ANALYSIS AND PREDICTION OF GEOLOGICAL STRUCTURES ASSOCIATED WITH OUTBURSTS AT COLLINSVILLE, QUEENSLAND

By

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ABSTRACT

Underground mining in the Bowen Seam has shown that the majority of outbursts have coincided with faults, igneous dykes and sills, stone roof rolls or some combination of these. The coal measures are deformed principally by N-S trending, easterly dipping thrusts presumed to be associated with the major, reverse Collinsville Fault. The old Collinsville State Mine records suggest that thrusts and strike-slip faults have been common sites of outbursts. In contrast, normal faults have not been outburst-prone.

Detailed geological mapping in Bowen No. 2 Colliery 53 east and west panels has been carried out in the hanging wall of a thrust zone of 6.1 m throw. The associated sheared coal has been defined and several fracture sets delineated. Sheared coal can be observed up to 170 m from this thrust zone, but this is dependent on the vitrinite content of the upper seam section worked. Evidence indicates that outbursts have occurred only in extremely sheared coal.

Curious spherical- to cylindrical-shaped coal objects ("apples" and "rods") are related to the deformation in the vicinity of the thrust zone. The frequency of rods rises from 0 at 300 m, to 1 per metre at 150 m, and to 2.5-8.5 per metre at 30 m from the zone.

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The early detection of sheared coal and the development of a technique for objectively assessing the degree of shearing are important aspects of forecasting outburst-prone structures.

Preliminary results of microscopic and fracture mapping techniques are discussed.

INTRODUCTION

Coal extraction at levels deeper than 180 m in the Bowen Seam of the Collinsville coal measures has been hindered by instantaneous outbursts of coal and carbon dioxide (Hargraves, 1958, 1963 and 1967). These coal measures outcrop at the northern tip of the Bowen Basin, the eastern margin of which is truncated by a large reverse fault known as the Collinsville Fault (Fig. 1). The throw of this fault is considered to be at least 213 m (Webb and Crapp, 1960, p.59; Mengel, 1975, p.87).

The investigations reported in this paper have been carried out in the Bowen No. 2 Mine, which has entered the Bowen Seam between two thrust faults presumed to be associated with the Collinsville Fault (Fig. 2). This seam is relatively steeply dipping (8^{o}) and thick (5.8-6.0 m).

The results are of a preliminary nature. The aims of detailed geological work in outburst-prone areas are to identify the geological structures, define the nature of outburst-prone coal and develop techniques of forecasting outburst-prone structures.

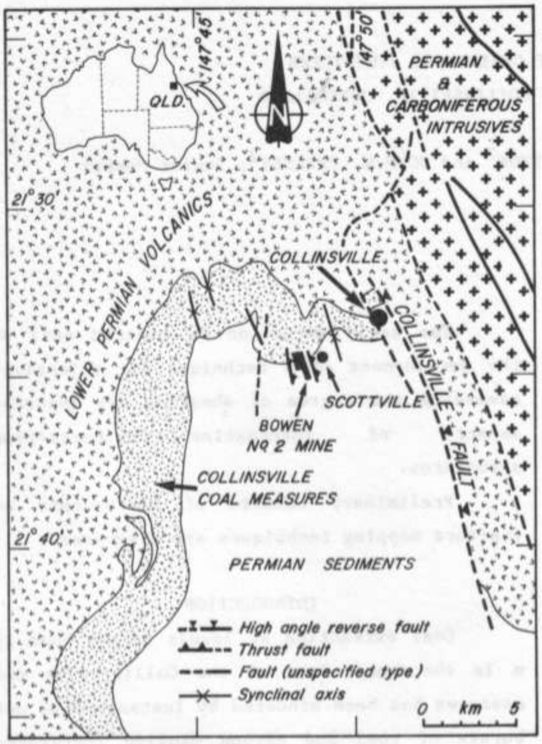

Fig. 1 - Location and geological setting of the Bowen No. 2 Mine near Collinsville, Queensland.

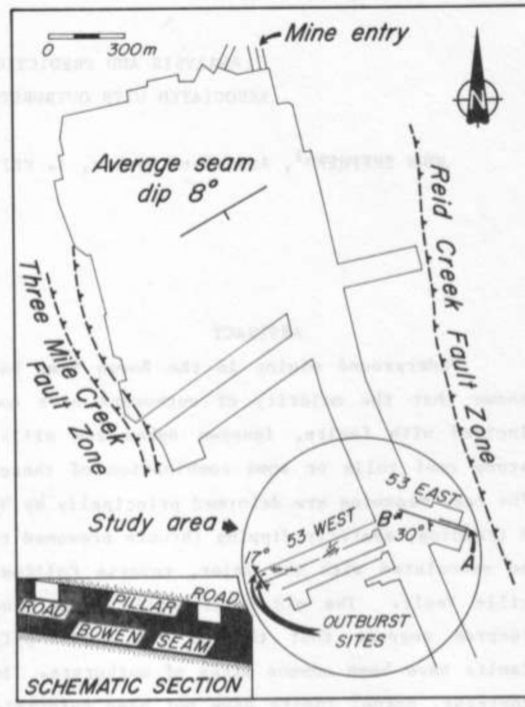

Fig. 2 - Outline map of the Bowen No. 2 Mine, showing the principal structures and study area.

In this paper headings within panels are referred to as levels; for example, in 53 west-panel, the return, belt and travelling roads are identified as 53 west-level, 53½ west-level and 54 west-level respectively.

Most of the data originate from the study area marked in Fig. 2, and the studies in 53 west-panel relate specifically to a thrust of 6.1 m throw, which is not connected to the Three Mile Creek Fault (Williams, personal communication). In this panel, carbon dioxide gas emissions were abnormally high as the thrust was approached and two outbursts occurred in two separate headings driven into the thrust zone (Fig. 2).

All directional data discussed are plotted with respect to magnetic north, which was 7°44′ east of true north when the data were collected.

Definitions of some structural terms that have been used in this paper are given in Appendix 1.

PREVIOUS STUDIES OF OUTBURST-PRONE COAL FROM THRUST ZONES

From the viewpoint of geological structure, the most significant studies of outburst-prone coal have been reported from Canada and Great Britain. While a complete review of these investigations is outside the scope of this paper, it should be mentioned that outburst-prone coals have been studied at the mesoscopic and mine scales in Canada and mainly at the electron microscopic scale in South Wales, Great Britain (Shepherd, Rixon and Griffiths, in preparation). A summary table of structural scales is given in Appendix 2.

In the Canadian Rocky Mountains, the Canmore and Crows Nest coalfields worked outburst-prone bituminous coal seams. According to Ignatieff *et al.* (1954) and Norris (1958), the seams are folded, sheared, faulted and thrusted at all scales. In many parts of the seams the cleat has been obliterated and the coal is soft and friable. The shearing is especially related to thrusts. The coal seams pinch and swell, and as a result of this thrusting they were very difficult to work and highly outburst-prone (Bielenstein, 1975). Full descriptions of the mesoscopic structures, however, have not been published.

In South Wales (Great Britain) outburst investigations have centred on examining sheared anthracite. The major structural features of the Welsh coalfield have been identified during regional geological studies (Trotter, 1947; Archer, 1968). Pooley (1967) and Evans and Brown (1972-3) have examined anthracite using scanning electron microscope techniques. Evans and Brown found that in the outburst-prone variety "the dominant structural control appears to be that of shearing and slickensiding, together with associated striation marks" (1972-3, p.175). Although non-outburst-prone anthracite was also shown to have a high density of fracturing, the fractures were found to be predominantly conchoidal with little or no sign of shears.

OUTBURSTS IN THE STATE COAL MINE

Outbursts became a hazard in the Bowen Seam as mining reached depths of over 180 m (Hargraves, 1958, p.29). According to the State Coal Mine Records (1960-61) for the No. 1 Tunnel area, all outbursts were associated with faults, and igneous intrusions and stone roof rolls were present at the sites of some outbursts.

Although numerous faults were crossed in the No. 1 Tunnel area, only some of them yielded outbursts. Hargraves (1958, p.38) discussed the fatal outburst of 1954, which occurred in this area at a fault zone characterized by a normal fault of variable throw (0.60-1.20 m) and a thrust of 3.66 m throw. In Table 1 the map data from the No. 1 Tunnel area have been used and the faults classified according to their observed separation (State Coal Mine Records, 1960-61). These data show that all eight outbursts occurred at the sites of inferred strike-slip and thrust faults. It appears that both normal and reverse faults were not outburst-prone.

Table 1

Number of outburst events in headings where they intersect faults in the old State Coal Mine, No. 1 Tunnel area, Collinsville

	Outburst occurrence	
Fault type	Yes	No
Normal	0	7
Reverse*	0	12
Thrust	2	1
Inferred strike-slip	6	2

*Possibly including some thrusts

One particular WNW-ESE trending fault (which is inferred by the present authors to be a strike-slip type) is of especial interest. Of six headings traversing this fault, four experienced outbursts, although these outbursts were induced by multiple shot-firing of the faces. The throw of this fault was variable (<0.61 m), and its separation in transverse sections indicated both normal and reverse movements in different headings. Crapp (unpublished data, 1960) noted that the gouge in the fault reached a thickness of 375 mm, which he regarded as large, and he concluded that lateral movement had occurred.

53 WEST-PANEL THRUST ZONE MAPPING TECHNIQUES

Geological mapping in thrust zones requires a meticulous and systematic approach to record as objectively as possible the structures that are regarded as significant.

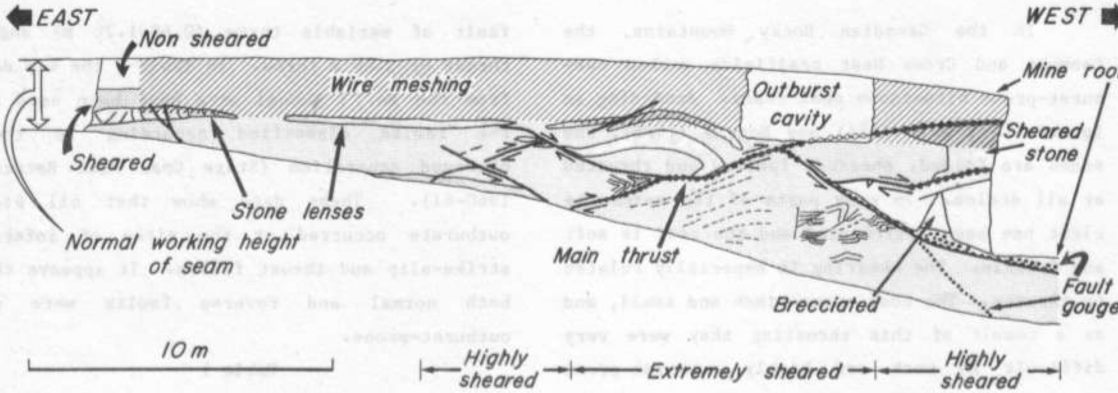

Fig. 3 - Transverse section of the thrust zone in 53½ west-level at the Bowen No. 2 Mine.

In 53 west-panel two long traverses were examined, starting at the thrust zone and continuing outbye for a distance of approximately 300 m. The southern ribsides in the belt and travelling roads were marked out in 1 m segments along these traverses. In each 1 m interval the orientations, lengths and profiles of mesoscopic fractures were recorded on CSIRO data sheets. The locations of all measurements were marked underground on sections drawn transverse to the structure at a scale of 1:100.

Fracture orientations were measured by using Breithaupt Cocla geological compasses and the data were plotted in the laboratory using a computer program called SNAP (Jeran and Mashey, 1970). This program has been modified and extended to plot rosette diagrams (circular histograms). Fracture spacings were measured using the scan-line technique (Priest and Hudson, 1976; Shepherd and Creasey, 1979).

Initially, reconnaissance observations along these traverses indicated that six classes of fractures existed in the sheared coal: face cleat, butt cleat, low-angle shear fractures parallel to the main thrust zone, inclined at an angle of less than 45°; other low-angle shear fractures similarly inclined, high-angle fractures dipping at greater than 45°; and mining-induced fractures. These classes were confirmed during detailed mapping.

Samples of the sheared coal were collected for microscopic study. The sheared coal was so weak that samples required resin grouting applied *in situ* to enable intact specimens to be collected and transported.

THE STRUCTURES

Geological mapping in 53 west-panel has shown that the two outburst sites are associated with a N-S trending thrust fault that displaces the seam 6.1 m vertically and dips at 17-19° to the east.

The outburst in 53½ west-level (Fig. 3) occurred where the heading intersected the main thrust plane in the floor. The outbursts in 53 west-level occurred as the heading was being driven in the footwall beneath the main thrust plane. Two small faults (one with a vertical displacement of 0.15 m, and vertical and horizontal slickenlines; one with a vertical displacement of 0.13 m, and horizontal slickenlines) are present in the roof of the outburst cavity. The usage of the term slickenline follows Fleuty (1975). Smaller thrust faults and other strike-slip faults occur elsewhere in the 53 west-panel (Fig. 2), although these did not outburst.

In detail (Fig. 3) the thrust is a complex network of major east- and west-dipping curviplanar shear fractures and zones. Major

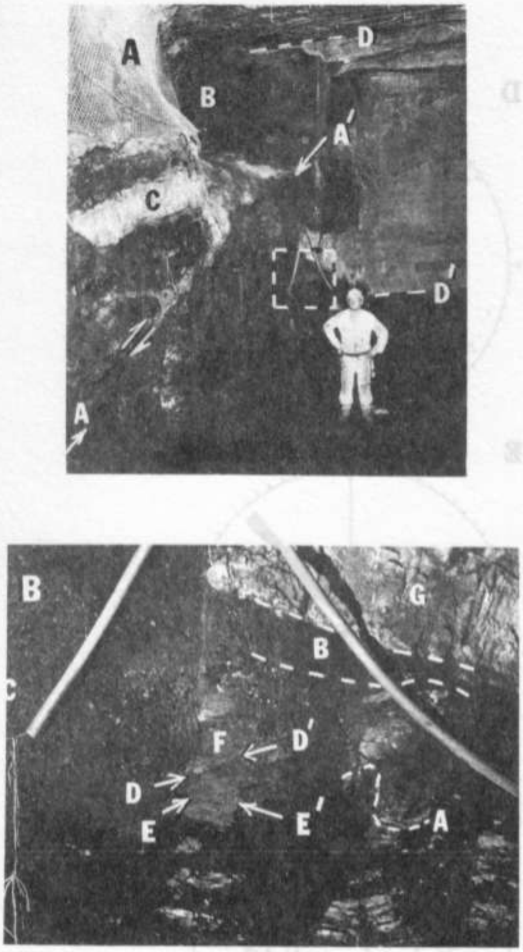

Fig. 4 - Outburst site in 53½ west-level. A - View of thrust and outburst cavity looking west. A-A′ is trace of thrust plane (arrows indicate relative movement of the block); B is outburst cavity; C is deformed stone lens; D is normal roof level in hanging wall block and D′ is roof level in footwall block. B - Enlargement of area enclosed by dashed line in A. A is trace of folded coal plies; B is gouge zone along thrust; C is extremely sheared coal (ply structure has been destroyed); D-D′ is low-angle shear plane; E-E′ is low-angle shear plane conjugate to D-D′; F is relict face cleat plane (almost parallel to plane of the rib); G is deformed stone.

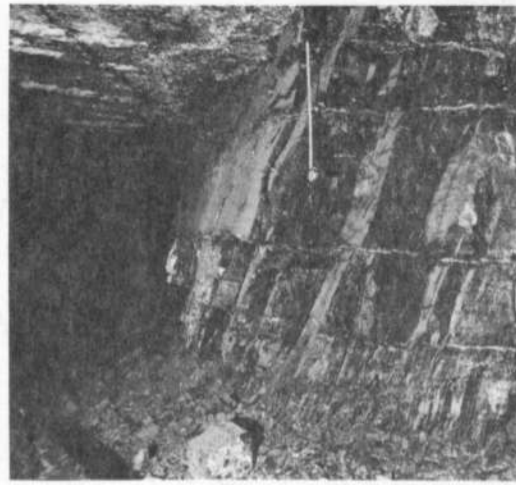

Fig. 5 - View of unsheared and non outburst-prone coal in 53 west-panel, showing face cleat planes. Steel tape is extended 1 m.

shear fractures are commonly associated with a thickness of less than 0.15 m of coal gouge and may have an attendant zone of highly folded, chevron-like coal plies, particularly in the footwalls. The geometry and movement senses of the faults are consistent with the E-W alignment of the axis of greatest principal compression. The shallow west-dipping faults with reverse movement are conjugate to the main thrust.

Structural mapping in 53 west-panel indicates that the coal is extremely sheared near the thrust fault where the outbursts occurred (Figs. 4A,B). The coal then becomes progressively less sheared for a distance of 170 m outbye of the fault, where the coal is not sheared and resembles the coal elsewhere in the mine (Fig. 5). The fracturing of coal in different plies is dependent on the nature and resultant strength of the microlithotype (Williams, personal communication). Vitrain is the most highly fractured, so its distribution around a thrust may influence the width of a sheared zone.

Mesoscopic investigation (see Appendix 2) of the coal near the thrust fault has shown that

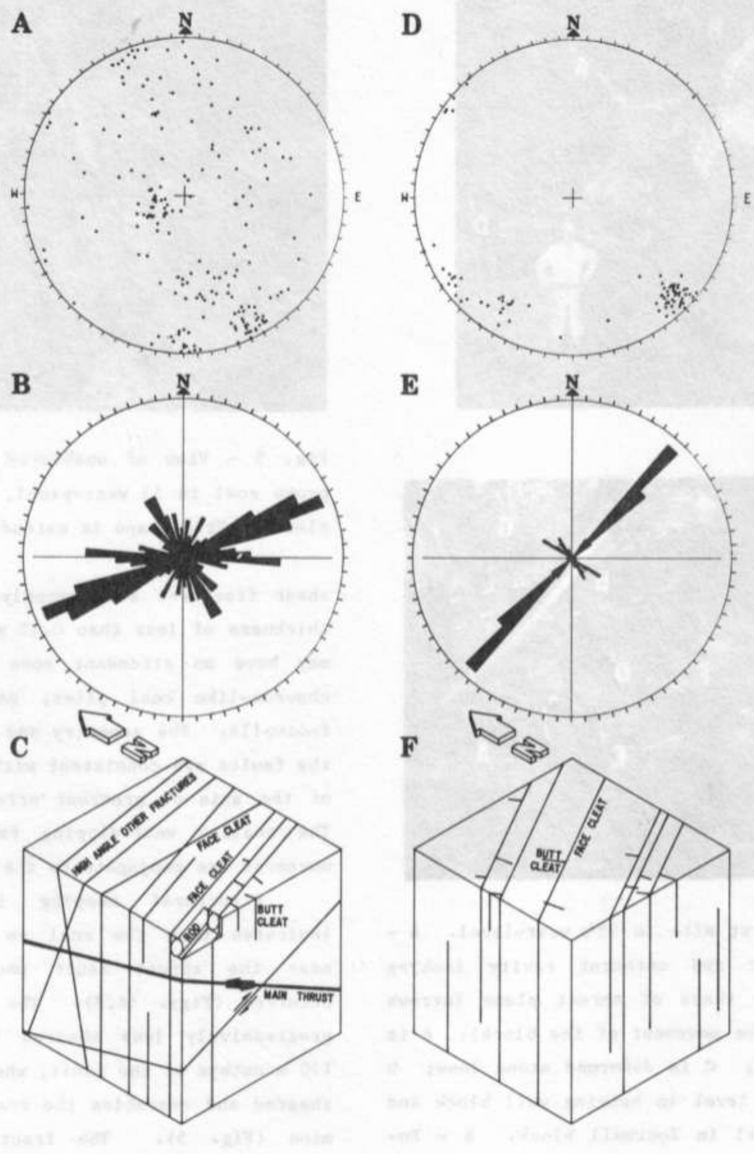

Fig. 6 - Comparison of fracture orientations from Bowen No. 2 Mine outburst-prone coal (A-C, from 53 west-level) and non outburst-prone coal (D-F, from main entries, 50-51 level). A - Stereoplot of poles to 202 fracture planes plotted on polar equal area projection. B - Rosette plot of fracture planes (linear frequency) of data in A. C - Schematic block diagram of fracture sets plotted in A and B, and their relationships to coal rod. D - Stereoplot of 92 fracture planes plotted on polar equal area projection. E - Rosette plot of fracture planes (linear frequency) of data in D. F - Schematic block diagram of fracture sets plotted in D and E.

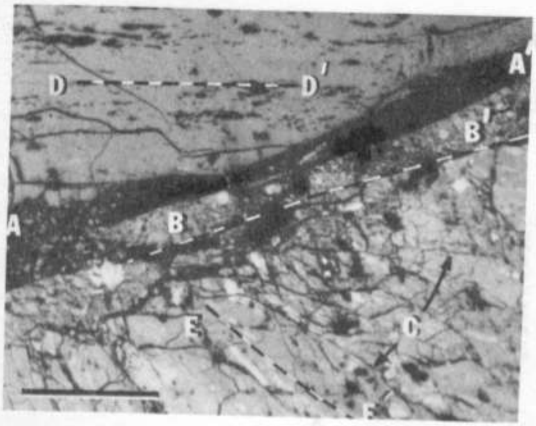

Fig. 7 - Photomicrograph of a minor thrust. A-A' is the trace of the thrust plane; B-B' is the gouge zone; C is a zone of low-angle fractures in the footwall block; D-D' is the trace of ply structure in the hanging wall block; E-E' is the curving trace of the ply structure in the footwall block. Scale bar is 100 μm long.

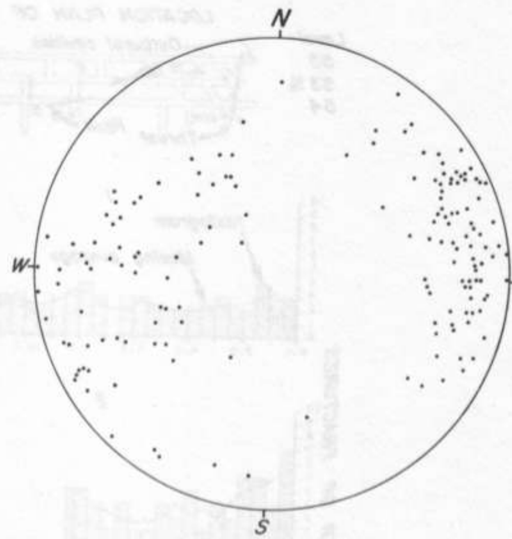

Fig. 8 - Composite stereoplot of 157 slickenline plunges on some fracture planes from 53 east-panel and 53 west-panel, plotted on polar equal area projection.

sheared coal consists of normal coal that has been divided into a multitude of small shear lenses (Skempton, 1966) by several sets of close-spaced intersecting fractures. These fracture sets have not been measured in the actual outburst cavities, owing to the unconsolidated nature of the outburst coal. However, fracture orientations were measured in the thrust zone adjacent to the outburst cavities and outbye through the sheared coal for a distance of 247 m. These data are plotted in Fig. 6A-C and can be compared with the much simpler fracture pattern from unsheared coal in the main entries (Fig. 6D-F).

Microscopic examination of polished sections of sheared coal shows that fracturing is intense around small low-angle shears, particularly in the footwalls. In Fig. 7 the deformed coal plies in the footwall of a small thrust can be seen curving into the thrust plane, which has a gouge zone of comminuted coal along its length. Both the more deformed footwall material and the presence of comminuted coal gouge along the thrust fault plane are features that are also commonly observed at the mesoscopic and mine scales.

The presence of microscopic and mesoscopic folds in the coal plies, and the extensive fracturing of the coal, indicate that both ductile and brittle deformation mechanisms have been operative at the time of thrust faulting. However, the major deformation mechanism has been brittle fracturing and cataclasis of the coal, which produces the extensive fracture systems and abundant comminuted or brecciated coal (gouge) along the faults.

Slickenlines were measured on fractures of varying orientations from both 53 east-panel and 53 west-panel and the plunges are plotted in Fig. 8. Movement directions as indicated by the plunges are quite variable, but strong concentrations define an eastern shallow-dipping field and a western, more steeply dipping field. Thus directions are mainly east-west and are compatible with the major principal axis of

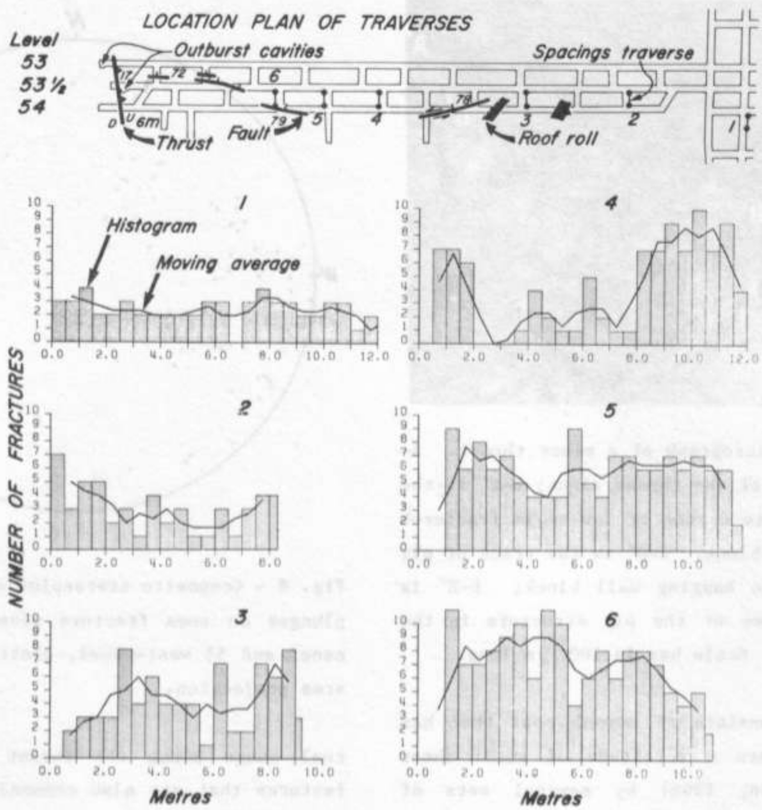

Fig. 9 - Frequency of fractures along traverses 1 to 6 between 53 and 54 west-levels. The histogram class interval is 0.5 m along the traverse, and the moving average is 1.5 m.

stress (σ_1) deduced from east- and west-dipping thrust planes.

Face cleat spacings in 53 west-panel were measured by using the scan line technique. Spacings traverse locations and frequency data are shown in Fig. 9. Mean fracture spacing at traverse 1 is 0.20 m and decreases to 0.06 m at traverse 6. This represents an increase in frequency from 4.9 fractures per metre to 16.2 fractures per metre over a distance of 450 m towards the thrust. On the basis of these preliminary data, an increase in cleat frequency may be a diagnostic feature of the coal approaching a thrust zone.

Coal rods are curious structures found in 53 west-panel. The rods (Fig. 10) are principally found in the upper 1.2 m of the seam, where the coal is predominantly dull. The long axis of each rod is horizontal, and essentially parallel to the face cleat. The rod distribution, as counted from the thrust outbye, is shown in Fig. 11. Rod frequencies increase steadily from less than 1 per metre at a distance of 180 m from the thrust, to about 8 per metre near the thrust. Beyond 300 m from the thrust, no rods are found.

Coal apples (Briggs, 1934-35) are another curiosity found in 53 west-panel and other isolated parts of the mine. They are rounded, subspherical objects composed of a type of coal that as a hand specimen is indistinguishable from the enclosing coal. Their distribution is

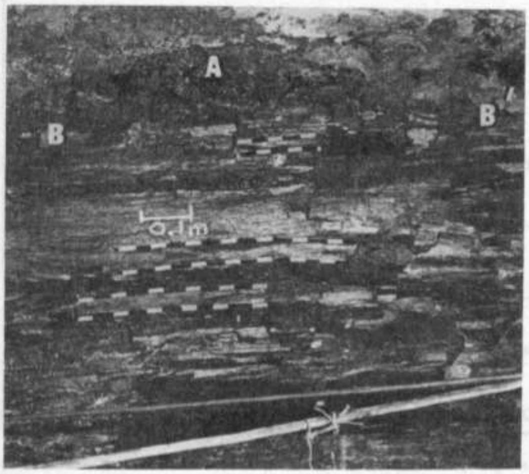

Fig. 10 - View of uppermost 1 m of coal in 53 west-level, showing numerous rod structures. The traces of some rods are marked. A is the stone roof and B-B' is the coal/stone parting.

much more erratic than that of rods (Fig. 11), and the only relationship between coal apples and the thrust is that no coal apples have been found further than 300 m from the thrust in 54 west-level. However, coal apples have also been found in other parts of the mine, associated with geological structures such as stone roof rolls and coked coal.

Preliminary examination of coal rods and coal apples has allowed a tentative explanation of their mode of formation. Coal rods appear to be formed by close-spaced, unidirectional, planar and curviplanar fractures. Apples appear to be formed by several intersecting sets of close-spaced, planar and curviplanar fractures.

FORECASTING STRUCTURES

The problem of forecasting hazards in coal seams by using geological techniques hinges on the identification of diagnostic structures in the coal or enclosing sediments. Elliott (1973) considered hazard risk and formulated a comprehensive scheme of intrinsic predictability categories. The principal aim of forecasting in collieries is to identify unforeseeable (precipitant) hazards in advance and allow risk assessments to be made at regular intervals. Once a hazard is identified, it may be reclassified into reviewable or predictable categories as further information is collected.

In this study several significant structural elements have been identified in 53 west-panel. These elements are coal rods, coal apples, low-angle fractures and cleat. Investigations so far have concentrated on devising techniques to understand the spatial distributions of these elements. At this stage there is some evidence that coal rods, low-angle fractures and cleat spacing may be diagnostic of thrust zones in the Bowen Seam. Coal rods are not developed ubiquitously in the Bowen No. 2 Mine, and in 53 west-panel they are entirely absent at a distance of 300 m from the thrust zone. Between 170 and 300 m from this thrust, rods are present at an average frequency of less than 1 per metre. However, in the coal between the thrust and 180 m outbye, a much higher frequency of rods exists (Fig. 11). A sustained increase in the numbers of rods from 170 m to 140 m from the thrust is analogous to a prediction threshold defined elsewhere (Shepherd and Creasey, 1979). Therefore, the presence of rods at a frequency of greater than 2 to 3 per metre in the top coal plies appears to be indicative of the forthcoming thrust zone.

FORECASTING THE REID CREEK FAULT ZONE

The workings of 53 east-panel were advanced south-eastwards towards the footwall of the Reid Creek Fault Zone, which is a thrust. The fault has been identified from surface drilling, but it has never been mined. Therefore, it was appropriate to investigate these headings to apply the knowledge of coal structures gained in 53 west-panel and to determine any early warning signs that might assist in determining a more precise position for the fault.

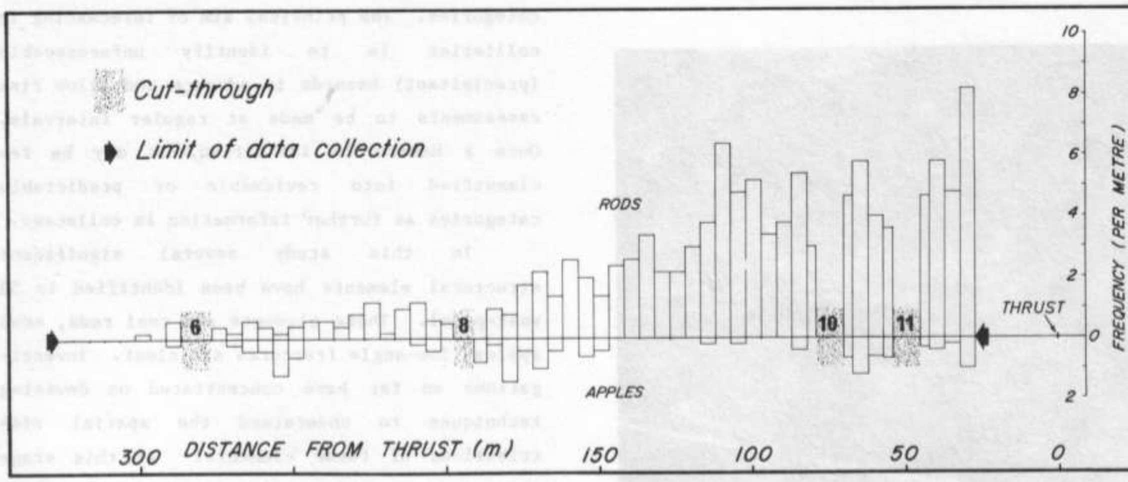

Fig. 11 – Histogram of coal rod and coal apple counts in the top 1.2 m of the seam in the vicinity of the thrust zone in 54 west-level.

At 53 east-panel, coal rods and coal apples are only present at a frequency of less than 1 per metre.

In 1979 a qualitative assessment of the degree of shearing was made, and it was forecast that the Reid Creek Fault Zone was a further 30 m distant into the solid than was previously inferred from the surface drilling. This new location is the intersection of the fault in the top of the coal seam and not with the horizontal plane. Entirely separate evidence from an additional recent drilling programme supports this interpretation (Williams, personal communication).

Some work began in early 1980 to develop a quantitative technique that would assist in forecasting the fault zone. Low-angle fractures were counted in segments along two traverses marked as A and B in Fig. 2, and the results are presented as histograms in Fig. 12. Fractures restricted to a single ply were counted in 3 m intervals (Fig. 12A) and although this figure only represents a relatively small data set, it is considered that this technique is worth developing. Larger numbers of fractures occur between 12 and 13 cut-throughs, which correspond to qualitative visual assessments of greater intensity of shearing. Larger and more penetrative fractures (including some minor thrusts) were counted in 5 m intervals and the results are given in Fig. 12B.

To minimize the smoothing effect of large sample intervals, the 5 m interval was chosen as the smallest acceptable segment in which to avoid counting a single fracture in consecutive segments. Although there is a general increase in the numbers of these larger fractures in an easterly direction towards the Reid Creek Fault Zone, this technique has not been sufficiently tested. For the technique to be useful in future forecasting, much more data are needed to assess its sensitivity.

CONCLUSIONS

Outbursts in the Bowen Seam are generally associated with extremely sheared coal close to and at faults. The degree of outburst proneness of faults is related to their type, and to the intensity of fracturing and comminution of the coal. The extent of fracturing in the coal is partly dependent on the ply structure and the different strengths of the microlithotypes (vitrain is the most highly fractured), and it is greatest in and close to thrust, reverse and

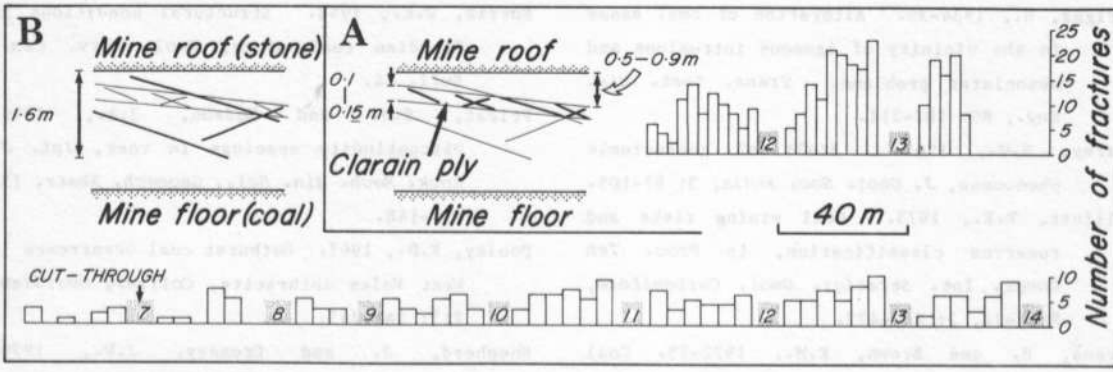

Fig. 12 - Histograms of counts of low-angle fractures in 52 east-level. A - fractures in a single ply, plotted using a 3 m class interval. B - fractures within the top 1.6 m of the seam, plotted using a 5 m class interval. Fractures counted are shown as heavy lines.

strike-slip faults. Consequently the degree of outburst proneness of different types of faults can be inferred for faults occurring at depths of greater than 180 m.

Outburst-prone coal is characterized by multiple fracture sets, in contrast to non outburst-prone coal which is fractured by only one prominent set (face cleat). The presence of fault gouge (soft coal) may also be an essential condition for outbursts to occur.

Significant structural features in the coal such as rods and the presence of low-angle fractures that constitute sheared coal, are diagnostic of the thrust zone in 53 west-panel. The frequency of low-angle fractures has also been tentatively related to the Reid Creek Fault in the 53 east-panel. Because the present study has been restricted mainly to the hanging wall of only one thrust, the future predictive value of these features has yet to be fully tested.

The development and refinement of techniques discussed in this paper hinge on sequential data collection in existing workings and behind development faces. Successful underground forewarning of thrusts and other faults is only possible if the structural pattern is established in good mining conditions and it is repeatedly compared with those patterns exposed in new development work. Changes in the structural pattern need to be closely monitored by continuous observations, which can enable the early identification of diagnostic structures and thus provide some warning of outburst-prone coal ahead of the faces.

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APPENDIX 1

GLOSSARY OF TERMS

Cleat

A joint or system of joints in coal, which are usually roughly perpendicular to the stratification and along which the coal is more easily cleaved.

Conjugate

Two intersecting sets of joints or faults, which formed simultaneously under the same conditions.

Face cleat

The most prominent cleat in a coal seam.

Fault

A planar discontinuity between blocks of rock that have been displaced past one another, in a direction parallel to the discontinuity.

Fault zone

A tabular region containing many parallel or anastomosing faults.

Fracture

A general term for a surface or crack along which loss of cohesion has taken place.

Gouge

A relatively soft material consisting of fragmented or pulverized rock (or coal), which is found along some fault planes.

Joint

A fracture along which extremely little or no discernible movement has taken place.

Normal fault

A high-angle, dip-slip fault on which the hanging wall has moved down relative to the footwall.

Reverse fault

A dip-slip fault, either high or low angle, on which the hanging wall has moved up relative to the footwall.

Shear

A general term used to describe a surface of discontinuity along which slip takes place.

Shear lens

A piece of material that is bounded by various sets of slip surfaces. Shear lenses are commonly bounded by shear fractures characteristic to shear zones, which gives them an approximately rhombic or modified rhombic cross section.

Shear zone

A zone of finite width over which evident failure by shear has been distributed, usually along numerous closely spaced and anastomosing slip surfaces.

Strike-slip fault

A fault where net slip is practically in the direction of fault strike.

Structure

Structural discontinuities of any kind occurring in rock (coal) bodies.

Thrust

A reverse fault that dips at less than 45°.

APPENDIX 2

The table shows the lengths of geological structures encountered in colliery holdings, which span at least thirteen orders of magnitude. It is adapted from Carey (1962), and Turner and Weiss (1963).