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Rock Mechanics and Mining: Their Interrelationship at Sifto Canada Inc.'s Goderich Mine

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ABSTRACT

At the Sifto Canada Inc. Goderich salt mine, a rock mechanics program was developed to address safety, productivity, and operational needs. Beginning with basic testing in trial areas in the mid-1970s, this initiative has grown in size, scope, and importance to become an indispensable tool to the operation. The program has improved safety, productivity, and design flexibility while greatly improving roof stability and extraction ratios.

A site-specific finite element computer model of the mine was developed to simulate long-term behavior of the ground. Through field instrumentation, the model was calibrated to a level of accuracy adequate for mine design studies. Through model analysis and testing, the initial conventional room-and-pillar method of mining was successfully converted to the stress control method. The proven success of the new system has given the mine's management the confidence to further improve the mining method.

This paper describes the chronological development of the rock mechanics work and the evolution of the new mining method.

INTRODUCTION

Severe roof safety problems were encountered at Goderich Mine since its opening in 1959 and continued into the 1980s. Following excavation, the roof strata started to deteriorate by slabbing. Even after rehabilitation of the damaged roof, deterioration often continued to progressively higher levels with time, requiring repeated rehabilitation. The operational impact of the roof failures was severe, ranging from a considerable safety hazard to major production interruptions. As the years passed, this deterioration became a serious threat to the underground processing facilities including conveyorways, crushers and screening mills. Full operational shutdowns of up to six weeks were required annually to rehabilitate the failing roof and were becoming increasingly costly.

Until 1975, conventional methods of controlling ground instability had been applied. These included reducing intersection spans, reducing extraction ratio, and cable bolting. None were successful and long-range planning capabilities for travelways, ventilationways, and processing facilities were limited.

Trial testing of the stress control method began in 1975. Tests were successful, and in 1982 the mine management decided to completely convert the room-and-pillar mining method to the stress control method. During the following months, the conversion of the active production areas was successfully completed. In the following years, all processing and conveying facilities were relocated. Extraction ratios have risen from 38% to over 50%. Rehabilitation costs have dropped by 90% of the amount prior to the conversion. Costly production shutdowns due to ground instability have been virtually eliminated, and long-range mine planning is feasible.

MINING OPERATION

The Goderich Mine of Sifto Canada Inc. is located on the eastern shore of Lake Huron at Goderich, Ontario (Fig. 1). Opened in 1959, the mine has expanded production several times and currently stands as one of the highest output salt mines in North America. Rated at 3.2 million tonnes of rock salt annually, production in the most recent fiscal year exceeded 3.3 million tonnes.

Several salt beds are present in the Goderich area between the depths of 275 and 580 m (900 and 1900 ft), as shown in Fig. 2. Mining is from the A-2 salt unit (24.4 - 33.5 m thick) of the Salina Formation

Fig. 1. Location of Sifto Canada Inc., Goderich Mine.

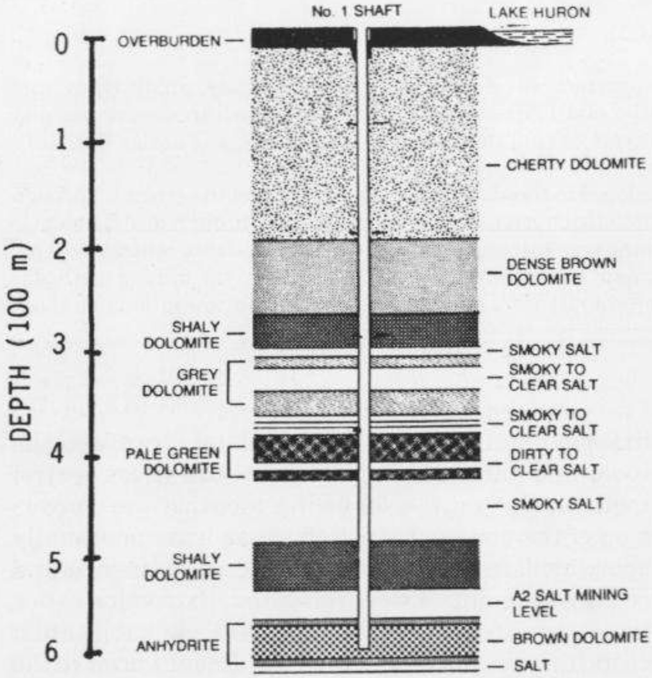

Fig. 2. Geological profile of Michigan salt basin, Goderich area, showing A-2 salt unit.

within the Michigan Basin. The Salina Formation is composed of interbedded dolomite, shaley dolomite, and salt, all gently dipping approximately 0.5 degrees to the southwest.

Mining is conducted on a single level approximately 550 m (1800 ft) below the surface of Lake Huron. Current extraction is through undercut, drill and blast. Rooms are 13.1 m (43 ft) high by 18.3 m (60 ft) wide, each delivering approximately 2000 tonnes per blasted round with each advance of 3.8 m (12.5 ft). Raw material is transported by trackless haulage to a high volume feeder breaker. An underground crushing and screening plant is fed from an 18,000 tonne primary crushed surge pile. The finished product is located in a 50,000 tonne storage area prior to hoisting.

HISTORY

The initial room-and-pillar design of the mine used 18.3 m (60 ft) wide rooms on 82.3 m (270 ft) centers. This design was modified several times to arrive at the current mine layout (Fig. 3). The extraction height has been consistent at 13.1 m (43 ft), although the mining horizon has been adjusted. In addition, intersection spans were reduced by leaving pillar projections. All of these changes were introduced through a conventional rock mechanics program in an unsuccessful effort to stabilize roof deterioration.

In 1975, Serata Geomechanics, Inc. (SGI) was asked to assess the mine conditions. Sifto was led to SGI because of their development and implementation of the stress control method in the Saskatchewan potash mining industry. SGI was asked to evaluate the potential of using the method at Goderich Mine.

ADAPTATION OF STRESS CONTROL METHOD

Stress control mining is based on the formation of a stress envelope created by grouping together a number of rooms, separated only by narrow yielding

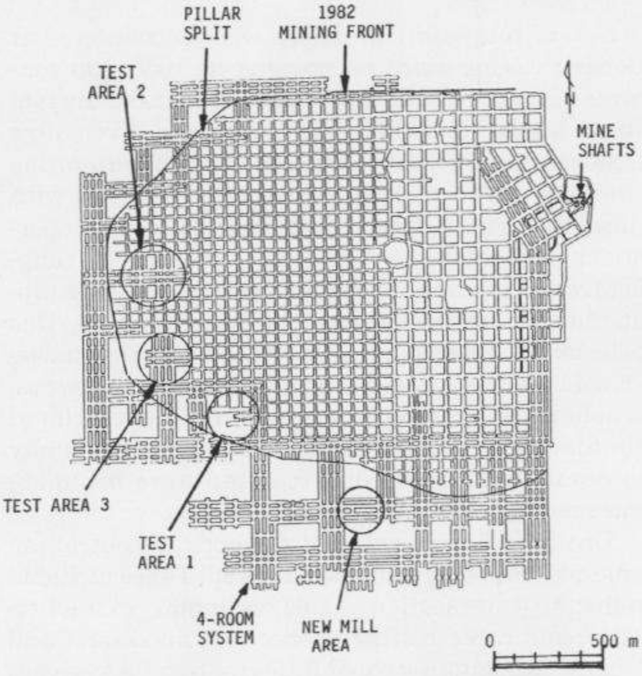

Fig. 3. Current mine layout showing history of conversion of mining method from room-and-pillar to stress control starting in 1982.

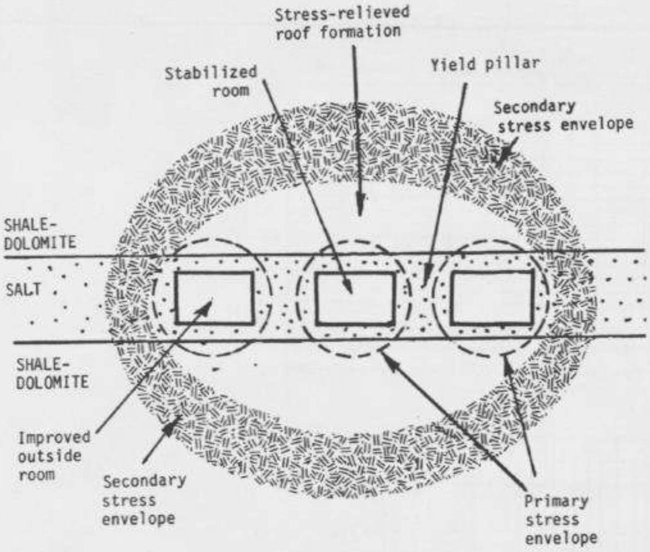

Fig. 4. Mechanism of stabilizing center roof using Stress Control Method.

pillars. More specifically, in the case of a three-room entry, two parallel outside rooms are excavated first, developing primary stress envelopes around each opening. The center room is then cut between the two outside rooms, thus forming two yield pillars, as illustrated in Fig. 4. Upon excavation of the center room the three separate stress envelopes are transformed into a single secondary stress envelope by immediate yielding of the newly formed pillars as shown in the figure. The self-protective structure of the secondary stress envelope is thus formed, providing long-term stability to the center room. The outside rooms will fail over time. Full adaptation of the stress control method at the Goderich Mine is summarized below in four chronological phases:

Phase 1: Basic testing (1975–1983)

Over the eight-year period 1975–1983, the validity and adaptability of the stress control method to the mine were tested quantitatively. Three test areas (designated 1, 2, and 3) were mined in succession. Figure 3 shows the successful, initial three-room entry system (Test Area 1).

Test Area 2 was then developed to evaluate the intersection of two three-room entry systems. The intersection proved to be fully stable. The test also allowed for experimentation with various sizes of yield and abutment pillars. Encouraged by this result, Test Area 3 was developed to test the intersection of three- and four-room entries and further refine pillar dimensions. The four-room entry proved to be even more stable than the three-room entry.

Using SGI's geological finite element code (GEO), the computer model of the mine ground was constructed to simulate these stress-control entries for adaptation to future mine design (Serata and Fuenkajorn, 1993). To provide input for model construction, the stress state and material properties of the ground were measured using a set of borehole probes developed by SGI for this purpose (Serata et al., 1992; Serata Geomechanics, 1988).

The site-specific computer model was applied to predict the long-term behavior of the stress control entries of the test areas. Simultaneously, the actual stress conditions and ground movement were also measured. The close match achieved between the model prediction and mine measurements enabled validation of the computer model as well as the stress control method. Figure 5 shows a profile of the mine model with an introduction of the four-room stress control entry system. Using this model, the computer projection of the four-room entry of Test Area 3 was compared with field measurements with regard to room closure ΔH and roof separation ΔR (Fig. 6). Here, the steady reduction of ΔH indicates consolidation of the stress envelope with roof stabilization shown by the disappearing ΔR. The same model predicts pillar expansion ΔW, which also closely matches the field measurements, as shown in Fig. 7.

The model-predicted stress-strain distribution of Fig. 8 illustrates the ultimate natural state of stability achieved in the four-room entry as compared to the failing condition of the room-and-pillar design (Fig. 9). The formation of the protective stress envelope surrounding the entire four-room entry is clearly seen. Also shown here are the reduced stresses in the immediate roof formation under the stress envelope (Serata, 1982).

Phase 2: Production transition (1982–1983)

By 1982, costs were rising and ground stability was such that the operational viability of the mine was in question. At this point, Sifto management determined that the operation would be converted completely and rapidly from conventional room-and-pillar mining to stress control mining. The single-room headings were converted to three- and four-room entry systems at all production locations.

Pillar splitting was devised as the means of tying together the new production headings with stable travelways (Fig. 3). SGI analyzed the pillar split model and confirmed stable excavation geometries. A single room was then developed through the center of a series of old pillars, thereby simulating a three-room entry system. The older rooms which defined the pillar acted as outside rooms; the split down the center of the pillar formed a stable center room. Where the center room intersected the old room-and-

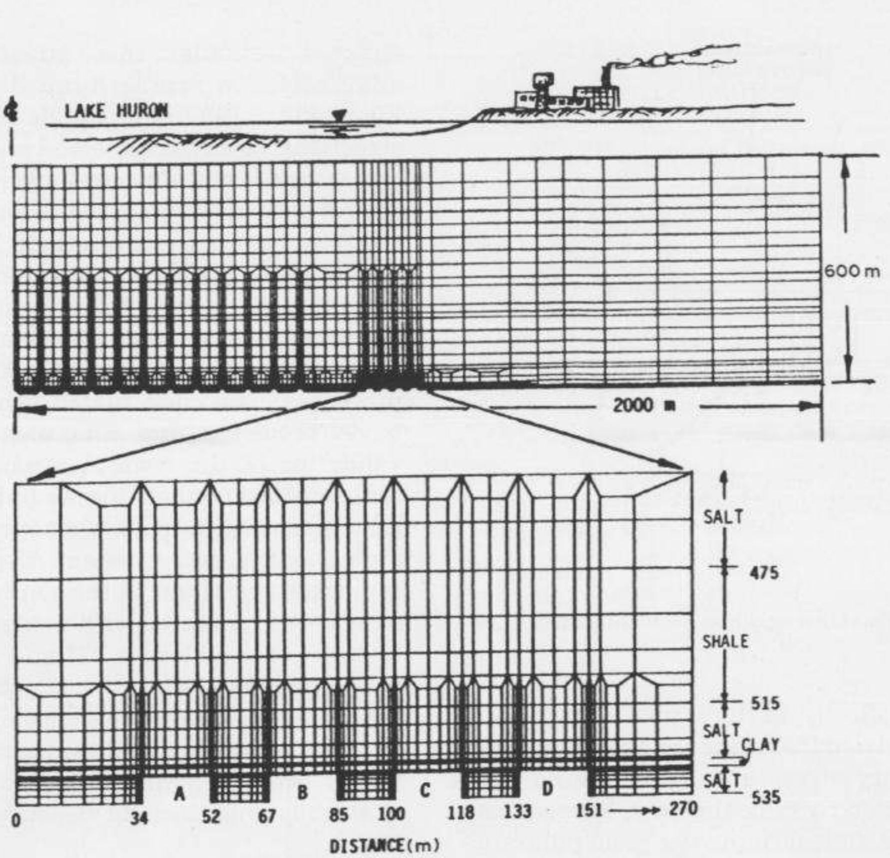

Fig. 5. Profile of finite element model of Goderich mine designed to simulate time-dependent behavior of entire ground.

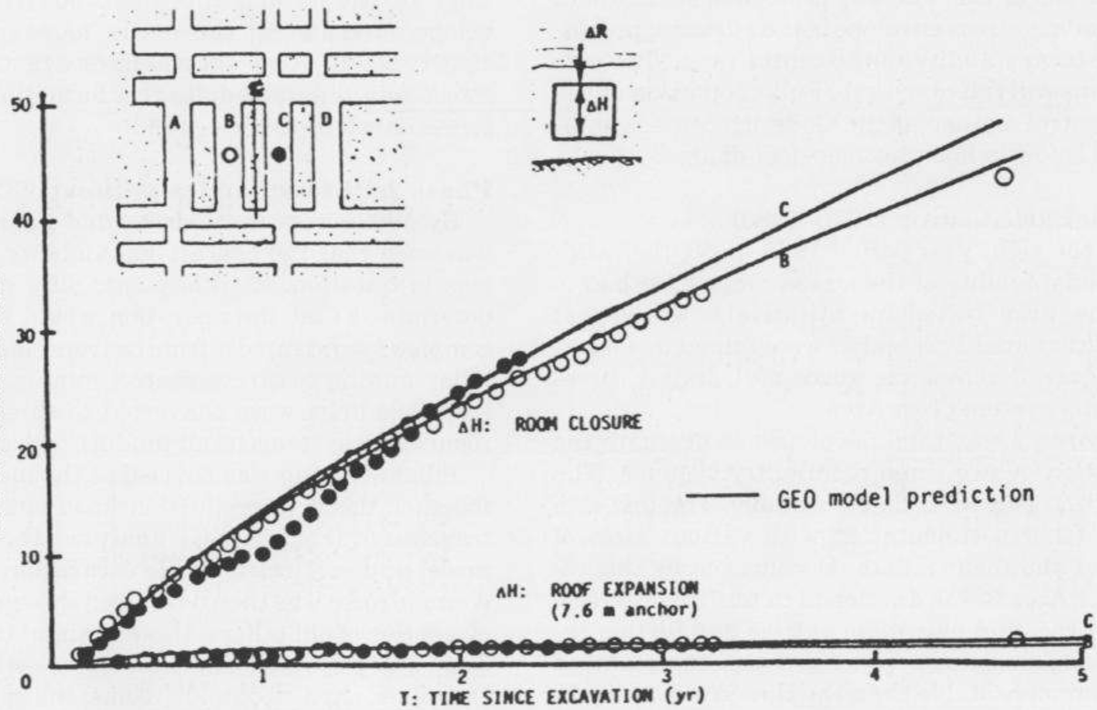

Fig. 6. Measurements of room closure ΔH and roof expansion ΔR compared with GEO computer model prediction.

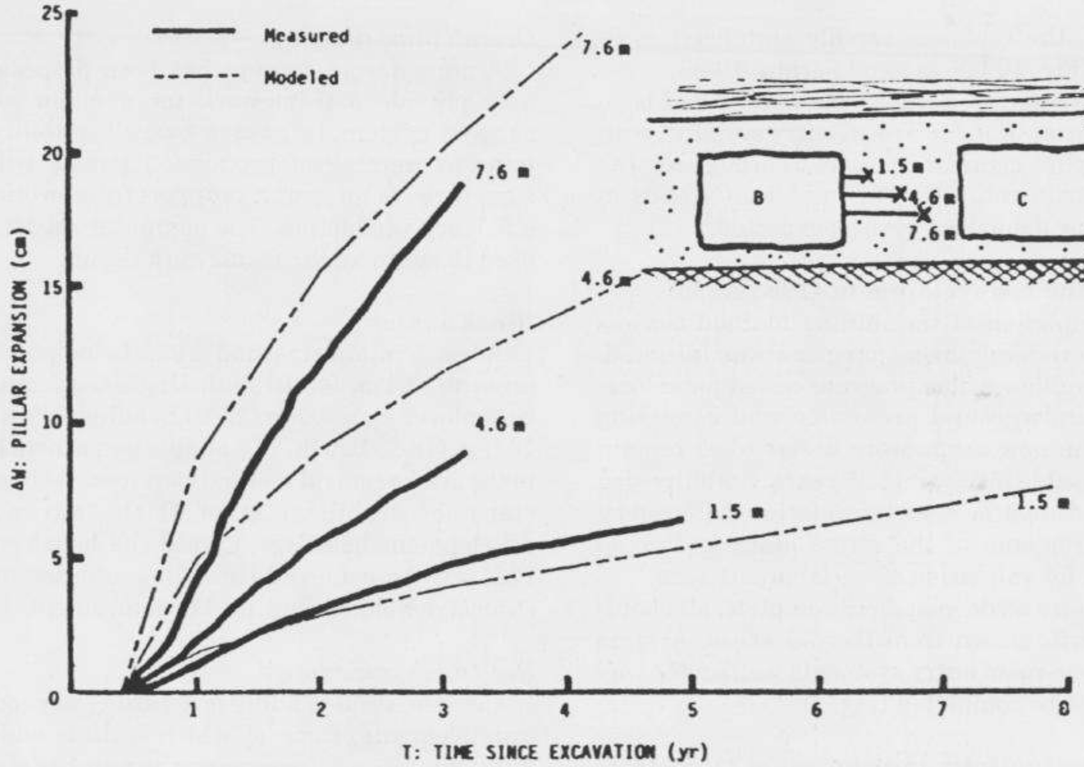

Fig. 7. Measurement of pillar expansion ΔW in 4-room entry compared with GEO computer model prediction.

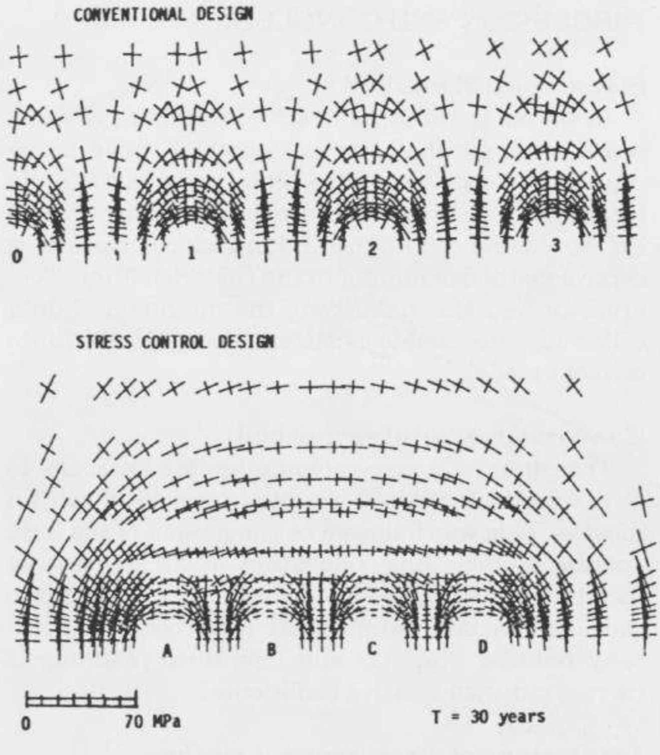

Fig. 8. Comparison of principal stress distributions between conventional and stress-control entries, showing mechanism of stress control.

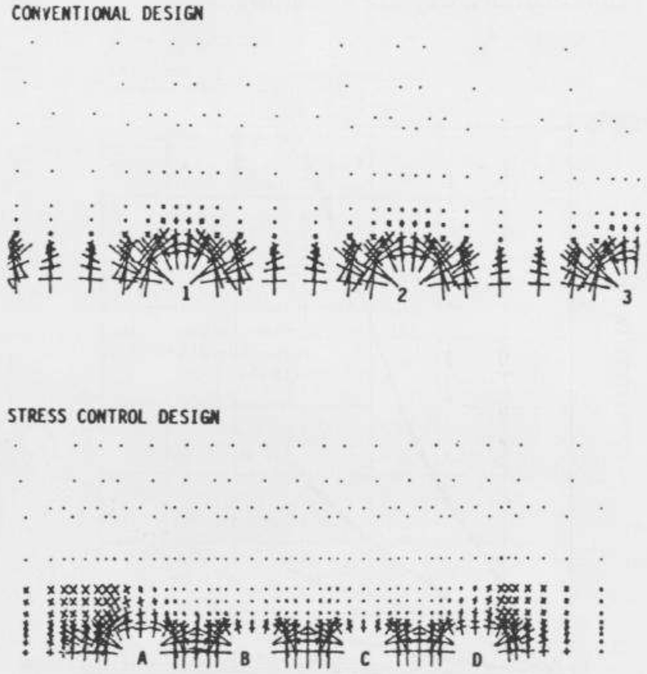

Fig. 9. Comparison of principal strain distributions between conventional and stress-controlled entries, corresponding to stress distributions of Fig. 8.

pillar entry, the roof was rapidly stabilized as illustrated in Fig. 10 (Dickie and Serata, 1985).

Within six months, all production faces had been changed to three- and four-room entry systems, with the pillar splits connecting them. Throughout the process, instrumentation confirmed that trends in roof and pillar behaviors were as expected.

Phase 3: Mine redevelopment (1983–1989)

Upon completion of the mining method conversion, a mine redevelopment program was initiated. This multi-million dollar program called for relocation of all underground processing and conveying facilities. The new areas were designed to remain stable and usable for at least 25 years. Stability was assessed by computer model simulation, followed by field measurements of the stress state and creep deformation for validation of model predictions.

With design and development complete, all operations were withdrawn from the old areas. A mine perimeter four-room entry system is well under way but has yet to be completed (Fig. 3).

Phase 4: Productivity improvement (1989 to date)

The goal of the current rock mechanics program is to improve productivity and safety by maximizing the benefits of the stress control method. Some of the projects under way are as follows:

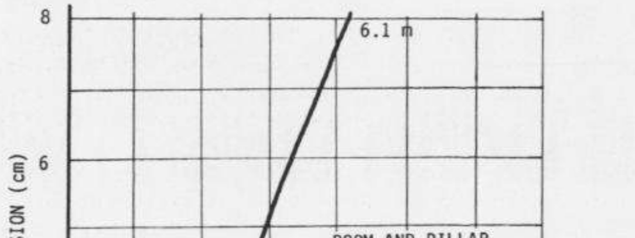

Fig. 10. Comparison of roof expansion rates across various depths between old room-and-pillar opening and new split opening.

Overall mine design

A mine design concept has been proposed which may provide a framework for a major abutment support system to assure overall stability of the mine. A number of production panels will be designed inside the ground support framework for high efficiency production. The computer model is being used to optimize the framework design.

Bench mining

A bench mining method is also being planned. The present 13.1-m (43-ft) high single-level mining will be replaced by a 3.6-m (12-ft) heading followed by an 14.6-m (48-ft) bench. The adaptation of bench mining to the stress control method requires two operational steps for stabilization of 1) the advancing top development headings, and 2) the bench headings. This will be achieved through computer modeling, extensive field testing, and measurement.

Rock mechanics design

Current studies address a variety of productivity improvements, some of which include widening of individual rooms, increasing the number of rooms in each entry, reducing yield pillar spalling, and eliminating the need for roof bolts.

DISCUSSION AND CONCLUSIONS

Stress control method

In the early 1980s, severe roof stability problems were driving rehabilitation costs to near unacceptable levels. Long-term planning was virtually impossible. Serata Geomechanics, Inc. (SGI) assessed mine conditions and introduced the stress control method of mining to the Goderich Mine. Test areas proved the viability of the method and data collected were used to construct a site-specific finite element model.

Conversion of mining method

Transition of active room-and-pillar headings to stress control method headings occurred within months. This was followed by conversion of the total operation, including relocation of all processing facilities into stress-controlled areas by 1989. Since then, roof rehabilitation costs have been dramatically reduced (Fig. 11) and long-term planning is carried out with relative confidence.

Limitations of stress control method

The stress control method is not without its limitations (i.e., natural gas, yield pillar spalling, outside room failure); however, these limitations are manageable as discussed further below.

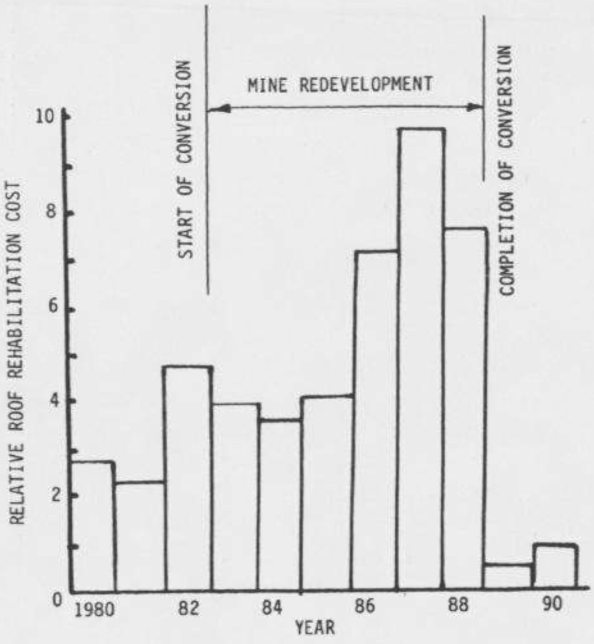

Fig. 11. Relative roof rehabilitation cost of Goderich mine, illustrating major cost reduction following mine redevelopment after 1989.

Natural gas

In 1986 and early 1987, unusual conditions occurred in some of the development areas cut by stress control mining. Rapid vertical closure combined with substantial roof bolt deformation was noted. Soon after, a large roof fall occurred, releasing several thousand cubic meters of natural gas derived from the strata above the A-2 salt. This ignited, causing a significant explosion. Two more occurrences followed, a month apart. Investigations indicated that these areas had been mined without regard to the proven stress control principles. Corrections were made combined with a degassing program to overcome this setback.

Outside room deterioration

Although long-term stability is achieved in the center rooms of the stress-controlled entry, its outside rooms suffer shallow roof deterioration resulting in eventual slabbing. The outside rooms are safely abandoned by effective use of the center rooms. The safe period of the outside room is monitored through instrumentation; the lifespan can be prolonged by roof bolting as needed.

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Sifto Canada Inc. expresses its appreciation to SGI for its independent research, development, and innovation, which have assisted in making Goderich mine a safe, more productive workplace.

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