A REAPPRAISAL OF INVESTIGATIONS INTO STRATA PERMEABILITY CHANGES ASSOCIATED WITH LONGWALL MINING

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ABSTRACT

Longwall mining results in a redistribution of strata stresses, which affect the natural insitu permeability regime. After a brief review of current conceptual models used to explain this phenomena, a comprehensive examination is made of all results obtained from investigations undertaken by Nottingham University to monitor insitu permeability changes under field conditions. To facilitate a unified approach, all the original results, where available, have been re-analysed using cumulative difference analysis. The results are discussed with respect to three identifiable areas which occur around a longwall panel: ahead of the face line, the face end and the ribside pillar.

INTRODUCTION

Extraction of coal by longwall mining results in a redistribution of stress in the surrounding strata. This in turn causes 'strata failure' on both the micro and macro level, with a resultant change in insitu permeability. A change in strata permeability can affect the migration of fluids, such as water or methane, through the rock mass and into the mine workings. Gradual or rapid changes in these migrations can alter localised mining conditions and lead under exceptional circumstances to disasterous consequences.

A research group over the past five years has conducted a series of investigations, using field techniques, to monitor insitu permeability changes within British Coal Measures strata [1, 2, 3, 4].

The object of this paper is to examine existing work undertaken by the University and present a comprehensive understanding of the changes in permeability which occur around a longwall extraction panel.

CONCEPTUAL THEORIES ON PERMEABILITY CHANGE

Two distinct conceptual theories exist to explain the mechanism of permeability change associated with longwall extraction. McPherson [5] proposes that the induced forward abutment stress due to mining results in the microfracturing of strata ahead of the face and in particular along bands of inherently weak rock, such as coal seams. This occurs in front of the face, both above and below the working horizon. Induced strain causes partial sealing to occur along the planes of microfracture, which reduces permeability to a level below that of the virgin strata.

Other workers have suggested that once microfracturing starts to occur within the strata, it intensifies in magnitude with increasing face proximity. In both models, a face position is reached when macrofissure development becomes dominent. However, once extraction has occurred and the stress becomes relaxed, a large increase in strata permeability occurs, where the degree of relaxation experienced is dependent upon physical properties of the sorrounding strata. Similarly, once caving and initial compaction has occurred, further time dependent compaction of the goaf material will result in a decreased level of permeability below the maximum value obtained, but still above the original virgin value.

FACE ADVANCE VS. PERMEABILITY

The spatial position of each test site in relation to the extraction panel is given in Figure 1. However, a full description and discussion of each site is considered beyond the scope of this paper and has already been adequately covered by other authors [1, 2, 3, and 4].

Existing work allows the permeability change around a longwall extraction to be divided into three identifiable areas:

(1) Permeability ahead of the Face

(2) Permeability at the Face End

(3) Permeability in the Ribside Pillar

The test data has been analysed using a variety of techniques, including cumulative sum analysis [4, 6]. However, it was concluded that all the test data should be re-examined for overall trends, rather than attempt an interpretation based on individual or consecutive readings. Cumulative sum difference analysis was therefore adopted for each test site. This technique involves calculating the difference between consecutive readings and summing the resulting values. In this way, fluctuations within the original data are smoothed and the results can be examined for positive or negative trends with respect to increased face proximity to the test site. Using this technique, a series of hypothetical fluctuating test results which produce a straight line, will indicate that no overall change in permeability is occurring with increased face proximity [7].

PERMEABILITY AHEAD OF THE FACE

Two sites have monitored permeability changes ahead of the face line and full details of these can be found elsewhere [3, 4]. At site 1, Lynemouth, the cumulative difference graphs, Figures 2 - 7, show that until the face comes to within 70 m of the site, strata permeability values remain remarkably consistent in all the test cavities, even allowing for minor fluctuations. These values can therefore be used to estimate virgin insitu strata permeability. Once 70 m is exceeded, a general increase in

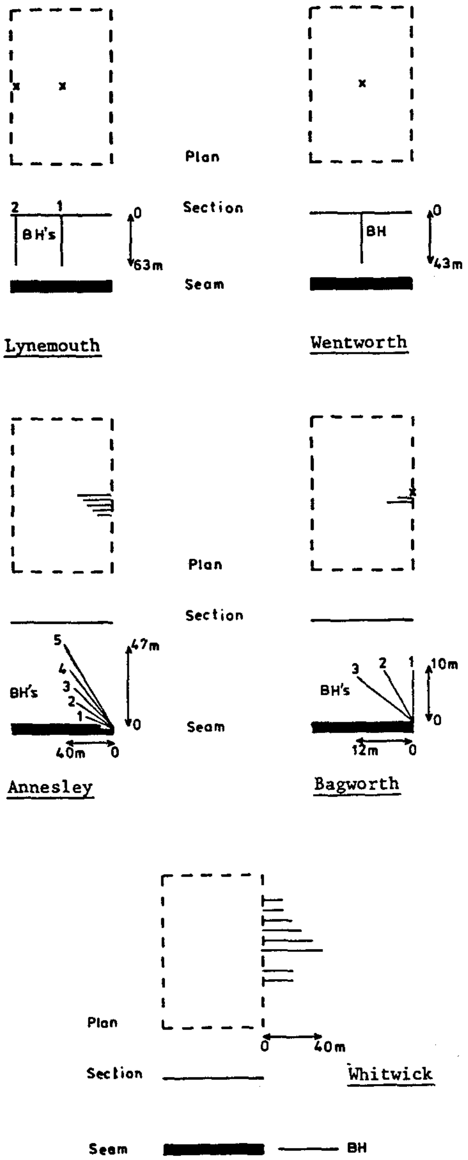

Figure 1 Spatial Position of the Test Sites in Relation to the Extraction Panel

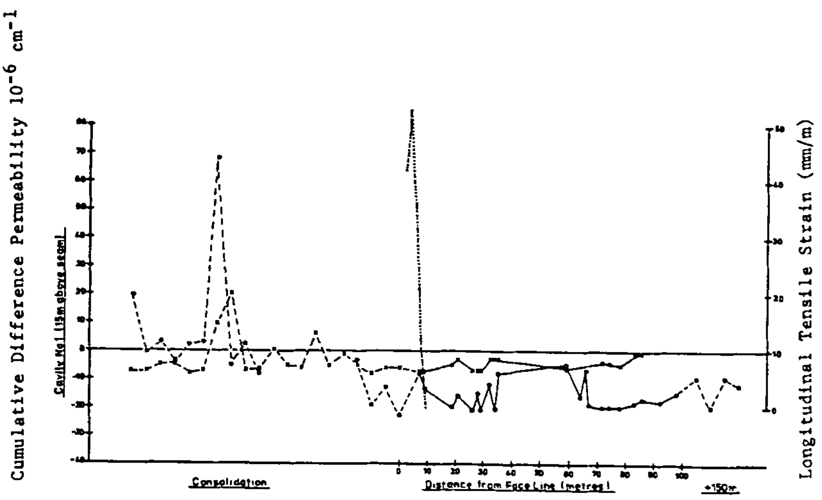

Figure 2

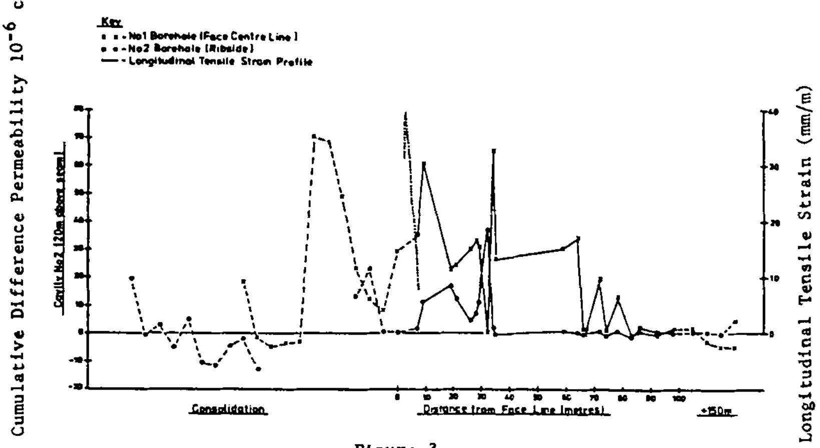

Figure 3

Figures 2 and 3 Cumulative Difference Permeability Values for Lynmouth Nos 1 and 2 Boreholes, Cavities 1 and 2 against Distance from Face Line

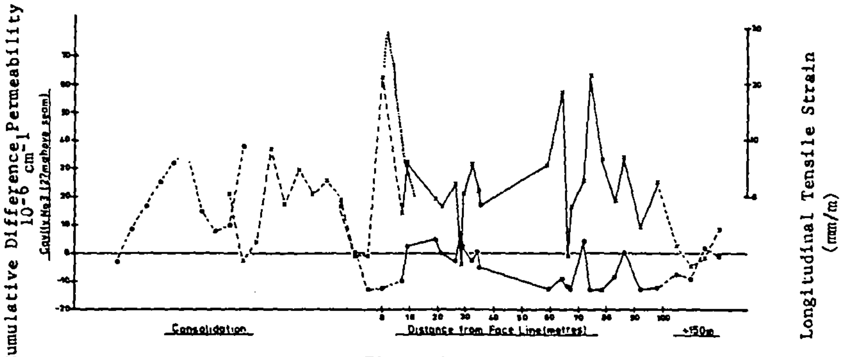

Figure 4

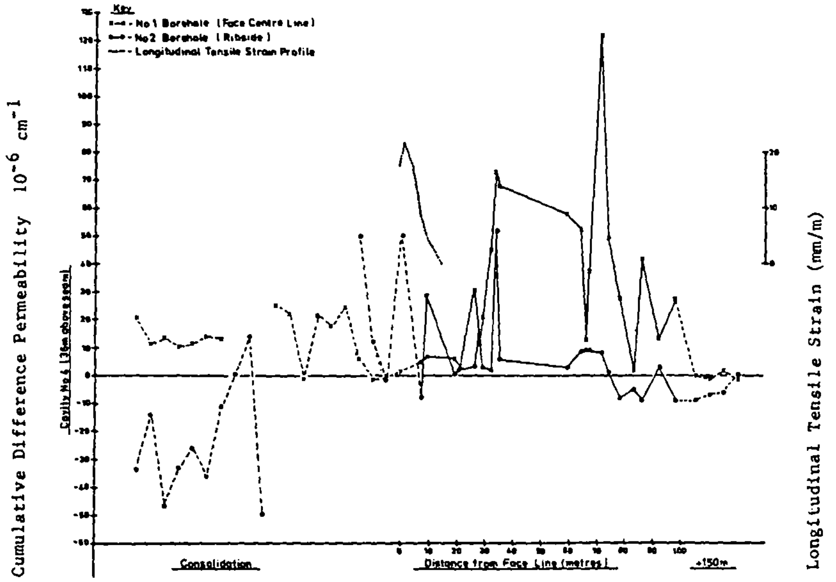

Figure 5

Figures 4 and 5 Cumulative Difference Permeability Values for Lynmouth Nos 1 and 2 Boreholes, Cavities 3 and 4 against Distance From Face Line

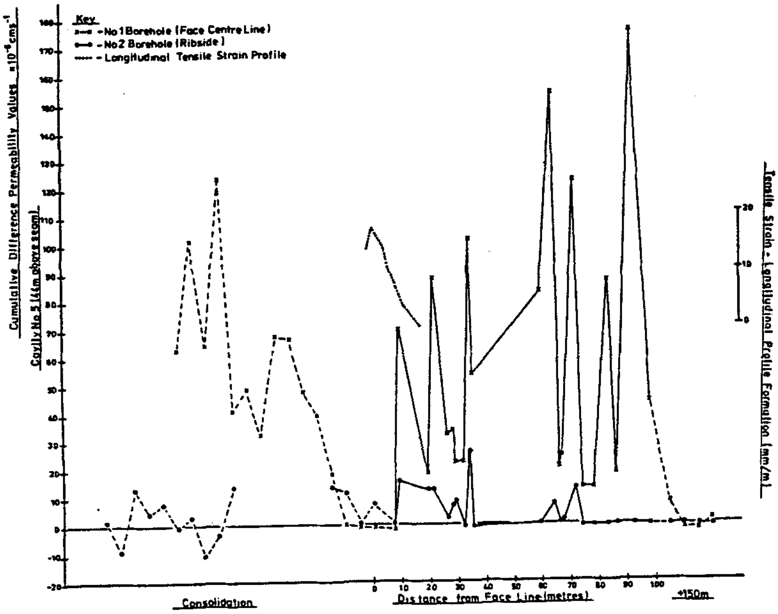

Figure 6

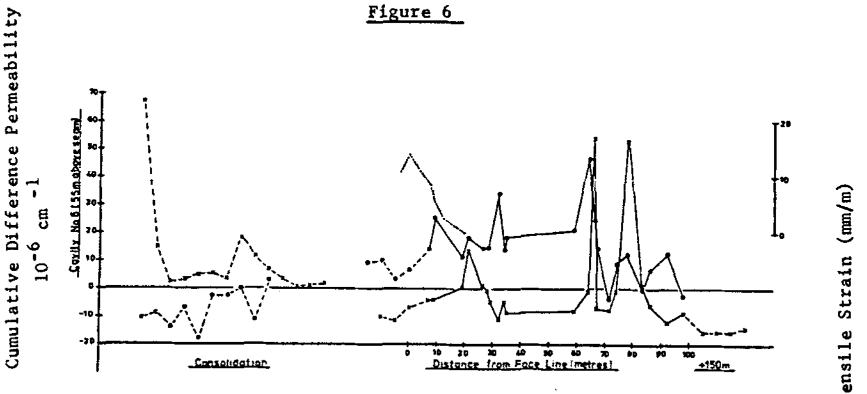

Figure 7

Figures 6 and 7 Cumulative Difference Permeability Values for Lynmouth Nos 1 and 2 Boreholes, Cavities 5 and 6 against Distance from Face Line

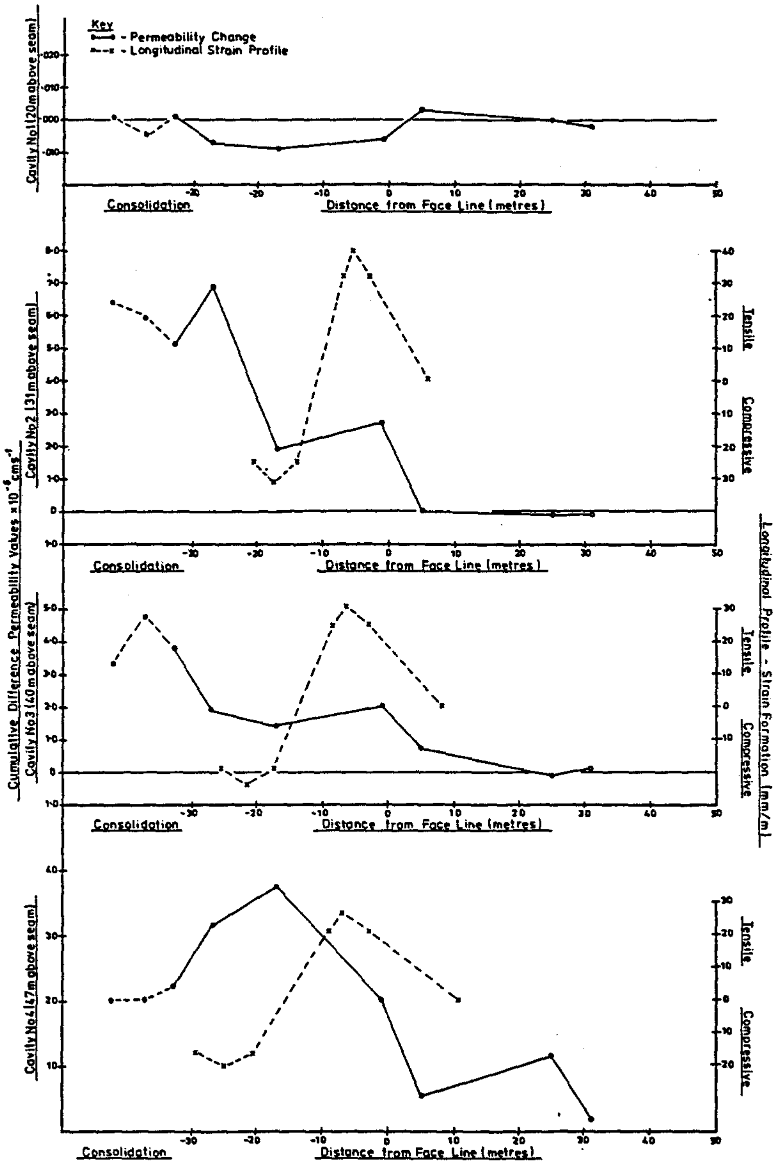

Figure 8 Cumulative Difference Permeability Values for the Wentworth Test Cavities against Distance from Face Line

permeability occurs, with significant fluctuations occurring at 30 m and 10 m from site. Although the face stopped 7 m in front of the site, readings were continued to monitor consolidation effects and an increase in permeability in this region can be seen for all test cavities. This can be associated with the time dependent effects of strata consolidation and a redistribution of stresses.

The fluctuation in permeability indicates that strata behaviour is occurring in discrete units rather than as a typically elastic deformation. This can be explained by the variable lithological and structural properties exhibited by different rock types. The effect of test site geology on the measured permeability is fully discussed elsewhere [7 , 8]. It has been observed that changes first begin to occur at the top of the site and move progressively downward as the face advances, with the onset of change appearing independent of rock type [4]. However, this only indicates when changes begin to occur, rather than their actual magnitude. Similarly, it has been shown that permeability does not appear to increase linearly or otherwise with increased height above the seam and that both the top and bottom test cavities experienced changes within the same order of magnitude [4].

Vertical strain development was also monitored at the site, although the results were disappointing since it was not undermined. However, an initial drift demonstrated that permeability fluctuations were occurring without large and obvious changes in ground strain [4]. Conventional subsidence theory predicts that the onset of longitudinal tensile strain should occur between 12 - 13 m in front of the face line [7, 9]. However, when these values are superimposed onto the cumulative difference graphs, Figures 2 - 7, fluctuations and a general increase in permeability are seen to start well in advance of the conventionally predicted values.

At site 2, Wentworth, a steady increase in permeability associated with face advance, in all test cavities (except No. 1), can be seen until 20 m passed site, Figure 8. A general decrease then occurs, which is associated with the onset of consolidation effects. Although the face stopped 33 m passed the site, readings were continued to monitor consolidation effects.

Conventional subsidence theory predicts that in the top test cavity, No. 4, the onset of permeability change, if linked directly to longitudinal tensile strain, will occur 11 m in front of the face. Longitudinal tensile strain profiles have been superimposed onto the other test cavities, Figure 8, and show that the onset of permeability change occurs well in advance of the conventionally predicted values [7]. The extremely low permeability values seen in test cavity No. 1 are due to a blockage caused during installation.

Finally, it is suggested that the onset of permeability change occurs well in advance of that observed by the onset of surface subsidence, by a distance of 40 m [4]. However, small dilations seen on the extensometer wires cannot be confidently linked to permeability onset curves, since at this degree of precision the variable tension extensometer is at the limit of its measurable accuracy.

PERMEABILITY AT THE FACE END

Two sites have monitored permeability changes in the face end region and full details of these can be found in earlier publications [2, 4].

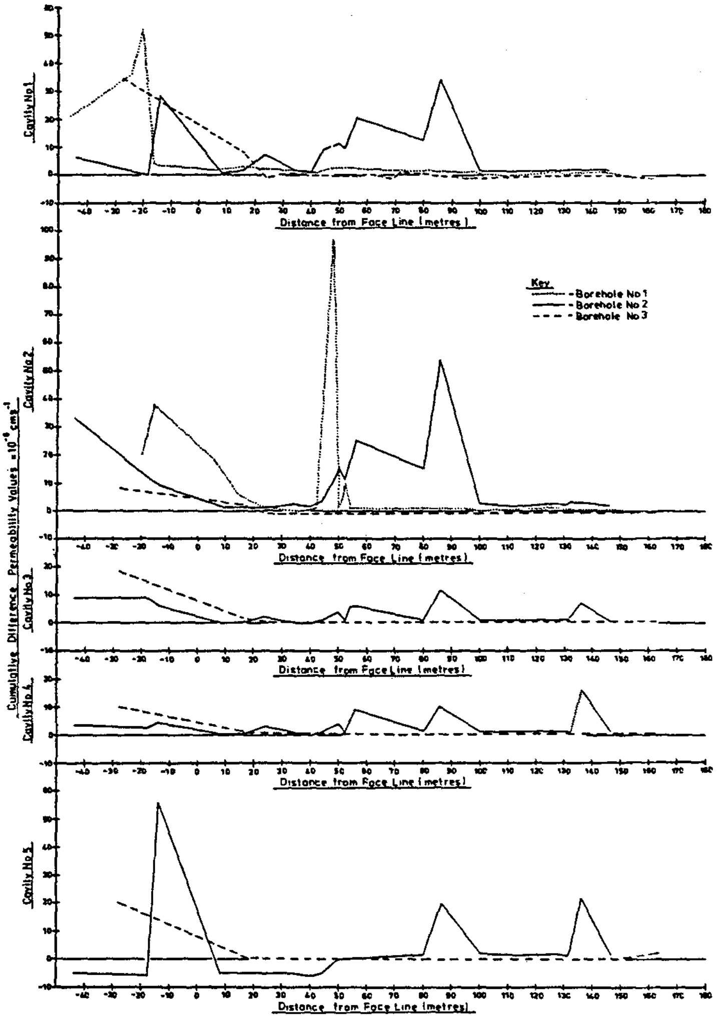

Figure 9 Cumulative Difference Permeability Values for the Bagworth Test Cavities against Distance from Face Line

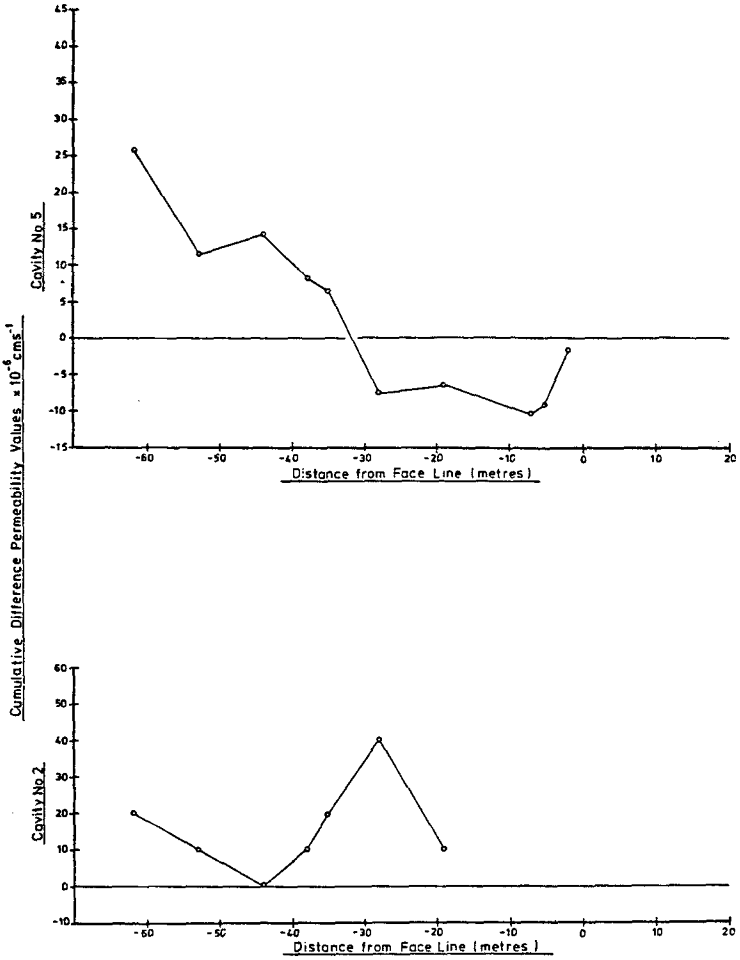

Figure 10 Cumulative Difference Permeability Values for the Annesley No. 2 and 5 Test Cavities against Distance from Face Line

At site 1, Bagworth, consistent base permeability values are seen until the face is 20 m from site, after which a general increase occurs, Figure 9. However, some fluctuations are seen prior to 20 m, with significant ones observable at 140 m, 85 m and 50 m from site.

Records show that in holes 1 and 2 an increase in permeability is seen in going from the lowest to the highest test compartments, with increased face proximity [4]. However, in hole 3 a negative gradient occurs, with the highest compartments being affected first.

Roadway deformation measurements were correlated with the onset of permeability in the boreholes. In holes 1 and 2, no effect of increased permeability associated with roadway closure can be found, although in hole 3 there does seem to be a correlation. To explain this, if the roadway is initially sited in solid ground, then as the face advances, interaction occurs within the strata surrounding hole 3, which in turn affects the bridging properties of the strata overlying the roadway [4]. Initial permeability responses seen in the two inclined holes (1 and 2) might be due to yield zone effects in the roadway periphery which have been aggravated by increased face end proximity.

At site 2, Annesley, monitoring was only successfully undertaken once the face had passed the site. It was observed that a variation in flow exists between test cavities when compared with the face position [2]. Similarly, a progressive upward movement in permeability occurred behind the face line which it is thought was related to the opening and closure of natural strata discontinuities and bed separation networks during undermining. However, at a point 40 m behind the face line, consolidation effects are seen to start reducing the overall permeability changes experienced.

Examination of the cumulative difference graph, Figure 10, reveals a general increase in permeability once the face has passed and this appears to occur at all levels in a progressively upward manner, irrespective of test cavity geology. Readings from only two test cavities have been plotted due to data availability problems. Some fluctuations do occur, but it is unfortunate that more readings could not be obtained prior to the face reaching the site, thus allowing changes in this region to be monitored and compared with those from Bagworth.

PERMEABILITY IN THE RIBSIDE PILLAR

One site exists at which investigations into the permeability changes associated with barrier and ribside pillars have been monitored [1].

If a pillar is constrained both vertically and horizontally along its major axis, the direction of principal stress should lie towards the extracted region and result in the formation of fissive networks, which run parallel to the pillar edge. It has been shown, [1], that a zone of gradual fracture promotes flow with increasing depth into the pillar and that once the face has passed, equilibrium becomes established when the face is approximately 120 m behind the site [1]. A correlation between vertical roadway closure and flow characteristics and hence the pillar permeability, appears to exist. It is therefore proposed that a stress abutment zone develops near the pillar edge, which is similar in nature to that experienced during longwall advance [10].

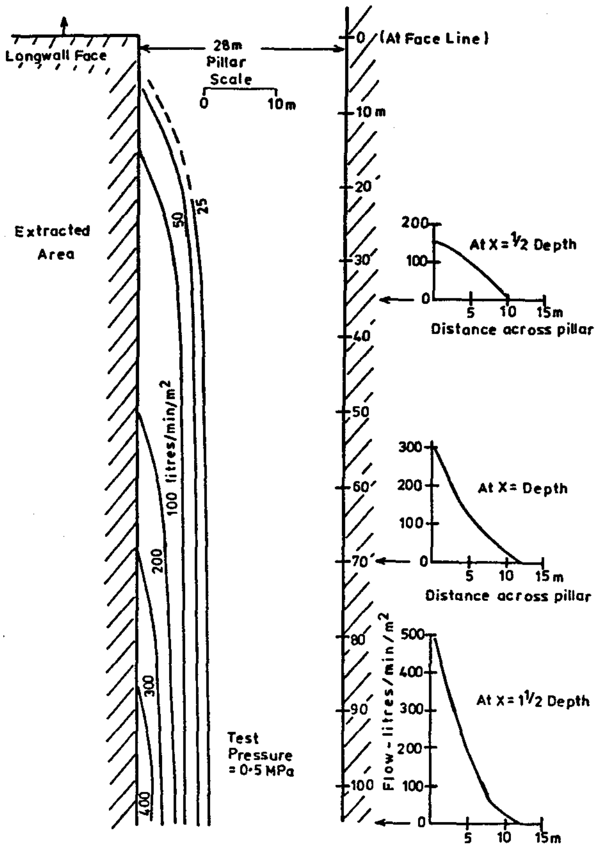

Figure 11 Iso-flow Lines for a Ribside Coal Pillar, Whitwick Colliery

(after Whittaker and Singh (1))

No cumulative difference analysis was undertaken, although flow characteristics within the pillar are shown as iso-flow lines in Figure 11. Flow appears to increase appreciably within the first 5 m of pillar, after which a steady decrease occurs, which eventually becomes minimal at a distance of greater than 10 m. It is therefore concluded that a narrow fracture zone develops in the pillars of shallow workings, before confining pressures within the pillar core significantly reduce the effect of increased permeability. Similarly, in deeper workings, a more intense fracture zone will occur which increases both the flow rate and penetration depth into the pillar.

DISCUSSION OF RESULTS

The overall objective of the investigation was to monitor permeability changes associated with subsidence profile formation around longwall extraction panels. In essence, this has been achieved although certain limiting criteria and generalized assumptions have been necessary when interpreting the data.

The Bagworth site was only installed on the understanding that the boreholes would not exceed a vertical height of 10 m. The resultant test cavities were therefore sited in close proximity to the roadway and may have been subject to the effects of yield zone formation.

The Lynemouth and Wentworth sites both reveal that permeability changes cannot be directly linked to conventional subsidence theory. However, permeability does appear to be a sensitive indicator of change in strata behaviour occurring around dynamic longwall extractions, which cannot be monitored by conventional instrumentation techniques.

At Wentworth, the magnitude of the permeability changes experienced were considered very small for such a shallow site, with the greatest change being monitored near surface rather than near the seam [4]. This might be due to physical properties of the intervening strata accommodating most of the induced strain. Similarly, effects in the topmost strata section may have been altered by a change in physical properties due to weathering.

At Whitwick, the current design criteria for barrier and ribside pillars, based on one tenth depth, appears to provide an adequate margin of safety even though it was not devised on a permeability basis. Finally, at each of the sites monitored, potential errors may exist due to instrumentation and/or operational errors, although their magnitude is difficult to quantify.

CONCLUSION

Changes in strata permeability can be linked to the induced ground strains formed around longwall extractions during subsidence profile formation. However, insufficient data exists at present to quantify these effects and either confirm or dispute the model concepts mentioned previously. Data from a great many sites is still required before permeability changes occurring around a longwall extraction can be either comprehensively understood or predicted by empirical methods.

ACKNOWLEDGEMENT

The authors would like to acknowledge the assistance provided by the National Coal Board and their departmental colleagues in the support of this research work. The views expressed in this paper are those of the authors and not necessarily the National Coal Board.

REFERENCES

1. Whittaker, B. N. and Singh, R. N., "Design aspects of barrier pillars against water logged workings in coal mining operations", Symposium on Water in Mining and Underground Works, SIAMOS 1978, Granada, Spain, Vol. 1, pp. 675-692.

2. Whittaker, B. N., Singh, R. N. and Neate, C. J., "Effect of longwall mining on ground permeability and sub-surface drainage", 1st International Mine Water Drainage Symposium, Denver, May 1979.

3. Neate, C. J. and Whittaker, B. N., "Influence of proximity of longwall mining on strata permeability and groundwater", 20th U.S. Symposium on Rock Mechanics, Austin, Texas, June 1979.

4. Neate, C. J., "Effects of mining subsidence on the permeability of coal measures rocks", Ph.D. Thesis, University of Nottingham, October 1980.

5. McPherson, M. J., "The occurrence of methane in mine workings", Jl. Mine Vent Soc of SA, Vol. 28, No. 8, August 1975.

6. Picteau, D. R. and Russell, L., "Cumulative sums technique - A new approach to analysing joints in rock", Proc. Symposium on Rock Fracture, Nancy, France, 1971.

7. Aston, T. R. C., "Hydrogeological aspects of rock mechanics and mining subsidence around longwall extractions", Ph.D. Thesis, University of Nottingham, October 1982.

8. Aston, T. R. C. and Singh, R. N., "The insitu permeability of coal measures strata associated with longwall mining", Paper in Preparation.

9. Subsidence Engineers Handbook, (1975), National Coal Board, Production Department, London.

10. Whittaker, B. N. and Singh, R. N., "Evaluation of the design requirements and performance of gate roadways", Trans. IME (Mining Engineer), February 1979, pp. 101-119.