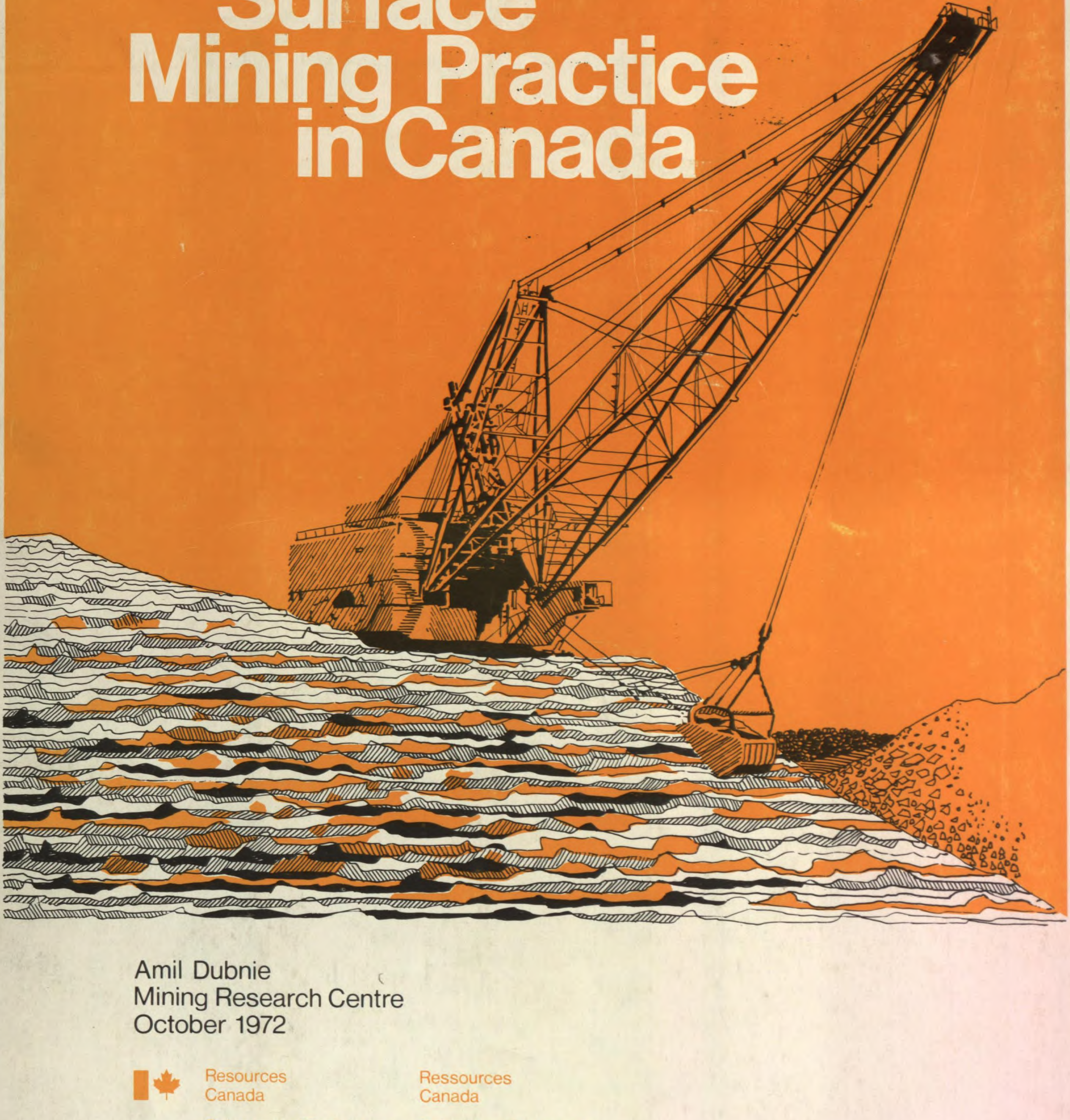
Surface Mining Practice in Canada



Amil Dubnie
Mining Research Centre
October 1972

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Mines Branch Information Circular 292

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FOREWORD

Surface mining has been part of the Canadian mining scene for many years but, in the last two decades, it has grown to surpass underground mining by a substantial margin. During the period 1950-1970, tonnages of ore recovered by surface mining increased from 15 per cent of the Canadian total to over 65 per cent and the trend continues. Much of this interest is due to improved technology which has enabled large-scale mining of low-grade ores to be pursued. Recent increases in Canadian coal production have further accelerated the trend towards surface mining which has been important to the competitive position of Canadian coal deposits.

This publication provides a general survey of the equipment, methods and costs of surface mining in Canada. The objective has been to provide a basic understanding of current Canadian practice. Considerable descriptive material has been included to assist those who are unfamiliar with mining operations. Those working in the industry will probably find a greater use for that portion of the study which describes details of Canadian procedures and practices, particularly such data as could be tabulated.

Information for this publication was gathered by questionnaire supplemented by personal visits to selected mining areas. Some published material was included where necessary to complete the presentation. The Mines Branch is indebted to all who contributed information, and their assistance is gratefully acknowledged.

John Convey,
Director

Ottawa, October, 1972

AVANT-PROPOS

Depuis nombre d'années l'extraction à ciel ouvert fait partie de l'exploitation minière au Canada mais, dans les deux dernières décennies, l'emploi de cette méthode a augmenté au point de surpasser substantiellement l'exploitation minière souterraine. De 1950 à 1970, le tonnage de minerai extrait par exploitation à ciel ouvert est passé de 15 à 65 p. 100 du volume total et cette tendance se maintient. L'intérêt porté à cette méthode est dû surtout au perfectionnement des techniques qui ont permis de poursuivre l'exploitation à grande échelle de minerais à faible teneur. L'augmentation récente de la production de charbon a accéléré la tendance vers l'exploitation à ciel ouvert qui a influé sur la position concurrentielle du charbon canadien.

La présente publication donne une vue d'ensemble du matériel, des méthodes et des coûts de l'exploitation à ciel ouvert au Canada. L'objectif était de donner une documentation de base des méthodes couramment utilisées au Canada. Elle inclut de nombreux éléments descriptifs susceptibles d'aider les personnes non familiarisées avec les travaux d'exploitation minière. Les employés de l'industrie trouveront probablement plus utile cette partie de l'étude qui décrit en détail les procédés et les méthodes canadiennes, particulièrement les données qu'on peut disposer en tableaux.

Les renseignements ont été obtenus par questionnaire et par des visites personnelles de régions minières choisies. L'auteur a inclu de la documentation déjà publiée afin de compléter la présentation. La Direction des mines est redevable aux personnes qui ont fourni des renseignements et les remercie vivement de leur aide.

Le directeur
John Convey

Ottawa, octobre 1972

Mines Branch Information Circular IC 292

SURFACE MINING PRACTICE IN CANADA

by

Amil Dubnie*

ABSTRACT

Examination of the practices in 52 Canadian surface mines shows a marked similarity in equipment, procedures, and productivity.

The unit operations of planning, stripping, breaking, and haulage are analyzed. The high degree of mechanization in the surface mines is conducive to a labour productivity which is several times that for underground mining.

As replacements occur, the established trend towards larger equipment tends to reduce surface mining costs. As a result, the increased use of surface mining methods in the recovery of minerals appears assured.

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RÉSUMÉ

L'étude des méthodes utilisées dans 52 mines canadiennes à ciel ouvert révèle une ressemblance remarquable dans le matériel, les procédés et la productivité.

L'auteur analyse la planification, le décapelage, l'abattage et le transport. Le haut degré de mécanisation dans les mines à ciel ouvert contribue à une productivité de la main-d'oeuvre bien supérieure à celle de la main-d'oeuvre des mines souterraines.

La tendance à installer du matériel plus lourd lors des renouvellements contribue à réduire les coûts d'exploitation à ciel ouvert. En conclusion, l'emploi croissant de méthodes d'extraction à ciel ouvert des minéraux semble certain.

CONTENTS

PLANNING

STRIPPING

BREAKING

LOADING

HAULAGE

Page

SUPPORTING OPERATIONS

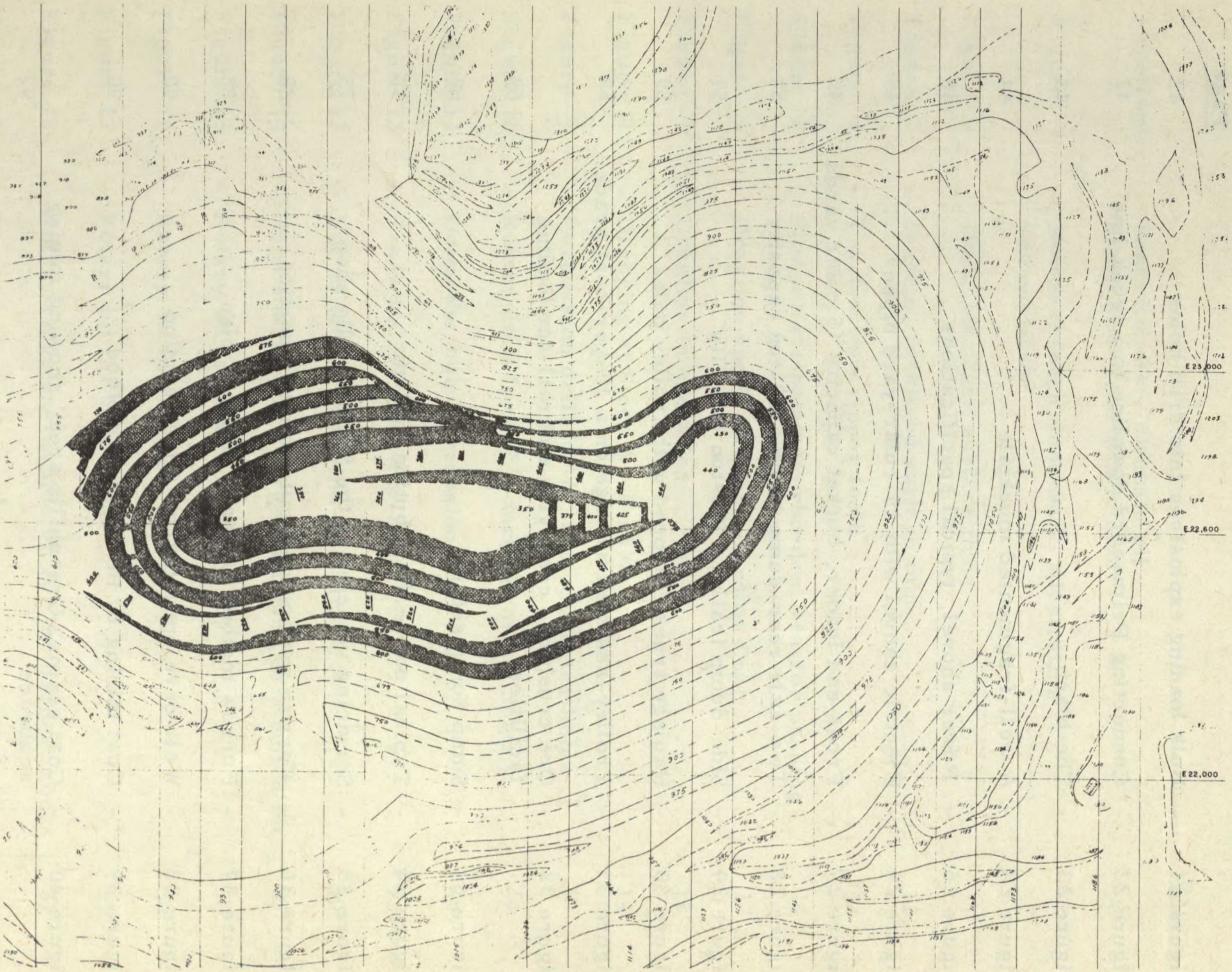
OPERATING COSTS

SURFACE COAL MINING

TABLES

FIGURES

Figures (Cont'd)



Frontispiece - South Roberts, ultimate pit, Steep Rock Iron Mines Ltd.

INTRODUCTION

For many years, Canadian mining has in the popular image been synonymous with underground mining, despite some outstanding surface operations in the Asbestos area of the Eastern Townships of Quebec, in the Sudbury area, and elsewhere. Except for industrial minerals, the amount of ore mined from underground workings exceeded that mined from surface mines until 1963 when an approximate balance was achieved. Since 1963, surface mining grew more rapidly than underground mining so that by 1970 approximately two thirds of Canadian ores were surface-mined. This trend commenced when the iron ore industry experienced a surge in growth in the 1960's and has been further accelerated by selection of surface mining for the large-scale non-ferrous developments of the 1960's. It is now apparent that further large-scale surface mining developments in the 1970's will occur owing to the approved projects in coal and non-ferrous metals which are underway. The importance of equipment and technique development in promoting surface mining must not be overlooked, nor must the effect of constantly rising labour costs in underground mines.

This paper presents information on operating practice that is readily available on most of the iron-ore, asbestos, non-ferrous metal, and coal surface mines in Canada. For purposes of clarity, information on surface mining of coal is presented at the end. In the main, facts gathered on visits to the mines are presented; in some instances, estimates were made from related data in attempts to offer a more comprehensive presentation.

While trying to compile information on a number of mines, the observer is impressed with the uniqueness of each and every operation. This uniqueness extends towards selection of equipment, methods of operating this equipment, and methods of compiling performance and cost records. Differences are to be expected because orebodies differ and present different operating conditions. However, the unit operations follow similar patterns, and, wherever possible, information is presented in a uniform manner. All numerical data presented should be considered as estimates for which the author is solely responsible. Data on selected surface mines, excluding coal, that were in operation in mid-1972 are shown in Table 2.

For more than eighty-five years, asbestos has been mined in the Eastern Townships of Quebec. Small-scale mining in the early days made use mostly of manual labour employed in small open cuts. Increases in the use of asbestos led to larger operations that used horses and, later steam engines as sources of power. From these primitive methods, advanced as they were for their day, modern surface mines have evolved.

TABLE 1 - CANADIAN SURFACE MINE SURVEY, 1972 - MINES SURVEYED

Mining Company	Mine Location	Reference Name	Material Mined	Nominal Mine Production, Ore, (000) Tons/Year
Iron and Associated Mineral Mines				
Caland Ore Company Ltd.	Atikokan, Ontario	Caland	hematite - goethite	2,640
Cliffs of Canada Ltd.	Temagami, Ontario	Sherman	magnetite	4,000
Pickands, Mather and Company	Bruce Lake, Ontario	Griffith	magnetite	4,730
Hilton Mines Ltd.	Bristol, Quebec	Hilton	magnetite	3,360
Iron Ore Company of Canada	Schefferville, Quebec	Schefferville	hematite - goethite	7,560
Iron Ore Company of Canada	Carol Lake, Labrador	Carol	hematite - magnetite	27,800
Dominion Foundries and Steel Ltd.	Kirkland Lake, Ontario	Adams	magnetite	4,680
Marmoraton Mining Co. Ltd.	Marmora, Ontario	Marmoraton	magnetite	1,250
National Steel Corporation of Canada	Capreol, Ontario	Moose Mountain	magnetite	1,800
Quebec Cartier MiningCompany	Gagnon, Quebec	Cartier	specular hematite	21,800
Quebec Iron and Titanium Corp.	Havre St. Pierre, Quebec	LacTio	ilmenite - hematite	2,680
Steep Rock Iron Mines Limited	Atikokan, Ontario	Steep Rock	hematite - goethite	2,460
Wabush Mines	Wabush, Labrador	Wabush	specular hematite	14,900
Westfrob Mines Ltd.	Moresby Is., B.C.	Westfrob	magnetite	2,050
Asbestos Mines				
Advocate Mines Ltd.	Baie Verte, Newfoundland	Advocate	chrysotile	2,850
Asbestos Corporation Limited				
British Canadian Mine	Black Lake, Quebec	B-C	chrysotile	5,200
King-Beaver Mine	Thetford Mines, Quebec	K-B	chrysotile	2,580
Normandie Mine	Black Lake, Quebec	Normandie	chrysotile	2,850
Canadian Johns-Manville Co. Ltd.	Asbestos, Quebec	Jeffrey	chrysotile	9,900
Johns-Manville Mining and Trading Ltd.	Timmins, Ontario	Reeves	chrysotile	1,300
Carey-Canadian Mines Ltd.	East Broughton, Quebec	Carey	chrysotile	1,800
Cassiar Asbestos Corporation Ltd.	Cassiar, B.C.	Cassiar	chrysotile	1,100
Cassiar Asbestos Corporation Ltd.	Clinton, Creek, Y.T.	Clinton	chrysotile	2,000
Lake Asbestos of Quebec Ltd.	Black Lake, Quebec	Lake	chrysotile	4,110
National Asbestos Mines	Thetford Mines, Quebec	National	chrysotile	1,030
Non-Ferrous Metal Mines				
Anvil Mining Corporation Ltd.	Faro, Y.T.	Anvil	zinc - lead	2,900
(1) Bethlehem Copper Corp. Ltd.	Ashcroft, B.C.	Bethlehem	copper	5,475
Brenda Mines Ltd.	Peachland, B.C.	Brenda	copper - molybdenum	8,500
(1) Brunswick Mining and Smelting	Bathurst, N.B.	Brunswick	zinc - lead - copper	1,100
Canada Tungsten Mining Corp. Ltd.	Tungsten, N.W.T.	Tungsten	Tungsten	180
Ecstall Mining Ltd.	Timmins, Ontario	Ecstall	zinc - copper - lead - silver	3,630
Gaspe Copper Mines Ltd.	Murdochville, Quebec	Gaspe	copper - silver - etc.	2,740
Gibraltar Mines Ltd.	McLeese Lake, B.C.	Gibraltar	copper - molybdenum	(2) 14,600
Granby Mining Company Ltd.	Grand Forks, B.C.	Phoenix	copper - gold	634
Granisle Copper Ltd.	Granisle, B.C.	Granisle	copper	2,280
International Nickel Co. of Canada Ltd., The	Copper Cliff, Ontario	Clarabelle	nickel - copper	1,370
International Nickel Co. of Canada Ltd., The	Thompson, Manitoba	Pipe Lake	nickel - copper	4,500
Lornex Mining Corp. Ltd.	Logan Lake, B.C.	Lornex	copper - molybdenum	13,700
Pine Point Mines, Ltd.	Pine Point, N.W.T.	Pine Point	zinc - lead	3,570
Placer Development Ltd.	Endako, B.C.	Endako	molybdenum	13,500
Similkameen Mining Company	Princeton, B.C.	Similkameen	copper	5,475
(1) Utah International	Coal Harbour, B.C.	Island Copper	copper - molybdenum	11,800

(1) Data obtained from published sources

(2) Exceeds design capacity

The amount of asbestos ore now mined in Canadian surface mines exceeds by a wide margin the amount mined underground. In 1972, only two asbestos mines were being worked by underground methods and twelve were being mined on surface. The total tonnage of asbestos ore from underground in 1970 was about two million against about thirty three million from surface. Although the asbestos industry has for many years been dominated by the mines of the Eastern Townships, the more recently opened mines at Cassiar, British Columbia, Clinton Creek, Yukon Territory, and Baie Verte, Newfoundland have become substantial producers of surface-mined asbestos.

Non-ferrous metal mining in Canada was formerly dominated by underground mining, but some surface mining was successful. Substantial quantities of nickel-copper ore were mined at the Frood and Stobie pits of the International Nickel Company of Canada, Limited, at Sudbury, Ontario. Lead-zinc ore was mined by surface methods at the Kimberley, British Columbia mine of Cominco Limited. The Copper Mountain mine of The Granby Mining Company was mined by surface methods in its final years. Lead-zinc ore was surface mined for a period at Barvue Mines, Barraute, Quebec.

The extensive experience acquired in the older non-ferrous surface mines has been successfully applied to newer deposits. In eastern Canada, the Clarabelle mine of the International Nickel Company of Canada Limited commenced production in 1962. Gaspé Copper Mines Limited at Murdochville, Quebec uses surface methods for a large part of its production. In western Canada, surface methods were in use for mining of uranium, copper, molybdenum, and zinc-lead ores. One of the early Highland Valley copper mines which was mined by surface methods was that of Bethlehem Copper Corporation Limited, near Ashcroft, British Columbia, which commenced production in 1962, and another was Craigmont which used surface methods for several years commencing in 1961. Since the early 1960's, there have been a number of large, prominent surface mines which have achieved production. Operations such as Endako, Granisle, Brenda, Gibraltar, Island Copper, Similkameen, and Lornex are well known. The latter company, Lornex, at 38,000 tons of ore daily is designed as the largest non-ferrous metal surface mine in Canada.

Notwithstanding the recent substantial surface mining developments in non-ferrous mining, the early impetus came from spectacular increases in surface mining of iron ore. Prior to 1923, only about 6.5 million tons of iron ore were mined in Canada. All production was later suspended until Algoma Ore Properties Limited, in the Michipocoten area of Ontario, resumed operations in 1939. In 1944 Steep Rock Iron Mines commenced surface mining of a direct shipping hematite near Atikokan, Ontario.

TABLE 2 - SELECTED CANADIAN SURFACE MINES, 1972 - MINE DESIGN FACTORS

Reference Name	Mine Dimensions (ft x ft)	Present Depth (ft)[1]	Ultimate Depth (ft)	Bench Height (ft)	Stripping Ratio (Waste/Ore)	Overall Wall Slope (degrees)
Iron and Associated Mineral Mines						
Caland	8,000 x 1,000	800	900	30	2. 20	45
Sherman	4 mines, various	n/a	n/a	40	0. 70	55 to 60
Griffiths	4,400 x 1,700	175	1,100	70	1. 10	53. 5
Hilton	98 acres	530	750	33	0. 13	53
Schefferville	6 mines, various	100 (av)	450 (av)	38	1. 35	45
Carol	300 & 350 acres	225 350	700 1,300	45 to 60	0. 17	38 f. w. 55 h. w.
Adams	3,000 x 1,500 (largest of several)	120	600	40	0. 84	58
Marmoraton	2,800 x 1,500	520	740	55	3. 20	45(w) 55(e)
Moose Mountain	1,000 x 1,200	200	380	45	0. 24	55 to 67
Cartier	5,000 x 2,400	500	900	40	0. 50	45(Sw) 48-53(Ne)
Lac Tio	2,800 x 1,500	140	n/a	35	0. 63	44 final 60
Steep Rock	3,500 x 1,700 (largest of three mines)	(1) 750 (2) 250 (3) 700	900 350 1,000	25	5. 00	37. 5 to 58
Wabush	3 mines, over 2 sq mi	250	700	40	0. 24	45
Westfrob	1,400 x 1,000	(1) 560 (2) 205 (3) 645	700 625 790	35	1. 19	52 65 52
Asbestos Mines						
Advocate	5,000 x 1,500	350	1,000	50	3. 31	45
B. C.	2,500 x 5,000	195	475	50	2. 20	45
K. B.	2,400 x 3,000	470	-	40 to 50	2. 84	45
Normandie	2,500 x 2,560	525	685	40	0. 60	45
Jeffrey	3,500 x 5,000	870	1,500	35	1. 15	29 - 45
Reeves	980 x 830	175	595	35	1. 23	48 & 54
Carey	1,500 x 3,000	350	700	45	2. 67	62
Cassiar	2,000 x 2,000	500	n/a	30	4. 85	43
Clinton	1,800 x 1,500	510	900	30 & 45	6. 00	44
Lake	4,000 x 3,500	630	1,230	40	1,05	40
National	2,400 x 1,500	180	585	45	1. 39	45

Non-Ferrous Metal Mines						
Anvil	2,400 x 1,400	510	900	35 & 40	5.50	45
Bethlehem	-	700 & 400	-	33	2.50	45 to 50
Brenda	2,600 x 2,000	450	900	50	1.00	45
Brunswick	1,500 x 1,100	220	-	36	2.00	-
Tungsten	800 x 400	300	300	65	1.33	-
Ecstall	2,600 x 1,600	420	760	40	2.30	53
Gaspe	2,600 x 2,000	n/a	1,790	40	1.47	45
Gibraltar	1,300 x 1,200	270	945	45	2.10	45 init. 63 final
Phoenix	63 acres	725	800	33	4.10	51
Granisle	2,000 x 1,300	265	1,070	35	1.10	45-50
Clarabelle	1,700 x 1,200	295	430	45	1.00	55
Pipe Lake	2,200 x 1,600	n/a	720	40	n/a	49
Lornex	3,500 x 2,500	300	900 - 1,400	50	2.08	20 - 45
Pine Point	-	125	n/a	25	1.35	45
Endako	5,800 x 1,400	460	1,000	33	0.25	45
Similkameen	3,500 x 2,500 (largest of three)	new	800	-	3.00 init. 2.00 final	45
Island Copper	-	new	800	40	2.00	-

During the 1950's iron ore mining activities in eastern Canada increased substantially. The existing mining operations at Michipocoten and Steep Rock were expanded. Quebec Iron and Titanium Corporation at Havre St. Pierre, Quebec, commenced surface mining of ilmenite ore. Substantial expansion in surface iron ore mining occurred in 1954 when the Iron Ore Company of Canada commenced shipments from Labrador-Quebec. This development was followed by increased production at Steep Rock Lake; at Marmora, Ontario; at Hilton Mines Limited, Bristol, Quebec; and Moose Mountain, near Capreol, Ontario. Developments in the Labrador-Ungava area of Quebec in the late fifties resulted in production in 1961 at the Quebec Cartier Mining Company property at Gagnon, Quebec. The sixties saw the achievement of large-scale production at the Carol Lake, Wabush, Adams, Griffiths and Sherman iron ore mines.

Accompanying market developments for iron ore, there has also been a trend towards greater use of beneficiated products for use in blast furnaces. The low-grade ores which are ideal feel for beneficiation plants cannot normally be mined economically by other than surface methods. Advances in equipment and techniques might eventually lead to utilization of surface methods for bulk mining a wider variety of ores, even possibly multi-vein systems which might normally be considered underground operations today. As wages continue to rise and as use of large surface mining equipment reduces costs to the point where higher stripping ratios are possible, extensions of the methods to new situations are likely.

Mining by surface methods encompasses many unit operations. From the operator's point of view, where drilling and blasting are required, it makes little difference whether ore or waste is being mined, unless there is an appreciable difference in their breaking characteristics. Removal of poorly consolidated overburden generally requires methods different than those used for rock and ore. Loading and hauling are other major operations that follow similar patterns at the various mines. This report will consider the planning, stripping, breaking, loading, haulage, ancillary operations, and operating costs in surface mining. The basic equipment, methods in use, performance, and cost estimates will be examined and discussed for each operation. Because technical terminology varies with mining districts, a glossary showing the usage in this report is given in Figure 1.

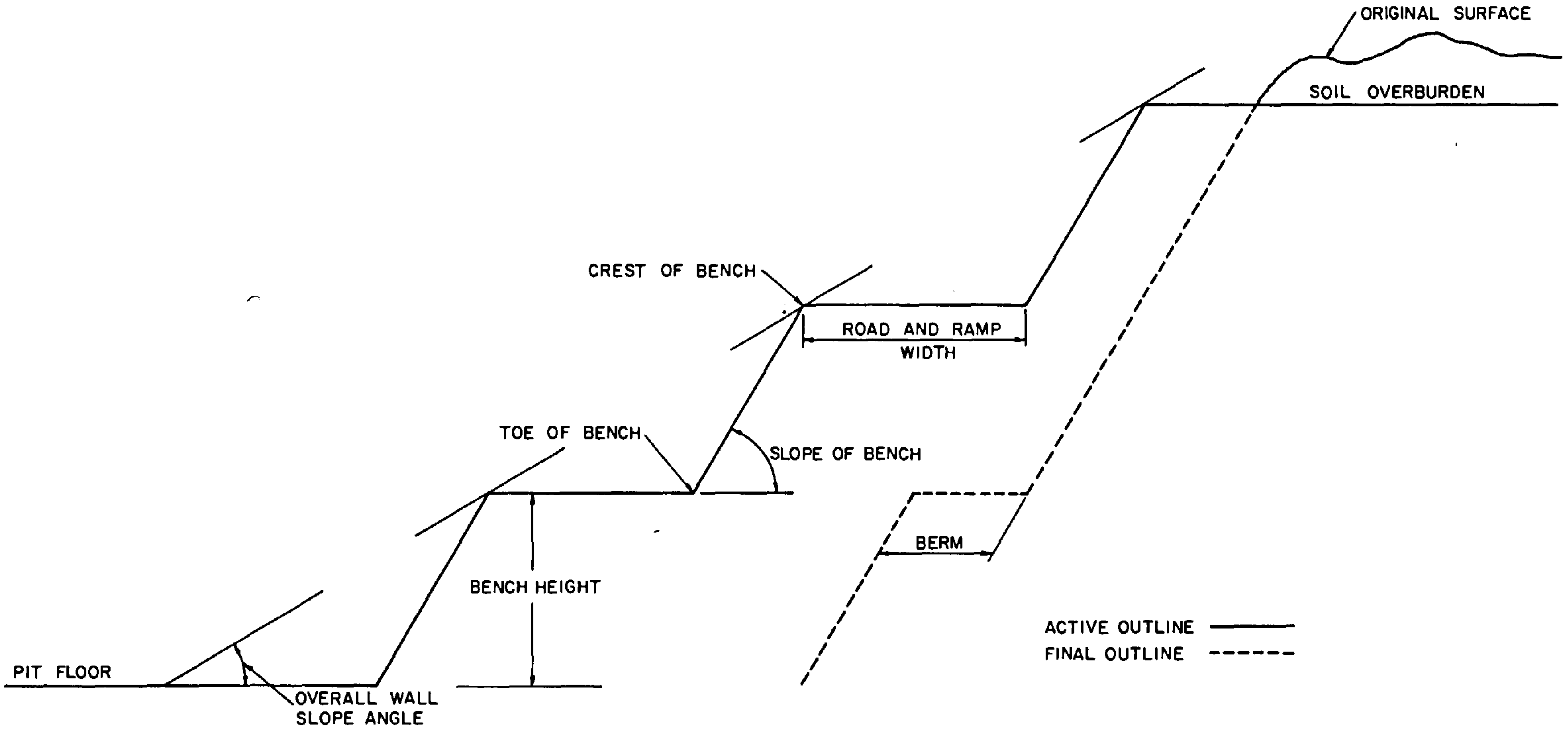


Figure 1. Sketch through mine wall, illustrating nomenclature.

PLANNING

Fundamental Concepts

Whether an orebody will be mined by surface or underground methods will be determined by the value of the ore. In all instances, the total capital and operating costs must be considered. A correct decision is extremely important inasmuch as contract commitments are made for product deliveries long before the mine is placed in production. Equipment for surface and underground mining is not interchangeable. Further, investment in equipment for either mining method and pre-production stripping expense for surface mining must be made long before any returns are received and before the method has been proven successful. Thorough engineering studies are therefore essential to help establish the most favourable mining method. In general, surface mining is found to be more economical when the orebody is large and the depth of overburden is not excessive.

Some predominant advantages are inherent in the surface mining method. First, it is flexible, allowing for large fluctuations in production schedules on short notice, without undue deterioration of the workings. Second, the method is safe. Loose material can be seen and removed or avoided, and crews can be readily observed at work by supervisors. The relatively small number of men employed contributes to safety because small crews are more easily trained in safe work practices. Third, selective mining is possible without difficulty. Grade control can be easily accomplished by leaving lean sections temporarily unmined, or by removing them as waste. Fourth, the total cost of surface mining per ton of ore recovered is usually only a fraction of the cost of underground mining. Further, the cost spread between the two methods is growing wider as larger-scale methods are applied to surface mines.

Layouts

Planning of the surface mine is a necessary concomitant to economic evaluation. One of the earliest considerations will be the quantity of waste stripping required. Sections will therefore be drawn at regular intervals approximately perpendicular to the strike of the orebody and the amount of stripping required for various mining depths will be calculated.

At this point, a preliminary decision would be required as to the wall slopes. The volume of stripping is seriously affected by the slope of the excavation walls, therefore careful appraisal of geological factors must be made to determine if there are natural planes of weakness in the ore and waste. Some useful information may be available from other mines in the same area. The amount of rainfall and its effect on the ore and waste may be an important consideration. Natural jointing and the dip must be carefully considered and may indeed be the governing factors. For example, if a formation is easily broken along the dip, and the dip is towards the central part of the mine as planned, the eventual slope of the mined wall will probably equal the dip of the formation, if the dip is equal to or steeper than the angle of repose of broken material. If the dip is vertical, or toward the edge of the excavation, the slope that can be maintained will be considerably steeper. Obviously, the steeper the slope that can be maintained with safety, the less the stripping cost will be. Slopes of the walls in several Canadian surface mines are shown in Table 2.

Closely allied with selection of walls slopes is the selection of bench height and of berm width. The bench height must be satisfactory for efficient operation of the drilling and loading equipment. It must also be a convenient height for the material being mined so that benches can be maintained with a minimum of scaling.

The scale of operations is another important consideration affecting mine layouts and bench heights. If ore reserves are large and adequate markets for the product are in sight, larger equipment may be selected and benches may be higher. On the other hand, equipment may already be owned and, unless it is obviously inadequate, the mine design may be modified to utilize the available equipment. Heights of benches at some operating Canadian mines are shown in Table 2.

Berms are normally left to catch any slough material that may come from the face and to provide travelways. When the mine is finally approaching the end of its life, some of the berms may be recovered. In Canadian surface mines, berms from twenty to thirty feet wide are in use. At some mines, owing to the effects of seepage and surface water on certain ores, berms gradually slough until they are almost indistinguishable.

When the scale of operations has been tentatively determined, more detailed study of the proposed excavation can be made. By plotting the benches at the correct wall slopes, the amount of material to be recovered at each "lift" of ore can be readily determined. Access roads and ramps to the various levels can be plotted on plans and then transferred to sections to assist in determining the extent of excavation required. The haulage method would have to be determined at this point so that location of access ramps and roads can be plotted accurately on the sections. Idealized sketches of plans and section of a typical surface mine are shown in Figures 2 and 3.

Workings can be planned far into the future and related economic studies can be made. Where there are varying values or assay walls, independent calculations would be made with varied parameters such as ore value and mining cost. A controlling factor is the predetermined profit requirement; then pit limits for various prices of product can be worked out. After careful analysis of all logically foreseeable conditions, the most desirable operating method will be indicated.

The number of calculations involved in planning alternative surface mine designs is extremely large. Fortunately, development of computers that can perform a large number of calculations in fractions of a second has considerably lightened the burden. Variables in mine design and operations to a number which cannot be satisfactorily handled by manual means can now be incorporated into a simulated mathematical model which a computer can handle. Practical experience in mine operation is necessary before selection of reasonable criteria can be made for incorporation into mathematical models. Some mining companies have used computer techniques only for totalling tonnages of ore and waste, thereby eliminating the most tedious calculations; others have used computer programs to develop optimization techniques.

Computer techniques have been applied on the widest scale in the production of iron ore. Optimization techniques have been applied to determine the economic depth of planned surface mines. Production schedules are computer controlled in another iron ore operation. Several mining companies have used computers to examine alternative haulage methods. In the newer western non-ferrous mines, computers are used mostly for calculating tonnages.

The general layout of the surface plant to service the mining operations falls within the planning phase of the operation. Location of ancillary facilities will have a direct effect on operating costs during the life of the mine, and therefore careful consideration of these factors is well warranted. What is apparently waste in a given year may become ore in the future. Some instances are known where old waste dumps had to be moved so that the ore underneath could be mined.

Full consideration must be given to uninterrupted power supply, waste disposal, drainage arrangements, and to the best location of crushing, milling, and transport facilities. Detailed discussion of these factors is beyond the scope of this paper; only those factors which are closely related to the mining phase will be considered.

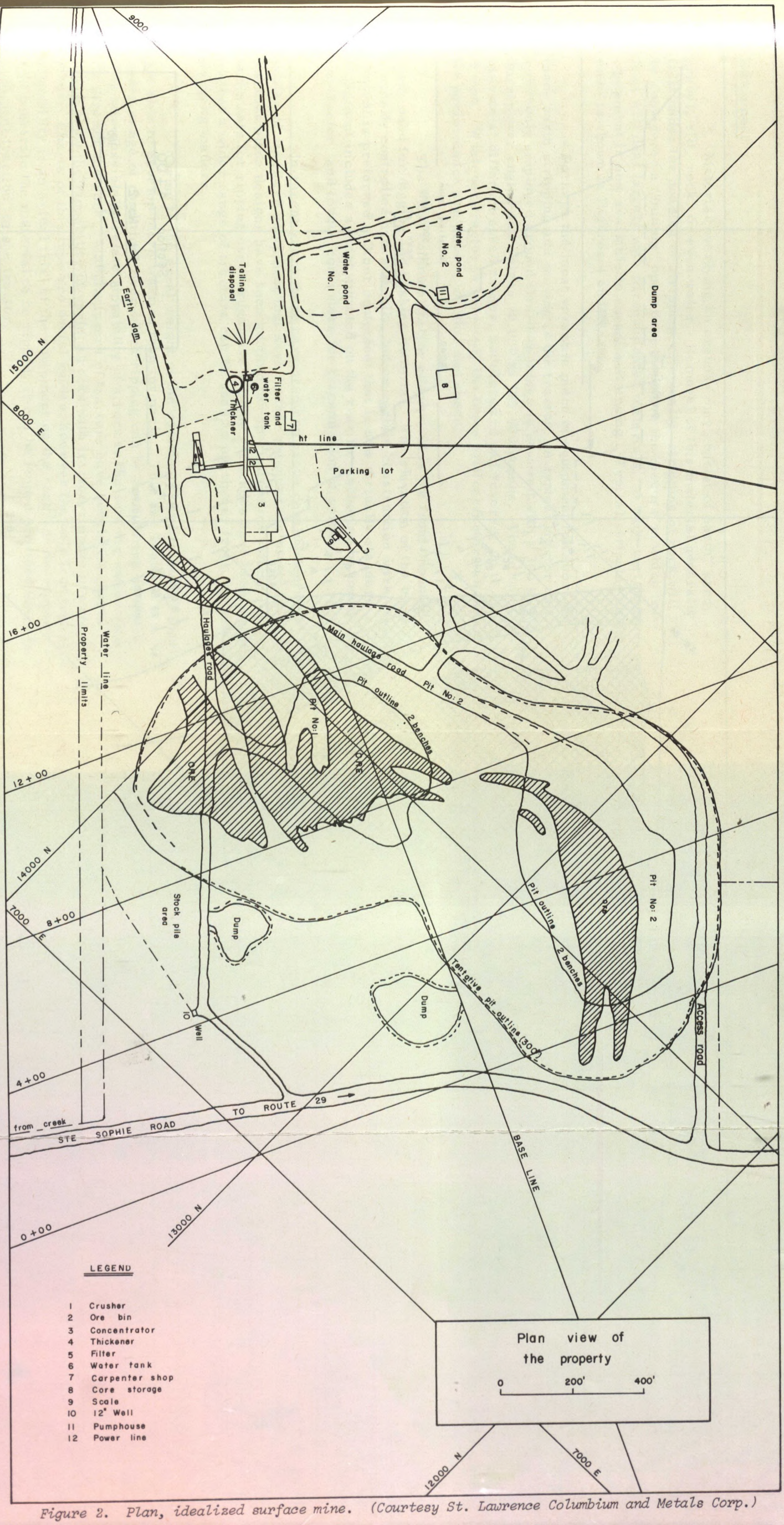


Figure 2. Plan, idealized surface mine. (Courtesy St. Lawrence Columbium and Metals Corp.)

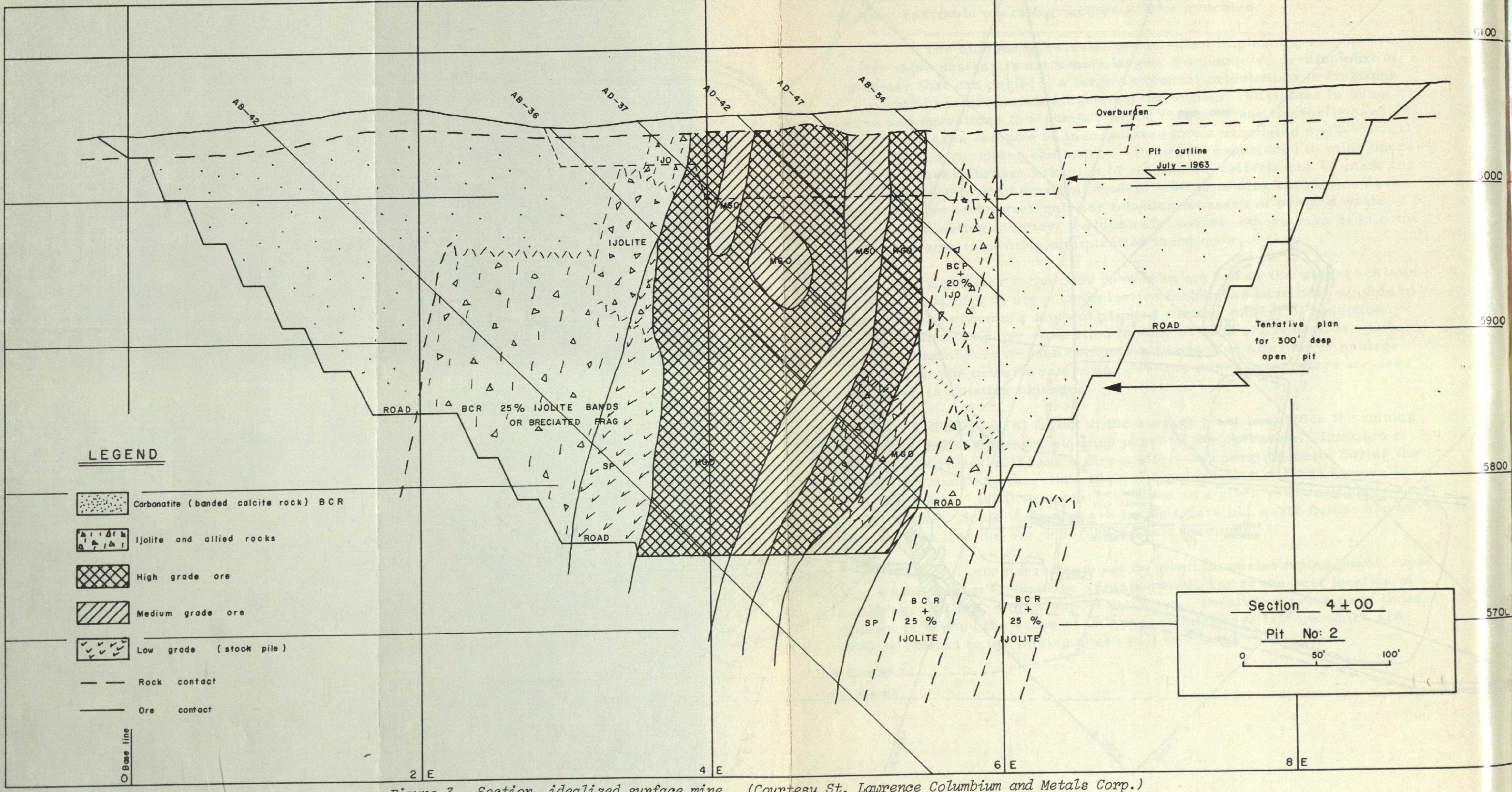


Figure 3. Section, idealized surface mine. (Courtesy St. Lawrence Columbium and Metals Corp.)

STRIPPING

Equipment

Material overlying an orebody may consist of earth, sand, gravel, silt, rock, or even water. Removal of this material generally falls under the heading of stripping. Normally, stripping of rock will be considered a "mining" operation; therefore the discussion which follows will deal largely with unconsolidated materials. A wide variety of equipment is now available to expedite stripping. Typical stripping equipment is shown in Figures 4 and 5.

Perhaps the most versatile piece of equipment for short distance earth stripping and moving is the tractor. A typical tractor unit commonly employed around Canadian mines is powered with a 300 to 400-horsepower engine and weighs 70,000 to 100,000 pounds. These units can operate at different speed ranges, both forward and reverse, up to about 8 mph. Whatever tractor is selected, the three critical factors affecting its performance are power, weight, and speed.

The most common tractor attachment is the front-mounted blade used for digging and pushing material. The elevation of the blade is normally controlled hydraulically, but on certain construction work, rope control is preferred. Other equipment that is now virtually standard equipment includes a hoist mounted on the rear for anchoring or towing the tractor, and torque converters for transmission of power.

In recent years there have been numerous developments in design of auxiliary equipment that have further extended the use of tractors. Various blade designs have been adopted for specialized operations. Attachments for ripping overburden have evolved. Buckets have been added so that a wider range of tractors can be used as overhead, front, or side-dumping loaders.

Owing to the great weight of the commonly used tractors, they are able to develop more traction than formerly. This has resulted in a wider range of conditions over which ripping can be used during stripping. It is now possible to relate rippability of a rock to the seismic wave velocity through the rock. Manufacturers of tractors have developed charts which show the rippability of various rocks with tractor-rippers of various sizes. Charts of this type are useful guides; however the only true test of rippability is an actual trial of the equipment on the rock. If the ripper will penetrate the material to be ripped, it can be ripped provided there is sufficient traction for the tractor.

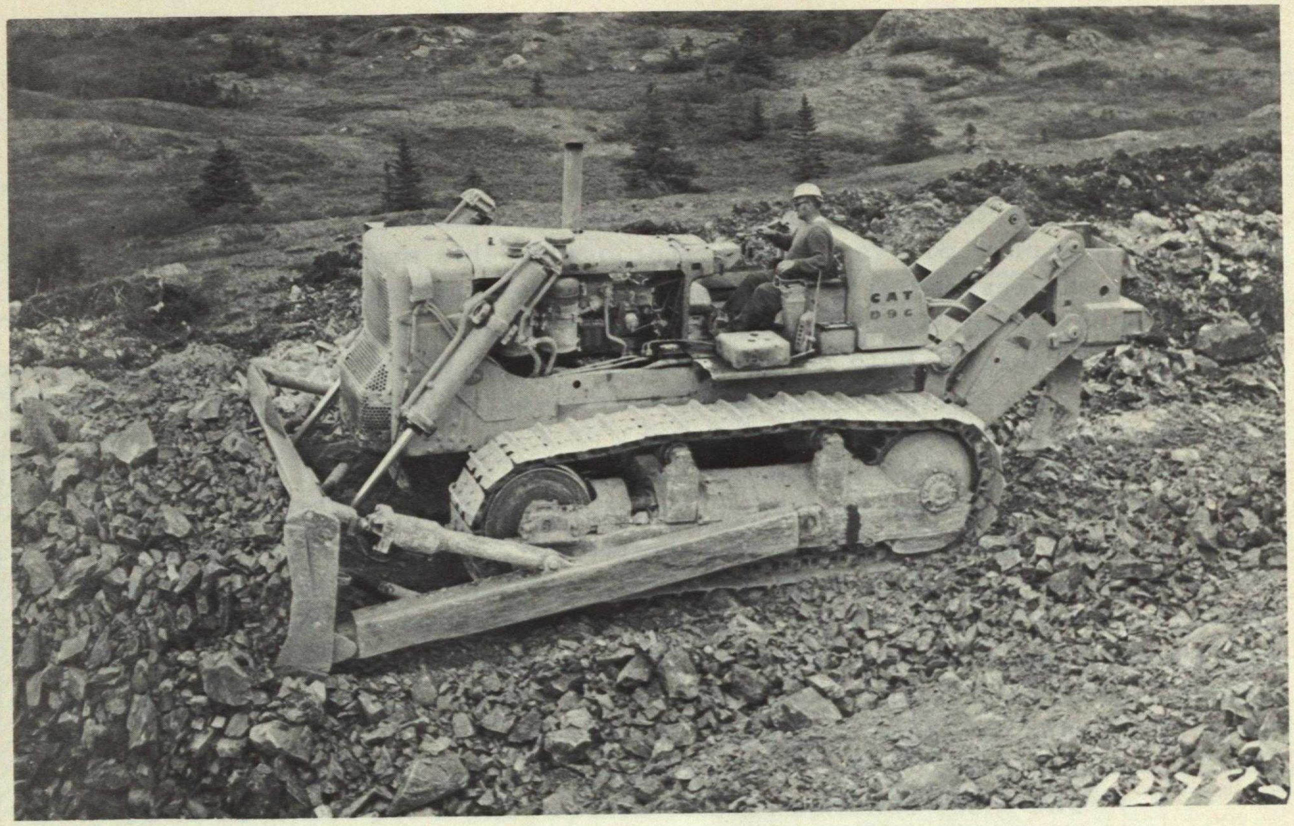


Figure 4. Tractor with ripper tooth. (Courtesy Crothers)

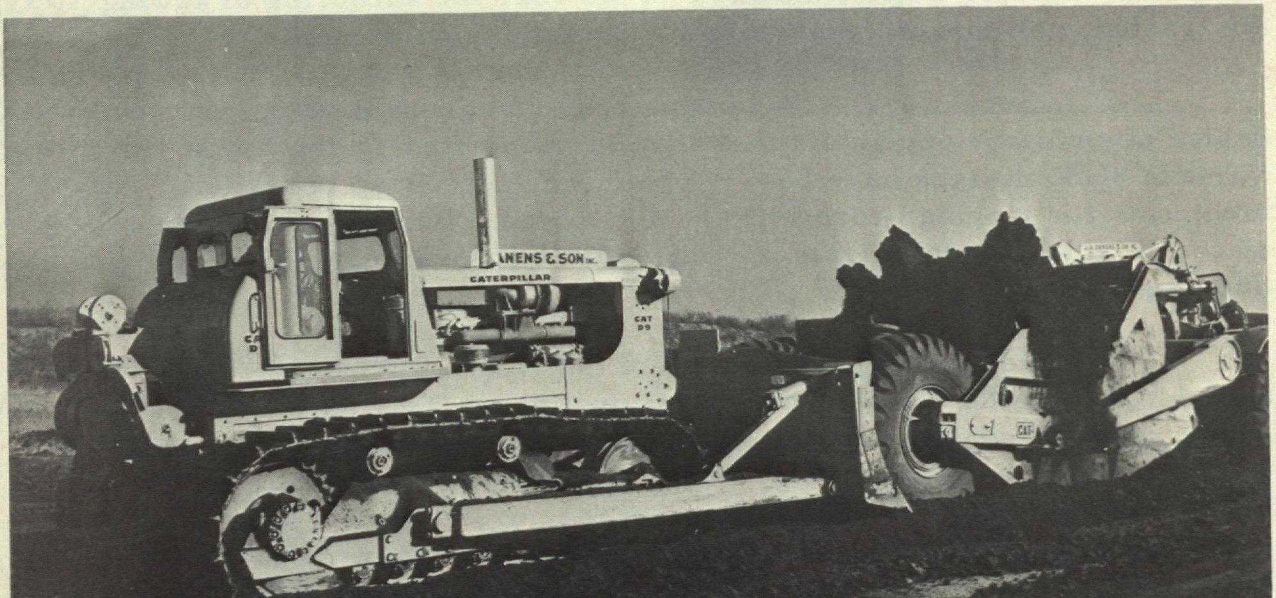


Figure 5. Scraper stripping overburden, tractor pushing. (Courtesy Crothers)

At some sacrifice of traction, tractors have been designed on rubber wheels, thus eliminating the major disadvantage of low speed encountered in track-type tractors. Wheeled tractors have made large inroads into the fields where tractors formerly served as loaders and where speed of travel from one brief task to another was important. Where the work is heavy, such as bulldozing of coarse rock or clearing of large trees before stripping, the track mounted vehicle has no peer.

The scraper is less versatile than the tractor but is often used on similar operations. In essence, this unit is either a self-powered or towed vehicle that digs into loose or semi-consolidated material and transports the load to a disposal area. Large numbers of these units are used by roadbuilding contractors and those engaged in earth excavation at shallow depth over a large area. The equipment is expensive and specialized and consequently, not generally owned by mining companies. In one Canadian mining operation, now closed, scrapers were used for mining loose gravels for their hematite content. As an indication of the low costs at which the mining operation was conducted, it might be noted that the iron ore content of the loose gravels was about 10 per cent.

Power for operation of scrapers can be provided by self-contained units or by tractors that tow the vehicles. In difficult digging conditions, an extra tractor may be used for pushing the scraper. Experienced operators plan the excavation so that the scraper travels downhill during the digging cycle, thereby working to most advantage. Speed during the transport cycle has received attention, so many scrapers are mounted on wheels and powered to travel at high speeds to disposal areas.

A method of stripping unconsolidated overburden was adopted at a major eastern Canadian asbestos mine. By the method, tractors were used to push overburden to an electrically powered belt loader, which in turn loaded 45-ton-capacity off-highway trucks. The tractors employed on this operation were D 8 s and the belt loader was fitted with a 72-inch belt which could load the trucks in ninety seconds. Scheduled production on the operation was ten thousand tons daily, which was successfully moved at an operating cost of twenty cents a cubic yard against a former fifty-five cents a cubic yard by an earthmoving contractor.

The dragline is often associated with stripping operations. The tractor unit of a dragline is similar to that used in power shovels, but the familiar dipper and stick are replaced by a long boom and a freely-suspended "bucket". This modification allows the dragline to reach much farther than a power shovel and to cast the excavated material farther. All bucket movements are controlled by wire ropes connected to appropriate hoists within the cab. A dragline normally digs below the level of the tractor unit, so that the bucket fills as it is dragged uphill towards the operator. The dragline finds its widest use where the material to be moved is relatively loose and where long reach can be used to advantage. Many draglines are used for excavation of muskeg or soils on construction projects, for excavation under water, for transfer of relatively loose materials from stockpiles at mining operations, and for stripping of overburden. The largest draglines in use in Canada are used for stripping waste overlying coal deposits. Most of the rock in the large Canadian coal mines is drilled and blasted before stripping with draglines. Specifications of a large dragline at Fording Coal is shown in Figure 6, and a similar dragline in operation is shown in Figure 7.

Suction and cutter dredges have also been used for overburden removal in Canada. Design, assembly, and operation of large dredging equipment is a highly specialized job. Detailed description of the equipment is beyond the scope of this paper, but procedures employed at the major Canadian dredging projects are described under the next heading in this report. A large-scale dredging project is shown in Figure 8.

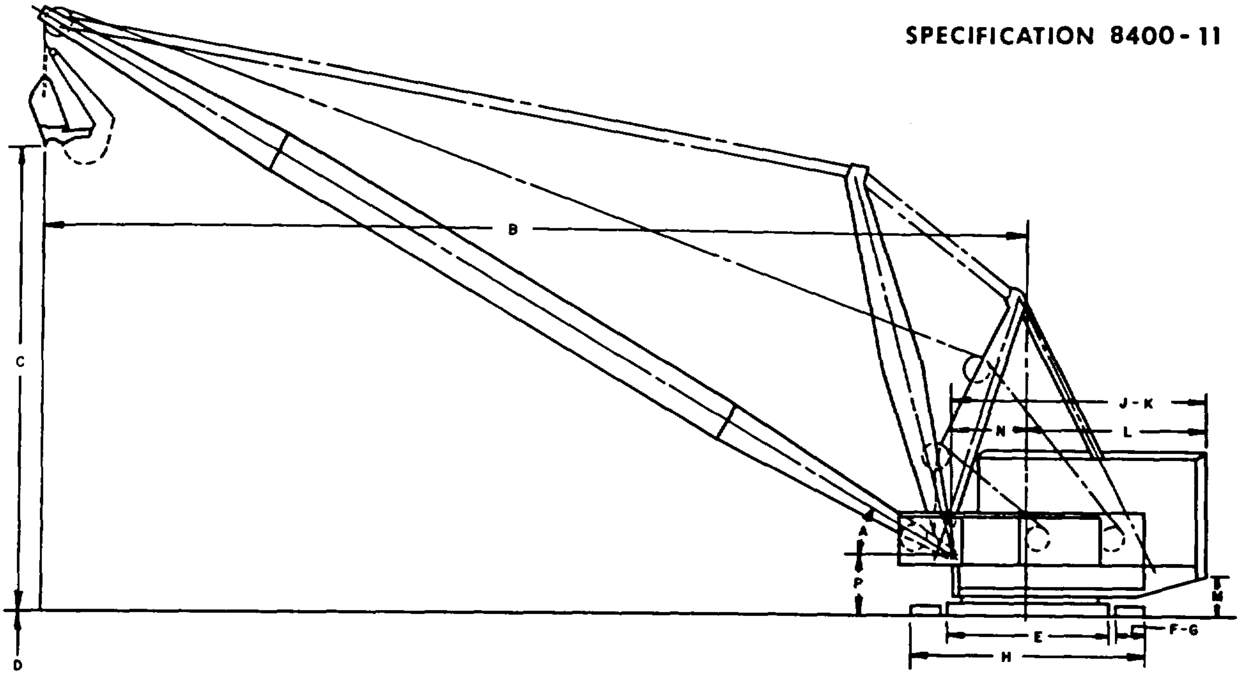
Among other machines used for stripping in mines in other countries are the Kolbe wheel excavator and hydraulic monitors. The first application of the Kolbe wheel to regular stripping (and mining) in Canada is in the Athabasca tar sands. After some years of operation, full-scale operation has been successfully achieved in a wheel-conveyor operation. This equipment has not been used in the mines surveyed in the report, so it will not be discussed further. Monitors have been used to some extent for stripping of overburden over asbestos and iron ore deposits. They have also been used in conjunction with early dredging at Steep Rock Lake. Use of monitors at Canadian surface mines cannot be considered a typical practice or serious rival to other stripping methods.

Power shovels are also in general use for stripping, either for direct digging of overburden or in conjunction with gathering equipment. Their use is almost mandatory where the material to be stripped is rock that must be drilled and blasted then hauled away in trucks. Inasmuch as power shovels are basic units more generally applicable to the whole mining operation, they will be more fully discussed in connection with loading.

Procedures

Removal of overburden generally takes place concurrently with construction of the surface plant, after a decision to mine by surface methods has been reached. Analysis of the conditions up to this point would have indicated which method of overburden removal would be most desirable. Some of the methods employed at Canadian mines will illustrate the usual Canadian preference.

SPECIFICATION 8400-11



WORKING RANGES

Boom Length	305'-0"
A - Boom Angle, Approx.	30-1/2°
B - Dumping Radius	290'-0"
C - Dumping Height	120'-0"
D - Depth	200'-0"
Maximum Allowable Load, lbs.	330,000
Hoist Drum, Pitch Dia.	126"
Hoist Ropes, Twin, Dia.	3-1/4"
Hoist Speed, Single Hitch, fpm	636
Drag Drum, Pitch Dia.	126"
Drag Rope, Twin, Single Hitch, Dia.	3-1/4"

BASE

E - Outside Diameter - Nominal	65'-0"	57'-0"
Bearing Area - Effective, sq.ft.	3320	2552
Rail Circle - Mean Dia.	48'-0"	48'-0"
Circle Rollers - Mean Dia.	12"	12"
Main Swing Gear - Pitch Dia. Approx.	39'-9"	39'-9"

WALKING TRACTION

F - Width of Shoe	12'-0"	11'-0"
G - Length of Shoe	55'-2"	55'-2"
H - Width Over Both Shoes	92'-0"	82'-6"
Bearing Area of Both Shoes, sq.ft.	1320	1210
Length of Step - Approx.	7'-3"	7'-3"
Walking Speed - Approx., mph	0.12	0.12

ROTATING FRAME

J - Width @ Rear End	66'-6"
K - Length	90'-0"
Depth Sill Members	130"
L - Clearance Radius - Rear End	66'-0"
M - Clearance Under Frame	13'-0"
N - Center Rotation to Boom Foot	23'-3"
P - Ground to Boom Foot	19'-2"

ELECTRICAL EQUIPMENT

Hoist Motors, Four, 1250 hp each @ 460 V, Total hp	5000
Drag Motors, Four, 1250 hp each @ 460 V, Total hp	5000
Swing Motors, Four, 750 hp each @ 460 V, Total hp	3000
Propel Motors, Four, 500 hp each @ 460 V, Total hp	2000
*AC Driving Motors, Total hp	7200

*Includes 200 hp Induction Motor for Exciter Set.

WEIGHTS

Domestic Shipping Weight (Inc. Bucket), lbs.	6,420,000
Working Weight, lbs.	7,120,000
Ballast (Furnished by Purchaser), lbs.	700,000

Add for 65'-0" Tub - 230,000 lbs.

Shipping Weight Subject to (± 5%) Variation.

Figure 6. Dragline specifications, Fording Coal. (Courtesy Marion Power Shovel Company)

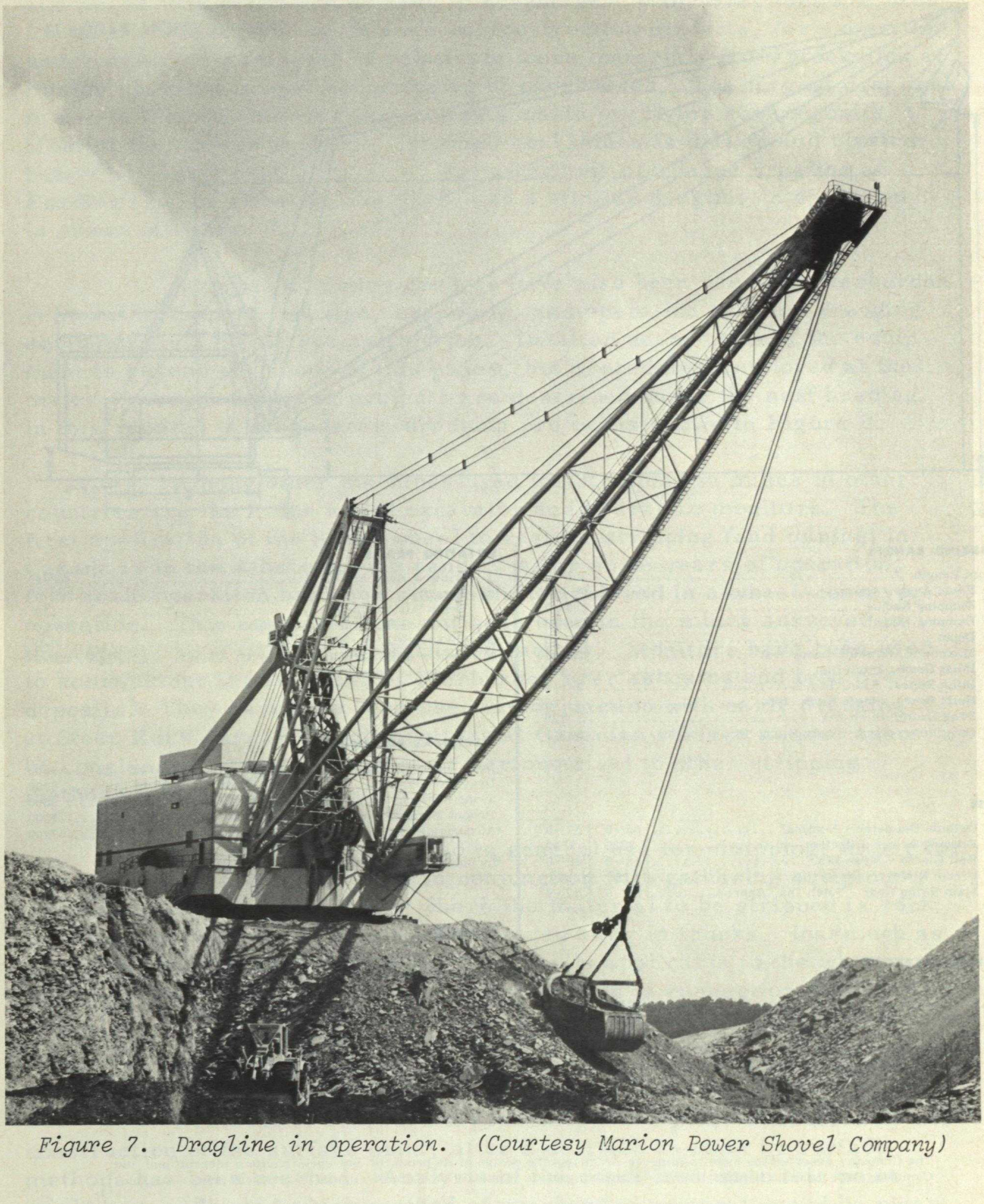


Figure 7. Dragline in operation. (Courtesy Marion Power Shovel Company)

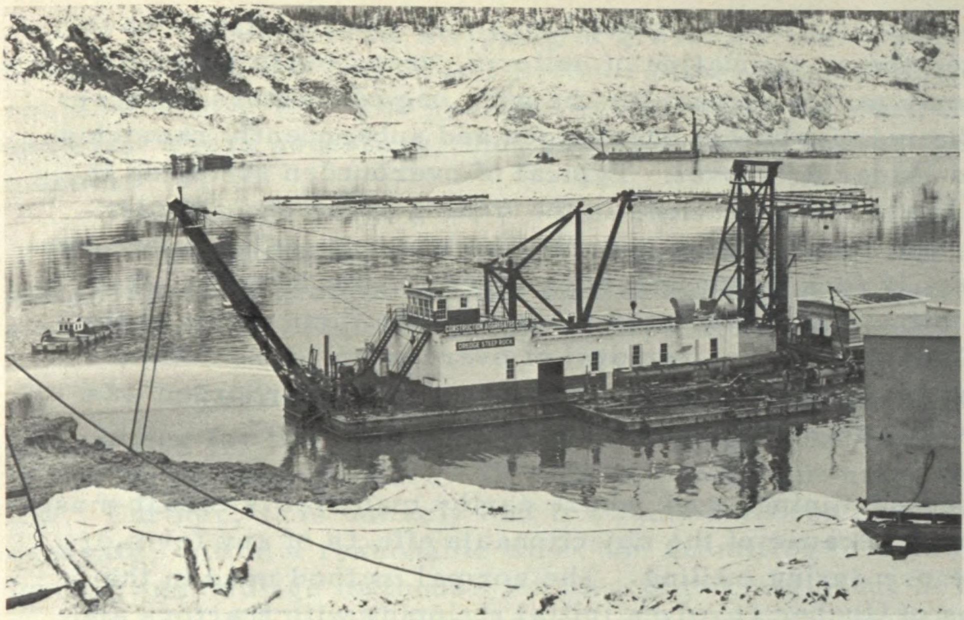


Figure 8. Dredging at Steep Rock Lake. (Courtesy N.F.B.)

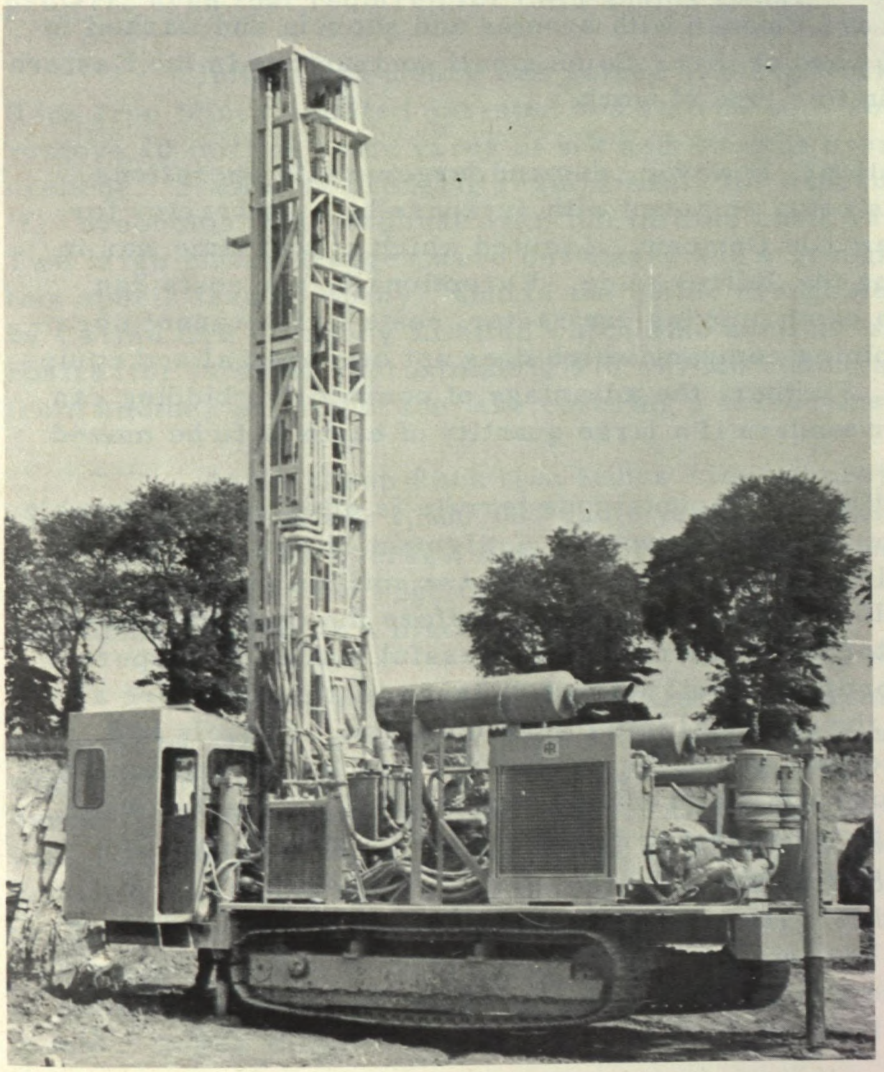


Figure 9. Percussion drill for 6½-inch-diam. holes. (Courtesy Canadian Ingersoll Rand Company)

In the Canadian Shield, glaciation and northern climate have generally prevented the accumulation of uniform, deep, earth cover over the rocks. This may partly account for the wide use of tractors in these areas for piling the relatively thin overburden and subsequently removing it with a front-end loader or shovel. Typical of overburden stripping in the Canadian Shield are the operations in the mining areas of Labrador-Quebec where the thin dirt covering over the ore presents only minor problems. In this area, if rock waste underlies detritus, the latter is often thin enough to be initially ignored but is taken with the first cut in waste. In other eastern Canadian mines, removal of overburden presented no particular problems. At one mine, the thin covering of overburden was readily stripped with a front-end loader and truck.

In asbestos mining, even where earthy material is thin it must be carefully removed because of the objectionable effects of any form of wood or dirt in the ore during milling. The normal method used in the Eastern Townships of Quebec involves initial stripping with tractors and shovels or front end loaders; some use has been made of draglines. After the mechanical equipment has removed as much overburden as possible, the areas over the ore are cleaned with brooms and shovels and washed to remove every trace of wood or dirt. Some small contractors in the Eastern Townships specialize in this type of work.

Some situations, however, demand larger-scale operations. In 1961, soil cover was being removed with scrapers by a contractor for the Canadian Johns-Manville Company, Limited which at that time was in the process of extending the Jeffrey mine. Exceptionally low costs can often be achieved by an earth-moving contractor; costs which cannot normally be matched by a mining company which does not own specialized equipment for this purpose. Further, the advantage of competitive bidding can be gained by calling for tenders if a large quantity of earth is to be moved.

In the Cordilleran, mountainous terrain is often of considerable aid to overburden stripping. For example, Craigmont Mines Limited in British Columbia required the removal of about two million cubic yards of soil, and about 1.5 million cubic yards of rock before the orebody was uncovered. The contractor who tendered the successful bid used scrapers for digging and transporting the soil a short distance to a dump where a tractor merely pushed the material into the valley below. Shovels and trucks were used in sections where the overburden was loaded conventionally. Later, a conveyor loaded dirt into haulage trucks. A tractor was used to push the earth to the conveyor loader, thereby releasing a $2\frac{1}{2}$-cubic-yard shovel for other duty.

Considerable stripping of gravel and waste rock was required before the iron ore deposits of Brynnor Mines Limited at Kennedy Lake could be uncovered. The procedure followed by the contractor was to drill and blast where necessary, then shovel-load and haul in the conventional manner.

Also in the Cordilleran, a contractor successfully used rippers and scrapers to remove 400,000 tons of loose rock and soil at $28\frac{1}{2}$ cents a cubic yard for Bethlehem Copper Corporation Limited.

Outstanding success has been achieved on overburden removal by dredging for two mining companies at Steep Rock Lake, Ontario, and one at Black Lake, Quebec. In each instance, unit costs were extremely low. Further, it is unlikely that it would have been physically possible to excavate, within a reasonable time, the quantities involved by conventional loading and haulage methods. An idea of the magnitude of these projects may be gained from the total volume of overburden moved on the three projects - about 317 million cubic yards, exceeding every other dredging project, even that required for the Panama Canal.

Initial experience was gained at Steep Rock Lake when Steep Rock Iron Mines Limited operated two sixteen-inch suction dredges to remove 20 million cubic yards of silt and detritus overlying the Errington orebody. Studies of dredging requirements for exposure of the Hogarth and "G" orebodies indicated that over 100 million cubic yards required removal. Two large cutter dredges were purchased and a dredging contract was let to a specialized company. One of the cutter dredges was later purchased by Caland Ore Company Limited which also used the services of the same contractor to move approximately 170 million cubic yards of silt and clay from another portion of the lake covering a leased orebody.

At the Steep Rock Iron Mines Limited project, the rate of dredging was approximately 1,500,000 cubic yards per month. Dredged material was transported an average distance of about 3,200 feet through 28-inch discharge lines to the edge of the lake and through 30-inch lines in a 1,450-foot tunnel leading to a discharge area.

In the Eastern Township of Quebec an achievement in overburden removal by dredging was the project of Lake Asbestos of Quebec, Limited, where 30 million cubic yards of solids were removed by suction dredge concurrently with draining of Black Lake. A 30-inch suction dredge provided with pumps capable of handling 34,000 to 45,000 gallons per minute and powered, including booster pump, with 14,500 horsepower, moved the dredged material to four disposal areas, the largest being four miles away. At a sludge density of 17 per cent solids, the average rate of sludge removal when the dredge was working to capacity was one million cubic yards a month. Solids removal and lowering of the lake level by about two hundred feet took place during the dreding period which extended from June, 1955, to October, 1959. Mining commenced on one section of the orebody in 1958 after the lake level had been lowered sufficiently to expose this portion.

From the foregoing it will be noted that no hard and fast rule is followed for removal of overburden. Every situation is judged on its merits and the available equipment, or modifications thereof, are applied to best advantage to achieve the desirable result. The relatively thin overburden in the Canadian Shield and steep topography in many areas of the Cordilleran often aid stripping operations by making waste disposal a lesser problem than it might otherwise be. On the other hand, there is the difficulty caused by densely forested surfaces such as may occur in the Cordilleran.

BREAKING

Drilling Equipment

Drilling is a basic part of the breaking operation in surface mining; considerable effort has therefore been expended to develop equipment for drilling holes at the lowest possible cost. There are several types of drills which can be used, such as churn drills, percussion drills, rotary drills, and jet-piercing drills. All are designed with one objective in mind; to produce a hole of required diameter, depth, and direction in rock for later insertion of explosives.

The fundamental problem in drill design is to provide a cutting tool to work on the rock and adequate power to drive it. All other considerations are related to improving the efficiency of the application of power to the suitable cutting tool. The resulting power as used in the drill may be by rotation, thrust or impact, or some combination of these. The source of power may be electrical, compressed air, or fuel. The cutting tool itself must be designed to chip the rock when the power is applied. The chips of rocks must be removed by flushing, and suitable connections between the cutting tool and driving power must be maintained; hence the elaborate structures such as masts and the high quality of equipment such as drill rods, cables, or other connecting linkage. Two common types of drills are illustrated in Figures 9 and 10.

The earliest types of drills still in use for some applications are churn drills, A churn drill has a heavy solid metal cylinder with one end forged and hardened to provide a cutting surface; the upper end of the cylinder is fitted with an adaptor for connecting a rope or cable. Power is supplied by an engine that activates an arm or crank. linked to the rope, thus alternately raising and dropping the cutting tool in the hole. This constant pounding of the tool upon the rock in the hole bottom chips the rock.

Water maintained in the hole mixes with the chips and dust to form a sludge which is baled out. Although churn drills are disappearing from the scene, they are still useful for production of holes four to twelve inches in diameter, where the rock to be drilled is severely broken or when low hourly operating cost is essential. As far as is known, no Canadian company mining by surface methods is using churn drills for production drilling. Some companies are known to be using this method for drilling wells as part of a water control program.

The wagon drill evolved from the earliest designs of air-operated percussion drills. The wagon drill unit usually consists of a wheel-mounted tubular frame supporting a mast that serves as a travelway for the drill proper. The drill proper is usually advanced and retracted by a chain feed. Steel rods inserted into the chuck of the power conversion unit provide the connection between the driving parts and the cutting tool. Power is usually provided by compressed air supplied from mobile compressors. While the rotation mechanism turns the drill, a piston strikes rapid blows on the drill steel within the drill chuck. These blows are transmitted through the assembled "string" of drill rods to the cutting bit in the bottom of the hole. The rock chips are flushed out by air or water sent through the hollow centre of the drill steel. In surface mines, air flushing is most commonly used. When the bit has travelled the limit allowed by the length of drill steel, extensions are added and the drilling process continues until the required depth is reached.

The basic wagon drill is undergoing constant modification and improvement. Larger drills are being mounted on stronger frames. Units are being mounted on tracks for easier travel over rough terrain. Higher masts are being built to allow longer steel rods to be used so that deeper holes can be drilled before extension rods are added. The more powerful wagon-type drills can drive bits up to about four inches diameter, thereby increasing the drills usefulness. Improvements are being made to allow for more accurate control of pressures, rotation and bit extraction. These improvements have not detracted from the wagon drills usefulness for pioneering work in established mines and at times for secondary drilling.

The self-propelled percussion drills designed to drill large diameter holes are a further development from the wagon drill. The standard parts of percussion drills such as power units, masts, rods and bits are of necessity scaled up for large-diameter holes. Mobility for the resulting heavy equipment is usually provided by a tractor that carries the essential equipment. Hydraulic power is provided for levelling the tractor on rough terrain, and power is provided for handling the heavy drill rods. Power to operate the equipment may be provided by diesel air compressors mounted directly on the tractor or by an external source of electricity; the latter is preferred when available. Cuttings are usually flushed out by compressed air, but collecting systems are normally used to gather them owing to their volume. The earliest percussion drills transmitted the energy through the string of drill rods connected directly to the bit.

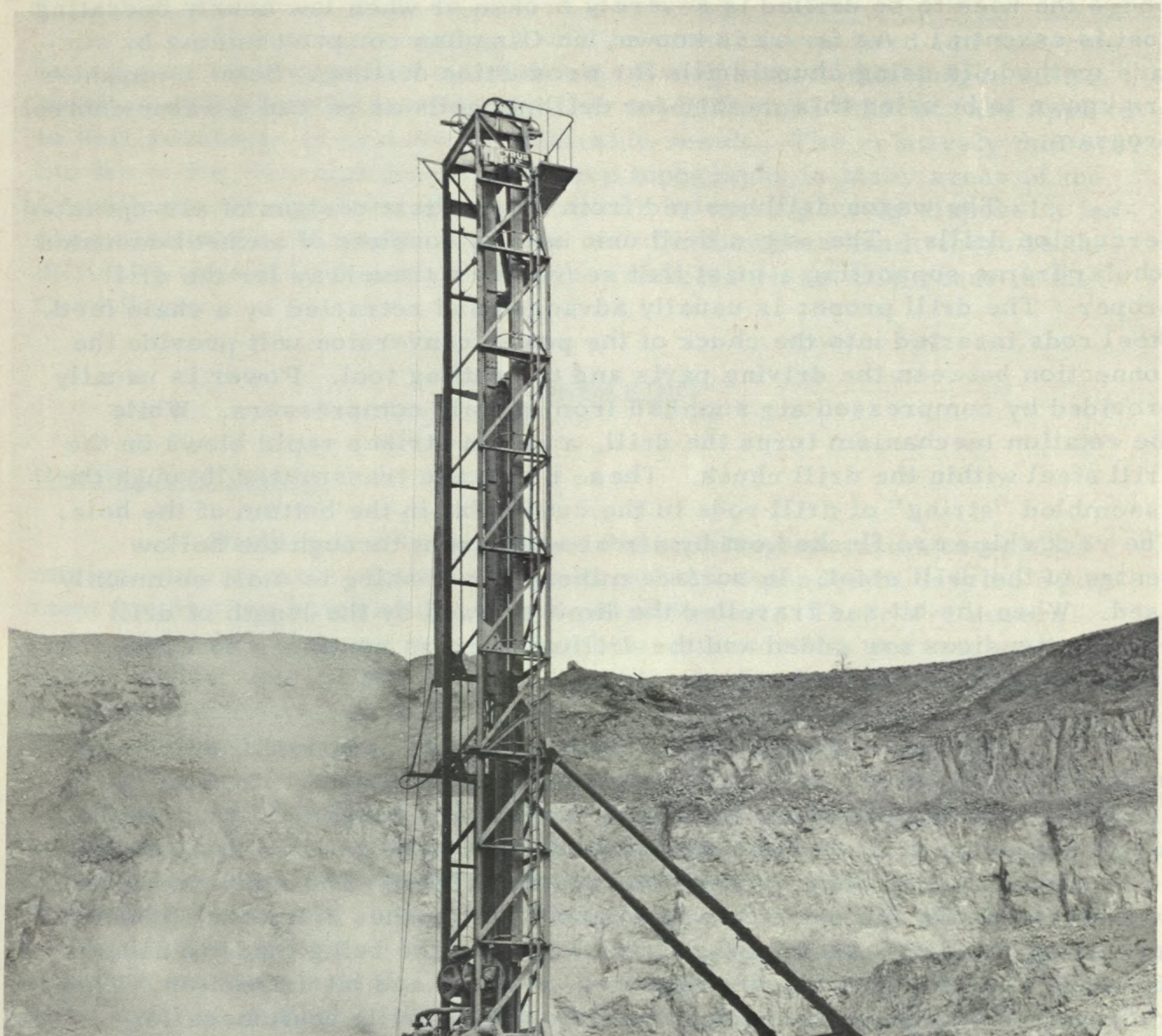


Figure 10. Rotary drill for 9 7/8-inch-diam. holes. (Courtesy Bucyrus Erie Company)

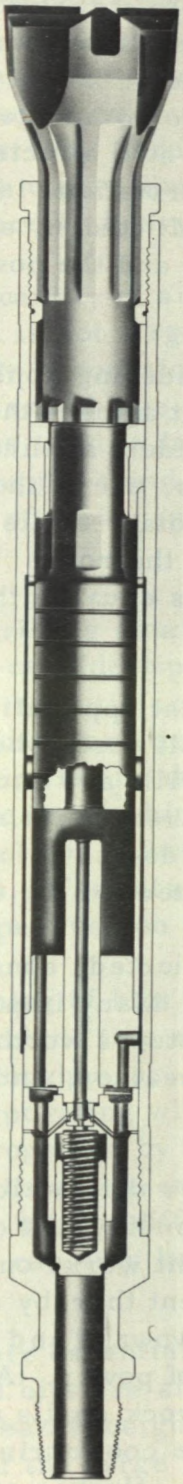


Figure 11.
Down-the-hole
percussion drill.
(Courtesy
Canadian Ingersoll
Rand Company)

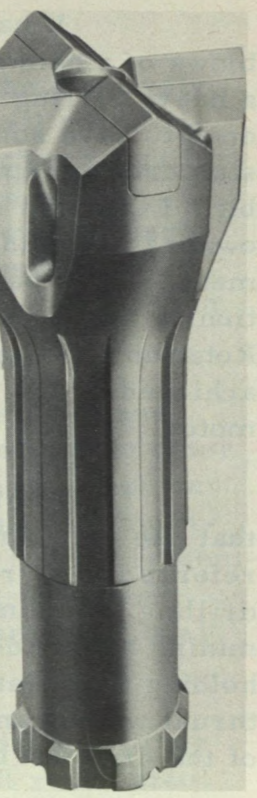


Figure 12.
Cross bit for
down-the-hole
drill.
(Courtesy
Canadian Ingersoll
Rand Company)

Figure 13.
Button bit for
down-the-hole
drill.
(Courtesy
Canadian Ingersoll
Rand Company)

It has long been known that considerable energy is lost when blows of a hammer within a drill are transmitted to the cutting tool through a heavy "string" of steel rods. The "down-the-hole" drill has been developed to save some of this energy; it is similar to a normal large percussion drill except that the striking hammer is positional directly behind the bit. Figure 11 shows the arrangement in the hole. Many percussion drill owners have since converted their drills to take advantage of this development. In its basic concept, a percussion ddill still affects tool penetration by application of power as represented by rotation, impact, and thrust. Rotation and impact are provided for in the drill design, and thrust is achieved by the weight of equipment in the hole and the power of the feed motor.

There is, however, a constantly widening application for drills that use only thrust and rotation to force the bit against the rock. Generally referred to as rotary drills, they have their widest application for oil-well drilling in sedimentary rocks. In recent years, use of these drills in mining has made rapid strides. In essence, rotary drills provide for holding the rotating cutting tool in contact with the rock. The maximum thrust which can be applied in rotary drilling is equal to the total weight of the drill itself.

Percussion drills find their broadest application in extremely hard rock, inasmuch as they show the lowest bit costs where conditions are difficult. Where rocks are soft, rotary drills are usually chosen. Between these two extremes there is a broad area where either type of drill could be used. Where the selection is in doubt, actual drill tests will determine which type of drill is better suited for the application.

Regardless what type of drill is selected, constant improvements and modifications to it can be expected. Many improvements are related to use under Canadian conditions. Features worth noting are greater mobility, higher alloy parts for cold weather, and control of all operations from within a comfortable cab.

The jet-piercing drill is yet another drill which has made its Canadian appearance for large-scale surface mining and could find wider applications in the future. The jet-piercing unit works on the principle of heat application to rocks of high silica content thereby causing spalling. The cutting tool is a tube with jets pointing downward and around its lower perimeter. A fuel-air mixture is the source of power. As the mixture burns in the bottom of the hole, the siliceous rock spalls and sometimes melts into drops of slag. Water keeps the tube cool during drilling and, after turning to steam in the bottom of the hole, flushes out the spalled material. Because the jet-piercing process achieves its effect chiefly by thermal rather than mechanical effects, its uses only a small number of moving parts. The simplicity of the process requires only a light superstructure to handle the fuel and water.

The hole produced by jet-piercing differs from the relatively smooth and uniform holes produced by other drills. Within all rock formations there are bands or beds of varying composition which react differently to heat and have different spalling rates. A jet-pierced hole is, therefore, not of uniform diameter; this is no disadvantage with modern bulk-loaded explosives. Indeed, the phenomenon can often be turned to good advantage; by controlling the drill, enlargements can be produced in hole bottoms to receive heavy explosive charges.

The quantity of auxiliary equipment such as rods, bits and moving equipment is not large for jet-piercing and churn drills. On other types, particularly percussion and rotary drills, the auxiliary equipment includes a large assemblage of bits, rods, hose, lubricants and a multitude of other items used in large quantities. Many of these items are common industrical supplies and need not be described in detail. However, bits and rods are of major importance and therefore, warrant additional comment.

For drilling small-diameter holes with wagon drills, either steel or tungsten-carbide-tipped bits may be used. For soft rock steel bits will probably be satisfactory at a cost of a few cents each; if the rocks are hard, a tungsten-carbide bit at a cost of several dollars will be necessary. Both are similar in shape and general design. The essential parts are the cutting edges, flushing holes and thread or taper connection for attaching to a steel rod. Two types of percussion bits are illustrated in Figures 12 and 13. The bits shown are actually for down-the-hole drills, but the design of percussion bits for other applications in similar.

Matching of bits to the rock and the drill is a highly skilled task. Tunsten carbide tips range through several levels of hardness, brittleness, and toughness. These factors can be varied by the bit manufacturers by incorporating within the inserts tungsten carbide of various grain sizes held together by bonding agents of various compositions. The bond between the tungsten-carbide insert and steel bit body can also be varied to produce bits of different characteristics. Ultimately, the performance of a bit can only be determined by practical drilling tests on the site.

In their essential features, large-diameter tungsten-carbide-tipped percussion bits are similar to small-diameter bits. However, because of the greater weight of the drilling equipment, stronger blows, and higher cost of the large bits, elaborate care is taken during their manufacture. Connections between drill rods and large bits are always machine threaded whereas small bits may be attached to the steel by a simple taper connection. Great care is taken when large-diameter bits are resharpened; they are normally dressed to shape by a hand-held grinding wheel. An operation of this type is shown in Figure 14. Small-diameter bits are sharpened on a machine with a jig to hold the bit against the grinding wheel.

Drill rods for wagon drills are usually quality carbon or alloy steel in hexagonal, quarter-octagon or round shape, with a central hole within the rod for flush water or air. Ends may be threaded or tapered to take couplings. The rods are usually supplied in standard lengths, ten and twenty feet being most common. A great variety of alloys, treatments and connections are possible. Rods are offered with shot-peened surfaces, carburized surfaces or as-rolled. The relative ease with which a company can enter the field of fabricating light drill rods from bar stock makes competition in this field intense.

The suppliers of drill rods for large rotary or percussion drills, however, are not numerous. The drill manufacturer usually supplies the rods with which the drill is equipped. The rods themselves are heavy tubular goods with reinforced ends which are threaded to a male or female joint. Large rods generally screw into each other so that the assembled rods present a flush exterior surface. Common lengths are 20, 30, and 40 feet, and they are too heavy for manual handling. Auxiliary equipment is therefore provided on the drill structure for this task.

Bits for rotary drilling all follow the same basic design including independently mounted toothed rollers that cut into the rock as thrust and rotation are applied. A high thrust is hard on the bearings and failures sometimes occur at this point. Teeth on rollers may be of alloy steel or of tungsten carbide in a variety of shapes. Examples of large-diameter rotary drill bits are shown in Figures 15, 16, 17, and 18.

Blasting Equipment and Supplies

Basically, explosives are comprised of chemicals, which, when confined, contain all the requirements for complete combustion without external oxygen supply. The ingredients must also be sensitive enough to detonate when a shock is applied so that combustion will be rapid and complete. Early explosives consisted chiefly of sensitive nitro-glycerine, an oxidizing agent, and carbonaceous material. These mixtures were packaged into cartridges for convenience in handling and placing charges. Many explosives are still manufactured to the basic formulas and packaged into cartridges. An example is the gelatin type which is listed in the table on page 32.

Figure 14. Hand sharpening a large-diameter percussion bit. (Courtesy Canadian Ingersoll Rand Company)

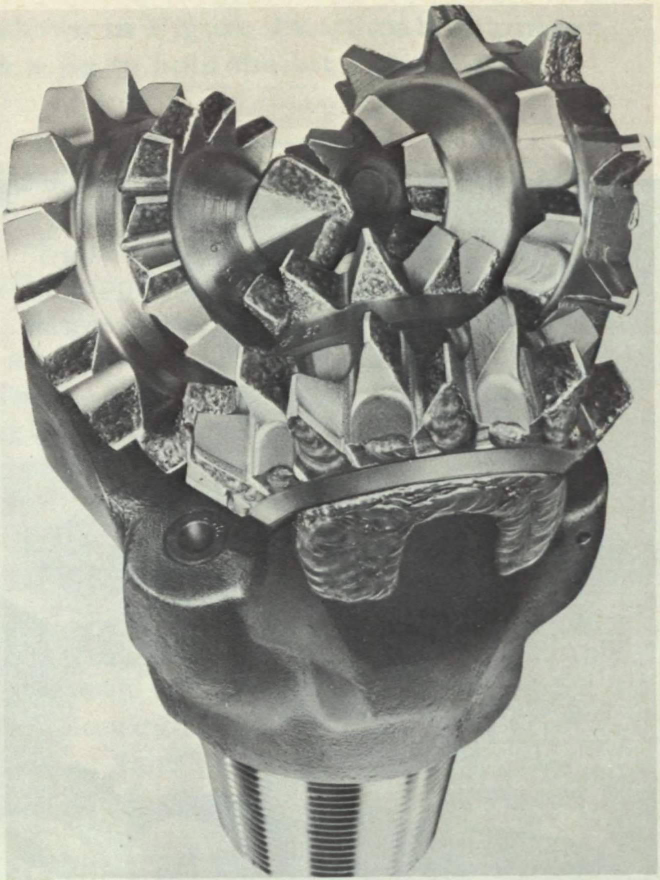


Figure 15. Rotary bit for soft rocks. (Courtesy Hughes Tool Company)

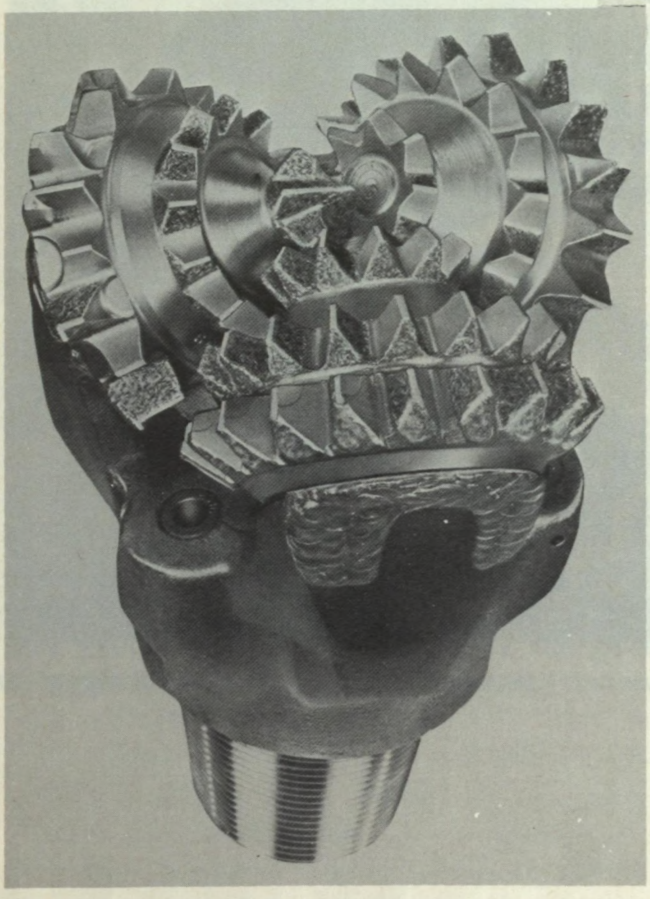


Figure 16. Rotary bit for medium rocks. (Courtesy Hughes Tool Company)

Figure 17. Rotary bit for hard rocks. (Courtesy Hughes Tool Company)

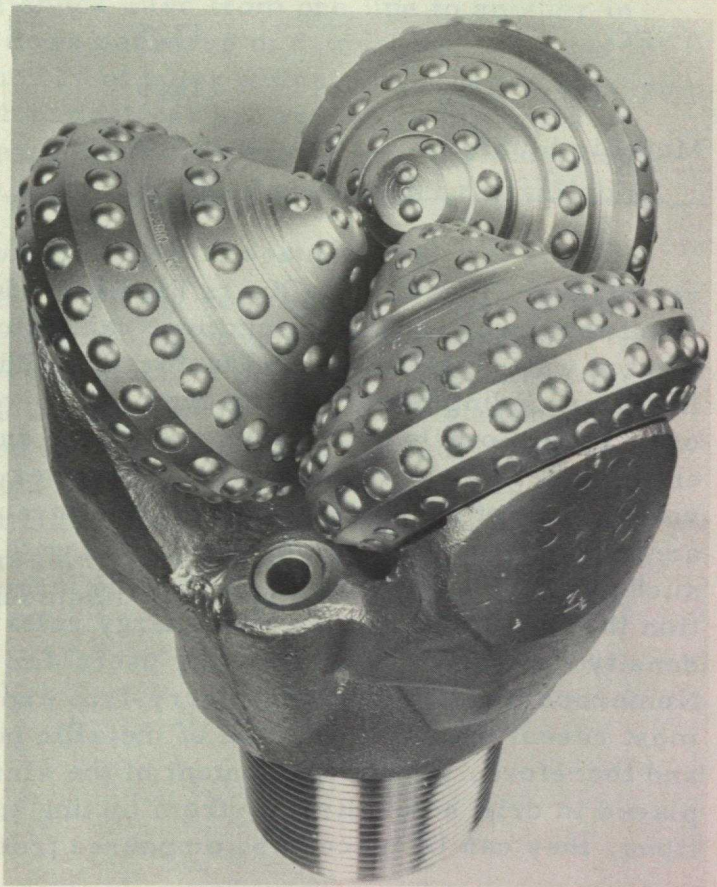


Figure 18. Rotary tungsten-carbide bit for the hardest rocks. (Courtesy Hughes Tool Company)

In recent years, it has been discovered that fertilizer-grade ammonium nitrate mixed with carbonaceous material could be detonated by a high-explosive primer. The initial carbon was lamp black or charcoal but it was found that bout 6 per cent fuel oil would do equally well and be more convenient. This new application has spread to the point where virtually all surface mining companies use the mixture for some or all of the primary blasting.

An explosives efficiency is measured by the velocity with which it detonates, the total energy produced on detonation, and the pressure which the detonating explosive produces on the surface of the borehole. In the practical sense, the user of explosives has purchased energy; therefore he thinks in terms of unit cost of this energy. Because of the cheapness of ammonium nitrate - fuel oil (ANFO) mixtures, the unit cost of energy from this source is extremely low. A comparison of some of the explosives used in surface mines is shown below.

Explosives	Velocity ft/sec (in 000's)	Energy cal/gm	Borehole Pressure kilobars	Cost $/lb
Gelatin, 60%	15.4	990	100	0.26
ANFO	13.5	890	13	0.05
TNT Slurry	18.5	890	85	0.18
Metallic Slurry	15.0	1,500	110	0.20

One disadvantage of ANFO mixtures is that they have low water resistance. Plastic hole liners have been developed to extend the range of conditions over which the mixtures can be used. However, because of limited water resistance and factors related to energy content, as shown in the preceding table, slurry-type explosives have been developed. These offer exceptionally good water resistance and cost reductions per unit of energy over conventional gelatin explosives, increased energy content per volume unit of borehole and increased borehole pressure. Slurry explosives are mixtures of ammonium nitrate and water to which a sensitizing agent such as TNT has been added. All the ingredients take part in the detonation that results in a very high energy release. Slurry explosives are high-density explosives, exceptionally useful for breaking the toe of the bench. Numerous improvements to slurry-type explosives have been made, the most recent involving addition of metallic powders that increase the mass and therefore, the energy content of the slurry. Slurry explosives can be placed in drill holes directly from mixing trucks or, for isolated applications, they can be placed as, or poured from, plastic bags.

Explosives are set off or initiated by electric caps, detonating fuse (Primacord), or by some combination of these with or without special primers. Conventional gelatin-type explosives require no special primer, but relatively insensitive materials such as ANFO and slurries are commonly initiated with high explosive cartridges, or with specially manufactured boosters such as Pentolite. Detonators which are capable of detonating ANFO directly have been developed but the practice of using boosters is still in common use.

The electric cap is manufactured to fire either instantaneously or at some predetermined time interval after electric current is applied. Caps have been designed to fire at relatively long intervals - about half a second - or at intervals measured in thousandths of a second. The latter are often referred to as "short-period" or "millisecond" delays. Many years of experience are required to establish the correct timing for optimum blasting results.

Detonating fuse or Primacord is merely a cylindrical train of explosive about 0.2 inch in diameter confined within an outer carcass of fabric or plastic. The particular explosive used in detonating fuse detonates at a velocity that is much greater than the main explosive used in the borehole so, for practical purposes, it can be assumed that the shock wave which travels along the detonating fuse in instantaneous. Detonating fuse is also capable of transmitting a shock wave from one line to another in intimate contact with it. This allows networks of detonating fuse lines to be set up for shooting a large number of holes with a single cap to start the detonation. Coverings of detonating fuse are varied to suit special uses and conditions. For example, plastic coverings are now most common but fabric, reinforced fabric, or wirebound coverings are available for use under severe conditions.

A further development in timing devices is the delay connector incorporated into detonating fuse lines. These devices are particularly useful where stray electric currents may be a problem. Internally, the delay connector resembles the delay element in an electric blasting cap; delay times are usually measured in thousandths of a second. They are therefore similar to delay caps but are more convenient owing to the absence of long wires. In all blast hookups with detonating fuse, electric or other blasting caps are still required to start the shot. Reliable power provided by a special blasting machine or from power lines is required where electric caps are used.

Drilling Procedures

Given the wide variety of equipment available for drilling, one might wonder how choices about drills are made and what Canadian preference may be. Scale of operations largely determines the size of the drill. Operations which rely on large loading equipment and haulage units can adequately handle large pieces of ore and waste. Consequently, more widely spaced, large-diameter holes can be accepted. It does not follow that large-diameter holes will always produce coarse broken material because fragmentation is affected by many other factors, the chief of which is the nature of the material being broken.

Where formations are relatively soft, rotary drills are preferred, and they have in some instances produced outstanding drilling rates. In hard formations, percussion drills are normally used. Drills are now available which can be used either as percussion or as rotary machines. Many mining companies have rotary and percussion drills on hand and employ them to best advantage as conditions warrant.

The physical design of the drill may be an important factor affecting its selection. For example, some drills are designed to drill holes much closer to the crest of a bench than other drills; this factor may influence selection if considerable back break is expected. Other drills provide greater comfort and convenience to the crew and this may become important in unfavourable climates. Some mine managers who have had success with equipment from a certain manufacturer are reluctant to consider any alternative source.

For production drilling, Canadian mining companies use self-propelled drills. However, opinion appears to be divided; it depends partly on pit layout whether to use compressed air from a central source or from portable compressors. The trend is to wider use of electric power for operating drills. Table 3 lists the drills used in some Canadian surface mines.

Canadian practice in metal mines now leans heavily toward vertical downhole drilling with allowances of up to 10 per cent for subgrade drilling. Inclined holes are preferred at one iron ore mine and in some of the asbestos mines in the Eastern Townships of Quebec. In the latter, practice favours holes inclined at 70 degrees; long experience indicates that inclined holes in these ores largely reduce back break and scaling. Some researchers have recently studied inclined drilling and claim it is superior to vertical drilling for toe breakout. Whether holes are vertical or inclined, a standard pattern finally evolves at each mine. Figure 19 shows a bench drilling off and ready for blasting.

In one part of its surface mining operations, an asbestos mining company drills off a portion of the bench with three rows of holes inclined at 70 degrees, increasing in length with distance from the face. The longest downholes are 60 feet. Toe holes are also drilled from the bench below to a point underneath the vertical holes, to produce a bench height of 75 feet. This drilling and blasting procedure produces a smooth working floor which contributes materially to shovel performance.

Another asbestos mining company is faced with an unusually incompetent ore that is easily turned into mud when rains occur. To avoid fracture of the mine floor, holes are drilled to within four or five feet of the required grade. The shovel appears to experience no difficulty in digging to the required grade, yet the mine floor is largely undisturbed.

Hole diameters, bench heights, burdens, and spacings depend on mine conditions and operator preferences. It will be noted from Table 2, however, that the majority of the mining companies listed prefer bench heights between thirty and sixty feet. The usual practice is to select burden and spacing that are suitable for the equipment available and that have been indicated, by previous experience, to be approximately correct. Burden distance is usually less than spacing as shown in Table 3. During several trial blasts, the parameters are varied until optimum results are achieved.

In an entirely new mining area, where experience upon which to base initial blasting trials is not available, considerable success has been achieved by applying the Livingston Theory, whereby cratering experiments rapidly narrow down the problems in designing blasts. When blasting techniques in use in the established mines are compared with the techniques which would result from the Livingston Theory, it is surprising what degree of agreement appears.

Drilling is tailored to suit the shovel in use, but the overall objective is to achieve the lowest mining costs. The general trend is towards larger-diameter, more widely spaced holes as equipment becomes larger. In many asbestos mines, holes about four inches in diameter are still in use. Production of ore is from 5 to 12 tons per foot of hole for these small-diameter holes. In metal and coal mines, hole diameters are commonly 9 7/8 inches and 12 1/4 inches. Ore production per foot of hole is between 50 and 100 tons.

For secondary drilling, a choice of equipment usually exists. Owing to the trend towards larger and more powerful drills as a mine develops, lighter drills often become surplus but still remain useful for toe cleanup and block-holing. Wagon drills probably were used extensively during the pioneering phase of the mine but now serve admirably for secondary drilling. In some instances, pluggers and portable compressors are

Figure 19. Bench drilled off, loaded and ready for blasting. (Courtesy Canadian Industries Limited)

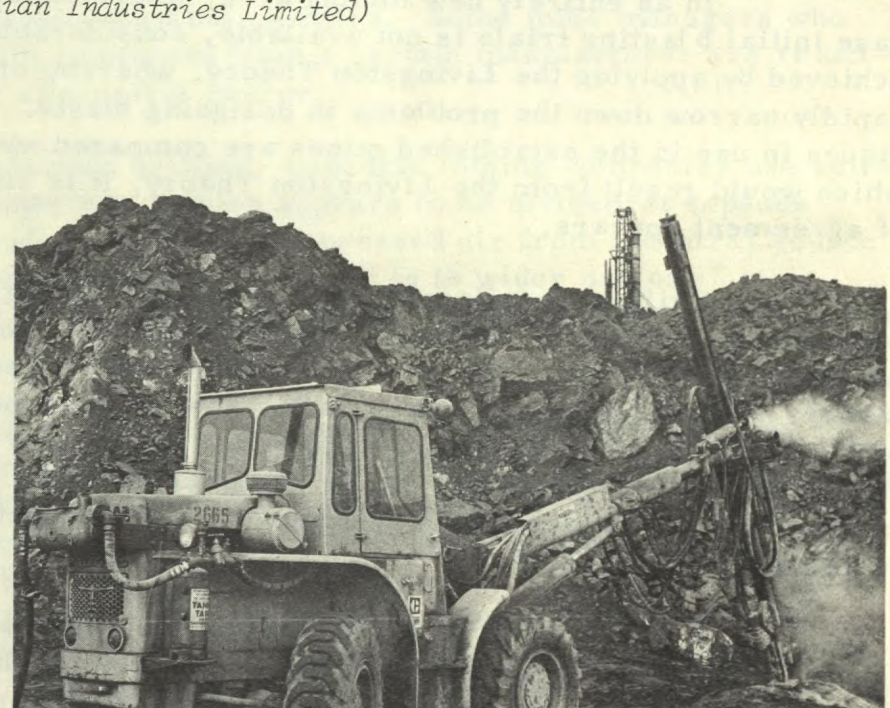


Figure 20. Specialized secondary drilling unit. (Courtesy Iron Ore Company of Canada)

in use; in others, specialized drilling equipment has been purchased specifically for efficient secondary breaking. A specialized secondary drilling unit in use in an iron ore mine is illustrated in Figure 20.

At some mines, secondary drilling and blasting is dispensed with in favour of a crane-mounted drop ball weighing between three and five tons. One requirement for successful operation of a drop ball is adequate space to swing the ball. Usually a surplus crane is available, but the operator must be experienced. Instances are known where the crane-activated drop ball was not successful; however, where conditions are satisfactory, exceptionally low secondary breaking costs are reported. Where the oversize material is exceptionally easy to break, it may be possible to use a spherical drop ball directly in the shovel dipper. The height of drop in this case is of course less, but instances are known of the method being successful.

Blasting Procedures

Blasting procedures have undergone a rapid revision owing to large-scale introduction of ANFO and slurries. The Marmoraton Mining Company Limited at Marmora, Ontario, started to use ANFO in 1954. Advances in application of low-cost blasting agents has also taken place in the mines of the Iron Ore. Company of Canada at Schefferville. Early experiments at Marmora and Schefferville included on-site mixing of fertilizer-grade ammonium nitrate prills with six per cent of No. 2 fuel oil. Early mixes were comprised of fifty to eighty pounds of prills and one imperical gallon of No. 2 fuel oil, fed simultaneously into the drill hole through a light metal funnel. One-site mixing is still practiced but usually a specially fitted mixing truck automatically mixes and dispenses explosives directly into the drill hole. The success achieved with ANFO at Schefferville led to further experimentation with other blasting techniques and blasting agents, resulting in the development of slurry-type explosives.

As early as the 1960's, research on explosives and their handling at Schefferville progressed to the point where a special ANFO mixing plant was put into service. Prills in sealed, 3000-gallon containers, and diesel fuel, in tank cars, arrived by rail. From storage, quantities of prills and fuel oil were measured, "fluidized" and pumped into a remotely controlled mixing plant. When ready for use, the mixture was pumped into a special delivery truck and "fluidized" directly into drill holes. Blasting requiring one or two men only, was suddenly less expensive than before. Use of mixing trucks and bulk handling of explosives into drill holes has become a standard method at the large mines. For small mines, explosives manufacturers have introduced uniformly pre-mixed ANFO which requires little labour for its placement.

TABLE 3 - SELECTED CANADIAN SURFACE MINES, 1972 - DRILL DATA

Reference Name	Primary Drill or Drills Model	Primary Drill or Drills Type	Auxiliary and Secondary Drills Model	Auxiliary and Secondary Drills Type	Primary Hole Depth (ft)	Primary Hole Diameter (inches)	Burden and Spacing (ft)	Estimated Primary Performance (ft/drill shift)
Iron and Associated Mineral Mines								
Caland	40-R	Rotary			30-36	7-7/8	18x8(w)	200-300(w)
	C750	Rotary			30-36	7-7/8	15x18(o)	225-250(o)
Sherman	60-R, 61-R	Rotary	500 R. R.	Percussive	44(w)	$12\frac{1}{4}$	28x30	225
	CP	Rotary			46 (o)	$12\frac{1}{4}$	28x30	150(w)
Griffith	40R	Rotary	Air Trac	Percussive	40	9	25x25	100(w)
	45R	Rotary				9-7/8	26x26	130(o)
Hilton	D400	Percussive			37	7	20x20(w)	120(o)
							18x20(o)	90(w)
Schefferville	50-R	Rotary			44	9-7/8 & 10-5/8	27x27	300(o)
								270(w)
Carol	50 R	Rotary	40-R	Rotary		9-7/8	25x25(w)	100(w)
	60 R	Rotary				9-7/8	24x24(o)	600(o)
Adams	50R	Rotary	UD475	Percussive	45	9-7/8	22x24 - 25x27(w)	n/a
							22x24 - 23x25(o)	
Marmoraton	QM	Down-the-hole	Ram-Trac	Percussive	60	7	21x22(w), 18x19(o)	95
Moose Mountain	50-R	Rotary	Sidewinder	Percussive	50	9-7/8	27x27(w)	145
							26.5x26.5(o)	145
Cartier	60-R, $60\frac{1}{2}$R	Rotary	Air Trac	Percussive	45	$12\frac{1}{4}$	21x29	200
	61-R						31x30	
LacTio	Crawlmaster	Down-the-hole	Air-Trac	Percussive	40	$6\frac{1}{2}$	15x21(w)	390(w)
							14x17(o)	360(o)
Steep Rock	40R	Rotary	Air Trac	Percussive	25 - 30	7-7/8	12x16 - 18x18	172 - 222
	45R	Rotary				9	14x18 - 21x21	180 - 239
Wabush	60R	Rotary			43	9-7/8	26x32	275
Westfrob	40R	Rotary	ATD 3100	Percussive	40	9	14x16(w)	300
	40R	Rotary	ATD 3200				14x14(o)	200

Asbestos Mines

Advocate	735 BH	Rotary	PR123J	Percussive	55	7-3/8	26x26	240
B-C	TM-600 TM-650	Percussive Percussive	S-83	Percussive	55 56	4 6¼	12x15 18x22	279 213
K-B	PR143J IM 600 IMP III	Percussive " "	BBE-57	Percussive	55	4 & 4½	15x15	240 - 390
Normandie	T-650	"			50	6¼	20x22	250
Jeffrey	PR-123 R-40, RDC-30	Percussive Rotary			40-55	4 - 4-3/4 6-3/4	12x15 - 15x15 22x22	530 295
Reeves	PR123J	Percussive			37 - 39	5	14x18	110
Carey	PR123J	Percussive	Jackhammer	Percussive	50	4	13x16 & 10x12	350
Cassiar	40R	Rotary			33	9	20x20	250(w) 300(o)
Clinton	40-R	Rotary	Air Trac	Percussive	36(o) 50(w)	9(o) 9-7/8(w)	18x18(o) 20x20(w) 26x34(w)	500(o) 200-600(w)
Lake	DHD 1060A	Percussive	Air Trac Traveldrill	Percussive Percussive	46	6½	23x26	165
National	PR-143	Percussive	123	Percussive	52	5	14x16	225

Non-Ferrous Metal Mines

Anvil	40-R	Rotary	Jackhammer	Percussive	40 & 45	9	20 x 20 (o) 23 x 23 (w)	300 (w), 200 (o)
Bethlehem	45-R	"			39	9-7/8	20 x 20 to 25 x 25	700
Brenda	60-R	"	Air Trac	Percussive	58	12¼	26 x 32	400
Brunswick	30-R 40-R	" "			N/A	9 (o) 6-3/4 (w)	20 x 20 (o) 16 x 16 (w)	120 168
Tungsten	PR 123	Percussive			25	3½	7 x 7	100 (o) 500 (w)
Ecstall	40-R 45-R 50-R	Rotary			45	9 & 9-7/8	22 x 28	n/a
Gaspe	60-R	"	PR 123	Percussive	43	9-7/8	16 x 32	200
Gibraltar	45-R	"			52	9-7/8	22 x 22	600
Phoenix	40-R	"			40	9	16 x 16	400
Granisle	40-R	"			40	9	16 x 32 & 18 x 36	200
Clarabelle	45-R	"	AR 47	Percussive	52	9	17 x 32 & 20 x 20	109
Pipe Lake	45-R	"			n/a	9-7/8	23 x 23	n/a
Lornex	45-R	"			50	8-5/8	37 x 37 (w) 33 x 33 (o)	200 (w) 600 (o)
Pine Point	30, 40, 45-R	"			32	4-3/4 & 9-7/8	17 x 17 & 21 x 21 (w) 15 x 15 (o)	179 to 333 (w) 151 to 239 (o)
Endako	40-R	"			39	9	20 x 22	450
Similkameen	60-R	"			49	9-7/8	22 x 22	450
Island Copper		"				9-7/8		

(o) = ore
(w) = waste

Despite extensive use of ANFO at the larger mines and favourable reception of pre-mixed ANFO at the small operations, certain blasting conditions require special consideration. Where there is considerable moisture, or where satisfactory fragmentation is difficult to achieve, slurry explosives or standard cartridged explosives must be used; however cartridged explosives are not in general use today. Where ANFO is used for loading the holes, primers having high detonation velocity are required to initiate the blast; practice appears to favour cast "Pentomex" or similar boosters for this purpose. In certain circumstances, conventional cartridged explosives are preferred for blockholing. Some data on Canadian blasting practice are shown in Table 4.

The steps in loading and blasting are illustrated in Figure 19 to 24. Figure 20 shows explosives being bulk-loaded directly into drill holes, Figure 19 the loaded blast and succeeding figures show the other stages. The explosives used in this blast were metallized TNT-based slurry and ANFO initiated with millisecond caps taped to trunk lines.

The term "powder factor" refers to the amount of explosive per ton or cubic yard of material blasted and it varies widely at the different mines. In some mines, powder factor is described as the number of tons broken per pound of explosive. As a general rule, lower power factors can be achieved in large operations using heavy loading equipment than in small operations. In the asbestos areas of Quebec, mining companies are able to achieve extremely favourable powder factors. Although one asbestos mine records a primary powder factor of 0.6 pounds per ton mined, most powder factors are between 0.25 and 0.50 pounds per ton mined. In the iron ore mines of Labrador-Quebec, powder factors are approximately 0.50 pounds per ton mined. In the Atikokan area of Ontario, a good estimate would be 0.45 pounds per ton mined, and in the western Canadian copper mines from 0.21 to 0.50 pounds per ton mined.

Holes are primed by one or more standard cartridges of explosives attached to Primacord down lines, or by specially prepared boosters instead of standard explosives. Primacord down lines are normally initiated by trunk lines to which are attached millisecond trunkline delays. One or two electric caps initiate the shot from the ends. Individual holes are sometimes fired with millisecond delay caps, even in multiple-row blasts, but the former method is more widely used. Multiple-row shooting is preferred but, where toe breakout is expected to be difficult, single-row shooting is the practice. Where comprehensive tests were conducted in several mines, multiple-row shooting often resulted in better fragmentation. Stemming of holes has proven worthwhile in most mines and is rarely omitted. Holes are usually loaded solidly with explosives to within burden distance of the collar, after which drill cuttings are used to stem the remainder of the hole. The practice of decking, or alternating explosives and stemming within holes, appears to be declining as more explosives are bulk loaded.

[illegible] SURFACE MINES, 1972 - BLASTING DATA

Reference Name	Explosives, Type	Initiation	Explosives (lb/hole)	Stemming (ft)	Powder Factor lb/ton	Secondary Explosives
Iron and Associated Mineral Mines						
Caland	ANFO & Slurry	Primacord, Elec. Caps	n/a	15	0.47 (o) 0.42 (w)	
Sherman	ANFO & NCN Slurry	El. Blasting Caps	1,650(w) 1,900(o)	20(w) 15(o)	0.75	
Griffiths	ANFO & Slurries	Primacord, El. Caps	900(w), 1,050(o)	8	0.60	
Hilton	ANFO & Slurry	El. Caps	150 to 400	8(w) 5(o)	0.38	
Schefferville	Slurry & ANFO	El. Caps	960	13	0.40(o) 0.47(w)	
Carol	Metallized Slurry	El. Caps	1700 to 3000	12 - 17	0.90(o) 0.25(w)	
Adams	Slurries and ANFO	Primacord & El. Caps	1,200	none	0.55 (w)	
Marmoraton	Metallized Slurry	El. Caps	950	16	0.36	
Moose Mountain	Metallized Slurry	El. Caps	1,700	16	0.40(o) 0.30(w)	2 x 16-Inch Cartridge 75%
Cartier	Slurry, 17% Al.	Primacord & El. Caps	1,856	19	0.55(o)	2 x 16- " " 70%
Lac Tio	ANFO & Slurry	El. Caps	575 (o) 365(w)	10	0.50(o) 0.35(w)	
Steep Rock	ANFO, some Slurry	Primacord & El. caps	n/a		0.30 (med. ore) 0.65 (carbonate) ANFO	1 x 8-Inch Cartridge 40% 1 x 8- " " 70%
Wabush	ANFO, Slurry in toe	Primacord & El. cap	n/a	13 & 15	0.40	
Westfrob	ANFO	Primacord & El. cap	560(o) 550(w)	15	0.60(o) 0.50(w)	Cartridged Explosive
Asbestos Mines						
Advocate	Slurry	Primacord & El. caps	1,000 - 1,100	15	0.54	
B-C	Slurry & ANFO	Primacord & MS Relays	248 & 600	14 & 15	0.33 & 0.36	
K-B	Slurry	Primacord & El. caps	280 to 360	15	0.40	
Normandie	Slurry	Primacord & El. caps	600	15	0.40	
Jeffrey	Slurry & ANFO		150 & 550	11 - 15	0.25 - 0.30	
Reeves	ANFO & Slurry	El. caps	n/a	10	n/a	
Carey	Slurry	Primacord & El. caps	280(w), 100(o)	10 & 15	0.36(w), 0.19(o)	
Cassiar	70% ANFO 30% Slurry	El. caps	500(o) 600(w)	10	10.50	
Clinton	ANFO	Primacord	500 & 1,000(w)	14	0.60(o) 0.40 to 0.60(w)	
Lake	T-40 & T-30	Primacord	580	14	0.32(o)	
National	ANFO & Slurries	El. Caps	250	11	0.33	
Non-Ferrous Metal Mines						
Anvil	ANFO & Slurry	Primacord & El. caps	700(o) 650(w)	16(o) 17(w)	0.15(o) 0.39(w)	
Bethlehem	ANFO & Slurry	-	-		0.35	
Brenda	60% Slurry - 40% ANFO	S.P. caps	3,000	25	0.50	
Brunswick	Tovex 20, Tovex 40	-	-	-	0.38	
Tungsten	Slurry	Primacord & Fuse	100	7	0.75	
Ecstall	ANFO & Slurry	Primacord & Caps	350 & 1,200	10 to 25	0.40 to 0.60	Drop Ball
Gaspe	ANFO	El. caps	1,000	20	0.40	Cartridges
Gibraltar	ANFO & Slurry	El. caps & Primacord	-	22	0.50	
Phoenix	ANFO	Primacord & El. caps	468	12	0.80	Drop Ball
Granisle	ANFO & Slurries	Primacord & Fuse	680 & 710	15	0.38 to 0.45	
Clarabelle	ANFO	Primacord & El. caps	1,000	24	0.44	1 x 8-Inch Cartridge
Pipe Lake	Aluminized Slurry	-	-	-	0.60	
Lornex	316 Slurry	S.P. cap	1,100 to 1,500	24	0.21	
Pine Point	ANFO & Slurry	Primacord	400 to 675	12	0.70(o) 0.60(w)	NCN
Endako	ANFO	Primacord & El. caps	320	23	0.40	
Similkameen	ANFO	Primacord	n/a	26	0.33	
Island Copper	ANFO	-	n/a	n/a	n/a	

(o) = ore
(w) = waste

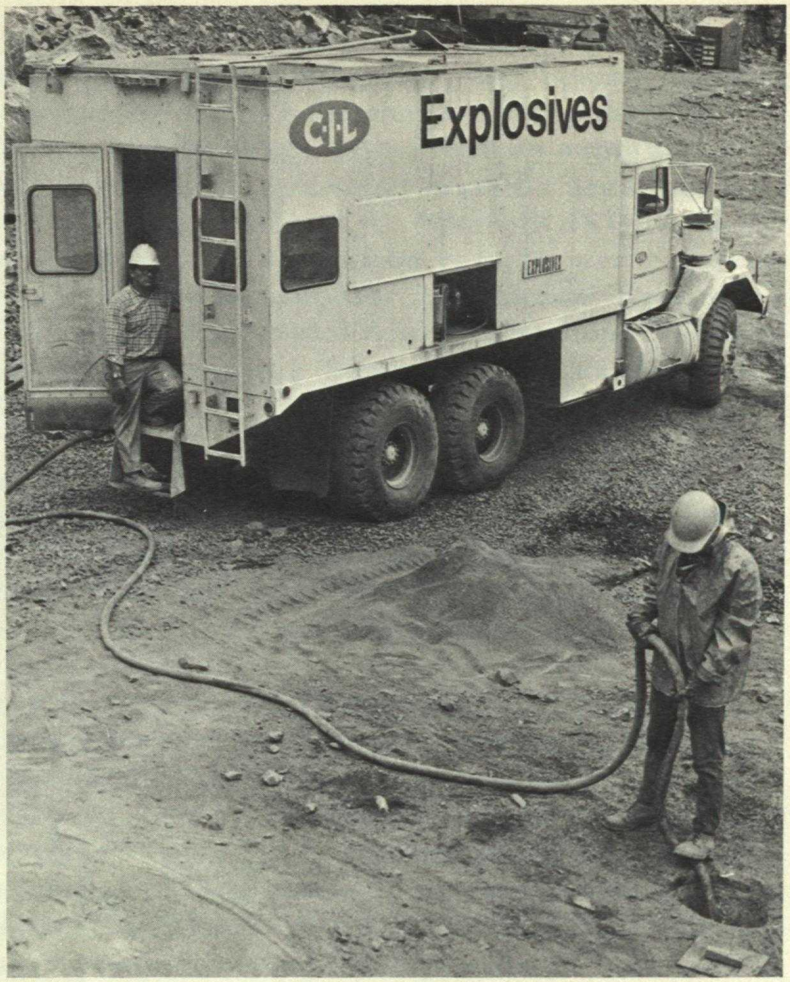


Figure 21. Bulk loading explosives into drill holes. (Courtesy Canadian Industries Limited)

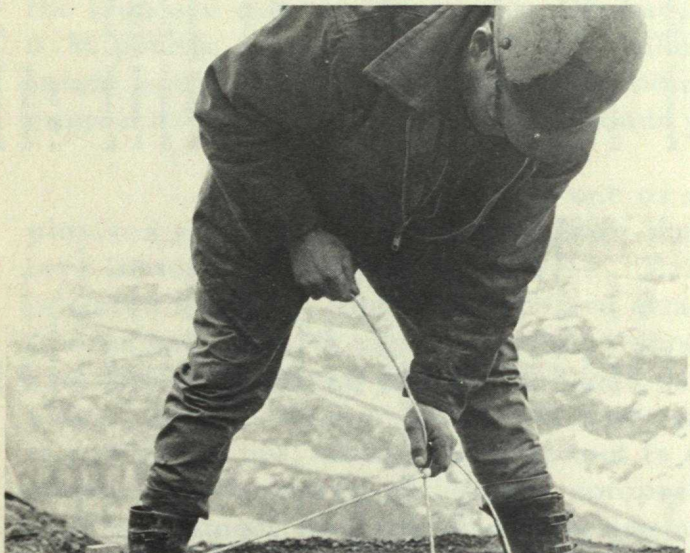


Figure 22. Connecting Primacord downline to a trunk line. (Courtesy Canadian Industries Limited)

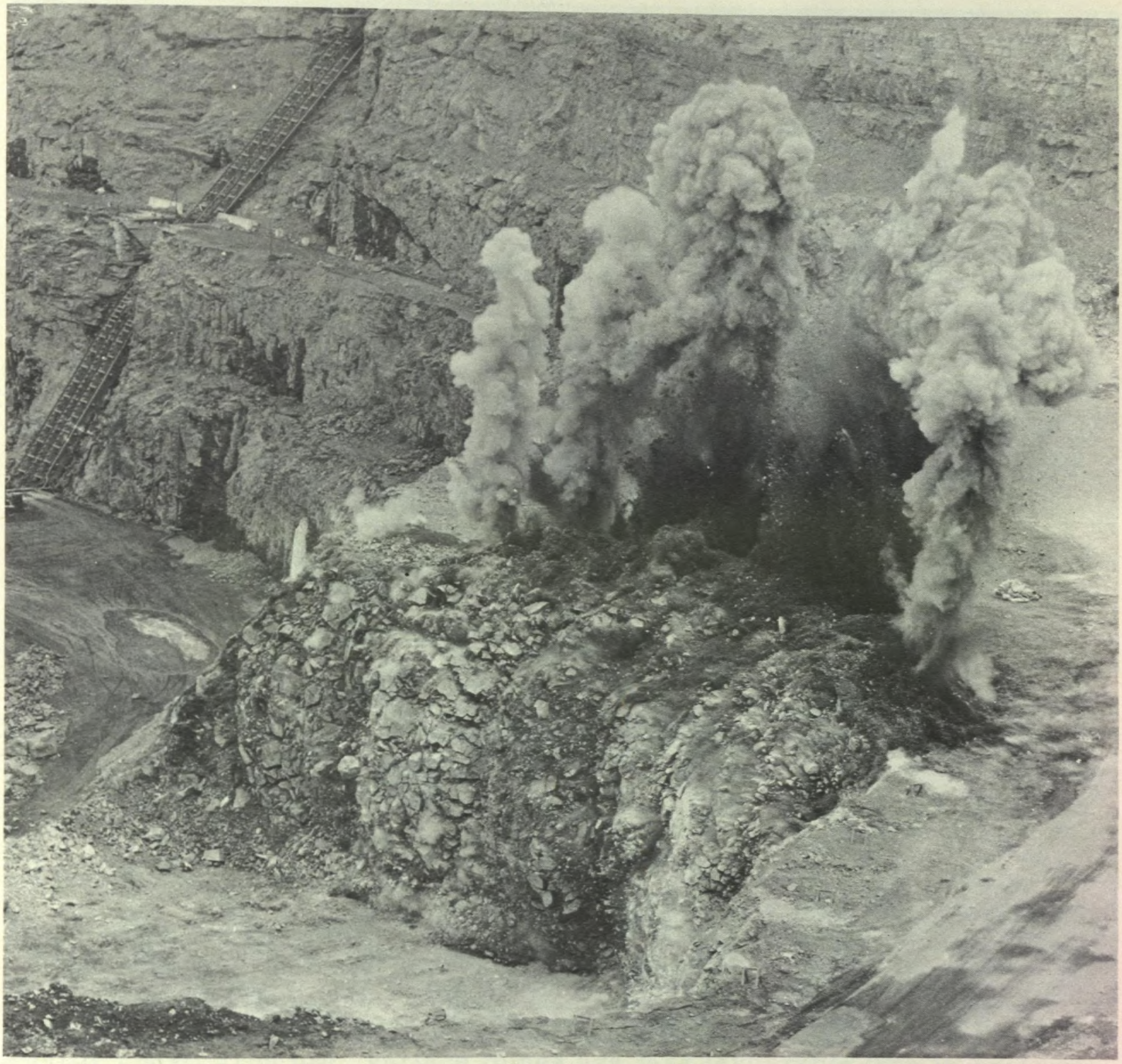


Figure 23. The blast. (Courtesy Canadian Industries Limited)

Figure 24. A well-fragmented muckpile. (Courtesy Canadian Industries Limited)

Secondary blasting is usually done at the end of the shift by means of cartridged explosives and electric caps. As mine equipment becomes larger and as the scale of operations increases, secondary blasting becomes a relatively smaller part of the mining operation. Of the Canadian surface mines discussed in this survey, none are known to have a serious secondary breaking problem.

Drilling Costs

Depending on the scale of operations and the hardness and toughness of the ore and waste, considerable variation can be found in drilling cost. The relation between hourly cost of operation of the equipment and its performance is of primary importance.

Some of the smaller track-mounted drills, for holes up to four inches in diameter, are difficult to assess on an hourly basis. A simple matter such as size of crew can appreciably affect hourly operating cost. Where rotary drills that produce holes up to ten inches in diameter are used, hourly operating cost is between $15 and $20; labour represents about 40 per cent, mechanical parts often equal the cost of labour, and bits, lubricants and fuel or power account for the remainder.

Records indicate that drilling costs may vary from two to twelve cents per cubic yard broken in asbestos mines. One instance is known in a western Ontario iron ore mine where a drilling cost of 18 cents per cubic yard broken was achieved. Where recorded costs were not available, estimates were based on performance data. In most eastern Canadian surface iron ore mines, the cost of drilling averages between ten and twenty cents per cubic yard broken, but unusual local conditions can cause drilling costs to exceed the average by a wide margin. Even within well-defined mining areas that generally experience low costs, instances are known of drilling costs as high as $1.25 per cubic yard broken.

In some surface mines on the Pacific coast, cost of wagon drill holes up to three inches in diameter are between 30 and 60 cents a foot drilled. Rotary and percussion drill holes, six and nine inches in diameter, are estimated to cost $2.50 a foot. In general, drilling conditions in Pacific coast, iron ore, surface mines are less favourable than in eastern Canadian mines because the ore is harder and more abrasive.

Blasting Costs

Although the blasting agent accounts for most of the blasting costs, there are others such as detonators, detonating cord, and primers. An appreciable expense may be incurred in handling and loading.

Mixtures of ANFO and slurries used on a large scale lend themselves to bulk handling which can lead to substantial cost reductions. A few difficulties with moisture have been encountered in large-scale adoption of ANFO, but its use where possible has reduced costs so substantially that the ANFO developments represent one of the outstanding advances in surface mining in recent years.

In some Eastern Township asbestos mines where ANFO is in use, a total blasting cost of 8 to 12 cents per cubic yard mined can be shown. In these instances, the data were compiled for ore alone. It should be noted that with few exceptions, conditions in the asbestos areas favour low breaking costs.

Cost data for blasting in iron ore mines are not easily obtainable although adequate information is available on explosives and blasting procedures. The indicated blasting costs in iron ore mines appear to be similar to those in asbestos mines except for slightly higher explosives costs and lower handling costs. The relatively small amount of secondary blasting normally required exerts an influence toward reduction of blasting costs in direct-shipping iron ore mines.

In surface copper mines, the ground is usually more competent; so, for successful fragmentation, considerably higher powder factors are required than those in asbestos and iron ore mines. A typical mining company, which records a powder factor of 0.45 pound per ton mined, reports the cost of blasting alone as 8 cents per ton mined. Another mining company, producing hard ore by a surface method, uses conventional cartridged explosives and reports a blasting cost of 40 cents a ton mined. This latter case is the highest cost reported.

The recent trend towards drastic reduction in blasting costs is likely to continue. Cost per pound of explosives is not likely to decrease, but better performance may reduce blasting costs, and, more important, overall breaking costs.

With large-scale use of ANFO and slurries now an accomplished fact, it is conceivable that on-site mixing of ingredients and automatic dispensing of mixed explosives into drill holes will be the standard method. Improvement of ingredient storage facilities at mines would enable some companies to affect almost immediate economies in bulk purchasing and handling. Blasting costs of less than five cents per ton may well become commomplace.

LOADING

Equipment

The key equipment around which mining procedures are developed is that selected for loading. It follows that loading equipment must be selected with great care to ensure that minimum costs will be achieved. It is further necessary to match the equipment selected for use ahead and after the loader. Equipment that could theoretically be used for loading includes shovels, draglines, clamshells, and front-end loaders of various types. However, for regular duty in most surface mines, practical selection of loading equipment would narrow down to choice of shovels of various sizes and tracked or wheeled front-end loaders. Of these, the most usual loading equipment is the power shovel.

A power shovel is essentially a tractor-mounted boom and stick, controlled by cables to actuate the dipper (see Figures 25 and 26). Power can be supplied by diesel engine, diesel-electric, or all-electric sources. Diesel-electric units are supplied with a diesel prime mover to drive the generators of the Ward-Leonard system. However, electrically powered shovels are usually preferred for normal mine production because they are cheap to operate. Under some circumstances, however, the flexibility of diesel equipment, which can operate in areas where power is difficult to supply, becomes an advantage. The absence of trailing power cables is also an advantage. Early models of shovels were provided with one or two motors to operate the shovel parts by means of a system of clutches. Modern shovels are equipped with a number of motors, each designed to provide power for a specific function.

A shovel is a somewhat inflexible, loading or digging machine which is too costly for any but long-term projects. Owing to its inflexibility, a single shovel cannot be considered if several places in a mine must be worked concurrently. Nor can purchased shovels be considered unless several years of operation are in sight.

Front-end loaders mounted on tracks or tyres are now available in a wide variety for mine duty. While actually loading, production of wheel- and track-mounted front-end loaders is about the same, but the wheeled type is usually selected owing to its greater mobility and versatility. Although the tracked loader is a superior digging tool, the wheeled vehicle can also be used effectively for carrying over short distances. The life of a front-end loader is about 10,000 hours against about 50,000 hours for a power shovel. However, capital costs of front-end loaders are usually lower than power shovels of comparable performance. In recent years, front-end loaders have been built to large sizes so they can be considered as primary loading equipment where multi-bench work is envisaged. However, haulage vehicles have also increased in size and care must be taken to

WEIGHTS	**STANDARD**
Net weight, domestic, without ballast, approx.	397,000 #
Working weight, approx., including ballast	459,000 #
Ballast, furnished by purchaser	62,000 #
Shipping weight, prepared for export, no ballast, approx.	413,000 #
Ships option tons, approx.	302

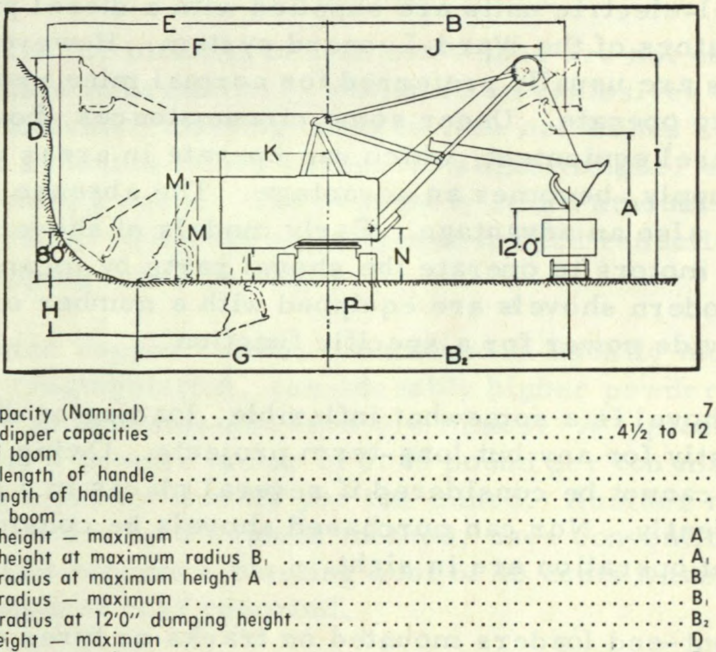
CRAWLER MOUNTING:

Width of treads — standard	3′ 0″
Width of treads — wide	3′ 6″
Overall width of mounting (3′ 0″ treads)	17′ 0″
Overall width of mounting (3′ 6″ treads)	17′ 6″
Overall length of mounting	20′ 6″

ELECTRICAL EQUIPMENT — WARD LEONARD:

Hoist motor (blown)	1	(375 h.p. @ 460 V.) (187½ h.p. @ 230 V.)	75°
Swing motors	2	(70 h.p. @ 460 V.) (35 h.p. @ 230 V.)	C
Crowd motor (blown)	1	(88 h.p. @ 460 V.) (44 h.p. @ 230 V.)	Cont.

WORKING DIMENSIONS



Dipper capacity (Nominal)		7 Cu. Yd.
Range of dipper capacities		4½ to 12 Cu. Yds.
Length of boom		37′ 6″
Effective length of handle		22′ 8″
Overall length of handle		27′ 9″
Angle of boom		45°
Dumping height — maximum	A	24′ 3″
Dumping height at maximum radius B_1	A_1	17′ 0″
Dumping radius at maximum height A	B	40′ 6″
Dumping radius — maximum	B_1	42′0″
Dumping radius at 12′0″ dumping height	B_2	41′ 6″
Cutting height — maximum	D	36′ 6″
Cutting radius — maximum	E	48′ 9″
Cutting radius at 8′ 0″ elevation	F	46′ 0″
Radius at level floor	G	33′ 0″
Digging depth below grade	H	10′ 0″
Clearance height — boom point sheaves	I	38′ 0″
Clearance radius — boom point sheaves	J	36′ 6″
Clearance radius — revolving frame	K	18′ 3″
Clearance under revolving frame — to ground level	L	5′ 5″
Clearance height — boom and A-frame — lowered	M	17′ 2″
Height of A-frame	M_1	27′ 5″
Height of boom foot above ground level	N	8′ 9″
Distance — boom foot to center of rotation	P	7′ 6″

Figure 25. Power shovel, typical specifications.

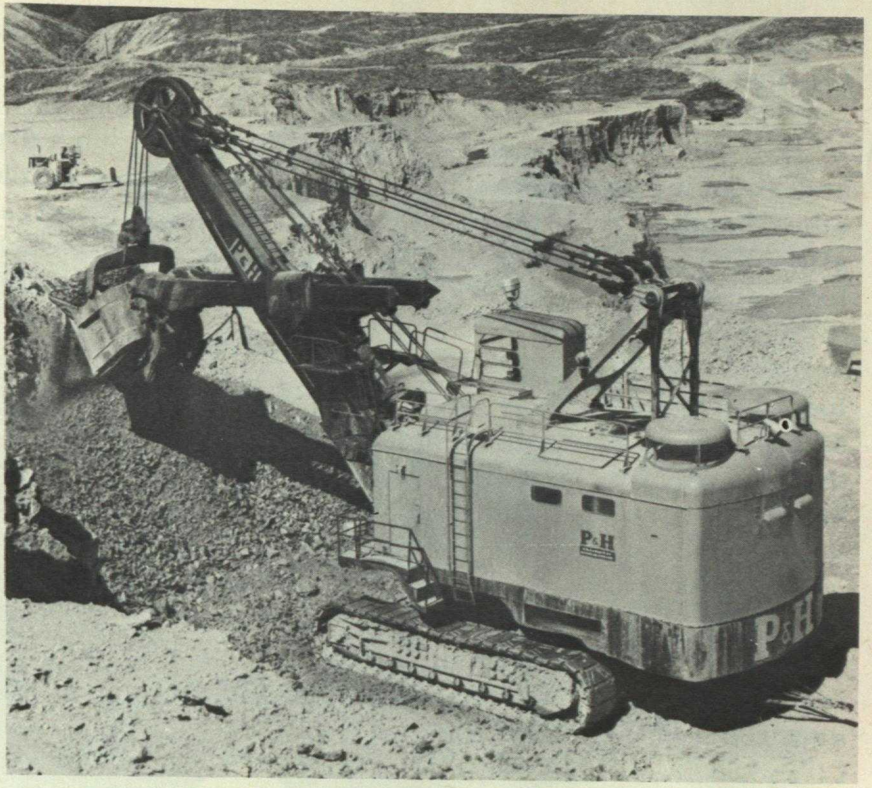


Figure 26. Electric shovel with 15-cubic-yard dipper. (Courtesy Harnischfeger Corp.)

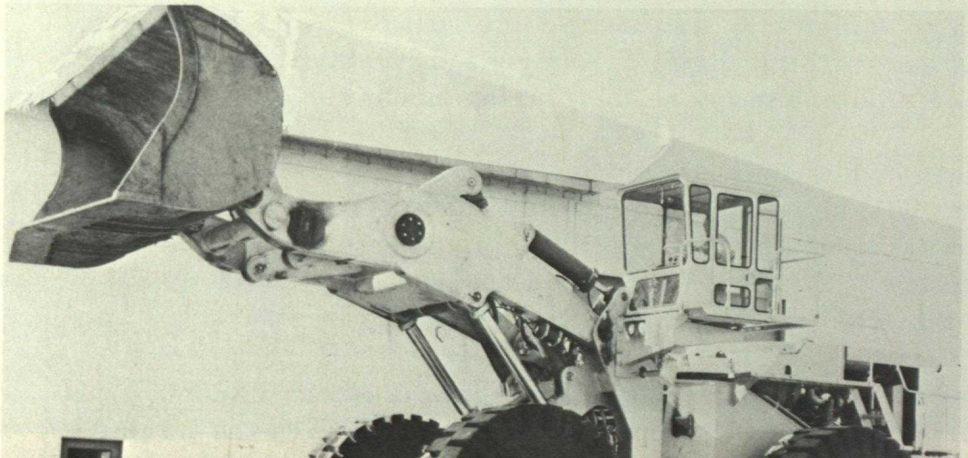


Figure 27. Front-end loader, bucket capacity 15 cubic yards. (Courtesy Sicard)

ensure that the loaders can reach the height required for dumping into the trucks.

A power shovel loads by scooping up a dipperful of material and swinging through some angle to dump into a haulage vehicle. On the other hand, a mobile loader does not "swing"; it digs by crowding into the pile. Dumping is affected by backing off from the pile and turning the entire loader for dumping into the truck. It is apparent that cycle times are longer for front-end loaders than for power shovels. One rule of thumb used to estimate the performance of power shovels and loaders is that the shovel, loading with a normal swing of 90 degrees, will load approximately the same amount of material in a fixed time as a front-end loader with double the bucket capacity. This would probably not hold where the material is very fine (crushed) and the front-end loader is very large.

The widest use of front-end loaders has been as an auxiliary loading tool which can fill in when shovels break down or when production is required from widely dispersed parts of a mine. While not in use for loading, a front-end loader may be put to work on road maintenance or used as a tractor for pioneering or clean-up. A 15-cubic-yard front-end loader is shown in Figure 27.

Loading Equipment Selection

A primary consideration when shovels are selected is the scale of production. Owing to the inflexibility of this equipment, a minimum of two will be required; one on ore and one on waste. In addition, another shovel or front-end loader will be required to ensure some loading capacity in the event of equipment breakdown. Within these limitations, a decision to choose equipment of a certain size will also be influenced by the nature of the material to be mined. A larger machine will probably be required for hard material and difficult digging, whereas the overall cost may be lower with smaller equipment where the digging is easy.

Where low benches are in use, and moving up is frequent, smaller equipment will probably be more suitable. Where benches are high, a larger shovel with a greater cutting height may be preferable. The objectives are to always obtain a full dipper, to scale the bench where necessary, and to use the least time on moves.

Performance of any shovel can be increased by reducing the angle of swing through which the dipper must move to reach the haulage vehicle. A 90-degree swing is usually considered as standard for a power shovel, but swings of less than this are possible where ample space exists, or more than this where the work is "tight". Obviously, the cycle time is increased with increased angle of swing and less for the converse.

Figure 28. Two-axle rear-dump truck, 120-ton capacity. (Courtesy Sicard)

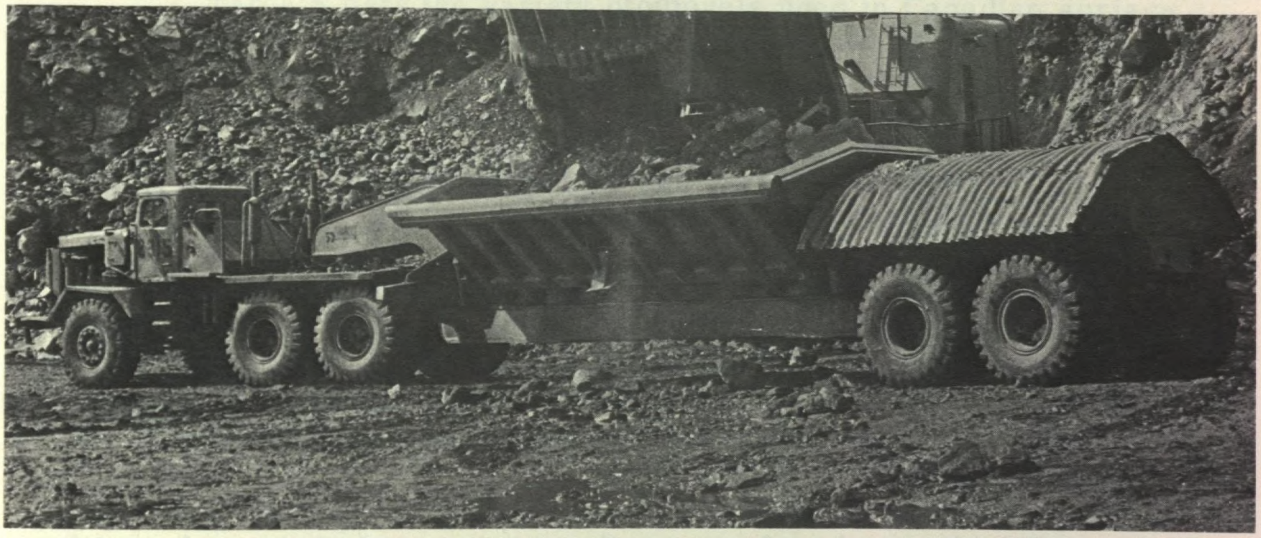


Figure 29. Side-dump trailer, 100-ton capacity. (Courtesy Iron Ore Company of Canada)

When ore or waste is in place, the space it occupies is referred to as "bank yards". When the material is blasted or otherwise loosened, the volume is increased a specific amount for each type of material. This increase in volume is known as "swell" and the final volume is referred to as "loose measure". Another factor which must be taken into account is the "fill factor" which refers to the approximate load the dipper actually carries expressed as a percentage of the rated dipper capacity. Normally, the fill factor will be higher where material is easy to dig and lower where digging is hard but, generally, about 0.85. However, where material breaks finely, the swell factors will be higher. As a general rule, fill factors are higher for large equipment and lower for small equipment.

When selecting shovels, therefore, the first step is to determine the minimum number needed and then to divide the required production between them. Given the expected production per shovel, a decision with respect to annual shovel shifts, and from this a required hourly production, a formula can be applied to determine the shovel size. One such formula is:

$$\text{Bank Measure, cu yd/hr} = \frac{(3{,}600)(C_d)(F)(A)(E)(S)}{t_s}, \quad \text{where}$$

C_d = Rated dipper capacity in cubic yards

F = Fill factor

A = Angle of swing correction (use only if conditions are unusual)

E = Efficiency (assumed)

S = Swell factor $\left[= \frac{100}{100 + \text{per cent swell}}\right]$

t_s = Cycle time in seconds.

To obtain the loose measure in cubic yards per hour, eliminate the swell factor (S) from the right-hand side.

From the above formula, the approximate size of shovel required can be obtained. Application of judgment here will usually result in a decision to purchase the nearest standard size which is slightly larger than that calculated. In the smaller shovel sizes, dipper sizes may increase in increments of 1/2 cubic yard but in the large sizes the increment may be 1 cubic yard or more.

Whether a shovel or any other equipment is being selected for an established mine, the most useful information about productivity will be the existing production records. Where these are available, it is relatively easy to extrapolate production data to predict performance more closely than by formula.

After the size of shovel has been determined, specifications can be written for the required equipment. At this time, it is desirable to include any other options which may be important to the specific mining operation before calling for tenders from manufacturers. Shovel specifications, illustrated in Figure 25, outline optional equipment that can be so assembled as to make a shovel suitable for unusual loading operations. Modifications to even these basic elements may be made to fit the requirements of a particular mine or to prolong the life of the equipment. For example, where the ore is abrasive, manganese steel dippers ought to be purchased instead of standard steel dippers and dipper teeth and track pads ought to be hard-surfaced. For northern operations, specifications may provide for parts of the shovel to be manufactured from high-alloy steels which will more readily endure low temperatures.

If front-end loaders are to be considered, their performance can be estimated in a way similar to that for shovels. Cycle times for loading with front-end loaders are usually considered in minutes because they are longer. One formula in common use is:

$$\text{Loose Measure, cu yd/hr} = \frac{60(C_b)(F)(E)}{t_m} \quad \text{where}$$

C_b = Bucket capacity in cubic yards

F = Fill factor

E = Efficiency (time utilization) and

t_m = Cycle time in minutes.

Table 5 lists the variety of shovels used in Canadian surface mines. Before large-scale mining of iron ore started in Canada, shovels of 3 to 4-cubic-yard capacity were common. The iron ore companies then selected 6 to 8-yard shovels and one company pioneered 10-yard shovels. The newer large non-ferrous mines in western Canada appear to have settled on 10 to 15-cubic-yard shovels and some surface coal mines have selected 25-cubic-yard units for waste stripping. It is understandable that larger loading equipment will show lower unit loading costs because hourly operating costs do not increase in proportion to shovel size as one moves to larger equipment. It appears that the large shovels will increase in popularity as Canadian surface mines become larger and can effectively take advantage of them.

Loading Performance

It is evident that two shovels, even if the same size, will not achieve equal performance. But in certain mining districts where different companies handle similar ore under like conditions, production rates tend to be consistent. Three general areas where this phenomenon is noted are the Eastern Townships of Quebec, the iron ore operations of Quebec-Labrador, and the Highland Valley area of British Columbis. It is possible, therefore, by grouping mines in which a particular ore has a stated daily production and in which shovels of the same size are used, to arrive at a rate of performance. Company records were used in compiling the tabulated information.

Size of shovels (cu yd)	Performance (cu yd/hr)	Type of ore and average daily production (cu yd)
4 to $6\frac{1}{2}$	125 to 140	Asbestos and iron ore 10,000
8	250 to 400	Iron ore 25,000
10	350 to 500	Iron ore 25,000
15	600 to 1100	Copper 50,000

The data should be used with caution because company policy, shovel idle time, ore composition, efficiency of material removal, shape of pit, manoeuverability of equipment, loading capacity, and operator proficiency all affect performance.

In summary then, one shovel could theoretically handle all the loading duty in a surface mine but, because of the need for working multiple faces, stripping, maintaining production during breakdowns and scheduled maintenance, the minimum requirement for continuous and economical operation, even at small mines, is two shovels. In addition, some standby loading capacity in the form of a shovel or suitably large front-end loader should be available for emergencies.

Loading Procedures

Loading procedures are designed to keep the shovel operating' at optimum efficiency without interruptions. Actual loading-cycle time includes digging into the pile, swinging the dipper over the haulage vehicle to deposit the load, then returning to the pile. Even if the very best practice is followed, it is not possible to load continuously without interruption because, eventually, the shovel will not be able to reach the material, or there may be some oversize material to be cast aside for secondary breaking. However, it is better that a truck than a shovel be waiting because of the higher hourly operating cost of the latter. A good shovel operator dresses the muckpile, scales the face, and moves up at such times as will result in a minimum of delay.

There are several points of view with respect to the most efficient methods of truck spotting at the shovel. The most common practice is to spot trucks alternately on each side of the shovel so that as one truck is being loaded another is being spotted on the other side. If a tractor were cleaning up at the time, it would work on the side where loading was not in progress, immediately before the empty truck was backed in. Loading of trucks on either side of the shovel ensures that the swing will be about 90 degrees.

Another truck handling technique is for the shovel to load along the bench and the trucks to come alongside in a continuous stream without backing up. Under favourable conditions, the angle of swing can often be less than 90 degrees. However, there usually is some spill and operations are occasionally held up while a tractor cleans up.

Loading operations are materially aided by attention to details which can prevent delays. For example, some foresight in locating trailing power cables so they will not interfere with truck movement is conducive to efficiency. An important matter is the working width allowed on active benches. Skimping on width can result only in cramped quarters for the shovel, delays in moving the haulage fleet, and difficulties in maintaining a clean workplace.

Loading Costs

Current prices for new Diesel shovels are from about $125,000 for dipper capacities of four to six cubic yards to about $250,000 for electric shovels with ten-cubic-yard dippers and about $400,000 for fifteen-cubic-yard units. This ownership cost, written-off over a shovel life of about 50,000 hours, is appreciable.

The hourly cost of operating shovels is even more significant. A serious difficulty occurs in comparing the hourly operating cost at different mines because of the nature of the ore and the degree of fragmentation. Company policy with respect to operating procedures, crew allotment, and maintenance exert an influence. Comparison of data indicates that shovels produced by certain manufacturers are more economical in certain areas. Relative costs of shovels at other operations may show opposite results. This leads to the conclusion that hourly operating costs are valid only for the specific conditions under which the shovel is operated. In general, larger shovels cost more per hour to operate than smaller shovels, but increased performance of larger equipment results in lower loading costs per unit of production. Hourly cost of operating shovels in Canadian surface mines appears to be between \$10 and \$60. Shovels in the 4 to $6\frac{1}{2}$-cubic-yard range cost between \$10 and \$26 an hour to operate; shovels in the 10 to 15-cubic-yard size cost \$40 to \$60 an hour.

Unit costs of loading vary appreciably in Canadian mines. Typical loading costs in selected mines, with equipment of certain sizes, are shown below.

Ore	Daily Production (tons)	Shovel Capacity (cu yd)	Loading Cost (cents/ton)(a)
Copper and uranium	15,000	4	7.0
Asbestos	40,000	5 to 6	6.0
Iron Ore	60,000	8	4.7(b)
Iron Ore	40,000	10	4.5(b)
Copper Ore	50,000	15	6.0

(a) Weighted average cost
(b) Estimated from other production data.

When shovels are efficiently operated and maintained, loading costs are largely determined by the size of the equipment and the suitability of the material being loaded. The total operating cost of loading includes labour, maintenance, fuel or power, lubricants, and the like.

Shovels in the 5 to 6-cubic-yard size, operating on iron ore, show a loading cost of 1 to 6 cents per ton mined. At one iron ore mine, labour (operation and maintenance) and parts each account for 40 per cent of the cost. At another, where 5 shovels in the 4 to 6-cubic-yard size were in use, repair parts averaged 55.5 per cent, labour 30.0 per cent, fuel and power 7.6 per cent, and miscellaneous 6.9 per cent.

Where 8-cubic-yard shovels are in use on an iron ore, unit loading costs are estimated to be 4 to 8 cents per ton. The indicated Canadian loading cost for 10 to 15-cubic-yard shovels is 4 to 6 cents per ton.

HAULAGE

Equipment

For moving the production from the shovel or loader at a surface mine to the next stage in the process, (i.e. crushing) choices of equipment can be made between haulage trucks of various types and sizes, skipways, and conveyors. Each type of transport equipment has its best application, and the essence of good design of the haulage system is to select that equipment which will result in the lowest overall costs.

In most surface mines, rock is hauled in ruggedly constructed off-highway rear-dump trucks. Highway-type equipment has to the present been considered unsuitable because it would not stand up to the rough usage. Tires on highway-type vehicles have been considered too small for mine service. However, one mining company is known to be experimenting with highway-type vehicles for mine haulage.

Off-highway end-dump trucks can be either two- or three-axle types, the selection being made according to the conditions of use. The small 2-axle unit (say up to 50-ton capacity) has a small turning radius; it is manoeuverable in confined spaces and can easily be switched from one work area to another. The small three-axle unit has almost disappeared from surface mine use, owing partly to tire costs.

The three-axle haulage unit, when built to a large size, usually has more power and speed than a two-axle unit. The additional axle imposes a requirement for ample turning space so that wear on tires will be reduced. The three-axle truck is safer when unloading over the end of a dump.

By the early 1960's, the average size of rear-dump truck used in Canadian surface mines was about 27-ton capacity. In recent years, the size has gradually crept up to about 50-ton capacity in small mines, and to 85-, 100-, 120- and 150-ton capacity in the large mines.

The very large trucks which are now coming into general use became practical with the development of sufficiently large power plants. From the 500 to 700-hp units which powered the medium-size trucks, power was provided to a total of 1,000 to 1,500 hp, distributed to motors in the individual wheels. The power units enabled trucks to climb steeper grades than formerly, thereby making truck haulage more economic in the deep mines. The ratio of payload to body weight of a haulage vehicle increases as the size of the vehicle increases, making the large sizes more attractive. Trucks of 200-ton capacity and larger, with power units of about 2,000 horsepower are now available.

The carrying part of rear dump truck bodies (boxes) are usually of heavy steel plate construction with a protecting extension over the cab. Some users pay particular attention to the weight of plate used in box construction because this affects the payload and the haulage economics. **Boxes** as supplied by the manufacturers are sometimes lined in the purchaser's shop with replaceable steel plates, cushioned on hardwood planks. Dumping edges subjected to heavy wear may be hard-surfaced. In some instances where the ore is not abrasive, aluminum truck boxes are used to reduce the truck weight and thereby permit increased payload. On most of the new large trucks, the bodies have been designed to place the centre of gravity of the load more centrally between the front and rear wheels. Typical haulage units are shown in Figures 28 and 29. Haulage units with a "Trolley assist" system are shown in Figures 30 and 31.

The side dumping trailer has been adopted in some Canadian mines. This vehicle is similar to the conventional end-dump truck, but the carried load can be spread over a larger number of axles without sacrificing the turning radius. The body can be provided with self-contained dumping cylinders, or can be dumped by cylinders and hooks at the dump. In Canada, the towing unit is the tractor portion of a standard 40-ton capacity off-highway truck. This power unit, towing a 100-ton load is not suitable for steep grades.

Bottom-dump trailers have not found a place in any metal mine, but are used in increasing amounts for coal haulage. Their turning radius is similar to that of side-dump trailers. Grades which can be climbed depend on the size of the power unit, but are usually kept below 7 per cent. A bottom-dumping trailer is most suitable for products (coal, asbestos) that must not be degraded through handling. They are also useful vehicles if the products such as coal produce objectionable dust.

The largest single maintenance cost item in the operation of haulage trucks is the cost of tires. It is desirable to consult with a tire manufacturer to determine ply ratings, inflation pressures, and maintenance procedures which will result in the lowest tire costs for the particular service.

A sufficient number of trucks must be available to ensure that despite haulage distances, the shovel, or other loader, will not be idle. The truck cycle time includes time for travel while loaded, for return while empty, for spotting, and for dumping; the time is increased by some factor to account for some inevitable loss of efficiency. A rule of thumb which is commonly used in surface mines is that 3 to 6 passes of the shovel should fill the truck. The minimum number of trucks (n_t) required per shovel can be calculated by the formula:

Figure 30.
Haulage truck equipped with trolley poles.
(Courtesy Quebec Cartier Mining Company)

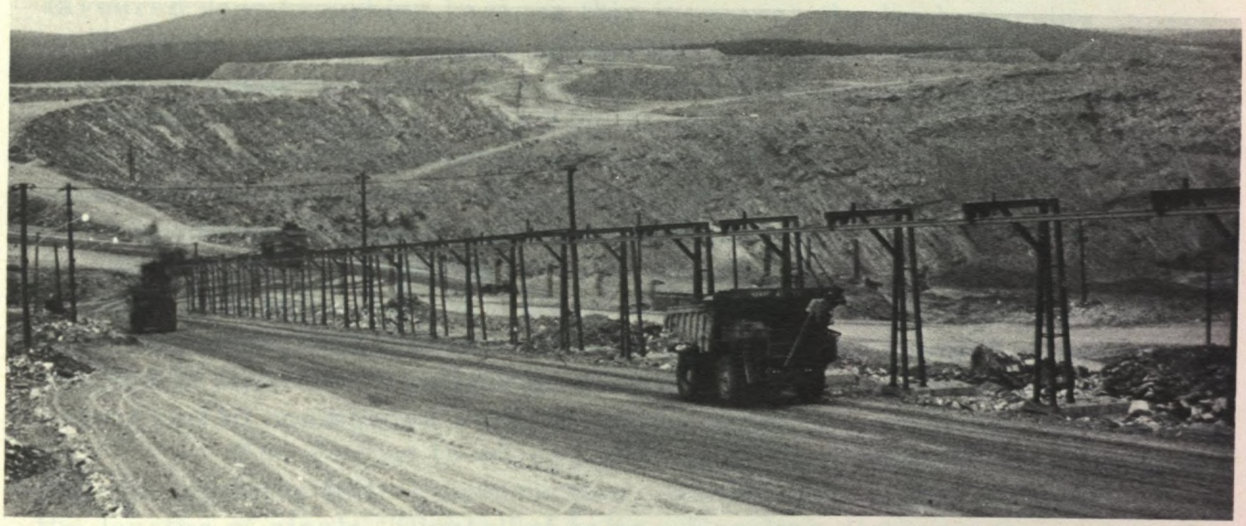


Figure 31. Trolley-assisted haulage on a 10-per-cent grade. (Courtesy Quebec Cartier Mining Company)

$$n_t = 1 + \frac{60\,(t_t)(A)}{(n)(t_s)}, \quad \text{where,}$$

t_t = the truck cycle time in minutes,

A = the angle of swing correction from 90° standard,

n = the shovel passes required to fill the truck, and

t_s = the shovel cycle time in seconds.

In addition to the trucks required for servicing a shovel, spare units must be on hand to ensure production without interruption during vehicle maintenance and to provide capacity during breakdowns. The number of spare units required is related to the availability of the trucks and to the severity of service as described by the number of operating shifts. Where single shift operation is in effect, availability may be as high as 80 per cent. Availability may be as low as 60 per cent on multi-shift operation.

It is not a good policy to skimp on the supply of spare vehicles because spare units entail only an ownership cost. They further provide opportunities to implement preventive maintenance programs which would otherwise be impossible.

In some mines it has been found advantageous to use skipways or conveyors over part of the ore haul. In recent years, the use of skipways has declined in response to the introduction of large trucks with superior power plants. The net effect of skipways and conveyors is to allow steeper wall slopes, hence to reduce the required waste excavation. The same effect is achieved by using haulage vehicles which can negotiate steeper grades.

All of the skipways observed in Canadian surface mines follow the same design principles. A headframe and hoist are installed at the rim of the mine and a dual railway is built along the slope. Downward rail extensions are added as required. Dumping platforms are constructed over the rails near the floor of the mine so that haulage trucks will have the minimum length of haul. Balanced hoisting is usually employed. After their downward motion, skips come to rest against rubber stop blocks backed with heavy steel beams placed so that the skip is in exact position for loading. Skipways are similar to inclined mine shafts, except that loading pockets are not usually provided on surface. The size of surface skips must, therefore, be large enough to allow acceptance of full truckloads, thereby eliminating delays.

Skipways are similar to haulage trucks with respect to dumping of material for ore or waste. However, for skipway operation, ore and waste bins are required at the dumping point if sorting is to take place.

Conveyor belts serve the same purpose as skipways long and costly hauls by slow Diesel-powered trucks are replaced by short and fast haulage-hoisting operations. Two factors must be taken into account when conveyor belt hoisting is contemplated: (1) the conveyor will probably not operate satisfactorily unless the conveyed material is pre-crushed, and (2) it is impossible to change rapidly from ore to waste and vice versa. Owing to the first factor, a crusher must be located near the start of the conveying system and owing to the second, only a specific product (ore or waste) can be handled at one time. Location of a crusher near the point of ore transfer from trucks to the conveyor has an advantage in that, as soon as the ore is crushed, it becomes easier to handle and productivity on succeeding handling improves. In the mine, crushing systems are, however, continually becoming more elaborate and, hence more costly. Further, because a conveyor operates efficiently only on a fine product, material rejected to waste would also have to be crushed before dumping. Conveyor haulage (or hoisting) from a surface mine is therefore applicable if a large volume of uniform crushed material is to be transported between fixed points.

A fixed conveyor is essentially a continuous belt supported on idlers, mounted on a platform or on cables which may be constructed to a maximum grade of about 16 degrees. Belts can be of various contructions depending upon the particular service requirement. A typical belt may consist of 6-ply, 60-ounce cotton and nylon with 5/16-inch rubber facing and 3/32-inch rubber backing. The idlers on the load carrying side are spaced about 4 feet apart and may be so constructed that either a deep or shallow trough is formed by the belt. Recent practice has favoured deep troughing because this increases the load carrying capacity of the belt. However, a deep trough requires more flexibility in a belt. Idlers on the return side of the belt are usually spaced at 10 or more feet.

Tension is maintained on the belt by a take-up device and the drive pulley, both usually located at the head of the belt. The load carrying capacity of the belt is partly dependent upon the tension which can be applied, so careful attention is paid to this point during belt design. A variety of hydraulic and other take-up devices are available for maintaining belt tension, however a simple gravity take-up is usually adopted because there is usually plenty of space.

The amount to which a belt can be tensioned for a given load depends upon the initial construction. Limits are therefore imposed on the lengths of single "flights" of belts. For long distances, a series of shorter belts with transfer points may be more economic. The need for extra personnel to man transfer points has been partly eliminated by closed-circuit television monitors. An advantage of multi-flight conveyor systems is the ease with which they can be made to change direction to avoid difficult terrain.

A relatively new conveyor system based on wire rope support has recently gained attention; wire ropes travelling on widely spaced pulleys support a specially constructed belt. The wire ropes and belt are independently tensioned, although both of them move together while carrying the load. Inasmuch as the belt is not supported by idlers, transverse metal straps are incorporated into the belt construction. There is a wide choice of belt lengths in a single flight as the main tension is in the wire ropes. There is also less need for uniform grading with this conveyor design.

Yet another haulage method used in one location for low cost transport is the aerial ropeway. By this method, towers support a cable on which buckets are suspended at regular intervals. During construction, the towers can be built to different heights, thereby permitting the system to operate over exceptionally rough terrain. The ropeway equipment can be used over steeper gradients than truck or conveyor transport and is most economical under some conditions.

There are two types of aerial ropeways; the mono-cable and bi-cable. The mono-cable type uses an endless rope that supports and moves the buckets, whereas on the bi-cable type, buckets are supported on a heavy stationary rope and pulled by a lighter, continuous rope. The one Canadian surface mining company that uses an aerial ropeway has decided to phase-out the system in favour of truck haulage.

Procedures

Wheeled haulage equipment used in selected Canadian surface mines is listed in Table 5. It is noted that trucks most commonly used in asbestos mines are of 50-ton capacity, but one asbestos mining company has chosen 100-ton capacity and larger trucks. As replacements to haulage fleets are made, the sizes selected appear to be larger.

Iron ore mining companies in the Labrador and Atikokan areas use 85 to 120-ton capacity vehicles. In other areas of Ontario and Quebec, 45-ton capacity rear-dumping trucks are most commonly used.

In the older surface mines in western Canada, rear-dumping primary haulage units of 35 to 60-ton capacity are in common use. For the operations which have recently started up, vehicles of 100-ton capacity and larger have gained acceptance.

Twenty-four 100-ton capacity semi-trailers are in use for haulage at the Iron Ore Company of Canada operations at Carol Lake in Labrador. The semi-trailers, drawn by 40-ton Euclid tractors, are operated on 4 per cent grades.

The most common grades adopted for haulage roads in Canadian surface mines are 8 to 10 per cent, the latter occurring most frequently where the newer large trucks with power plants of about 1,500 horsepower and up are in use.

Although high-power units do improve productivity, the additional capital costs and fuel consumption of such plants have tended to cancel some of the advantages. At the Lac Jeannine mine of Quebec Cartier Mining Company, tests have been conducted with trolley assist haulage. In this method, Diesel-electric trucks are switched to a trolley line for the haul out of the mine.

Developments under test conditions resulted in a trolley pole arrangement which could swing to a protected position under the box while the truck was being loaded.

The trolley assist haulage procedure then, is to haul initially under Diesel-generated power supplied to the wheels, each of which is a motor. When the major haul commences, trolley poles engage the power line and the Diesel engine switches automatically to "idle". At the top of the incline, the trolley poles disengage while the Diesel generator cuts in. Two view of the truck and trolley system are shown in Figures 30 and 31.

The main improvement in haulage productivity from the trolley assist system results from faster climbing. Data from mid-1961 indicate an improvement in productivity of 8 to 20 per cent on a 10 per cent grade.

In Canadian operations, slight modifications to design of haulage facilities and to haulage procedures are necessary because of the climate. Floor-heated garages may be provided for storage of vehicles and for all except the most minor maintenance. Engine exhaust is discharged directly underneath the tailgates to prevent ice build-up. Block heaters ensure rapid, trouble-free starting. These preparations are compensated for by the ease with which excellent haulage roads can be maintained at freezing temperatures.

Whether mining is done in summer or winter, careful attention is paid to design and maintenance of mine roads. Roads are laid out to standard widths and grades, usually with special surfacing. Grading equipment is used continuously. Specifications of haulage roads in selected Canadian mines are shown in Table 6. It should be noted that the widths shown in the second column of the table are travel surfaces. The overall

TABLE 5 - SELECTED CANADIAN SURFACE MINES, 1972 - SHOVEL AND TRUCK DATA

Reference	Primary Loading Units			Auxiliary Loading Units			Primary Haulage Units			Auxiliary Haulage Units		
	No.	Model	Dipper Size cu yd	No.	Model	Size cu yd	No.	Model	Nom. Capacity tons	No.	Model	Nom. Capacity tons
Iron and Associated Mines												
Caland	2	Shovel	6½	1	Shovel	4½	8	Rear dump	65	4	Rear dump	45
	1	"	6				3	"	75			
Sherman	3	"	7	1	"	8	7	"	60	-	-	-
				1	F.E. Loader	13	6	"	85	-	-	-
Griffiths	4	"	6				15	"	45	-	-	-
Hilton	-	"	4½	-	-	-	18	"	45	-	-	-
Schefferville	5	"	10	1	Shovel	6	15	"	120	8	"	35
	3	"	6				5	"	120			
Carol	8	"	10	6	Shovel	6	24	Side dump	100	9	"	30
										2		42
Adams	5	"	6	-	-	-	12	Rear dump	45	3	"	50
Marmoraton	3	"	6	1	Shovel	6	6	"	105	2	"	55
	1	"	11									
Moose Mountain	-	"	5½	-	F.E. Loader	5	6	"	47	1	"	52
	1	F.E. Loader	8-10									
Cartier	6	Shovel	10	1	F.E. Loader	13½	10	"	85	5	"	85
	2	"	8				7	"	100			
Lac Tio	1	"	5	1	F.E. Loader	6	11	"	45	-	-	-
	2	"	4	1	"	7½						
Steep Rock	2	"	4½	1	Dragline	7	8	"	100	-	-	-
	1	"	6				11	"	85			
	1	"	9	1	Shovel	4½						
	1	"	10									
Wabush	7	"	8	2	F.E. Loader	6	9	"	100	1	"	100
							3	"	150			
Westfrob	1	"	7	1	F.E. Loader	5½	8	"	35	-	-	-
	1	"	4½									
Advocate	2	Shovel	8	1	F E. Loader	10	16	Rear dump	50	-	-	-
	1	"	5½									
	2	"	4				6	"	50	-	-	-
P-C	5	"	6	2	Shovel	4	32	"	45			
	4	"	5	1	F.E. Loader	10						
K-B	2	"	6	2	Shovel	3	18	"	45	3	Rear dump	45
	1	"	5	1	F.E. Loader	10						
	1	"	4	1	"	9						
Normandie	-	"	5				7	"	45			
							7	"	37			
Jeffrey	5	"	15	5	F.E. Loader	-	13	"	120	26	"	35
	3	"	8-10				12	"	100	3	"	50
	7	"	6				4	"	200			
Reeves	2	F.E. Loader	10	2	"	6	7	"	35			
							2	"	50			
Carey	2	Shovel	6	1	"	12	8	"	50	2	"	37
	1	"	4½				4	"	37			
Cassiar	1	"	5	1	Shovel	2½	4	"	50	2	"	35
	1	"	3½	1	F E Loader	10	3	"	40			
Clinton	1	"	5½	1	Shovel	2½	8	"	65			
	2	F.E Loader	10	1	F.E. Loader	10						
Lake	4	Shovel	4½	1	"	6	17	"	48			
	2		[illegible]	[illegible]		[illegible]	[illegible]		40	[illegible]		[illegible]
National	-	"	4½	1	Shovel	6	5	"	45	1	"	22

National	-	"	4½	1	Shovel	6	5	"	45	1	"	22
Non-Ferrous Metal Mines												
Anvil	-	Shovel	5	-	F.E. Loader	10	15	Rear dump	65	1	Rear dump	85
Bethlehem	3	"	5½	3	"	12	17	"	50			
Brenda	3	"	11	1	"	15	12	"	100	-	-	-
Brunswick	2	"	5	1	"	10	5	"	70	9	Rear dump	45
							4	"	50			
Tungsten	1	"	3½	1	Shovel	1½	6	"	22			
	1	"	2½									
Ecstall	2	"	6	3	F.E. Loader	10	20	"	50			
	3	"	4									
Gaspe	3	"	15	1	Shovel	8	12	"	100	5	Rear dump	50
				1	"	4	6	"	85			
Gibraltar	3	"	14	-	"	-	13	"	100	1	"	150
Phoenix	1	"	5	1	F.E. Loader	3 to 5	6	"	34	2	"	34
	1	"	4½	1	Shovel	2½						
Granisle	2	"	5	1	F.E. Loader	6	8	"	50	-	-	-
Clarabelle	2	"	6	1	"	10	17	"	35	-	-	-
Pipe Lake	1	"	8	1	"	12	8	"	65	-	-	-
	1	"	8									
Lornex	4	"	15	-	-	-	22	"	120	-	-	-
Pine Point	1	"	5	1	F E Loader	10	18	"	50	4	Rear dump	35
	1	"	7				1	"	150			
	1	"	9									
Endako	1	"	13	1	Shovel	5	10	"	85	-	-	-
	1	"	8									
Similkameen	4	"	10	-	"	-	15	"	100	-	-	-
Island Copper	3	"	15	-	"	-	25	"	120			

width of the roads is usually greater.

Numerous expedients are adopted to control dust. At some mines, tank trucks keep the roads wet at all times during the summer; other mining companies prefer to spray waste oil occasionally. In the Eastern Townships of Quebec, some of the asbestos mining companies use calcium lignosulfinate as both a surface binder and a compaction aid that practically eliminates dust. A by-product of the paper industry, calcium lignosulfinate is mixed with water and sprayed at a rate of 0.1 gallons of 25 per cent solution per square yard of road.

Some mining companies provide paved roads on part of the ore haulageways and have reported improved performance and less maintenance to vehicles. A paved road has been provided from the mine to the crusher at the Clarabelle mine of The International Nickel Company of Canada, Limited. At Asbestos, Quebec, Canadian Johns-Manville Company, Limited has achieved good results with a paving mix of asphalt and asbestos fibres.

Two main methods of utilizing belts have been employed in surface mines: crusher-belt systems at individual mines and long-belt systems from mining areas to screening and loading plants. The crusher-belt systems were most widely used in Labrador-Quebec and the long-belt at Atikokan.

During 1962, the Gagnon, Ferriman, French, Ruth Lake, and Wishart mines of the Iron Ore Company at Schefferville were operated approximately at capacity. At three of the mines, screening plants were in operation near the mine floor and at two, the plants were located at the rim. Crushed ore was conveyed from screening plant up a 15- to 16-degree slope to rail-car loading plants near the rim. Conveying systems at the different mines were approximately standard.

Early belts at Schefferville were 36 inches wide, supported on 20-degree troughing idlers. Although spoil and maintenance were not excessive, experience indicated that substantially less attention would be required if the belts were wider. After tests, a change was made to 48-inch wide belts and 35-degree troughing idlers. Gravity take-up was used exclusively. At speeds of 600 feet per minute, 48-inch belts were adequate to remove up to 1,800 tons per hour. All belts were 6-ply, 60-ounce, cotton and nylon, with 5/16-inch rubber facing and 3/32-inch rubber backing. Crushers and belts in use during 1962 are shown in the accompanying table.

TABLE 6 - SELECTED CANADIAN SURFACE MINES, 1972 - HAULAGE DATA

Reference Name	Minimum Road and Ramp Width (ft)	Maximum Grades (per cent)	Estimated One-Way Haulage Distance (ft)		Estimated Overall Truck Performance (tons/truck hr)	
			Ore	Waste		
Iron and Associated Mineral Mines						
Caland	80	10	4,000	6,000	170(o)	160(w)
Sherman	80	8	7,500(est)	2,500	-	-
Griffiths	70	10	5,700	2,500	80(o)	-
Hilton	55	10	6,500	9,500	114(o)	-
Schefferville	80-90	7	2,500 av.	4,000 av.	580(o)	500(w)
Carol	65-90	4	7,000 av.	3,500 av.	270(o)	160(w)
Adams	80-100	10	3,000	3,000	-	-
Marmoraton	80	10	5,300	8,600	-	-
Moose Mountain	60-80	10	4,750	1,600	165	
Cartier	60	8(1)	2,500 est.		-	
Lac Tio	40	7	4,300	6,050	103	
Steep Rock	70	10	9,400	10,500	110	
Wabush	120	5	5,000	short	-	
Westfrob	50	10	800	1,200	-	

(1) 10% on portions of grade which are trolley assisted.

Reference Name	Minimum Road and Ramp Width (ft)	Maximum Grades (per cent)	Estimated One-Way Haulage Distance (ft)		Estimated Overall Truck Performance (tons/truck hr)	
			Ore	Waste		
Asbestos Mines						
Advocate	80	10	3,500	5,000	-	
B-C	50	10	5,600	8,200	130	
K-B	50	10	-	-	-	
Normandie	50	10	13,000	15,000	-	
Jeffrey	85	10	6,000	10,000	-	
Reeves	50	10	4,400	3,000	-	
Carey	80	8	3,600	5,600	170	-
Cassiar	40	10	1,200	2,000	-	
Clinton	50	10	-	-	-	
Lake	70	8	6,000	8,350	-	
National	50	8	-	-	-	
Non-Ferrous Metal Mines						
Anvil	40-60	8	5,200	4,600	285(w)	250(o)
Brenda	80	8	3,800	3,800	-	
Brunswick	-	7.5	-	-	-	
Tungsten	50	10	16,000	900	40(o)	
Ecstall	60	10	5,200	5,200	112	
Gaspe	100	8	-	-	-	
Gibraltar	80	10	2,100	1,600	400	
Phoenix	50	10	3,300	3,000	108	
Granisle	60	10	3,600	5,800	-	
Clarabelle	50	10	3,500	6,500	103	
Pipe Lake	-	8	-	-	-	
Lornex	80	8	6,500	5,500	-	
Pine Point	60	8	2 to 7 miles	5,000	100(50t)	188(150t)
Endako	80	10	-	-	350	
Similkameen	65	10	4,000	5,000	-	
Island Copper	-	-	5,300	-	-	

(o) = ore
(w) = waste

Mine	Crusher	Belts Width, inches		Length, feet
Ruth Lake	36" x 72" single roll	36		600
Gagnon	48" x 72" single roll and N.V. 500, single rotor	36 48	and	396 675
Wishart	N.V. 500 single rotor	48		410
French	48" x 72" roll (primary) N.V. 500, single rotor (secondary)	48 36	and	1,033

The crushing and loading plants at Schefferville consisted of two major facilities: the screening and crushing plants in the mine bottom and the rail loading facilities at the top. The facilities were joined by fixed conveyors up the sides of the mines. Drive-through trucks dumped their loads directly over 60-ton storage bins at the crushers with practically no loss of time. At the railway loading plants, the installations were provided with 72-inch wide shuttle belts.

The crusher-conveyor systems which were in use at Schefferville during the 1960's operated efficiently. However, one of the problems with installations of this type was the need to frequently move the crusher to lower elevations as the mines were deepened. Such movements were costly and resulted in reduced production from a given mine while a changeover was made. In addition, if for any reason the mine was not operated to capacity, the crushing-conveying system was partly idle. Further, the advent of larger haulage vehicles with superior power plants, made longer hauls more economic.

Although essentially the same crushing and conveying equipment is in use, the more recent procedure is to install the facilities on the rim of a mine, or at a central point between two mines. By hauling to this central point, greater utilization of the expensive facilities is possible and costly construction incidental to movement of crusher location is eliminated. An example of recent practice appears in Figure 32 which shows the crusher station, haulage belt, and rail haulage facilities.

At most of the large surface mines, haulage vehicles (and other equipment) are equipped with two-way radio communications so that rapid changes in assignments can be made.

Long conveyors were formerly in wide use in the Atikokan area of Ontario for moving ore to screening plants. The current practice is to rely on trucks for hauling to stockpiles where the appropriate blending can be achieved before transporting further.

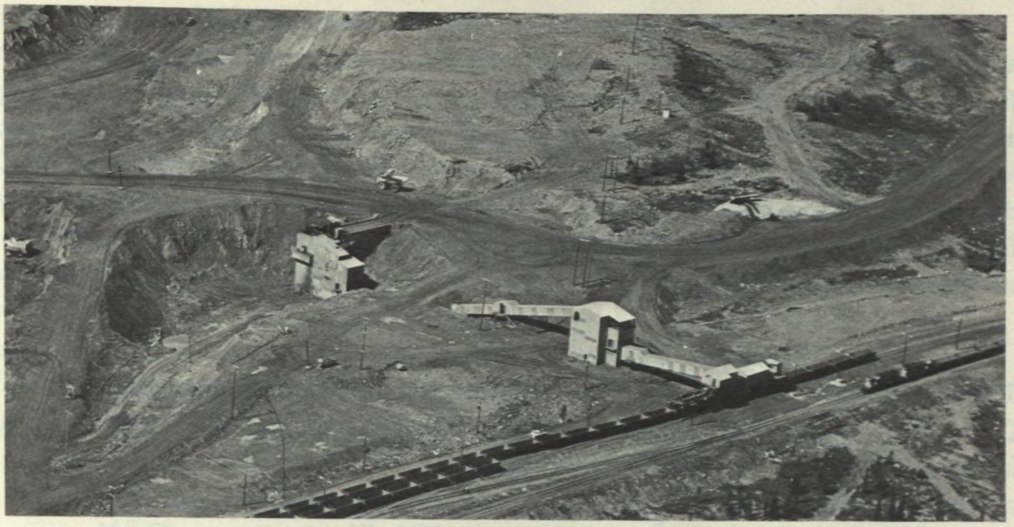


Figure 32. Ore crushing, conveying and rail-car loading facilities. (Courtesy Iron Ore Company of Canada)

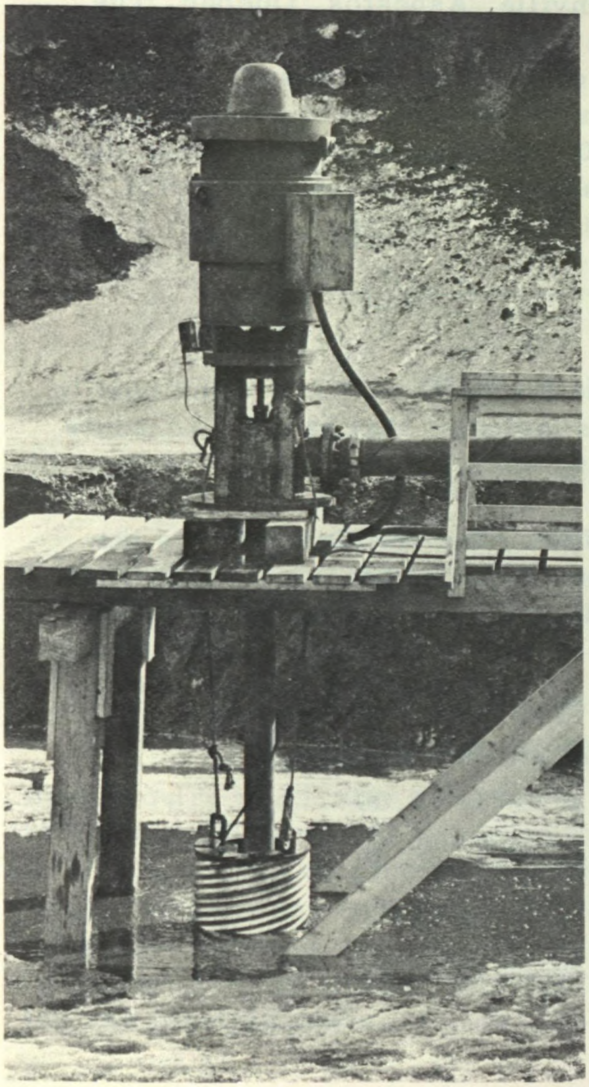


Figure 33. Sump pump setup. (Courtesy Iron Ore Company of Canada)

A conveying system which is no longer in use attracted considerable attention during the surface mining at the Craigmont mine near Merritt, B.C. This installation was the first known North American application of a rope-supported, cable belt gravity conveying system. The installation was approximately 5,700 feet long in a single stage, installed at an average downhill grade of 9 per cent. The ore was lowered approximately 1,000 feet vertically and its weight generated about 350 horsepower, sufficient to operate the crushing plant.

Skipways enjoyed a brief period of use in several Canadian mines. The first installation was at Marmoraton Mining Company Ltd., Marmora, Ontario. This unit was built on a 45-degree incline, 240 feet long, and was later extended. A 1,250-horsepower, double-drum hoist hauled two 22-ton-capacity skips in balance. A similar but smaller skipway was used for a period at Flintkote Mines Limited, Thetford Mines, Quebec, and a short skipway with 34-ton ships was used at Steep Rock Iron Mines, Atikokan, Ontario.

Separate skipways for both ore and waste were installed in 1961 at the Jeffrey mine of Canadian Johns-Manville, Asbestos, Quebec. The skipway, using 35-ton skips in balance on a 45-degree incline, was eventually extended to 1,100 feet as the depth of the mine increased. Hoisted ore was crushed in a headframe at the rim of the mine before it was conveyed to the mill. Storage capacity of 300 tons was provided between the skipway and crushers. With the appearance of larger, more powerful trucks, the skipways are being phased out.

Costs

Haulage usually represents the largest single operating cost in surface mining. Data from several mines indicates that haulage accounts for 30 to 50 per cent of total mine operating costs.

Where haulage is done by vehicles, the critical figure is the hourly operating cost. Examination of considerable data of this type indicates that, for Diesel trucks of various sizes, operating costs are generally within the following range:

Vehicle Capacity (ton)	Operating Cost ($ operating hour)
34 to 40	10.00 to 28.00
45 to 50	12.89 to 25.00
65 to 85	28.85 to 30.00
100	30.00 to 35.20

Of the costs shown above, the majority of Canadian surface mines are nearer to the lower range. Some northern mining companies have reported hourly operating costs at and near the upper range.

Conversion of hourly operating costs to unit haulage costs is difficult owing to the wide differences in grades, road conditions, and haulage distances. Some haulage costs are shown below, however the conditions under which haulage occurs are so different that no distinct cost pattern can be observed.

Truck Capacity (tons)	Haulage Distance (feet)	Cost per Ton Hauled (cents)
34	3,300	14.2
45	12,000	20.4
	5,600	20.2
	4,300	25.0
	7,700	23.3
50	3,500	24.5
	3,600	12.0
65	5,200	12.8
100	3,800	36.4

SUPPORTING OPERATIONS

Drainage

Drainage systems vary with the extent of water flow and the topography of the mine area. Several Canadian surface mines are located on hills where ditches along the roads and ramps satisfactorily provide for surface runoff. Iron ore mines on the Pacific coast and a few mines in eastern Canada are examples.

Even though drainage may be a minor item at some mines, it may require particular attention if the stability of slopes or roads is affected by moisture. Drainage problems can be particularly acute in the mining of earthy or structurally weak ores at some iron ore mines in Quebec-Labrador and near Atikokan. Special attention to moisture control is also necessary in some asbestos mines; but fortunately, where additional expense is incurred for drainage and slope control, it is often offset by lower drilling and blasting costs.

In yet other mines, though stability is usually unaffected by water owing to the competence of the ore and waste, adequate provision must still be made to handle seasonal run-off that may wash away road dressings. A typical example is the mine of the Marmoraton Mining Company Ltd., at Marmora, Ontario.

One would expect that drainage would present a formidable problem where surface mines are located in drained lake beds. This is not so at Atikokan or Black Lake where substantial dredging was done before mining commenced.

In some mines, the fortuitous presence of underground workings has been utilized to assist in drainage of the surface mine. An example of this situation exists in the Steep Rock Iron mine. Some diamond drill holes have been drilled from the underground workings to intercept the surface mine and the water is pumped out via the mine shaft.

During the spring break-up, sump pumps are pressed into service for handling the excess water. One main sump is located on the crest of the South Roberts pit to intercept water running down the ore ramp, and smaller sumps are provided elsewhere as necessary. Small gasoline or electric sump pumps are used to pump the water either out of the surface mine or to areas where it will drain to the underground mine.

In Schefferville, where earthy ores are also mined, most of the workings are below the water table. Excess water caused ore-handling problems, poor operating conditions, lowering of shipping grades, and eventually would have contributed to unstable wall slopes. Small sumps fitted with 250-gallon-per-minute pumps were used as a temporary measure. A sump pump set-up is illustrated in Figure 33. A large-scale program was devised to solve the seepage problem: wells about 250 feet deep and 12 to 18 inches in diameter were churn-drilled into the mine floors and fitted with 250-, 1,000-, or 2,000-gallon-per-minute vertical turbine pumps connected directly to discharge lines leading out of the mine. Two or three wells were adequate initially to lower the water table when new benches were established, but as the workings became deeper, more wells were needed. The worst situation was encountered in one mine where 14 holes were drilled. When the location was inspected, 12 of these 'wells' were fitted with pumps that were handling a total of 7,000 gallons per minute. The procedure of sinking wells to lower the water table appears, under certain conditions, to be an effective method of water control and results in economies in haulage and pit maintenance.

The drainage and pumping system which was installed at Marmora is worthy of note. Two pumps were installed on the 230 level, 410 feet below ground elevation. The permanent pump station had open metal walkways, overhead covers, and conveniently located electrical controls. Water was discharged through a 10-inch victaulic pipe hung on the wall of the pit. Movable submersible pumps, 110 feet below, discharged into the main pump sump.

In some areas along the Pacific coast where sidehill drainage cannot be used, exceptionally heavy rainfall necessitates a large standby pumping capacity. Fortunately, all the mines in this area have competent walls, so slope stability is not a serious problem.

In the interior of British Columbia, in the Highland Valley copper area, only a minimum of pumping is required because rainfall is not excessive here; however pumping is necessary when it does rain also during spring break-up and when sinking.

Power Supply

Electric power is used in Canadian surface mines for operation of drills, shovels, crushers, pumps, and sometimes for haulage. All of the major Canadian surface mines are serviced with electric power. In large mines, a specially constructed plant is often provided; these can be seen at the newer iron ore mines. At other mines, power is purchased directly from the nearest utility that can provide the service. The cost of purchased power to large users is believed to be between 3 and 10 mills per kilowatt hour.

Three methods of power distribution are noted in the immediate mine area. Some companies prefer to install a high-voltage line along one side of the mine and transform the power at selected points to the voltage required for operation of the equipment. Other companies, more concerned with the cost of power interruptions, circle the pit with a continuous line connected to transformers on a high-voltage source. One instance is known where the mine is circled by two complete loops, the outer carrying a higher voltage.

National Steel Corporation of Canada, Limited, near Capreol, Ontario has a typical power layout. Power is obtained at 44,000 volts from the Hydro-Electric Power Commission of Ontario. Connected horse-power for the mine and mill is 14,000. Major mine equipment operates at 4,160 volts. A 4,160-volt line is installed along one side of the mine and two take-off points are provided.

At the Hilton mine, Bristol, Quebec, the distribution system is similar to that at Capreol but with three take-off points.

The main source of power for the Schefferville mines of the Iron Ore Company of Canada is the Menehik power plant, approximately 25 miles from the iron ore mines. Three generating units at the Menehik plant have a total capacity of 22,000-kVA at 6,900 volts; power is transformed to 69,000 volts and transmitted to Schefferville on two lines supported on wooden H frames.

A typical power distribution system that has been used in an iron ore location is illustrated in Figure 34. By means of this system, power is received at 69,000 volts and transformed to 4,160 volts for use in major mine equipment. The loop around any mine can be isolated by sections for maintenance and repairs.

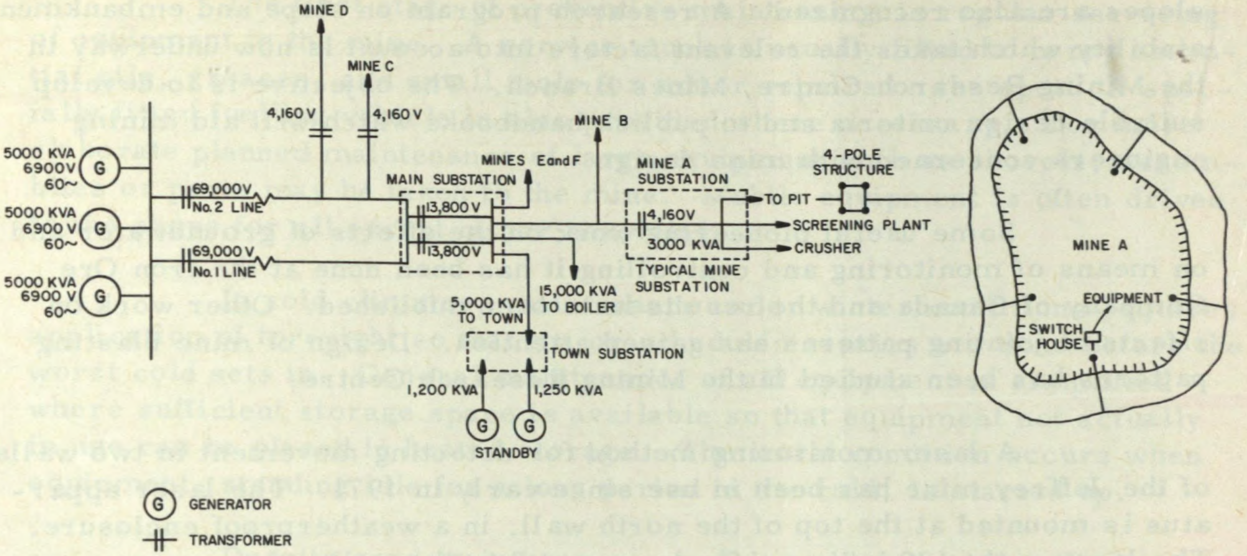
In another eastern Canadian mine, the power plant can provide a total of 66,000 horsepower from three generators. Two generators are adequate for normal operation of all facilities; they produce power at 13.8 kV which is stepped up to 138 kV for transmission to the mine over nine miles away. Transmission is by two circuits carried on a single row of steel towers.

At the mine substation, power is distributed to the mill, mine, and townsite. The townsite is served by a six-mile line mounted on wooden poles. In the immediate mine area, power is distributed in approximately the following proportions: 25,000 hp to the mill, 8,000 hp to the mine, 2,000 hp to the shop, and 5,000 hp to the townsite and other facilities. Two complete power lines circle the pit: the outer loop at 13,800 volts and the inner at 4,160 volts. The step-down transformers are mounted on the outer loop. From the inner loop, extensions are made to terminal switches strategically located in the mine for connection of portable trailing cables.

For the trolley-assist haulage system that has been tested at Quebec Cartier, steel towers, spaced at 40 feet, carry two aluminum bus-bars 26 feet above the road surface. A 5,000-kW transformer and static rectifier system were installed to provide DC power at a maximum of 850 volts (but initially adjusted to 780 volts). The steel towers have cantilevered arms which reach 11 feet horizontally from the concrete bases. This allows haulage vehicles to deviate 5 feet to either side of the centre line of the bus bars while still leaving a minimum clearance of 3 feet from the tower bases.

Monitoring of Slopes

There is now an intense interest in slope stability in Canadian mines. It is recognized that some of the factors which affect stability are: residual stresses, wall slopes, jointing patterns, blasting effects, and groundwater. The economic effects of stripping waste to specific wall



SINGLE LINE DRAWING. SWITCHES. CIRCUIT BREAKERS AND FUSES OMITTED

Figure 34. Typical power distribution system.

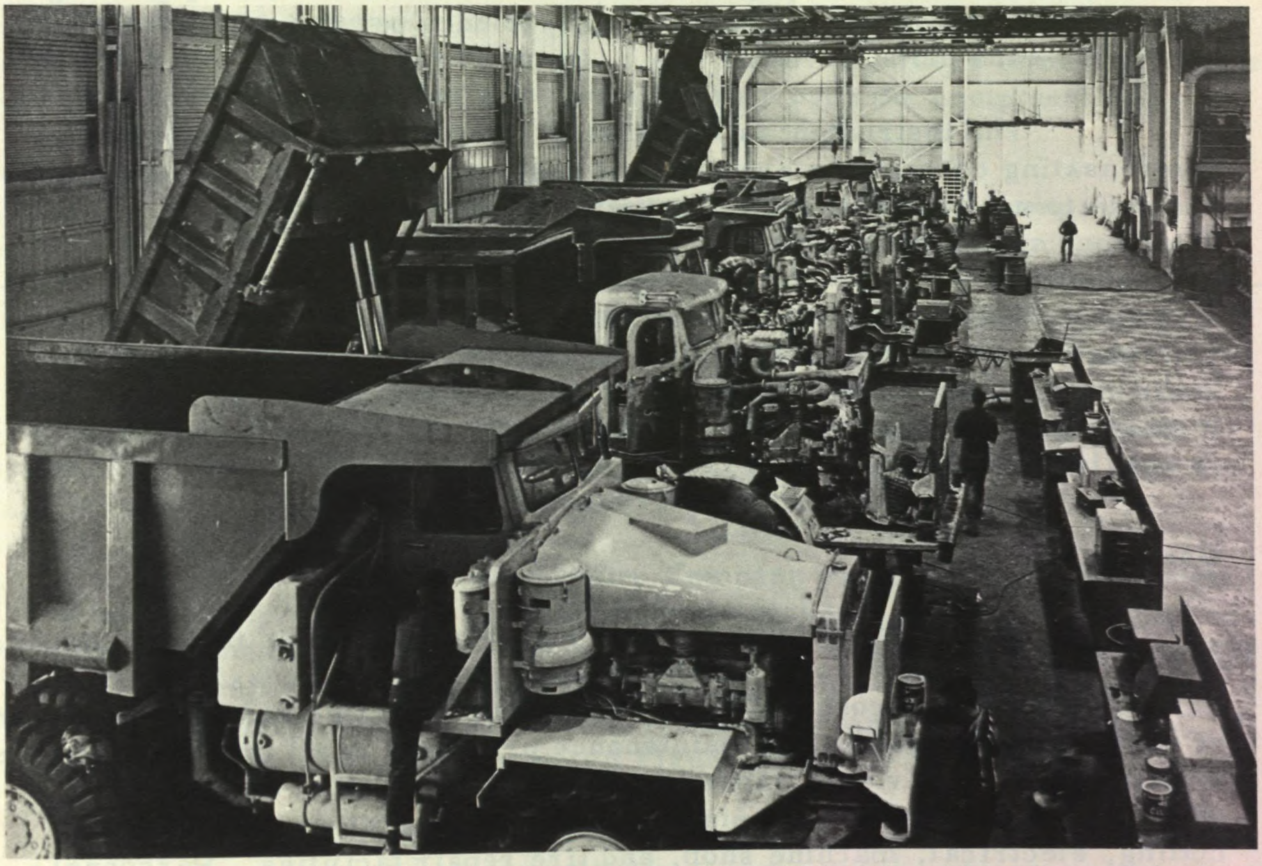


Figure 35. Servicing vehicles in the Schefferville shop. (Courtesy Iron Ore Company of Canada)

slopes are also recognized. A research program on slope and embankment stability which takes the relevant factors into account is now underway in the Mining Research Centre, Mines Branch. The objective is to develop suitable design criteria and to publish handbooks which will aid mining engineers concerned with mine design.

Some useful pioneering work on the effects of groundwater and on means of monitoring and controlling it has been done at the Iron Ore Company of Canada and the results have been published. Other work on effects of jointing patterns has gained attention. Design of mine blasting patterns has been studied in the Mining Research Centre.

A laser monitoring method for detecting movement in two walls of the Jeffrey mine has been in use since early in 1971. The laser apparatus is mounted at the top of the north wall, in a weatherproof enclosure. The laser sights 20 prism reflectors, set into the walls where movement monitoring is required. The instrument is simple to use; a surveying assistant takes the readings every second day.

The accuracy of the instrument is 1 in 25,000. The largest sighting is 4,000 feet, giving an accuracy of 2 inches. However, the main use of the instrument is in revealing movement trends, found by plotting the readings. Movements greater than 1/16-inch per day are revealed quickly by such plots.

The instrument is sensitive to temperature and pressure, so compensating corrections are made; it has proven reliable, convenient, and safe to use. Once targets are installed, no further access to possibly dangerous slopes is required.

Movements of the laser itself are checked by sighting onto a reference point away from the mine. With further development work the laser instrument will be an invaluable tool for the mine operator because it makes possible the safe, convenient monitoring essential to the location of wall instability.

Maintenance

Most surface mine operators will readily agree that maintenance is the most important single auxiliary function in any successful mechanized mining plan. The recognized importance of this function has led to adoption of comprehensive preventive maintenance programs in all Canadian surface mines. This has involved extensive outlays on facilities, on training of personnel, and on record keeping. The shops generally include welding, cutting, electrical, machine shop, and tire repair facilities. Personnel employed on maintenance are usually highly skilled and their number may exceed those on direct production.

The first stage of preventive maintenance is regular servicing of equipment in the mine. A service truck is usually fitted to carry essential oils, greases, and small tools for minor repairs on the spot. A specially fitted fuelling vehicle is also provided where necessary. For more elaborate planned maintenance of large equipment such as shovels, assemblies or parts may be taken to the mine. Mobile equipment is often driven to the shops for all except minor servicing.

In cold climates, maintenance under winter conditions requires application of foresight so that major scheduled repairs are done before the worst cold sets in. General maintenance of all equipment is simplified where sufficient storage space is available so that equipment not actually in use can be placed in heated storage. The worst condition occurs when equipment, standing idle for a long period in the cold, is started up.

Despite good maintenance schedules which take the climate into account, breakdowns due to unforseen conditions do occur, and repairs must be made in spite of the weather. Welding is exceptionally difficult during intense cold. The procedure then is to move the equipment to a heated shop for repairs. It may not be possible to do so, depending on the particular breakdown. The usual procedure then is to provide some temporary protection for the maintenance crew while the equipment is made mobile and then tow it into a shop for completion of repairs. This procedure is not possible with very large equipment, i.e., a shovel. There is no alternative, in this case to constructing a temporary cover over the equipment and heating it while completing the repairs.

To achieve success in preventive maintenance, comprehensive record-keeping systems have been instituted in Canadian surface mines. The assemblage of check lists, records of service and mechanical performance data on individual pieces of equipment is impressive. Most commonly adopted equipment maintenance programs are based on hours of operation. At specified periods, certain steps in the program are followed. Typical maintenance schedules for trucks may call for greasing and suspension inspection every 24 hours of operation, wheel inspection and repacking every 1, 100 hours, and engine overhaul every 5,000 hours.

The operations of Iron Ore Company of Canada at Schefferville, Quebec are representative of facilities and procedures provided at the large iron-ore mines in Quebec-Labrador. Each mine has a garage that provides servicing and light repairs for its equipment. Repairs beyond the means of individual mine garages are completed in the main shops. A typical maintenance activity is illustrated in Figure 35.

The maintenance facilities and systems adopted by Cassiar Asbestos Corporation Limited at Clinton Creek, Yukon, are representative of the medium-size mines. A mobile lubrication truck is used for servicing equipment in the mine. A 600-ampere portable gas-powered welder is available for mine service. Repairs beyond the capacity of the mobile crew are completed in the shop which has about 11,000 square feet of floor space including 12 bays. Cranes of 3 to 25-ton capacity are available. The main garage is heated by hot water piping in the concrete floor.

All equipment is inspected daily in the field at which time operators' log books are checked and minor repairs and adjustments made. A weekly inspection is made in the shop of all units except shovels and drills. Oil and filter changes are made on all units during the weekly inspection. Major repairs are planned, for example, such as changing and overhaul of engines and transmissions on haulage vehicles at 7,000 and 5,000 hours respectively.

Isolated small surface mines usually have maintenance facilities comparable to those at medium surface mines. The extent of major repairs that will normally be undertaken is related to the distance from industrial centres. For example, the extensive facilities provided for a 2,000 tons-a-day operation in northern Saskatchewan, compared favourably with the facilities found at many large operations. The company could handle practically any repair or overhaul job.

Operations at Canadian surface mines fully justify the facilities provided for preventive maintenance. Average mechanical availability of over 80 per cent for tractors and shovels, and almost 80 per cent for haulage vehicles is usual.

OPERATING COSTS

Labour and Wages

Surface mine operators are fortunate in that the labour share of the total mining cost is usually more readily predictable than in underground mining. It does not follow, however, that labour content will always be less in surface mines, but, generally, the low cost of labour per production unit is one of the major advantages of the method. Although at some mines, labour cost ranges up to 50 per cent of total cost - matched by some underground mines - it would be rare to find labour costs of 60 to 75 per cent in surface mines; these are usual for underground mining.

The last year for which complete cost data was available is 1970. A survey for this year shows the following:

Operating Costs per Ton of Ore and Waste Broken

	Surface Mines		
	Asbestos	Iron Ore	Non-Ferrous Metals
Number of mines analyzed	10	10	9
	$	$	$
Explor. and development	0.10	0.19	0.08
Mining	0.61	1.31	0.37
Milling	0.63	1.02	0.44
General	0.54	0.37	0.18
Depreciation	0.68	1.36	0.23
Total	2.56	4.25	1.30
Labour, per cent of total	27	13	26

Note that the costs shown above are the average costs distributed over the total material (ore + waste) which was mined. Data in each of the vertical columns above are not directly comparable owing to differences in practice within specific segments of the mining industry. For example, the total mining cost as shown is affected by the ratio of waste to ore mined. In asbestos mining, the average ratio for 1970 was about 1.4, whereas in iron ore mining it was about 1. The average ratio for non-ferrous mines was considerably less than 1 during 1970. In addition, the high charges for materials handling and stockpiling are reflected in the data for iron ore mines. The data above do show, however, the small part of total costs which are required for labour, in such a capital intensive industry as surface mining.

The relatively small crews employed in surface mines makes supervision less difficult than in underground mining. Small numbers make for easier implementation of employee training programs. Labour policies based on constant training and up-grading of employees contribute to the excellent safety records enjoyed in Canadian surface mines. New employees normally progress from one occupation to another, commencing as general mine labour, through truck spotting, driving, and so on, until a position of shovel operator is reached. Comparable progressive programs are followed in mechanical servicing. Practical training programs are often supplemented by more technical training leading to certificates of qualification. The usual rules of seniority and upgrading, often written into labour agreements, promote exceptional labour stability in surface mine employment.

Wage rates in surface mining vary only slightly from company to company, depending on the mine location and on company policy concerning fringe benefits. The more isolated mines bear a considerable cost burden for housing, messing, and recreational facilities which can be provided only by the company. Mines near previously established communities avoid many burdens and, where the ore grade is not marginal, they are sometimes able to pay slightly higher wages.

The usual method of grading wage scales is to divide all occupations into a number of classes, commonly about 20. The lowest-rated occupation may have a wage rate of about $3.00 an hour. Increments of about 8 cents an hour are added until almost $5.00 an hour is reached for the highest-rated occupation, usually shovel operating. There are some exceptions to the general trend and these appear in some parts of the country where the district wage rates are below or above the national average.

Surface mine wage rates in 1971-72 within selected areas are shown below. The low rate shown represents the lowest base rate for labour, whereas the upper represents estimated shovel-operator rates

Location	Ore Mined	Hourly Wage ($)
Quebec-Labrador	Iron ore	3.18-4.80
Eastern Townships	Asbestos	3.00-3.73
Eastern Ontario	Iron ore	3.38-4.74
Western Ontario	Iron ore	2.88-4.60
Interior B.C.	Copper	3.60-4.83
Pacific Coast	Copper-iron	3.60-4.60
Yukon Territory	Various	3.70-5.48

Productivity and Composite Costs

One of the advantages of surface mining is the high productivity, as measured by units of product per unit of labour. However, there are wide differences in methods of recording these data, so that they are not readily comparable. Considering only the labour content of the mining operations, some surface mines show a productivity of between 100 and 900 tons per man-shift. The high productivities are found in the newer, large-scale mines, particularly at the start of operations.

Labour performance in surface mines appears much better than that in underground mines. However, if all labour, including maintenance labour, related to surface mining operations is considered, the performance spread between surface and underground mining is somewhat narrowed. Despite these adjustments, overall output per man in surface operations is several times that for underground. This can logically be expected because of the comparatively high degree of mechanization in surface mining, which in turn means high capital investment.

The composite costs shown in Table 7 are based largely on actual data provided by mining companies. Where data were not available for operations within a certain scale, estimates were made by the author for a more complete presentation. Because the disclosure of costs at specific operations would be undesirable, mines where conditions and scale of operations are roughly comparable have been grouped to produce a weighted average cost As many combinations as could logically be made were assembled so that the weighted average costs would represent as complete an analysis as possible.

It should be noted that owing to different methods of compilation, cost values do not appear under every heading; if a specific cost item is absent, the expenditure is probably included under some other heading. For example, costs for secondary breaking are often not shown. In such instances, the actual cost was either so small that it was included with primary breaking, or it is covered in the miscellaneous cost.

Column A represents a group of relatively small operations in hard ores. The higher breaking costs in these ores is worthy of note.

With some exceptions, loading costs show a decreasing trend towards the right of the table where costs were incurred by use of the largest shovels. Less abrasiveness in asbestos and earthy iron ores may also be a factor which leads to lower loading costs, but this cannot be stated with certainty without more detailed knowledge of the elements of loading cost.

Although it cannot be directly deduced from the table, an analysis of the individual mine costs before assembly into groups for presentation, indicate a trend to lower costs on large-scale operations. Another point which came to light was the consistently favourable cost picture in the porphyry copper deposits. Costs in asbestos and iron ore mining were not so consistent.

The total operating cost as presented in the table is for one ton of ore only. To obtain the total cost of mining, one must consider the stripping ratio and apportion waste mining over the tons of ore mined. Again, in the porphyry coppers, there appears to be little cost difference per ton whether ore or waste is mined. In the mining of iron ore and asbestos, there appears to be a considerable difference. When the actual cost of

TABLE 7 - SELECTED CANADIAN SURFACE MINES, 1971-72 - MINE OPERATING COST DATA

Mines	A	B	C	D	E	F	G	H
Unit Operation								
Nominal production, tons ore daily	20,000	12,000	30,000	20,000	35,000	40,000	40,000	50,000
Shovel size, cu yd	4	5	5	6	6	8	10	15
Costs								
Primary drilling	0.07	0.05	0.03	0.08	0.02	0.04	0.03	0.03
Primary blasting	0.10	0.07	0.05	0.08	0.05	0.07	0.04	0.03
Secondary breaking		0.001			0.01			
Loading	0.13	0.05	0.05	0.04	0.055	0.07	0.05	0.07
Scaling				0.02				
Bulldozing				0.02	0.006			
Road Maintenance	0.08	0.05	0.02	0.05	0.03	0.04	0.01	0.02
Haulage	0.17	0.09	0.11	0.30	0.18	0.20	0.08	0.14
Drainage	0.01			0.005	0.04	0.005	0.002	
Supervision	0.04	0.02	0.02	0.06	0.02	0.01	0.006	0.01
Miscellaneous	0.23		0.02	0.18	0.03	0.02		0.02
Total per ton of ore	0.83	0.33	0.30	0.83	0.44	0.46	0.22	0.32

mining waste is distributed over the tons of ore mined, the operating costs will be considerably higher than the totals shown in the table. A total cost table will be similar to the table which appears earlier in this chapter where costs for 29 mines are analyzed.

SURFACE COAL MINING

Introduction

Commencing in 1970, the Canadian coal industry has experienced a revival which is expected to continue for at least a decade. The main cause of the expansion has been the demand for coking coal by the Japanese steel industry, however, there has also been an increased demand for domestic coal for thermal power generation.

Most of the increased production has been achieved in surface mining which now accounts for about 75 per cent of all coal mined in Canada. Owing to gradually reduced production in eastern Canadian underground coal mines, the bulk of the increased production has come from western deposits, where the largest surface mines are located.

There are also many small surface mines which supply mainly domestic markets. Except for size of equipment and scale of operations, methods in use in the smaller operations resemble those used elsewhere. Therefore, to illustrate the general surface coal mining techniques, only those mines where production equals or exceeds 200,000 net tons per year are considered. These mines are listed in Table 8 which shows the mines by areas, rank of coal, and scale of production. The techniques of surface coal mining are illustrated by the operations in three areas: the Souris Valley of Saskatchewan, the Crowsnest area of Alberta, and the East Kootenays of British Columbia.

The inherent difference between surface metal and industrial mineral as opposed to coal mining, is the lateral extent of the workings. Metal and asbestos orebodies usually occupy a limited surface area. The large tonnages are accounted for by persistence of the ore to depth. On the other hand, coal seams are comparatively thin and are generally horizontal or slightly inclined. Production of a sustained large tonnage of coal, therefore, involves mining over a large area.

Owing to the large areas involved, the terrain in a mined out coal area will be scarred to a high degree unless surface reclamation procedures are incorporated into the mining plan. The degree to which reclamation can be achieved is influenced by the topography of the area. Where prairie terrain is disturbed, reclamation is a simple, inexpensive process, requiring mostly the will to reclaim, or if necessary, legislation

TABLE 8 - SURFACE COAL MINES, 1972 - PRODUCING over 2,000,000 tons coal per year

Company	Location	Reference Name	Nominal Production (tons coal/yr)	Coal Rank	Total Coal Thickness ft	Seam Attitude	Overburden Depth ft
Minto Coalfield							
N. B. Coal Company	Minto, New Brunswick	Minto	360,000	Hvb	22 inches		
Souris Valley District							
Battle River Coal	Estevan, Saskatchewan	Battle River	980,000	Lig	8	Dip 10°	20 to 65
Utility Coals Limited	Estevan, Saskatchewan	Utility	2,030,000	Lig	8	Horizontal	25 to 75
Manitoba & Saskatchewan Coal Co.	Bienfait, Saskatchewan	Bienfait	815,000	Lig	14 total (2 seams)	Horizontal	15 to 75
Castor Area, Alberta							
Battle River Coal (Vesta Mine)	Halkirk, Alberta	Vesta	371,000	Sub "C"	6	Horizontal	20 to 50
Forestburg Collieries Ltd.	Forestburg, Alberta	Forestburg	700,000	Sub "C"	4	Horizontal	35
Pembina Area							
Alberta Coal Ltd. (Whitewood)	Wabamun, Alberta	Whitewood	2,420,000	Sub "A" & 'B"	21 total (5 seams)	Undulating	30 to 75
Alberta Coal Ltd (Highvale)	Wabamun, Alberta	Highvale		Sub "C"	21 total (2 seams)	Dip 5°	40
Crows Nest Area							
Coleman Collieries Limited	Coleman, Alberta	Coleman	300,000	Mvb	18-40	25° to 30°	30 to 150
Mountain Park Area							
Cardinal River Coals Ltd	Luscar, Alberta	Cardinal River	550,000	Mvb	25-35 (2 seams)	Dip 60°	200
East Kootenay District (B.C)							
Kaiser Resources Ltd.	Natal, B.C.	Kaiser	3,200,000	Lvb & Mvb	100 (5 seams)	Dip 0 to 35°	500
Fording Coal Ltd.	Sparwood, B.C.	Fording	3,000,000				

which imposes this requirement. On the other hand, reclamation of mountainous terrain is difficult and costly. Fortunately, difficulties can be minimized by adequate pre-planning which results in mining sequences which are programmed with reclamation.

Planning

The governing condition which determines whether surface mining is feasible is the extent of waste cover and the cost of removing this waste. Fortunately, the low unit cost at which waste can be mined by large-scale modern equipment makes a high stripping ratio (waste:coal) feasible. Ultimately, where coal becomes less accessible, stripping ratios increase to the point where returns from mining become marginal. A 10:1 volume stripping ratio is known to have been absorbed in some cases.

As in any other mining venture, the prerequisite for successful surface coal mining is a thorough knowledge of the coal occurrences. This information can only be developed after an adequate drilling and sampling program which fully outlines the coal measures and enables the coal quality to be evaluated. Fortunately, coal seams are usually regular and information from drilling can usually be evaluated with confidence. In addition to information about the coal seams, accurate knowledge must be accumulated on the nature of the waste and its depth over every part of the coal seam. Without such full information it is impossible to make realistic mining cost estimates.

For example, rock waste which overlies the coal seams in the east Kootenay's of British Columbia is largely sandstone and shale which requires drilling and blasting before digging. On the other hand, rock waste overlying the lignite deposits in southeastern Saskatchewan is largely fractured limestone and dolomite which can be dug without blasting, provided sufficiently large equipment is used. Elimination of blasting in the latter case has a beneficial effect on mining costs and enables a higher stripping ratio to be absorbed, or more profit, or a lower rank of coal to be mined at a profit.

Given a thorough knowledge of the coal measures and overlying waste, the information can be readily plotted on plans and sections and a mining plan can be developed. The plan will take into account the various thicknesses of the overburden to arrive at an overall stripping ratio for the life of the deposit. From experience, it is known what stripping ratio can be endured while still maintaining a profitable mining operation. Cost estimates, of course, cover both mining and reclamation costs.

Equipment requirements for coal mining in the various areas are listed in Table 9 which shows that Cordilleran mine operators must absorb the costs of drilling and blasting. Further, those companies operating in mountainous terrain require a larger number of haulage vehicles for waste disposal.

Three general methods of surface coal mining can be identified: the furrow method applicable to flat terrain, the contour method normally used on a convex sidehill, and the terrace method, normally used on a concave sidehill where the overburden must be removed in benches. The descriptions which follow illustrate the methods.

Souris Valley Area

As shown in Figure 36 lignite occurs in horizontal seams covered by 15 to 75 ft of waste. Some companies mine one 8-ft seam whereas others mine two seams for a total thickness of 15 ft. A typical single-seam mining operation will be used as an example. At this operation, an 8-ft seam of lignite is covered by approximately 50 ft of overburden. When a new furrow is started, the top soil is stripped with tractors and front-end loaders and piled for future use. Next, a 35-cu-yd dragline is used to excavate a cut down to the coal and the waste is cast to the side. The resulting trench is provided with an access ramp at one end. The width of cut, depending upon the reach of the dragline, is about 150 ft. The coal is exposed by tractor scraper and its surface is cleaned with a mechanical rotary brush.

The cleaned coal is dug from the solid with 8-cu-yd shovels and placed directly into 70-ton coal haulers for transport to the washing plant. The loaded haulers can climb a 10 per cent grade. When the required length of furrow is reached, the dragline "walks" over to begin the next cut. This time the spoil is placed into the furrow from which coal has been removed. A plan of the furrow method is shown in Figure 37, and a well-developed furrow operation is illustrated in Figure 38 which shows the rough spoil piles which results from casting of waste. Where one seam has been mined, spoil piles are about 30 feet above the original terrain. Where two seams have been mined, they are about 50 feet higher.

At some distance behind active mining, the spoil piles are cut down and the outer slopes are flattened to make smooth contours. Stockpiled topsoil is spread and the area is seeded and fertilized. Reclaimed land can support grazing for cattle or, in more isolated areas, range for wildlife. In many instances, the reclaimed land is more productive than the original.

TABLE 9 - SELECTED SURFACE COAL MINES, 1972 - EQUIPMENT DATA

Reference Name	Specific Mining Method	LOADING EQUIPMENT			Drills	Haulage Equipment (capacity
		Draglines	Shovels	Front-End Loaders		
Minto	Furrow	1, 14-cu-yd 1, 12-cu-yd 1, 10-cu-yd, 1, 7-cu-yd 2, 6-cu-yd		6, 2 to 5-cu-yd. capacity		
Battle River	Furrow	1, 12-cu-yd 11, 6-cu-yd	4, 3 3/4 to 7-cu-yd			3, 50-ton 5, 40-ton
Utility	Furrow	1, 35-cu-yd 1, 13-cu-yd	4, 5 to 20-cu-yd			6, 70-ton 3, 45-ton
Bienfait	Contouring	1, 11-cu-yd 1, 7-cu-yd				2, 20-ton 4, 50-ton
Vesta	Furrow	1, 13-cu-yd 1, 8-cu-yd	1, 8-cu-yd 1, 2-cu-yd			3, 35-ton 2, 45-ton
Forestburg	Furrow	1, 30-cu-yd 2, 8-cu-yd			1, 2-in. auger	4, 60-ton bottom dump
Whitewood	Furrow	1, 33-cu-yd 1, 13-cu-yd 1, 5-cu-yd 1, 3-cu-yd	1, 7-cu-yd 1, 5-cu-yd			7, 50-ton
Highvale	Furrow	1, 30-cu-yd	2, 7 1/2-cu-yd			5, 55-ton
Coleman	Terrace		6, 2 to 4 1/2-cu-yd			9, 30 & 50-ton
Cardinal River	Terrace and Contour		2, 15-cu-yd 1, 5 1/2-cu-yd	1, 15-cu-yd 1, 12-cu-yd	2, 10-in.	8, 105-ton
Kaiser	Terrace	1, 54-cu-yd	4, 25-cu-yd 2, 15-cu-yd 2, 8 to 10-cu-yd	3, 25-cu-yd	4, 12 1/4-in. 1, 9 7/8-in	23, 100-ton 17, 200-ton
Fording	Terrace and Furrow	1, 60-cu-yd	2, 15-cu-yd	4, 12 1/2-cu-yd (use 23- & 30-cu-yd buckets for coal)	1, 12 1/4-in. 2, 9 7/8-in.	13, 120-ton (waste) 6, 150-ton (coal)

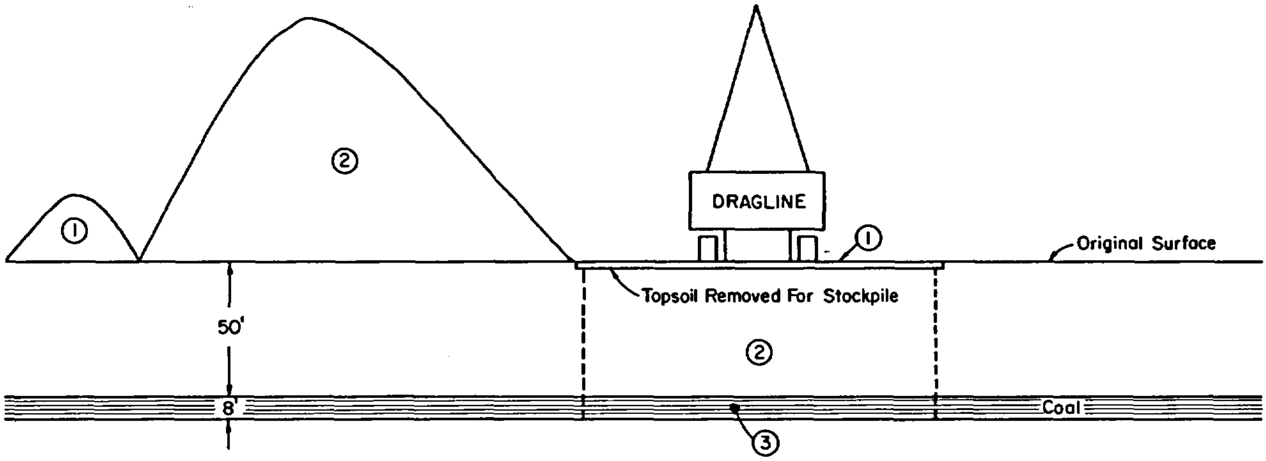


Figure 36. Furrow method of lignite mining, section.

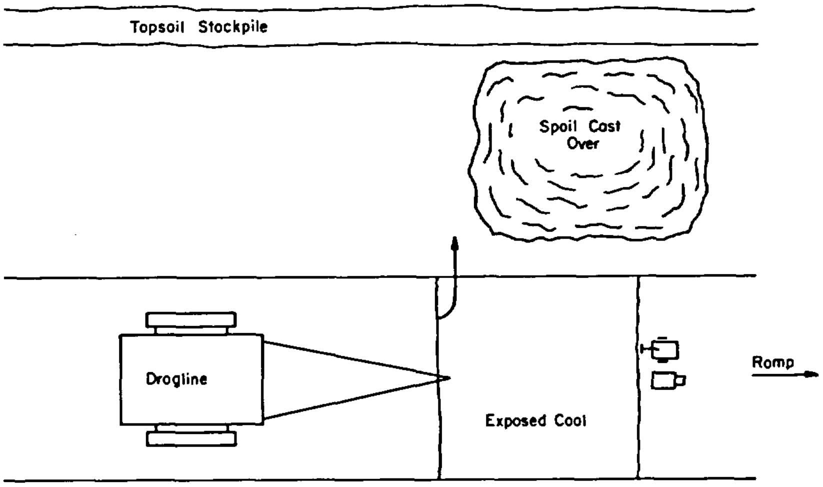


Figure 37. Furrow method of lignite mining, plan.

The furrow method as practiced in southeastern Saskatchewan is most economical in that neither drilling nor blasting are necessary and haulage equipment is required only for coal. The large size of the equipment makes a high labour content unnecessary. Productivity therefore exceeds that which is obtainable in any other Canadian coalfield. Overall performance of over 90 tons per man-shift is normal.

Cordilleran Area

Although considerable coal is mined by the furrow method in the flat terrain of Alberta, many of the newer mines are located in mountainous terrain. The well-known deposits are the Harmer Ridge deposits of Kaiser Resources, the Clode and Greenhills deposits of Fording Coal Ltd., and the Tent Mountain and Race Horse deposits of Coleman Collieries Ltd. A feature common to all these deposits is the overlying sandstone and shale which usually makes a drill-shovel-truck operation mandatory. Kaiser and Coleman mine single seams whereas Fording mines multiple seams.

A problem which is common to the operations, except for the Greenhills, is the difficulty of providing for waste dump rehabilitation. At Kaiser and Coleman, the general practice is to dump waste "over the side", well clear of mining areas. At Fording, a stream has been diverted above the mine and the U-shaped valley which it formerly occupied is used as a dumping area. The dump resembles the tailings impoundment of a metal mine except that the coal mine produces waste that has a broader size distribution. A coarse dump tends to stabilize more quickly than a sand dump therefore this offers more promise of success in rehabilitation programs. After about 3 years, the shale within the waste breaks down into a silt that will support plant growth. One company has definite plans to dump spoil so that dumps contain a covering of shale that favours replanting programs.

To illustrate the mining methods, one actual seam will be used. As shown in Figure 39, the coal is about 50 ft thick, dips about 30 degrees at the outcrop, and flattens down the slope. The dip of the coal is approximately the same as the surface topography, therefore the stripping ratio is fairly constant. For an average waste thickness of 275 feet, the stipping ratio on a volume basis is about $5\frac{1}{2}$ to 1.

Benches are established by tractors and front-end loaders to ensure reasonably flat areas for rotary drills to work. If the area is isolated, a Diesel-powered rotary drill is used to drill 9 7/8-inch holes on a 28 by 28-ft pattern. Holes are drilled 66 ft deep, but the final bench height is 60 ft and working width 150 ft. On well-established benches, large electric rotary drills are used to drill $12\frac{1}{4}$-inch holes, 66 ft deep, on a 32 by 32-ft pattern. Holes are blasted mostly with ANFO but some

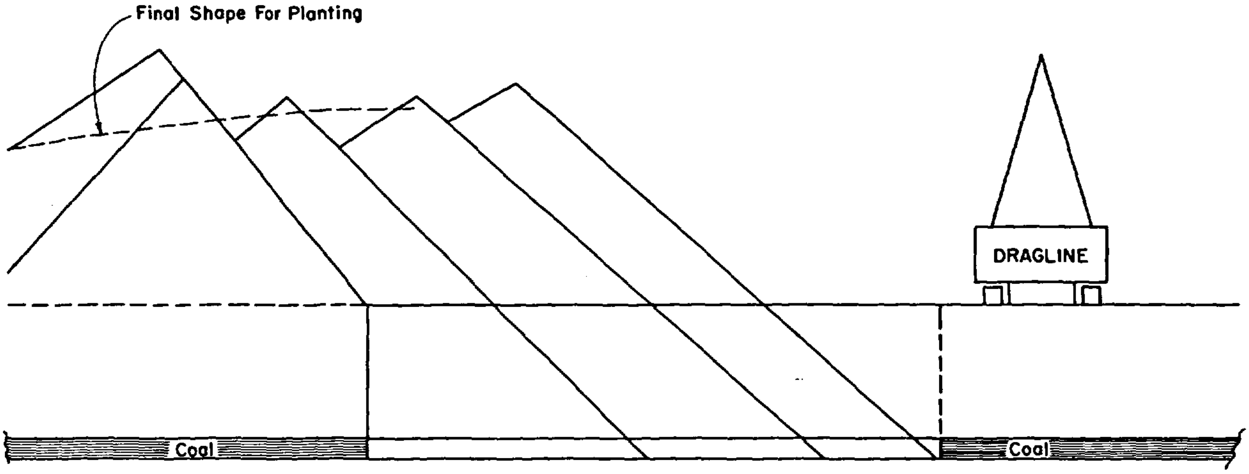


Figure 38. Well-developed furrow mine, section.

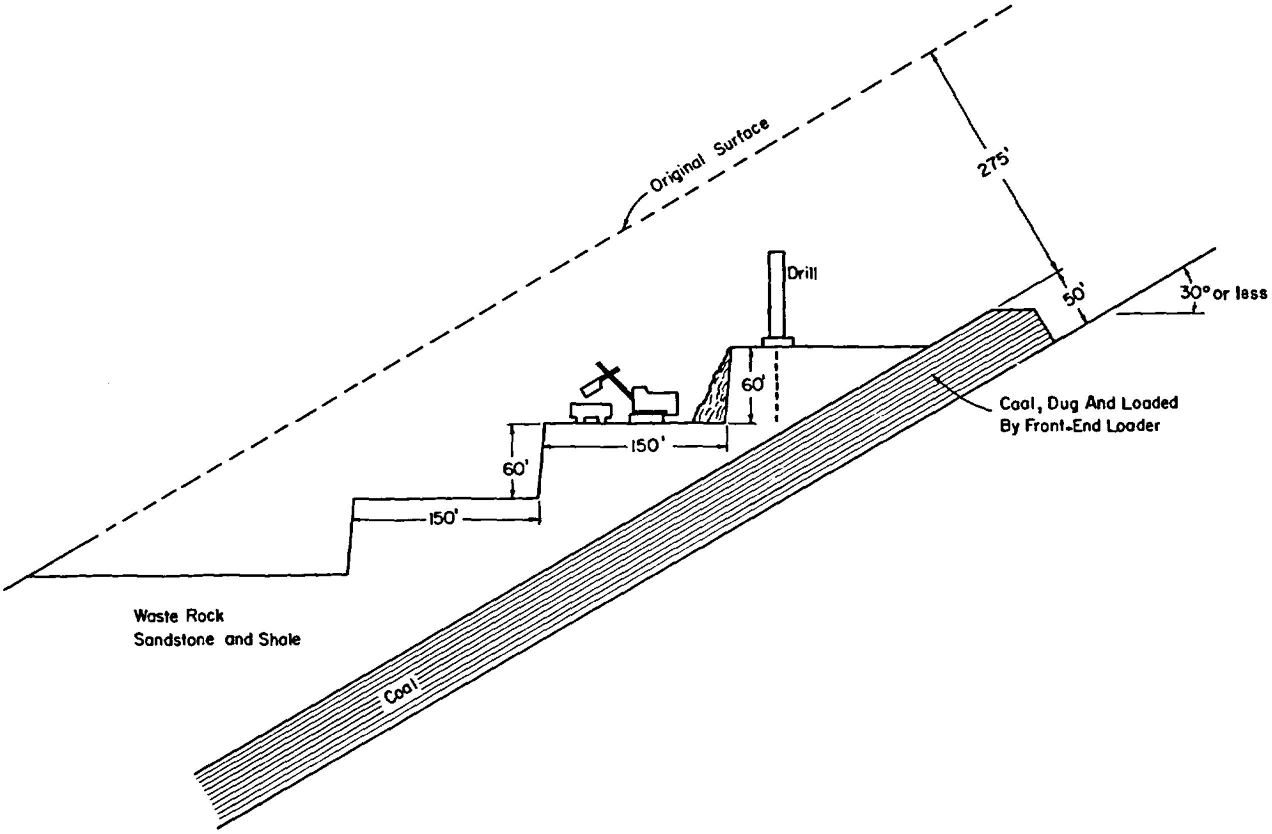


Figure 39. Coal mining by the terrace method.

slurries are used where holes are wet. The overall explosives factor is about 0.5 lb per ton of waste.

At one mine, waste is loaded by 25-cu-yd shovels into 200-ton trucks of which 17 are in use. Waste dumps have been established clear of the mine limits and the waste haul is, by design, almost flat.

As benching proceeds, the coal is eventually exposed as shown schematically in Figure 39. For coal digging and loading, 25-cu-yd front-end loaders, with sufficient crowding capacity to dig from the solid, are used most efficiently in the thick seam. Coal is hauled in twenty-three 100-ton trucks which can climb 8 per cent grades. Maximum permitted speeds are 6 mph uphill and 15 mph downhill.

Where multiple seams of good-quality coal occur, it is necessary to develop a technique for mining as many of these seams as possible. The deposits of Fording Coal Ltd. in the Greenhills area contain multiple seams and are in a shallow valley that is the ideal situation for dragline stripping.

As shown in Figure 40 the seams have been lettered for ease of reference. The seams are between 20 and 50-ft thick to average about 30 ft. Waste is about 70-ft thick between seams D and E and up to 270-ft thick between E and F. Over the four seams, the stripping ratio on a volume basis is about 5 to 1.

The stripping dragline has a 60-cu-yd bucket and 200-ft boom. The length of the boom provides for a long cast for the waste and greatly reduces the rehandling which may be necessary.

The sandstone and shale waste is drilled off with 12¼-in. rotary drills. Depth of the blastholes is determined by the thickness of the waste. The waste between seams is removed in one lift except between seams E and F which is removed in two lifts. The sequence of excavation is illustrated in Figure 40, and a section of the final appearance before reclamation is illustrated in Figure 41. This shape of spoil pile will be convenient to contour and replant, so that the reclaimed land will be equal to or better than the original.

Coal is loaded by shovels and front-end loaders into 150-ton trucks to make a short, almost flat, haul to the coal cleaning plant.

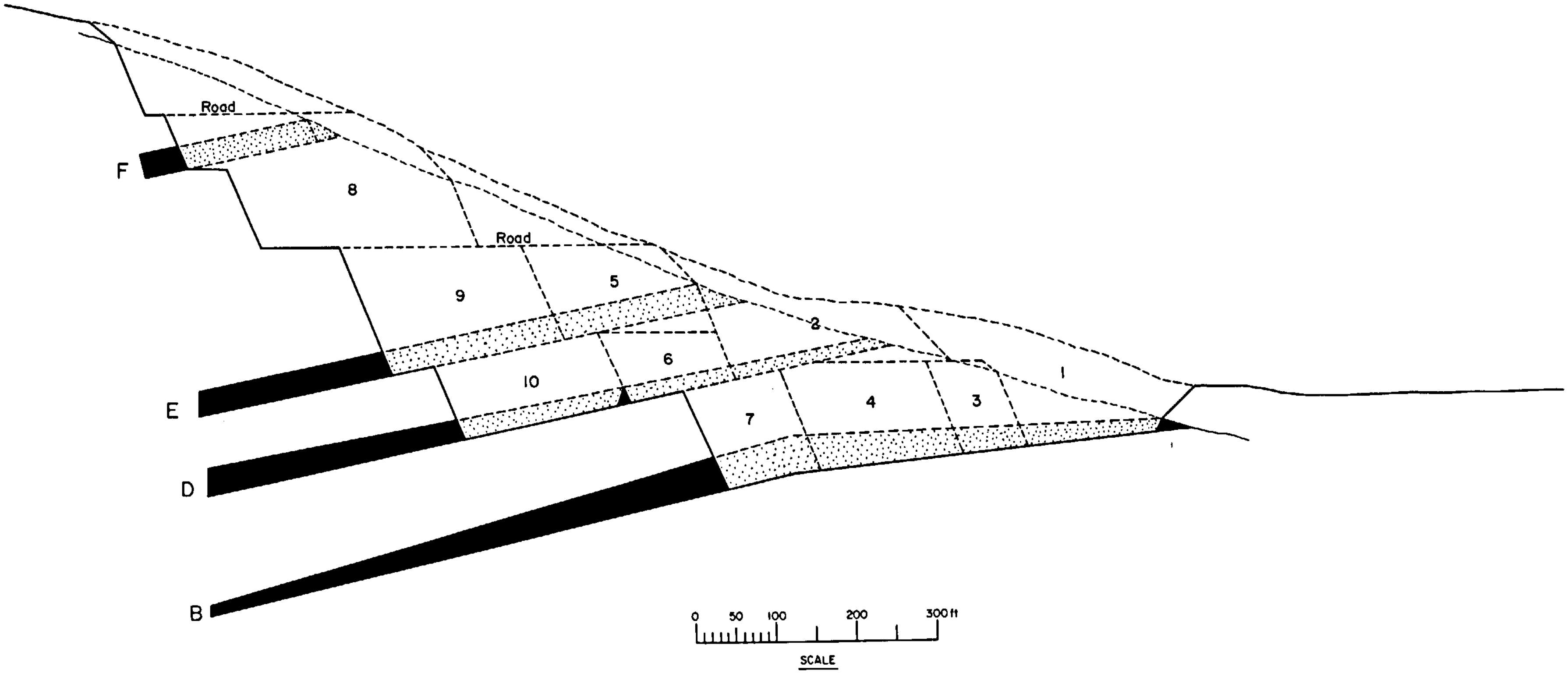


Figure 40. Coal seams, Greenhills area, showing mining sequence.

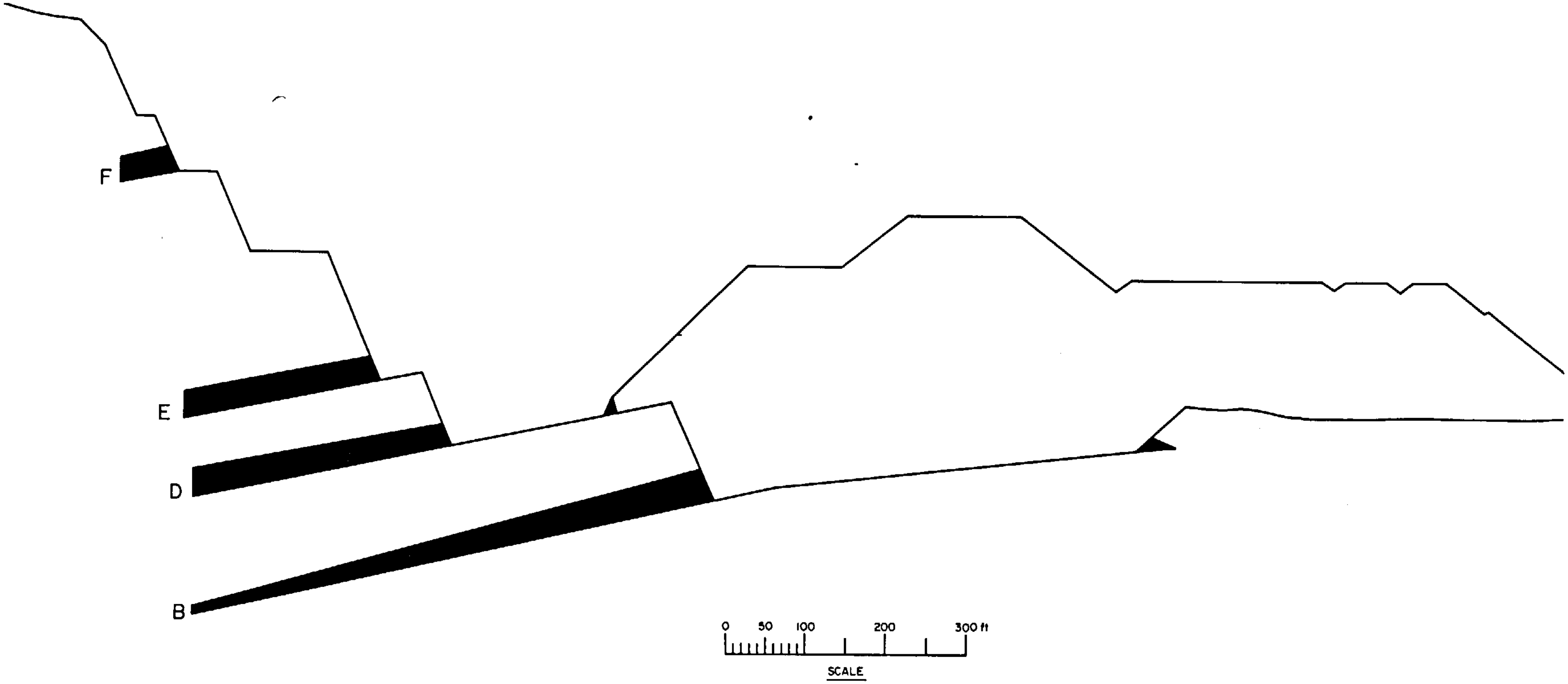


Figure 41. Final spoil pile before reclamation, Fording Coal Ltd.

Miscellaneous

Coal mining companies are the big consumers of power where they operate. Thus far, all coal producers purchase power from the nearest utility that can supply on a sustained basis. Most of the large equipment in a modern mine is electrically powered. The operations are always moving laterally, so a single high-voltage line, with strategically located substations, is usually a satisfactory power supply. One large surface coal mine in the East Kootenays is known to use 12 million kWh per month; this gives an indication of the power requirements of the larger operations.

Labour for surface mining is no longer as scarce as it was a few years ago. Many Canadian surface miners have already been trained to operate and maintain large equipment in the numerous surface non-coal mines. One of the major western coal mining companies has in effect set the wage patterns for coal mines and the other companies pay almost identical wages. Effective January, 1972, some typical wage rates are:

Occupation	$/hr
Dragline operator	5.17
Shovel operator, 25-yd	4.87
Shovel operator, under 25-yd	4.77
Truck driver, 200-ton	4.70
Truck driver, 100-ton	4.47
Truck driver, 25-50 ton	4.10
Labourer (lowest rate)	3.73

The success which has been achieved in exporting coking coals from western Canada to Japan and in domestic sales of other coals for thermal power generation, combined with the existence of adequate coal reserves, indicates that the Canadian coal industry will continue to grow for the forseeable future.

It is difficult to visualize larger equipment for the mountainous terrain because equipment must be mobile. Larger equipment and operations on horizontal deposits on the prairie are to be expected as the concepts of scale are applied and as the demand for western coal increases.

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