Water Inflows at Phalen Colliery in the Sydney Coalfield and their Relation to Interaction of Workings

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ABSTRACT

Phalen Colliery has a history of relatively minor inflows of water. However, in November of 1992, Phalen workings appear to have induced a major incident in the overlying Harbour Seam workings when undermining the barrier pillar between Lingan and No. 26 Collieries. This subsequently involved flooding of Lingan Colliery, advancing its closure by four months from the planned date in March 1993. In turn, this has led to the gradual filling of Lingan workings with water, meaning that Phalen Colliery will now be working under extensive old flooded workings for the next few years. CBDC immediately initiated expert investigations which led to an ongoing research program to firstly, identify the cause and mechanism and secondly, to assess implications including water chemistry analyses and Tritium dating. The situation is one of complex interaction between workings in a coalfield where there is relatively little quantitative rock mechanics data. There are no direct hydraulic connections between the two seams but there is increasing evidence of minor indirect percolations. It is still too early to draw final conclusions, although a tentative mechanism has been identified which has significant implications to other operators who may be planning to undermine flooded old workings.

INTRODUCTION

The Sydney Coalfield is located on the eastern coast of Canada, offshore of Cape Breton Island, Nova Scotia (Figure 1). The high/medium volatile bituminous coals are of Upper Carboniferous age, part of the Pictou Group of the Upper Carboniferous rocks of eastern Canada. The Harbour and Phalen Seams outcrop on land and dip northward, under the ocean, at gradients from 15% to 30%. The strata between the Harbour and Phalen Seams consists of about 140 m of siltstones and sandstones, with interbedded mudstones, shales and occasional limestones. Two thin coal seams are also present, at 40 m and 120 m above the Phalen Seam. Of particular concern with respect to the water inflows are two thick sandstone deposits, one just above the Phalen Seam, and one just below the Harbour Seam. These sandstones are strong, massive, and contain hypersaline connate water. Traces of oil have also been occasionally reported in the strata immediately on top of the Phalen Seam. The sandstones may also contain methane gas.

In the Harbour Seam, the area immediately to the east of Lingan Colliery, includes the interconnected No. 26 Colliery and No. 1B Phalen Seam Colliery complex. Access was through a 200 m vertical shaft to No. 1B workings on the coastline at Glace Bay, which, in turn, gave access to the No. 26 Harbour Seam workings by a cross measures drift far offshore under the ocean. The old colliery workings are still interconnected and thus water collecting in abandoned workings of the Phalen Seam can flow freely into No. 1B and then down into No. 26. Figure 2 shows a plan of the Lingan/No. 26 and Phalen/No. 1B workings. Old flooded workings in the Phalen Seam flank the Phalen Colliery workings to the east (No. 1B Colliery) and west (No. 15 Colliery).

In 1987, extraction in the Phalen Seam recommenced with the new Phalen Colliery. It was planned for the most part to work Phalen Colliery beneath the Harbour Seam workings of Lingan Colliery and the eastern extremities also beneath flooded workings in No. 26 Colliery and eventually from virgin ground.

In November of 1992, flows of water were experienced in both Lingan and Phalen Colliery. The flows occurred almost simultaneously and the initial reaction was that they were connected hydraulically. The serious implications of this to the continued safe working of Phalen Colliery prompted the mine operators, Cape Breton Development Corporation (CBDC), to initiate an investigation of the incident. They were assisted by the CANMET Cape Breton Coal Research Laboratory (CBCRL) and external consultants. The investigations included reports, geological and mining reviews, in-situ monitoring, and physical and numerical modelling. As a result of these investigations, immediate fears of a possible direct hydraulic connection and associated major water inrushes into the Phalen Seam were allayed and production recommenced. Research studies into the mechanisms and possible implications continues.

EVENTS PRIOR TO NOVEMBER 1992

Lingan, September 1988

Occurrences of significant water flows had interrupted operations in both Lingan and Phalen Collieries once before November 1992, in the late fall of 1988. In September 1988, as the Phalen 1 East Panel worked for the first time beneath parts of the Lingan "A" section and the Lingan "Joy" room and pillar sections in the Harbour Seam at a depth of between 90 m and 245 m (Figure 2). The lowest ventilation stopping in the Lingan "A" section workings failed, allowing about 400 gpm to flow into the main slopes of Lingan Colliery. The flow was steady but fell slowly to 250 gpm over the next four weeks. This flow proceeded to reduce over the next several years, stabilising at about 50 gpm by 1990.

Phalen, November 1988

Later, on November 15, 1988, an inflow of water estimated at 400 to 500 gpm was observed flowing from the caved waste close to the faceline at the lower end of Phalen 1 East and into Phalen No. 5 Slope.

1988 Investigation

CBDC management believed that the two incidents could be connected, and could therefore represent a serious threat to safety at both mines. Workers were temporarily withdrawn until a team of consultants reported on the problem.

Water chemistry data indicated that the flow from the Lingan "A" section had a chemistry quite close to that of seawater, while the flow from the Phalen 1 East Panel was hypersaline, and resembled a connate strata water. It was concluded that the Lingan flow was derived from increased permeability of the saturated zone extending down maybe 100 m beneath the seafloor and induced by undermining. The different chemistry exhibited by the flow from the Phalen 1 East Panel suggested that a sandstone aquifer lying between the seams had been intersected by high permeability zones developed by caving above the Phalen 1 East Panel.

Having satisfactorily determined that the two water flows were hydraulically unrelated in origin, CBDC resumed production from both collieries but closed and sealed the Phalen 1 East Panel. As a precaution, the length of Phalen 2 East Panel was truncated by about a half so that it did not undermine the remaining Lingan "A" section workings. However, the Phalen 3 East Panel did operate under the flooded dip-side workings of Lingan "A" but with a restricted extraction height, whereas Phalen 4 East Panel had no restrictions. All had no further water inflows of any significance. In 1992, in the absence of local data on interaction/subsidence effects and as No. 26 Colliery was then known to be flooded, the extracted heights in Phalen 5 East Panel were restricted under No. 26 as a precaution to reduce interaction effects.

EVENTS OF NOVEMBER 1992

Phalen 5 East Panel, October 1992

In mid-October 1992, the 5 East Panel at Phalen Colliery was retreating beneath the pillar separating workings in No. 26 and Lingan Colliery (Figure 3). Face workers reported 'weighting' activity in the form of a series of bumps from the roof, with associated water inflow. A number of yield valves of the powered support system needed repairs and the problem was eventually controlled and roof conditions returned to normal.

Associated water flow from the roof at the faceline close to the maingate was found to be highly saline, at about three times more saline than seawater, and was considered to be strata water. When flows increased to 250 gpm, production was temporarily stopped as a precautionary measure. Water was pumped from the level and there was no accumulation. As the flows subsided, production was restarted and small amounts of water continued to flow (30 gpm) for some time, with no effect on production.

Lingan 2 East Panel, November 1992

The configuration of old Harbour Seam workings which the Phalen 5 East panel underworked is shown in Figure 3. This included a barrier pillar with a minimum width of 325 m between No. 26 2 North Panel and Lingan 2 East Panel. Lingan 2 East Panel, which was a 180 m wide advancing longwall face in the Harbour Seam, worked between February 1975 and December 1977 and was sealed off as a sump in 1982/83.

On November 20, 1992 as Phalen 5 East Panel worked beneath the Harbour Seam old workings and the barrier pillar, water was observed running down Lingan 5 Deep from the previously dry sump outbye the Lingan 2 East Bottom Level Seal. The source of the water was unknown.

The water overflowing the collection dam caused the workforce to be evacuated on November 21 leaving only a skeleton crew for emergency work. As work continued on improvements to the water handling system, pressures increased on both Lingan 2 East Bottom and then Top Level Seals.

Faced with continually rising pressures on the seals, water was diverted through pipelines into both the abandoned Lingan 1 East and 3 East workings. Eventually, on November 26 the water pressure on the Lingan 2 East Seals was still rising and reluctantly a valve was opened and water to free flow into the mine and all men were withdrawn from the mine. It was estimated that about 3000 gpm was entering the Lingan 2 East District. Pumping capacity was increased to match this.

Also at this time, water level monitoring at the No. 1B shaft revealed a drop of 1.5 m (5 ft) in the water level in the abandoned No. 26 Colliery complex. The water level continued to fall, indicating a hydraulic connection between the No. 26 and Lingan Collieries. In order to try to reduce the head acting on the inflow into the Lingan 2 East, pumping from the No. 1B shaft was started on November 25. The estimated capacity of this pumping system was also 4000 gpm.

The water from both the No. 1B shaft and from Lingan Colliery was pumped into the ocean, with the result that the ocean water became discoloured. Local environmental officials soon instructed CBDC to stop discharging the water in this way. With the pumps turned off, Lingan Colliery flooded and it was abandoned.

INVESTIGATION

The investigation of the 1992 incident started as soon as the water inflow was noticed. The investigation aim was to determine the cause and mechanism of the water flows and assess the requirements to allow safe resumption of operations. It involved CBDC staff, local and international consultants, and the CANMET CBCRL at Sydney, N.S. The key areas of investigation were: monitoring of water levels and pressures in Lingan and No. 1B/No. 26 collieries; determination of water chemistry; monitoring of interaction; empirical modelling of the caving/fracturing process above the Phalen Colliery workings; and numerical modelling of the interaction effects. Readings of water levels at the No. 1B shaft and at Lingan Colliery, as it slowly flooded, were taken with vibrating-wire piezometers and datalogging (Figure 4).

Water Chemistry

Since the November 1988 inflows, groundwater seepages and flows have been regularly sampled and tested by chemical analysis and for conductivity. The ions tested were typically, Calcium, Carbonate, Chloride, Iron, Magnesium, Potassium, Strontium, Sodium and Sulphate. From time to time special analysis for Tritium has also been carried out. Water from strata and old workings have distinctively different chemistries (Figure 5).

Tritium is generally accepted to have only been widely present in the atmosphere since nuclear testing first began in the 1940's. Tritium is present in the waters from the old No. 26 Colliery, which has been flooded since 1940. Some water samples taken from the roof of the Phalen Seam beneath flooded No. 26/Lingan workings were found to contain Tritium but other samples from elsewhere in the Phalen workings do not. Thus a convincing argument can be made that the Phalen samples containing Tritium infact represent a mix of strata water and water from old workings, implying that percolation is occurring via indirect flow paths down through 140 m of interburden strata. This is obviously important supporting evidence, clarifying our understanding.

Modelling

The Department of Mining Engineering at Nottingham University (U.K.) provided access, through Jacques Whitford & Associates (JWA) of Dartmouth, to an empirical fracture model based on scaled physical models (Figure 6). The model, described in more detail elsewhere (CANMET, 1994), distinguishes between zones (Figure 7) subject to three types of fracturing: *Continuous fracturing*, where fractures migrate vertically with continuity; *Discontinuous fracturing*, where there are a number of fractures migrating vertically but there is no apparent connection between them; and *Dissipating fracturing*, comprising fractures that are barely visible and mainly horizontal. Although only these two tests have been conducted, the results appear to coincide with observations in-situ. Further work is ongoing.

DISCUSSION

Three important facts are clear from the above investigations:

(i) the water chemistry of the water coming into Lingan 2 East is very different from strata water elsewhere;
(ii) the Tritium evidence indicates some recent contact with the atmosphere;
(iii) the significant drop in water level at the No. 1B/No. 26 shaft when both 5 and 6 East Panels at Phalen mined under the barrier pillar from No. 26 to Lingan.

These combine to indicate that the water entering Lingan 2 East was from No. 26 Colliery.

This, in turn, implies that the 300 m (1,000 ft) barrier pillar left in the Harbour Seam between No. 26 and Lingan Collieries was breached, at that horizon, during the undermining of that pillar by the Phalen 5 East Panel 140 m below. There are now indirect, but not direct, hydaulic connections between the Phalen workings and those in the Harbour Seam above.

As studies continue, it is still too early to draw conclusions. However, the explanation which is now generally accepted to best fit the known facts is based on the formation of horizontal bed separation cavities in the subsiding strata above a longwall, as follows:

- as the caving process over Phalen 5 East waste fully developed, subsidence deformations developed in the overlying strata, creating both dynamic transitional movements travelling through the strata as the face retreated and residual deformations left permanently in the ground as a trough like depression in the strata;

- as these deformations migrated upwards over time and eventually reached up to the seabed, strong strata (e.g. sandstones) bridged the larger settlements induced in weaker strata (e.g. mudstones), causing bed separation cavities to form (Figure 8);

- where these cavities formed below sandstone either just above or below the Harbour Seam in the No. 26 workings they linked, through fractures, to the flooded old workings and filled with water;

- as Phalen 5 East retreated, under but towards Lingan, these cavities formed in a continuous lateral pattern parallel to the 5 East retreat direction and remained hydraulically connected to No. 26 workings, probably above the ribside/gob area of Phalen 5 East;

- as Phalen 5 East retreated from under the barrier pillar to beneath the old, mainly dry Lingan 2 East Gob, these laterally continuous cavities connected with open fractures around the Lingan 2 East Gob to provide a direct hydraulic connection from No. 26 to the sealed Lingan 2 East Panel. This then filled with water at about 3000 gpm.

This conceptual mechanism best fits the known facts and until further evidence should become available, it forms the generally accepted explanation of the occurrence.

At present there is no direct evidence of a hydraulic connection between the Harbour and Phalen Seam workings. This has important implications for the continued safe working of Phalen Colliery. There is, however, growing geochemical evidence to support the conclusion that some percolation through indirect flow paths is occurring from Lingan into the Phalen gobs. Investigation and monitoring of the component factors are ongoing, wherever possible, which continues to improve the knowledge and understanding of the complex interaction effects.

POSTSCRIPT

In March of 1994 a second panel, Phalen 6 East, worked beneath the No. 26/Lingan pillar. As it did, face supports experienced severe weighting, and a cavity developed up to 5 m in height and extending 35 m along the faceline. This was then filled with foam cement, the face recovered and production continued. The fracturing that was associated with the cavity made up to 200 gpm of water. In the Harbour Seam above, reductions in water level were again noticed at the No. 1B shaft, and the water level in Lingan Colliery began to rise faster. This implies that a similar event to the 5 East inflow had taken place, and that once more the intercolliery boundary pillar had been breached.

Investigations of these two events is continuing, with the help of international consultants, contract research and CBCRL and CBDC's in-house efforts. The aim is to determine long-term planning procedures which will incorporate the above experiences and ensure that mining the Phalen Seam will safely continue.

ACKNOWLEDGMENTS

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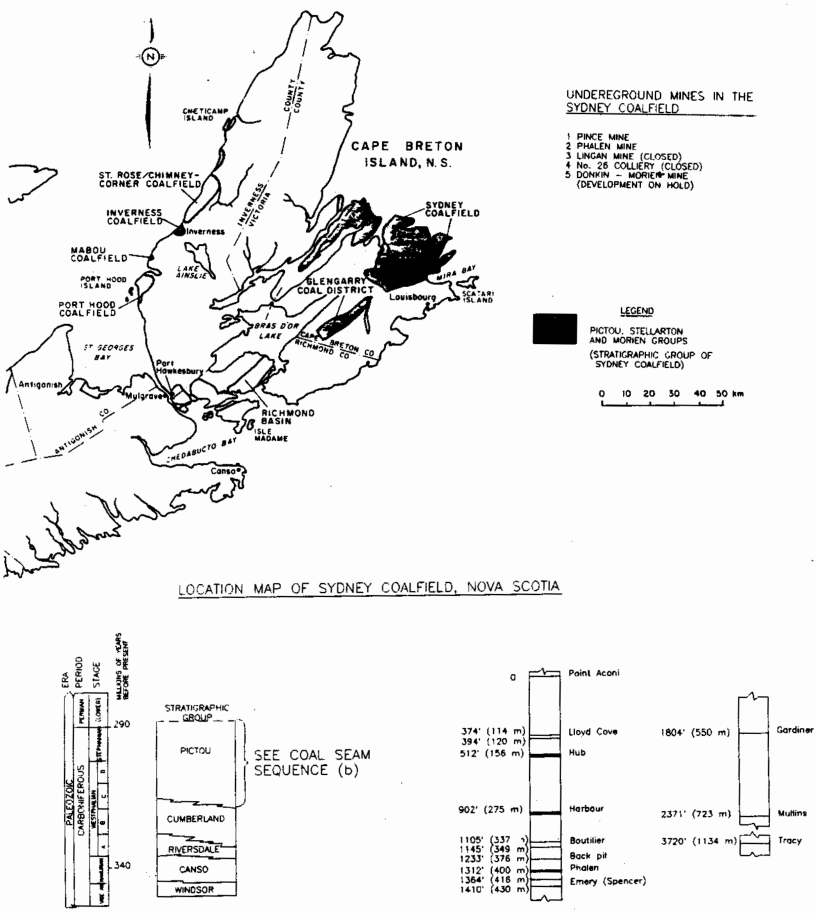
REFERENCES

CANMET (1994); "Development of a Sydney Coalfield Subsidence Model, N.S.". Final Report on DSS Contract #23440-2-9221, by Jacques, Whitford and Associates Ltd., Dartmouth, N.S.

Figure 1: Regional geology of the Sydney Coalfield (after Calder, 1985)



a) GEOLOGICAL GROUPS OF THE CARBONIFEROUS PERIOD IN NOVA SCOTIA

b) IDEALIZED STRATIGRAPHIC COLUMN OF THE SYDNEY COALFIELD SHOWING MAJOR COAL SEAMS

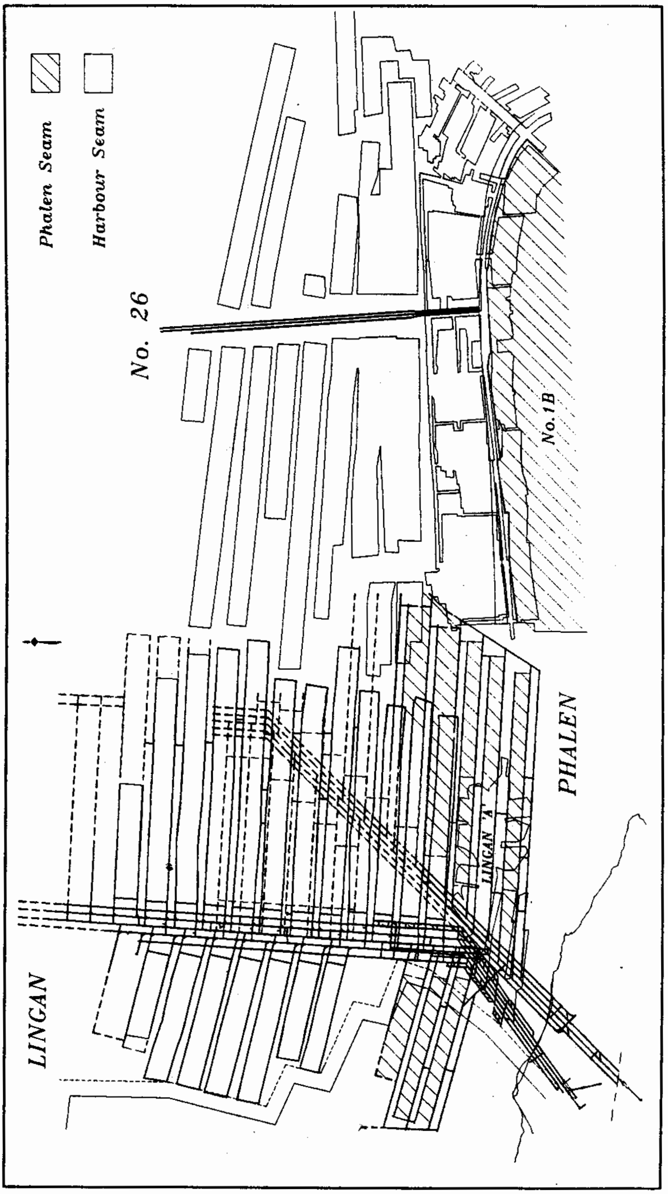


Figure 2: Mine Plans of Lingan, No. 26 and Phalen Collieries

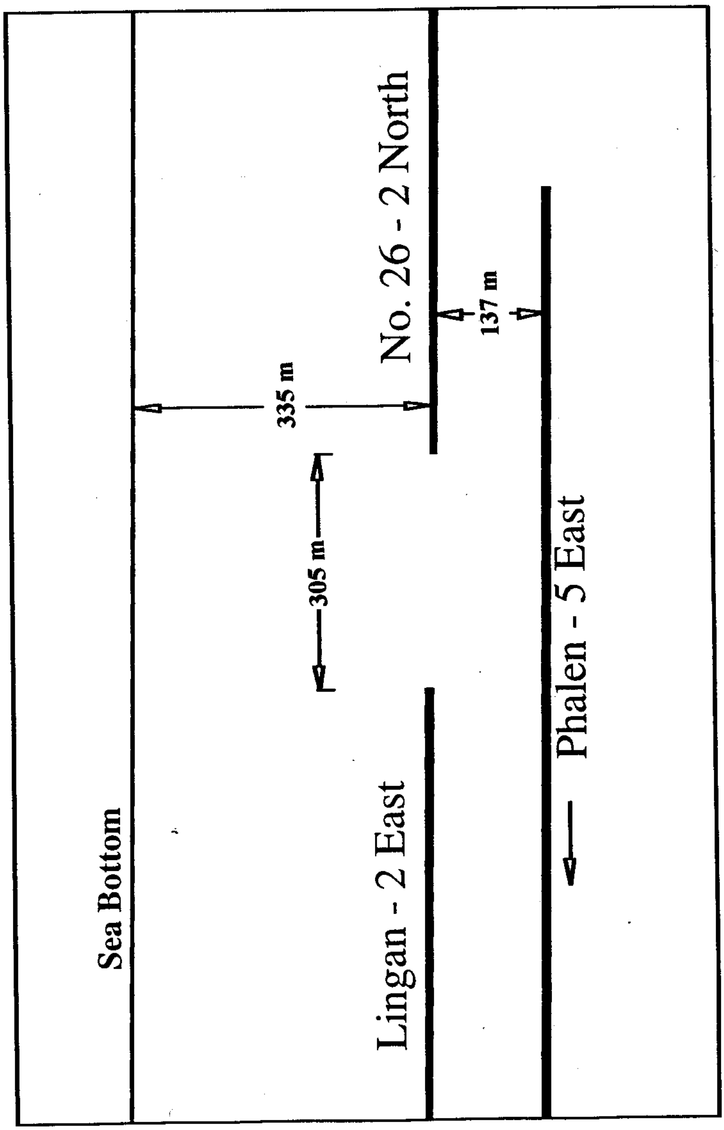


Figure 3: Profile, Harbour and Phalen Seams

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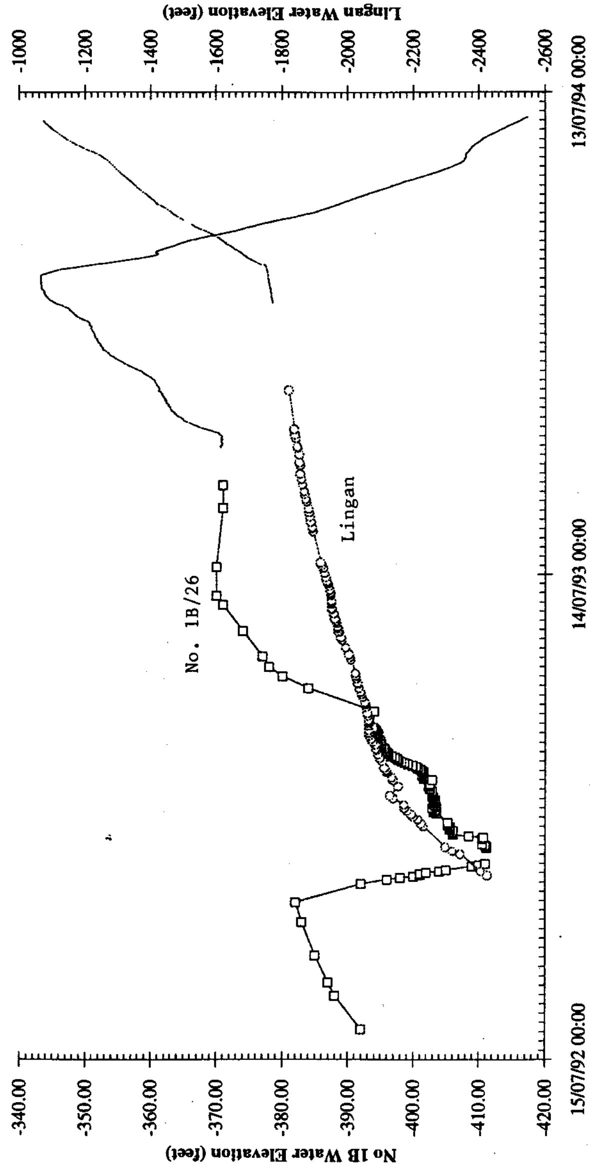

Figure 4: Water levels in No. 26/1B Shaft and at Lingan Colliery, 1992 to 1994

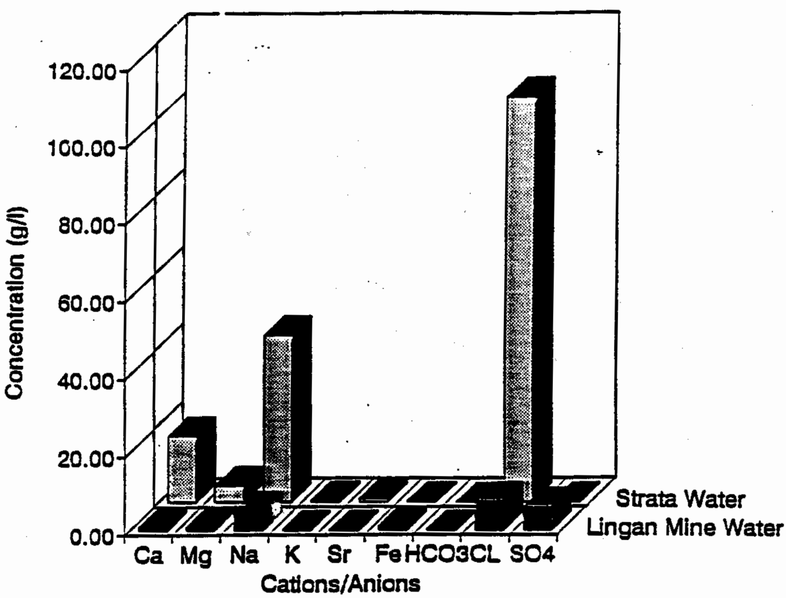

Figure 5: Typical water chemistries (after Bursey, Fracflow Consultants)

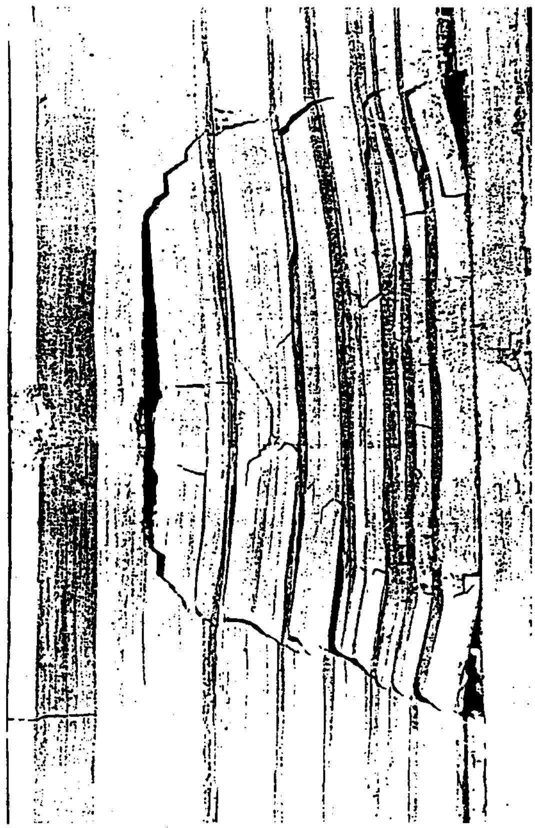

Figure 6: Typical physical model showing fracturing over a longwall panel

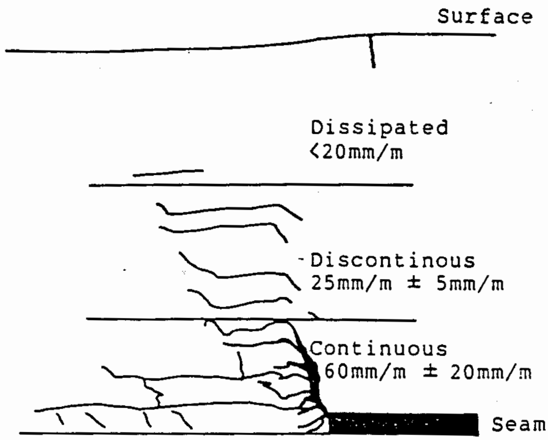

Figure 7: Typical types of fracturing shown in physical models

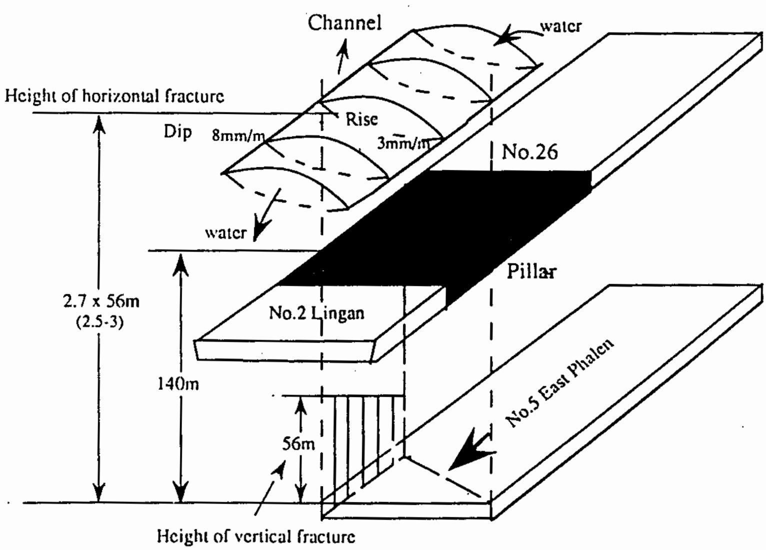

Figure 8: Possible bed separation mechanism