Mines Branch Information Circular IC 141

BACKFILL METHODS IN CANADIAN MINES*

by

M. A. Twidale**

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ABSTRACT

In recent years, more and more attention has been paid to the use and effect of filling empty stopes with material that is available at the individual mine and will satisfactorily arrest ground movement. A few years ago, the attitude in some cases was to recover the economic minerals at as low a cost as possible, paying little attention to the future life and profits of the mine. Fortunately, the attitude to-day is to look more to the future and to the use of fill to preserve the mine workings.

The use of hydraulically transported sand that has been obtained from the crushed and ground ore as tailings or from alluvial deposits is described in some detail.

The use of coarse waste rock and of sand and gravel, involving handling and placing in the dry state, is discussed and some operating costs are supplied. An outline is given of the Resuing method of stoping.

Details are given of two mines in which a consolidating fill material is used that does not require any support after the consolidation has taken place.

In most cases, cost figures are given for comparison purposes; this is meant merely as a guide for European engineers, for it is recognized that there is little similarity with European conditions and wage rates.

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Direction des mines

Circulaire d'information IC 141

TECHNIQUES DE REMBLAYAGE DANS LES MINES CANADIENNES*

par

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RÉSUMÉ

Depuis quelques années, on étudie de plus en plus le remblayage des chantiers épuisés à l'aide des stériles et autres matériaux disponibles qui peuvent avantageusement empêcher les déplacements de terrain. Dans le passé, on ne se préoccupait dans certains cas que de récupérer les minéraux d'importance économique au coût le plus bas possible, sans accorder beaucoup d'attention à l'avenir de la mine ou à ses bénéfices. Heureusement, de nos jours on pense davantage à l'avenir et à l'utilisation du remblayage afin de préserver les chantiers souterrains.

La présente circulaire décrit assez en détail la technique du transport hydraulique de sables obtenus soit des stériles des minerais après concassage et broyage, soit de gisements d'alluvion.

L'auteur traite de l'emploi de stériles grossiers, et de sable et gravier, tenant compte de la manutention et la mise en place à sec, ainsi que de certains éléments des frais de fonctionnement. Il donne également un aperçu du procédé d'exploitation "Resuing".

L'auteur examine par le detail les travaux de remblayage à deux mines ou l'on utilise un matériau de remplissage consolidant qui n'a pas besoin de soutènement une fois consolidé.

Dans la plupart des cas, les détails du coût sont donnés à seule fin de comparaison. Ils ne sont mentionnés qu'à titre d'indication pour les ingénieurs européens, car on admet que les conditions et les salaires au Canada ont peu de ressemblance avec ceux de l'Europe.

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INTRODUCTION

With the objective of the Second International Mining Congress in mind, namely, reduction of the cost of mine products, the author presents herein information on one operation in mining.

The use of fill in mines has several aspects in the consideration of overall costs of the products of the mine. It has been proven that in underground mines, particularly where mining is carried on at depths of greater than 1000 feet, the filling of empty stopes has greatly reduced the pressures and stresses placed on the pillars and the adjacent workings. This has meant a reduction in rock bursts and the development of loose walls and backs in adjoining workings. Also, the use of fill has made the recovery of pillars of ore both possible and economical. The period of useful production has been increased as a result of mining of the pillars and of mining at greater depth. The use of fill concurrently with the stoping operations not only accomplishes the purposes previously mentioned, but reduces the accident rate among the workers by providing a safe working platform close to the walls and back. The fill supports the walls and reduces the sluffing of waste material that dilutes the broken ore. Likewise, waste material broken with the ore can be left in the stope as fill. The effect of these factors on the overall cost of products is hard to estimate accurately, but it has been proven to be appreciable in many of Canada's metal mines and could well be equally effective in mining coal and industrial minerals.

Although the efficiency and cost figures used in this paper will have little significance to operations in Europe, they are meant as a comparative guide and as part of the description. Many of the details of the Canadian operations are governed by the local conditions of the individual mines and districts. The choice of medium to be used as fill will be governed by the material available. The method of placing fill will be governed by the characteristics of the mine. The method used in ore extraction will be governed largely by the character and structure of the orebody, as well as the type of fill available.

HYDRAULICALLY-PLACED SAND FILL

The type of fill commonly called 'hydraulic sand' has grown in importance in the past few years and is now more widely used than any other individual type. This product is used in the metal mines where mineral extraction yields a waste sand product. The main criterion for the use of hydraulic sand is a minimum water percolation rate of four inches to six inches per hour. To obtain this percolation rate, it is usually necessary to remove some of the slimes and fine particles by classification in hydraulic cyclones. There are cases where very fine grinding is necessary to liberate the economic minerals and the resultant tailings are too fine to give the necessary percolation rate.

Tables I and II show typical screen analyses of hydraulic-sand fill material.

Table I

Typical Screen Analysis of Gold Mine Sand Fill

Mesh	Weight, %	Cumulative Weight, %
+ 65 m	0.2	0.2
-65 + 100 m	1.4	1.6
-100 + 150 m	7.7	9.3
-150 + 200 m	25.5	34.8
-200 + 325 m	28.8	63.6
-325 m	36.4	100.0
Percolation rate: 4 inches per hour		

Table II

Typical Screen Analysis of Metal Mine Flotation Tailings Fill

Mesh	Weight %	Cumulative Weight, %
+ 65 m	15.7	15.7
- 65 + 200 m	54.2	69.9
-200 + 800 m	26.4	96.3
-800 m	3.7	100.0
Percolation rate: 4.8 inches per hour		

The filling of mined-out areas is not a continuous operation. As a rule, it is desirable to fill at a rate faster than that at which the mill is capable of supplying material; this results in an intermittent supply to the mine. This necessitates having storage bins on the surface to contain the sand either in suspension in water or in the dry state, the latter state being more popular because of the saving in the cost of agitation. Storage in the dry state can be accomplished in an empty stope near the surface, in which case provision must be made for drainage. High pressure water points must also be provided to assist in removing the sand as required.

The economics of the operation dictate that the fill slurry should contain a maximum amount of solids. 50 to 60 per cent solids by weight is a common proportion, but each distribution system varies as to the maximum permissible before settling causes stoppage. This percentage can only be determined by experience. It is considered advantageous to retain as much of the fine slimes as possible, within the limits of the percolation rate, to act as a lubricant. One mine added 25 per cent alluvial till of minus 5/8 inch size to the regular fill with good results. Undoubtedly, a larger size of sand and gravel could have been used.

Transporting Fill

Figure 1 illustrates a typical mine using bore holes for the distribution of the hydraulic fill directly from the fill preparation plant of the mineral extraction mill to the underground workings. The sections are diagrammatic, to assist the distribution explanation.

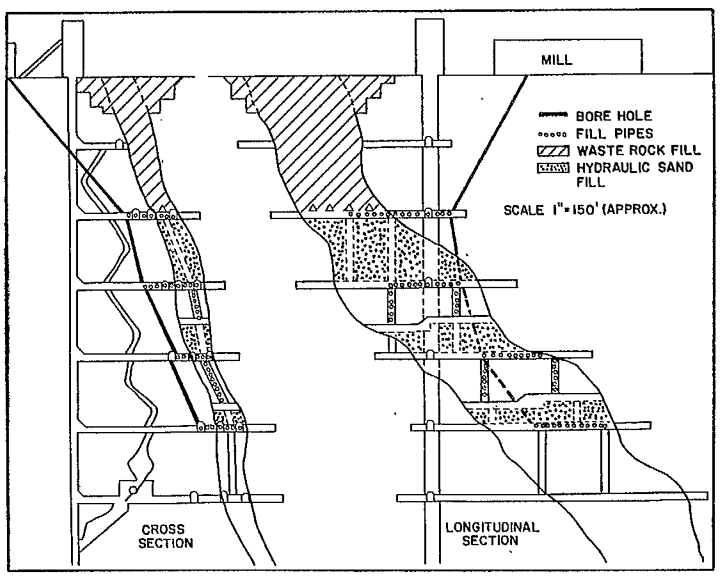

Figure 1. Sections of a typical mine using hydraulic sand fill.

Wherever practical, bore holes are used to carry the fill underground and from working level to working level (where branches of standard Victaulic pipe distribute the fill to working stopes). Where large stoped-out areas are to be filled, it has often proved advantageous to deliver the fill by an inclined bore hole. One gold mine transports fill from surface to the 2500-foot level, at the rate of 43 dry tons per hour, in a slurry containing 54 per cent solids by weight, by means of a 2-3/8 inch bore hole. When bore holes are used, it is customary to enlarge each end of the hole; a 4-foot section of pipe is then grouted and sealed securely to the wall of the hole. The section of the pipe extending outside the hole is then anchored to the rock wall with anchor bolts. The connection from one bore hole to another is made with a removable section of pipe. Similarly, an adaptor hose can be inserted to deliver fill to the distribution pipeline on the level. When mine workings are widespread, more than one system of bore holes is used. Another gold mine, with two distribution systems, uses 7000 feet of bore hole.

In none of the hydraulic-fill systems are valves used for distributing fill. Also, each fill operation underground is in telephone communication with the surface point of origin. A filling operation starts with the introduction of clear water into the system. When this reaches the delivery point, the surface operator is advised and fill is introduced. The flow of fill is not interrupted until the surface source is exhausted, or sufficient fill has been delivered, at which time the system is again flushed with clear water.

Under conditions in which bore holes are deemed less suitable than pipes, and space is available in service or air shafts, pipe lines are used for the main transportation system. These main lines are universally lined with 1/4-inch soft rubber. The lateral distribution pipe lines are not rubber-lined, since only a reduced service is required.

One mine uses 6-inch pipe with a bursting pressure of 4300 psi and 400-pound lap flanges, with 1/4-inch rubber lining extending over the face of the flange. This main line extends from the surface to the 3400-foot level, with take-off points at intermediate levels where needed. The intermediate level connections are made with a 6-inch hose having a 5/8-inch rubber wall with a wire-reinforced, three-ply fabric carcass. The estimated bursting pressure is 3000 psi. The lateral pipes, in some cases 2000 feet long, are of 4-inch extra strong, unlined, black iron pipe with an internal diameter of 3.826 inches and a wall thickness of 0.377 inch. It has been found advantageous to use 5-inch Victaulic couplings by welding onto the 4-inch pipe a 5/8-inch-square ring flush with the end of the 4-inch pipe. This eliminates cutting the Victaulic groove and weakening the pipe. This system is capable of handling fill, at the rate of 120 dry cubic yards per hour, in a slurry containing 60 per cent solids. The velocity in the 6-inch pipe is 7 feet per second, and in the 4-inch pipe, 14.5 feet per second. The normal filling rate is some 70 cubic yards per hour, with a corresponding reduction in velocity. To date, some 3-1/2 million cubic yards of fill have been transported through this system, which figure includes some 13 per cent alluvial sand screened to minus 5/8 inch. The 6-inch-diameter, rubber-lined pipe showed little wear at the end of 3-1/2 million cubic yards, but since then has been breaking loose, chiefly because of the presence of copper sulphate, which destroys the resilience of the rubber. The working life of the flexible hoses represented 200,000 to 400,000 cubic yards of fill.

Placing Fill

Pipes carrying fill to the working areas are generally graded for self cleaning and, in the working stope, are generally carried on a light trestle (Figure 2) so that fill is poured at the farthest point from main drainage points. Drainage of water from the fill occurs chiefly through surface openings that have been covered with 10-ounce burlap (Figures 3, 4 and 5). Drainage by percolation through the fill is minor.

Because of the rotting in time of the burlap, travel ways are generally constructed of tightly-lined timber, usually 3" x 6" tongue-and-groove covered with burlap. In some cases, fill is poured directly against ore pillars, which means that when recovering the pillars a small amount of ore must be left to contain the fill from the stope. If the value of the ore warrants it, a fence is left (Figure 4) and pillar mining recovers 100 per cent of the ore. Where horizontal openings are required in a filled area, the timber support carries the sealing burlap (Figure 6).

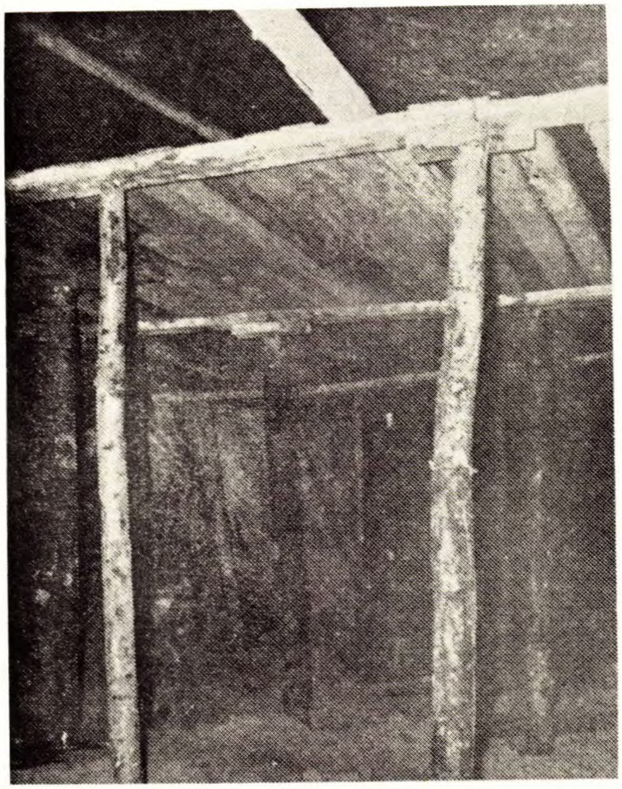

Figure 2. Elevated stope floor carrying fill pipes.

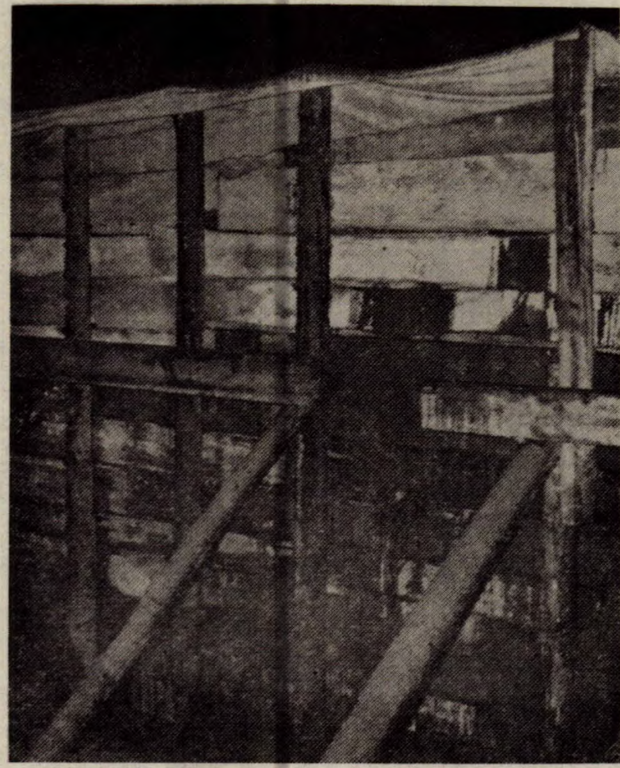

Figure 3. Fill fence with burlap.

Figure 4. Fill fence against ore pillar which will be mined later.

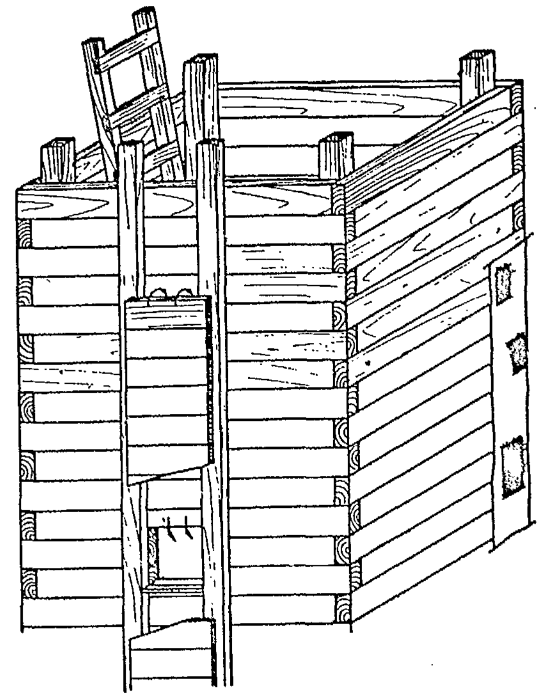

Figure 5. Manway, of 3" x 6" plank, showing decanting slot.

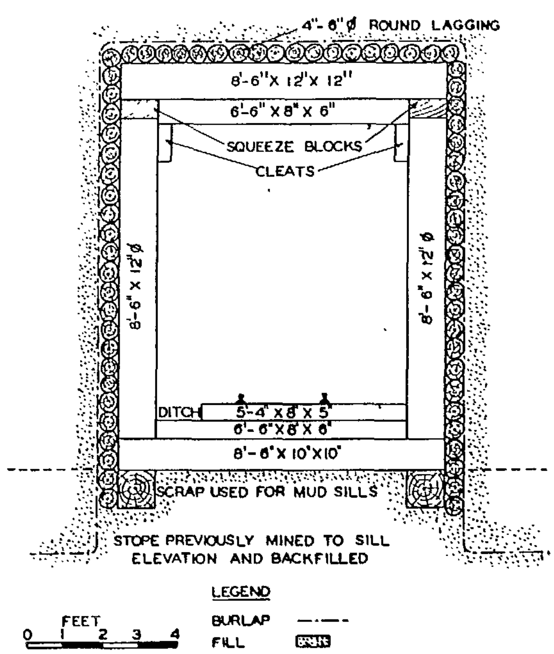

Figure 6. Haulageway through fill.

Openings under an area to be filled must be of such construction as to withstand the weight of the fill and provide adequate drainage to avoid the building-up of a hydraulic head of excessive pressure. Figure 7 illustrates a stope being filled in sections; Figure 8, a drain collecting point (called a "mouse trap" in Canada); Figure 9, a haulageway bulkhead and "mouse trap"; and Figure 10, a bulkhead in a vertical opening, with the burlap seal on the outside to facilitate repairs.

In filling large openings of considerable vertical height (i.e., of hundreds of feet), the rate of placing the fill must be carefully controlled in order to avoid the build-up of an excessive hydraulic head. Drainage points at the bottom of the area must be watched, and pressure gauges must be installed to record pressures. If drain points are functioning properly, the stopping of fill placing will rapidly result in a reduction of the hydraulic head.

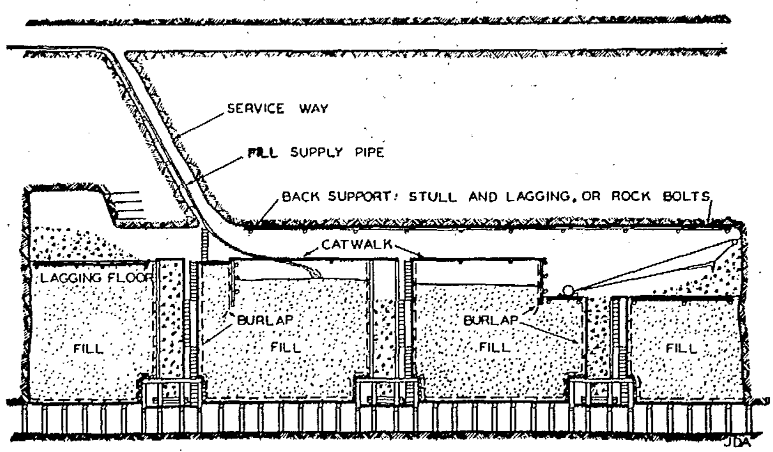

Figure 7. Stope being filled in sections.

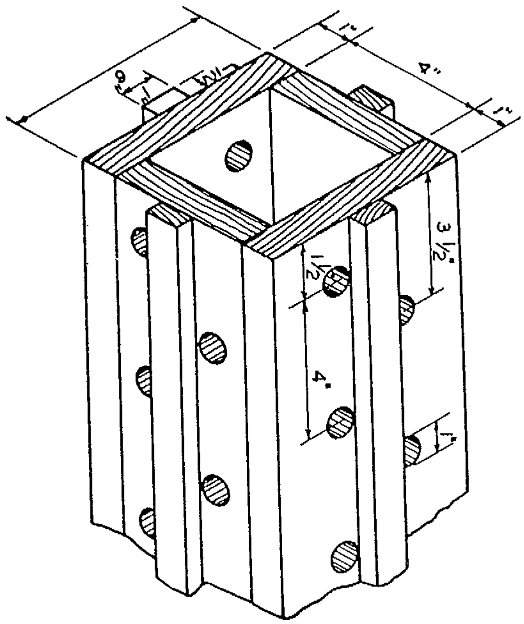

Figure 8. "Mouse trap" (drain collecting point).

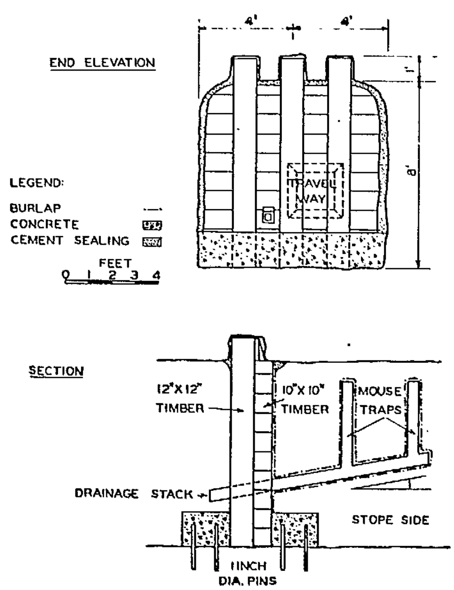

Figure 9. Haulageway bulkhead.

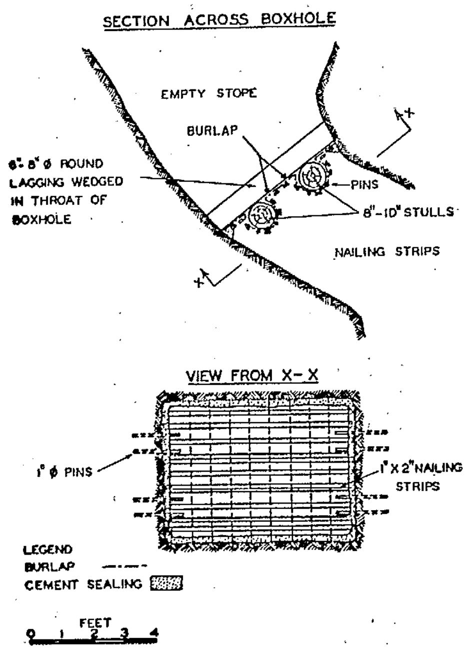

Figure 10. Bulkhead in vertical mine opening.

Where economic, waste rock is added to the fill while pouring is progressing. This has no effect other than to reduce the volume of hydraulic fill. Wall and back support timber left in the fill has no bad effect, since air is excluded.

In many cases stopes have been filled with coarse waste rock and later it has been found necessary to have this fill strengthened by the addition of hydraulic sand. It is estimated that 50 to 60 per cent of the voids are then filled with the sand, the resulting pillar being greatly strengthened. Hydraulic fill has also been used successfully where an opening has been partly filled with waste rock. In all cases, the openings in the lower horizons must be sealed with bulkheads (preferably of timber) fitted with burlap as a filter medium; otherwise the hydraulic fill will leak and flow through the coarse rock fill.

Pumping

It has been found that some 10 to 15 per cent of the water used remains in the fill and the balance must be pumped from the mine. It is essential to provide adequate settling sumps to settle the slimes prior to centrifugal pumping to surface.

Advantages of Hydraulic Sand Fill

1. This method is adaptable to sands of large particle size.
2. The fill gives excellent support to the walls, all small spaces being filled with a dense medium.
3. The cost is low (Table III).
4. Waste material can be added advantageously.
5. Recovery of pillars is possible between solid supports.

TABLE III

Some Costs of Hydraulic Sand Filling in a Canadian Mine, Based on 700,000 Cubic Yards Placed

		Cut-and-Fill Stopes, per Cubic Yard	Open Stopes, per Cubic Yard
Spreading fill in stopes	-	$0.19	$0.09
Operation and maintenance of supply lines	-	$0.035	$0.035
Fill bore holes	-	--	$0.01
Preparation of fill	-	$0.15	$0.15
Miscellaneous	-	$0.16	$0.01
Concrete bulkheads	-	--	$0.26
Direct cost	-	$0.535	$0.555
Capital cost of sand storage plant and main pipe lines	-	$0.149	$0.149
Total	-	$0.684	$0.704
Total per ton of fill		$0.46	$0.474

HYDRAULICALLY-PLACED GLACIAL TILL

Alluvial sands are placed as fill in the same general way as described for hydraulically-placed sand fill. The following information relates to a base metal mine which uses this type of fill.

The sand is mined hydraulically from a deposit some 50 feet thick. The +2 inch material is discarded and the balance is pumped some 13,000 feet through an 8-inch standard steel pipe to the mine. The rate of flow is 2200 U.S. gallons per minute at 20 per cent solids by weight. There are five pumping stations on the line, each having two 10" x 8" SRL-C pumps. Any change in direction of the pipe line is accomplished with rubber-lined hose instead of elbows. At the mine four cyclones remove the slimes and water and deposit the sands in a storage tank.

Table IV gives a comparative screen analysis of the pit run sand (after the +2 inch material has been discarded) and the finished backfill as it is sent underground.

Table IV

Comparative Screen Analysis of Pit Run Sand and Sand Backfill

Pit Run Sand			Sand Backfill		
Mesh	Weight %	Cumulative Weight %	Mesh	Weight %	Cumulative Weight %
-2" +1/4"	18.4	18.4	-1/4" +4 m	3.4	3.4
-1/4" +10 m	14.7	33.1	-4 +10 m	15.3	18.7
-10 +20 m	11.9	45.0	-10 +20 m	15.4	34.1
-20 +48 m	22.5	67.5	-20 +48 m	28.9	63.0
-48 +100 m	14.8	82.3	-48 +100 m	18.8	81.8
-100 +150 m	5.5	87.8	-100 +150 m	7.2	89.0
-150 +200 m	5.0	92.8	-150 +200 m	6.4	95.4
-200 m	7.2	100.0	-200 m	4.6	100.0

Two storage stopes, each 25 feet x 100 feet x 160 feet, are used to store sand fill for the winter months. Draw points are located on 25-foot centres. The sand is reclaimed by high-pressure water jets in cylindrical mixing boxes, with conical bottoms, located in the draw point bulkheads. The sand is further mixed to the density of 70 per cent solids and pumped to the underground supply system. This underground distribution is a closed system using 4-inch rubber-lined pipe (3-1/2 inch I.D.) in the main vertical line, with a maximum length of 1350 feet. The horizontal lines, maximum length of 1250 feet, are of standard 4-inch pipe. The system has handled some 580,000 tons of fill to date, with no appreciable wear. The mine uses about 150,000 tons annually. The details of telephone system, mining methods, placing fill, fences, bulkheads, etc., are similar to operations previously described for hydraulically-placed sand fill. The approximate costs are illustrated in Table V.

Table V

Cost of Hydraulically-Placed Glacial Till

Capital cost of system		-	$450,000.00
Operating plus maintenance and repair:			
Surface			
1.	Power	-	$0.040 per ton
2.	Supplies	-	0.159 " "
3.	Mobile equip.	-	0.162 " "
4.	Labour	-	0.211 " "
Underground			
	Placing fill	-	0.107 " "
	Total		$0.679 per ton ($1.007 per cubic yard)

SAND AND GRAVEL FILL

This type of fill is used in several mines to fit particular conditions. Sand and gravel along with any waste rock available may be used to fill the empty stopes in the case of a mine with shrinkage stopes, less than 1000 feet below surface, that have been emptied of ore and where stability is consequently necessary to prevent ground movement. This fill is usually procured by shovel excavation from a nearby glacial deposit and is hauled by truck to the mine site. For stopes, the upper extremities of which approach the surface, the fill material is dumped directly or through short connecting openings; the cost is about $0.42 per cubic yard or $0.31 per ton. For filling empty stopes that do not approach the surface, fill is handled in a sand pass, generally 6 feet by 6 feet in cross section, which is connected to each haulage horizon for distribution to the stopes. A near-surface stope is often used as a storage bin and is connected to the sand pass through control gates.

Two of Canada's oldest gold mines use dry sand fill. These mines are deep, and fill is required in a multitude of small vein-mining operations.

The practice of sand filling existed before hydraulic types came into use, and it is not considered economical to change the material and methods. The pit run of sand is mined by mechanical shovel and transported some 3-1/2 miles to the mine site by aerial tramway. The fill is stored in near-surface stopes and fed to a sand pass that connects with mining horizons to a total depth of nearly 6000 feet.

Some 90 per cent of the ore is extracted by the horizontal cut-and-fill method of stoping (Figure 11). Where the ore zones are narrow, say from 6 to 30 feet wide, the stopes are laid out lengthwise to the strike of the ore. The length is governed by the continuity of the ore. If the ore and walls are unstable, pillars of ore are left to be mined later. Where ore zones are wider than 30 feet, stopes are generally laid out transverse to the strike of the ore zone, with stopes and pillars alternating and of nearly equal width. The width of stopes is governed by the strength of the ore, and the length is governed by the distance from wall to wall of the ore.

The fill is drawn from the fill pass in the stope through a small control gate, and is distributed by a mechanical scraper. The hoist used to move the scraper is usually 15 HP to 25 HP, air-or electric-powered. A three-drum hoist is more versatile than the conventional two-drum type, particularly in wider stopes. The scraper is normally 36 to 42 inches wide. The ropes on the hoist are 1/2-inch to 5/8-inch in diameter. The scraper is used to move broken ore to the ore chute as well as to distribute the fill. In the case of higher-grade ore a plank floor is laid on the fill prior to the blasting of ore. In other cases a round-pole floor is laid flush with the top of the fill to control the digging action of the scraper. Dilution of the ore with fill material is negligible. The fill is kept currently close to the ore-breaking face for maximum support. Control of the ore in the back is attained by the use of rock bolts, timber cribs or packs, and posts standing on mud sills on the fill. The pole or plank floor is recovered for re-use prior to the placing of fill. Back-support timber is generally recovered, but can be left and built on again if necessary.

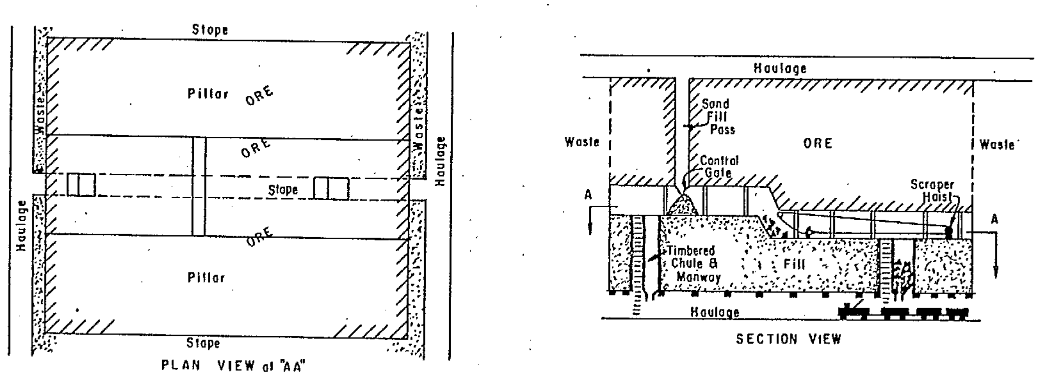

Figure 11. Plan and section of transverse stope.

Where pillars of ore are left beside a stope a "gob fence" made of rough planks and pole posts (Figure 4) is left against the pillar. During subsequent mining of the pillar this fence is supported until fresh fill is poured in order to prevent dilution of the broken ore.

In mining the stope and pillar sand fill has an advantage over hydraulic fill in that it can be kept daily close to the working face. Table VI shows present costs at such mines.

Cut-and-fill stoping in a gold mine, as described, produces from 10 to 18 tons of ore per man shift per day, when using two shifts of two men each.

Table VI

Approximate Cost of Sand and Gravel Fill Per Ton of Fill Placed in Stopes

Surface cost delivered to mine	-	$0.45
Underground tramming	-	$0.33
Distribution in stopes	-	$0.24
Hoist and scraper maintenance	-	$0.03
Tramming maintenance	-	$0.07
Overhead and miscellaneous	-	$0.10
Total	-	$1.22
Cost per cu yd	-	$1.75

DRY ROCK FILL

Rock from development in waste and coarse rock separated from ore in mineral separation operations are still extensively used as fill in metal mining, although the trend of recent developments is to replace them with hydraulic sand fill. The reasons for the change are primarily lower cost and the better support given by the denser hydraulic sand fill. Both types of rock fill are sent underground and distributed in the same manner as was described in the preceding "Sand and Gravel Fill" section.

In cut-and-fill and square-set stopes with an irregular hanging wall, efficient stowing of the fill against the hanging wall has been difficult. Also, a flat hanging wall would leave 10 to 20 feet of unsupported hanging wall above the stope floor. Several methods have been used to fill this area, namely pneumatic stowing, scraper plows, and pneumatic pushers.

In one mine, with a limited size orebody that did not reach surface, a stope was opened in waste rock above the orebody. The location was such that short fill passes fed the fill through control gates directly to the stopes. A stope and pillar method of mining was used. The stopes were mined by the sub-level blast hole method. When a stope was completed and all ore had been drawn, the void was filled from the rock fill stope above. The ore pillar between filled stopes was then broken by one large blast and the broken ore selectively drawn through box-holes.

The rock fill stopes measured 600 feet x 200 feet x 180 feet high. The rock was broken, using long blast holes. The fill cost $1.40 per ton or $2.37 per cubic yard when in place in the stopes. This is not considered to be an efficient method, but it answered the problem of a limited size, high-grade orebody.

One of our small gold mines is successfully using the Resuing method of stoping. The gold ore is in a steeply-dipping fissure-type quartz vein with comparatively weak grey-wacke walls. The hanging wall develops loose slabs that are dangerous and dilute the ore if not supported by fill. The stoping procedure is to drill and blast the gold-bearing vein onto a plank floor. The ore is moved by hand to a timbered ore-pass. The floor is then lifted and waste rock is blasted from the foot-wall. The plank floor is replaced on the waste fill and the cycle is repeated.

Stoping has now reached a depth of 3900 feet. With increased depth the hanging wall requires additional support with rock bolts and short timbers. In some cases a small ore pillar is left, to be removed as the waste filling is in progress. The overall cost of ore delivered on surface is about $12.00 per ton; it is estimated that the filling cost, which is included, amounts to $1.50 per ton of ore produced. This type of fill meets a particular set of conditions.

CONSOLIDATING FILL

Several mines have been using slag and rock fill for some years with an additive that cements the particles together into a solid mass. The primary advantage of this fill is strength; moreover, fill can be poured against an ore pillar without a containing fence, and it does not dilute the ore during the mining of the pillar. Haulageways and ventilation passages can be left when pouring the fill, or can be driven when the fill has consolidated. No support is needed for these openings.

One mine uses granulated copper smelter slag with pyrrhotite concentrate as a cementing agent. The slag is granulated by dumping when hot into a tank of water. The fine material is recovered with a "clam shell" excavator. The granulated product is mixed with coarse slag (-4 inch) and sent underground by a fill pass. At the first level the slag is conveyed by a fixed-weight conveyor to the main fill pass, at which point pyrrhotite concentrate in slurry form is added (Figure 12). This pyrrhotite is a waste product from the flotation concentrator. The main fill pass delivers the fill, as required, at the working horizons as in the case of "sand and gravel" fill previously described.

The reaction that consolidates the fill is one of oxidation of the pyrrhotite to form a hydrous ferric oxide, which is the cementing agent. Heat and sulphur dioxide are given off. When a large mass is poured into an empty stope the surface temperature reaches 100°F, the internal temperature being higher. When used in 6-foot to 8-foot layers in a cut-and-fill stope, the heat effect of the reaction is dissipated in normal ventilation and is not felt. The sulphur dioxide is dissipated and hardly noticeable.

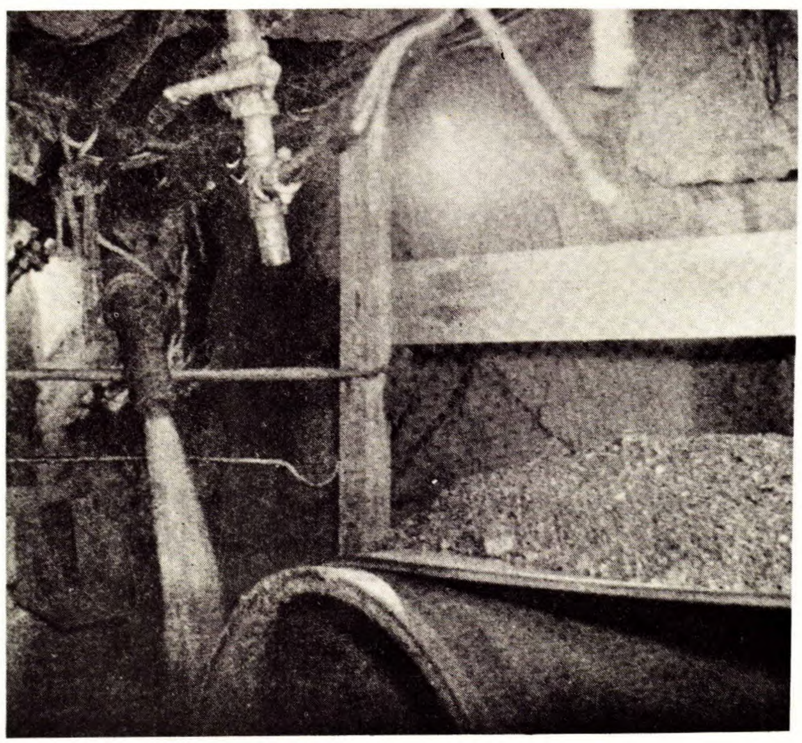

Figure 12. Mixing slag and pyrrhotite concentrate.

Table VII

Composition of Consolidating Fill, Pyrrhotite Concentrate, and Slag

Composition of Consolidating Fill:*

72% Granulated slag
25% Dump slag (-4 inch)
3% Pyrrhotite concentrate

Composition of Pyrrhotite Concentrate:

56% Pyrrhotite
6% Pyrite
10% Magnetite
28% Insoluble

Average Analysis of Slag:

36.5% Fe
38.0% SiO_2
6.5% Al_2O_3
1.5% S
1.5% CaO
1.0% MgO

*The compressive strength of the consolidated fill was 300 to 1000 psi.

Figure 13 shows a pillar recovery operation against consolidated fill (left wall). Figure 14 shows a haulageway through fill, formed with light corrugated metal.

Figure 15 shows a manway, left in stope fill, being used in pillar recovery. In cut-and-fill mining, stopes are normally transverse to the strike of the ore. Openings left in the fill below the mining floor, such as manways and ore passes, are located against the pillar wall. An opening is also left to feed fill to the pillar-recovery mining that is to come later. The manways and ore passes are then used for the pillar mining. If these passes are not required for ventilation when pillar recovery is complete, they are filled.

Figure 13. Pillar mining. Note consolidated fill, left wall.

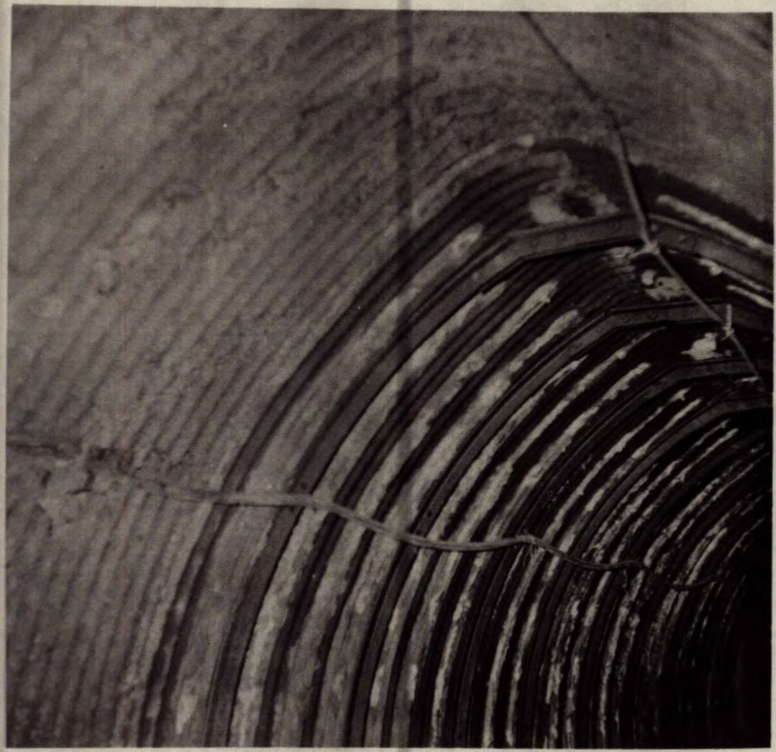

Figure 14. Haulageway through consolidated fill.

Figure 15. Manway left in consolidated fill.

Table VIII

Some Costs of Preparation and Placing of Consolidated Slag Fill

	Costs per Ton of Fill	
	Cut-and Fill Stopes	Open Stopes
Surface slag	\$0.286	\$0.286
Pyrrhotite concentrate	\$0.026	\$0.026
Tramming and conveying	\$0.230	\$0.230
Placing in stope	\$0.228	\$0.005
Totals	\$0.770	\$0.547
Cost per cubic yard	\$1.83	\$1.30

One metal mine is using a heavy-media-separation waste product, of mesh size -2 inch + 1/4 inch, mixed with 5 per cent pyrrhotite concentrate as a consolidating agent. This product has been used in filling open stopes. Considerable amounts of heat and SO_2 are developed, so that pourings of fill have been limited to 25,000 cubic yards each. The mine management reports a compressive strength of 300 to 400 psi. The porous nature of the fill probably accelerates the reaction of the pyrrhotite, resulting in higher temperatures and the giving off of greater amount of SO_2 gas. The mine now seals off ventilation openings and reduces the amount of fill in any one operation.

A limited amount of research work is being done on additives for consolidating fill, particularly in the field of hydraulically-placed mill tailings. This method shows lower costs and better support than does dry fill and, it is hoped, will have the advantages of the consolidating fill.

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