F O R E W O R D

Increasingly the resources of the Mining Research Centre of the Mines Branch are being employed in appraising the potential application of advanced technology to mining operations. The ground control research program has been concerned with the ability to predict ground reactions in underground and open-pit mining, with some projects being more concerned with basic studies of stress distributions using computer simulation and of strength prediction based on laboratory and field testing.

One aspect of ground control which is of great interest to the mining industry is the development of a primary means of ground support which could be integrated with new methods of rapid excavation (such as the use of mechanical boring machines for rock excavation) and with improved methods of material handling to give a higher degree of automation to the whole mining cycle.

A relatively new method of ground support, readily adaptable to automated methods of rapid excavation, is that of sprayed coarse-aggregate concrete. This was used extensively for support of tunnel walls in Europe but was only recently introduced in North America.

This coarse-aggregate type of sprayed concrete has been used as a means of ground support in some Canadian mines. The report that follows contains a brief review of the history of sprayed concrete as used in the support of underground excavations and an investigation into its use in Canadian underground mines.

John Convey,
Director

Ottawa, March 1971

AVANT-PROPOS

De plus en plus, les ressources du Centre de recherches minières de la Direction des mines servent à étudier les applications possibles de la technologie moderne aux exploitations minières. Le programme de recherche sur la mécanique des sols traite des possibilités de prédire les réactions du sol dans les mines souterraines et à ciel ouvert, et comprend également certaines études de base sur la répartition des contraintes à l'aide de simulation avec un ordinateur, et sur la prédiction de la résistance basée sur des essais en laboratoire et sur le terrain.

Un aspect de la mécanique des sols qui intéresse grandement l'industrie minière est la mise au point d'un moyen simple de soutènement qui pourrait s'intégrer aux nouvelles méthodes d'excavation rapide (comme l'usage de foreuses mécaniques pour les travaux en terrains rocheux) et aux méthodes améliorées de manutention des matériaux afin d'automatiser davantage l'exploitation minière.

Une méthode de soutènement relativement nouvelle qui s'adapte facilement aux techniques automatisées d'excavation rapide est celle du gunitage. Cette méthode a été très employée en Europe pour la consolidation des murs de tunnels mais elle n'a été introduite en Amérique du Nord que récémment.

La gunite a servi au soutènement dans certaines mines canadiennes. Le rapport qui suit résume les emplois du gunitage dans les excavations souterraines et donne les résultats d'une étude sur ses usages dans les mines souterraines canadiennes.

John Convey,
Directeur

Ottawa, Mars 1971

Mines Branch Information Circular IC 258

GROUND SUPPORT WITH SPRAYED CONCRETE IN CANADIAN UNDERGROUND MINES

by

T. W. Verity, P. Eng.*

ABSTRACT

A new type of sprayed concrete using coarse-grained aggregates and cement, with special additives to accelerate the hardening of the concrete, has been developed in Europe. Known as "shotcrete", it has found increasing application as a means of ground support for underground excavations in Europe and North America.

Its use in Canadian underground mines has been largely experimental. It was found that it could be used as a substitute for more conventional methods of ground support under normal underground ground conditions but that under adverse situations, such as talc schist and very wet conditions, it was not possible to apply it successfully.

Use of shotcrete as a means of ground support in underground mines is expected to increase. New research in the use of sprayed cement with plastic types of additives is underway that may further increase the scope of its applications. Sprayed concrete associated with wire mesh or expanded metal is already finding wider application in underground excavations.

* Mining Engineer, Mining Research Centre, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

KEY WORDS: Concrete, Gunite, Shotcrete, Ground Control

Direction des mines

Circulaire d'information IC 258

SOUTÈNEMENT PAR GUNITAGE DANS LES MINES SOUTERRAINES CANADIENNES

par

T. W. Verity, Ing. Prof.*

RÉSUMÉ

On a mis au point en Europe un nouveau type de gunite composée d'agrégats grossiers et de ciment, renforcée d'additifs spéciaux qui accélèrent le durcissement du béton. Connue sous le nom de "shotcrete", cette gunite est utilisée de plus en plus en guise de soutènement dans les excavations souterraines en Europe et Amérique du nord.

Au Canada, on s'en est servi plutôt à titre d'expérience dans les mines souterraines. On a trouvé qu'elle pouvait servir de substitut aux méthodes de soutènement classiques dans les conditions souterraines normales, mais que dans des conditions défavorables caractérisées par un excès d'humidité ou la présence de talcschiste, il était impossible de l'utiliser avec succès.

On prévoit un accroissement du gunitage comme moyen de soutènement dans les mines souterraines. Des recherches en cours sur l'emploi d'additifs du genre plastique permettraient d'en étendre les applications. La gunite associée à un grillage métallique ou un métal ajouré est déjà utilisée plus couramment dans les excavations souterraines.

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* Ingénieur minier, Centre de recherches minières, Direction des mines, ministère de l'Energie, des Mines et des Ressources, Ottawa, Canada.

MOTS CLEFS: Béton, gunite, shotcrete, soutènement.

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Background

A literature survey of the use of sprayed concrete as a means of ground support in underground excavations indicated that it could compete successfully with more conventional methods for ground control in underground mining operations.

Manufacturers of the coarse-aggregate type of sprayed concrete equipment claim that sprayed concrete of good quality, when properly applied immediately after the exposure of a fresh rock face, will act as a tough surface whereby a rock of minor strength is transformed into a stable one. It is said to form an integral part of the rock on which it is applied, and it prevents loosening of the rock and the build-up of stress rearrangement pressures. The result is a continuity of support and an ability to conform to the stresses of the ground formation that are greater and more durable than are obtained from other methods of ground support.

The author visited two metal mines in the Joutel area of north-western Quebec to investigate the experimental use of sprayed concrete as a means of primary ground support in underground excavations. The investigations indicated that this type of concrete could be used as an alternative to the use of rock bolts or timber as a means of ground support.

All excavations examined had, however, been sprayed with concrete shortly before the author's visit and it was considered that a much longer period of time would be required to assess the merits of this method of ground support.

Correspondence with one mine, some eight months later, gave favourable reactions to the use of sprayed concrete. Concrete applied to such underground excavations as shaft level stations or development drifts, and as a cover to timbered bulkheads, was still in good condition. Minor deterioration had occurred on the concrete lining applied to stope drawpoints, but this type of cover had provided a more effective support for a longer period of time than had the conventional methods of rock bolting and timbering. This was said to be mainly due to the fact that rock bolts and timber were more easily damanged by the sandblasting of large chunks of rock caught in drawpoint openings.

It was concluded that sprayed concrete of good quality, properly applied, could be used successfully as a substitute for rock bolts or timber as a means of ground support in underground mines, if the concrete would readily bond to the rock. Investigation had disclosed that in at least one underground mine the application of sprayed concrete had been unsuccessful when used as support in a talc schist zone, because there was a heavy flow of water from the schist and the concrete would not readily bond to its slippery surface. It was apparent that the use of sprayed concrete as a means of ground support was not always successful under adverse ground conditions and that further research into its application will be necessary if the full potential of this type of ground control is to be realized.

Further research into methods of underground ground support using sprayed concrete is to be carried out by the Bureau of Reclamation, United States Department of the Interior, in the Stillwater Tunnel, on the Central Utah Project, commencing early in 1972. New types of quick-setting cements and new types of additives, which are expected to improve the economy and ease of application of sprayed concrete, will be tested in this tunnel.

History of Sprayed Concrete

The method of applying a cement mixture by spraying is said to have been first developed in 1907 by Carl E. Akely, Curator of the Chicago Field Museum. The cement gun with its principle and mechanical construction, the process, and the product were all patented by the Cement Gun Company, Inc., Allentown, Pa., U.S.A. "Gunite" was a trade name given to a mixture of sand and cement applied with pneumatic pressure by a machine manufactured under the trade name "Cement Gun". A dry sand-cement mixture was fed, by compressed air, through a hose to a nozzle where water was introduced and the resulting mixture was sprayed on the prepared surface[(1)].

Modern tunnelling methods have been derived from the development of gunite and rock anchorage. The problem of simplification and mechanization of the production and transportation of mortar led the German building contractor, Adolf Wölfsholz, some sixty years ago, to construct a mortar-spraying machine. This was later used for ground control purposes by the Austrian Federal Railway system[(2)].

Gunite was first used underground in 1914, in the United States, at the Brucetown Experimental Mine, to smooth mine openings and maintain rock surfaces against weathering. Following World War II, there was an upsurge in underground work in Europe, mainly in connection with hydroelectric power plants. The gunite machines had been limited to particle sizes under about 10 mm. New machines were developed to utilize coarser aggregates and build up thicker layers of concrete. This new sprayed concrete was called "shotcrete". In the United States, the term "shotcrete" had been applied by the American Concrete Institute to all cement-sand-aggregate spray mixes, including gunite[3]. In Europe the pneumatically applied mortar (spritz mortel or gunite), using a fine aggregate sprayed to only about 1 in. thickness, was differentiated from concrete (spritz beton or shotcrete) in which the aggregate used was much larger and could be applied to 4 to 6 in. thickness in one pass[2,4].

Development of coarse-aggregate shotcrete concrete for underground support was said to have begun during the driving of a penstock tunnel in 1953-54 at Kaprun, Austria, and followed through at the Salzach-Schwarzach development in the Austrian Tyrol in 1955-58. Until then, shotcrete machines had been incapable of handling aggregate larger than ½ in. It was found that at least a 15- to 20-mm aggregate was required to build up a layer of shotcrete thick enough to function as a support. First, the Aliva BS-12 shotcrete machine was developed for the Kaprun project, and then the BSM and Torkret machines for the second project. These machines could handle concrete containing aggregate of from 1 to 1 1/4 in. in diameter and special admixtures accelerated the hardening of the concrete[4].

Fine-aggregate spray concrete, without the accelerators or machines used in Europe, had been used extensively for many years in North America as an economical and versatile general construction material. It had limited use, however, for underground support. More recently, the European type of coarse-aggregate shotcrete had found acceptance in North and South America.

The Canadian National Railways Burnaby-Vancouver railway tunnel, 1966-1968, was the first tunnel in North America to be driven with a temporary and permanent support system of coarse-aggregate sprayed concrete instead of steel arch sets and poured concrete. An instrumentation program showed that the lining achieved a relative equilibrium level at three representative points and nowhere had the measured stresses and strains been excessive, nor had they even approached the allowable design values. The cost of the sprayed concrete was approximately $98 per running foot for the 10,800-ft tunnel, as opposed to an estimated $400 per foot for a conventional steel support system having an 8-in. concrete cover, making a saving of approximately $3 1/4 million on the contract. The rocks in the tunnel consisted of a late Tertiary series of conglomerates, sandstones and shales[3,4].

The Balboa Tunnel, Castaic, Los Angeles, was the first tunnel supported entirely by sprayed concrete in the U.S.A., and the first in the world drive through such fragile and unstable ground conditions and depending only on sprayed concrete for support. This circular tunnel, 15 ft in diameter, was driven with a Scott tunnelling machine for the Metropolitan Water District of Los Angeles between October 1968 and May 1969. The sprayed concrete system was mounted on a skid and towed behind the tunnelling machine as the rams were advanced, being at a distance of approximately 100 ft from the cutterhead. The ground was poorly consolidated sandstone with running gravel, silt, clay, and considerable water. The average coat of sprayed concrete in place was 3 in. thick but, due to the very soft ground conditions, it was only possible at times to apply a 1-in. coating because the weight of a heavier coat tended to pull down the very unstable sand and gravel and to form domes and fallouts. When domes did occur, they were immediately covered and supported by sprayed concrete. The cost to the contractor, R.A. Wattson Company of Los Angeles, for the sprayed-concrete liner was approximately $90 per running foot, for the 3,800-ft tunnel. This was said to be a saving of between $750,000 and $1,000,000 over conventional methods of lining, such as spiling[5].

Application of Shotcrete

There are two methods of mixing coarse-aggregate shotcrete, namely wet-mix and dry-mix. The wet-mix process involves the mixing of all the concrete constituents with water and pumping the thick mixture through the delivery hose to the nozzle, where additional air is added and the material is sprayed onto the subject surface. The dry-mix process batches all the components dry and the material is blown through the delivery hose to the nozzle, where all the water is added. The dry-mix process allows an easier introduction of accelerating admixtures for rapid setting of concrete. The accelerators generally are mixtures of water-soluble salts which react chemically to alter the dissolution time of silica, alumina and lime in the cement, thus accelerating the hydration process. Accelerators have been developed that enable the concrete to adhere to rock surfaces and to set under a heavy flow of water[3].

The wet-mix machines have not yet been developed to the stage where they can practically handle aggregates that are larger than 3/4 in. These types of machines are mainly used for underground stabilization rather than for support in poor ground. A machine of this type is the True Gun-All Model H, distributed by Mining Equipment Company, and which is in relatively common use for underground applications where a thin coating of concrete, up to about 2 in. thick and having an aggregate of about ½ in. maximum size, is required for relatively dry conditions[6].

The dry-mix shotcrete is applied with Aliva equipment and Monoset additive, sometimes known by its European name, Tricosal T-1, which is a dry white mixture of inorganic compounds, chiefly carbonates and hydroxides of sodium and aluminum. Canadian Formwork Corporation of Montreal is the exclusive North American representative for the Aliva equipment and Monoset additive, and it licenses users in the United States and Canada.

The Supporting Function of Shotcrete[3,4]

Shotcrete can be used either as a structural or as a non-structural support. Weak to plastic rocks and cohesionless soils require the application of a rigid, competent structure to prevent the ground from loosening and flowing into the opening. This may be achieved by applying 4 or more inches of shotcrete.

In more competent rocks, it may be applied to joints and fractures, to prevent the lesser rock movements that trigger rock pressures and failures. The shotcrete is applied 2 to 4 in. thick on the rough rock, to fill cracks and hollows, to create an almost flat surface, and to eliminate notch effects; only a thin application is required on smooth surfaces. In this case, the intimately bonded concrete matrix acts as a glue to hold the keys and wedges that support the larger pieces of rock and, ultimately, the tunnel arch. This type of application is common in Sweden, where design of tunnel support based on shotcrete is very popular because of its effectiveness and low cost.

The shotcrete can also be used in the form of a thin sheet to protect newly excavated rock surfaces from attack and deterioration by air and water. In this form, it is a continuous flexible membrane against which the atmospheric pressure may act as a support.

Composition and Costs of Shotcreting

The shotcrete mix used in the Vancouver tunnel was as follows:[3,4]

Portland Cement, Type I	650 lb
Sand	1,520 lb
Stone, 1/4 in.	850 lb
Stone, 3/4 in.	900 lb
Accelerator (Tricosal T1KA or Sika Sigunit)	25 lb

A maximum stand time of 60 minutes was used for the dry-mix. To combat dusting, a limit of 2 to 10% was placed on the minus-100-mesh and of 2% on the minus-200-mesh material. An initial set of 1.5 to 2.0 minutes was required for the shotcrete. A 2-in. layer was sprayed on the arched roof within 45 minutes of blasting, using a flying deck mounted over the drilling jumbo and extending over the muck pile. During the mucking cycle, the arch support was brought up to 6-in. thickness and the walls were sprayed 4 in. thick during the drilling cycle. A six-drill jumbo was used to drill a 10-ft round, with 110 holes being blasted three times daily. The shotcrete machines and aggregate bins were mounted on the drilling jumbo. The railway tunnel was 29 ft high, 20 ft wide, and 10,760 ft long. The cost of the sprayed concrete was $98 a linear ft. An additional $10 to $12 per ft was incurred for draining and waterproofing wet areas and for finalizing the support as a tunnel lining[4].

At the Lucky Friday shaft at Hecla Mines, Wallace, Idaho, an Aliva 600 dry-mix machine and a Monoset accelerator were used to shotcrete a fault zone encountered 3,850 ft below surface. Heavy squeezing ground had been encountered and a heavy pattern of epoxy-grouted rockbolts and jacket sets could not control the ground movement. A 20-ft height at the bottom of the shaft was lined with up to 10 in. of concrete. This soon failed, and the walls closed by about 6 in. during the next 4 months. The concrete was removed, a minimum 6-in. layer of shotcrete was then applied to the walls of the shaft, and the shaft timbering was replaced. Extensometer measuring stations showed a steady decline in the closure rate of the shaft after shotcreting. The mix used was: 6 cu yd aggregate, 7 sacks cement, and 3.3% (by weight) of accelerator. Rebound losses were high. The actual volume through the machine was 1.63 cu yd for each theoretical yd in place. Total cost through the machine was $68.46

a cu yd, or $99.59 per ft of shaft. The average cross-sectional area shotcreted measured 13.3 x 24.8 ft, with a perimeter of 76.2 ft. The dry-mix method was also preferred for general shotcrete operations. The wet-mix method had an average rebound loss of 47%; the application rate was 3 cu yd per hour for a thickness of from 1 to 3 in. The dry-mix method had a rebound loss of 23%, the application rate was 5 cu yd per hour for a thickness of at least 6 in. Improvements in material handling and shotcrete equipment have now reduced the cost of the dry-mix method for general use to $51 per cu yd in place[7].

Table 1 gives a comparison between the wet and dry shotcrete processes as used by the Hecla Mining Co. Table 2 gives the anticipated cost of shotcreting using a proposed new materials handling system. To date, Hecla's use of shotcrete has been limited to openings where long-term and high-quality ground support was required, to specific areas where exceptionally difficult ground conditions were encountered, and occasionally to stope support. It is expected that, with a more efficient materials handling system, shotcrete can be used on a routine basis in stoping and development operations. Hecla engineers consider the future use of shotcreting to be based on the fact that this form of support offers greater opportunity for mechanization than the use of rock bolts, timber, or steel. Unlike all other support operations, which are cyclic, shotcrete is a continuous process and has excellent potential for incorporation into an efficient rapid excavation system[8].

At Craigmont Mines Limited, at Merritt, B.C., a wet-mix type of shotcrete machine was used for applying shotcrete. A True Gun-All Model H pneumatic concrete machine was used to spray shotcrete up to 2 in. thick, using a minus 7/16-in. aggregate. This machine had an 11-cu-ft-capacity mixing chamber, mounted on a rubber-tired truck. A hopper on the top of the machine held 4½ cu ft of screened sand and one bag of cement. This material was fed into the mixing chamber and mixed by air agitation (60 psi), with 3 to 4 gallons of water being added when the chamber was full. Calcium chloride, to 2% of the weight of the cement, could be added if a quicker set were required. The material was sprayed directly through a 2-in. hose to give a 1-in. thickness of concrete. The 1968 cost for a 12 x 12 ft shotcreted drift was given as $15.61 per lineal ft[6].

TABLE 1

Comparison of Wet and Dry Shotcrete Processes at Hecla Mining Company[8]

Item	Wet Process	Dry Process
Maximum aggregate size	3/8 in.	3/4 in.
Cement type	III	III
Mix	8-sack	7-sack
Compression strength		
3-day	4,070 psi	-
7-day	-	3,255 psi
14-day	6,129 psi	-
28-day	6,618 psi	5,470 psi
Accelerator type	Liquid	Powder
Rebound loss*	47.0%	22.5%
Application rate	3.0 cu yd per hr	5.0 cu yd per hr
Thickness of application	1 to 3 in.	+ 6 in.
Ability to handle water	Very poor	Excellent

* i.e. non-adherent material.

TABLE 2

Anticipated Cost of Shotcrete, with Material Handling System as Proposed by Hecla Mining Company[8]

	Cost per cu yd through machine
Aggregate	
Delivered cost to mine	$ 7.00
Cement	
Type III cement at $1.50 per sack, using 7-sack mix	10.50
Accelerator	
Based on average use of 2.75% and price of 30¢ per lb	5.40
	Cost per cu yd through machine
Equipment Maintenance Cost	
Based on average cost to date of $2.50 plus estimated $1.50 to account for additional complexity of equipment	$ 4.00
Materials Handling	2.00
Equipment operating labour	
Based on throughput of 5.0 cu yd and 5 hrs operation per shift	5.00
Total cost per cubic yard through machine	$33.90

A Comparison of Gunite and Shotcrete[3,4]

Coarse-aggregate shotcrete differs from similarly mixed and applied gunite in that the shotcrete is a true concrete containing coarse (up to 1 1/4-in.) stone in its aggregate, while gunite is commonly a cement-sand mortar. The shotcrete differs from gunite in application and function in the following ways:

1. The gunite tends to form a thin cover over the rock, but shotcrete, if applied immediately after blasting, will supply both a seal and a support to stabilize a new rock surface. The intimacy of the rock-shotcrete bond is such that a tough new skin is formed that prevents the loosening, decomposition, and bending that accompany normal relaxation. Tensile stresses due to bending are diminished and compressive stresses are absorbed by the surrounding rock. The strong shotcrete-rock bond is thought to be due to the action of the specially developed accelerating admixtures which do not allow the concrete to slough away from the rock surface, the peening effect of the large aggregate particles on the finer particles, and the design of the shotcreting machines used.

2. The shotcrete uses large (up to 1 1/4-in.) aggregate which may be mixed with cement and sand at its inherent moisture content without the expensive drying that is often required with gunite. It can also be applied in thicknesses of up to 6 in. in one pass, whereas gunite is necessarily restricted to thicknesses of not over 1 inch. Thus the shotcrete quickly becomes a strong support as well as a stabilizer of rough open ground.

3. The accelerating admixtures used in shotcreting aid it in achieving a bond with the rock, even though the shotcrete may actually be weaker than conventional concrete of similar mix proportions but with less accelerator. It is waterproof and characterized by high early strength (about 200 psi in one hour), due not only to the admixtures used but also to the degree of compaction received from impact velocities of 250-500 ft per sec and to its low water/cement ratio (about 0.35). Shotcrete, with special additives, can transform a rock of minor strength into a stable one, and weak to plastic rocks sprayed with it can remain stable with only a few inches of shotcrete support. Because of its creep properties, shotcrete can sustain significant deformation over months or years without failure by cracking.

GROUND SUPPORT WITH SPRAYED CONCRETE IN CANADIAN UNDERGROUND MINES

Mr. Francis Hughes, president of the Canadian Formwork Corporation, a company specializing in sprayed concrete as a primary means of ground support, has in recent years used concrete spraying equipment in two mines in the Joutel area of northwestern Quebec. He requested that the Mines Branch of the Department of Energy, Mines and Resources send a mining engineer to these mines to evaluate this work.

Subsequently, the writer visited these mines in December 1969. Mines de Poirier, Inc. had used sprayed concrete on the walls and roofs of several underground shaft level stations and on stoping drawpoints and drifts on the 1,600 level. Eagle Gold Mines Limited had used sprayed concrete on shaft walls between the 1,200- and 1,500-ft levels and on ore-passes, drifts, and cross-cuts. These applications were inspected in both mines[9].

Mines de Poirier, Inc.

The Mines de Poirier property is located in the northwest corner of Poirier township in the Joutel mining area, 85 miles north of Amos in northwestern Quebec and about 400 miles northeast of Ottawa, Ontario. Its copper-zinc ore zones occur in granite, rhyolite and dacite rocks.

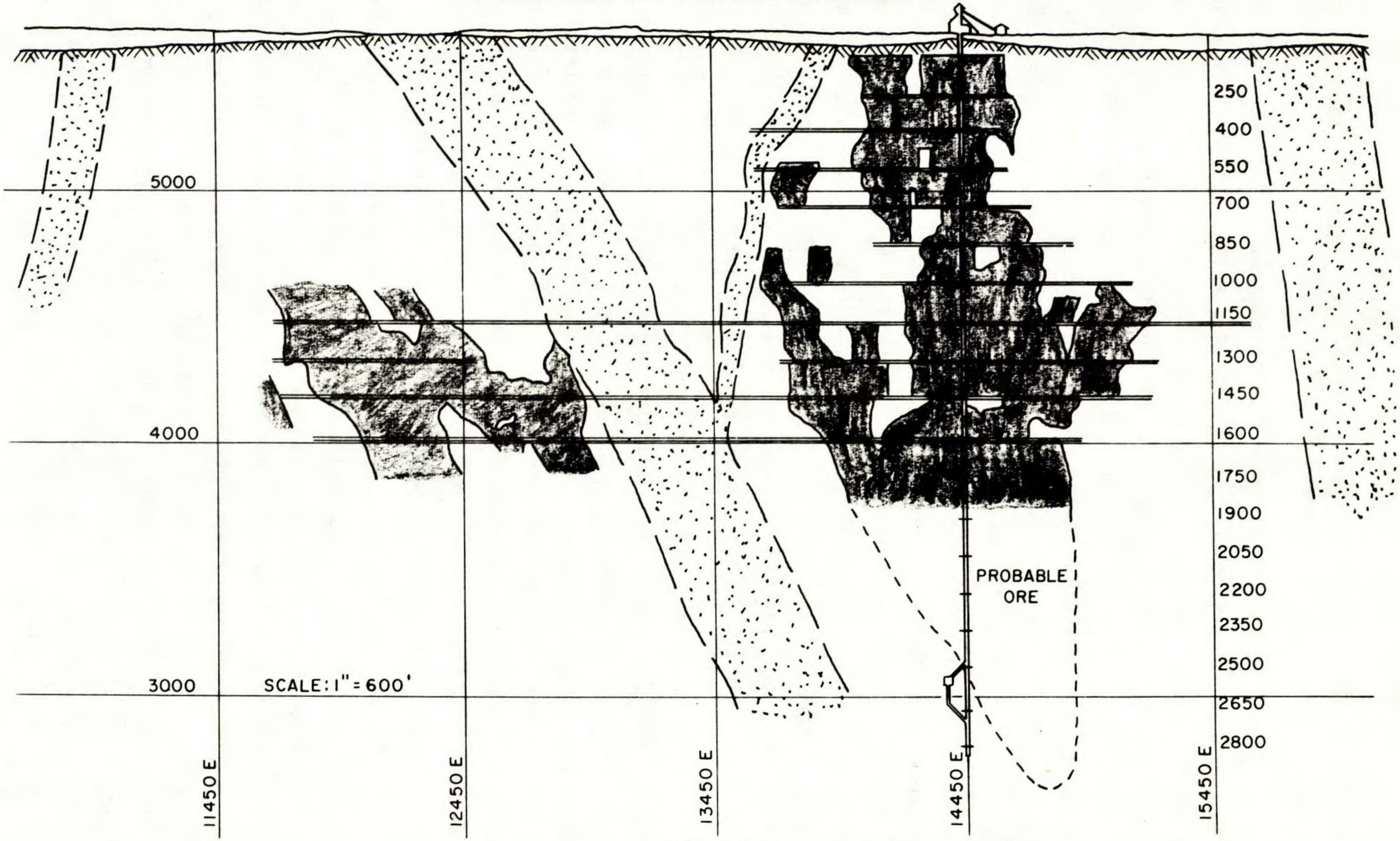
The mine was originally developed by a 3-compartment shaft sunk to 1,850 ft with working levels cut at 150-ft intervals. During 1968, the shaft was deepened to 2,849 ft to accommodate a new loading pocket at 2,700 ft and a new crusher station at 2,555 ft. This expansion program will provide six more mining levels from 1,600 to 2,500 ft at 150-ft intervals (see Figure 1).

Cross cuts, 9 x 9 ft in size, were driven due south from the station on each level, through the mineralized zone, and footwall drifts, 8 x 8 ft, were driven east and west about 40 ft north of the rhyolite-dacite contact. After diamond drilling to outline the individual ore zones, cross cuts were driven from the footwall drift to provide access (drawpoints) to the ore (see Figure 2).

Copper ore zones were mined by blasthole, shrinkage and cut-and-fill stoping methods, depending on the stoping width, ore grade (value), and competency of the ore and host rock. In general, blasthole stoping was used in ore zones in narrow, lower-grade lenses of ore. The remaining ore was mined by

MINES DE POIRIER INC.

LONGITUDINAL PROJECTION
SHOWING
ORE OUTLINES AND PROPOSED DEVELOPMENT



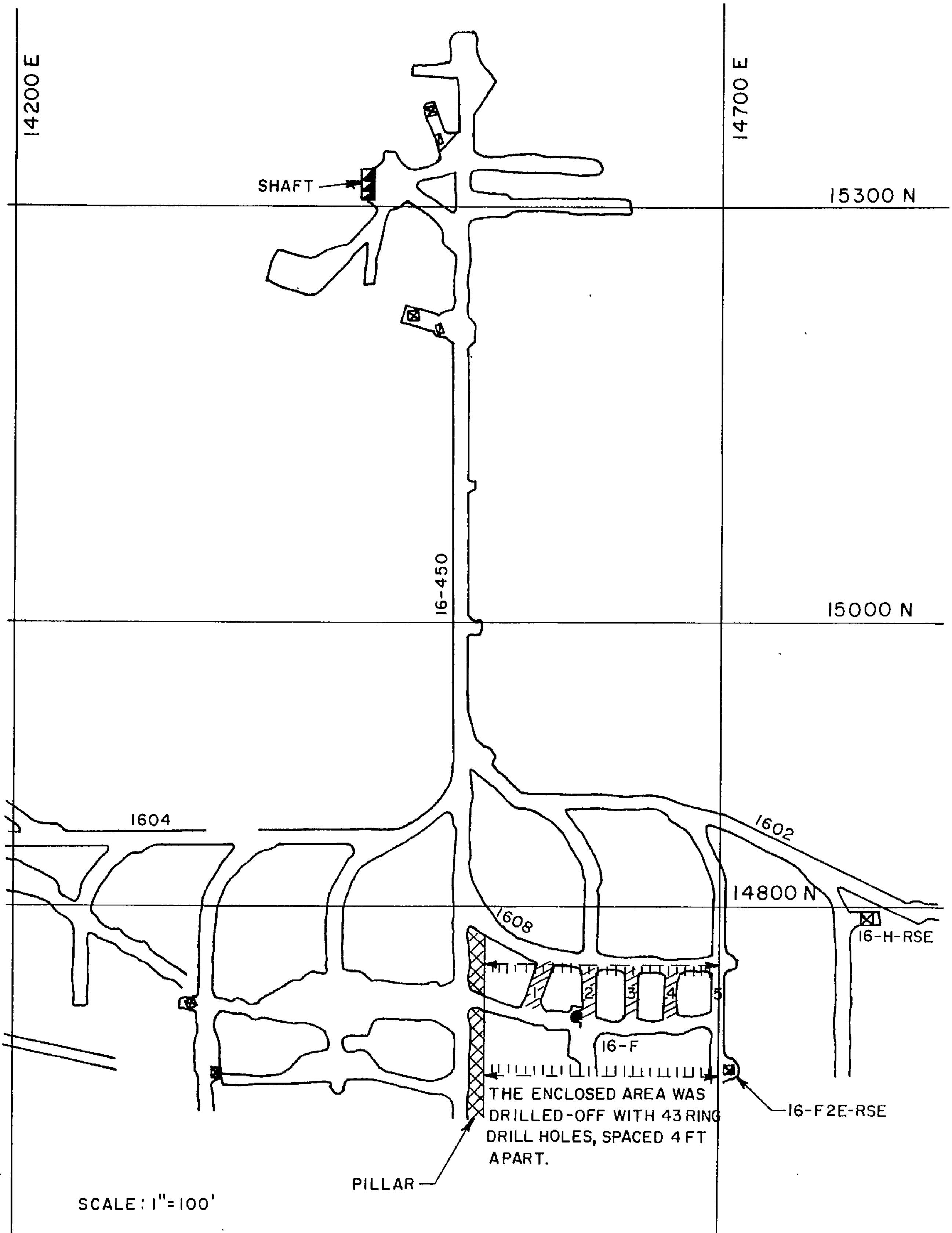
– FIGURE I –

cut-and-fill methods, which provided some 60% of the total mill feed of 1,500 tons per day.

Blasthole stopes were prepared by establishing mucking machine drawpoints (cross cuts) at right angles to the footwall drift on 30-ft centres. An 8 x 8-ft sill drift was driven along the footwall contact of ore, from drawpoint to drawpoint, to provide a drilling drift for the undercut (see Figures 2 and 3). A centrally located slot-raise was driven to the level above and a sub-level established 100 ft above the track. Sub-levels consisted of a slot cross-cut from contact to contact, 14 ft wide, with 8 x 8-ft drilling drifts being driven on the hanging wall and footwall (see Figure 4). Cribbed raises, 5 x 5 ft, were driven at the ends of the stope to provide access after blasting began. Slot-raises were driven, 6 x 7 ft, at inclines from 65° to vertical (see Figure 5). Raises were timbered with stulls. The sub-drift backs (roofs) were rock-bolted with 5/8-in. x 7-ft rock bolts on a 4 x 4-ft drilling pattern. The blasthole rings drilled in the slot consisted of parallel holes on a 3 x 3-ft pattern. Standard rings in the stope were drilled with a 4-ft burden and 10-ft toe spacing (ends of ring holes 10 ft apart).

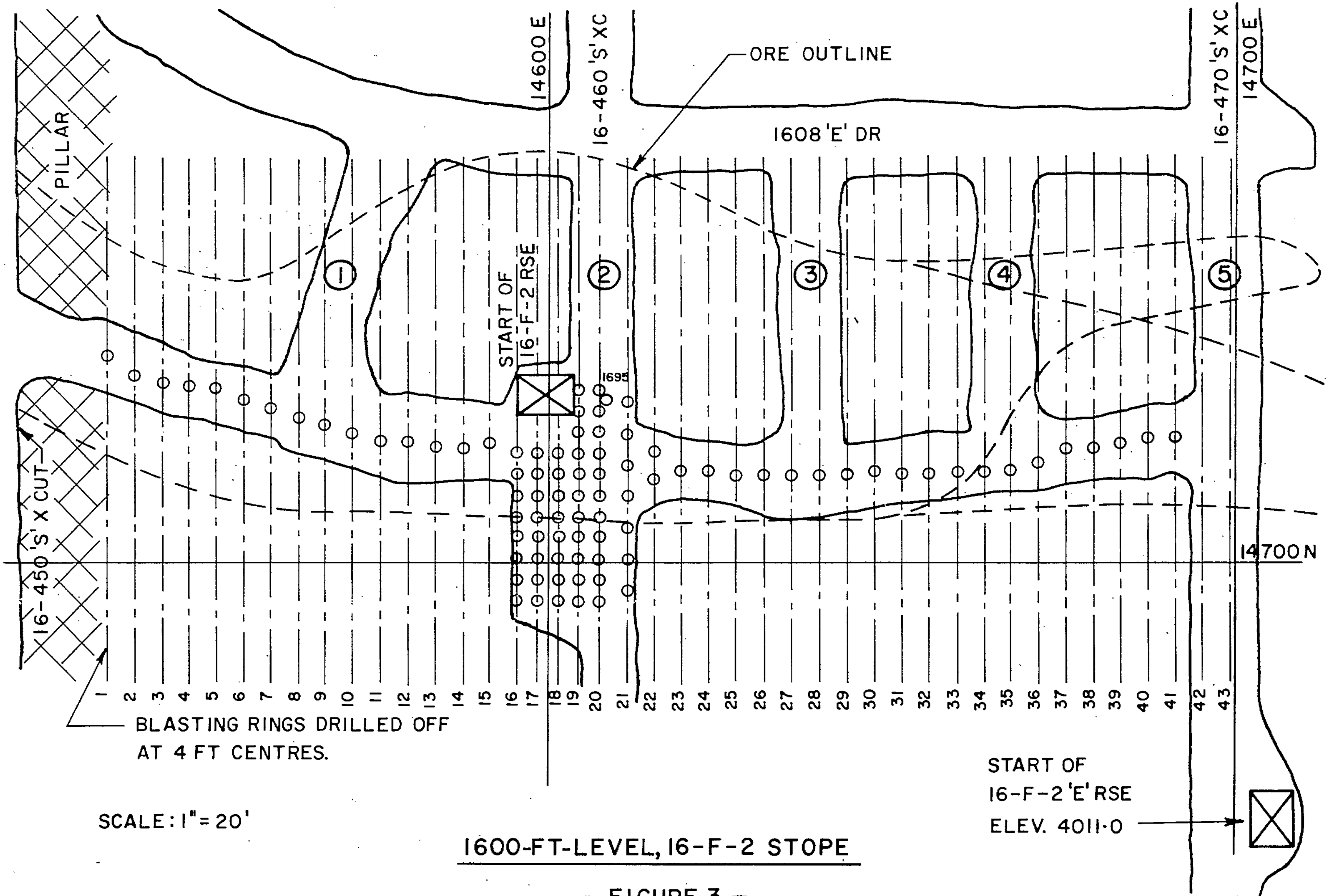
Figures 2 to 5 illustrated a typical blasthole stope development. This was for the 16-F-2 stope and was of special significance because the drawpoints 2 to 4, as shown on the plans, had been treated with sprayed concrete whereas drawpoints 1 and 5 had been left with a conventional pattern of rock bolts with steel plate washers for comparison in assessing the effectiveness of sprayed concrete for ground control in stope drawpoints. The author visited the 1,600 stope location, the sub-level above it, and the 1,450-ft level to inspect the ground conditions prevailing in this experiment.

The spraying of the underground drawpoints was done in October 1969. The writer visited the underground workings in December 1969. At that time, there was no evidence of any ground movement having taken place in either the headings sprayed with concrete (shotcrete) or the control headings. The drawpoint headings had been sprayed about 3 in. thick with a relatively fine concrete in which the aggregate was minus 5/8-in. gravel. One cu yd of the sprayed concrete covered approximately 80 sq ft of the rock surface. The control headings had been rock-bolted with 5/8-in. x 7-ft rock bolts on a standard 4 x 4-ft drilling pattern. The roofs of the actual drawpoints had also been rock-bolted during excavation prior to being sprayed with concrete.



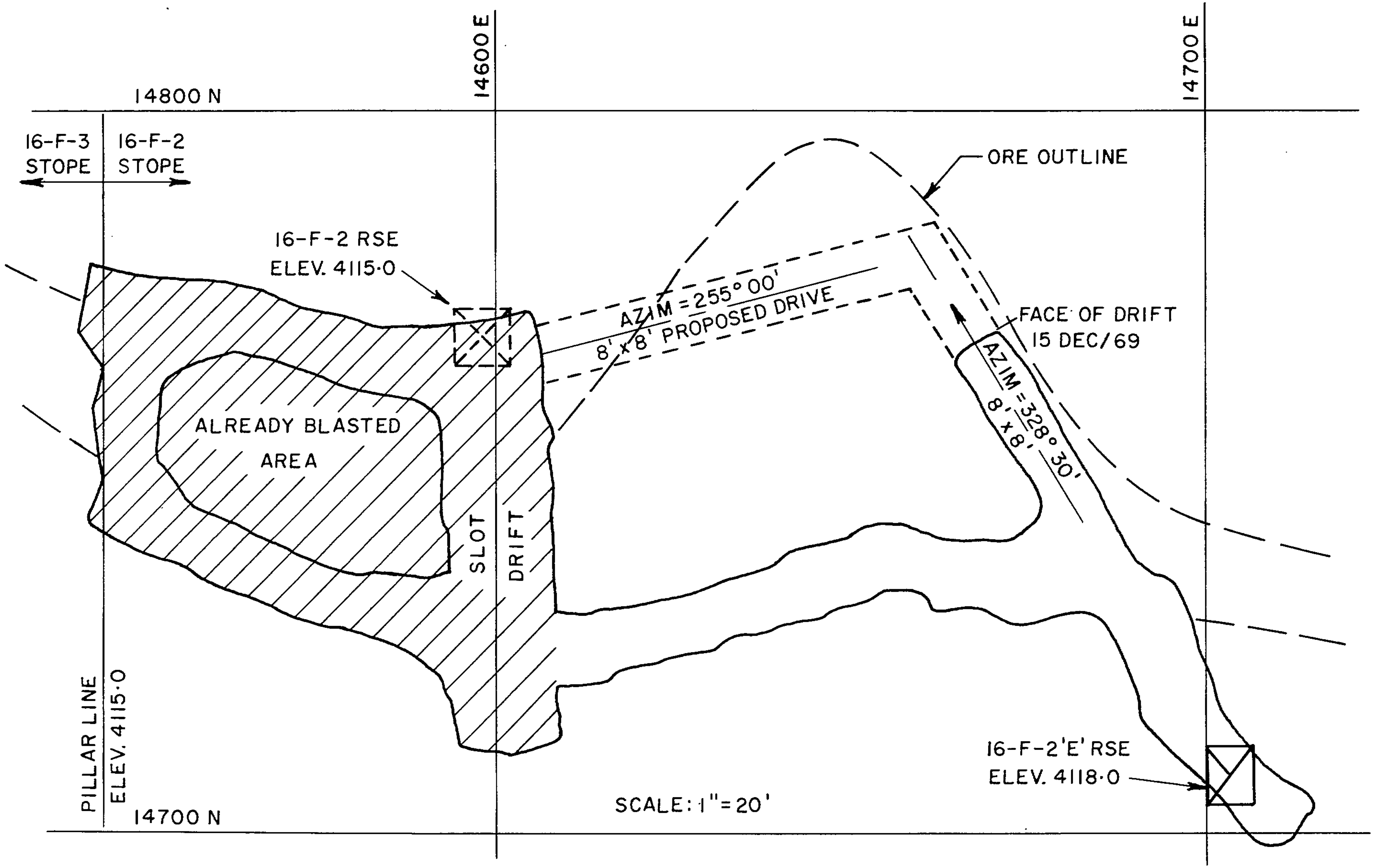
1600-FT-LEVEL PLAN

- FIGURE 2 -



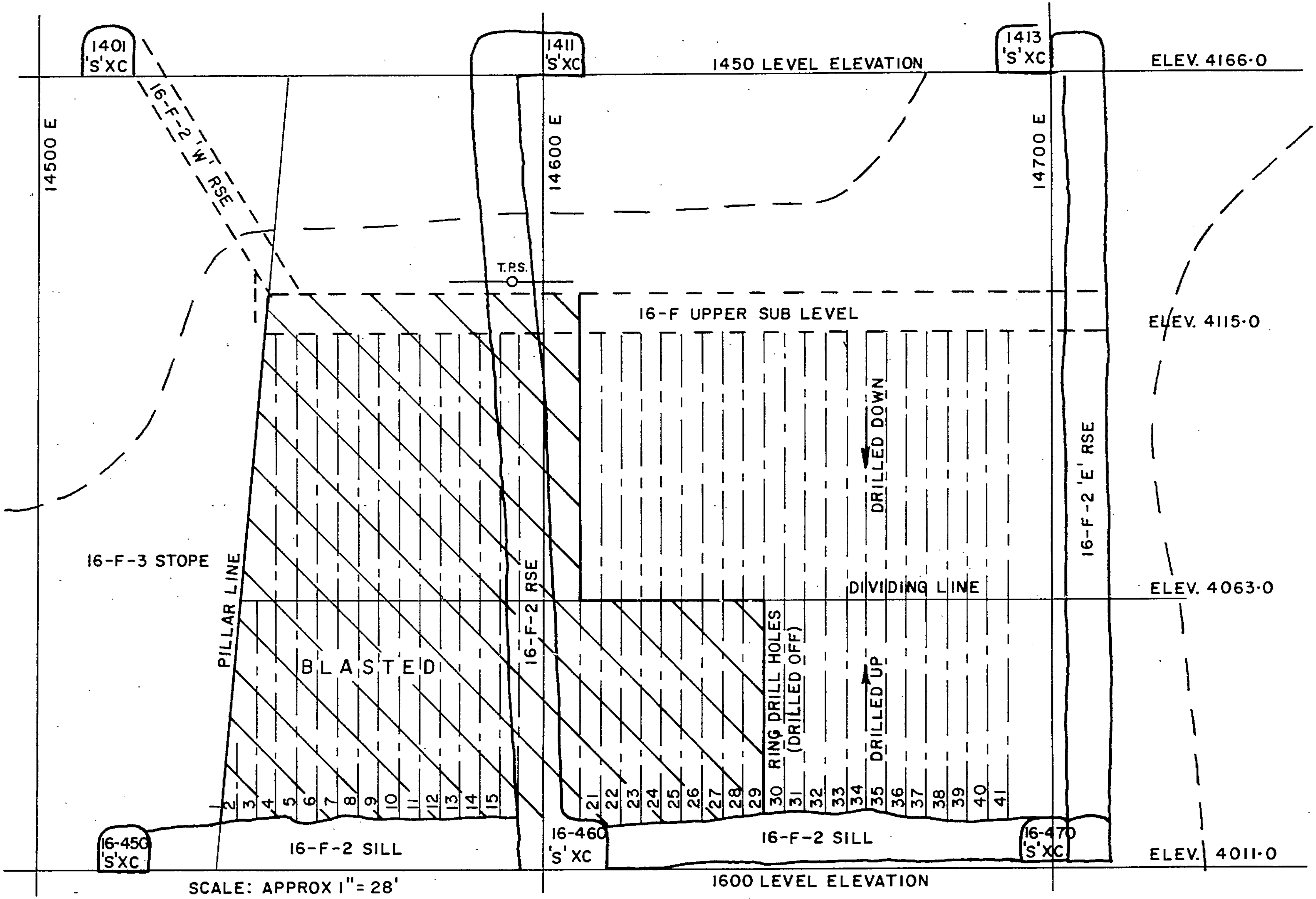
1600-FT-LEVEL, 16-F-2 STOPE

– FIGURE 3 –



1600-FT-LEVEL, 16-F-2 UPPER SUB-LEVEL PLAN

- FIGURE 4 -



1600-FT-LEVEL, 16-F-2 STOPE LONGITUDINAL SECTION

— FIGURE 5 —

The wall rock in the drawpoints, running off 1,608 E Drift, was of medium-hard volcanic tuff, moderately competent in condition. A portion of the 16-F-2 stope above the level had been blasted in September 1969, and some caving had occurred above the sub-level, towards the 1,450 level. The walls in the sub-level, when visited by the author in December, were tending to cave and had to be held by rock bolting. These walls in the sub-level could be said to be incompetent.

At the time of the visit, no ore had yet been removed from the drawpoints. The real test of the relative merits of the two types of ground control was yet to come. Rock flowing through the drawpoints after mucking commenced would tend to break down the brow of the drawpoint, or where its roof turned away from the stope above.

The walls and back of the level stations at the 1,600 level had also been sprayed with concrete. In this case, the aggregate used was coarser and was sprayed about 4 in. thick. A few rock bolts had also been used prior to applying the concrete. Again, an inspection showed no deterioration of the concrete.

Later correspondence with Mr. M. McKee, general superintendent at Mines de Poirier, in April 1970, resulted in the following information[10]:

Current shotcreting operations at the mine were being done under contract by Canadian Formwork Corporation. This contract covered equipment rental and Monoset additive at a rate of $16 per cu yd through the Aliva spraying machine. The cost of aggregate, cement and labour was extra and would vary from mine to mine.

The mine was just beginning to experience some failure of the support in the 16-F-2 stope drawpoints. Failure to date had occurred as some spalling of shotcrete from drawpoint brows and some failure beginning about 1 ft above the track elevation and working up the walls behind the shotcrete. There was also one occurrence of crushing at the arch where roof and walls meet. It was difficult to determine whether these failure were due to local conditions--such as structure, frequent sand blasting, and length of time drawpoints were open before support was applied, or insufficient thickness of shotcrete and the failure to extend shotcrete all the way down to the drawpoint flow--or to a breakdown in the shotcrete cover itself. Other applications of shotcrete in such locations as shaft stations and a pump room were still holding well.

In the case of drawpoints 1 and 5, that had not been sprayed with concrete, ground failure occurred sooner than in the sprayed drifts and breaking-down of the brow was more pronounced. It was concluded that shotcrete provided effective support in drawpoints for a longer period of time than conventional methods such as rock bolts or timber, which are easily damaged by sand blasting (used to break up large pieces of rock blocking the drawpoint).

Eagle Gold Mines Limited

Eagle Gold Mines Limited is located on the west bank of the Harricana River in Joutel township, six miles northwest of the community of Joutel in northwestern Quebec. The company name was changed from Equity Explorations Limited in March 1967. The geology at the mine property is rather similar to that at Mines de Poirier, with indicated ore zones occurring at the contact of rhyolitic and pyroclastic rocks with mafic lava flows.

At the time of the author's visit to the property in December 1969, a 1,000-tpd mill was being erected and a large combined shops and office building was under construction. Lateral development was also underway underground on several levels. A 3-compartment shaft had been sunk to a depth of 1,860 ft in 1968 and six level stations had been cut. Subsequent to the visit, the mine closed down suddenly in January 1970, and the company is said to be awaiting more favourable economic conditions before re-opening the property.

Since the Eagle Gold Mine was still under development at the time of the visit, the primary purpose was to investigate the use of sprayed concrete in underground development. Shotcrete of dry-mix type had been used in portions of the shaft, and wet-mix shotcrete had been used fairly extensively in development headings. An underground visit was made to inspect the sprayed portion of the shaft and the use of concrete on ore passes, drifts and cross-cuts and at an underground crusher station.

During shaft sinking, the shaft had passed through two fault zones at the 1,200- and 1,500-ft levels that had caused considerable ground movement and caving around the shaft, necessitating repairs to, and the resetting of, several shaft timber sets. The walls of the shaft were also very wet, which added to the difficulties. Difficulties were being experienced in holding the ground around the shaft by ordinary ground-control methods, and it was decided to try using sprayed concrete as a means of ground support. The Canadian

Formwork Corporation was called upon and used its Aliva concrete spraying equipment and Monoset additive to combat the adverse ground conditions.

The methods of ground control used by Canadian Formwork Corporation were very similar to those used in the Lucky Friday shaft at Hecla Mines, Wallace, Idaho, U.S.A.[7]. The aggregate and cement was premixed prior to application. Two men were required to operate the machine. The mixture was fed through a 2-in.-diam hose, with the accelerator and water being added at the nozzle. Air pressure to the hose was about 45 psi. Where water was running down the walls, the concrete was applied right through it and onto the walls. The nozzle was concentrated on one area until some 6 in. of material had been built up, and then another section was sprayed. Water would then flow over the top of the concrete, wash out the outer 1/8 in. or so of cement and sand, and then the concrete would set. No sloughing of newly applied concrete over a wet area occurred after it once set hard. The timber sets had to be moved enough to allow spraying the cement and were then reset.

The shaft walls were inspected above and below the 1,200-ft level, from the shaft cage which was stopped to allow a closer investigation. No deterioration of the shaft walls was apparent. The walls and back of the level station had also been sprayed with concrete. An inspection disclosed some minor sloughing on one wall. The rock was very friable and crumbly at this point. There was no evidence, however, of any working of the walls or pressure build-up on the walls around the shaft or on the shaft timbers at the station location. The ore and waste passes at the station had also been treated with sprayed concrete. Here again, there was no sign of deterioration of the rock surface.

A number of cross cuts and drifts on the level were also examined. These had been sprayed by shotcrete, using the wet-mix method of application. The equipment used was a True Gun-All Model H, purchased from Mining Equipment Company. A concrete mix, containing minus ½-in. sand, was mixed with water in the 30-in.-diameter chamber of this machine and sprayed directly on to the rock surface through a 2-in. hose equipped with a nozzle. Air pressure used was about 60 psi and the thickness of material sprayed was about 2 in. The actual equipment used was viewed by the author but was not in operation at the time of the visit. The back and walls of these sprayed drifts and cross cuts also showed no signs of deterioration.

A further inspection was made of an excavation being made for the installation of an underground crusher. The ground here was poor, joint and slip planes were evident, and the walls were tending to cave. Ordinary rock-bolting methods could not control the ground. Special techniques were being tried to hold the rock. Cyanamid Rock-Loc polyester resin was being added to the rock bolts to grout the bolts more firmly in the rock. The use of wire mesh or sprayed concrete was also being considered. It was thought that a combination of Roc-Loc and rock bolts with sprayed concrete might hold the ground.

Cost of Spraying the Eagle Gold Shaft

An estimate of the cost of sprayed concrete on the Eagle Gold shaft by the dry-mix method, was as follows:

		Per ft of shaft
Aliva machine rental costs, additives and supervision	-	$30.00
Material (aggregate) costs	-	34.00
Labour costs	-	60.00
Total costs		$124.00

Since the Eagle Gold mine was still only in the initial development stage, the engineering and office facilities and mine records were rather primitive. No mine plans, cost records, or operating reports were available. At the time of writing, the mine has not reopened and information is not available as to the present condition of the underground workings that had been sprayed with concrete.

Other Canadian Applications of Sprayed Concrete

Craigmont Mines Limited, Merritt, B.C.(6)

Sprayed concrete was first used at Craigmont in March 1965. A wet-mix type of shotcrete was applied, up to 3 in. thick, by means of Model H True Gun-All machines. This type of machine, distributed by Mining Equipment Company, is in relatively common use for underground applications where a thin coating of concrete is required. The main rock types encountered in underground development at Craigmont were altered limy sediments (greywacke and skarn), volcanics (andesite), and intrusives (diorite). There was not much evidence of pressure or squeezing in mine opening, but support was required mainly because of the high degree of faulting, fracturing, and jointing which affected all the rock types to a greater or lesser extent. Some of the ground also seemed to deteriorate slowly with prolonged exposure to air. The types of ground conditions encountered were ideally suited to the application of a relatively thin coating of sprayed concrete, using as aggregate minus 7/16-in. sandy gravel, obtained locally, with no additives being required.

Various applications of shotcreting at Craigmont Mines included: (1) ground support in new development, (2) ground support after removal of deteriorated timber, and (3) construction of ventilation bulkheads, seals and doors.

The use of timber for ground support at Craigmont has been virtually eliminated in favour of sprayed concrete. Actual cost comparisons, in 1967-68, showed considerable savings in using shotcreting rather than timbering in 12 x 12-ft (trackless) drifts. Table 3 shows a theoretical cost comparison between a 12 x 12-ft timbered and shotcreted drift in December 1968[6].

TABLE 3

Theoretical Cost of 12 x 12-ft Timbered Drift (Trackless)

	Shotcreted Drift (actual costs)	Timbered Drift (estimated costs)
Drilling	$ 9.80 per ft	$ 13.20 per ft
Blasting	13.28	17.90
Mucking	6.39	9.90
Shotcreting	15.61	-
Timbering	-	24.00
Miscellaneous	2.65	-
	$ 47.73 per ft	$ 65.00 per ft

Cupra Mines Limited (Sullivan Mining Group Limited), Stratford Centre, Quebec (11)

The Cupra Mine main ore zone is a massive sulphide deposit, dipping at approximately 40°, within a sericite schist formation. Exploration drifts and cross cuts were driven in badly sheared volcanic rocks and had very incompetent walls. The hanging wall was particularly bad, being composed of an altered soft and loosely laminated schist. As a result, the ground conditions were poor in the drifts and high rock pressures were experienced.

Dry-mix sprayed concrete was applied experimentally in a 7 x 7-ft drift, immediately after blasting, as a primary support and also as a means of preventing further air slaking or ground movement. Sprayed concrete was also applied in repair shop, loading pocket, and shaft station excavations. In some of these areas, rock bolts were the primary support but were unable to hold the ground and a 2-in. layer of sprayed concrete was also applied. It was found that this 2-in. application was not sufficient to hold the wall pressure and prevent spalling of the loosely laminated schist. Some cracking occurred. A second layer of 2 in. of sprayed concrete was applied and there was then no further sign of loosening of the concrete layer.

The spray-gun equipment used at the Cupra Mine was an Aliva-600 machine equipped with an additive dispenser; the whole was mounted on a frame on track wheels for easy transportation on rails. The aggregate consisted of minus 3/4-in. gravel, and the Monoset (Tricosal T-1) accelerator added amounted to 3% of the weight of cement used. The cement was Portland Type I, in the proportion of 658 lb per cu yd, with 3,100 lb of gravel per cu yd being added. The cost per cu yd through the machine was $44.00, including all labour, materials, and use of equipment.

Normandie Mine, Asbestos Corporation Limited, Black Lake, Quebec

The new Penhole shaft, 16 x 13-ft in cross section, was being sunk by the Cementation Company of Canada, to open up a new underground mine close to the Normandie open-pit operation. It was planned to line this shaft, to its total depth of 1,645 ft, with sprayed concrete.

Initially, a 60-ft concrete collar was poured in the shaft, at which point very poor ground conditions were encountered. Instead of extending the poured concrete collar, it was decided to use sprayed concrete as a primary and permanent means of support, on a trial basis. The sprayed concrete was first deposited at a thickness equivalent to the poured concrete section but was gradually thinned down to approximately 3 in. A 5-ft round was blasted six hours after the last application of sprayed concrete. Visual examination showed no loss or cracking in the sprayed concrete section, and it was decided to complete the shaft sinking operation using sprayed concrete as a primary means of ground support.

The spraying equipment used in the first 400 ft of shaft was an Aliva-600 spray-gun fed directly from a 6-cu-yd ready-mix (concrete) truck; an intercom-system was used to direct the operations. Below the 400-ft depth, a frame was built around the spraying machine so that it could be lowered onto working platform and fed by means of a cu-yd bucket. The shaft was very wet in some sections and a higher-than-usual (approx. 4.5%) percentage of Monoset additive was used, with an average of 3 in. of sprayed concrete being applied. Level stations were also sprayed to a thickness of 3 in.

From shaft elevation 332 to 355, a layer of talcose rock was encountered that was so incompetent that, for safety reasons, rock bolts, wire mesh and poured concrete were used to hole the ground; here, sprayed concrete was not tried. Other sections of the shaft, however, down to the 674-ft depth, required only sprayed concrete for primary support. From 674 to 1,050 ft, a very hard, grey-black, amphibolite was encountered that required no support at all. It was planned to complete the shaft and lateral development using only sprayed concrete for primary ground support.

The average cost per cu yd to-date was given as $41.00, including transportation above and below ground, heating of aggregates, materials, and use of the equipment.

Madsen Red Lake Gold Mines Limited, Madsen, Ontario

This gold mine is located in the Red Lake mining district of northwestern Ontario. The rocks in the area are mainly Pre-Cambrian, Keewatin basic lavas, overlain by Temiskaming sediments. The Madsen Mine itself has mined in a relatively competent type of ground for over 30 years, but a new potential ore zone, located north of the shaft at a depth of some 3,500 ft below surface, presented ground control problems. A cross cut, driven from the shaft to the potential ore zone (indicated by diamond-drilling), passed through several hundred feet of talc schist, which contained many faults, slips, and zones of weakness. A peculiarity of this talc schist zone was that, as soon as it was blasted, it became very wet, soapy, and slippery and the roof, walls, and back commenced to swell (or move) inwards. It was very difficult to control the movement of the ground because timber sets, the normal means of ground support used in the mine, tended to either break down or be gradually squeezed out by the ground movement[12].

An attempt was made to use sprayed concrete in this talc schist zone as a means of ground control. The sprayed concrete, however, would not adhere to the wet, slippery walls. It was apparent that special methods and equipment would be required if the use of sprayed concrete were to succeed in controlling the ground movement. The Canadian Formwork Corporation investigated the problem and suggested infra-red heaters to dry the walls after blasting, and immediate concrete spraying on the newly dried walls. This method would have resulted in considerably increased costs, so the mining company decided to abandon the idea of using sprayed concrete as ground support in the talc schist zone[13].

PRESENT FIELDS OF RESEARCH IN THE USE OF SPRAYED CONCRETE[14]

Further research is necessary into the present methods of applying sprayed concrete to rock surfaces in order to give greater flexibility to this method of ground support.

The Bureau of Reclamation, United States Department of the Interior, has formulated a plan to conduct a rapid-excavation research in an actual tunnel. The tentative site for the proposed research is the Stillwater Tunnel of the Central Utah Project, which is scheduled to start in the spring of 1972.

The research in this tunnel will include a study of the use of sprayed concrete, both alone and in association with perforated metal plates, and the use of precast concrete as means of ground support. Also to be studied will be the use of new quick-setting cements and new types of additives which are becoming available and which may improve the economy and ease of application of sprayed concrete.

Another field of research is the use of polymer concrete, i.e., concrete that is impregnated with a liquid plastic and treated either by radiation or by thermal-catalytic techniques. This treatment process induces substantial changes in the characteristics of concrete: compressive and tensile strength and modulus of rupture are increased by more than 250%, and permeability is decreased by 95%. Improved properties of polymer concrete represent potential benefits in the area of in-situ impregnation of concrete for protection against deterioration by weathering or by cavitation from high-velocity flows of liquids through tunnels. The polymer may also find application in the manufacture of precast concrete sections for tunnel support, and of other structural items such as concrete pipelines.

SUMMARY AND CONCLUSIONS

A new type of sprayed concrete has been developed in Europe using coarse-grained aggregates and cement with special additives that accelerate the hardening of the concrete. Known as "shotcrete", it has found increasing applications as a means of ground support in tunnelling operations and underground excavations in Europe and, more recently, in North America.

With proper methods of application, the shotcrete will form an intimate bond with the rock to which it is applied. This newly formed skin has the ability to expand and contract with the rock surface, will resist weathering, and will give additional strength to the rock surface in resisting ground movement.

The use of shotcrete in Canadian underground mines to date has been largely experimental. It was found that it could compete successfully with more conventional methods of ground support, such as rockbolts, timber and steel sets, in development headings and as a substitute for poured concrete in ore and waste passes, and ventilation bulkheads. However, under some adverse conditions, such as talc-schist and very wet conditions, the present types of shotcrete could not be applied successfully to the rock surface.

Research is now under way in the United States of America, using new additives such as plastics, and the scope for the application of sprayed concrete under varying types of ground conditions is expected to widen. Combinations of sprayed concrete (of various degrees of coarseness) in conjunction with wire mesh or expanded metal are already finding wider applications in underground excavations in Europe, North America, and Canada.

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