10 Ground Control

To inquire into . . .

(d) whether there was any defect in or about the Mine or the modes of working the Mine;

(e) whether the Mine and its operations were in keeping with the known geological structures or formations in the area;

(f) whether there was compliance with applicable statutes, regulations, orders, rules, or directions

Coal mining has been described as the equivalent of "trying to get the filling out of a layer cake – without disturbing the layers."[1] From my reading and research on the subject, that is an apt description.[2] Maintaining the "layers" while extracting the coal "filling" encompasses the science of ground control – also referred to variously as strata control or roof control.[3] A somewhat technical definition of ground control is:

> the science that studies the behaviour of rock mass in transition from one state of equilibrium to another. It provides a basis for the design of support systems to prevent or control the collapse or failure of the roof, floor, and ribs [walls] both safely and economically.[4]

Less technically, strata control may be defined as:

> that which encompasses control and prediction of strata behaviour during development and extraction operations. This definition includes a wide range of tasks such as roadway design, pillar design, subsidence prediction, definition of caving characteristics and longwall face control.[5]

Well-planned and well-executed ground control techniques can, therefore, result in threefold benefits. Such techniques can increase efficiency by maintaining production levels and keeping the roadways clear of rock-fall debris; they can substantially lessen the chance of injuries and fatalities; and, finally, they can minimize the possibility of methane entrapment and the resulting explosion hazard.

Geological Conditions

The Pictou Coal Basin

The geological formations inherent in the Pictou coal basin have been known for many years. The Pictou basin, an extension of the Appalachian field,[6] seems to have been subjected to tectonic pressures and movement, which caused faulting and substantial tilting of strata. These characteristics, especially as they apply to the Foord and associated seams, make ground stabilization while mining a major challenge. Some 60 years

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1 Conversation with Craig Hilton, manager, technical support, Skyline Mines, Helper, Utah.

2 Throughout this chapter, I have relied greatly on the judgment of Dr Miklos Salamon, the Inquiry's expert on ground control, and Roy MacLean, the Inquiry's coal mining adviser. Many of the specifics included in the text are from discussions with them.

3 We will also be using another common expression, "rock mechanics," which is the measurement, study, and understanding of stresses in rock and their effects. Rock mechanics is the tool with which mining engineers plan and effect ground control in underground mines.

4 Syd S. Peng, *Coal Mine Ground Control* (Toronto: John Wiley & Sons, 1978), 1.

5 R.G. Siddall and W. J. Gale, "Strata Control – A New Science for an Old Problem," *The Mining Engineer* 151 (June 1992): 341.

6 Communication with Charles Byrer, U.S. Department of Energy, Unconventional Gas Projects.

ago, one mining authority made the following observation about the Pictou coalfield:

> The most striking features of the coal seams and enclosing strata are the irregular folds and numerous faults in different directions which together with the rapid variation in thickness makes the most difficult mining conditions your investigator has observed in any of the coal fields of North America or in Europe.[7]

It may be that, in the ensuing years, advances in mining technology – including better geological assessments and ground control methods – have rendered these features less formidable. Certainly, ground control techniques have advanced substantially. Nevertheless, hardly a day went by in Westray's brief history when ground problems did not beset the operation. Although continual roof and pillar failures contributed to the ultimate failure of the mine, human failures allowed the ground problems to get out of control.

Experienced underground miners believe that the ground talks to them. They know, by a myriad of signals, whether a roof or a rib is solid or on the verge of failure. They know from long experience what is inherently safe, and what needs support to make it safe. Similarly, an experienced mining engineering team will learn to plan a mine according to the ore body's individual characteristics. A prudent mining engineer uses every available source of information, including history, geological and geotechnical data derived from drilling and from other means of testing, the experience of others, and experience acquired from ongoing mining operations.

Geology – the makeup of the various components of the earth and the interrelationships among them – determines in large part how the ground will behave when disturbed by mining activities. This chapter will examine some of the knowledge that was available to the planners and operators of the Westray mine. It will then show how this knowledge of potential and actual ground conditions was misused, misunderstood, or ignored, and will examine the human failures that may have contributed to the massive ground control problems encountered underground at Westray.

Feasibility Studies

The Foord seam that Westray chose to mine came with a wealth of mining history. Over the course of 120 years, some 60 million tonnes of coal have been mined from 18 seams in Pictou County, 5.3 million of them from the Allan mine, Westray's next-door neighbour on the Foord seam.

Before Westray commissioned Kilborn Limited to plan the mine, a large body of knowledge about the Pictou coalfield had accumulated, with no small amount of wisdom acquired about the real difficulties facing any

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[7] George S. Rice, "Report on Pictou Coal Field," prepared for the Royal Commission on Acadia Coal Company Limited (1937). Dr Rice was the retired chief mining engineer for the U.S. Bureau of Mines.

mining operator there. A number of feasibility studies had already been carried out. Throughout the 1980s, Suncor Inc., Associated Mining Consultants Ltd, Golder Associates, Dames & Moore, Norwest Resource Consultants Ltd, and Placer Development Ltd contributed to the body of knowledge about the potential coal orebody and its associated ground.[8] As many as 73 exploration holes have been drilled from surface within the Westray mine boundaries, 50 of them since 1981. Geophysical data have supplemented drill core analysis of the more than 40 holes that intersected the Foord seam.

Over the course of the various feasibility studies, analysis of the data suffered from breaks in continuity whenever consulting firms changed. A disclaimer in volume I of the Kilborn report identifies this problem:

> Constrained by shortage of time, neither Kilborn nor Dames & Moore has examined exploratory drill cores, interpreted geological data or separately calculated reserves, but has used information prepared by Suncor Inc., Placer Development Limited and Associated Mining Consultants Limited. Kilborn and Dames & Moore have reviewed the geological and reserve data and are satisfied that the geological analysis and reserve estimation have been completed in accordance with procedures which are well-proven and accepted in the industry.[9]

A further disclaimer appears in section 3.1 of the same report:

> Mine design, planning and scheduling have been completed under time constraints and are largely based upon the work of Suncor Inc., Norwest Resource Consultants Limited, Golder Associates, Associated Mining Consultants Limited and Placer Development Limited. Whilst the current mining proposals represent a reasonable and realistic approach, future work will consider alternative technical practices and approaches in order to further improve mining efficiency and operation.

Thus, it seems that the Kilborn study did not re-examine the physical conditions in the mining area, nor did it attempt to re-examine the feasibility and suitability of the mining plan. As we shall see, the time constraints that prevented such re-examination ultimately led to serious consequences when the mine plan did prove to be neither "reasonable" nor "realistic." The lesson to be learned here is that a lack of continuity between feasibility studies and in mine planning can lead to the perpetuation of faulty reasoning or to the misinterpretation of earlier conclusions.

Geology at the Mine Property

The mining area in the Foord seam is bounded by the outcrop to the south, old workings of the Allan mine to the west, and faulting to the north. It is open-ended to the east, where the depth increases to about 850 m. The

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8 See Chapter 2, Development of Westray, and Chapter 11, Department of Natural Resources, for more complete discussions of the various feasibility studies. The studies are listed in Appendix L, Chronology of Westray.

9 Kilborn Limited, "Technical and Cost Review of the Pictou County Coal Project" (1989) (Exhibit 4, s. 2.6).

seam dips from the outcrop in an east-northeast direction at approximately 20 degrees. In the centre of the reserve area, the inclination seems to range from 8 to 12 degrees. On the eastern side of the property, the seam dip increases to over 20 degrees. The seam thickness increases downdip from the outcrop and, in the mining area, appears to range between 2.5 and 8.5 m.

The Kilborn report located and plotted faults in the Allan mine.[10] Apparently, several normal faults striking in a north-south direction were encountered, with vertical displacements ranging up to 25 m. By studying the drill hole logs, Kilborn attempted to anticipate faults in the Westray area. In some holes, the full sequence of strata was not intercepted, suggesting the presence of faults. The full interpretation of the data suggested that faulting to the north and south, with displacements in excess of 100 m, would limit mining. Within the mining area, normal faulting was anticipated; in particular, a north-south–trending fault located on the east side was expected to have a displacement of 50 to 70 m. The Kilborn report did not, however, alert Westray about the limited number of boreholes on which it based its predictions. A comparison of the faulting experienced in the Allan mine with the forecast for the Westray mine would have warned of a possibly overoptimistic prediction. There is no evidence that such a comparison was made.

Kilborn's examination of the cores indicated that the immediate roof of the Foord seam consists of "thin shaley coal, often containing a thin coal band, overlain by carbonaceous shale which grades into an oil shale or shale/mudstone containing silty bands and sandstone which attains a thickness of 15 m in one core hole."[11] This description appears to forewarn of the terrible roof conditions the mine had to endure during its relatively brief operation. The drill-hole data suggest that the immediate floor of the seam is a carbonaceous shale overlying shale/mudstone with interspersed thin sandstone layers. (Because the floor of the seam did not play a significant role in the disaster, its quality will not be the subject of any further discussion.)

Based on laboratory findings, Kilborn predicted "moderately strong" roof and floor strata. With hindsight, this picture is misleading. The author of the Kilborn report's geological section sensed that problems could lie ahead. The report states: "Roof and floor conditions are anticipated to be variable . . . Partial or complete removal of weaker carbonaceous shale, and/or oil shale bands, may be necessary to expose competent roof strata."[12] Such a measure would either seriously degrade coal quality by dilution or, if the waste rock were handled separately, undermine productivity. Neither prospect would appear to be attractive for a mining company.

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10 Exhibit 4, figure 2.4.

11 Exhibit 4, s. 2.4.3.

12 Exhibit 4, s. 2.4.3.

Tests on coal samples yielded uniaxial compressive strengths in the range of 6 to 18 MPa, suggesting a moderately competent seam.[13] In assessing these strength values, the consultants apparently overlooked the fact that laboratory tests carried out on small samples tend to overestimate the strength of coal.

According to the Kilborn report, information from the Allan mine indicated, and the surface boreholes confirmed, that the Foord seam contains ironstone bands in some areas.[14] These bands, with an average thickness of 70 to 120 mm, generally occur in the upper part of the seam and are known to contain pyrites. Such hard material as ironstone may be significant as a potential source of sparks when hit by the hard metal of the continuous miner picks. Clearly its presence was known to mine planners, who nevertheless seem to have insisted that the roof of entries should coincide with the top of the seam. As a result, continuous miners had to cut through the ironstone bands.[15]

Mining Conditions

Kilborn defined the expected mining conditions in section 3.2 of its report. It is important to look at some of them to illustrate the physical conditions in which Westray was expected to operate. These mining conditions appear in table 10.1.

Following the ideas put forward in the Placer study, Kilborn chose the room-and-pillar method, with 6 m-wide entries, as the basis for underground operations. This choice fulfilled a number of Kilborn's 12 listed requirements for mining, many of which are reasonable.[16] Given the physical conditions of the ore body, however, two of the items pose a formidable problem for mine planners:

- coal extraction height of up to 7 m and mining to a depth of 700 m
- minimum roof support requirements.

The room-and-pillar method is ideal for relatively shallow depths, the environment in which it was originally developed (see the section on mining methods later in this chapter). At a depth of 100 m, the pressure arising from the weight of the overburden, or the "coverload," is about 2.5 MPa. This pressure increases to 17.5 MPa at a depth of 700 m. The pillars in room-and-pillar workings are *always* burdened by a load that is higher than the pressure from the coverload. At 700 m, the value of the coverload approaches the upper limit of the coal strength presented in

13 Uniaxial compressive strength is a measurement of how much pressure in one direction it takes to break up the material in question. The megapascal (MPa) is a unit of measurement equal to 145 pounds per square inch (psi). To put the strength of coal in perspective, even shales and sandstones can have compressive strengths greater than 100 MPa. Rock such as granite and limestone can have strengths exceeding 200 MPa.

14 Exhibit 4, s. 2.4.5.

15 My conclusion, as set out in Chapter 6, The Explosion, is that the Westray explosion was initiated by sparking from sandstone or pyrites at the continuous miner in the SW2-1 heading.

16 Exhibit 4, s. 3.4.

Table 10.1 Mining Conditions – Kilborn Report

Seam thickness	2.5 to 8.5 m
Seam inclination	0° to 28° but generally less than 14°
Depth of cover	200 to more than 700 m
Areal extent	Approximately 362 ha
Seam composition	Thinly banded bright and dull coal with occasional ironstone band averaging 70 to 120 mm
Coal strength	6 to 18 MPa in uniaxial compression
ASTM coal rank code	High-volatile A bituminous
Methane emission rate	Less than 6.2 m^3/t
Spontaneous combustion risk	Not clearly defined
Seam roof and floor strata	Moderately strong shales, >20 MPa in uniaxial compression, RQD > 75%

Source: Exhibit 4, s. 3.2.

table 10.1. Because the tabulated values overestimate the true strength, ordinary room-and-pillar mining can be expected to result in difficulties in most of the depth range of the Westray mine. Also, it is a well-known phenomenon that the strength of pillars of fixed horizontal area decreases with increasing height. Hence, the great depth of cover, in combination with a thick seam, should have warned of possible ground control problems.

Most coal mining is carried out today in seams that are nearly horizontal. The Foord seam is fairly steep. The planners should have foreseen that this inclination would hamper mining in a number of ways. Kilborn should have anticipated that underground productivity would suffer and that the strength of coal pillars would be reduced.

Perhaps the most surprising statement in section 3.2 of the Kilborn report is the reference to the quality of the roof. The remark "moderately strong shales," together with a RQD (rock quality designation) value of 75 per cent (of a maximum 100 per cent), suggests a reasonably competent roof. This portrayal does not appear to be corroborated by the geological description (section 2.4) of a roof "composed of thin shaley coal, often containing a thin coal band, overlain by carbonaceous shale which grades into an oil shale/mudstone containing silty bands and sandstone . . ." The subsequent underground problems with roof control proved beyond any doubt the validity of the geological assessment.

Finding

The following combination of mining conditions made Westray a potentially difficult mine to develop and operate:

- **depth of coal in the mining area**

- **thickness of the seam**
- **relatively steep pitch of the seam**
- **virtually unknown faulting in the mining area**
- **poor roof quality**
- **wide entries.**

The cost of operating in such an adverse environment and the inherent uncertainties would suggest that the financial viability of the Westray project should have been in doubt from the very beginning.

Mining Methods

I think many readers may find it helpful, for their understanding of this Report and its recommendations, to have a brief description of the various underground coal mining methods in use. The mining method directly affects ventilation requirements, dust control, the control and dispersal of methane and other hazardous gases, and the particular ground control system to be used. The selection of a particular method will depend on many factors, including capital cost of equipment; geological structure, width, and thickness of the coal seam; estimated coal reserves; and the estimated productive life of the mine. The three principal methods of mining, in descending order of the frequency of use within the industry, are longwall, room and pillar, and shortwall. The last is a hybrid of longwall and room and pillar.

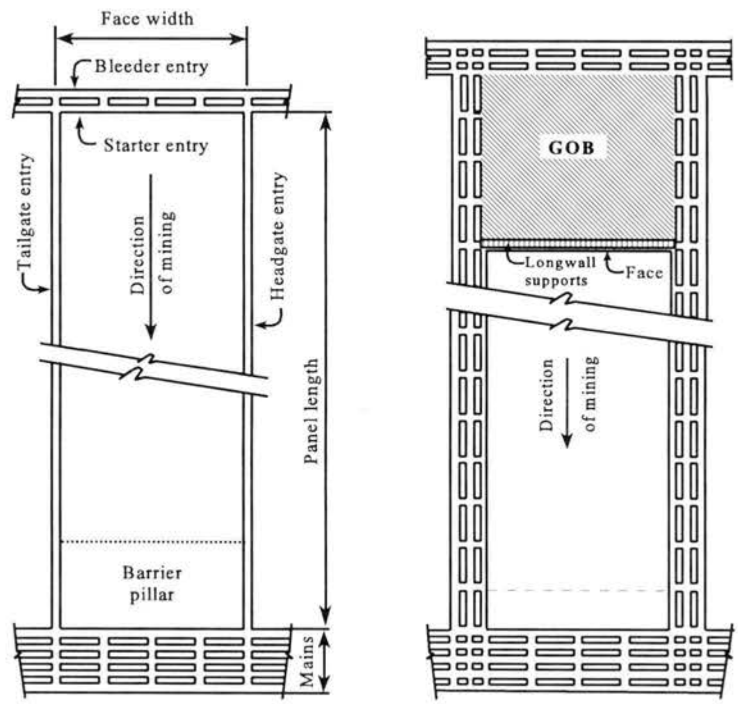
Longwall Mining

Typical longwall layouts are shown in figure 10.1. The drawings are merely illustrative and were chosen for their simplicity. In practice, a mine layout would likely be more complex. For a more detailed, and accordingly more accurate, description of a longwall operation, the reader's attention is directed to several texts listed in the bibliography.[17]

Construction begins with the driving of a set of mains along the total width of the coal seam. The mains provide the means to connect the mine infrastructure, such as ventilation and transport (of materials, miners, and coal), to the proposed longwall panel. Depending on the size of the seam and its relation to the developed sections of the mine, the mains could extend for several kilometres. There are two longwall mining methods: "advancing" (moving away from the mains into the coal face); and "retreating" (the face moving towards the mains). Since modern trends seem to favour the retreat longwall, I will limit my comments to that method. Entries (the headgate and the tailgate) are driven at right angles to the mains through the coal seam to its end or to a point determined by geological or other factors. The panel of coal is isolated by the two "gates," and the distance between them determines the face length.

[17] *Longwall-Shortwall Mining, State of the Art*, ed. R.V. Ramani (New York: Society of Mining Engineers, 1981); Society of Mining Engineers (SME), *Underground Mining Methods Handbook*, ed. W.A. Hustrulid (New York: Port City Press, 1982).

Figure 10.1 Typical Longwall Layouts



Typical single-entry longwall panel

Typical triple-entry longwall panel during mining

Source: Society of Mining Engineers, *Underground Mining Methods Handbook*, ed. W.A. Hustrulid (New York: Port City Press, 1982), 291–92.

Although figure 10.1 shows a single-entry system and a triple-entry system, the number of such entries, in practice, is determined by local mining methods and regulations.[18]

The entries required to develop a retreating longwall face are usually driven by a continuous miner, the machine commonly used in room-and-pillar mining.[19] The roof of the resulting passage is then secured by roof bolts (or other means) before passage of workers is permitted. To protect the miners while they are working under an otherwise unsupported roof, the roof may be secured by a temporary roof support (TRS) system until bolting or other permanent support is installed. The TRS is often a hydraulic or screw jack of a type similar to those sometimes used to support beams in home basements.

Longwall mining areas for coal are developed in panels that commonly range from 100 to 365 m wide, and 300 to 4,000 m long. The size of a

18 The multiple-entry system is more typical of the U.S. approach to longwall mining, with a minimum of three entries on each side of the panel, than the European practice of using single entries. The multi-entry mains resemble room-and-pillar workings. The single-entry example more closely resembles the setup in the Devco mines on Cape Breton.

19 The equipment and methods for mining longwall entries and securing the roof are similar to those described in Chapter 6, The Explosion, for the Westray operation.

panel is generally based on geological conditions and projected mine layout. Once the headgate and tailgate entries are developed to the full length of the panel, they are connected by a "starter entry" to establish a circuit for ventilation and to provide the work space necessary for the installation of the longwall equipment.

The equipment consists of a shearer (the coal-cutting device), a chain conveyor, and a system of self-advancing hydraulic roof supports. The shearer heads are large-diameter drums with picks or cutters that rotate into the coal face, cutting the coal. The coal falls onto the face conveyor, which transfers the coal to the entry conveyor belt for transport to the surface. The shearer moves along the coal face, cutting off as much as 1 m of coal on each pass.[20]

The operators and service people are protected by the self-advancing hydraulic roof supports. As the shearer cuts into the face, these massive steel canopies move towards the face, preventing roof falls between the face and the supports, thus protecting the working area. As the shearer advances, the roof usually falls behind the roof supports into the gob (the area from which the coal has been extracted). This controlled roof fall, or "caving," takes place regularly with the movement of the face. Thus, there is no need for roof support in the gob, since the roof collapses behind the operation and out of harm's way. After the shearer passes, hydraulic rams connected to the bases of the supports push the face conveyor forward, and the shearer is ready to cut the next "web."

The mining engineers and others to whom I spoke generally agree that longwall mining is the safest of all current coal mining methods because the miner is protected at all times from the hazards of roof fall – provided that the system is operated properly. It is also the most efficient method.[21] Because of its efficiency and speed, there are times when the longwall operation may have to be curtailed in order to bring methane levels down to acceptable levels. The shearer moves so rapidly across the coal face that methane may be liberated at a rate with which the ventilation system cannot cope. There is also the problem of methane accumulation in the gob.

Room-and-Pillar Mining

In room-and-pillar mining, rectangular blocks of coal left untouched (pillars) constitute the support for the roof in the mined area. A working room-and-pillar panel constitutes a series of parallel passageways with connecting cross-cuts at regular intervals. Part of a room-and-pillar panel is illustrated in figure 10.2.

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20 In one such operation, the Skyline mine in Helper, Utah, I observed that the shearer could reach a height of 15 feet (4.5 m) along a coal face of about 700 feet (215 m). I was told by my guide that this installation is one of the largest longwall operations in the world. I am informed that shearers are presently available that can cut to a height of 20 feet (6 m).

21 Inquiry experts place the coal extraction in the order of 65 to 80 per cent for longwall, compared to 50 per cent or less for room-and-pillar mining.

Room-and-pillar mining, the method used at Westray, employs the continuous miner as the extraction mechanism. Some continuous miners have cutting heads that occupy the full width of the entry, but the body of the machine is commonly about 3 m wide. Room widths normally range from about 5 m to 7 m. As the cutting head removes coal from the face, the coal falls onto a chain conveyor built into the continuous miner, and is loaded onto a shuttle car. The shuttle car transports the coal to a belt conveyor system for transport to the surface. As the continuous miner advances and creates the "rooms," it establishes the checkerboard pattern seen in figure 10.2.

For reasons of space, roof control in continuous miner operations is almost exclusively roof bolting (see the following section on ground control methods for a description of roof bolting). The double roof bolters used at Westray, with their built-in automatic temporary roof support system and hydraulically operated operator canopies, are typical of the equipment used in modern room-and-pillar mining. The machine drills the appropriate-sized holes into the roof to the depth set out in the roof control plan and then sets the bolts either mechanically or with resin. A further advance on this machine is the dual bolter built onto, and forming part of, the continuous miner. With such a machine, the length of time that a mine roof remains unsupported is reduced, thus increasing the safety factor considerably.

Room-and-pillar mining does not have the potential to be as efficient or productive as longwall, since it is necessary to leave so much coal in the mine for support. Because of the necessity for immediate roof bolting, it also lacks the speed of the longwall shearer. After advance mining in the room-and-pillar system, it is possible to do some "retreat" mining or depillaring on the way back. Room-and-pillar mining survives for two reasons: (1) it requires a much lower capital investment than longwall; and (2) it has greater flexibility, which is important when operating in geologically disturbed areas.[22]

Shortwall Mining

Robert Stefanko sets out four conditions – economic, technical, geological, and safety – that can make shortwall mining attractive.[23] Since this method uses the continuous miner, the mine operator may change from room-and-pillar mining while fully utilizing existing equipment. The major addition to the equipment required is the hydraulic roof supports similar to those used in longwall mining. The shortwall method may have an advantage over longwall in circumstances where geological conditions provide discontinuous seams of coal. It is also much easier to relocate the shortwall operation than it is the longwall. Since miners are provided the

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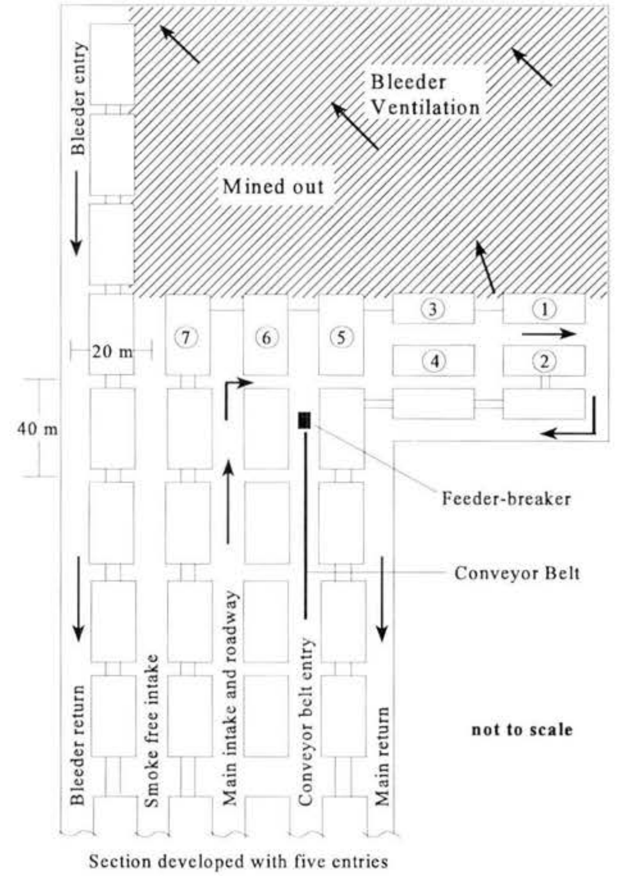
22 For a more complete and technical explanation of room-and-pillar mining, refer to Dr Salamon's report to the Inquiry (Exhibit 58.2, s. 2.2).

23 Robert Stefanko, *Coal Mining Technology: Theory and Practice* (New York: Society of Mining Engineers, 1983), 159.

Figure 10.2 Typical Room-and-Pillar Layout



Source: Prepared from John T. Boyd Company, "Mine Feasibility Study – Westray Mine Foord Seam, Pictou County, Nova Scotia, Canada," Report to Industry Canada (Pittsburgh, June 1994), figure 6.1.

protection of the overhead shield, the operation is safer, and, since the continuous miner operates in an open-ended airway, personnel at the face are able to work in fresh air, not the commonly dust-laden air of room-and-pillar headings.

The shortwall method is much less popular than longwall or room-and-pillar, and most of the mining engineers with whom I have spoken are generally indifferent to it. Because of its attributes, however, the shortwall method should not be overlooked where conditions are favourable.

Roof Support

Roof bolting seems to be the most widely used system of roof support in use today. One source attributes the origin of roof bolting (or rock bolting) in coal mines to the United States: "The origins of roof bolting are obscure, but its introduction into American mines in the 1940s led to rapid reduction in accidents due to falls of ground."[24]

The traditional roof bolt resembles a length of rebar (the steel rods used for concrete reinforcement) from 1 to 2.5 m long and threaded on one end. A hole is drilled in the roof or rib of the mine, and the bolt is inserted into the hole and secured with resin. (Mechanical anchors are still widely used in hard-rock mining.) Tubes of resin are inserted into the hole and the bolt is then pushed into the hole with an upward spinning motion, which mixes the resin and forces it into the cracks and crevices around the hole. When the resin hardens, a steel face plate (100 to 200 mm square) is placed on the threaded base of the bolt and secured with a large nut. Often, a wire or vinyl mesh is held against the roof by the face plates to catch small material that may come loose from the roof. The bolt, secured by the hardened resin, holds the roof strata together. Where the roof is particularly unstable, it may be necessary to make the bolt holes deeper, with longer bolts or a wire cable replacing the roof bolt. Roof bolts can also be used in several different ways to combat various roof conditions common in underground coal mines. Several applications of roof bolts are illustrated in figure 10.3.

The advantages of bolting in comparison to other and more conventional forms of roof support are set out in a training manual for mine examiners and shotfirers at Devco:

- Bolting allows for the maximum, unhindered movement of men, materials and equipment.
- Bolts can be placed very close to the face and not be in the way of mining machinery.
- Bolts can be spaced very close together, providing a very strong support system.
- Bolting aids in mine ventilation by eliminating timbers and props.
- Bolts can be used in combination with steel beams, wooden bars, or planking to provide extra support.[25]

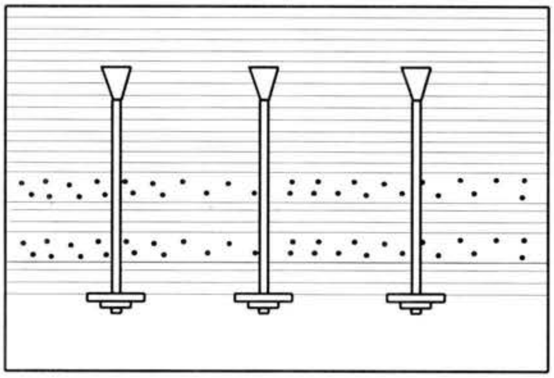
Proper roof bolting is an exacting skill that requires a knowledge of rock mechanics as applied in the geological structures being supported. Finally, it must be emphasized that a bolting system must be designed specifically for the conditions present:

> The choice of the system is based on the capability of each system under the particular geological conditions, the anticipated stresses (both vertical and horizontal), the extent of deformation anticipated and operational constraints.
>
> . . .
>
> At present, the complexity of strata properties and stressfield interactions due to mining operations has prevented the use of formulae or calculator [computer?] designed bolting systems. The actual design of the

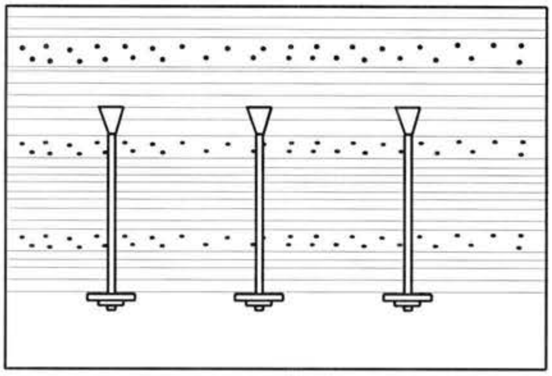
[24] Siddall and Gale, "Strata Control," 341.

[25] Cape Breton Development Corporation, *Mine Examiner/Shotfirer Training Programme*, Module C/MO 4/5 (Sydney, NS: CBDC, 1987), 27.

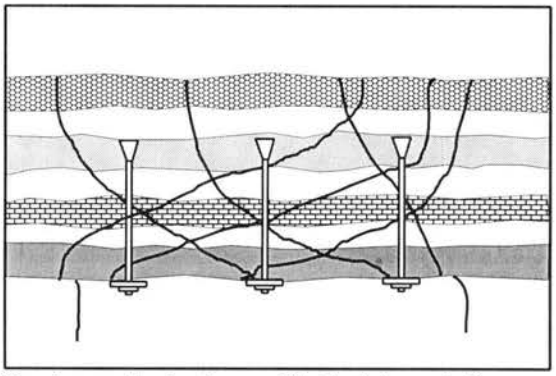
Figure 10.3 Roof Bolting



Suspension method – layers of strata anchored in stronger strata



Beam method – layers of strata laminated to make a beam



Keying method – the roof bolts intersect slip planes of randomly jointed rock, forming them into a stronger unit.

Source: Cape Breton Development Corporation, *Mine Examiner/Shotfirer Training Programme*, Module C/MO 4/5 (Sydney, NS, 1987), 25.

bolting system is determined from an initial appraisal of the site conditions followed by detailed monitoring of the performance of the bolts and then by the actual response of the roadway under the conditions defined.[26]

[26] Siddall and Gale, "Strata Control," 345.

The Westray Mine Plan

The mine design outlined in sections 3.1 through 3.4 of the Kilborn report was apparently the most recent mine plan in Westray's possession before operations in the mine began. The same plan was used in the licence application and must be regarded, at least for the initial stages of the mine's operation, as the blueprint for the eventual mine layout. It is noteworthy that the plan is virtually identical to that suggested in the study by Placer Development Limited, a plan apparently formulated by Associated Mining Consultants Ltd.[27]

Although the Kilborn study includes no substantive discussion of the options available to Westray, it is difficult to dispute the conclusion that led to the choice of room-and-pillar mining. In a faulted and thick coal bed such as the Foord seam, longwall or even shortwall mining would have been technically and economically at a serious disadvantage. It is therefore not the choice of method that I question, but the selection of the operating parameters – for example, upper limit of mining depth, upper limit of mining height, unchanged pillar layout throughout the depth range from 200 to 600 m, and choice of the seam's top as the roof of the entries. In the absence of contrary evidence, the explanation for these unfortunate choices might be based in reasons beyond simple mining consideration. A plausible explanation could be that the need for these extreme limits was motivated by a need to increase extractable coal reserves. The prospects for Westray (or its successor) may have been more realistically assessed by John T. Boyd Company in 1994. According to the Boyd report, "reopening of the Westray Mine is not economically viable in the foreseeable future."[28] Indeed, the report noted that the [1994] market price of coal would have to double to reach viability.

These controversial mining parameters were introduced during the July 1987 study conducted by Placer. This study represented a bold departure from previous investigations, which suggested shortwall mining as the main mining method. In the shortwall system, a continuous miner, along with self-advancing hydraulic supports, is deployed along a relatively short face (40 to 60 m). In all likelihood, the hydraulic supports would be quite capable of containing the weak, layered roof of the Foord seam. However, the team involved in the Placer study did not re-evaluate the tentative recommendations of Golder Associates when it decided to change to the room-and-pillar method.

Lack of Continuity in Planning

Golder Associates produced two early reports for Suncor concerning the geotechnical factors in a possible mining venture. The first report recommended, among other things, that the roof plane of the entries

27 Exhibit 10.2, pp. 1–3.

28 Exhibit 26, pp. 2-6–2-8. John T. Boyd Company, "Mine Feasibility Study – Westray Mine Foord Seam" (June 1994). This report was commissioned by Industry Canada.

should coincide with the coal-rock contact.[29] This recommendation was accepted by subsequent consultants and persisted – to the mine's and its workers' peril – into Westray's operational phase, despite Golder's obvious assumption that mining would be based on either a longwall or a shortwall system and that, in either case, longwall-type supports would be used to secure the roof of the producing faces. The second Golder report, while retaining the original recommendation concerning the roof plane, made important additional comments, including the assessment that the thickness of the shale would be a controlling factor in roof conditions.[30] Furthermore, the report presented preliminary coal strength data, indicating a range from 6 to 18 MPa, with a mean strength of 14 MPa.

The two Golder reports were prepared before any of the mining feasibility studies were carried out. Nevertheless, the recommendation for roof control made in the first of the Golder reports in 1984 was adopted by the Norwest team in 1986 and retained by the subsequent investigators. Because Norwest was considering mining methods that involved hydraulic support systems, this choice may have been justified.[31] However, in the next feasibility study, the Placer group decided to place the room-and-pillar method at the core of its plans. This method involves the exposure of a considerable roof area and employs large moving machines (shuttle cars and continuous miners), so the use of longwall-type supports would have been impractical. In these circumstances, it would have been prudent to avoid using the inferior coal-rock interface as the entry roof.

It appears that no fresh geotechnical investigation preceded the decision to change the mining method, and the original Golder recommendation was carried forward. The Kilborn team, the next group performing a study, did not revisit the technical issues and seems to have ignored the warnings in the Golder reports. Thus, the Placer change in mine plans was adopted by Kilborn, and consequently the roof of the entries in the Westray mine coincided with the weak roof of the Foord seam. This sequence of steps, as events have shown, put Westray in a vulnerable position. Three separate teams conducted three feasibility studies. Gerald Phillips, subsequently Westray's general manager, was apparently the only person who participated in all three studies. The lack of continuity in experienced and knowledgeable personnel during the planning and feasibility stages may have contributed to the exceptionally bad roof conditions in the Westray mine.

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29 Exhibit 13.1, p. 28. Golder Associates, "Geotechnical Aspects Related to the Acadia Coal Project – Pictou County, Nova Scotia" (Vancouver, October 1984).

30 Exhibit 13.2, p. 15. Golder Associates, "Rock Mechanics Advice for the Acadia Coal Project – Pictou County, Nova Scotia" (Halifax, April 1986).

31 Exhibit 9.3, s. 2.1.1.

Finding

In spite of several warnings of potentially serious ground control problems, the management of Westray proceeded with mine development without having completed verification of many of the tentative estimates contained in several feasibility studies.

Ground Conditions at Westray

The Mine

Access to the Westray mine was through two inclined tunnels, or slopes. Excavation of the slopes started in May 1990, and (after an interruption of several months) in February 1991 the slopes reached the Foord seam (near No. 5 Cross-cut), at this point too thin and dirty to be considered minable. Here the slopes were continued in the Foord seam in a north-northeast direction until, at about No. 9 Cross-cut, the seam thickness and dirt content had improved to a more or less minable quality. There, the development of the B and C1 Roads commenced in a northwest direction. The aim of these drives was to open up the Southwest section. Maps 1 and 2 in Reference illustrate the mine's roadways and the chronology of its development.

In the meantime, the two main slopes, No. 1 and No. 2 Mains, continued in the original direction for about 110 m, at which point the mains were turned, because of faulting, into an east-northeast direction for about another 110 m. Here the development split. Three drives, 1, 2, and 3 North Mains, were driven in a north-northeast direction, and two entries continued in the original direction for a short distance. These two were stopped and abandoned, obviously for some geological reasons. After about 120 m, two drives were turned off from 3 North Main towards the east (2 East and 1 East), which, after 60 to 70 m, turned right and joined, to become 1 Southeast. This single entry was driven until it was in line with the earlier-abandoned No. 2 Main heading, at which point it was turned to the southwest, with the apparent intention of holing into the abandoned drive. At the time of the explosion, work was in progress in the Southeast heading. See map 9 in Reference for a geotechnical view of the North mains and Southeast sections.

The North mains continued for some distance, but eventually 3 North Main was discontinued. Some 260 m from the start of the North mains, the development split: three headings turned northwest, 2 North Main proceeded in its original direction, and North 6 Cross-cut turned to the east. Apart from the cross-cut, mining was in progress in all these drives at the time of the explosion.

Let us now look at the development of Southwest 1. (Map 8 in Reference is a geotechnical view of the Southwest section.) This panel was planned to come into being on the northeast side of SW1-B and SW1-C1 Roads. It was intended to be a room-and-pillar section. As the plan of the area reveals, the attempts to establish this panel were unsuccessful. Six cross-cuts were initiated, but proved insufficient to form a healthy coal-producing section. According to the geological plan, (see map 4 in Reference), the east side of Southwest 1 was badly disturbed by a series of parallel faults. Eventually, the idea of having an effective production section in this area was abandoned, and SW1-4 Cross-cut was developed on the southwest side of SW1-B Road. From this and a parallel cross-cut, a number of parallel entries were driven unusually close to each other in the northwest direction. Phillips, in a memorandum dated 13 April 1992 that was addressed to all Westray employees, stated that these pillars were designed to have a width of 12 m "but were cut to as little as 6 metres. . . ." The relatively undisturbed pattern of the area reveals that it was an effective section. The plan divulges also that, unfortunately, the panel was abandoned in haste.[32] (This is apparent from the unfinished appearance of the layout.) There were no activities in this area at the time of the explosion.

The last development in the short-lived Westray mine was in Southwest 2, developed via SW2-A and SW2-B Roads. These entries, which were started at points close to SW1-2 Cross-cut in SW1-B Road, were driven almost due west. The development to open up this panel followed the departure from Southwest 1. Little was accomplished in the area before the disaster. This was the third section of the mine being actively mined at the time of the explosion.

This brief survey of the mine plan found no convincing indication of management's plans.

Production Shortages

The seriousness of Westray's mining problems was aggravated by the company's contractual obligations to supply coal to Nova Scotia Power Corporation (NS Power). This becomes obvious from an examination of Westray's production records, as presented by Salamon in his report to the Inquiry:[33]

- The contract with NS Power called for total sales of 445,000 tonnes in 1991. The actual delivery was less than 6,000 tonnes.
- The underground (run-of-mine) coal production jumped significantly in January 1992, to 63,804 tonnes from 23,625 tonnes in December 1991. This increase coincided with the full development of the section with the narrow pillars.
- During 1992, the contract required delivery at a rate of 58,333 tonnes per month (700,000 tonnes per year). The highest sales, which occurred in March 1992, represented only 84.5 per cent of the contract. One reason

32 The retreat from Southwest 1 is covered in its various aspects later in this chapter (in the section on ground conditions at Westray, Southwest 1) and in Chapters 7 and 8, Ventilation and Methane.

33 Exhibit 58.2, s. 3.2. The contractual and financial implications of the deal with the power company are covered in Chapter 2, Development of Westray. They are touched upon here simply to add context to the geological problems being encountered.

for the shortfall is that at no time had the saleable tonnage of clean coal reached 54 per cent of the run-of-mine production.

- Underground production dropped significantly in April 1992, to 40,495 tonnes from 69,780 tonnes in March, a 42 per cent reduction. It is noteworthy that Southwest 1 was abandoned at the end of March.
- To the shortfall in sales during the period of production, October 1991 to 7 May 1992, the delay of some 13 months in the start of production should be added.[34]

From this perspective, Westray management laboured under considerable pressure to produce coal.

Ground Control Problems

It is clear that Westray's production problems stemmed from unexpectedly severe geological conditions and ground control problems. Evidence of the adverse ground conditions is manifold.

Westray miners were preoccupied with the state of the deteriorating roof conditions. Miners felt that it was only a matter of time before someone would suffer serious injury or death from a rock fall. Ted Deane testified that he and his partner often spoke with their foreman, John Bates, about the ground conditions. Bates was certain that someone would eventually be injured by a roof fall; he was, at that time, less concerned about an explosion.[35] According to Randy Facette, the drive to unionize the workforce was motivated, in large part, by the roof conditions: "I guess our main concern [was] that someone was going to get killed there soon by a rock fall . . . because we had so many of them."[36] Buddy Robinson was an experienced miner whose fears could not be taken lightly. He testified that the men at Westray were under significant stress, due in great part to the instability of the roof:

> Q. What was putting you under stress?
> A. The whole concept of the mine and the way – working with all these inexperienced people and the way the mine was being handled and – it was – like I said before, it was only a matter of time I thought before a rock fall would kill a bunch of these rock bolters. And it was just phenomenal that it didn't in the end.
> Q. It was just a matter of luck, you're saying?
> A. Like I said, it was more good luck than good management.[37]

Indeed, the close calls attested to by miners during this Inquiry support Robinson's characterization of the situation as "phenomenal." Shaun Comish related an incident in which he was breaking through at the intersection of No. 1 Main and 2 North Main with the continuous miner.

34 See Chapter 2, Development of Westray, for details about the delay in development.

35 Hearing transcript, vol. 26, pp. 5380–81.

36 Hearing transcript, vol. 33, p. 7228. The United Mine Workers of America failed in its attempt to unionize the workforce in late 1991. The United Steelworkers of America later succeeded in 1992.

37 Hearing transcript, vol. 30, p. 6432.

A co-worker advised Comish to "pull back under the arches, get back quick."[38] Just seconds after Comish pulled the machine back and stepped out, the whole roof caved in. He went on to describe another time when the back end of the continuous miner he had been operating was buried by a roof fall.[39]

Lenny Bonner testified to such an episode occurring in SW1-A3 Road, where he was operating one of two shuttle cars. Bonner had expressed some concern to his foreman about going under an overhang on the left-hand rib to load the coal from the continuous miner. While he was dumping a load, a big piece of the rib caved in, blocking the continuous miner. Bonner said that, had he been in his shuttle car loading coal, he would have been dead.[40]

In November 1991, Ron MacDonnell and Jack Matthews were in the bucket of the Scooptram setting steel arches at the intersection of No. 1 Main and No. 11 Cross-cut. MacDonnell testified that "part of the roof came in," snapping off the chock blocks they had been tying in. MacDonnell was knocked down into the bucket by a large chunk of roof "a couple of feet thick and a few feet wide." Admitted to the hospital with a sore neck and back, he took the next three working days off.[41]

Tom MacKay told of an episode when he and other crew members were roof bolting a caved area in SW1-7 Cross-cut. One worker was standing on the full extended temporary roof support (about 5 m off the ground), while MacKay was standing on top of the driller's canopy.[42] They were hanging screen with mechanical bolts. MacKay told the Inquiry:

> There was a great big rock behind Buddy's back. And I told him, I said, "You'd better get over here." . . . I said, "That rock there looks like it . . . " because it was starting to work, dribble a little bit. I said, "It looks like it's going to let go." And he just never done too much, never moved. So I let a little holler at him and I said, "You'd better get over here." So then he turned around and I hollered again, and he jumped. And just as he jumped, it came down and landed where he was standing there.[43]

These men had been standing precariously under the unsupported roof on the very devices designed to protect them from falling rock. The Inquiry heard many similar tales of horrific roof conditions and close calls.

The geotechnical maps, maps 8 and 9 in Reference, indicate that roof overbreaks occurred frequently. Overbreaks varied in thickness, from 0.2 m to 1.5 m, and involved a significant proportion – roughly one-third

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38 Hearing transcript, vol. 28, p. 5799.

39 Hearing transcript, vol. 28, pp. 5799–5800.

40 Hearing transcript, vol. 24, pp. 4729–30.

41 Hearing transcript, vol. 29, pp. 6069–72.

42 Both practices are extremely dangerous. The temporary roof support is on the bolter to keep the roof from falling while the miners are bolting. The driller's canopy is a protective covering under which the miner can work in relative safety. It stretches credulity that these hazardous practices could be carried out without the knowledge and consent of the shift foreman and the underground manager.

43 Hearing transcript, vol. 32, pp. 7048–49.

to one-half – of the exposed roof. The overbreaks had a significant impact on a number of aspects of the mine's operation. Perhaps the most obvious of these was the impairment of coal quality resulting from the addition of waste rock. The dilution caused by overbreak is estimated to be in the range of 20 to 40 per cent.[44] A second adverse effect of overbreak is on roof support. An irregular roof is always harder to secure than a reasonably uniform roof surface.

The geotechnical maps show a number of other conditions that represent adverse roof and rib conditions in many places in the mine. These conditions include "cutter roof," "pillar slabbing," and "cleat separation."[45] Most of these phenomena suggest movement or loosening in the roof strata.

Perhaps the clearest evidence of excessive roof movement is provided by the extensometer measurements obtained in the rock mechanics monitoring holes drilled into the roof. These vertical holes are located mostly at the intersections of roadways. A program for drilling the holes is given in a memorandum, dated 13 November 1991, from engineering superintendent David Waugh to underground manager Roger Parry.[46] The results from the monitoring holes indicate that the roof mass frequently sagged quite appreciably, often at heights of more than 3 or 4 m above the roof surface.[47] Analysis of the graphs of observed sag in 39 roof holes reveals that some 62, 46, 28, and 15 per cent of the holes show a maximum sag in excess of 50, 100, 150, and 200 mm, respectively. Salamon suggests, as a rough guide, that sag in excess of 50 mm constitutes a warning of undue loosening in the roof.[48] This being so, more than half the holes showed unduly large roof movement. Therefore, considerable danger of major roof falls existed in the mine.

A set of reports collated by Westray staff contains the descriptions of 16 roof falls. These events occurred during the period of approximately seven months between 28 September 1991 and 24 April 1992.[49] Most of the falls took place at three- or four-way intersections. The falls were estimated to range from 3 m to 15 m in height and from 5 m to 20 m in length. They were major roof falls, constituting grave danger to the men working in the mine.

In all but two cases, the roof fall reports refer to the thinly bedded nature of the shales that form the roof of the roadways. The report on "ground fall no. 1" describes the roof conditions: "The original roof was flat, cut to the shale. The overlying shale was the normal sequence of thinly bedded, laminated, polished shales." This description fits exactly

44 Exhibit 58.2, table 2.

45 Cutter roof is a localized break in the roof that first shows up as a longitudinal crack. Pillar slabbing involves pieces of rib falling onto the roadway. Cleat separation occurs in natural planes of weakness in bedded coal.

46 Exhibit 15.0030.

47 Exhibit 15.0033.

48 Exhibit 58.2, p.12.

49 Exhibit 15.0076–0120.

the conditions observed by Salamon at a roof fall inspected during an underground visit on 8 August 1992. This feature of the roof appears to be the most obvious reason for the exceptionally poor roof behaviour experienced at Westray. This thinly bedded shale had been noted in the exploratory surface hole logs. Golder's 1986 report also emphasized the need to make a "roof conditions plan."[50] These warnings appear to have been overlooked by those who planned and later operated the mine.

One symptom of adverse ground conditions is the sheer variety of support systems that Westray experimented with during the short span of the mine's life. These experiments included various roof and side bolting schemes, trusses, rigid and yielding arches, and square sets. A number of documents reveal the scale of experimentation:

- Westray Bolting History, draft, 28 November 1991 (Exhibit 15.0121–22)
- Westray Coal: Ground Support Standards, draft, 17 March 1992 (Exhibit 15.0123)
- Bolting Procedure, draft, 5 March 1992 (Exhibit 15.0124)
- geotechnical maps (Exhibit 45.15)
- ground support maps (Exhibit 45.07)
- Report on Ground Falls and Recommendations for the Support of Intersections (Exhibit 15.0191-97)

In late February 1992, Jack Parker of Jack Parker and Associates, Inc., was invited to visit Westray. Parker is a rock mechanics consultant with wide experience in a great variety of mining conditions. In a letter dated 29 February 1992 to Waugh, Parker reported on his first impressions of the mine:

> During the first day underground I was thinking that roof conditions were horrendous – that most folks would have walked away from them, that except on "government projects" few operators would want to rehabilitate the very high roof failures, for example. But after a good night's sleep and second look I came to feel more comfortable, seeing that management and miners had learned to handle those difficult situations, carefully, and without complaints.[51]

Regardless of Parker's second thoughts, his statement, coming from an experienced and solid professional, reveals exceptionally bad conditions. There are many reasons to suggest that the miners endured these dangerous conditions "without complaints," but the evidence belies any suggestion that they did so without fear. There is much evidence to show that the miners were extremely apprehensive about the roof situation at Westray.

Perhaps the most revealing description of the ground control situation at Westray was given by Waugh to the RCMP on 9 May 1994, two years after the disaster: "The Westray Project was driven by ground problems.

50 Exhibit 13.2, ss. 6.2–6.3.

51 Exhibit 15.0207.

The ground problems affected production and development. I felt someone would get hurt but strictly from ground fall."[52] Waugh was the only person in Westray Coal who had professional experience in ground control, although most of that experience related to potash mining.

Finding

Mining at Westray consistently encountered unexpected and adverse geological conditions. It is obvious that Westray managers were ill prepared to deal with these conditions, and, as a result, when they encountered an unexpected condition, they did not know how to deal with it.

Southwest 1

The Southwest 1 section was the panel in which long, narrow, and ultimately high "finger" pillars were employed. This layout evolved from attempts to improve ground conditions. Resulting side benefits included high productivity and fairly regular output. The mine achieved its highest rate of production during the brief time this panel was in operation.

It is unclear how the idea of this particular plan was planted in the minds of management. It could have come from Waugh or from any of several consultants with whom the mine management was in contact during the last months of 1991. According to many reports, poor roof conditions occur when the *horizontal* pre-mining stresses are high; however, this situation can be alleviated by driving follow-on entries in the "shadow" of a leading drive. The idea is to divert the stress trajectories away from the to-be-protected rooms. Placing several rooms in the shadows of one another may result in an extended protection scheme.

High *vertical* stress can also cause poor roof and rib conditions. Such a state can be observed frequently in entries along a longwall panel. These roadways are usually protected by so-called "chain pillars." A number of operators have reported that the deterioration of such entries can be alleviated through the use of "yield" pillars. The idea is that the yield pillar will shed some of its load to nearby abutments and, as a result, relieve bad roof and rib conditions.

While the shadow and the yield-pillar mechanisms are entirely different, the implementation of the two ideas leads to virtually identical mining layouts – that is, to rooms separated by narrow pillars. When the overall width of a panel created in this manner is small, improvements are often achieved, and it is immaterial whether the improvement results from the stress shadow effect or the load shedding by yielding pillars.

It would appear, however, that there is a definite limit to the applicability of these two methods. To gain overlapping stress shadows, the rooms must be close to one another; therefore, the intervening pillars must be narrow. Similarly, experience shows that pillar yielding is

[52] RCMP transcript, p. 6.

achieved only if the pillars are narrow. Hence, in many instances, the pillars designed to fulfil the requirements of either of these concepts will become yield pillars. Common sense suggests that there is an upper limit on the span up to which yield pillars can be effective. This limit, or critical span, is defined by the distance to which the yield pillars can shed their load. If this span is exceeded, the rapid deterioration of the panel, and often even its sudden collapse, becomes inevitable. It seems that the sudden and drastic deterioration of Southwest 1 at Westray is a textbook example of such failure.

Westray management became convinced towards the end of 1991 that high horizontal stresses were responsible for their ground control problems. Presumably, to combat this phenomenon through the stress shadow concept, Southwest 1 was developed with narrow pillars. Both production records and observations seem to indicate that conditions did improve, at least for a while. It is unclear whether mine management was aware of the need to keep the panel width within a critical span. Whatever the case, the events that started to unfold on 23 March 1992 proved that the 100 m-wide panel was too wide.

A bare outline of the sequence of events, but not the environmental conditions, can be deduced from the underground operating shift foreman's reports over the period of withdrawal from Southwest 1.[53] It takes little imagination to see the horror story unfolding during those days.

Day shift, 23 March: Owen McNeil (This appears to be the last date on which mining (depillaring) occurred in SW1-A Road.) The continuous miner (No. 2000) was moved into SW1-A2 and then into SW1-A3. The Stamler feeder-breaker was also removed from SW1-A to SW1-A3.

Night shift, 23 March: Bryce Capstick (Indications of roof stresses are evident from this report.) Chocks were built in SW1-A, SW1-A1 and SW1-A2 Roads. A second continuous miner (No. 2002) was in SW-A2.

Day shift, 24 March: McNeil Mining took place in both SW1-8 Cross-cut and SW1-A3 Road. (The mining was reported as being slow.) Roof trusses had to be adjusted and additional blocks added for support in SW1-A2. The shift ended with mining in SW1-A2.

Night shift, 24 March: Capstick A plastic stopping was erected in SW1-8 Cross-cut between SW1-A2 and SW1-A3 Roads. The pillar in this area was reported to be giving indications of failure. The continuous miner, shuttle car, and roof bolter were moved out of the "top roads" (presumably meaning the SW1-A3 heading and the inbye end of SW1-8 Cross-cut). A continuous miner, roof bolter, and shuttle car were removed from the section. All equipment was reported to have been "backed" outbye of SW1-8 Cross-cut.

53 Exhibit 42f.0153–207.

Day shift, 25 March: McNeil Cables, a fan, and ducting were removed from SW1-9 Cross-cut. A roof bolter and Stamler feeder-breaker were removed.

Night shift, 25 March: Capstick It was necessary to reinforce roof supports during this shift. Arrangements were made to install additional supports under carrier beams in SW1-B Road at the junctions of both SW1-8 and SW1-6 Cross-cuts. A further chock was erected in SW1-8 Cross-cut outbye SW1-A Road. More items of equipment, including an auxiliary fan and ducting, were removed from the SW1-A heading.

Day shift, 26 March: Ferris Dewan Nine hundred and twelve tonnes of coal were mined by depillaring in SW1-A3, despite a third day of indications of pillar failure. (This would seem to have been a last dash for coal production in SW1-A3.) The continuous miner had been moved back along SW1-A3 beyond SW1-8 Cross-cut, indicating further deterioration of conditions. Four double-width and two normal chocks were set in locations not clearly identified. The roof trusses were tightened in SW1-A1 and SW1-A3.

Night shift, 26 March: Arnie Smith (This was the final shift in which coal was produced from Southwest 1.) A further 432 tonnes were extracted from depillaring, although the site is not given. The continuous miner was in SW1-A3.[54] At some point, the rib collapsed behind the continuous miner. An unsuccessful attempt was made to pull it out with a shuttle car.

Day shift, 27 March: Dewan The conveyor in SW1-4 Cross-cut was dismantled. The box end, together with a continuous miner and two shuttle cars from SW1-A3, was moved to the SW1-B Road and SW1-4 Cross-cut intersection. The conveyor drive head was moved to SW1-C1 Road.

Day shift and night shift, 27 March: Smith More pieces of equipment, including a fan, electrical panels, and conveyor structure, were removed from SW1-A3. Two stoppings were rebuilt in an unspecified location.

Day shift, 28 March: Dewan On this Saturday, a fan, ducting, and other items were retrieved from SW1-B and SW1-C1 Roads. A chock and a belt stopping were installed in SW1-4 Cross-cut. Four arches were set in SW1-B Road, and a transformer was recovered from SW1-A Road.

Night shift, 28 March: Smith Most of this shift was spent continuing the recovery of smaller items from Southwest 1, including loads of chocks, pipes, conveyor structure, and electrical equipment. There were entries on roof bolting in No. 3 and repairing of belt flaps.[55]

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54 The foreman's report does not identify the location of this continuous miner, but Eagles recalled that it was in SW1-A3 Road (Hearing transcript, vol. 76, pp. 16473, 16475).

55 Presumably referring to the poor roof conditions in SW1-3 Cross-cut and the "belt strip" stopping that was hung in that same location in an attempt to divert air into the Southwest 1 section.

Night shift, 29 March: Smith A steel "intersection" was begun in SW1-3 Cross-cut. (The ground control problems around the SW1-C1 Road and SW1-3 Cross-cut intersection led to the installation of the Southwest 2 conveyor in SW2-B Road (intake), which required vehicular traffic to be diverted through SW1-2 Cross-cut into SW2-A Road (return). (See Chapter 7, Ventilation, for details.) The chock in SW1-B Road was completed.

Day shift, 30 March: Capstick An additional chock was built at each of the two stopping sites in SW1-B and SW1-C1 Roads inbye SW1-3 Cross-cut. That same cross-cut received further supports, including chocks and cross-beams.[56]

Other descriptions add further details about the scene. In a memo dated 7 April 1992, engineering superintendent David Waugh and geotechnologist Stan Chesal described the events vividly:

> On Monday, March 23, 1992, at 6:00 pm a loud noise was reported high above A-2 roadway. Later that night a floor heave occurred 1 metre high along the updip rib in the A-1 road outbye #9 crosscut. By the morning of March 24, 1992, the pillars inbye #8 crosscut were reported under load, cracking and slabbing with the back dribbling and bagging into the wire screen. Dywidag trusses had slackened up to 6 inches within 12 hours.
>
> . . .
>
> The area was abandoned on March 27, 1992, with all men and equipment safely removed. The area was barricaded against entry at the time.[57]

In his statement to the RCMP, Waugh characterized the scene during the retreat, stating that "the ground conditions were extremely bad."[58]

Wyman Gosbee described the retreat from the Southwest 1 section:

> It was scary. It was like a nightmare. We were rushing. We were trying to get it out, and we knew that the ground conditions were real bad at the back. And you could hear it, and you could, you know, even along – I believe along one of these roads it was dribbling a little rock. And we were all trying to work as fast as we could to get that out of there.[59]

Jay Dooley testified to the conditions in the Southwest 1 section prior to the retreat: "It was working all over, it wasn't just one roadway. The whole thing was in motion."[60] Dooley alerted Roger Parry to the condition, and they decided to retrieve the equipment from the area. At that point, there was agreement that it was not a temporary withdrawal: "I was under the understanding that we're out of here," Dooley told the Inquiry. "And if we get everything out of here, we're going to be very lucky."

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56 Eagles made the point that "it was critical that we kept the [SW1-3] cross-cut open," as it was a primary ventilation route for the new Southwest 2 section (Hearing transcript, vol. 76, p. 16479).

57 Exhibit 15.0216.

58 RCMP transcript, p. 4.

59 Hearing transcript, vol. 25, p. 4983.

60 Hearing transcript, vol. 38, p. 8525.

Wayne Cheverie was also present during Westray's retreat from the section. He testified that his crew was depillaring in SW1-A3 Road, the only minable roadway left in the Southwest 1 section, when a piece of coal about 10 feet square popped out of the rib and wedged the continuous miner down in the cut. The continuous miner was stuck, and attempts at using the shuttle car to pull it out failed. Parry gave the crew approval to take a Scooptram into the section to break the coal blocking the machine. Cheverie had the following to say about the condition of the roof at this time:

> [T]he roof started to bid over our heads . . . small flakes of coal started coming off the roof, therefore indicating that there was pressure coming on the roof, and usually in that situation you get out and make sure that, you know, it's going to be all right before you go back in there. But because we had the machine stuck in there, we stayed in there and tried to facilitate getting the machine out.[61]

At this point, Cheverie left to service the Scooptram. On its way to the section, the Scooptram quit as a result of high methane. (The methanometer on the machine was registering 6.9 per cent methane.) Cheverie testified that workers were not asked to evacuate the mine at that time, but to move down into the fresh air. By then, Cheverie was nearing the end of his shift.[62]

Gosbee had been driving the Scooptram when it quit. At this point, Parry took a methane reading and informed the workers of the high methane. Gosbee and a few others then began to fix an old stopping on SW1-A Road in an attempt to direct the airflow into the high-methane area. They continued to work in the section despite the methane, working on the stopping until the end of their shift and then leaving the mine.[63] When Gosbee came in for his next shift, a transformer and fan in SW1-A3 Road were the only pieces of equipment left to be retrieved. Arnie Smith, Gosbee's foreman, asked if there was a Scooptram driver. Gosbee asked how the Scooptram would function in such high methane. According to Gosbee, Smith responded that " 'the Scooptram is not going to shut down.' " Gosbee then realized that the methane sensor on the machine had been unhooked during the retrieval of the equipment.[64] He refused to drive the Scooptram into Southwest 1.

Bonner drove the Scooptram into the Southwest 1 section that night. He said that the engine was "knocking and banging and the visibility was very poor. . . . It was unventilated." Bonner and two others went up the SW1-A3 Road. Bonner raised the bucket as the men attempted to get the fan. He described what followed:

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61 Hearing transcript, vol. 20, pp. 3962–64.

62 Hearing transcript, vol. 20, pp. 3965–66. **Comment** It is appalling that this took place with the underground manager present. He must have known that the explosive concentration of methane is 5 to 15 per cent and that regulation required withdrawal from the area at 2.5 per cent methane.

63 Hearing transcript, vol. 25, pp. 4987–89.

64 Hearing transcript, vol. 25, pp. 4990–91.

> Yes, we were going in to get a fan, and at some point during that we got a light flashing in at us kind of frantically to get out. So I started lowering the bucket and moving it away from the wall . . . and before the bucket actually got down, the men were jumping out and running ahead of me. . . .
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> So I had to drive relatively slow because the visibility was bad and I didn't want to run over anybody in front of me. And as soon as we got out past that intersection . . . just outbye that intersection of A-3 Road . . . it caved in.[65]

On 13 April 1992, Gerald Phillips informed all Westray employees by memo of the abandonment of Southwest 1.[66] He tried to analyse the reasons for the failure: "As you can tell from reading this, we are not sure which was the critical factor." He went on to write: "There is a right panel size (length/width) and depillaring method for our deposit. We just need to adjust what we know and have learned to date, and we will find it."

Finding

Miners were chased out of the Southwest 1 section in March 1992 as a result of horrific ground conditions. This is a clear indication that Westray management had not yet learned to operate the mine safely and productively. Without adequate planning, management was confronting each problem on an ad hoc basis and was still searching for solutions up to the time of the explosion.

Experience and Expertise in Ground Control

Rock mechanics is a highly complex area of study requiring expertise, usually acquired through a post-graduate engineering program. Over the years, its obvious benefits to safety and production have gained wide recognition. As stated in a South African text:

> During the last few decades a great deal of effort has been devoted to the development of rock mechanics as applied to engineering. The basic principles of the subject have been established and a variety of methods and tools specifically relevant to this field of application have been developed. In mining, rock mechanics has become an important tool in planning the layout of underground mines, in the evaluation of support requirements, in the alleviation of mining hazards and in making various technical decisions. Most of these activities today are part of the work of the rock mechanics specialist.[67]

The importance of rock mechanics as applied to mining has been recognized in Canada. An Ontario provincial inquiry report contained the following comment:

> Mine design is critical to the success of any mining operation. Good, well thought out planning can ensure maximum safety, with minimum disruption

65 Hearing transcript, vol. 24, pp. 4756–58.

66 Exhibit 64.18.

67 S. Budavari, *Rock Mechanics in Mining Practice*, Monograph Series No. 5 (Johannesburg: South African Institute of Mining and Metallurgy, 1993).

> to production. On the other hand, poor design can lead to serious local and regional stability problems.
>
> Historically, mining techniques in Ontario mines and in other mines around the world have evolved in response to pragmatic concerns. Much of the mine design and planning was based on site-specific experience, with little rock mechanics input. In some instances this resulted in major stability problems. However, growing economic and safety concerns are directing companies to choose mining methods and to plan mines with due consideration for ground conditions.[68]

It is important that coal mine managers have adequate training in ground control. Miners should also receive sufficient training to allow them to recognize problems as they arise and take whatever emergency remedial action appears necessary.

Experience and Expertise at Westray

One of the main problems of Westray was a lack of in-house experience in underground coal mining. As has been noted, nature had endowed the Westray mine with unusually difficult mining conditions. In the circumstances, it is regrettable that the management team, except for Phillips, had no previous underground coal mine management experience.[69] Phillips, the general manager, had trained and worked in British coal mines, but the conditions and working practices there are significantly different from those encountered at Westray. Generally, British collieries use longwall mining methods and extract relatively thin flat seams.

The combination of the inherently difficult physical conditions and the inexperienced management (and crew) led to serious problems in the new mine. It appears that management regarded ground control as the most serious and persistent problem at Westray. At about the end of October or in early November 1991, Marvin Pelley, Curragh Resources' president of development and projects, named Graham Clow, a Curragh vice-president, to coordinate a task force on rock mechanics at Westray.[70] At about the same time, Westray decided to engage a consultant on ground control; David Waugh accepted the appointment for three months. Neither Clow nor Waugh had coal mining experience. Clow was an experienced mining engineer, with rock mechanics experience in potash, gypsum, and hard-rock mining. He had also dealt with consultants in the field and was

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68 Ontario, Provincial Inquiry into Ground Control and Emergency Preparedness in Ontario Mines, *Improving Ground Stability and Mine Rescue* (Ontario: Queen's Printer, 1986) (Chair Trevor Stevenson), 4.

69 Phillips was the most senior manager in the Curragh organization with any underground coal mining experience. Roger Parry and Glyn Jones had previous mining experience, but no management experience. Marvin Pelley and Clifford Frame had only been involved in surface coal mines.

70 Clow (Hearing transcript, vol. 74, pp. 16181–85).

familiar with rock mechanics procedures.[71] Waugh had considerable exposure to rock mechanics in potash mines but, as he put it, "[t]his was my first experience in . . . or near a coal mine."[72]

Largely as a result of Waugh's appointment, serious attempts were made at Westray to learn about and to understand the significance of the roof displacements and other ground control phenomena. At about thesame time, the task force under Clow's leadership started a major campaign to gain some insight into ground control problems associated with mining coal at depth. These were the correct steps, but they came late. They should have been initiated before mining commenced, and they should have been an integral part of the mine-planning process.

External Expertise

Major consulting firms had been involved with the Westray project since its inception. Of these consultants in the pre-mining days, probably only Golder Associates and Dames & Moore would be recognized as having expertise in rock mechanics. According to Waugh, "Golder had been the main consultant and were still there. Dr Richard Brummer was the main consultant with Golder. Golder had been involved with the project from inception and I believe had also been involved with Placer."[73] It is unclear whether Golder's involvement was continuous; it is more likely that the firm was invited from time to time to carry out investigations of specific problems.

Between about November 1991 and the day of the explosion, six different consultants had advised Westray management.[74] Unfortunately, this turn from famine to feast was not entirely beneficial. Each consultant had a particular background that influenced its approach. Westray management, the recipient of the advice, was ill-equipped to evaluate the recommendations. In the following crucial instance, it accepted inappropriate advice that resulted in a wrong decision. Management was persuaded that high horizontal ground stresses were largely responsible for poor roof conditions, so it implemented the suggestion of forming panels supported by narrow "finger" pillars, as has been described above. This decision led to the loss of Southwest 1. Fortunately no one was injured as a result of the hasty abandonment. It should be noted, however, that the failure could have been disastrous, causing the death of the people working in the area.

Three of the consultants raised red flags about using narrow pillars to create stress shadows that would relieve the alleged horizontal stresses. Two of the warnings were quite specific; the third was implied. Salamon

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71 Hearing transcript, vol. 74, pp. 16180–83.

72 RCMP transcript, p. 1.

73 RCMP transcript, p. 1.

74 Golder, Dames & Moore, Denis Mraz, Jack Parker, John T. Boyd, and Chris Mark.

discussed these warnings at length during his testimony at the Inquiry.[75] As far as he could determine they had been ignored by Westray.

Finding

Westray management, from the chief executive officer down, seemed unable to implement the advice of competent professionals. This incapacity discloses a serious defect in the Westray management mentality that is probably related to a combination of incompetence and inexperience.

Several basic points may be drawn from the Westray experience:

- **Comprehensive planning should be done as far in advance as possible so that problems may be anticipated and surprises kept to a minimum. This was not evident in the manner Westray attempted to deal with its ground control problems.**
- **It seems almost axiomatic that an underground coal mine should retain the services of competent management and engineering personnel with proven experience and technical competence. Westray was significantly lacking in this regard.**

RECOMMENDATION

42 **Consultants, when required, should be selected carefully to ensure that their background and expertise are consistent with the specific requirements of the problem to be analysed. Any conflicts in the advice from these consultants ought be resolved through discussion and, if necessary, through further advice. Conflicts in technical advice must be resolved, not ignored, as seemed to be the practice of Westray management.**

Impact of Ground Control on the Explosion

Although the evidence does not lead to the conclusion that ground control problems played a direct role in the ignition of the explosion at the Westray mine, the possibility of indirect contributions cannot be excluded. Four consequences of poor ground conditions may be significant in this respect.

[75] Hearing transcript, vol. 7, pp. 1298–1316. Richard Brummer of Golder Associates faxed to Kevin Atherton his calculations on the narrow pillars (4 November 1991). He predicted they would fail (Exhibit 15.0128–31). Derek Steele of Dames & Moore faxed a letter to Phillips on 13 November 1991. Among other things, he warned that not enough was known at that point about underground conditions to be able to plan panel development (Exhibit 15.0147–51). Jack Parker faxed a letter to Graham Clow on 28 December 1991. He questioned the wisdom of 100 m pillars, stating that they were too wide, and he questioned the horizontal stress model on which Westray was basing its planning (Exhibit 15.0198–201).

Roof Cavities

Roof falls and, probably more importantly in the present context, roof overbreaks resulted in many small and large roof cavities. These cavities obviously provided opportunity for the accumulation of pockets of methane, particularly in the presence of methane layering, a condition that existed at Westray as a result of inadequate ventilation.

Since roof cavities must be supported for roof control purposes, their existence is often obscured. Consequently, a methane accumulation or pocket may go undetected. Pockets of gas add to the accumulation of methane in the mine roadways, especially in the absence of adequate ventilation, thus increasing the danger of methane ignitions.

Release of Gas from Crushed Coal

Where ground stress conditions are adverse, coal permeability may be increased considerably – to some significant depth into the solid coal seam – by fissures, cracks, opening cleats, and such. This enhanced permeability would promote further methane release. In parts of the Westray mine, high stress conditions probably caused a greater than normal rate of gas emission. For example, the conditions in Southwest 1 are likely to have contributed to an increase of methane liberation. It is impossible, in the absence of data, to quantify the increase.

Possible Sudden Release of Gas from Southwest 1

The weight of the evidence presented to the Inquiry reveals convincingly that Southwest 1 was inadequately designed. The section was abandoned and barricaded against entry on 27 March 1992.[76] Following abandonment, this panel was standing in a considerably weakened condition – just prior to the explosion on 9 May. It is widely known that a room-and-pillar panel, standing on narrow yielding pillars, can collapse suddenly and violently. Experience has shown that a large volume of methane will accumulate in such a panel, which contains openings and is surrounded by crushed coal, if not properly ventilated,. A sudden failure of the pillars will cause the rapid lowering of the roof, which in turn will lead to the abrupt ejection of the accumulated gas into the main body of the mine's air.[77]

This is a likely scenario for the sudden movement of large volumes of methane into the Westray ventilation system at any time during April or early May 1992. Hence, an unsatisfactory design of a mining panel not only leads to risks arising from a major roof fall, but can also create a potential explosion hazard.

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76 The barricades are the infamous "stoppings" located inbye SW1-3 Cross-cut on SW1-C1 and SW1-B Roads. As discussed at length in Chapter 7, Ventilation, they did nothing to decrease the flow of methane out of the abandoned Southwest 1 section.

77 Malcolm McPherson (Hearing transcript, vol. 10, p. 1802).

Diversion of Attention

Perhaps the most serious effect of the ground control problems that burdened the Westray mine was not physical but mental. The adverse roof and rib conditions posed a continuous hazard and hampered production. Major falls week after week, daily overbreaks, and the ultimate loss of Southwest 1 must have constituted a serious threat to the mining crew and placed Westray management under considerable stress. It was probably obvious to everyone concerned that the very existence of the mine was in question. Senior managers were preoccupied with finding the solution to the ground control problems. As a result, attention was diverted from other major issues and hazards. Although it is impossible to quantify the contribution of such a major diversion to the disaster, it was likely significant.

Finding

The entire ground control situation at the Westray mine is singularly significant in that it typifies the lack of planning, of competence, and of responsibility of senior Westray management. The response of Westray management to these continuing problems seemed to exacerbate them and divert attention from other serious safety concerns. In the result, the entire safety mentality at Westray deteriorated while management was consumed with its apparent inability to deal with ground control.

Legislation and Regulations

The *Coal Mines Regulation Act* is quite inadequate in dealing with the subject of ground control, as well as other aspects of safety-oriented mining techniques. The subject is dealt with under section 75, Support of Roof and Sides. Subsection (1) includes the general statement: "The roof and sides of every roadway and working place shall be made secure . . ." Subsection (2) sets out the requirements for the dimensions of the roadway, which "shall be of sufficient dimensions to allow the horse or other animal to pass without rubbing itself or its harness against the roof or sides." Subsections (3) and (4) are equally outdated in their requirements.

These provisions of the act invite comparison with comparable legislation in other jurisdictions. In the United States, the requirements for ground control are set out in 30 CFR 75, Subpart C – Roof Support. Section 75.200, Scope, reads in part: "This subpart C sets forth requirements for controlling roof, face and ribs, including coal or rock bursts, in underground coal mines." Subpart C then details the requirements for the following:

- Protection from falls of roof, face and ribs
- Mining methods
- Roof bolting

- Installation of roof support using mining machines with integrated roof bolters
- Conventional roof support
- Pillar recovery
- Warning devices
- Automated Temporary Roof Support (ATRS) systems
- Manual installation of temporary support
- Roof testing and scaling
- Rehabilitation of areas with unsupported roof
- Roof support removal
- Supplemental support materials, equipment and tools
- Longwall mining systems
- Roof control plan
- Control plan information
- Roof control plan-approval criteria
- Evaluation and revision of roof control plan.

I have reviewed legislative regimes from several jurisdictions, including the United Kingdom, South Africa, British Columbia, Ontario, Alberta, and those under the *Canada Labour Code*. None has schemes as detailed as that of the United States or as outdated and skeletal as those of Nova Scotia.

I have a preference for the approach illustrated by the U.S. regime. It sets out, in great particularity, the requirements for ground control, as well as other areas, so that operators know the regulatory environment in which they will operate. This may be troublesome at the outset, but on balance it may be preferable to wide discretionary powers exercisable by the regulatory official or body. Section 159 of the *Coal Mines (CBDC) Occupational Health and Safety Regulations* requires the mine operator to "prepare a plan of strata control for any proposed underground workings of a coal mine that is designed to prevent the collapse of the roof and sides of those workings," after which the plan "shall be posted . . . in such a manner that it is readily available for examination by employees."[78]

RECOMMENDATIONS

Planning, Equipment, and Materials

43 **A legislative regime should be put in place to ensure regulatory involvement in all areas of ground control in which safety is a consideration. The regime should encompass planning approval, materials and equipment certification, and any other aspect of ground control having safety implications.**

[78] SOR 90-97.

44 The regulations should specify the following at a minimum:

(a) Ground control plans and any revisions to those plans should be prepared by the mine operator and submitted to the regulator for approval prior to the implementation of any such plans.
(b) The ground control plan should show the existing geological conditions and the mining system to be used. The plan should also indicate any unusual hazards and outline the manner in which these will be handled.
(c) Approved plans should be available to miners and other underground workers and should be posted in the mine at the area affected by the plan.

(d) What the plan is required to specify should be set forth by the regulator from time to time, and should include:

 (i) a columnar section of mine strata;
 (ii) planned width of openings and size of pillar (if required);
 (iii) thickness of seam;
 (iv) method of support to be used;
 (v) type, sequence, and spacing of support materials;
 (vi) requirements for temporary roof support systems; and
 (vii) type and thickness of strata in the roof and in the floor for a depth of 3 m below the coal bed.

(e) The regulator may require further and better information on the plan and may require that the plan be reviewed by a qualified specialist in rock mechanics.
(f) The regulator may require revisions to the plan at any time if satisfied that conditions or accident experience indicate that such revisions are necessary or conducive to safety.
(g) The ground control plan should be reviewed at least once every six months by the regulator.
(h) The mine operator should record on the plan and report to the regulator any unplanned fall of roof or rib or any significant rock burst (more than 0.3 m in thickness) that occurs above the bolt anchorage area, impairs ventilation, impedes the passage of persons, causes injury to miners, or causes miners' withdrawal from the area, or that disrupts activities for more than one hour.
(i) All roof control materials should conform with standards as established by various testing agencies such as the Canadian Standards Association (CSA) or the American Society for Testing and Materials Specifications (ASTMS). In the absence of standards, such materials could be approved by the regulator.
(j) The regulator should from time to time issue directions, such as found in 30 CFR 75.204, respecting the use of roof bolts, torquing requirements for roof bolts, and testing requirements for roof bolts and for other types of roof support systems.
(k) All entries and drives where roof bolting is the main means of roof support should have imbedded warning devices that monitor any downward movement in the roof strata. Such warning devices should be of a type approved by the regulator and should be placed at intervals specified on the plan. Installation of such devices should not relieve the operator from making regular inspections as prescribed.

(The type of device referred to here is that generic category in which the "tell-tale" extensometer – the simple mechanical gauge produced at the CANMET Coal Research Laboratory in Cape Breton – would be included.)

Internal Expertise

45 The legislation governing coal mines should be revised to ensure that every underground coal mine operator be required to engage, when required, the services of a qualified mining engineer with specialized post-graduate training in rock mechanics relating to coal mines.

46 The legislation and regulations governing coal mines should be reviewed to ensure that all personnel working underground receive training in ground control as appropriate to their activities and responsibilities. In particular,

(a) Coal miners should receive a course on ground control as part of their basic mine training, plus annual refresher courses on ground control.
(b) Mining supervisory staff, including mine managers, underground managers, and overmen, should receive extensive training in ground control.
(c) Non-mining personnel employed underground should receive sufficient training in ground control to enable them to recognize potential hazards.
(d) Training programs for these three categories of employee should be developed by mine management in cooperation with the joint occupational health and safety committee and the regulator. The regulator should review these training programs to ensure that they reflect changing technology and mining practices.