Hydrogeological Investigations and Ground Treatment for Shaft Sinking at Asfordby New Mine

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ABSTRACT

The paper describes the detailed hydrogeological studies carried out prior to the sinking of twin shafts at British Coal's new mine at Asfordby, Leicestershire, UK. The test methods for assessing potential groundwater inflows to the shafts are discussed and details are given of the ground freezing scheme employed through the major aquifer zone in the Sherwood Sandstone at a depth of 375 metres. During shaft sinking pressure recovery tests were carried out to further assess potential inflows and the results are compared with those from the surface tests prior to sinking.

INTRODUCTION

The North-East Leicestershire Coalfield (also referred to as the Vale of Belvoir) covers an area of some 235km² in a roughly triangular shaped block between the city of Nottingham and the towns of Grantham and Melton Mowbray in the UK Midlands region. (Fig.1) The new Asfordby mine with an output of 3 million tonnes per annum, will be the largest colliery in the Midlands region covering an area of 60km² and will replace long established collieries in Leicestershire that are nearing exhaustion.

Access to the reserves in the Deep Main, Parkgate and Blackshale seams will be provided by twin vertical shafts of 7.32m diameter and depths of 534m (downcast) and 547m (upcast). Prior to the start of development work boreholes were drilled on the centrelines of the two shafts, and a full programme of testing was carried out to describe the hydrogeological and geotechnical ground conditions through which the shafts would have to pass.

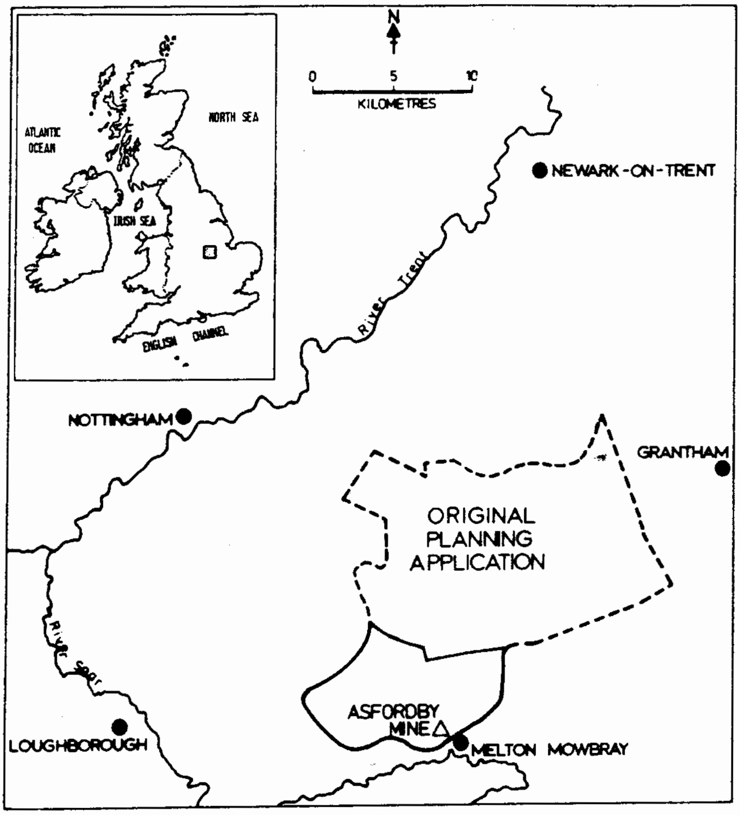

Fig. 1 Location of Asfordby Mine

The paper describes this borehole investigation programme, the use of the results to locate and estimate potential groundwater inflows to the excavated shafts, further hydrological tests carried out during shaft sinking, and the employment of the ground freezing method to eliminate inflows from the major aquifer zone.

HYDROGEOLOGY

The generalised geological section for the shaft centreline boreholes is shown in Figure 2.

From the hydrological point of view the main area of concern for shaftsinking is the Sherwood Sandstone (Bunter), a major aquifer comprising coarse grained poorly cemented sandstone with thin breccia beds, and the overlying fine grained and muddy sandstones of the Colwick Formation (Keuper Waterstones) which are permeable but to a much lesser extent. This sequence between depths of approximately 330 and 390 m is confined above by the Mercia Mudstone (Keuper Marl) and below by the Moira Breccia which marks the base of the Permian Strata.

The 3 main coal seams occur within the upper 75m of the underlying Coal Measures, which are themselves underlain by the Namurian (Millstone Grit). In the upcast shaft borehole evidence was found of an igneous intrusion below a depth of 591m.

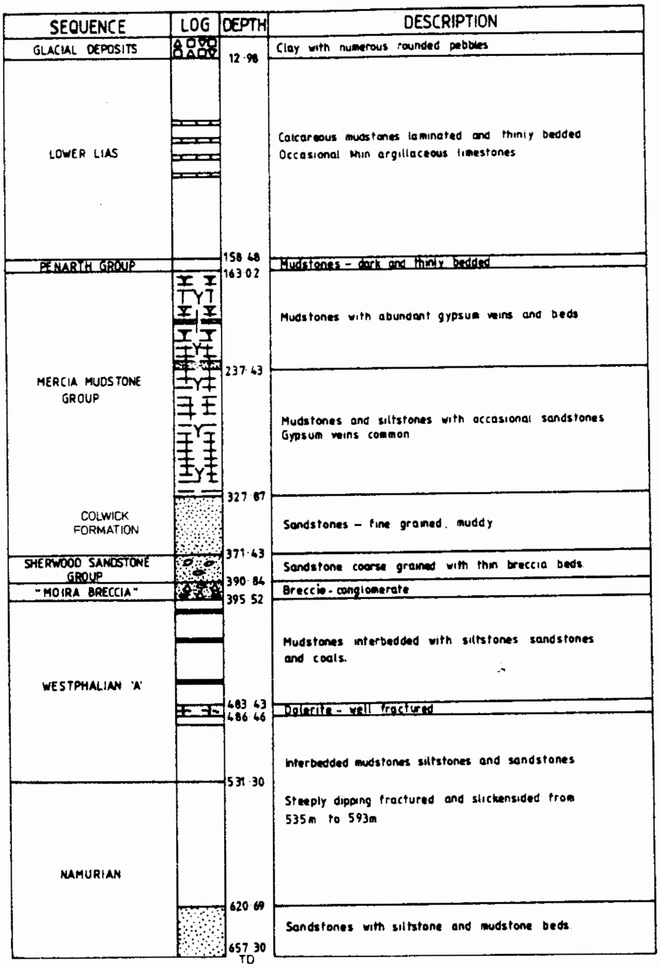

Fig. 2 Geological Section for Shaft Boreholes

SITE INVESTIGATION PROGRAMME

The two boreholes were drilled at 158mm diameter producing core of 88mm diameter with the upcast borehole cored fully but the downcast borehole only cored between 298.0m and 631.7m depths. There was minimal core loss in either borehole and the general condition of the core was good.

At the completion of borehole drilling a full suite of geological logs were run in each borehole, followed by a programme of hydrological testing, details of which are given in the next section.

The core was logged according to the Geological Society of London guidelines (1) and fully photographed in colour. Samples of the core were selected for testing using a standard sampling interval of 3m but with variations as dictated by the detailed lithology and state of the core. A wide ranging programme of testing was carried out including tests on both frozen and unfrozen samples from the main aquifer zone.

In addition formation water samples collected during the hydrological testing were analysed.

HYDROLOGICAL ASSESSMENT

Test Methods

A series of sixteen Drill Stem Tests (DSTs) were conducted in the upcast shaft borehole between depths of 307 and 409m and ten tests in the downcast shaft borehole between depths of 342 and 409m, and 591.5 and 601.5m - the latter within the igneous zone. In addition, a series of injection tests were carried out in the downcast shaft borehole over the same basic intervals.

Conventional DST equipment supplied by Lynes Petrotech Ltd. (2) included a straddle packer system of 140mm deflated diameter which was inflated by a downhole mud pump. Tests were conducted over packer intervals of between 4m and 25m.

Two Digital Memory Recorders (DMRs) using quartz crystal transducers and set to record data every 15 seconds, and a mechanical Bourdon pressure gauge were positioned to measure pressure and temperature changes within the test interval. Real-time surface monitoring of the flow periods was also available using a conductor wireline pressure gauge (CWL) lowered through the drill-pipe to just above the shut in valve.

Test Results and Discussion

The DST data was analysed according to Horner (3), the recovery profiles via a finite difference radial flow model, and the injection tests using a steady-state equation with a radius of influence set at 100m. The results of the test programme summarised in relation to the geological formation are presented in Table 1.

The test programme in the Colwick formation indicated a low permeability aquifer, with values ranging from 2E-8 to 4E-7m/s. The standard Horner analysis and classical Drill Stem Test procedures are well suited to permeabilities of this magnitude. Very good straight line extrapolations were possible giving a high level of confidence to the analysis. Unfortunately the equipment and test method were not well suited to testing the high permeability zones within the Sherwood Sandstone. Two major problems were identified, viz. the severe choking of the flow period (initial flow rates greater than 15 l/sec) that completely masked the early flow characteristics, and the very short flow periods of less than 3 minutes which did not allow a significant pressure transient within the aquifer.

The range of permeability data derived from the outflow test for the upper 10m of the Sherwood Sandstone varied from 4E-6 to 8.4E-6m/s. The results from the injection tests were significantly lower, ranging from 1.6E-7 to 1.3E-6m/s; this has been attributed to mud invasion and particle movement within the matrix of the rock material.

Table 1. Derived permeability distribution for shaft sections

Depth (m)	Permeability (x E-8m/s)	Depth to Static Water (m)	Formation
0 - 322	0		
322 - 332	0.01		
332 - 337	10		
337 - 342	5		
342 - 347	12		Colwick
347 - 352	0	50	Formation
352 - 357	1		
357 - 366	4		
366 - 371	40		
371 - 381	750		Sherwood Sandstone
381 - 391	10		
391 - 570	0		Coal Measures
570 - 590	25	30	Volcanic
590 - 610	110		

A value of 7.5E-6m/s was allocated to this upper 10m of Sherwood Sandstone, whilst a value of E-7m/s was attributed to the lower uniformly bedded, fine-medium grained sandstone that lies directly above the Moira Breccia. As no fluid was ever recovered in any of the tests conducted within the Moira Breccia, zero value of permeability was attributed to this formation.

Groundwater Modelling and Shaft Inflow Rates

For a shaft diameter of 10m and a 10m to 20m length of open section, the permeability distribution given in Table 1 was modelled as extending radially outwards from the shaft centre for a distance of 500m. At this boundary the groundwater head was set equal to the static water level. Within the shaft, it was assumed that all water would be removed and that atmospheric conditions would prevail.

The modelling was conducted using a resistance analogue network whose finite difference mesh size was set at 2.5m. The results of the exercise are presented in the right hand column of Fig. 4. This analysis clearly illustrates the significance of the highly permeable zone, which when immediately exposed in the sump of the shaft at 370m increased the shaft inflow from 8.1 to 28.61/s . The maximum inflow rate when fully exposed was calculated to be 35.61/s.

GROUND TREATMENT

General

Recent shaft sinking experience within British Coal Mines involving the grouting of low strength sandstones under high hydrostatic pressure that exhibit a high primary and secondary phase of permeability indicated technical difficulties and unpredictability in terms of time, grout rate and residual inflow rates.

Therefore in view of the measured weak nature of the Sherwood Sandstone (unconfined compressive strength averaging 12 MPa) combined with the high potential inflow from both phases of permeability (measured laboratory values up to (9.2E-6m/s) British Coal decided to freeze the waterbearing strata between 330-390m (4).

Ground Freezing Details

Due to the competent and relatively 'dry' nature of the strata above 330m it was decided to carry out the freezing operation from an underground chamber constructed above the water-bearing zone. (Fig. 3). A ring of 39 vertical freeze holes of 200mm diameter and 3 monitoring holes were drilled on a 16.1m PCD from ground surface level to a depth of 405m into competent Coal Measures strata. Freeze casings, approximately 130m long and 125mm diameter with sealed top and bottom plugs and containing a steel inner pipe of 65mm diameter were then sealed into the bottom section of the drill holes. The shafts were then sunk to the freeze chamber level of 275m, and the freeze chambers were excavated to a radius of 9.6m (c.f. finished shaft diameter of 7.32m), and a height of 4.0m.

A sophisticated logging system was employed for monitoring the performance of the freezing operation with temperatures, flows and levels monitored at surface and underground and analysed by computer.

Ice Wall Design

Data from the test programme was used in a finite element model to

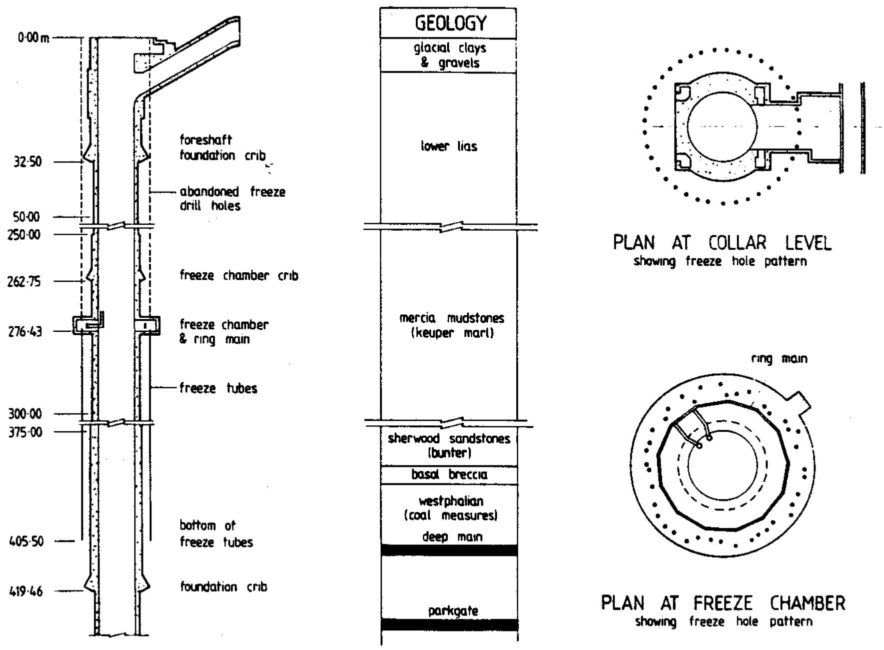

Fig. 3 Schematic Arrangement for Ground Freezing

estimate the required ice wall thickness to provide the structural support for the prevailing ground conditions and proposed methods of working. This indicated a worst case requirement of a 1.5m thick ice wall, and with due allowance for practical aspects and a factor of safety the minimum drilled ice wall thickness was set at 3.0m. Further analysis indicated that this could be achieved within 15 weeks of freezing. In practice the 3m thickness was achieved in 10 weeks at the U/C shaft and 12 weeks at the D/C shaft. Observations and measurements of water flow from a central pressure relief pipe supplemented the temperature measurements to determine the time of icewall closure.

During the period of the ground freezing operation the permanent winding tower construction works were carried out thus making good use of the time when shaft sinking was temporarily halted.

OBSERVATIONS AND MEASUREMENTS DURING SINKING

Pressure Recovery Tests of Aquifer Zone

The drilling of the pressure relief holes provided the opportunity to investigate in more detail the hydrological characteristics of the aquifer. At the upcast shaft inflow rates to the relief hole from the Colwick Formation between 339 and 351m increased to 0.381/s, but with no significant increase in inflow down to 371m (see Fig. 4). Very large makes of water were then encountered from the Sherwood Sandstone with increases at 372.5m from 0.27 to 2.51/s and at 377.7m from 2.5 to 3.51/s. These large increases in flowrate can be attributed to a series of highly permeable beds of conglomerate which characterise the upper section of this sandstone unit. Below 380m no significant rise in flow was recorded. Although this reflects a reduction in permeability, any flow from this lower section of Sherwood Sandstone would probably be masked by the very high entrance velocities issuing from the highly permeable conglomerates. Friction losses, etc, during drilling were high as the inflow increased from 3.5 to 14.51/s when the rods were pulled out.

On completion of drilling, a Pressure Recovery Test (PRT) was conducted to assess the cumulative transmissivity of the combined aquifer section. The equipment installation and test procedures for this test are described elsewhere (5). As this test was conducted from an underground level closer to the aquifer, a significantly greater quantity of water at a constant flowrate could be extracted c.f. 8,635.5 1 of water in 10 minutes as compared to 2271 extracted during the original Drill Stem Test. Analysis of the Horner Plot for the PRT (Fig. 5) yields a transmissivity of 1.67E-4m^2/s with the late-time data towards the end of the buildup of very good quality.

Revised Inflow Rate to Upcast Shaft

As the transmissivity derived from the PRT is a cumulative figure the distribution of permeability has been related directly to the rate of water ingress measured during drilling. Within the Colwick Formation, from 340 to 360m, the correlation between the predicted inflow derived from the pressure relief hole of 1.361/s and that predicted from the DST of 1.521/s is very close.

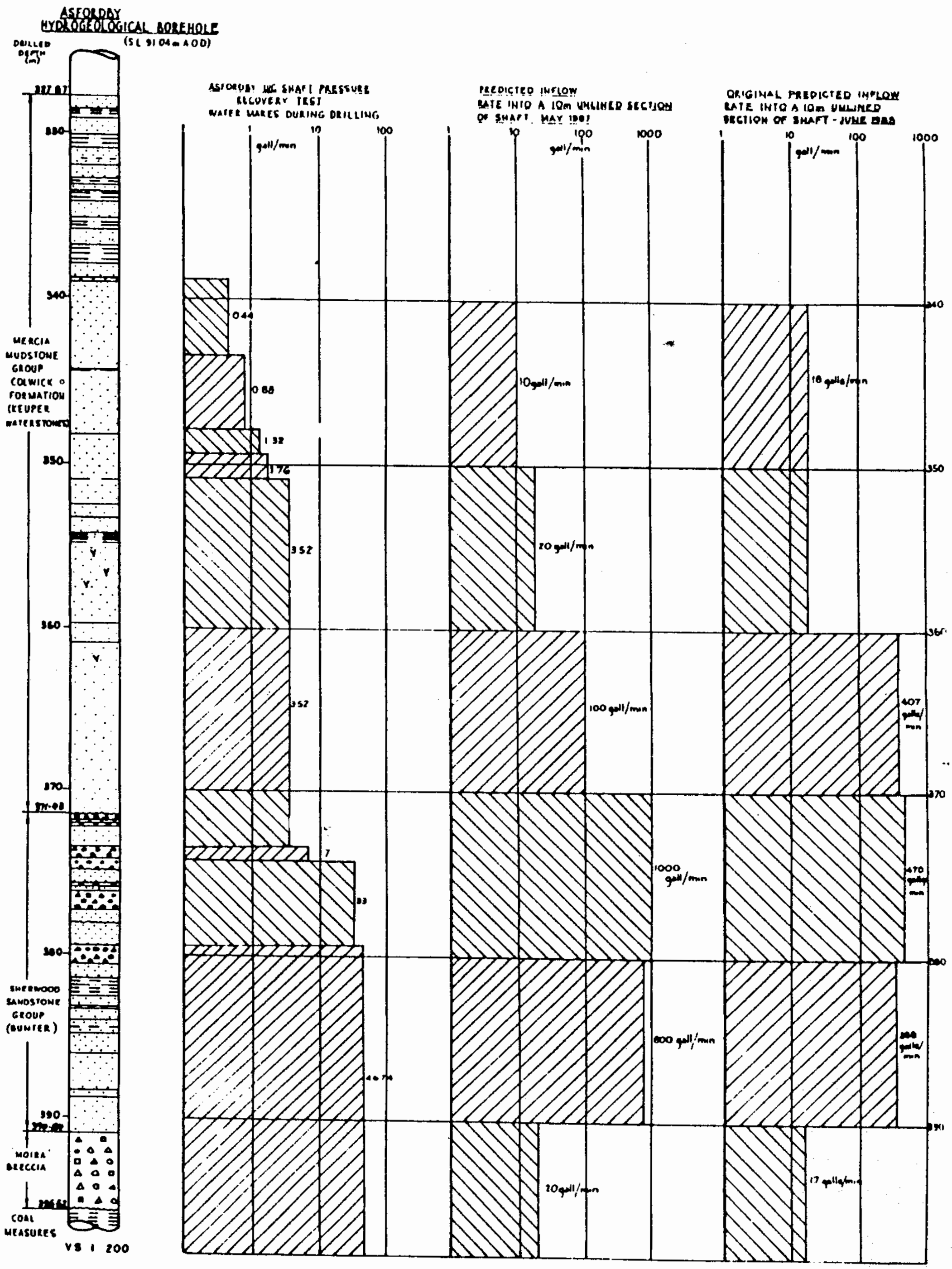

Fig. 4 Groundwater Profiles from Upcast Shaft Borehole

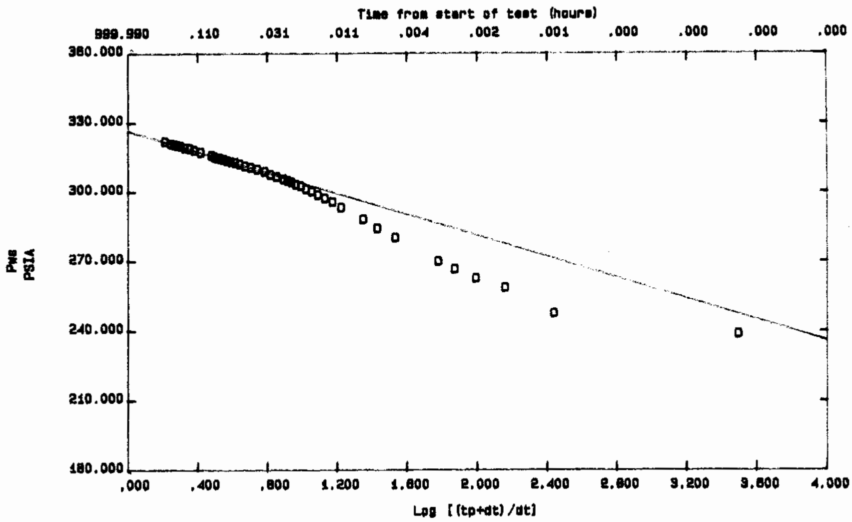

Fig. 5 Asfordby Upcast Shaft: Horner Plot

Below 360m the correlation is not good: the proposed increase in permeability between 366 and 371m was not proved and is therefore reflected in a lower predicted inflow rate of 7.61/s. For the 10m section between 371 and 381m, the predicted inflow rate for the Sherwood of 35.61/s was based on an average permeability of 7.5E-6m/s from the DST. This value of permeability is less than half the 1.6E-5m/s derived from the PRT. Predicted inflow rates based on the revised figure have been estimated up to 75.81/s. This apparent very significant increase in predicted inflow rate can be attributed directly to the poor quality of the Drill Stem Test data recorded in 1983. To illustrate the comparison, data recorded from the DST 3a between 371-381m is shown plotted in Fig. 6. The high scatter of data points make it very difficult to accurately define a permeability gradient. This poor quality of data has been attributed to the very short flow times (typically less than 3 mins) and the low resolution and sampling frequency of the downhole instrumentation.

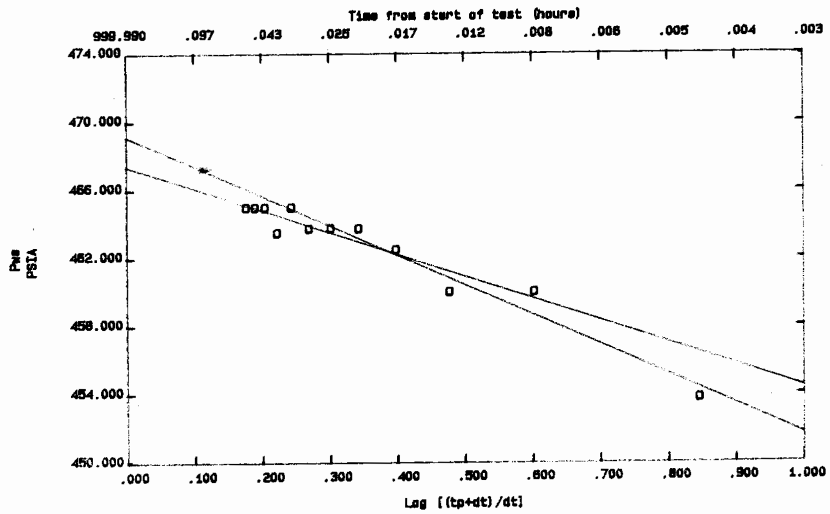

Fig. 6 Asfordby Hydrological Borehole DST 3a: Horner Plot

CONCLUSIONS

The detailed hydrogeological and geotechnical investigations and subsequent analysis required prior to the construction of a new mine shaft in waterbearing strata has been demonstrated by reference to British Coal's new mine at Asfordby.

The problems encountered during the testing of high permeability sandstones when using standard oil field based technology have been highlighted in comparison to the quality of the data achievable from an underground PRT where a much larger quantity of water can be extracted from the aquifer. The problems encountered at Asfordby prompted British Coal to radically redesign their downhole testing procedures and equipment. Downhole test assemblies now incorporate fluid evacuation, full bore flow area, and real-time monitoring from above and below the downhole valve that is capable of sampling changes in pressure and temperature at frequencies of less than 1.3 secs.

The ground freezing method was employed, in a relatively unusual application from an in-shaft freeze chamber at 275m depth, to contain potential inflows of more than 75 l/s (1000gpm) and allow the shafts to be sunk successfully through the weak water bearing strata.

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REFERENCES

1. Geological Society of London, The logging of rock cores for engineering purposes. Engineering Group Working Party Report Q.J. Engng. Geol Vol 3 pp 1-24 (1970).

2. Lloyd J.W. and Jeffery R.I. Deep Aquifer Testing Methods and Data Interpretation. Z.dt.geol.Ges Vol 134 pp 871-884 (1983).

3. Horner, D.R. Pressure build-up in wells. Proc. 3rd World Petroleum Congress, Leiden, pp 503-521 (1951).

4. Harvey, S.J. and Martin, C.J.H. Construction of the Asfordby mine shafts through the Bunter Sandstone by use of ground freezing. Proc. 5th Int. Symp. Ground Freezing, Nottingham, July (1988).

5. Daw, G.P. Application of aquifer testing to deep shaft investigations. Q.J. Engng Geol. Vol 17, pt 4 pp 367-379 (1984).