SUBSIDENCE EFFECTS IN THE UNDERSEA COALFIELD WORKINGS OF NORTH-EAST ENGLAND

B. N. Whittaker and T. R. C. Aston

Department of Mining Engineering
University of Nottingham
Nottingham, UK

ABSTRACT

The paper discusses effects of mining subsidence on the undersea workings of two coal mines, Blackhall and Westoe, in the North-East of England Coalfield. The general production methods, mine geology and means of water access to the workings at both coal mines are outlined and identified. The predicted tensile strain at two significant horizons, the base of Permian and seabed is discussed in relation to the occurrence of water on faces where it has been experienced. Various origins and transmission mechanisms of this water to the faces is also mentioned. Finally, a comparison of occurrences at the Blackhall and Westhoe workings reveals that water can be expected on any face near to a large fault, where potential aquifer horizons have been thrown into close proximity with the working district

INTRODUCTION

The historical depletion of inland reserves within the North-East Coalfield has necessitated working of the vast reserves which extend eastwards beneath the North Sea. Eight coastal coal mines currently produce about 60% of the area output from these reserves. However, as the workings continue to extend eastwards beneath the sea, the problems and costs associated with coal production increase.

One of the major problems associated with undersea mining or for that matter mining under any large surface water body or sub-surface aquifer, is prevention of water entering the workings. In the North-East Coalfield there has always been a general and healthy respect against the tapping and subsequent breakthrough of not only the sea, but also an 'underground sea' contained within the overlying Permian strata, Saul [1].

As a result of this and other experiences within various parts of the country, individual collieries and areas have always followed codes of practice, which it was hoped would prevent a major water occurrence within the workings. However, during the mid 1960's it was decided that these codes of practice should be rationalised and in 1968 the

National Coal Board issued an Instruction PI/1968/8 - 'Working Under the Sea' [2]. In summary, this states that for extraction by longwall methods 'the cover between the worked seam and seabed shall not be less than 105 m of which 60 m must be of Carboniferous strata. The tensile strain at sea-bed shall not exceed 10 mm/m for both first and successive seam workings.' Similar criteria are also laid down in the instruction for extraction by 'room and pillar' methods.

The object of this paper is to examine the geological conditions and predicted tensile subsidence strains with respect to water occurrences which have been experienced at two of the Durham coastal coal mines.

MINING SUBSIDENCE

In Great Britain the National Coal Board Subsidence Engineers Handbook (SEH) [3] allows prediction of surface subsidence to within an accuracy of 10%. However, in many cases it is necessary to calculate predicted strains for a sub-surface horizon from which water may originate. Observations by the National Coal Board have revealed that the SEH can provide an acceptable indication of strains at sub-surface strata interfaces as well as the normal strata-surface interface.

It should be noted that when dealing with subsidence strains, it is not so much actual strain values which are calculated, but rather a measure of the amount of deformation or displacement which the strata is being subjected to. Tensile strain represents a measure of strata separation, while compressive strain indicates a measure of strata compaction. This is supported by evidence collected during the monitoring of surface subsidence profiles, SEH [3]. Both these factors are important when considering the potential flow of water through disturbed strata.

Neate et al [4],[5] have established by field observation that stress redistribution around longwall workings does influence the in situ permeability of the surrounding strata and consequently the potential through flow of water. Garritty [6] lists 17 parameters which may effect the flow of water from an aquifer or water body to a working horizon. However, with only a few of these parameters is it possible to determine the effects, while others are considered either negligible or impossible to quantify under all but strict laboratory conditions.

NORTH-EAST COALFIELD

The location of the North-East Coalfield is shown in Figure 1. The two coastal coal mines under consideration, Blackhall and Westoe, along with the coalfield solid geology are shown in Figure 2.

The Coal Measures of the North-East, constitute an approximate triangle of area 2000 km^2. The sequence is some 725 m thick and can be divided into two parts: (1) a western exposed field and (2) an eastern concealed field. In the east, the Coal Measures are hidden beneath a transgressive cover of Permian rocks, the dominent member of which is the Magnesium Limestone. These outcrop along the Durham coast from the river Tyne to West Hartlepool, where they are faulted against the Trias. The main Permian outcrop does not extend north of the Tyne into Northumberland, Trueman et al [7].

The structure of the coalfield is comparatively simple and forms a classical irregular basin, with an axial trend of NW to SE. The strata dip eastwards at 5-10° beneath the North Sea, where they have been proved to extend 10 km by offshore boreholes. In the Durham Coalfield, the dominant structural feature is a pitching syncline, with an axis that trends SE. The coalfield is traversed by two main fault systems:

1) ENE to WSW
2) N-W to S-E

Minor fault systems are also found which can trend either N-S or E-W.

Two systems of intrusive igneous dykes traverse the coalfield. Geological evidence suggests that one (ENE to WSW) is of Upper Carboniferous age, while the other (ESE to WNW) is Tertiary, Trueman et al [7]. Mineral veins of barytes, galena and witherite are also found associated with the Coal Measures. Finally, both the dykes and large structural faults are thought, in most cases, to penetrate from the Coal Measures into the overlying Permian strata.

BLACKHALL COLLIERY - PRODUCTION METHODS

Production at Blackhall Colliery ceased during the early part of 1981, due to cumulative problems associated with water on the working districts. Extraction was restricted to single seam working in the Low Main (J) seam , although in the vicinity of the shaft, some working of the Hutton (L) seam has occurred. Development progressed steadily eastwards until at the time of closure, the workings extended some 8 km from shaft bottom.

Figures 3 and 4 show the workings currently under investigation, which only include those dating back to the late 1960's. A large E-W fault known as the Blackhall Fault, bisects the workings and conveniently divides them into the north and south areas.

In the southern area, workings comprise a J10 series which run parallel to the Blackhall Fault. A J20 series was then worked perpendicular to the fault and in all but one case terminated beneath it with considerable water problems. As a result, the J50 and 60 series were reorientated to run parallel to the fault. Face widths of about 200 m were used for the J10 and J20 series. However, the severe water problems encountered on the J20 series, resulted in a face width reduction to 65 m for the J50 and J60 series.

The Blackhall Fault was crossed in 1971-72 with little water being encountered. A J30 series of faces initially with widths of 200 m were developed eastwards running perpendicular to the fault. However, water problems encountered on some of these, plus those in the southern area resulted in face width again being reduced to 65 m. In some cases the J30 series terminated against a small E-W fault with a throw of between 7 - 12 m.

BLACKHALL COLLIERY - MINE GEOLOGY

Figure 5 shows geological sections across the north and south areas of the Blackhall workings.

In general, the overlying Coal Measures strata comprises a variable, interbedded sequence of sandstones, siltstones, mudstones and seatearth/ coal seams typical of a cyclothermal sequence. In the southern area, the thickness of cover between the Low Main (J) seam and base of Permian (BOP) thins to the east and south east. North of the Blackhall Fault the amount of cover thickens rapidly eastwards. Similarly, the localised strata lithology varies between the two areas. The thick sequence of sandstones above the High Main (E) seam in the north are not as well developed in the south. In both areas, the strata dips eastwards. Similarly the variable nature of the coal seams in the form of splitting and rejoining can be seen, particularly in the Maudlin (H) seam.

The Blackhall Fault is thought to be of a 'Hinge' type, with its 'pivot' somewhere to the west and a throw which increases progressively to the east (13-37 m). Numerous small faults have been intersected within the workings. In the southern area, most of these appear as low angle, small displacement (< 1 m) faults which trend NW-SE and are thought to be associated with a washout structure which crosses the area. Some larger faults (up to 5 m) have been encountered, but these are thought either to be associated with the Blackhall Fault or one of the minor regional trends mentioned previously.

BLACKHALL WATER OCCURRENCES

Two means of water access to the Blackhall workings have been identified which are discussed individually:

1) Development Roadways

All water yields encountered during roadway development have been very small in comparison with those encountered on the production faces. The water occurs as either small feeders or droppers and seldom constitutes more than a nuisance value.

2) Production Faces

All major water occurrences encountered within the workings have been associated with longwall faces. Figures 3 and 4 show the faces worked since the late 1960's which have experienced water, along with the maximum and current yield (November 1979). In each case, the water occurred as either intermittent or continuous droppers and/or feeders along the face line. Residual yields have also been encountered from the 'goaf' area.

BLACKHALL - WATER YIELD AND PREDICTED SUBSIDENCE

A total of 35 faces within the Low Main (J) seam, worked between 1967 and 1979 have been examined. Of these 19 (51%) have experienced water in more than nuisance quantities. A distribution of these occurrences is summarised in Table 1 and conveniently allows division into areas north and south of the Blackhall Fault:

1) Workings South of the Blackhall Fault

Figure 4 reveals that with the exception of J93, all the J20 series faces which worked perpendicular to the Blackhall Fault produced water in significant quantities. Predicted tensile strains at the base of Permian (BOP) of 6-8 mm/m and up to 2 mm/m at sea-bed could therefore be associated with these occurrences. However, not all the reorientated J50 and J60 series faces experienced water with tensile strains of 4-6 mm/m at BOP and upto 1 mm/m at sea-bed. Similarly, tensile strains of upto 7 mm/m at BOP on J11, J12 and J13 can only be associated with small quantities of water on J11.

2) Workings North of the Blackhall Fault

Figure 3 reveals that 4 faces encountered water and of these 3 have tensile strains at BOP of 6-7 mm/m, while one, J35 has a predicted BOP strain of 3 mm/m. The 7 remaining dry faces of the J30 series have BOP strains varying between 2-5 mm/m. In each case, the predicted tensile strain at sea-bed is less than 2 mm/m.

Total Predicted Tensile Strain

Total strain can be calculated for the interaction of parallel worked faces and these are given in Table 2. In summary, maximum predicted tensile strains of between 7-9 mm/m are associated with wet and dry faces in both areas of the Blackhall workings.

BLACKHALL GEOLOGICAL-STRAIN-WATER RELATIONSHIP

The two areas of Blackhall workings can be discussed separately.

1) South of the Blackhall Fault

The J20 series faces have been worked perpendicular to the Blackhall Fault, where geological evidence suggests that the Permian in the north has been brought into contact with the upper Coal Measures sequences of the south. Similarly, the High Main (E) sandstones in the north will also have been brought into contact with even lower lithological sequences in the south. The 'pivotal' nature of the Blackhall Fault suggests that the Permian and Coal Measures contact starts near the J10 (south) series faces and increases eastwards to 30 m of overlap in the vicinity of J27. This would partially explain the relatively dry nature of the Blackhall workings prior to the mid 1960's.

Two further points connected with the Blackhall Fault are also considered important. Firstly, the fault may penetrate the overlying Permian and be subject to recharge from this source. However, the variable nature of the 'fault gouge' would affect the rate of through flow. Secondly, all faults usually have a host of secondary structural features associated with them, Sherbourne Hills [8].

Water occurrences on the J20 series faces are thought to originate from the interaction of longitudinal and transverse tensile strains on saturated Coal Measures strata, recharged over geological time from the Permian, which are intersected by secondary fault structures associated with the Blackhall Fault. Similarly, intermittent water problems associated with the J50 and J60 series faces can be related to the interaction of the tensile strain on thinning strata cover containing numerous small structural discontinuities and an upper region subject to recharge over geological time from the Permian.

A natural flow regime can be envisaged which comprises a vertical component from the overlying Permian and a horizontal component which comes through the Coal Measures from the Permian interface at the Blackhall Fault. The formation of induced fracture networks onto this regime will then allow water to be transmitted from a saturated horizon to the workings. However, the network must be of sufficient magnitude to remain unaffected by the various strata sequences through which it must pass. Under ideal conditions an initial flow will climb to a maximum yield and remain near this value if direct recharge is occurring from an infinite reservoir i.e. the sea or Permian. However, the highly variable nature of the Permian and Coal Measures results in the formation of 'reservoirs', which will have been filled over geological time. The tapping of such a reservoir will result in a maximum yield which will then either decrease to some residual value, indicating steady state conditions (water in = water out) or dry up.

In each of the southern area occurrences, a maximum yield has always decreased to some residual value, indicating a reservoir draining effect. This is supported by feeders tapped in exploratory underground boreholes, which have produced either steady or decreasing yields over short time periods before subsequent sealing of the hole.

2) North of the Blackhall Fault

The water occurrences on J31 and J35 are thought to be associated with the interaction of longitudinal tensile strain profiles on geological fault structures against which the faces terminated. However, the two occurrences on J15 and J32 of consistent yield are probably related to secondary structural features associated with the Blackhall Fault, especially since neither J16 or J31 experienced problems in this region.

WESTOE COLLIERY - PRODUCTION METHODS

Coal production is currently by longwall mechanised working from 7 faces in 3 seams; the Main (F1), Maudlin (H) and Brass Thill (K). The method of working is either advance or retreat with face widths of about 200 m and an extraction height varying from 1.3 m in the Maudlin to 2.0 m in the Main seam. Development has currently extended some 10 km east and north eastwards from the shaft bottom and can be conveniently divided into 3 areas: the northern, central and southern, by two large faults which cross the workings.

Figures 7 to 12 show the workings in each of the 3 seams.

WESTOE COLLIERY - MINE GEOLOGY

Figure 6 shows the geological sequence of Coal Measures strata across the Westoe workings based on 4 offshore boreholes. Two of the boreholes are situated in the northen area and one in each of the central and southern areas. The lithology comprises a classic cyclothermal sequence of interbedded coal/seatearth, mudstone, siltstone and sandstone. Similarly, not only does the lithology vary, but so does the amount of cover between the base of Permian (BOP) and the Main Seam for the different areas. Approximately 45 m of strata exists between the Main and Maudlin seams, with a further 30 m between the Maudlin and Brass Thill.

Two major east-west trending faults cross the workings. The Ninety Fathom Fault in the north, comprises a high angle 'normal' fault with a throw of 150 m, with the down throw side on the south. The St Hilda Fault in the south, comprises a NE-SW 'pivot' fault which increases in throw westwards but decreases to zero eastwards.

Two further important features at Westoe are:

1) intersection of the workings by tertiary dyke systems
2) an offshore buried river channel of the R. Tyne.

WESTOE WATER OCCURRENCES

Three means of water access to the Westoe workings have been identified and are discussed individually.

1) Development Roadways

In general only nuisance water in the form of droppers and small feeders have been encountered. However, drivages across the Ninety Fathom Fault from the central area Main Seam, experienced large quantities of water which required the use of cement injection sealing methods. Examination revealed that most of the water appeared on the north side of the fault and associated with a thick sandstone sequence in close proximity to the 'D' seam, rather than with transmission along the fault plane.

Water in nuisance quantities has also been encountered in Main Seam drivages in the northern area associated with the F60 series faces and in the central area in the east drivages of the F30 series faces.

2) Production Faces

In general only nuisance water has been encountered on the majority of faces worked in all 3 seams. However, several exceptions do exist in the Main and Brass Thill seams and these are discussed later.

3) Intersection of the Dyke System

Several dykes have been intercepted either by development drivages or production faces. In some cases they have proved dry, while in others very large quantities of water have been liberated over short periods of time. A dyke intercepted by a drivage in the region of face F11 produced a maximum yield of 4.5 m^3/min (1000 gpm) which decreased steadily with time to zero. Similarly, face 3W in the Brass Thill had to be shortened when a dyke was intercepted which yielded a feeder of 2.3 m^3/min (500 gpm).

WESTOE - WATER YIELD AND PREDICTED SUBSIDENCE

A total of 63 faces within the Westoe workings have been examined and the results tabulated in Tables 3 and 4. In summary, only 18% of the total faces worked have experienced water in quantities greater than nuisance value. Both the Main and Brass Thill seams have encountered 'wet' faces, but none have occurred in the Maudlin.

1) Main Seam - Wet Faces

Of the 7 Main Seam faces which have liberated water, 4 have been in the central area and 3 in the northern. The 3 northern area faces F55, F56 and 57 all liberated quantities between 0.6 and 1.2 m^3/min. Each was worked perpendicular and in close proximity to the Ninety Fathom Fault. Predicted tensile strain at BOP vary between 7-10 mm/m and at seabed 3-5 mm/m. In the central sector, 4 faces F20, 21, 24 and 26 experienced water in quantities from 0.6 to 1.2 m^3/min. In each case the face is near the Ninety Fathom Fault and in all but one, F20, the direction of working perpendicular to it. Predicted tensile strain at BOP indicate values of 7-8 mm/m and at sea-bed 3-5 mm/m. In the case of F20, the direction of working is parallel to the Ninety Fathom Fault with a predicted tensile strain at BOP of 6 mm/m and sea-bed 3 mm/m. It is also recorded that a feeder of 0.6 m^3/min occurred in the vicinity of a 2 m fault intercepted by the face.

The 16 Main Seam dry faces indicate BOP tensile strains of 4-6 mm/m and sea-bed strains of 2-4 mm/m.

2) Brass Thill Seam - Wet Faces

Although only 4 out of 31 faces are recorded as wet, the faces K25 to 34 are known to have produced considerable amounts of nuisance water. Investigations at the time, concluded that the water rather than coming from an intervening aquifer horizon originated from the previously worked Main Seam faces F1 to 10. The goaf areas acting as reservoirs for the collection of continuing amounts of nuisance water. The onset of working in the Brass Thill induced fracture zones which allowed drainage of the overlying Main Seam goaf reservoirs. This theory is supported by the subsequent drying up of drainage points, installed within the Main Seam goafs.

The 4 wet faces K24 and W1-3 are situated on the western boundary of the Brass Thill workings, with cover to BOP of 115 m and to sea-bed of 135 m. Predicted tensile strains at BOP indicate values of 6-8 mm/m and at sea-bed 5-7 mm/m. However, it should be noted that water encountered on face 3W was associated with a dyke rather than roof droppers/feeders. Quantities varied from 0.9 to 2.3 m^3/min.

The 27 remaining Brass Thill dry faces indicate BOP tensile strains of 3-7 mm/m and sea-bed strains of 2-5 mm/m.

Total Predicted Tensile Strength

Total predicted tensile strains for the interaction of parallel faces in the same and adjacent seams, indicate that for the Main F1-10, Maudlin H2-6 and Brass Thill K25-37 series faces, maximum strains of 14 mm/m at the BOP and 9 mm/m at the sea-bed occurred. This suggests that in the case of multi-seam workings a total predicted BOP strain of upto 14 mm/m can be induced without the occurrence of water.

WESTOE GEOLOGICAL-STRAIN-WATER RELATIONSHIP

A total of 82% of the faces in the Westoe workings have remained dry and in the case of multi-seam extraction upto 14 mm/m of tensile strain can be induced at BOP without the occurrence of water. It is therefore proposed that the variable nature of the Coal Measures strata allows accommodation of the induced tensile strains while retaining its impermeable barriers. Similarly, the remaining wet faces can be divided into one of two types.

1) Proximity to the Ninety Fathom Fault

All Main Seam faces worked near the Ninety Fathom Fault have experienced water and with the exception of F20, the direction of working has been perpendicular to it. A combination of three mechanisms can explain the occurrence of this water:

(i) Recharge across the fault from the saturated 'D' seam sandstones in the north to the overlying strata of the Main Seam in the south.
(ii) Recharge along the fault plane, either from the Permian or some intervening aquiferous horizon.
(iii) The existence of secondary structures assocaited with the main fault, Sherbourne Hills [8].

The superimposition of a tensile strain zone onto any or all of these mechanisms will then provide an access route for water to the working horizon.

In the Main Seam, the formation of a tensile zone around the wet faces F55, 56 and 57 will have aggravated secondary structures associated with the Ninety Fathom Fault, which in turn aided the passage of water from the saturated 'D' seam sandstones and/or fault plane to the workings. In the central area wet faces, F20, 21, 24 and 26, the tensile zone will again have aggravated secondary fault structures, which then aided the passage of water from overlying strata recharged by the 'D' seam sandstones over geological time and/or the fault plane.

In the case of the St Hilda Fault, where faces have been worked to within very close proximity but with no occurrence of water, two significant features do not occur here, which do exist at the Ninety Fathom Fault. Firstly, the fault increases in throw westwards, so the number and magnitude of secondary structural features decreases eastwards towards the workings. Secondly, a saturated lithological sequence has not been moved into close proximity with a working horizon allowing recharge over geological time to the overlying strata.

Finally, all Maudlin and Brass Thill faces worked in close proximity to the Ninety Fathom Fault, have remained dry and this is due to two main reasons. Firstly, all water transmitted along the fault plane will be intercepted at the Main Seam. Secondly, no saturated strata exists between the Brass Thill and Main Seam, to provide a recharge medium comparable with the 'D' seam sandstones.

2) Proximity to the R. Tyne Buried River Channel

The Brass Thill faces K24 and W1-3 have all experienced water in quantity, even though no adjacent seam working has occurred. However, a buried channel of the R. Tyne is known to cross this area with a possible depth of 60 m below sea-bed. A depth of cover of 75 m or less of Coal Measures strata may exist over these workings and the predicted tensile strain at BOP of 6-8 mm/m will be too low. A combination of shallow cover, of unknown height and lithology coupled with minor insitu structural discontinuities will have led to the occurrence of water with the onset of tensile zone formation. In the case of face 3W water was associated with the interception of a dyke, rather than roof feeders/droppers.

DISCUSSION - BLACKHALL AND WESTOE COAL MINES

Four main points need to be considered when comparing the occurrence of water at the Blackhall and Westoe coal mines:

1) Quantity of Water
2) Subsidence Prediction
3) Coal Measures Geology and Cover
4) Proximity of Faults

1) Quantity of Water

At November 1979, Blackhall Colliery was pumping 12.3 m^3/min (2700 gpm) of which 10.2 m^3/min (2235 gpm) could be directly related to 35 faces in the Low Main Seam. Westoe Colliery is currently pumping 8.0 m^3/min (1760 gpm) from workings associated with 63 faces in 3 seams. Some 18% of the Westoe faces have experienced water compared to 51% of the Blackhall faces.

2) Subsidence Prediction

At Blackhall Colliery total predicted tensile strains of upto 9 mm/m at the base of Permian have been associated with water, while faces with BOP strains of 7 mm/m have remained dry. At Westoe Colliery, areas of multi-seam extraction have remained dry with BOP strains of 14 mm/m while areas of single seam extraction with BOP strains of 6 mm/m have experienced water.

3) Coal Measures Geology and Cover

Little variation in the amount of strata cover exists between the faces at Blackhall and Westoe which experienced water and those that did not. In the case of both wet and dry faces, the amount of cover at Blackhall varied between 91 and 140 m for the Low Main Seam to BOP and at Westoe 113 to 177 m for the Main Seam to BOP.

Strata lithology and the degree of localised structural features within the overlying Coal Measures is thought to be of greater significance than the amount of cover when considering the likelihood of water occurrences to a working area.

4) Proximity of Faults

This is probably the single most important feature concerning water occurrences. Faces at both Blackhall and Westoe have experienced water when worked in both close proximity and perpendicular to a major E-W fault.

The Blackhall and Ninety Fathom Faults have both produced a situation, whereby potentially saturated horizons have been brought into close proximity with strata overlying working districts, allowing recharge over geological time. Similarly, secondary structural features associated with these faults, when affected by induced subsidence profiles will be closely associated with water occurrences on nearby faces.

CONCLUSION

Mine water experienced at the Blackhall and Westoe Collieries have been identified as originating from either the Permian or overlying Coal Measures aquifers. This evidence is supported by hydrochemical analysis of samples collected from water occurrences. Several mechanisms for the transmission of this water, via recharge systems, to strata horizons overlying potential working areas have been outlined. However, the final movement of water to the working district is very closely related to localised strata lithology and structural features onto which is then superimposed a tensile strain zone of magnitude proportional to the face parameters. In general, water can be expected on faces worked close to major faults, where potentially saturated strata have been thrown into close proximity with a working horizon.

Finally, no direct relationships can be established between the magnitude of the induced tensile strain at either the base of Permian or sea-bed and the occurrence of water on working faces.

ACKNOWLEDGEMENTS

The authors would like to thank the North-East Area of the National Coal Board for their assistance with this research and in particular the Area Subsidence Department and the Survey and Geological staff of the Blackhall and Westoe Collieries. The views expressed in this paper are those of the authors and not necessarily the National Coal Board.

REFERENCES

[1] Saul, H. Current Mine Drainage Problems. The Mining Engineer Vol. 129, 1969-70, pp 643-657

[2] Working Under the Sea (1968), National Coal Board, Production Department Instruction, London, PI/1968/8

[3] Subsidence Engineers Handbook, (1975), National Coal Board, Production Department, London.

[4] Neate, C.J. and Whittaker, B.N. Infulence of Proximity of Longwall Mining on Strata Permeability and Groundwater, 20th U.S. Symposium on Rock Mechanics, Austin, Texas, June 1979

[5] Whittaker, B.N., Singh, R.N. and Neate, C.J. Effect of Longwall Mining on Ground Permeability and Sub-Surface Drainage, 1st International Mine Drainage Symposium, Denver, May 1979

[6] Garritty, P. Effects of Mining on Surface and Sub-surface Water Bodies, PhD Thesis, University of Newcastle upon Tyne, October 1980

[7] Trueman, Sir A. The Coalfields of Great Britain, pp 289-313 (1954) Published Edward Arnold (London)

[8] Sherbourne Hills, E. Elements of Structural Geology, pp 164-215 (1975) Published Chapman and Hall Ltd.

LIST OF FIGURES AND TABLES

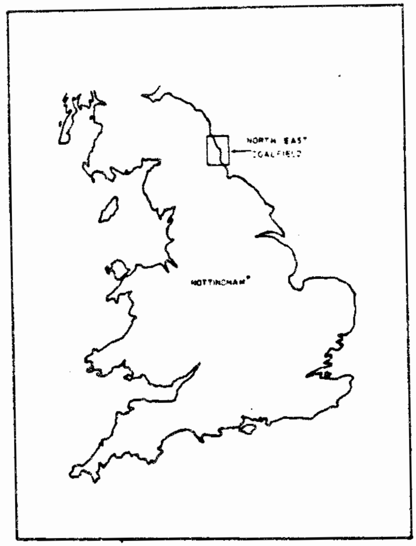
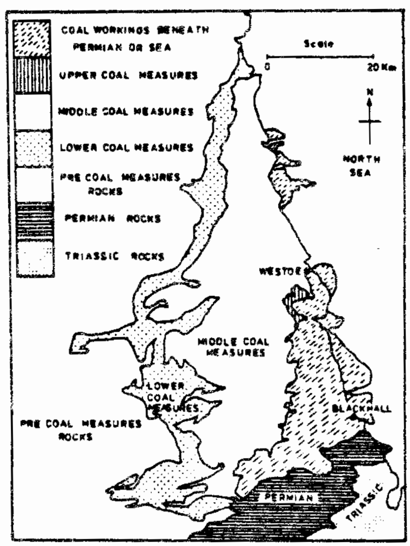


FIGURE 1 LOCATION MAP FOR THE NORTH EAST OF ENGLAND COALFIELD

FIGURE 2 SOLID GEOLOGICAL MAP OF THE NORTH EAST COALFIELD



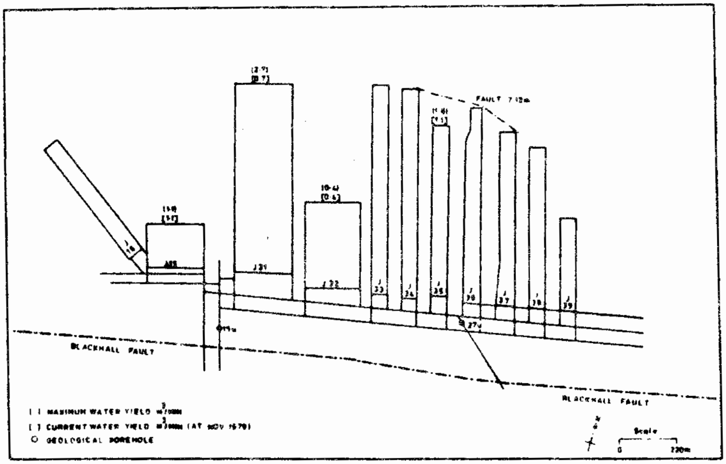
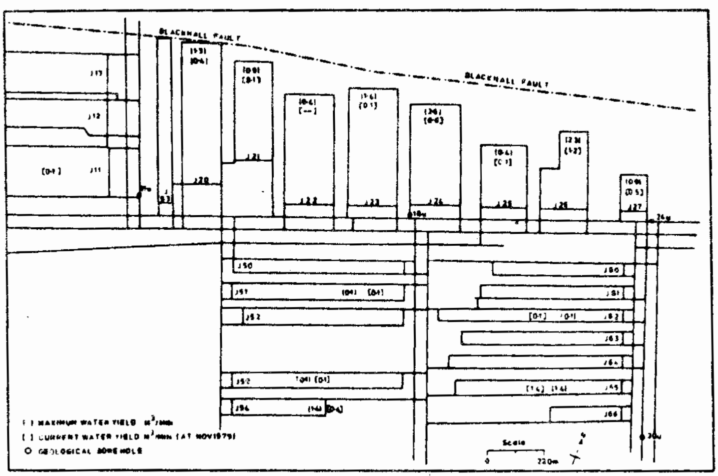


FIGURE 3 BLACKHALL WORKINGS - NORTH OF THE BLACKHALL FAULT

FIGURE 4 BLACKHALL WORKINGS - SOUTH OF THE BLACKHALL FAULT



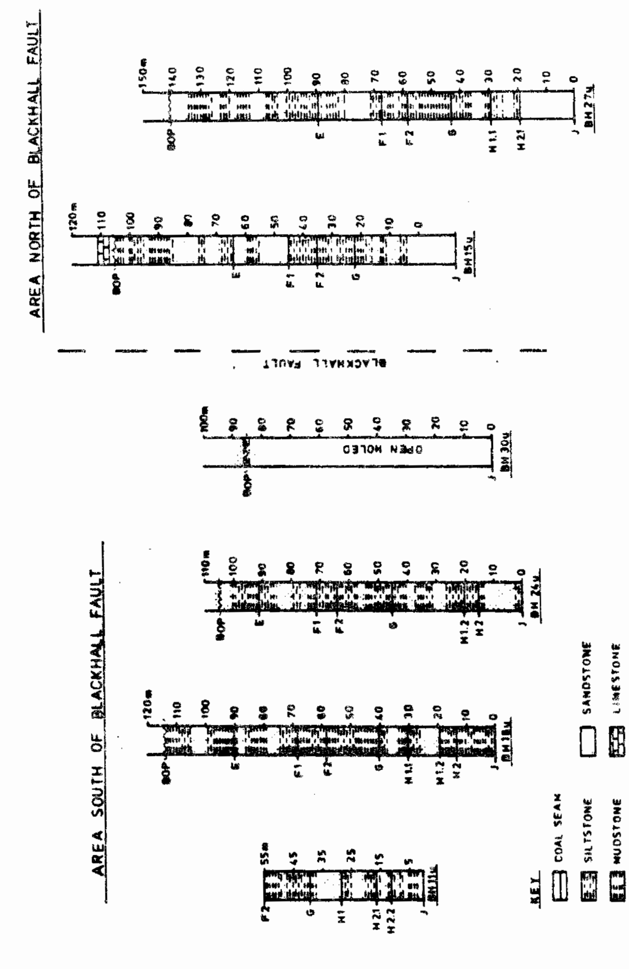


FIGURE 5 GENERALISED GEOLOGICAL SECTION ACROSS THE BLACKHALL WORKINGS

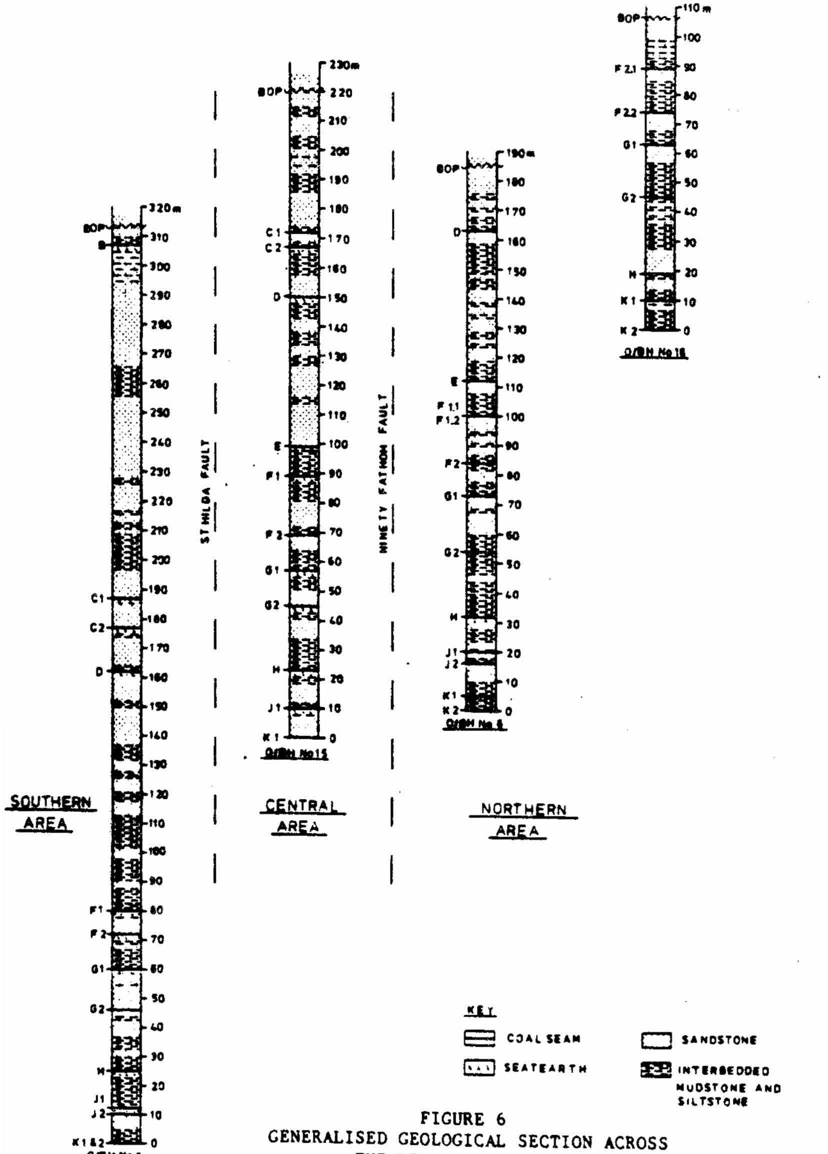


FIGURE 6
GENERALISED GEOLOGICAL SECTION ACROSS THE WESTOE WORKINGS

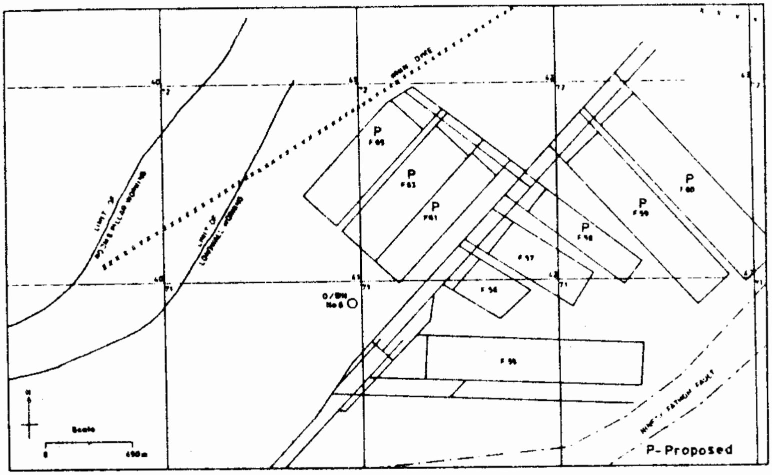
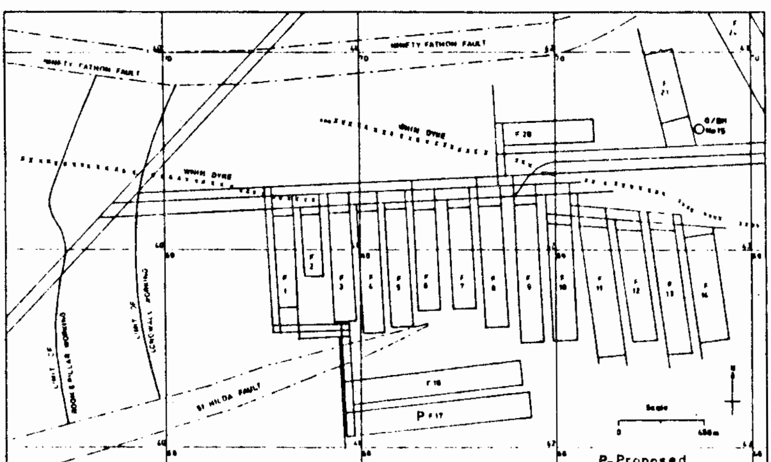


FIGURE 7 WESTOE WORKINGS - NORTHERN AREA, MAIN SEAM

FIGURE 8 WESTOE WORKINGS - CENTRAL AND SOUTHERN AREAS, MAIN SEAM



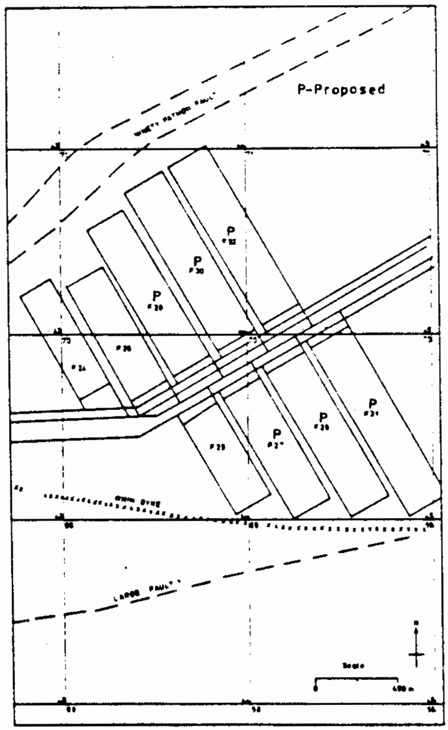
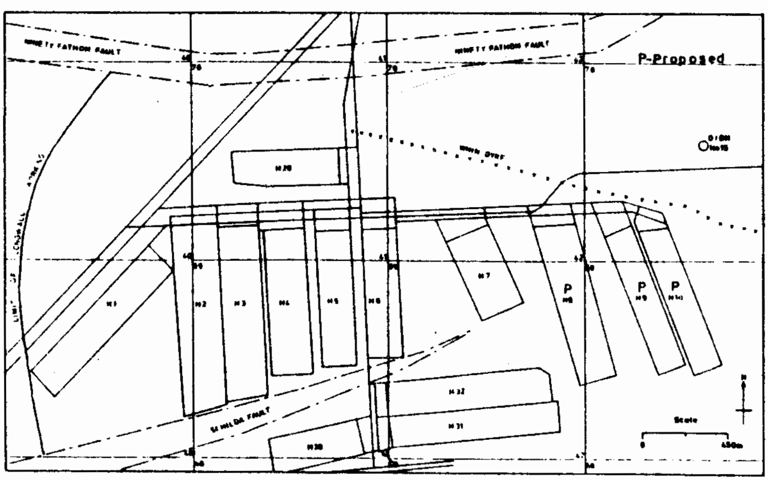


FIGURE 9 WESTOE WORKINGS - CENTRAL (EAST) AREA, MAIN SEAM

FIGURE 10 WESTOE WORKINGS - CENTRAL AND SOUTHERN AREAS, MAUDLIN SEAM



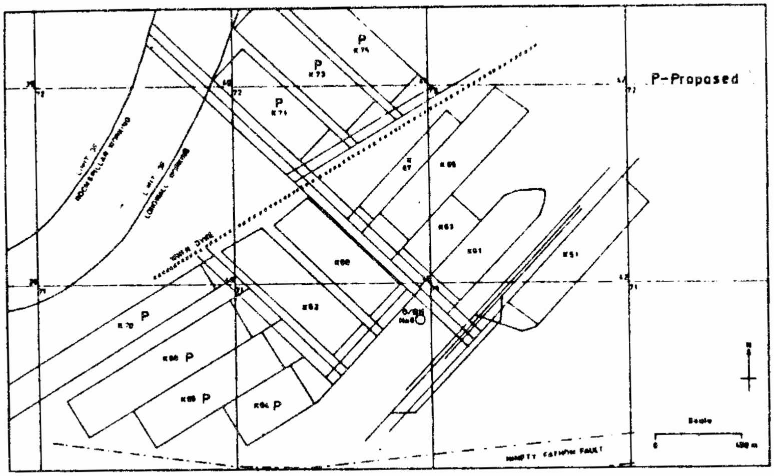


FIGURE 11 WESTOE WORKINGS - NORTHERN AREA, BRASS THILL SEAM

FIGURE 12
WESTOE WORKINGS - CENTRAL AND SOUTHERN AREAS, BRASS THILL SEAM

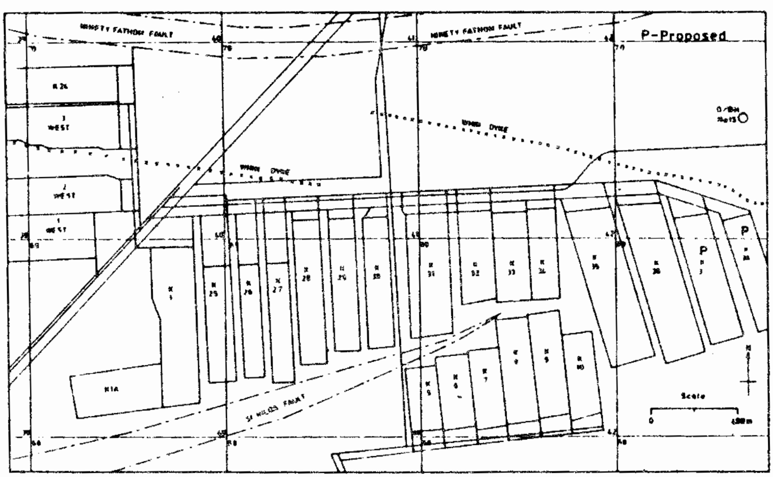


TABLE 1

QUANTITY OF WATER YIELDED FROM THE 1967-79 BLACKHALL FACES

(AT NOVEMBER 1979)

	No of Faces	Current Yield m^3/min	(gpm)
South of Blackhall Fault - Wet	14	6.8	(1485)
South of Blackhall Fault - Dry	10	-	-
North of Blackhall Fault - Wet	4	3.4	(750)
North of Blackhall Fault - Dry	7	-	-
	35	10.2	(2235)

TABLE 2

TOTAL PREDICTED TENSILE STRAIN DUE TO THE BLACKHALL FACES

	Total Predicted Tensile Strain (mm/m)	
Face Series	Base of Permian	Sea-Bed
J10 (South of Fault)	Upto 8 mm/m	Upto 2 mm/m
J20 (South of Fault)	Upto 9 mm/m	Upto 2 mm/m
J50 and J60 (South of Fault)	Upto 7 mm/m	Upto 2 mm/m
J10 and J 30 (North of Fault)	Upto 7 mm/m	Upto 2 mm/m

TABLE 3

QUANTITY OF WATER YIELDED FROM EACH WESTOE SEAM

Seam	Current Yield m^3/m	(gpm)	% Total
Main (F1)	6.3	(1385)	79
Maudlin (H)	0.2	(50)	3
Brass Thill (K)	1.5	(325)	18
	8.0	(1760)	100

TABLE 4

NUMBER OF WET AND DRY FACES IN EACH WESTOE SEAM

Seam	No of Faces	% Total
Main Seam (F1) Wet	7	11
Main Seam (F1) Dry	16	25
Maudlin (H) Wet	0	0
Maudlin (H) Dry	9	14
Brass Thill (K)Wet	4	7
Brass Thill (K)Dry	27	43
	63	100