. Faces; some galena (max. 1%); tr. Blende (v. fine gr.); tr. Black silicified rock (?cavings) NB. Yellowish green putty-like clay reported from around 84-85 m (not represented in the samples of cuttings)	
86	VEIN 95% fluorite, glassy, mostly very pale green, trs. Pale purple; occ. Calcite and ankerite; tr. Galena + blende; probably massive vein infill; tr. Black silicified rock (?cavings)	
87	VEIN 90% fluorite as above; 5% Q white xtalline; tr. ?cpt; tr. Ankerite; probably massive vein infill; trs. Black silicified rock containing tr. Py. + cpt (?cavings); tr. Fireclay	
88	5-10% fireclay, pale grey; 60% ss. Pale gy, fgr. Uniform; 20% Q with py. + ?cpt; 5% fluorite (cavings); 5% indeterminate black silicified rock (?cavings)	
89	10% fireclay; 30% ss. Gy. Fgr. Partly silicified; 60% Q mostly wh. Vein Q with some gy. Chalcedonic replacement; tr. Calcite and brown carb; tr. Py	
90	60% Q well xtalline wh. + clear vein material; 30-40% black totally silicified rock resembles fgr. Lst. (but only very weak acid reaction from cuttings); 2-3% calcite; occ. Ankerite; tr. Py. And ?cpt; trs. Pale green chloritic rock	
91	80% Q xtalline, clear, glassy, some xtal terminations; 10-20% black very fine gr. Xtalline rock (indeterminate), no acid reaction; occ. Calcite; tr. Ankerite; tr. Pyrite; some cavings of fireclay, ms. And lst. Driller reported strong influx of water at 91 m below table NB: Flushed lump rock cavings (2-5 cm) of fractured, quartz-veined/silicified limestone in range 88-91 m suggestive of fracture zone	
92	50% ?ss. v. fgr. Pale gy/wh, siliceous patches, v. hard (almost indeterminate – such heavy alteration); 50% Q wh + glassy vein/vnlt with minor calc. And ankerite; 2-3% black silicified rock and shale (?cavings); tr. Py.	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
93	50% pale gy, fgr. Uniform ?white whin (no visible ferromags); 30% black shale (?cavings); 15% Q wh. Vnlts; 5% ankerite; tr. Py NB. Casing installed to 92.7 m – so black shale is likely to have caved during Installation	Top of Whin Sill at about 92 m (extensively carbonated from 94 m)
94	50% pale gy. Fgr. Uniform, silicified ?white whin; 40% Q wh. + glassy vnlts; 10% ankerite; rare tr. Py	
95	20% pale gy. Fgr. Uniform, ?white whin; 30% ms, dk yellowish green gy, hard, probably ferruginous (resembles clayband ironstone except for colour) – unlike anything cut so far, but still possibly cavings; 20% black shale (presumably cavings); 30% Q wh, coarse vnlts including 2-3% ankerite meshwork throughout the vnlts	
96	60% white clay and Q wh and glassy vnlts; 35-40% pale gy. Fgr. Silicified slightly speckled, ?white whin	
97	75% pale gr. Frg. White whin (ferromag. Phenocryst remnants becoming more obvious); 25% Q wh. Vnlt; 1% ankerite; white clay matrix	
98	80% white whin a/a; 20% Q; wh. Vnlts; tr. Ankerite; white clay matrix	
99	90% white whin a/a; 10% Q/calc/ankerite vnlts. Driller reported strong influx of water at 99 m below table	
100	90% dolerite (about 70% mid grey, 20% white whin); 10% Q, wh. + glassy vnlts NB. 99-100. Flushed some subrounded lumps of white whin up to 5 cm bounded with all-round fracture faces showing corroded/dissolved wh. Calc. Vnlts, and dusted by tiny py. Xtals. And some coarse clear calc. Xtals. Indicative of an open fracture zone	
101	90% dolerite, dk. Gn/gy, fgr; tr. Q vnlts; tr. Haematite	
102	98% dolerite, mid gy; tr. Q vnlts	
103	95% dolerite, mid gy; 5% Q vnlts, tr. Chlorite	
104	As 103	
105	As 103	
106	70% white whin, mottled pink, pale grey, and grey green; 30% Q vnlts	
107	90% dolerite, gy; 10% Q wh. Vnlts; tr. Chlorite	
108	95% dolerite, mid gy; 5% Q vnlts	
109	98% dolerite, mid gy; 2% calc. And ankerite vnlts	
110	As 109 + chlorite traces	
111	80% white whin, mottled pink and brown; 20% Q/calc./ankerite vnlts; tr. Py. Driller reported strong influx of water at 111 m below table	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
112	98% dolerite mottled gy. + dk. gy. green; 2% calcite and tr. Q; tr. Chlorite	
113	98% dolerite, dk. yellowish green gy; 2% calc. + Q tr	
114	As 113	
115	95% white whin, mottled pink and pale yellowish green grey; 5% calc. and ankerite vnlts; tr. Chlorite	
116	55% white whin (as 115), 40% white whin, pale yellowish green gy; 15% calc. vnlts; trs. Chlorite	
117	95% white whin, mostly mottled pink and pale yellowish green gy; 5% calc. + ?Q vnlts; chlorite tr	
118	80% dol. mid gy. fgr; 20% white whin, pink w. Q vnlts; 2-3% Q wh. + glassy; some lump dol. flushed with dusting of tiny Q xtals. on fracture faces	
119	95% dol. gy./dk gy. med gr.; 5% white whin, pink cut by 1% Q vnlts.	
120	99% dol. gy. med gr.; 1% white whin with Q vnlts	
121	as 120, pink hue	
122	70% white whin, white + pink; 20% dol. gy. fine/med gr.; 10% Q vnlts wh + glassy	
123	90% dol. gy. fine/med gr; 10% white whin, pink, cut by tr. Q vnlts	
124	60% dol. dk gy. fine/med gr; 40% white whin, pale grey; rare tr. Q vnlts	
125	80% white whin; 20% Q vnlts w. turquoise chlorite	
126	60% white whin; 20% dol. mid gy. fgr.; tr. Q vnlts w. turq.chl. (chl. is in the Q vnlts); flushed some lumps of dol	
127	as 126 (but no lump flushings)	
128	70% white whin; 30% dol. mid gy. f. gr.; tr Q/chl. vnlts	
129	white whin; tr. Q/chl. Vnlts	
130	90% white whin; 10% Q wh. + glassy vnlts. No chlorite	
131	85% dol. pale/mid gy. med gr.; 10% white whin, pinkish; 5% Q vnlts. wh. with tr. Chl	
132	95% dol. pale gy. med gr.; 5% Q vnlts. wh. with chl. trs.; tr py; possible tr. ankerite in Q vnlts	
133	90% white whin; 10% Q wh. Vnlts + replacement	
134	68% white whin; 35% dol. gy. fgr.; 5% Q wh. vnlts with tr. chl	
135	80% dol. gy. f/med gr; 20% white whin; tr. Q vnlts with green chl	
136	dol. f/med gr. gy/dk gy; tr. Q vnlts	
137	As 136	
138	60% white whin, pale gy.; 40% dol. f/med gr, gy/dk gy; tr. Q + turq. chl. vnlts	
139	70% white whin (no texture); 30% Q wh. vnlts + vein; trs. turq. chl.	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
140	80% white whin (spotted with ferromag remnants); 20% Q wh. Vnlts;trs. Chl	
141	75% white whin, slight yellow/green hue; 15% dol. Pale gy. F/med gr.; 10%Q wh. Vnlts w. chl.	
142	70% white whin, slight yellowish green yellow hue; 30% Q wh. Vnlts	
143	60-70% white whin, mottled with gy. Ferromag remnants; 30-40% Q wh. Vnlts	
144	as 143	
145	60% white whin, speckled white + pale gy.; 40% Q wh. Vnlts; tr. Ankerite	
146	75% Q wh. + glassy; 25% white whin, speckled as above	
147	60% white whin, speckled a/a; 40% Q wh. Vnlts. Possible rare ankerite trs.	
148	60% Q wh. With rare trs. Py. + ?ankerite; 40% white whin, speckled	
149	50% Q wh. With some calcite and ankerite; 50% white whin, speckled	
150	95% altered dol. Pale gy. Fgr.; 5% Q wh. Vnlts. With turq. Chlorite trs	
151	as 150 with py. Or cpt. Trs. In Q	
152	60% Q wh. + glassy, xtalline (including 5% ankerite overgrowing Q xtals) + ?cpt. trs.; 40% white whin, fgr	
153	70% white whin,/pale grey dol.; 30% Q wh. Vnlts; tr. Chlorite	
154	70% white whin, pale gy, speckled; 30% Q + py. Vnlts; tr. Turq chlorite in Q vnlts. (not assoc. w. py.)	
155	80% white whin, uniform, pale grey, vf gr.; 45% Q wh. With tr. Py	
156	55% white whin, uniform, pale grey, vf gr.; 45% Q wh. With tr. Py	
157	50% dol. Dk gy. F gr.; 50% dol. Pale grey, f gr.; tr. Q vnlts. – some larger lumps of dol. – possible fracture zone	
158	70% dol. Dk gy. Very f gr.; 30% dol. Pale gy. Vf gr.; tr. Calcite vnlts	Base Whin Sill at ca. 158.5 m
159	60% whetstone, pale gy. Vf gr. Bedding traces; 40% Q wh. + glassy vein/vnlt; flushed a lump of whetstone with calcite xtals on fracture face	
160	95% Q wh + glassy with trs py; 5 % indeterminate, pale grey silicified rock	
161	58 % Q wh + gy with occ. Py trs; 2 % ankerite with the Q; 40 % whetstone, very pale grey, uniform texture	
162	Q wh + glassy; tr py – massive vein material	
163	70 % Q wh +glassy, tr py; 30 % ms black silicified brecciated and intensely veined with Q; tr py replacing ms	
164	80 % Q;20 % ms (as 163 m)	
165	As 164	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
166	60 % silicified gy/dk gy. Probable 1st, brecciated + Q veined, coarser texture than black ms seen above; 40 % Q wh; tr calcite	Lower Little Limestone ca. 165.5 to 167.5 m
167	60% Q mostly wh + gy, some glassy + some calcite; 40% probable 1st black, v. fgr, intensely silicified, veined and brecciated. Driller reported strong influx of water at 167 m below table	
168	40% ss. Pale gy. Fgr.; 30% 1st black, silicified (as 167 m); 30% Q wh w. gy and calcite – all as veinlets and replacements	
169	95% ss. Pale gy. Fgr. Nmic.; 5% Q vnlts with minor ankerite; tr py vnlts	
170	95% shaly siltstone, mid grey, spotted, baked hard; 5% Q wh vnlts + trs ankerite;	
171	80% shaly siltstone, mid/dk gy, spotted, baked hard; 20% Q wh vnlts + replacements with minor py	
172	80% silty ms, pale/mid gy, spotted, baked hard; 20% Q wh + glassy, vnlts with minor py; tr calcite	
173	60-70% Q glassy vn/vnlts with some calcite; 25-35% lst pale gy., v. fgr. Completely silicified + replaced; 5% spotted ms. As 172; tr py; trankerite	Grain Beck Limestone ca. 172.5 to 175.5 m
174	50% lst dk gy/black, intensely silicified, veined with Q + calcite, and brecciated; 40% Q wh vnlts; 10% spotted ms. (?cavings); films of py. On fracture surfaces	
175	50% lst dk gy/black, intensely silicified and veined with Q; 50% Q wh vnlts and gy replacement; frequent trs py. As grains in Q and replacing lst	
176	95% ss. Wh. Fgr. Nmic; 5% Q with minor calcite	
177	95% shaly ms. Gy/dk gy. Tough; 5% Q wh. Vnlts; trs py	
178	90% shaly siltstone, gy. Finely laminated with fgr. Ss., mic; 10% Q with vnlts. With py; some py trs as spots in the siltstone	
179	50% black shale with coal traces; 45% siltstone as 178 m; 5% Q wh vnlts with py; tr. Py vnlts	
180	Laminated siltstone, gy, v. fg., hard, fine mica; tr. Q vnlts	
181	85-90% laminated ss. Fgr, mic, hard; 10-15% py; tr Q vnlets; tr ankerite	
182	Silty ss. Laminated with thin partings of paler gy. F/med. Gr ss.; tr Q + calcite vnlts	
183	90% siltstone, gy. Fgr. Laminated mic.; with some cuttings of fgr. ss.; 10% py; tr Q vnlts	
184	50% shaly siltstone, dk gy; 50% lst., mid gy., v. fossiliferous/crinoidal, partly replaced and veined with calc. and Q	
185	Silty shale, dk gy., slightly spotted, tough; tr py	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
186	As 185	
187	50% silty shale (as 186); 50% lst. Dk gy. With fine shell debris; trs. Q calcite, py	
188	Shale, slightly silty, dk gy., possibly limy; trs. Q calcite, py vnlts	
189	80% silty shale, dk gy.; 10% silicified dark shale; 10% Q vnlts with trs. Py + calcite	
190	80% silty shale dk gy., possibly limy; 20% black shaly ms.; tr. Q and vnlts with py; some lumps of pyrite cemented shale breccia	
191	50% black shaly ms.; 50% lst. Dk gy. Fine shell debris; trs. Q and py vnlts	Smiddy Limestone ca. 190.5 to 200.5 m
192	60% lst. Shaly, impure, dk gy.; 40% silty shale, gy.; tr. Q calcite, py vnlts	
193	Earthy lst., gy/dk gy., occ. Shell debris, friable, carbonaceous, tr. Py; tr. Calcite vnlts	
194	as 193	
195	Lst gy. Coarse grained, crinoidal; calc. vnlts; py trs	
196	Lst (as 195 m) with 20% Q wh vnlts, and a py. Nodule	
197	70% lst. Pale/mid gy., coarse grained, shell debris, some brecciation + silicification; 30% Q wh vnlts and gy. Replacement; tr. Py	
198	80% lst. Pale gy. Coarse gr., crinoidal; 20% vnlts + replacement Q and calc NB. Occ. Lumps of fractured rock flushed from around here	
199	90% lst., pale/mid gy. Fgr.; 10% Q/calc. vnlts + replacements; tr. Py	
200	90% lst., mid/dk gy. Med/coarse grained; 10% Q/calc. vnlts + replacements; tr. Py	
201	ss. pale gy. Fgr. Hard, nmic. Unbedded; tr. Calc. vnlts; py. Trs. On fracture faces	
202	ss. pale and mid gy., fgr. Nmic. Unbedded; tr. Black shale; 2-3% py. As nodules and spotting on fracture faces; tr. Calc. vnlts	
203	Shaly ms., dk gy., with minor limy/earthy ss.; 2-3% py as 202 m	
204	Shaly ms., dk gy.; 2-3% py. (spotting and nodules)	
205	Black shaly ms.; 2-3% py (spotting and nodules)	
206	Lst. Pale gy. + gy.; calc. vnlts, with xtal terminations	Upper Peghorn Limestone ca. 205.5 to 206.5 m
207	Shaly siltstone, gy. Slightly mic. With laminae of fgr. Ss; tr. Pale gy. Lst; rare calc. vnlts	
208	As 207 (no lst. Trs)	
209	Silty ms., gy. Laminated; tr. Calc. vnlts; tr. Py	
210	ss., pale gy. Fgr. Nmic. Hard; 5% Q vnlts wh	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
211	Tr. Black shale + carbonaceous flush; 99% lst. Mottled wh. Pale gy; calc. vnlts; tr. Py	Lower Peghorn Limestone ca. 210.5 to 212.5 m
212	80% lst. Mottled wh/pale gy., partly silicified + replaced; 20% Q wh + calc. vnlts;	
213	95% ss. Gy. Fgr. Hard, mica partings; 5% Q vnlts	
214	As 213, but no vnlts	
215	Shaly siltstone, gy. Laminated, slightly mic.	
216	As 215; tr. Py as spots	
217	As 215; 5% Q vnlts; tr. Py as spots and nodules	
218	Shaly ms. Gy. Tough; tr. Py	
219	As 218	
220	95% lst. Gy. Coarse grained, with calc. vnlts; 5% earthy lst. Dark grey brown, pyretic	Birkdale Limestone ca. 219.5 to 220.5 m
221	ss. pale gy. Fgr. Slightly mic. Unbedded; tr. Q vnlts	
222	As 221	
223	Shaly ms. Dk gy	
224	Lst. Mottled pale gy. + white, intensely replaced with ca. 50% Q and calcite	Robinson Limestone ca. 223.5 to 228.5 m
225	As 224, with fracture surfaces coated in calcite xtals. NB. Flushed lumps of fractured and mineralised limestone around 224 and 225 m	
226	As 224 m, but with 20% Q, calcite and py. And unfractured, solid ground – noticeably pyretic	
227	As 224 m, with 30% Q + calcite, (no pyrite)	
228	As 224 m, with 20% calcite, some Q; tr. Ankerite; tr. Py	
229	90% earthy ss., soft, gy/dk gy; 10% lst. Gy.; tr. Calc. vnlts	
230	Lst. Gy. Fgr; tr. Calc. vnlts. Driller reported strong influx of water at 230 m below table	Melmerby Scar Limestone (Top Leaf) ca. 229.5 to 234.5 m
231	Lst. Pale gy., fgr.; tr. Calc. vnlts	
232	As 231 m	
233	95% Q wh vn/vnlt and gy. Replacement with trs. Calc. + ankerite; 5% silicified lst.	
234	60% Q wh + gy (as 233 m); 40% silicified lst; tr. Ankerite	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
235	40% Q wh. + gy. (as 233 m); 30% seatearth ms, pale cream/grey; 4 cm lump breccia of Q and silicified rock - the breccia is open textured and shows corrosion/ solution of Q on a later fracture surface NB. Flushed some large lumps of mineralised limestone and Q between about 230 and 235 m - suggestive of fractured rock	
236	70% seatearth ms, pale creamy grey; 30% shaly ms. gy; tr. Q vnlts	
237	80% Q wh + glassy with xtal terminations, some gy. replacement, some calcite; 20% silicified remnants of pale gy. lst NB. Changed bit at 236 m and reamed hole slightly whilst re-entering. Cuttings from 237 and 238 may be contaminated with reamed material	
238	40% Q wh + glassy, vnlts; 20% silicified lst. as 237 m; 30% ss. pale gy., quartzitic, fgr. nmic. occ. py spots, silicified; 10% calcite (vnlts?)	
239	70% seatearth mudstone, gy. roots; 30% silicified pale gy. lst.	
240	80% lst. mottled pale grey + white, extensively replaced/recrystallized, hard; 20% Q wh. vnlts	Melmerby Scar Limestone (Middle Leaf) ca. 239.5 to 249.5 m
241	60-70% lst. as 240 m, hard; 30-40% Q and calcite vnlts	
242	80% lst. as 240 m; 20% Q and calcite vnlts, some calc. xtal terminations	
243	50% lst. pale grey, extensively silicified + veined, stylolitic; 50% Q wh. vnlts; tr. calcite NB. Some lumps of mineralised lst. flushed from 242 and 243 m - possibly fractured rock	
244	60% lst. pale grey, mottled pale grey/white, silicified, hard; 40% Q wh. vnlts + gy. Replacements	
245	80% lst. pale gy + mid gy., silicified, hard; 20% Q wh. vnlts; tr. shale (?cavings)	
246	90% lst. pale gy. silicified, hard; 20% Q/calcite vnlt	
247	50% lst. pale gy. as 246 m, with Q/calc. vnlts (py. trs. in the Q); 50% silicified dark grey ?ms. with py. spots	
248	60% lst. pale gy. fgr. partly silicified; 20% Q. wh.+glassy vnlts; 30% dk.ms (?cavings)	
249	60% lst. pale gy. fgr. partly silicified; 30% Q. wh. vnlt.+gy. replacement; 20% dk.ms (?cavings)	
250	10% lst.+Q. vnlts; 70% ms. pale gy. fireclay; 20% dk.ms (?cavings) carbonaceous flush (?coal trace)	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
251	60% ms. Pale grey fireclay; 40% gy. Shaly ms	
252	90% ss. Wh. Fgr. Nmic. Quartzitic; 5% Q. wh. Vnlts; 5% ms	
253	75% ss. As 252 m; 2-3% Q. vnlts; 20% dk. Gy. Ms. (? Cavings); tr. Calc. NB. Some angular lumps of ss. Up to 4 cm. Flushed. Calcite xtals lining one face (open fracture)	
254	30% ss. As 252 m; 30% suspected 1st (mid grey, coarse, veined + replaced by Q + calc); 20% ss. Hard fgr. Dkgy. Rooty seatearth and dkgy. Ms; 20% Q sh. Vnlts with calc. [mixture of lithologies]	Melmerby Scar Limestone (Bottom Leaf, in bands) ca. 254 to 259.5 m
255	90% Q. wh. + glassy vn/vnlt. + frequent small inclusions of py. + cpt; 10% silicified, dkgy. Lst with py. Flecks; some zoned Q with xtal terminations – vuggy; trs calc	
256	70% Q wh. + glassy un/vnlt. W. py flecks; some zoned Q with xtal terminations – vuggy; trs calc	
257	90% ss. Wh. Frg. Nmic. Silicified; 10% Q wh. Vnlt. + grey replacement; tr. Calc	
258	50% ss. Wh. Fgr. Silicified; 50% Q. wh. + glassy vn/vnlt. With some xtal. Terminations; tr. Calc; tr. ?silicified lstn	
259	60% silicified, pgy. ?lst or ss?; 40% Q. vnlt. + gy. Replacement	
260	50% silicified, pale gy. ?ss? fgr.; 50% Q. wh. + glassy vn/vnlt, and gy replacement (with py. + cpt. Trs)	
261	60% ss. Grey, fgr; 30% bluish white chalcedony; 10% Q. wh. Vnlt; tr. Calc	
262	60% ss. Gy. Fgr. + some dkgy; 10% mx. Dkgy. Sandy (?cavings); 30% Q. wh. + glassy + chalcedony	
263	10% ss. As 262 m; 30% lst. Medium gr; mid grey; silicified; 50% Q. wh. + glassy with some calc; 10% ms. Dk.gy	
264	60% ms. Dkgy. Shaly; 25% Q wh. + glassy vnlt; 15% ss. Grey. Fgr; carbonaceous flush; tr. Grey sulphide (?galena)	
265	40% ms. Dkgy. Streaked with pale grey, silty; 30% Q. mixed glassy vn/vnlt, and grey replacement Q containing py flecks; 20% ss. Hard, v. fgr, pale grey; 10% suspect lst. mid gy. Coarse, silicified (no acid reaction); tr. Calc; tr. Fireclay NB. Angular lumps of ss. Flushed	
266	50% ss. Pale gy. Fgr; 30% ss. Dkgy, fgr; 20% Q wh. + glassy vnlt; ss. May be limy – good acid reaction; tr. Fireclay	
267	90% ss. Pale + mid gy. Fgr. Nmic. Silty; 5% Q. wh; 5% dk. Shaly ms. (?cavings) NB. Some angular lumps of ss. Flushed – with tiny py xtals dusting one fracture face (open joint indicated)	
268	90% ms. Dkgy. Hard, silty; 5% ss. (as above); 5% Q with calc. trs	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
269	limy ms, gy. + dkgy; tr Q + calc	
270	40% ss. Dkgy. Fgr; 40% ss. Gy. Fgr. Limy; 10% carbonaceous shale; 10% Q vnlts w. py. Trs. + calc/ankerite trs	
271	80% shaly ms. Gy. + dkgy; 20% Q. wh. + glassy vnlts w. tr. Py	
272	ss. dk. Brownish gy, silty/clayey, hard, earthy/nodular appearance, fine/med. Gr; tr. Q. vnlts	
273	60% ss. Pgr. Fgr. Nmic. Very clean as angular cuttings in clods of 40% white ?kaolinitic clay	
274	90% granite, coarse gr. Yellowish green; 10% Q vnlts; N.B. Granite is disaggregated into Q/feldspar/mica but apart from some recognisable cavings the sample is clean and suggestive of weathered bedrock; the pale yellow green colouration (which continues to depth – possibly more of a turquoise green tint at first, becoming more yellow with depth) seems to be altered feldspar	Top of Weardale Granite at ca. 273.5 m
275	70% granite, coarse gr. Yellowish green; 30% Q wh. Vnlts. + cpt. Trs.	
276	granite as above, with fgr. Aplite (?) and tr. Q vnlts	
277	as 276 with 30% Q vnlts	
278	granite, coarse gr. Yellowish green; 20% Q vnlts	
279	granite as above, 10% Q vnlts	
280	granite as above	
281-282	granite as above; 10-20% vnlts	
283	mixed cuttings (about 50% cavings); excluding cavings the cuttings consist of – 60% Q wh. Vnlt/vn; 20% granite as above	
284	20% cavings (ignored); 80% Q wh. Vn; 20% granite as above	
285	80% Q wh. Vn.; 20% granite as above	
286	Q wh. Vn; tr. Calc.	
287	Q wh. Vn; tr. Calc.; tr. Grey glassy mineral in the Q	
288	80% Q wh. Vn. With tr. Calc + rare py; 20% granite as above	
289-290	80% granite, coarse gr., yellowish green; 20% Q wh. Vnlt	
291	70% granite, coarse gr., yellowish green; 30% Q wh. Vnlt	
292	60% granite, coarse gr., yellowish green, some aplite; 40% Q wh. Vnlt	
293	40% cavings (ss. With tr. Carbonaceous shale); 60% Q wh. + trs. Grey sulphide; tr. Granite	
294	70% cavings (about 60% ss, 10% shale); 30% Q; tr. Granite NB. Assume 293 and 294 m comprised hard Q in soft granite (which disintegrated during drilling) hence only Q + cavings reported in sample	
295	50% granite, as above; 30% Q. wh. vnlt; 20% shale cavings	
296-299	granite, coarse gr., yellowish green; tr. Q vnlt	
300-304	granite, coarse gr., yellowish green	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
301	granite, coarse gr., yellowish green	
305	granite, coarse gr., yellowish green; 5-10% Q vnlts	
306-308	granite, coarse gr., yellowish green; 5% Q vnlts w. trs. Grey sulphide NB. Some lumps of granite flushed at ca. 308. One has a planar face with faint coating of ?chlorite, then nailhead calcite xtals with fine dusting of pyrite xtals, indicating an open fracture	
309	granite, coarse gr., yellowish green; tr. Q vnlt. With gy. Sulphide	
310	granite, coarse gr., yellowish green; some aplite(?); tr. Q vnlt	
311	granite, coarse gr., yellowish green	
312	granite, coarse gr., yellowish green; 10% Q vnlt	
313	granite, coarse gr., yellowish green; 5% Q	
314	granite, coarse gr., yellowish green; 5% Q (+ some ss. Cavings)	
315	granite, coarse gr., yellowish green	
316	granite, coarse gr., yellowish green; 20% Q	
317-318	granite, coarse gr., yellowish green; 5% Q	
319	only flushed large angular lumps pale gy. Fgr. Nmic. Ss. (- assumed cavings)	
320-322	granite, coarse gr. Yellowish green	
323-324	granite, coarse gr. Yellowish green; tr. Q	
325	granite, coarse gr. Yellowish green; 5% Q vnlts	
326-328	granite, coarse gr. Yellowish green; 5% Q vnlts; tr. Gy. Sulphide	
329-333	granite, coarse gr. Yellowish green	
334-335	granite, coarse gr. Yellowish green; 5% Q vnlts	
336	granite, coarse gr. Yellowish green	
337-338	granite, coarse gr. Yellowish green; 5-10% Q + calc. vnlts	
339	granite, coarse gr. Yellowish green	
340-361	granite, coarse gr. Yellowish green mottled; but markedly greyer than above; possibly tr. Q vnlts. But none definitely observed (all fine cuttings)	
362	granite, very coarse, possibly pegmatite	
363-379	granite, coarse gr., becoming progressively greyer overall, but still with occ. Yellowish green altered feldspars	
380-382	granite, coarse gr., noticeably yellowish green	
383-395	granite, coarse gr.; weakly yellowish green;	
396	granite, coarse gr.; weakly yellowish green; say 5% Q wh. + glassy, vnlts, with trs. Galena	
397	granite, coarse gr.; weakly yellowish green; ca.10-20% Q wh. + glassy, vnlts, with xtal terminations (as though open centres to vnlts),	
398-399	granite, coarse gr.; weakly yellowish green; ca. 20% vnlts (up to 10 mm width seen) of Q (wh.+glassy) enclosing some euhedral, very pale green, fluorite (cubes up to 5 mm seen)	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
400	granite, coarse gr.; weakly yellowish green; 10-20% Q with minor very pale green fluorite (cubes up to 5 mm)	
401-403	granite, coarse gr., greenish yellow; trs. Q vnlt	
404	granite, coarser gr., greenish yellow; trs. Q/chalcedony/galena vnlts [N.B. Panned the fines from about 380-404 m and recovered galena, and ?pyrite in the heavy concentrate]	
405-407	granite, grey, coarse gr.; totally disaggregated to coarse sand by drilling with DTH hammer, consequently impossible to see whether there is any Q mineralization; the cuttings comprise Q, mica and feldspar - mostly white + grey, but with occ. greenish yellow feldspar; if mineralization is present, then it is very minor, with no obvious sulphides	
408	granite, grey, coarse gr.; coarser cuttings than above, but still totally disaggregated rock; includes a single almost colourless, very pale blue green, fluorite cube ca. 3 mm - otherwise impossible to determine whether there are Q vnlt traces	
409-411	granite (as 405-407)	
411-411.5	driller reported open fracture or void, with strong influx of warm, saline water	
412-413	50% gran. grey (as 411); 50% calc. vnlts. mostly wh. some clear, mostly massive but with traces of ‘bladed’ texture, and nailhead wafer xtal. terminations (up to 5 mm across) into vughs, some dull grey inclusions that contain occ. fgr. pyrite; calc. also encloses traces of lilac fluor (up to 1 mm) assocd. with py. + ?glassy Q. N.B. lumps of granite and calc. flushed	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
414-615	granite, grey, with occ. greenish yellow feldspars, totally disaggregated by the drilling process, consequently very difficult to identify presence of Q mineralization (if any) except where larger pieces are included in the sample bag. The following occurrences were noted:-	
	415 - piece of 1 mm wide Q vnlt 418 - fragment of nailhead calc. resembling vein stuff from 412-413 m 419-424 - occ. frags. of hairline veinlets of Q 433 - coarse cuttings - not completely disaggregated, possibly indicative of broken ground 456 - minor calc. vnlts. - say 5% by volume? 457 - rather paler/whiter cuttings than before, possibly indicating presence of dispersed Q or calc. mineralization 466 - some veinlets of calcite with flattened nailhead terminations; there is a suggestion that there is increased alteration of feldspar (to greenish yellow) associated with the veinlets 470 - coarser cuttings (?slightly fractured ground) 488-489 - trs. calcite. vnlts 490 - flushed lumps of granite (broken ground), with some veinlets (up to 5mm width) of finely crystalline 'sugary' calcite 494-498 - flushed lumps of granite (broken ground), with some veinlets of calcite, up to say 10 mm width; flattened nailhead xtal terminations 514 - (specimens collected by driller) some pieces of flattened nailhead calcite, with glassy xtal terminations 567 & 570 - slightly coarser cuttings - possibly slightly fractured ground 595 - occ. Q vnlts., up to 5 mm wide (specimens collected by driller)	
*	NOTE: From 615 onwards, samples were taken at 5 m intervals only, unless unusual materials were noticed by the drilling contractor and a special sample collected	
620-655	granite, as above (414-615), mostly grey with rare greenish feldspars, no obvious mineralization seen in the cuttings, which consist of totally disaggregated granite	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
	N.B. Inspection of the waste cuttings dumped between 620 and about 650 m showed one barrow-load that contained veinlets of wh. and glassy Q (with xtal terminations), and glassy fluorite (pale green and pale lilac). The volume suggested a relatively small vein (probably tens of cm rather than a metre) or cluster of veinlets. Its exact depth is not known. Some samples of the fluorite were collected and bagged up.	
655.5	Minor Q py. Vnlts intersected – only a few mm in width, associated with sticky white clay (?kaolinite). Sampled and bagged up	
660-685	granite, as above (414-615), mostly grey with rare greenish feldspars, no obvious mineralization seen in the cuttings, which consist of totally disaggregated granite	
690	70% white vein Q with py. Trs; in granite	
695-715	granite, as above (414-615), mostly grey with rare greenish feldspars, no obvious mineralization seen in the cuttings, which consist of totally disaggregated granite	
720-721	sample handpicked by Contractor:- granite lumps with some white/glassy, crystalline vein Q (>1 cm width), tiny vughs with Q xtals; py. Traces in granite	
725-735	granite, as above (695-715)	
740	80% very pale grey, very finely crystalline Q, probably vein material; 20% granite	
740-742	sample selectively taken by Contractor and labelled 740 – 742 m:- lumps (up to 4 cm) of grey, finely xtalline Q with rare py. Trs. (isolated grains, and hairline veinlets) and rare reddish brown flecks and stains (?haematite); cut by more coarsely xtalline white Q incorporating very rare dustings of dull grey mineral and occasional rare flecks of pyrite; some lumps (up to 4 cm) of normal granite; occasional piece (up to 1 cm) of greenish yellow mineral presumably the altered feldspar present in the granite itself	
745-755	granite, as above (414-615), mostly grey with rare greenish feldspars, no obvious mineralization seen in the cuttings, which consist of totally disaggregated granite	
760	granite (as above) with ca. 10% white vn. Q	
765	granite (as above) with ca. 10% white vn. Q	
770-795	granite, as above (414-615), mostly grey with rare greenish feldspars, no obvious mineralization seen in the cuttings, which consist of totally disaggregated granite	

Table C1 contd.

SAMPLE DEPTH (METRES BELOW TABLE)	CUTTINGS LOG	KEY STRATA
796	sample selectively taken by Contractor:- granite lumps flushed (up to 3 cm), medium grained, with occasional traces black 'earthy' staining (one piece in particular), and suspected alteration of biotites	
800 - 885	granite, as above (770 - 795)	
888.5	sample selectively taken by Contractor:- 60% normal granite cuttings; 40% reddish brown, very fine grained, Q with some aggregates (up to 3 mm) of fine grained xtalline pyrite; with some thin (1-2 mm) veinlets of ?later, more coarsely xtalline, white Q with tiny vughs, and with less pyrite	
890 - 910	granite, as above (800 - 885)	
912	50% granite with distinctly yellowish green colouration due to increased size/proportion of plagioclase; 50% white, finely xtalline, vein Q	
913	sample selectively taken by Contractor:- 80% white vein Q, finely xtalline, one piece has a few tiny (<1 mm) grey sulphide xtals, several pieces dark brownish grey v. fine gr. Q with abundant pyrite flecks; 20% greenish plagioclase-rich, coarse gr. granite	
913.5	sample selectively taken by Contractor:- 80% mid to dark grey, very finely xtalline Q, sometimes with a reddish brown hue (reminiscent of colouration at 888.5 m), with abundant grains (individual xtals, and xtal aggregates) of iron sulphides, probably mostly pyrite, up to 0.5 mm; 15% white and pale reddish brown, very finely xtalline Q with iron sulphides as above; 5% white to glassy, more coarsely xtalline Q with tiny vughs, occasional xtals of pyrite and suspected chalcopyrite, appears to be later stage than the grey/brown Q [N.B. Similar style of mineralization to that seen at 888.5 m; and to grey quartz at 740-742 m]	
915 - 995	granite, as above (890 - 910)	

C2: Records of fracture zones and water strikes

This section records the fracture zones and water strikes as recorded during drilling from three sources (drillers reports, cutting logs and noticeable influxes of ground water). All depths are metres below table, which is 0.94 m above ground level.

Table C2: Fracture Zones and water strikes

	FRACTURED GROUND RECORDED BY DRILLER	FRACTURES INDICATED FROM CUTTINGS (SEE LOG)	NOTICEABLE INFLUXES OF GROUNDWATER	COMMENTS
1	47	40 - 51 (lump rock flushed)	47	mineralised Tynebottom Limestone
2	91	88 - 91 (lump rock flushed)	91	mineralized rock
3	98.5	99 - 100 (lump rock flushed)	-	whin Sill
4	101	99 - 100 (lump rock flushed)	-	whin Sill
5	111.5	-	111	whin Sill
6	-	118 (lump rock flushed)	-	whin Sill
7	-	126 (lump rock flushed)	-	whin Sill
8	-	157 (lump rock flushed)	-	whin Sill
9	167	-	167	mineralized Lower Little Limestone
10	-	198 (lump rock flushed)	-	mineralized Smiddy Limestone
11	-	224 - 225 (lump rock flushed)	-	mineralized Robinson Limestone
12	234.5 - 236	230 - 235 (lump rock flushed)	230	mineralised Melmerby Scar Limestone
13	-	242 - 243 (lump rock flushed)	-	mineralised Melmerby Scar Limestone
14	-	254 (lump rock flushed)	-	mineralised Melmerby Scar Limestone
15	267 - 267.5	265, 267 (lump rock flushed)	-	Basement Beds
16	282 - 283	(mostly cavings at 283 m)	-	quartz vein in Weardale Granite
17	-	308 (lump rock flushed)	-	Weardale Granite

Table C2 contd.

	FRACTURED GROUND RECORDED BY DRILLER	FRACTURES INDICATED FROM CUTTINGS (SEE LOG)	NOTICEABLE INFLUXES OF GROUNDWATER	COMMENTS
18	411 - 411.5	-	411 (warm water)	Weardale Granite
19	437			highly fractured Weardale Granite
20	465			Weardale Granite with veinlets
21	493 - 497			Weardale Granite with veinlets
22	655			Weardale Granite with veinlets
23	720 - 721	720 - 721 (lump rock flushed)		Weardale Granite with quartz veinlets
24	740.5	740 - 742 (lump rock flushed)		Weardale Granite and quartz veins
25		796 (lump rock flushed)		Weardale Granite
26	814 - 815.5			Weardale Granite

APPENDIX D – CHEMICAL COMPOSITION, SPECIFIC GRAVITIES AND CALCULATED HEAT PRODUCTION VALUES FOR CUTTINGS OF WEARDALE GRANITE FROM THE EASTGATE BOREHOLE

Table D1: Major elements

Sample depth, m		***280***	***300***	***350***	***400***	***450***	***505***	***550***	***600***	***650***	***700***	***750***	***800***	***850***	***900***	***950***	***995***
SiO_2	wt%	78.89	76.66	70.14	79.46	70.56	74.15	75.87	69.99	73.62	74.39	72.74	71.11	72.66	76.08	72.33	74.29
TiO_2	wt%	0.13	0.14	0.22	0.07	0.10	0.10	0.09	0.10	0.15	0.14	0.14	0.14	0.15	0.12	0.14	0.12
Al_2O_3	wt%	9.76	12.82	12.07	9.68	15.45	13.19	12.91	12.97	14.24	14.21	14.44	15.70	14.76	12.62	13.83	14.57
Fe_2O_3	wt%	0.83	0.67	2.50	0.62	0.80	0.79	1.02	5.66	0.95	1.03	1.26	1.11	1.20	1.15	1.18	0.85
MnO	wt%	0.04	0.02	0.08	0.02	0.03	0.02	0.01	0.06	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.03
MgO	wt%	0.74	0.61	0.94	0.32	0.28	0.30	0.29	0.31	0.28	0.29	0.33	0.30	0.38	0.49	0.37	0.33
CaO	wt%	1.21	0.89	2.87	2.13	0.92	0.82	0.56	0.51	0.53	0.60	0.81	0.77	0.65	0.52	0.65	0.67
Na_2O	wt%	1.22	1.63	2.12	1.55	3.60	2.66	2.41	2.55	3.30	3.35	3.43	3.96	3.49	1.82	3.49	3.34
K_2O	wt%	4.09	5.04	4.55	4.35	6.06	5.84	5.68	5.52	5.28	5.00	4.98	5.37	5.44	5.37	5.54	5.15
P_2O_5	wt%	0.13	0.14	0.22	0.18	0.27	0.22	0.21	0.24	0.28	0.26	0.26	0.29	0.29	0.24	0.26	0.26
SO_3	wt%	0.33	0.12	0.29	0.09	0.06	0.18	0.15	0.10	0.02	0.03	0.02	0.01	0.01	0.07	0.01	0.02
LOI	wt%	1.95	1.44	3.49	1.21	1.09	0.97	0.71	1.29	0.81	0.87	0.92	0.87	0.93	1.14	0.91	0.85
Total	wt%	99.30	100.18	99.48	99.68	99.21	99.23	99.90	99.28	99.50	100.19	99.37	99.66	99.99	99.66	98.75	100.47

LOI denotes ignition loss.

Chemical compositions determined at the Department of Geology, University of Leicester, using X-ray fluorescence.

Table D2: Trace elements, specific gravity and calculated heat production capacity

Sample depth, m		*280*	*300*	*350*	*400*	*450*	*505*	*550*	*600*	*650*	*700*	*750*	*800*	*850*	*900*	*950*	*995*
As	mg/kg	19.9	24.3	23.4	18.2	9.9	31.8	14.3	21.5	4.8	2.1	5.1	6.6	1.0	9.9	3.1	13.9
Ba	mg/kg	395.6	303.8	271.2	256.8	245.5	299.3	371.2	342.7	190.0	200.0	186.0	196.6	194.0	174.3	176.0	223.7
Bi	mg/kg	3.1	<1	2.1	<1	3.3	3.4	1.4	1.9	<1	1.3	<1	1.3	2.0	2.3	1.4	1.7
Ce	mg/kg	23.1	40.9	36.8	30.4	37.5	31.3	22.1	25.3	32.5	37.2	32.8	34.7	34.4	30.3	35.4	30.6
Co	mg/kg	<1	<1	3.5	<1	<1	<1	<1	15.3	<1	<1	<1	<1	<1	<1	<1	<1
Cr	mg/kg	198.5	214.2	171.5	205.8	152.6	173.3	225.3	584.7	147.3	171.5	171.0	197.5	145.2	217.2	153.8	149.4
Cs	mg/kg	31.1	32.9	38.8	26.8	29.7	23.6	31.1	45.8	33.5	37.6	31.4	37.8	44.6	61.9	54.2	33.8
Cu	mg/kg	23.9	15.6	23.7	7.5	19.9	1.8	2.3	27.8	<1	<1	3.7	1.4	2.5	5.6	<1	1.2
Ga	mg/kg	13.7	15.6	17.3	15.3	22.5	17.5	18.4	21.6	22.5	20.7	21.6	22.3	23.7	20.0	23.1	20.4
Ge	mg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Hf	mg/kg	3.2	4.1	4.2	2.8	3.7	2.2	2.5	1.9	3.8	3.4	2.3	2.6	4.2	2.3	2.9	3.5
La	mg/kg	19.1	25.6	25.1	17.5	21.7	23.0	18.2	20.2	23.7	20.2	20.8	20.7	20.6	22.5	23.2	20.0
Mo	mg/kg	2.7	2.3	3.4	2.7	<1	1.3	7.1	68.3	1.9	2.8	2.7	1.5	1.5	3.5	2.3	<1
Nb	mg/kg	8.5	9.4	11.5	10.6	9.6	11.5	10.2	10.7	15.2	13.7	13.0	15.5	16.0	14.2	16.4	12.4
Nd	mg/kg	11.8	17.6	17.4	15.3	19.3	16.6	14.1	13.0	19.4	18.4	13.8	17.3	18.1	15.8	18.1	15.1
Ni	mg/kg	<1	2.2	4.7	<1	1.3	<1	1.3	26.5	<1	<1	<1	<1	<1	<1	<1	<1
Pb	mg/kg	20.7	160.3	146.1	16.8	27.3	18.9	21.4	20.1	14.1	47.7	35.9	30.0	23.6	20.3	14.8	20.2
Rb	mg/kg	270.3	295.0	365.6	361.3	483.7	444.8	471.2	485.6	462.0	445.9	433.2	459.9	469.9	501.6	456.8	444.3
Sc	mg/kg	2.5	3.4	4.4	3.1	2.7	<1	<1	<1	1.5	3.6	3.1	<1	3.1	<1	2.2	<1
Sn	mg/kg	14.5	9.4	8.9	13.7	16.2	15.1	11.7	23.8	18.5	20.1	12.2	18.7	20.6	16.2	21.3	17.0
Sr	mg/kg	46.1	70.9	99.5	37.6	76.8	54.5	49.7	64.9	53.4	56.9	69.5	76.5	66.6	54.6	66.3	58.9
Ta	mg/kg	<1	<1	6.3	4.8	<1	<1	<1	<1	<1	1.4	6.3	6.4	<1	5.3	3.2	2.7
Th	mg/kg	8.6	13.2	15.0	11.1	12.4	12.3	13.1	10.5	12.2	14.4	15.2	14.7	16.5	12.6	15.6	10.0
U	mg/kg	6.2	4.9	7.1	5.3	9.5	8.9	11.2	8.2	9.4	10.1	13.4	10.7	11.5	3.9	10.5	8.9
V	mg/kg	15.9	21.6	29.1	10.3	10.8	15.2	11.5	14.7	11.6	14.6	12.4	14.3	11.4	12.9	15.3	12.4
W	mg/kg	<1	1.6	<1	<1	<1	<1	2.5	46.2	1.9	3.7	2.7	1.1	<1	1.5	2.3	1.9
Y	mg/kg	3.8	4.3	6.5	3.5	1.2	<1	<1	<1	<1	1.2	2.0	3.6	<1	1.6	<1	2.8
Zn	mg/kg	5.3	7.0	30.5	14.2	30.3	164.9	15.2	23.2	27.4	29.0	66.9	35.9	39.9	39.5	35.9	28.3
Zr	mg/kg	72.0	93.2	86.0	47.2	72.0	67.6	52.1	1.8	90.8	76.8	73.1	79.5	80.6	70.3	80.3	71.7
Cl	mg/kg	141.6	86.1	171.2	106.8	168.4	174.4	89.7	541.9	65.5	67.4	57.2	52.3	142.5	89.7	67.0	43.8
F	mg/kg	1147.6	2251.7	1591.7	11581.0	1464.8	2128.5	2826.3	2029.4	2182.5	2366.7	2784.4	2453.7	2720.6	1862.2	2147.9	1717.1
S	mg/kg	1172.8	129.0	588.7	133.6	192.4	251.9	699.6	100.8	338.0	229.6	382.8	360.8	111.8	288.8	252.2	357.0
volume of 100g, ml		38	39	37	38	38	38	39	39	39	39	38	39	39	39	39	40
specific gravity		2.63	2.56	2.70	2.63	2.63	2.63	2.56	2.56	2.56	2.56	2.63	2.56	2.56	2.56	2.56	2.50
heat production, μW/m^3		2.57	2.61	3.38	2.55	3.88	3.69	4.21	3.39	3.28	3.67	4.04	4.82	4.15	4.47	2.35	4.07

Chemical compositions determined at the Department of Geology, University of Leicester, using X-ray fluorescence.

APPENDIX E – CHEMICAL COMPOSITIONS OF WATER SAMPLES FROM THE EASTGATE BOREHOLE AND OTHER LOCATIONS.

Table E1: Water compositional data for samples taken from the Eastgate Borehole (135 m and deeper).

Sample		E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20
Date (2004)		11/9	11/9	11/9	12/9	15/9	15/9	16/9	16/9	16/9	6/10	6/10	7/10
Depth	metres	135	144	152	166	181	192	214.5	234	236.5	266.5	275	300
Temperature	C	14	14.1	14.1	14.3	14.6	15	14.9	16.4	17	17.2	17.9	18.9
Cond (field)	µS/cm	3750	3870	3900	4390	5150	5780	5680	11820	14940	27390	27130	26150
pH		7.6	7.8	7.8	7.8	7.9	8.1	8.1	7.7	7.8	6.4	6.8	6.9
Cond (lab)	µS/cm	3600	3794	3867	4215	5204	5502	5802	13290	14560	18740	16100	16030
Alkalinity	mg/l as CaCO3	256	246	240	246	250	256	246	202	206	110	142	126
Nitrate	mg/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloride	mg/l	559	648	826	761	1037	1123	1231	3895	4262	7449	5810	5906
Sulphate	mg/l	466	444	399	412	389	392	378	290	289	269	291	290
Bromide	mg/l												
Ammonium	mg/l												
Calcium	mg/l	222	228	231	244	293	316	339	807	969	1170	976	1066
Magnesium	mg/l	9.5	8.5	8.4	8.6	8.1	9.6	8.2	16.8	16.2	25	22.4	20.4
Sodium	mg/l	484	510	521	552	676	705	730	1984	2248	2697	2205	2243
Potassium	mg/l	40.1	42.9	44.1	42.3	51.2	52.4	52.5	103	111	159	138	140
Iron	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4
Manganese	mg/l	0.5	0.7	0.6	0.8	0.8	0.8	1.1	1.7	2	2.2	1.5	1.6
Zinc	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.2	<0.1	<0.1	<0.1
Copper	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lead	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Lithium	mg/l	3.4	3.7	3.8	4.3	5.5	5.9	6.2	16.1	17.4	25.1	20.1	20.5
Silicon	mg/l	6	6	6	6	6	6	6	6	6	5	5	4
Strontium	mg/l	8.1	8.5	8.7	10.0	12.5	13.7	14.3	39.6	45.65	76.8	60.5	61.8
Barium	mg/l												
Charge Balance (%)		6.2	5.4	0.5	5.3	5.4	5.1	4.5	5.5	8.3	-7.5	-5.6	-4.3

Table E1 contd.

Sample		E21	E22	E23	E24	E25	E26	E27	E28	E29	E29A	E30	E31
Date (2004)		8/10	19/10	27/10	28/10	29/10	2/11	6/11	9/11	25/11	30/11	1/12	2/12
Depth	metres	335	411.5	485	561	590	674	725	770	847	910	951	995
Temperature	C	19.2	26	24.5	26	25.5	26.2	26.6	26.5	26.6	26	27	-
Cond (field)	µS/cm	26010	181000	181200	188900	190100	279600	210903	221014	212000	215000	239000	-
pH		6.9	6.2	6.4	6.4	6.3	6.4	6.4	6.4	5.8	5.9	6	6
Cond (lab)	µS/cm	23210	65400	65700	66200	66500	66800	63200	64000	65800	66500	66200	65200
Alkalinity	mg/l as $CaCO_3$	130	60	56	56	58	54	56	50	54	58	47	56
Nitrate	mg/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloride	mg/l	9486	28750	25840	26970	25660	28560	25730	25700	28400	30000	31200	27800
Sulphate	mg/l	255	48.5	52.2	44.7	46.9	47.8	68	69	41.2	44.3	43.4	45.3
Bromide	mg/l		140	140	150	160	140	140	130	160	150	150	140
Ammonium	mg/l		11	-	-	-	-	-	-	11	12	11	11
Calcium	mg/l	1595	5285	5256	5424	5345	5250	5410	5620	5312	5375	5264	5009
Magnesium	mg/l	28.6	72.4	71.9	72.8	72.1	73.1	68.9	69.1	79.2	79.2	78.2	75.3
Sodium	mg/l	3333	9630	9580	9940	10000	9790	9930	9940	10100	10300	11000	10100
Potassium	mg/l	201	631	642	646	667	656	782	551	689	708	646	638
Iron	mg/l	<0.1	0.4	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Manganese	mg/l	4	20.3	19.1	18.3	19.8	17.6	21.5	22	19	18.7	19.4	19
Zinc	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lead	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Lithium	mg/l	30.7	90.6	91.7	93.2	93	93.5	92.8	94.8	94.3	91.3	91.3	89.5
Silicon	mg/l	5	6	4	4	3	3	6	4	5	4	5	6
Strontium	mg/l	103	343	344	352	350	353	304	313	311	315	313	305
Barium	mg/l		12.9	13.6	12	13	13.3	12.5	14.7	13.8	12.3	12.2	11.5
Charge Balance (%)		-7.0	-5.6	-0.5	-1.0	1.5	-4.8	1.4	1.8	-3.4	-5.3	-5.8	-3.5

Table E2: Chemical analyses of waters sampled (a) at Cambokeels (NB samples CK88/1 and CK89/4 are from underground; Manning and Strutt, 1990); (b) from shallow site investigation holes (depths corrected for inclination); (c) from a spring located close to a bend in the quarry conveyor; (d) from the River Wear, and (e) for make-up water used early in the deep drilling exercise. NB Ammonium, bromide and barium were not determined.

		Mine discharges						Site investigation holes			Spring water		River Wear		Make-up water	
Sample		CK88/1	CK89/4	CK04/1	CK04/2	CK0907	CK0809	Hole 3	Hole 4	Hole 4	CK010704	S1	CK090704	R1	B1	B2
Date, 2004						9/7	8/9	6/7	8/7	8/7	1/7	10/9	9/7	10/9	26/8	2/9
Depth	metres							53	26	46						
Temperature	C		16												17.4	12.4
Cond (field)	µS/cm													310	354	408
pH				6.99	7.42	6.53	6.9	8.11	7.81	8.05	7.88	7.3	8.03	7.7	6.6	6.6
Cond (lab)	µS/cm			1002	943	806	826	881	546	946	642	605	279	296	372	407
Alkalinity	mg/l CaCO3			154	186		144					150		106	150	166
Nitrate	mg/l			3.1	3.1	<2	<3	<2	11.1	<2	<2	<3	<2	<3	<2	<2
Chloride	mg/l	24600	12200	87.3	68.8	60.1	59.3	106	25.3	102	26.4	24.5	13.4	10.8	6.2	5.9
Sulphate	mg/l		106	179	157	149	146	2.2	41.1	12.2	92.3	94	24.7	24.8	14.3	17.2
Calcium	mg/l	5236	2482	133	137	108	123	30	29	20	88	137	41	61.8	67.7	77.3
Magnesium	mg/l	121	53.7	12.4	11.4	11.7	10.9	6.1	3.6	2.7	18.6	18.3	5.2	5.7	6.1	7.1
Sodium	mg/l	7345	3511	53	43	50	42.6	1840	66	1830	8.6	8.4	10	7.3	5.1	4.9
Potassium	mg/l	340	181	4.5	5	4.9	4.2	8.7	20	9.1	4.3	4.8	2	2	5.4	2.3
Iron	mg/l	0.73	0.2	< 0.1	< 0.1	< 0.5	1	< 0.1	< 0.3	< 0.2	< 0.6	0.4	< 0.4	0.2	0.2	<0.1
Manganese	mg/l						0.5					0.2		<0.1	<0.1	<0.1
Zinc	mg/l						2					<0.1		<0.1	<0.1	<0.1
Copper	mg/l						<0.1					<0.1		<0.1	<0.1	<0.1
Lead	mg/l						<0.2					<0.2		<0.2	<0.2	<0.2
Lithium	mg/l	70.5	42	0.22	0.17	0.1	0.2	0.56	1.7	0.6						
Silicon	mg/l		4.8	3	3	3	3	4	2	2	4	3	1	1	1	3
Strontium	mg/l						0.7					0.8		0.2	0.4	0.4
Charge Balance (%)		-6.4	-8.5	4.5	4.8		8.8					22.3		14.5	10.2	10.4

Table E3: Chemical compositions for early samples from Eastgate borehole; acidification prior to analysis invalidates these data for iron, manganese, zinc, copper and lead. NB Ammonium, bromide and barium were not determined.

Sample		E1	E2	E3	E4	E5	E6	E7	E8	E6	E7	E8
		All samples acidified; suspended solids report in analysis								Repeated; no added acid		
Date (2004)												
Depth	metres	48	60	66	77.5	86.5	88.5	99	111	88.5	99	111
Temperature	C		13.3	13.7	15	17	13.3	14.9	18.6			
Cond (field)	µS/cm	750	817	943	1061	1210	1189	2840	3050			
pH		8.1	8.1	7.7	7.6	7.6	8	8.3	7.3			
Cond (lab)	µS/cm	764	840	974	1103	1248	1120	2740	3260			
Alkalinity	mg/l as $CaCO_3$			264	272	262		116	176			
Nitrate	mg/l	<3	<3	<3	<3	<3	<3	<3	<3			
Chloride	mg/l	89.2	100	108	129	183	162	563	678			
Sulphate	mg/l	30.2	27.1	24.8	55.8	39.8	21.5	421	405			
Calcium	mg/l	44.2	175	187	290	340	710	345	730			
Magnesium	mg/l	7	43.6	53.6	91.3	108	201	23.1	83.5			
Sodium	mg/l	156	162	170	183	204	193	371	436			
Potassium	mg/l	14.2	21.4	21.5	17.9	16.3	24.3	45.4	50.2			
Iron	mg/l	5.2	32.9	30.5	88.7	54.1	60.1	33.8	78.3	<0.1	<0.1	<0.1
Manganese	mg/l	0.6	5.6	5.5	13.5	8.8	20.1	4.7	16.8	0.1	<0.1	0.3
Zinc	mg/l	0.2	0.2	0.2	1.6	1.1	2.4	2.1	2.2	0.3	<0.1	<0.1
Copper	mg/l	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
Lead	mg/l	<0.2	0.3	0.2	<0.2	2.6	3.4	0.3	<0.2	<0.2	<0.2	<0.2
Lithium	mg/l	0.7	0.8	0.9	1	1.1	1	2.7	3.2			
Silicon	mg/l	19	14	8	7	6	9	33	33			
Strontium	mg/l	0.8	1.2	1.4	1.7	1.5	1.8	6.8	8.6			
Charge Balance (%)		52.4	71.2	42.5	50.0	51.9	84.9	15.7	34.9			