Volume 2-Chapter 2

MINERAL EXTRACTION (Mining)

Minnesota Environmental Quality Board
Regional Copper-Nickel Study
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PRELIMINARY
SUBJECT TO REVIEW

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2.1 INTRODUCTION AND SUMMARY OF FINDINGS

The copper and nickel sulfide mineral resources of the Duluth Complex extend from surface outcrops to several thousand feet beneath the surface and if completely exploited the resources will be mined by open pit and underground mining methods, or combinations of the two systems, depending on the depth, configuration, and grade of the ore body. Open pit mining refers to a mining operation where the excavation created is open to the sky and weather. The techniques associated with open pit mining are adapted to the extraction of mineral resources from deposits which lie close to the surface. Underground mining methods are employed when the depth or size of a mineral deposit is such that removal of the overlying waste material makes surface mining techniques unprofitable or when external factors such as legal or environmental considerations prohibit the operation of a surface mine, for example, when the ore lies under a lake.

It is worth commenting at the outset of this chapter that the reader can expect to find the discussion of mining operations to be rather cursory in comparison to the more detailed discussions of processing and smelting/refining presented in subsequent chapters. This does not indicate that this aspect of a total operation received a less thorough examination than did the other aspects. Those wanting more detailed discussions of the various mining technologies and procedures are referred to reports by Oman (1977) and Oman and Ryan (1978). However, this present chapter is designed to focus on those aspects of mining which have major implications in terms of potential environmental impacts. In particular, the discussions focus on technology and procedural options, the choice of which may have significant impact implications (e.g. the choice of truck haulage versus conveyor haulage). In this context, analysis by Regional Study staff of the numerous choices to be made in designing a mining operation indicate that many of the choices to be made do not appear to have significant impact implications. For example, the selection of one type of blast hole drill over another may be an important task for the mining engineer, but the outcome of the decision does not appear to have major implications for the levels of air and water emissions likely to result from the drilling operation. Accordingly, in-depth discussions of this and other such aspects of the mining operation are omitted.

Copper-nickel resource estimates developed for the Study and adjusted for expected metal recoveries shows just under 4 X 10^9 mt of ore containing more than 18 X 10^6 mt of recoverable copper (see Volume 3-Chapter 2 for details). More than two-thirds of the resource is accessible only by underground mining methods, therefore dictating the preference for underground development over open pit development. However, in reality, open pit mining is generally less expensive to develop and on the basis of economics alone it would be the best choice initially. Underground mining might then follow, utilizing many of the facilities capitalized by earlier open pit mining, as a competitive economic venture.

Figure 1 shows, in an idealized situation, how ore grade and stripping ratio (the number of units of waste material that must be removed in order to mine one unit of ore) determine the economic limits of open pit and underground mining. To be economic, all mines must be able to recover sufficient quantities of minerals per unit of ore mined such that the value of the minerals will pay for the costs of their extraction. The minimum grade at which an orebody will meet all expenses is defined as the cut-off grade. Open pit mine operating costs are dependent on the stripping ratio; consequently, as the stripping ratio increases, mining must be limited to higher ore cut-off grades to be profitable. There is usually relatively little waste rock removal required with underground mining, and the cut-off grade is determined independent of stripping ratio. Open pit mining is generally cheaper per unit of material removed than underground mining and therefore, at low stripping ratios, permits the working of lower grade ore bodies which otherwise would be considered subeconomic resources. Figure 1 also indicates that there are a range of conditions under which both open pit and underground mining are feasible.

Figure 1

Table 1 lists a number of performance statistics for open pit and underground mining operations throughout the world. As shown, operating costs for open pit mining are generally less than for underground mining, typically by a factor of 4, and therefore permit the economic working of lower grade orebodies. In comparison with underground mining methods, open pit mining commonly achieves a higher percentage recovery of valuable minerals, thereby improving the overall resource utilization of the mineral deposit. Open pit mining is inherently safer, and generally achieves a higher productivity rate (typically a factor of 5 from the information in Table 1) than underground mining. Although mine sizes in terms of annual production of ore vary considerably within the two categories of mining systems, open pit mines tend to be larger than underground mines.

Table 1

FIGURE 1

THE ECONOMIC DOMAIN OF OPEN PIT AND UNDERGROUND MINES

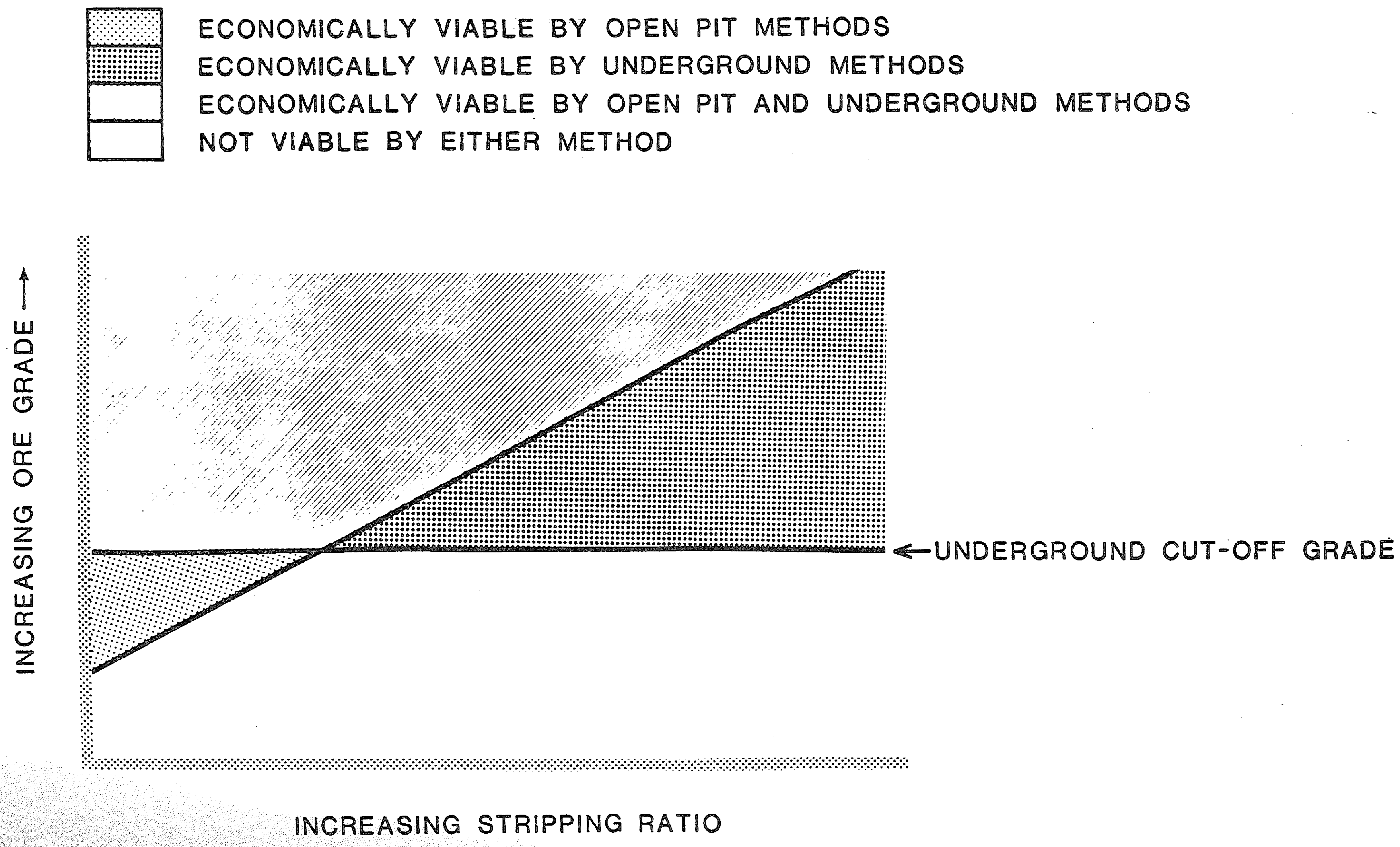


Table 1. Comparison of open pit and underground mining operations throughout the world.

PARAMETER	OPEN PIT			UNDERGROUND		
	Minimum	Typical	Maximum	Minimum	Typical	Maximum
Operating Cost, \$/mt ore	0.25	1.00	5.00	1.00	4.00	20.0
Average Ore Grades:						
Copper Mines (% Cu)	0.35	0.50	7.00	0.70	0.90	7.00
Nickel Mines (% Ni)	0.40	1.20	4.00	0.40	1.20	4.00
Percent Ore Recovery	90	95	100	40	70	100
Safety, disabling injuries per 10^6 man-hours	5	15	30	10	40	70
Productivity, mt/man-shift	50	150	500	3	30	150
Annual Production, 10^6 mt ore	0.10	7.00	32.0	0.10	1.75	20.0

SOURCES: SME Mining Engineering Handbook, 1973.
Dravo Report, 1974.
Mineral Commodity Profiles (USBM) MCP-3 and MCP-4, 1977.
Gentry and Hrebar (1976).
Peter Ashbrook, Volume 5-Chapter 2.

Underground mining normally reduces many environmental impacts which are at a maximum in open pit mining, including visual intrusion, noise, vibration, and air and water pollution. Three factors help to reduce the areal requirements and solid waste materials associated with underground mining.

1) the absence of an open pit excavation

2) the production of considerably smaller volumes of waste rock than with open pit mining, thereby requiring less surface storage of these waste materials

3) the options of disposing of waste rock underground and using a portion of the tailing from the processing plant to refill underground openings, thus reducing the quantities of these materials requiring surface disposal.

A potential environmental and public safety disadvantage of underground mining lies in the possibility of surface subsidence. Subsidence, the sinking or lowering of the earth's surface due to the excavation and subsequent collapse of underground workings, though not likely to be a problem in the Duluth Complex, can lead to widespread surface damage should it occur and not be controlled. This is discussed further in the geology report, Volume 3-Chapter 2.

The relative importance of open pit mining as a supplier of raw materials can be seen from the following statistics: in the United States in 1975, surface mines, excluding the categories of coal, sand and gravel, and stone, produced 713 million metric tons of ore - 86% of the national total - while underground mines produced the remaining 14%, or 112 million metric tons (E & MJ, June, 1977, p. 77). Table 2 is a summary of the estimated world mineral production in 1969, and the quantities produced by surface mining methods. Worldwide, an estimated 67% of the mineral commodities produced annually are derived from surface mines.

Table 2

From 1935 to 1970, annual production of copper ores in the United States increased from 34 to 236 million metric tons and the portion of ore mined by open pit methods increased from about 60 to 90% of the total amount (see Table 3). Waste rock stripping ratios for open pit mines range from about 0.5-10 to 1, and averaged 2.6 to 1 in 1970. Average copper ore grades have steadily declined from about 2% in 1935 to 0.5% at the present time. The only nickel mine operating in the United States is a surface mine producing approximately one million metric tons of oxide ore per year, averaging 1.2% nickel. The nickel sulfide ores of Canada average about 1.3% nickel.

Table 3

There are various authorities who feel that future conditions will force a reversal of the trend away from underground to surface mining--with a gradual shift back to underground. Changing public attitudes concerning environmental control may, to some extent, tend to increase the cost of surface operations relative to underground operations. Furthermore, in open pits where mineralization extends to great depths below the surface, the rapidly increasing amount of waste material to be handled imposes economic limits to depth, beyond which mining either must be abandoned or converted from an open pit to an underground operation (see Figure 2). However, maximum ore recovery (for conservation of mineral wealth), coupled with declining ore grades, pose numerous technical and cost problems that discourage consideration of underground operations. Perhaps the greatest force toward underground mining results from improved geological

Table 2. Estimated world production of metallic and nonmetallic ores and coal in 1969, and the percentage mined from the surface for each (million metric tons).

	WORLD TOTAL	SURFACE TOTAL	SURFACE PERCENT
Metallic ores	1900	1100	58
Nonmetallic ores	1400	1100	79
Clay, stone, sand, and gravel	3000	3000	100
Coal	2900	1000	34
TOTAL	9200	6200	67

SOURCE: SME Mining Engineering Handbook, 1973, p.17-2.

Table 3. Materials handled at surface and underground copper and nickel mines in the United States in 1970 (million metric tons).

	SURFACE			UNDERGROUND			ALL MINES		
COMMODITY	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total
Copper	211	550	761	25	1	26	236	551	787
Nickel	1.0	0.5	1.5	—	-	--	1.0	0.5	1.5

SOURCE: SME Mining Engineering Handbook, 1973, p. 17-4.

and geophysical exploration techniques capable of uncovering mineral deposits beyond the economic depths of surface mining.

Figure 2

2.2 THE OPEN PIT MINING PROCESS

An open pit mine is developed by progressively excavating a series of benches, as shown in the cross-sections in Figure 2. By expanding the benches outward and downward, mining can progress to depths as great as 400 to 600 m (1,300-2,000 ft). The mining system is fairly safe since the bank slope and the bench width can be varied to suit existing ground conditions and rock pressures.

Glacial drift and peat commonly overlie much of the Regional Copper-Nickel Study Area (Study Area) in depths ranging from zero (exposed bedrock) to as much as 60 m (see Volume 3-Chapter 1 for a detailed discussion). This unconsolidated material can be removed by scraping or digging, occasionally utilizing light blasting to loosen up the ground. Once the overburden is stripped and the bedrock exposed, mining becomes a cyclic operation in the sense that each unit of rock is subjected to each of the following sequential operations (see Figure 3):

Drilling
Blasting
Loading
Transporting

Figure 3

FIGURE 2 DEVELOPMENT OF AN OPEN PIT MINE OVER A PERIOD OF YEARS (TYPICALLY 10-30 YEARS)

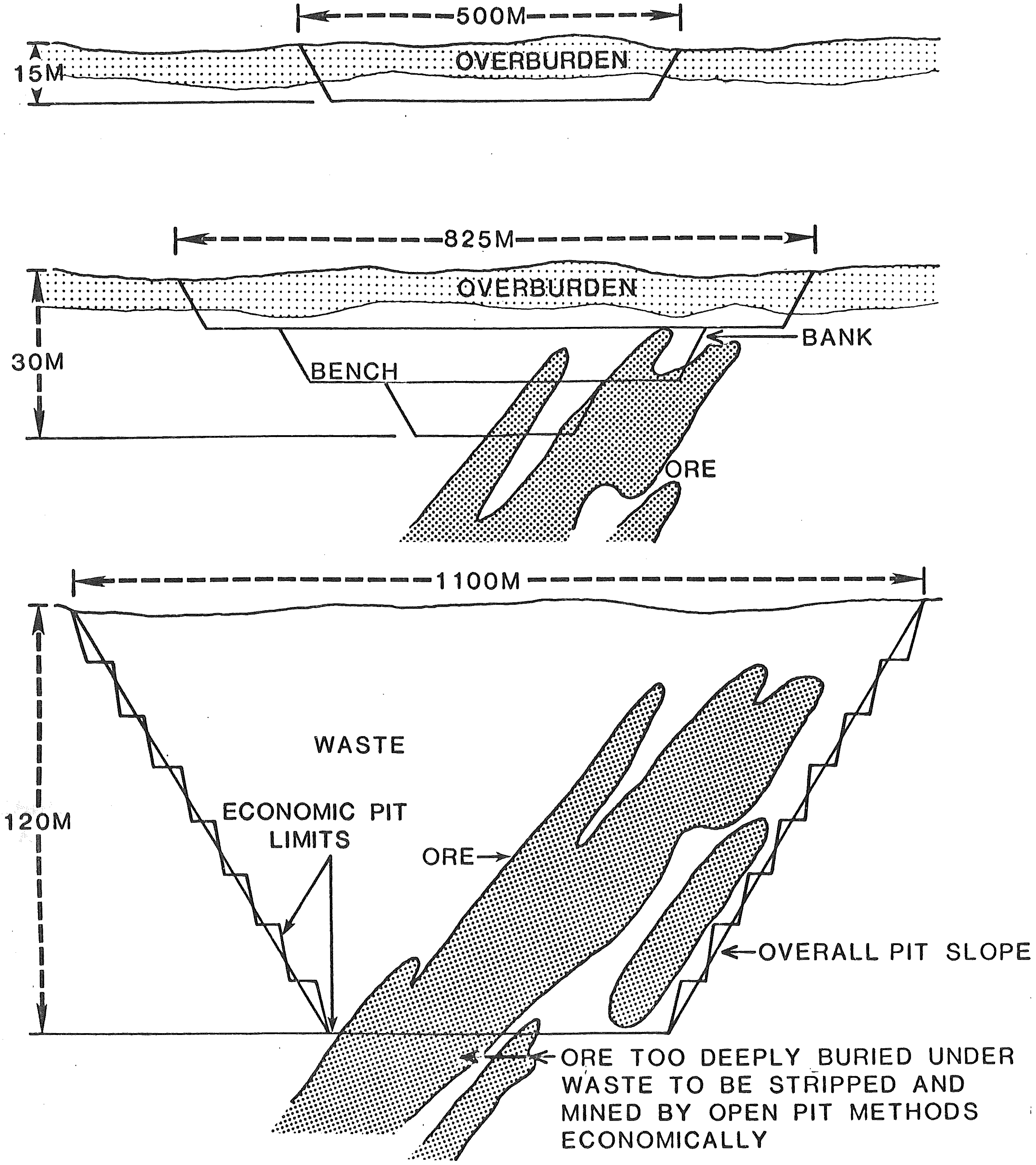
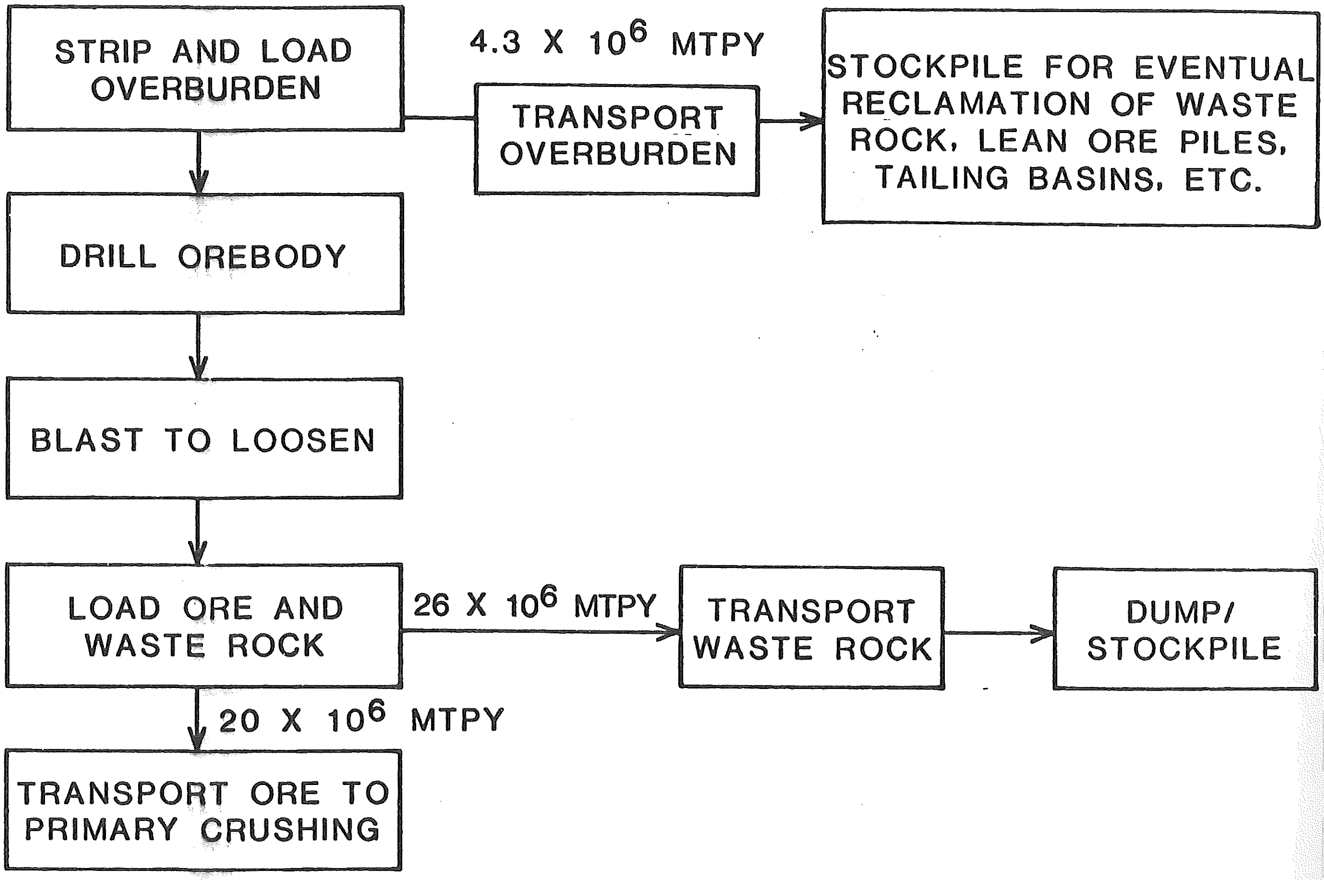


FIGURE 3 TYPICAL FLOW* OF MATERIAL AT AN OPEN PIT COPPER MINE



* FOR PURPOSES OF ILLUSTRATION THE VARIOUS MATERIAL FLOWS FOR A MINE PRODUCING 20 MILLION MTPY OF ORE AT A 1.3 TO 1 STRIPPING RATIO ARE SHOWN.

Consideration of the relationships between these operations is important in reducing overall mining, transporting, and crushing costs. The design of drilling patterns and the choice of blasting agents is based on attempts to provide a uniform size material which can best be handled by the subsequent operations of loading, transporting, and crushing. When properly executed, drilling and blasting reduce the likelihood of shovel and truck breakdowns due to oversize rock and uneven benches and haul roads, and limit the amount of secondary drilling and blasting required.

Once the rock has been broken, it can be loaded and transported to the primary crusher or waste piles as appropriate. The size of the broken rock and the capacity of the loading equipment are closely related, but the choice of a loading-transporting system is also based on pit size, shape, and depth, the life and production rate of the mine, the characteristics of the rock, the haulage distances to each dumping area, and the desired flexibility of the system. Unless ore must be blended from a number of pit locations, using fewer loaders of larger capacity is generally preferred over utilizing a greater number of smaller units.

The majority of open pit mines rely on off-the-highway trucks with capacities typically ranging from 50 to 200 mt to transport ore and waste rock. The coordination of loading and hauling equipment is a vital consideration in selecting a truck fleet. If there are many smaller trucks assigned to each loader, truck queuing will result, with a corresponding inefficient use of equipment and manpower. Incorporating trucks of too large capacity for the loading equipment will result in excessive loading time for each truck. Many mine operators consider the optimum truck size for a given loader to be that which can be filled by four to six passes of the loader.

The loaded trucks transport rock to several destinations:

1) Ore can be brought out of the pit and dumped at the primary crusher.

2) Waste rock and lean ore can be hauled out of the pit and dumped in areas reserved for their respective storage.

3) Either ore, or waste rock, or both can be transported to a loading pocket where the material would be transferred to railroad cars or conveyor belts and carried to its destination. The rock may be crushed at the transfer point to facilitate handling and transporting.

The number of trucks required for a mining operation is largely dependent on the mine production rate, the size of the trucks, and the haulage distances involved.

Nearly all large open pit mines operate around the clock on a seven days per week schedule. Frequently, one shift each week is scheduled as a maintenance shift. In order to perform all the tasks associated with the operation of a mine, a fairly large number of employees with a variety of skills is required. Table 4 presents a typical breakdown of employees for open pit mining assuming a productivity of 100-200 mt per man-shift.

Table 4

The personnel listed in Table 4 can be further broken down to 20% salaried personnel earning an average of $17,870/yr (1977 dollars) plus 30% fringe benefits and 80% hourly personnel earning an average of $14,059/yr plus 40% fringe benefits. The overall average including fringe benefits in 1977 dollars is $20,385/yr.

Table 4. Typical employment levels for open pit mining in the 100-200 mt ore/man shift production range.

	TYPICAL RANGE OF EMPLOYEE REQUIREMENTS[a]		
	AVERAGE PERCENTAGE BY JOB CATEGORY	TYPICAL LEVELS OF ORE PRODUCTION	
		100 mt/man shift	200 mt/man shift
Production	(42)	(225 - 510)	(385 - 830)
Supervisory	4	20 - 50	35 - 80
Drilling	4	20 - 50	35 - 80
Blasting	3	15 - 40	25 - 60
Loading	7	40 - 90	65 - 140
Transporting	24	130 - 280	225 - 470
Maintenance	32	180 - 380	300 - 620
Support	26	145 - 310	245 - 510
TOTAL	100	550 -1200	930 -1960

[a] Employee levels are given as ranges for typical operations in the 100 and 200 mt/man shift production levels. The range may indicate the level of efficiency, the level of difficulty of the operation, or the variation in associated needs such as waste rock removal. For the example production levels of 100 and 200 mt ore/man shift, average waste rock removal requirements are 200 and 300 mt/man shift, respectively.

Open pit personnel should be readily available in the Study Area due to the proximity of taconite mining, which is similar to proposed copper-nickel mining. Retraining of an iron miner to be an open pit copper-nickel miner should be minimal, which is not true for underground mining where special training will be necessary due to the greatly different techniques involved.

The region's labor pool is presently inadequate to support copper-nickel development without significant employment shifts (from the iron mining industry) and/or inmigration of workers from mining districts in other parts of the country (see Volume 5-Chapters 15 and 16 for labor force information). Copper-nickel development will naturally attract miners from the iron ore industry due to the novelty of a new venture, and with the potential for higher paying positions than they presently occupy in their union or company.

The drilling, blasting, loading, and transporting operations determine, to a large extent, the total operating cost of a mine. Operating costs are those costs which are not fixed, and include labor, supplies, and the cost of operating and repairing equipment. Mine operating costs may be reported as either dollars expended per metric ton of total material mined or dollars expended per metric ton of ore mined. A representative percentage breakdown of mining costs is given in Table 5.

Table 5

To maximize the efficiency of each of the unit operations, specialized and highly automated large-scale equipment has been developed.

Rotary drills now predominate for blasthole drilling at large open pit mines. Holes up to 430 mm (17 in.) in diameter can be drilled to 20 m (65 ft) in a

Table 5. Operating cost data from 18 open pit copper mines, by percent.

	COST PERCENTAGE RANGE	TYPICAL PERCENTAGE
Labor	27 - 63	42
Supplies	37 - 73	58
TOTAL		100
By Operation		
Drilling	3 - 18	8
Blasting	4 - 19	10
Loading	13 - 27	17
Transporting	26 - 60	43
General	9 - 34	22
TOTAL		100

SOURCE: Surface Mining, 1968, p. 885.

single pass, at penetration rates of from 6 to 15 m/hr (20-50 ft/hr). Mines generating 4 to 32 X 10^6 mtpy of ore will typically employ 3 to 12 drills. The cost of a rotary drilling rig can reach $750,000. Normally, a regular pattern of vertical holes are drilled in a portion of a mine bench (Figure 4), the holes are loaded with a predetermined quantity of explosives topped off with a filler material called stemming, and the explosives are detonated in a carefully timed sequence. Blasting reduces solid or consolidated rock to sufficiently small pieces to allow loading and transporting with relative ease. Single blasts can loosen up to 1.5 mt of rock. The frequency of blasting may range from several shots per day to one per week depending on the production rate of the mine and the size of the individual blasts. Bulk ammonium nitrate-fuel oil (ANFO) mixtures and/or pumped slurries are commonly used to blast and break rock at open pit mines. Powder factors range from 0.1 to 0.5 kg of explosive consumed per metric ton of rock loosened (0.2 to 1.0 lb/st). Blasting is a source of noise and fugitive dust at open pit mines.

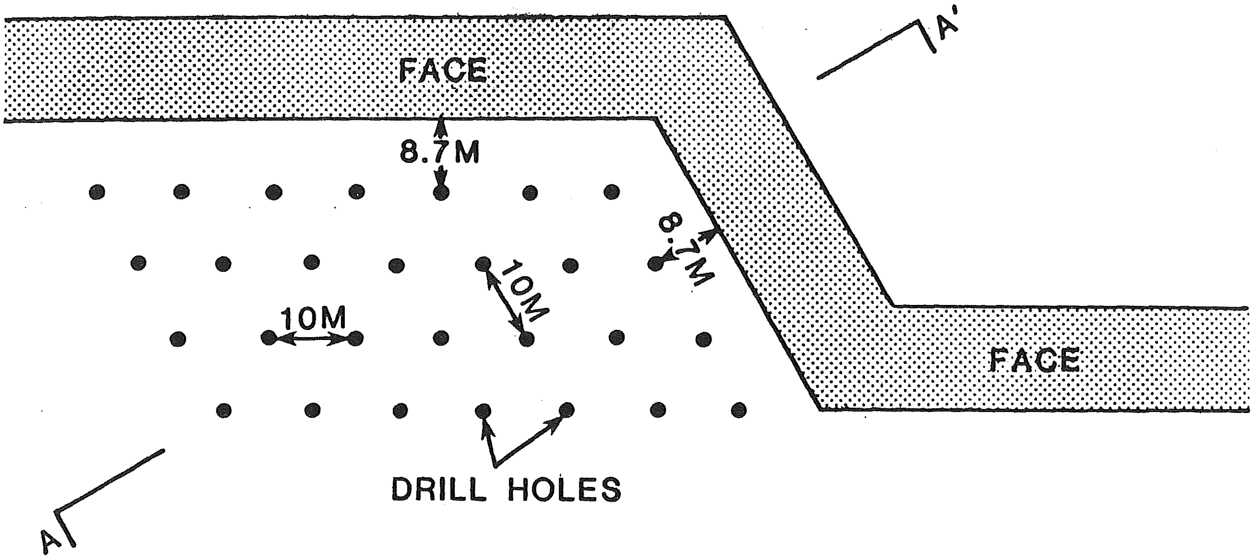
Figure 4

Most open pit mines employ electric shovels with dipper capacities in the 9 to 19 m^3 (12 to 25 yd^3) range for loading ore and waste rock. These massive units provide exceptional availability around the clock through many years of service. Mines generating 4 to 32 X 10^6 mtpy of ore will typically have from 2 to 15 shovels at work simultaneously, with 1 to 5 down for maintenance or held in reserve. Costs for these units range from $1,200,000 to $2,500,000. Selection of the largest possible shovel size for a given operation usually yields advantages in lower operating costs per metric ton moved, lower capital and labor costs, and fewer operating faces in the mine. However, the capability of blending ore and controlling ore grade diminishes as shovel size increases.

FIGURE 4

DETAILS OF A BLASTING PATTERN SHOWING TYPICAL DIMENSIONS*

PLAN VIEW



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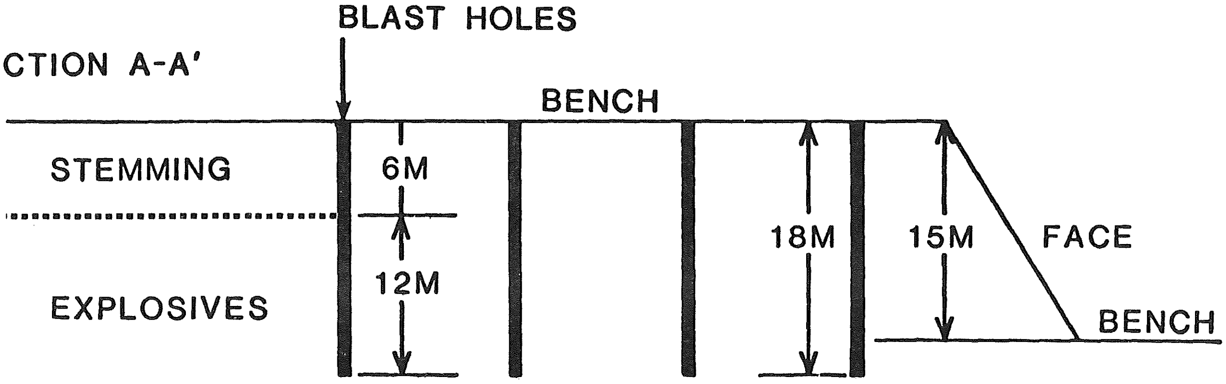


* THE ACTUAL NUMBER, DEPTH, AND DIAMETER OF BLASTHOLES AT A PARTICULAR OPERATION DEPEND ON THE CHARACTERISTICS OF THE EXPLOSIVES USED AND THE NATURE OF THE ROCK TO BE FRAGMENTED

A large part of a mine's operating cost is related to materials handling. It is not unusual, then, to find a variety of haulage systems in use in mines throughout the world since optimization of transportation can result in sizable cost savings. For open pit mines, the principal haulage methods applicable to transportation of bulk materials over distances less than 8 km (5 mi) are truck, rail, and belt conveyor systems.

For many, if not most mines, truck haulage remains the most practical method of transportation. These mines may have short hauls, numerous working faces, great depths, or ore blending requirements that demand the flexibility of truck haulage. However, high diesel fuel prices, fuel shortages, extensive and frequent maintenance, high tire costs, and high labor requirements for trucks are prompting mine operators to search for more economical forms of transportation.

Haulage trucks have been scaled up to meet demands for moving ever-larger tonnages of ore and waste, with a prototype 320 mt (350 st) capacity model being the largest yet built. The availability of this truck and the 180 mt (200 st) capacity haulers offered by a number of manufacturers will certainly influence future open pit design. However, for the present, trucks of 150 mt (170 st) capacity or smaller are in more widespread use. Mines generating 4 to 32 X 10^6 mtpy of ore will typically have from 15-75 trucks at work simultaneously, with an additional 5-25 down for repair work or held in reserve. The costs of haulage trucks range from about $300,000 for a 77 mt (85 st) truck to $600,000 for a 150 mt (170 st) truck. In terms of environmental effects, trucks traveling on unpaved haulage roads are the major single source of fugitive dust generated by mining operations. They are also a major noise source. These aspects are discussed in Volume 3 of this report.

Rail haulage enabled open pit mining to establish its reputation for efficiency. Prior to World War II it was the principal type of transportation used in large pits. Other successful surface mine haulage methods have been developed since that time which have served to supplement railroad transportation, permitting selection of a method that is best adapted to the particular requirements of each mining project. Railroads are well suited to physically large, but not excessively deep, mines from which large tonnages of ore and waste must be transported distances in excess of 5 km (3 mi). The primary disadvantages of railroad haulage are inflexibility and high initial capital cost. The capital investment can range from \$3 to \$20 X 10^6 and construction costs are approximately \$600,000/km of track (\$1,000,000/mi). Because railroad grades are limited to about 3%, the length of track needed to climb out of a deep mine may impose economic limits on a rail system.

Belt conveyor systems are becoming more and more viable in the face of rising costs for labor and energy. Many technological advances during the past decade have enabled conveyor systems to compete with the other open pit haulage systems in use for moving large tonnages of bulk materials over long distances. A complete belt haulage system for transport of ore and waste rock at a large open pit mine can cost from \$20 to \$40 X 10^6. To provide flexibility and complete the haulage system, some trucks are required for conveyor haulage and, in some cases, for rail haulage.

The actual choice of haulage methods is guided by consideration of physical factors such as the volume and characteristics of the material to be transported, the haulage profile, the life and production rate of the mine, the climate of the mining region, and the flexibility and reliability of the materials handling equipment. The decision-making process is also dependent on economic analysis of the various alternatives. The cost of materials handling is directly dependent on the tonnage to be moved, horizontal haul distance, and the height that the material must be lifted. When these variables are combined, a relationship similar to that shown in Figure 5 results for truck and conveyor haulage. Rail haulage costs commonly fall within the $0.02 to $0.06/mt-km range.

Figure 5

2.3 THE UNDERGROUND MINING PROCESS

Underground mining methods are designed to provide a means whereby mineral resources can be extracted from the ground with a minimum of surface disturbance. This reduces the quantity of subeconomic lean ore and waste rock that must be mined to obtain access to the ore and allows mining to be successful at depths which may be prohibitive for open pit mining. Several features are common to all underground mining methods (see Figure 6):

Figure 6

1) The points of entry to the mine (shaft, adit, or incline) are limited both in number and in size (cross-sectional area). All materials that enter or leave the mine must pass through these restrictive openings.

2) The ground must be sufficiently supported (either naturally or artificially) so that the mining plan can be implemented without loss of life or production due to the unintentional collapse of the rock which surrounds mine openings.

3) Most orebodies are oriented in such a way that the mine is developed by working simultaneously on a number of different horizontal levels. These levels

FIGURE 5 MATERIALS HANDLING COSTS

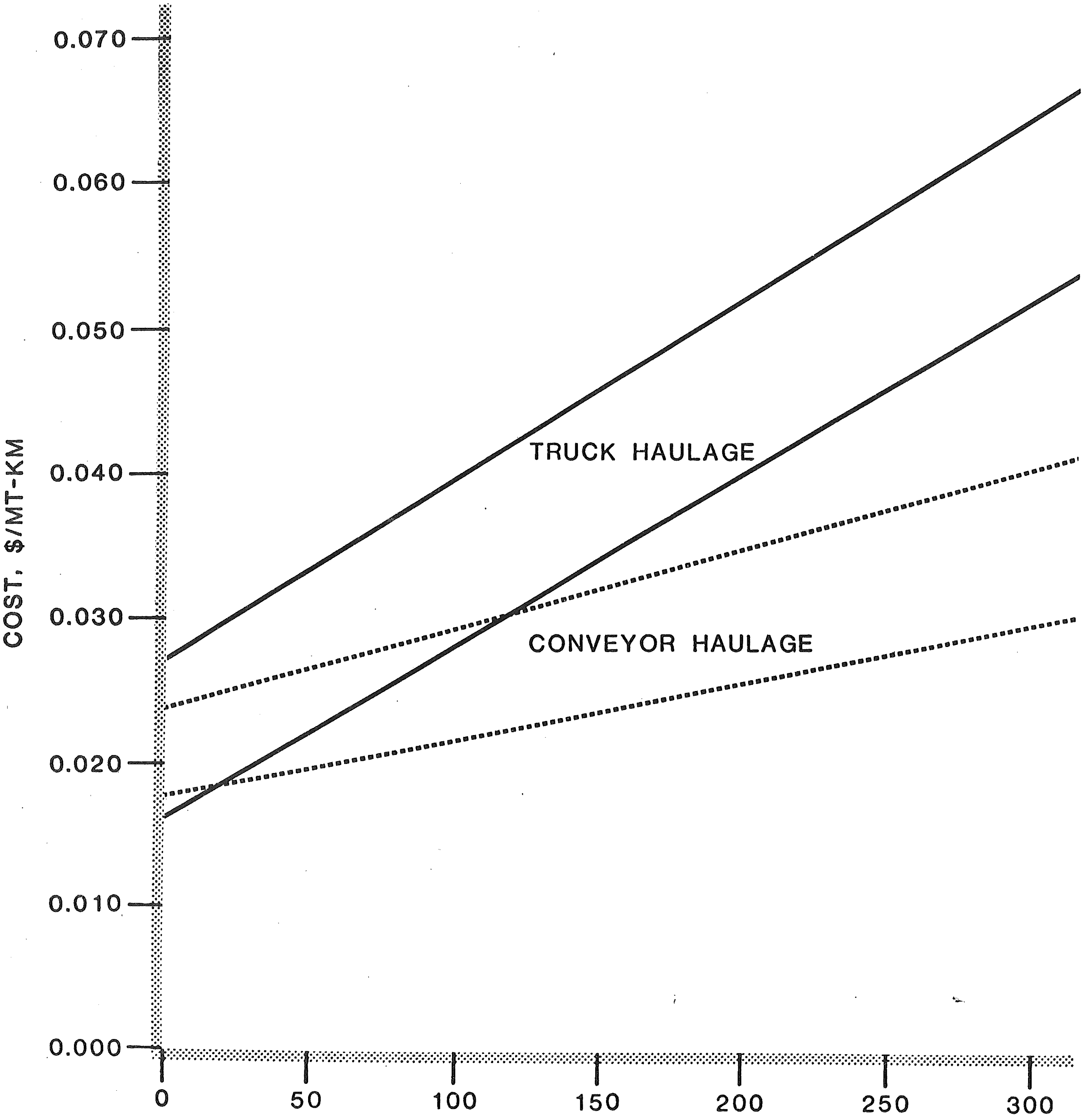
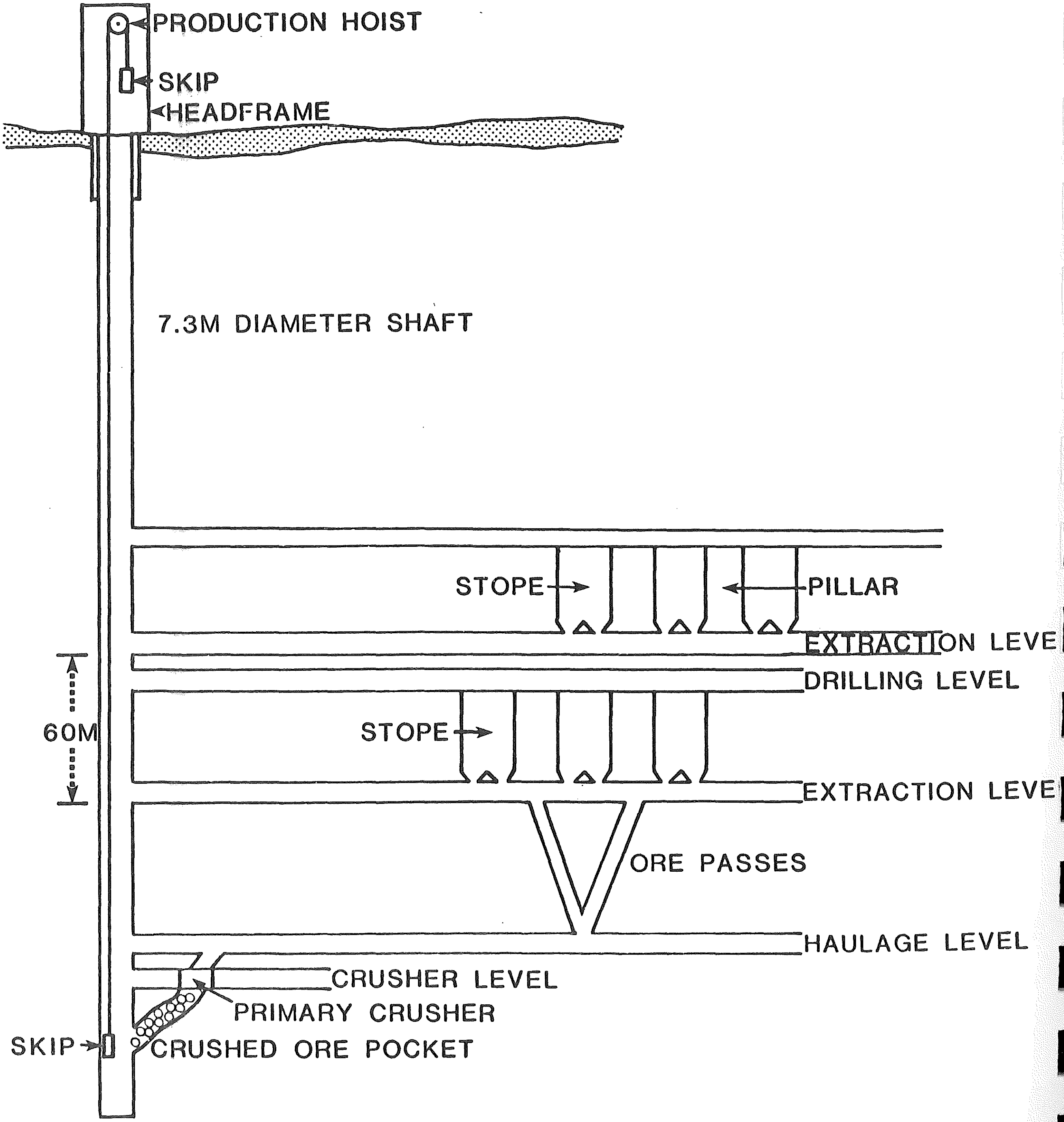


FIGURE 6

TYPICAL FEATURES OF AN UNDERGROUND MINE



are usually separated by a specific vertical distance and the activities which occur on any one level are likely to be duplicated on any other corresponding level, though not necessarily at the same time.

The planning and implementation of an underground mine is a complex process. The sites of the shafts, stopes, and haulage routes must be located during the early stages of mine development. The limitations of space, light, and air must be overcome in establishing a productive and safe work environment underground.

In order to open up an underground mine and insure a continuous level of production in the early years of a mine's life, a preproduction development stage is necessary. During this time period, the most important, and usually most permanent, mine openings are excavated and the extent of the ore is proven. Preproduction development makes a desired tonnage of ore available for immediate withdrawal from the mine.

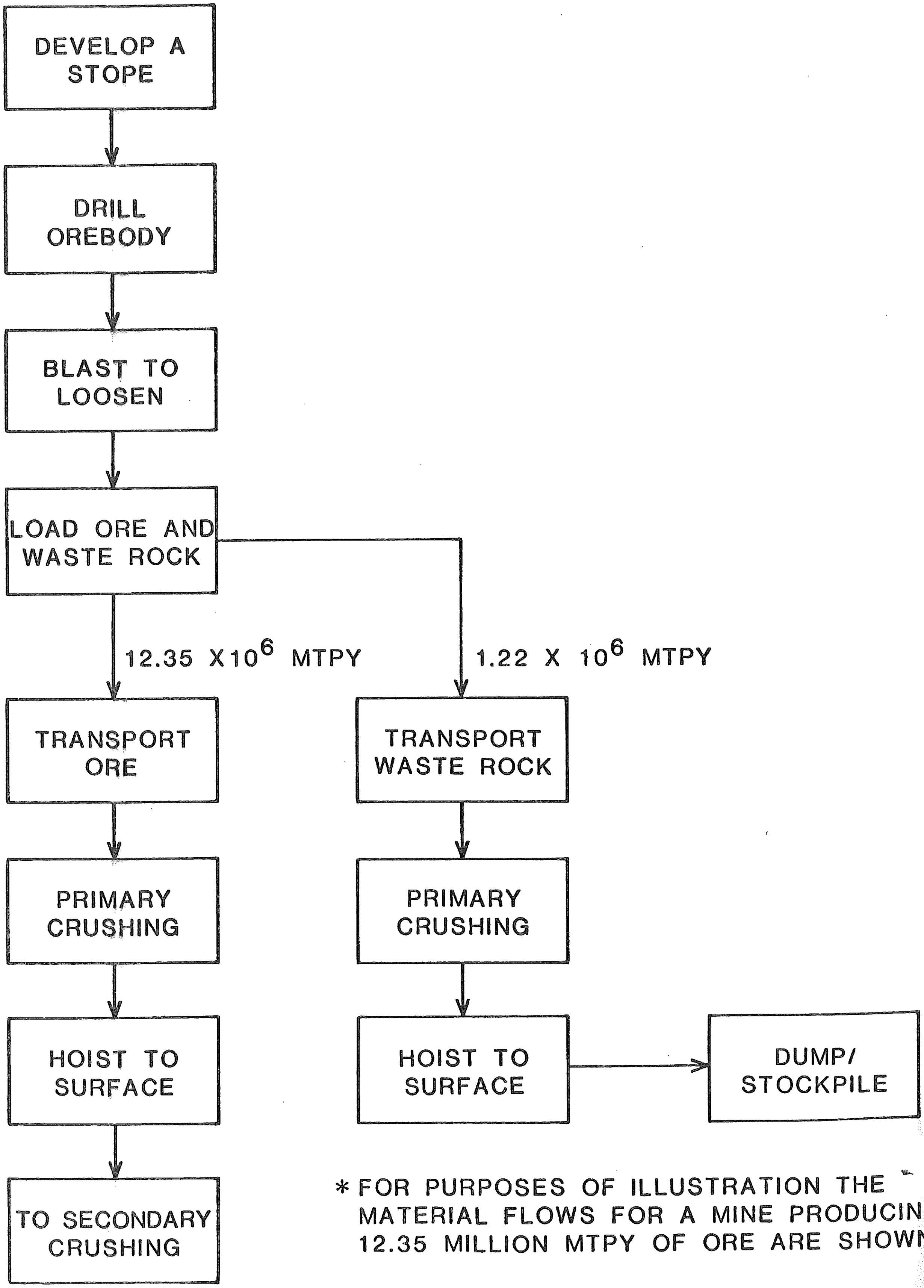
The typical steps through which ore and waste from an underground mine must pass are illustrated in Figure 7. Over the life of the mine, ton-for-ton production development is scheduled so that new areas of the ore deposit are continually being made accessible. As in open pit mining, the ore is then subject to the four operations of drilling, blasting, loading, and transporting. Except for physical size, much of the equipment employed underground to perform each of these operations is similar to that found in surface mines.

Figure 7

Drilling is primarily accomplished in one of two ways: by traditional percussive drills [hole diameters of 51-76 mm (2-3 in.)] or by down-the-hole hammer drills. Down-the-hole-hammer drills are capable of drilling 152 mm (6 in.)

FIGURE 7

TYPICAL FLOW* OF MATERIAL AT A LARGE UNDERGROUND COPPER MINE



* FOR PURPOSES OF ILLUSTRATION THE MATERIAL FLOWS FOR A MINE PRODUCING 12.35 MILLION MTPY OF ORE ARE SHOWN.

diameter blastholes at rates of from 3 to 4.6 m/hr (10-15 ft/hr). Normal hole lengths range between 24 and 53 m (80 and 175 ft), although longer holes are possible.

Ammonium nitrate-fuel oil (ANFO) mixtures and water gels are the principal explosives in use in underground mines. Underground blasts are typically much smaller than open pit blasts and are often scheduled for the end of each shift. Powder factors range from 0.15 to 0.6 kg per metric ton of rock (0.3 to 1.2 lb/st).

The current trends in loading and transporting are toward the increasing use of trackless rubber-tired mining vehicles and the development of conveyor technology, at the expense of rail haulage. For trackless mining, the use of loaders and trucks is diminishing in favor of load-haul-dump (LHD) units. These units, as their name implies, combine the loading and transporting operations so that one piece of equipment and one operator can perform both functions. This eliminates the need to match and coordinate several types of equipment. LHD bucket capacities range from 0.8 to 11 m^3 (1 to 15 yd^3). The flexibility, high productivity, and low cost of diesel LHD units is emphasized by the estimated 5,000 to 6,000 LHD units now operating in hard rock mines alone.

For long hauls, rail haulage systems are most commonly employed. Their use is increasingly confined to major haulage levels where loading conditions do not vary and where their relative inflexibility is not a disadvantage. Under these circumstances railway operation is becoming safer and more efficient. Automation by devices such as radio control decreases manpower requirements and the use of self-dumping cars improves train cycle time. Typically a rail haul system is operated in conjunction with LHD units working at the ore draw points and loading through ore passes into rail cars for the haul to the crushing/hoisting areas.

The use of belt conveyor systems for transporting rock within underground mines is also on the rise. These offer the advantages of continuous material flow, low operating cost, and low personnel requirements. Advances in conveying technology include improvements in drive mechanisms and belting materials, the use of computer control devices and closed-circuit television monitoring systems, and the development of new maintenance/repair equipment.

In addition to the four unit operations required to loosen and transport rock, a number of auxiliary operations are needed to provide for crushing, hoisting, ventilation, compressed air, pumping, and ground support.

Primary crushing is commonly performed underground so that a consistently sized material (-150 mm or -6 in.) can be loaded into the skips and hoisted to the surface. Typically, these crushers can accept rock chunks as large as 0.6 m (2 ft) in diameter. Dust from the primary crusher is controlled by dust collectors or water sprays.

Vertical shafts equipped with hoists are the predominate means of lifting and lowering men, materials, and rock at underground mines. The majority of new shafts constructed in the United States range from 110 to 1,460 m (350 to 4,800 ft) in depth, with the average depth being 500 m (1,630 ft). Seventy-three percent of all new shafts being constructed are circular and concrete lined. The inside diameter for circular shafts ranges from 3.7-8.5 m (12-28 ft) with an average diameter being 5.8 m (19 ft). Ore is hoisted to the surface in skips of from 5 to 20 mt capacity and at speeds of 300 to 600 m/min (1000-2000 fpm). The skips are usually operated in pairs--the weight of one skip descending helps to counterbalance the weight of the other skip that is being hoisted. With this system, one skip can be loaded as the other skip is being dumped.

Ventilation is essential to the operation of an underground mine. The primary function of mine ventilation is to dilute, render harmless, and carry away dangerous accumulations of gas, dust, and fumes from the working environment, and to provide an adequate supply of oxygen for men and diesel equipment. Primary ventilation requirements for trackless mines generally are determined by the guideline of 2.1 to 2.8 m^3/min (75 to 100 cfm) of air per net diesel horsepower that is operating underground. Other factors that affect ventilation, although they usually are not controlling factors when diesel equipment is used, include: 1) number of men working underground, requiring approximately 2.1 m^3/min (75 cfm) per man; 2) blasting practices; and 3) dust conditions in the mine. Ventilation fans operating on the surface are a major source of noise at underground mines (see Volume 3-Chapter 5). The flow of air through mine shafts and drifts can create winds that present possible safety hazards to workers. Typically, air velocities are kept below 32 to 40 km/hr (20 to 25 mph) to avoid such conditions.

Compressed air is used underground to power drills and mucking equipment. The compressors are nearly always electrically driven and housed in the hoisthouse with the main air lines installed in the shaft. A typical air pressure of 7 atmospheres (100 psi) is generally adequate to supply the requirements of most underground mining equipment.

For reasons of safety and productivity, water in an underground mine must be controlled. Generally, to accomplish this sumps are excavated to provide an area for holding the water while the solids settle out. The water is then pumped out of the mine where it can be utilized or discharged. Whether or not the water must be treated depends on its quality, destination, and use. This is discussed in Volume 3-Chapter 4. There is little likelihood of encountering substantial quantities of water in the Duluth Complex since the rock is highly impermeable. Preliminary estimates indicate an influx of less than 190 l/min (50 gpm) can be expected in Duluth Complex underground mines.

There is always the possibility of localized extensive fracturing of the rock which could result in significantly larger quantities of water production. Cases exist (INCO-Shebandowan Mine) where initial mine planning predicted low water production levels, but actual mine development resulted in an excessive amount of water. Actual water production cannot be predicted unless example operations exist in the immediate area. Therefore, in the case of new development, extreme care must be used in planning for water control and discharge.

It is particularly true of underground mines that localized groundwater or seepage water may be source of acid production or leached heavy metals. These localized sources, if identified and monitored, can be controlled such that the entire water production is not contaminated. They may be treated underground before being discharged with the uncontaminated water, or discharged separately for treatment on the surface. See Volume 3-Chapter 4 for a discussion of mine water management.

Post-production control of underground mine water should be no problem since access to the ore will be by vertical shaft which can easily be sealed. Mine access by adit which would provide easy water discharge would not be expected in the gabbro mines unless it were at the base of an exhausted open pit mine. Even then, only an artesian water source, which is not characteristic of the Duluth Complex hydrology, would be a problem.

To ensure that the underground openings will be sufficiently supported and protected against collapse, some ground support may be required. Support measures include the use of rockbolts, shotcrete, lagging, concrete, timber or steel sets, and backfill.

Personnel at an underground mine can be grouped into three broad categories: production, maintenance, and support. The numbers of workers in each category can vary greatly from mine to mine and with different mining methods. Table 6 illustrates a typical breakdown of employees for underground mining, assuming a productivity of 30 mt per man-shift.

Personnel needs at full production can be further broken down to 15% salaried personnel and 85% hourly personnel, earning average incomes of (1977 dollars) $18,000/yr plus 30% fringe benefits and $15,864/yr plus 40% fringe benefits, respectively. The overall average including fringe benefits in 1977 dollars is $21,860 per man.

Table 6

Underground mining differs from open pit due to physical location and the scale of each individual operation. Open pit workers are exposed to the weather where underground workers are restricted by the physical configuration of the mine. Large shovels and trucks on the surface perform the same function as relatively small LHDs underground, and production rates reflect these differences. Although underground mining skills are not greatly different from open pit skills, underground miners must be trained to work effectively in the confines of the mine. As noted earlier, open pit miners should be readily available due to the close proximity of open pit iron mines; however, underground miners are

Table 6. Typical employment requirements for underground mining with a productivity of 30 metric tons per man-shift.

	PERCENT	TYPICAL NUMBER OF EMPLOYEES 2 X 10^6 mtpy ore	 8 X 10^6 mtpy ore
Production	40	85 - 120	350 - 485
Maintenance	35	75 - 105	305 - 425
Support	25	55 - 75	215 - 300
TOTAL	100	215 - 300	870 -1210

not locally available and will either have to be imported or trained. Training periods of a few weeks provide adequate preparation to allow previously unskilled workers to begin work under the supervision of an experienced management staff. It is quite likely that, as is typical elsewhere, only the senior staff would be imported from outside the area. A training program would then be established to accept interested individuals from the local labor force.

The various underground mining methods can be classified on the basis of the ground support methods they utilize. Three broad classes of mining systems are recognized as follows:

1) Methods in which the underground openings (rooms or stopes) created by the extraction of the mineral are self-supported in that no regular artificial method of support is employed: that is, openings in which the loads due to the weight of the overlying rocks and overburden or resulting tectonic forces are carried on the sidewalls and/or pillars of unexcavated mineral or rock. This specification does not preclude the use of rockbolts or other light systems of roof support, provided that this artificial support does not significantly affect the load carried on the self-supported structure. Mining methods in this classification include open stopes, room-and-pillar mining, sublevel open stoping, and shrinkage stoping.

2) Methods in which stopes or rooms require significant support: that is, support to the degree that a significant part of the weight of the overlying rock is carried on the support system. Examples of mining methods in this class are cut-and-fill and square set methods.

3) Methods in which, because of spatial and mechanical properties, the deposit is induced to cave under the action of gravity to produce better results than

with more selective methods. Mining methods in this category include sublevel caving and block caving.

The process of choosing an underground mining method involves selecting the methods which are technically adaptable to the physical properties and configuration of the mineral deposit in question, and then, by the process of elimination, determining which is the most advantageous in terms of production rate, cost, safety, and environmental protection.

Table 7 shows the application of various large-scale mining methods in different geologic and mechanical settings. Considering the criteria typical of Minnesota gabbro, the most probably large-scale mining methods are room and pillar, sublevel stoping, and cut and fill. Each has application, depending on local conditions, as do the other methods, but these three seem most probable on an area-wide basis.

Table 7

Table 8 is a comparison of factors such as cost and safety for the principal mining methods. The results shown in Table 8 represent conditions which are generally true throughout the mining industry, but which are based on interpretations of statistics and subjective judgement. Often, the degree to which one mining method has an advantage over another for any one parameter is quite small and is dependent on individual company preference.

Table 8

Underground mine operating costs are highly dependent on the mining method being used and the nature of the ore deposit. Similarly, the distribution of the

Table 7. Geologic and mechanical criteria in large-scale mining methods.[d]
(X indicates situation where the indicated method is generally applicable)

MINING METHOD	ORE BODY CHARACTERISTICS						ORE BODY CONFIGURATION							
	ORE STRENGTH			WASTE STRENGTH			BEDS		VEINS		MASSIVE	ORE DIP		
	Weak	Moderate	Strong	Weak	Moderate	Strong	Thick	Thin	Narrow	Wide		Flat	Moderate	Steep
Room & Pillar[a]		X	X		X	X	X	X				X	X	
Sublevel Stoping[b]		X	X			X			X	X	X			X
Shrinkage		X	X	X	X				X	X			X	X
Cut & Fill		X	X	X	X				X	X	X		X	X
Square Set	X			X	X				X	X	X		X	X
Block Caving[c]	X	X		X	X					X	X			X
Sublevel Caving		X	X	X	X					X	X			X
Longwall	X	X		X				X				X	X	

[a] Uniform thickness and grade.
[b] Regular hanging and foot walls.
[c] Strong fractured rock also can be caved.
[d] Characteristics typical of Minnesota gabbro:
Ore strength-strong
Waste strength-strong
Ore body-thick beds to massive
Ore dip-moderate to steep

Table 8. Advantages of various underground mining methods.
(X indicates the generally advantageous aspects of the mining methods listed)

	OPEN STOPING	ROOM AND PILLAR	BLASTHOLE OPEN STOPING	SHRINKAGE STOPING	CUT AND FILL	SQUARE SET	SUBLEVEL CAVING	BLOCK CAVING
Low Initial Capital Investment (usually more rapid development)	X			X				
Low Cost		X	X					X
High Productivity		X	X				X	X
Amenable to Mechanization (often less labor intensive)		X	X				X	
Safety		X	X				X	
Selectivity	X				X	X		
Low Dilution	X	X	X	X	X	X		
High Percentage of Ore Recovery					X	X		X
Less Likely to Cause Subsidence	X	X	X	X	X	X		
Easily Modified and Flexible to Different Productivity Rates	X	X	X					

total cost among the mine operations varies with different mining methods, ore types, ore strengths, mine sizes, mine depths, etc. Table 9 illustrates the variability of underground mine costs.

Table 9

2.4 COMBINATIONS OF OPEN PIT AND UNDERGROUND MINING

Occasionally, the shape and geometric position of an ore deposit makes possible mining by a combination of both open pit and underground methods. When this occurs there are a number of approaches to successful mineral extraction, should the holder of the mineral rights elect to utilize both systems in recovering the ore. Most of the variations are related to the sequence and timing of the open pit and underground operations since they generally share very few facilities and are nearly independent of each other up to the point where their ores may be combined for processing treatment. While combining open pit and underground mining may offer greater flexibility, it also increases the complexity of the mining operation.

Combined open pit and underground mining operations span the range from distinctly separate facilities operated independently of each other, to fully integrated operations in which one is dependent on the other for its existance. An example of the first combination type would be ore bodies geographically separated from each other such that both could be mined by their respective extraction methods concurrently. As discussed above, these operations are independent of each other up to the point where their ores are combined for common processing, or they may have completely separate facilities through the production of concentrate or of the final metal products.

Table 9. Breakdown of mine operating costs for various underground mining methods, by percent.

	ROOM-AND-PILLAR	SUBLEVEL OPEN STOPING	CAVING MINE
Labor	51	N.A.[c]	52
Supplies	49		27
Other[a]	--		21
TOTAL	100		100
By Operation			
Development	--	30	15
Drilling	20	11	1
Blasting	9		
Loading	20	20	16
Transporting	22		9
Crushing	1	10[b]	--
Hoisting	3	5	12
Ventilation	1	--	2
Ground Control	7	--	12
Other[a]	17	24	33
TOTAL	100	100	100

SOURCE: Analysis of Large Non-Coal Underground Mining Methods, 1974.

[a] Indicates costs listed as miscellaneous, other, etc., and not identified as specific categories.

[b] Includes conveying.

[c] N.A. - Information is not available.

The second possibility exists where the ore extends to a depth exceeding the open pit limit (due to stripping ratio and grade) and underground operations are planned for once the open pit has been exhausted. Access to and material removal from the underground operation would be from the base of the open pit, through a shaft or adit. Such a development could result in a "glory hole" operation, in which vertical shafts are formed from the top of the underground ore zone to haulageways at the base of the ore zone. The uppermost ore is then mined first, transferred through the vertical shafts to the haulageways by gravity, and then hoisted to the surface for processing.

2.5 WASTE ROCK AND OVERBURDEN DISPOSAL AND USES

Waste rock includes both the barren rock and low grade rock produced during the course of mining which is too low in grade to be economically treated at the time of mining. Open pit mining commonly generates a substantial quantity of waste rock, the amount of which varies with the stripping ratio as shown in Figure 8. However, relatively little is brought to the surface with underground mining. In order to maintain an economic distinction between essentially barren rock and rock that has low grades of copper and/or nickel and may become ore in the forseeable future, the terms "waste rock" and "lean ore" are used, respectively. Using grades typical of the industry, for purposes of discussion, waste rock is defined as material with less than 0.1% Cu and lean ore is the material with 0.1-0.25% Cu. Waste rock to lean ore ratios will range between 1 and 10 to 1. In reality, these grades and ratios can vary considerably and must be determined for each operation in the context of the specific mining situation being dealt with. The distinction is made between waste rock and lean ore for two reasons:. 1) the lean ore will most probably be stored separately from the waste rock in the hope that it can be profitably treated in the future; and 2) because

PRELIMINARY
SUBJECT TO REVIEW

of a possible dissimilarity in the environmental leaching potential of the two types of rock. See Volume 3-Chapter 1 for further discussion.

Figure 8

In order to assess the impacts of the operation of a Cu-Ni mine, it is necessary to quantify some of the physical parameters of gabbro material. Based on available information, the waste rock and lean ore is assumed to have an in-place density of 3.00 mt/m^3 (187 lb/ft^3) ± 5%. The swell factor for broken rock is 67% ± 10% which results in a bulk density for rock piles of 2.00 mt/m^3 (125 lb/ft^3) ± 10%.

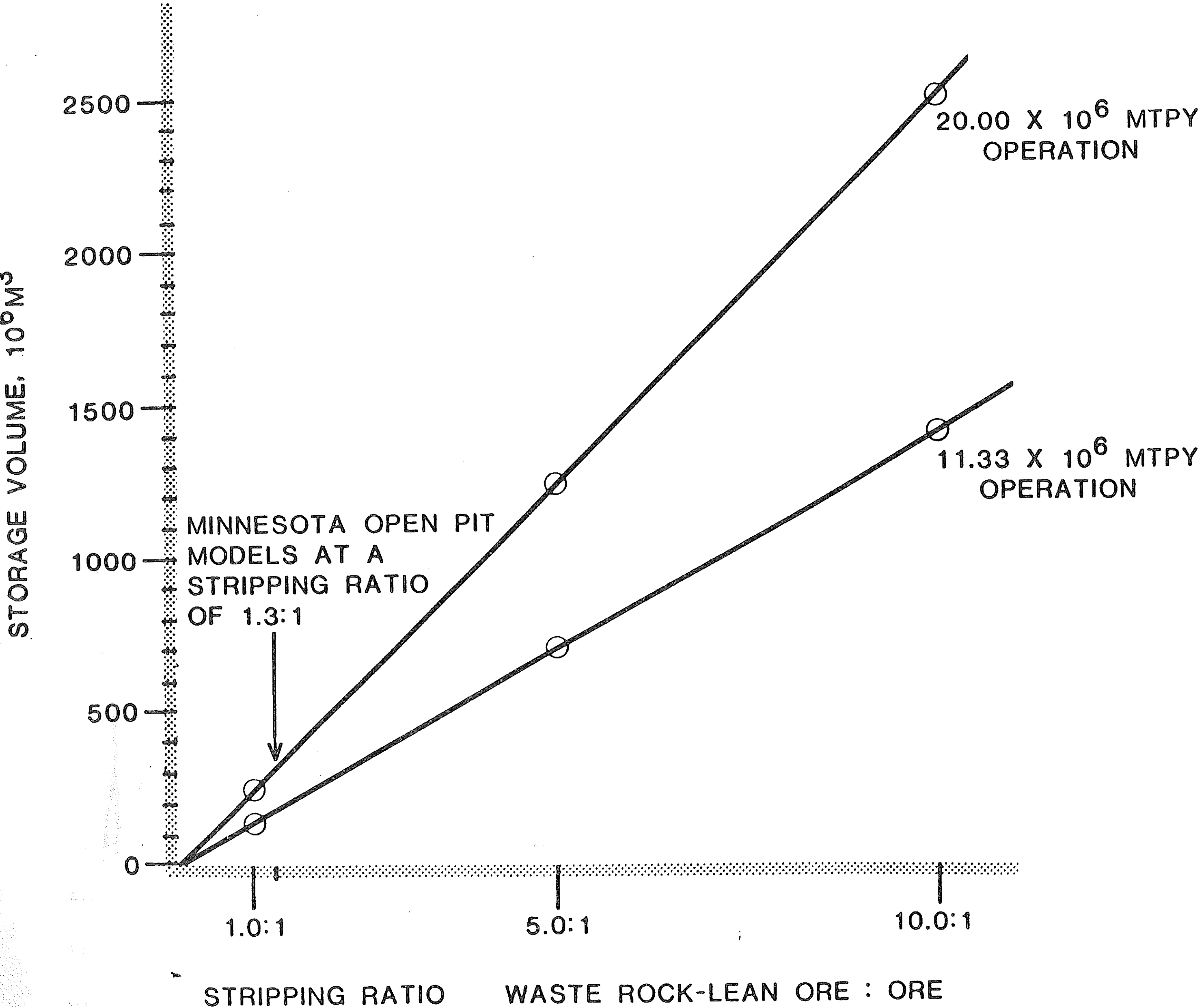
The waste rock and lean ore from a mine will be stored in one or several mining stockpiles. Proper care should be taken so that the stockpiles are not placed in areas where they may interfere with future mining activity or other important land uses. The grade of the minerals in the ground underneath rock piles should not be greater than the grade of the rock in the pile to assure that the piles will not prevent access to resources which may qualify as ore at some future time. Generalized views of a waste rock stockpile are shown in Figure 9.

Figure 9

In order to speak to appropriate methods of rock disposal, future use of the modified land surface must be considered. Future land use may determine the desirable height, slope, and location of the rock piles which in turn affects the number of piles needed and the total land area that they will cover. Once plans for future land use have been made the area in the vicinity of the mine must be evaluated in terms of foundation conditions and physiography in order to

FIGURE 8

COMPARISON OF WASTE ROCK-LEAN ORE STORAGE VOLUME* REQUIRED WITH VARYING STRIPPING RATIOS ASSUME 25 YEARS OF PRODUCTION

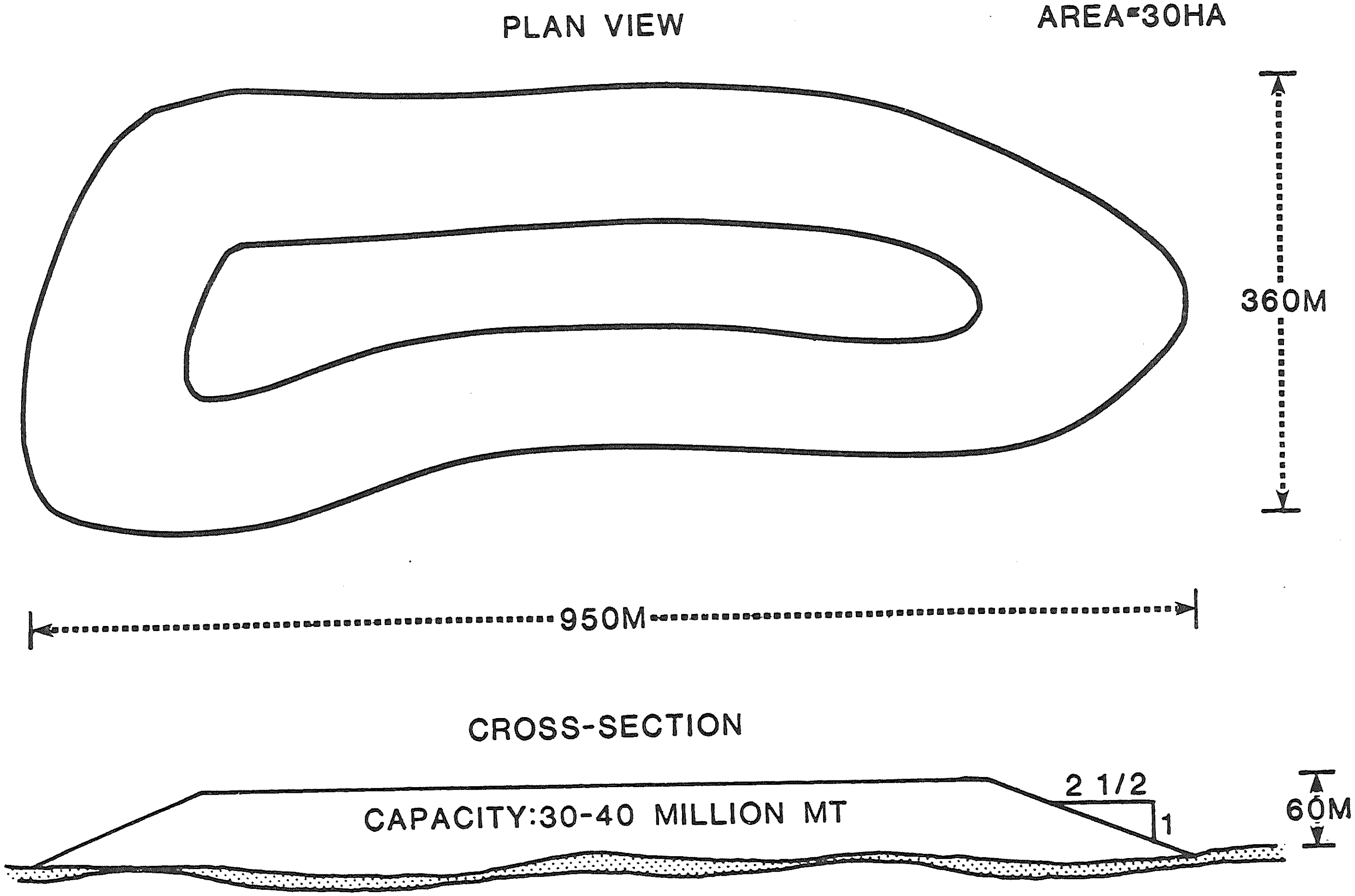


STRIPPING RATIO WASTE ROCK-LEAN ORE : ORE

*ASSUMED A WASTE ROCK/LEAN ORE BULK DENSITY OF 2 MT/M^3

FIGURE 9

GENERALIZED VIEWS OF WASTE ROCK STOCKPILE



determine its suitability for rock disposal. General ground conditions and soil types can be determined by examination of surficial geology maps and soil classifications (see Volume 3-Chapter 1). To reduce the potential for leaching, efforts should be made to limit the quantity of water which will come in contact with gabbro rock piles, especially in the case of lean ore piles (see Volume 3-Chapter 4).

If water mounding is likely in gabbro piles, placing the rock on elevated pads of inert material such as taconite waste may raise it above the water level (see Figure 10).

Figure 10

Table 10 shows how area requirements vary with the height, configuration, and number of rock piles. Increasing the height of the piles decreases the land area required and the surface area of the piles (a factor related to revegetation and dust lift-off considerations). A graph of land area versus the height of waste rock piles is shown in Figure 11.

Table 10, Figure 11

If land is in short supply or building conditions are such that rock piles will be restricted to specific foundation types, the number of suitable sites within a reasonable haulage distance from the mine may be reduced such that rock piles 120-150 m (400-500 ft) high may be planned. In the terrain typically found in the Study Area, when waste rock piles exceed approximately 15 m (50 ft) in height, they become the dominant physical feature of the area and will significantly change the character of the natural landscape. Heights greater than the

FIGURE 10

THE USE OF ROCK PADS TO ELEVATE WASTE ROCK

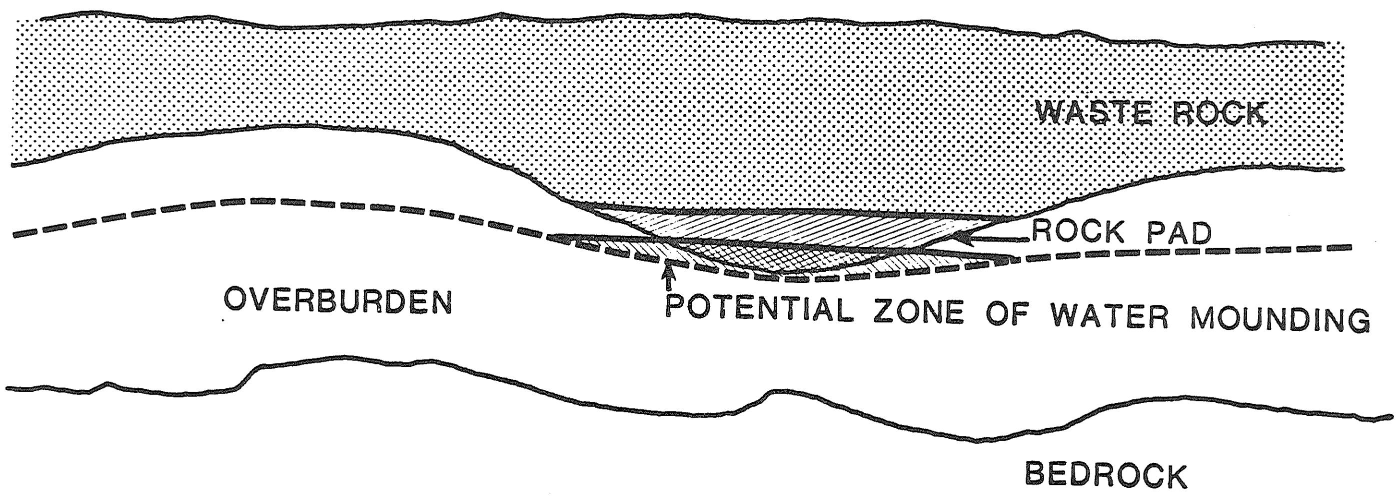


Table 10. The effect of height, configuration, and number of rock piles on land area and surface area.[a]

	ONE LARGE STOCKPILE (650×10^6 mt)		13 SMALL STOCKPILES (50×10^6 mt per pile)	
AREA MEASUREMENT	Round	Square	Round	Square
1. Stockpile height 30.5 m (100 ft)				
Land Area, ha	1,111	1,117	1,229	1,251
Actual Pile Surface Area, ha	1,118	1,124	1,254	1,278
2. Stockpile height 61.0 m (200 ft)				
Land Area, ha	597	605	772	805
Actual Pile Surface Area, ha	606	616	807	843
3. Stockpile height 122.0 m (400 ft)				
Land Area, ha	359	372	628	678
Actual Pile Surface Area, ha	373	387	674	729

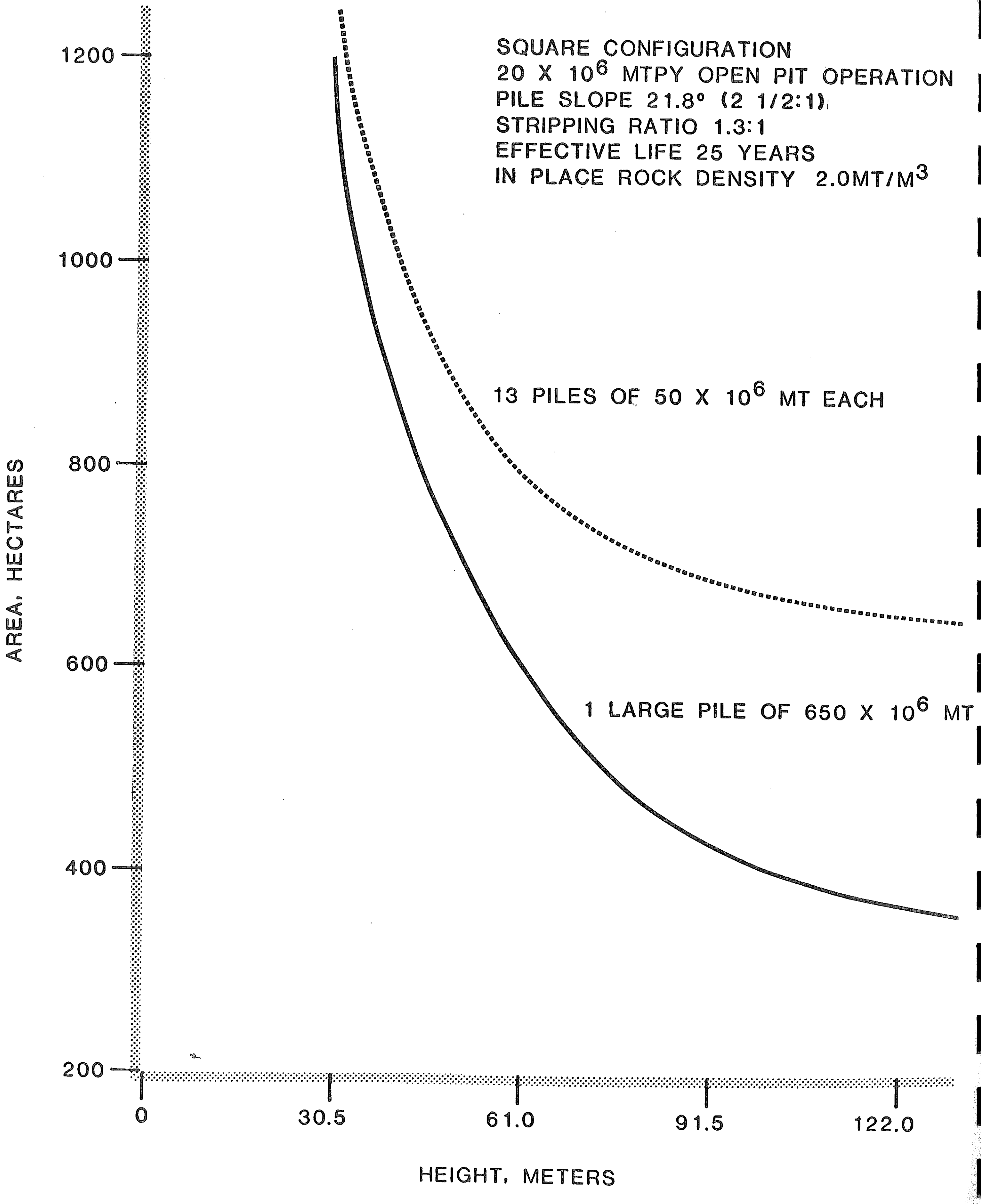
---

[a] Based on disposal of 650×10^6 mt of rock with a bulk density of 2 mt/m^3 and slopes of 2½ to 1.

[b] Includes surface area of slopes.

FIGURE 11

AREA COVERED BY WASTE ROCK PILES



tops of the surrounding trees may also hinder the natural revegetation process of the piles.

Figure 12 illustrates the relationship of waste rock dump pile height and capital cost, operating cost, manpower requirements and energy needs for the truck fleet necessary to transport the waste rock. Operating costs increase most rapidly, reflecting the additive energy and manpower needs.

Figure 13 relates equivalent horizontal haul distance to the lift height variation discussed above. On the average, 100 ft of vertical lift is equivalent to 3,000 to 5,000 ft of horizontal travel, depending on the total lift.

Figures 12 & 13

Because of the slopes on the perimeter of waste rock and lean ore piles, increasing the number of piles used to stockpile a fixed amount of rock results in less efficient use of land area. However, private mineral and/or surface ownership may restrict placement of the waste rock and lean ore in a single pile, even if both environmental and economic advantages would be gained by doing so. In the case of materials in which the state has an interest, state regulations (NR 94) provide flexibility as to segregation of removed materials, subject to approval of the Commissioner. It is conceivable that 5 classes of mineral ownership would be encountered in mining copper-nickel. These include lands controlled by the State of Minnesota, the Federal government, local government, mining companies, and private individuals. This could necessitate 5 or more piles being segregated for each disposal material type according to ownership.

FIGURE 12

WASTE ROCK PILE VARIATION-COMPARISON OF CAPITAL COST, OPERATING COST, MANPOWER. REQUIREMENTS AND ENERGY NEEDS (TRUCK HAULAGE ASSUMED)

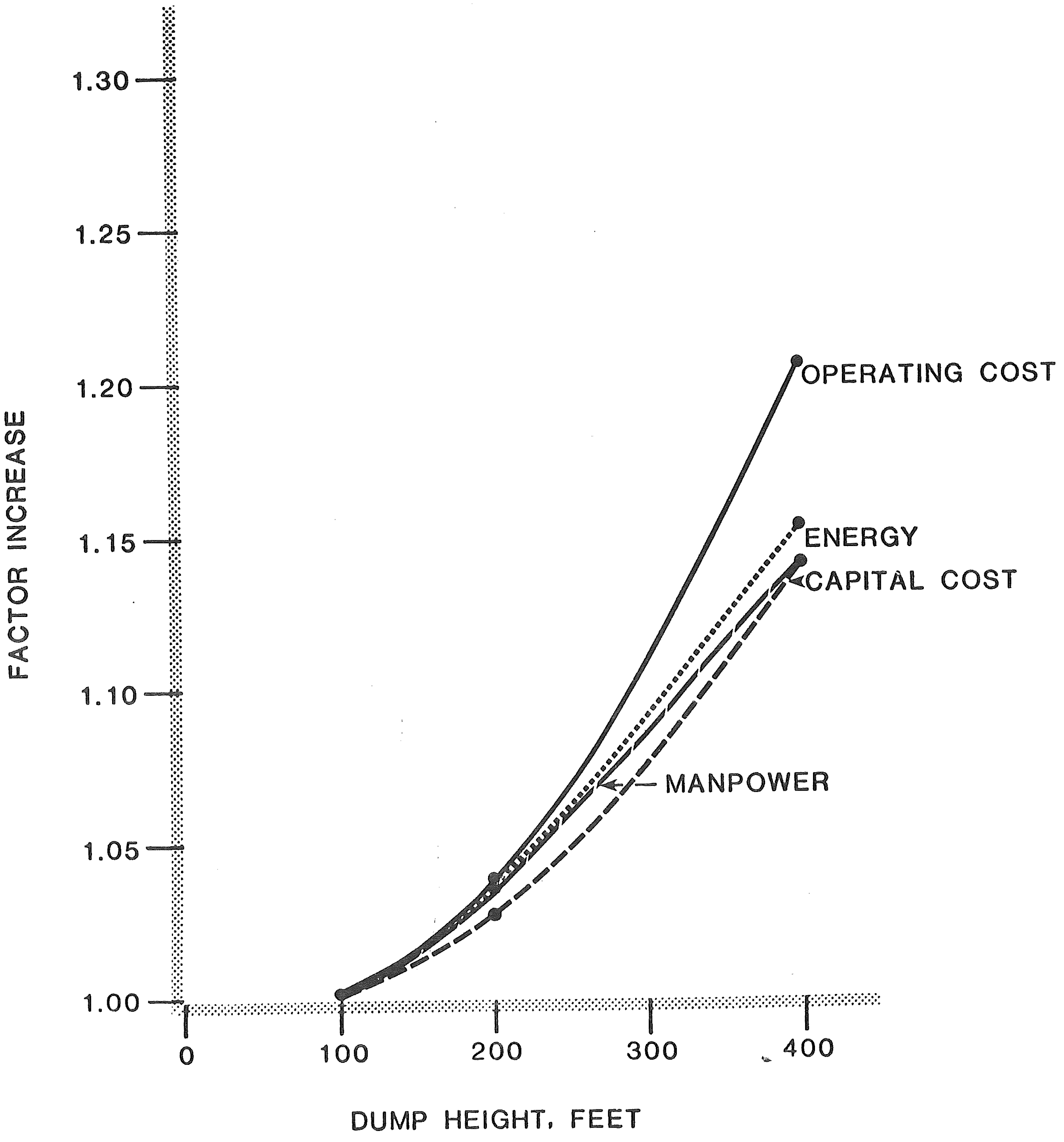
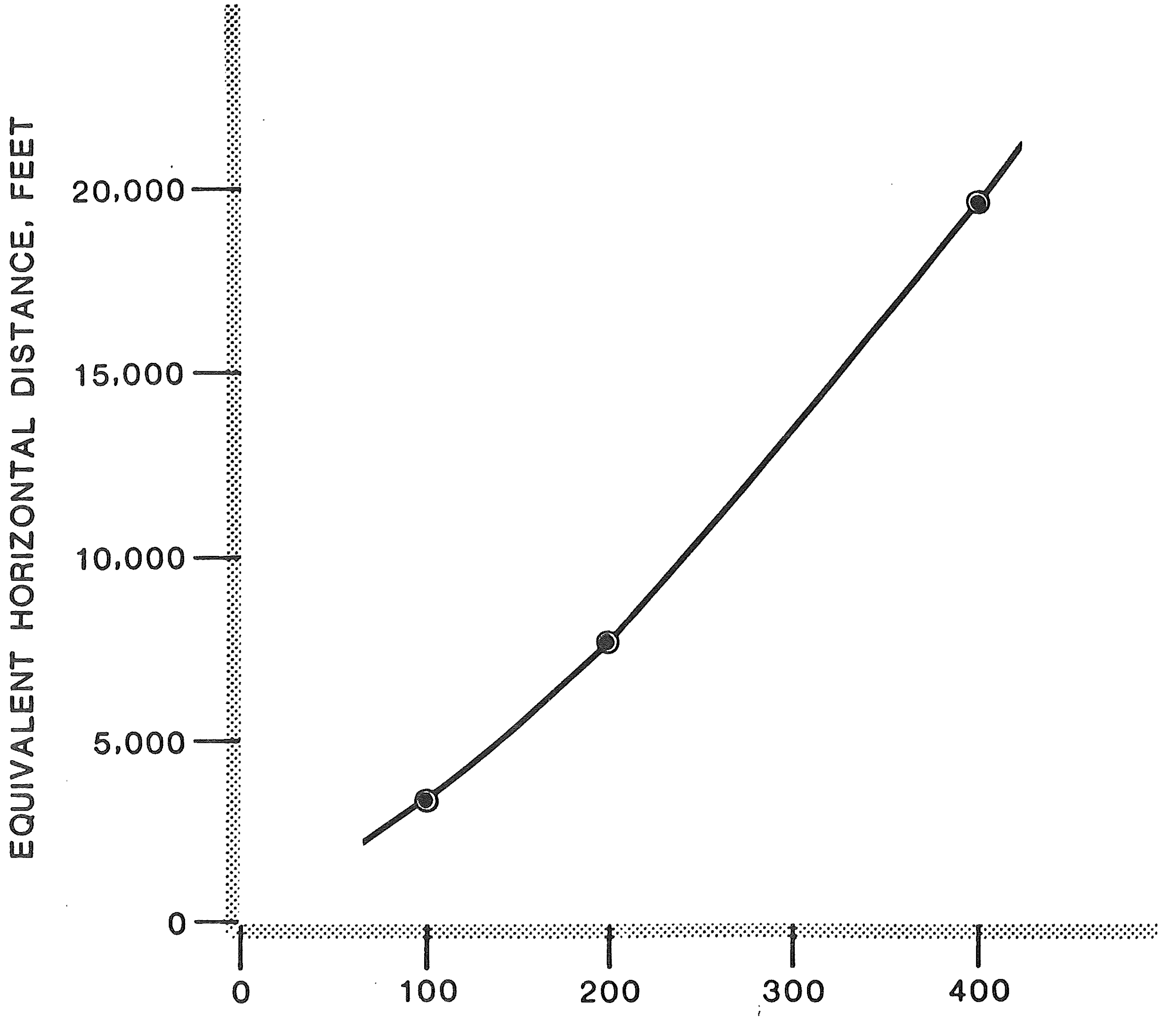


FIGURE 13

COMPARISON BETWEEN VERTICAL LIFT AND EQUIVALENT HORIZONTAL HAUL DISTANCE FOR WASTE ROCK DISPOSAL (TRUCK HAULAGE)



Most open pit mines will require the excavation of some overburden material. Overburden is defined as the unconsolidated soil, sand, gravel, peat, or clay that overlies, and must be removed to expose, the bedrock. The thickness of the overburden varies, both locally and throughout the Study Area, but it generally increases in thickness as one moves toward the southern part of the Study Area. Table 11 gives the thickness and volume of overburden that can be expected at six Study Area locations shown in Figure 14. Refer to the surficial geology discussion (Volume 3-Chapter 1) for more details.

Table 11, Figure 14

Any overburden material that can be used in the future, such as for reclamation purposes, should be segregated and stored. However, as mentioned above, some areas potentially would be short of sufficient overburden for significant reclamation practices, and it may have to be imported as part of the total reclamation program. Overburden, in some cases, can have high metal concentrations and when disturbed and stockpiled could become a potential source of ground and surface water contamination. Such piles, therefore, may require special mitigating measures similar to those necessary for waste rock and lean ore piles.

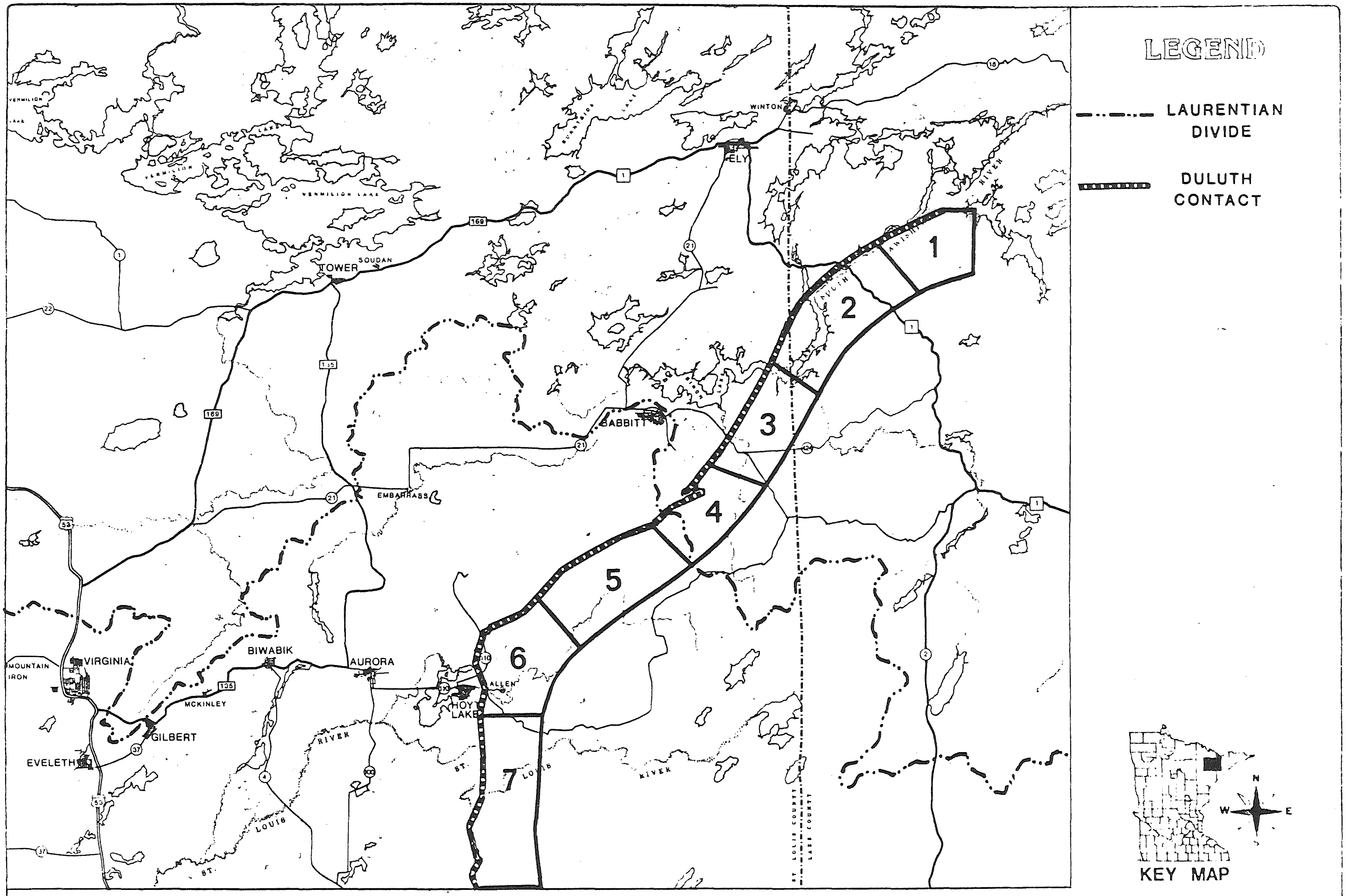
2.6 HYDRAULIC BACKFILLING (Extracted from Hydraulic Sandfill in Deep Metal Mines, 1975)

Hydraulic backfilling involves the use of coarse tailing sand or similar material in a slurry form to fill the voids in underground mining resulting from the removal of ore and other material in development openings. Backfilling stopes offers some degree of support to the adjacent pillars and overlying ground, allowing a greater degree of ore extraction than if no support is utilized. It

Table 11. Thickness and volume of overburden at six Study Area locations.

RESOURCE AREA[a]	OVERBURDEN THICKNESS, (m)	VOLUME OF OVERBURDEN (m^3/ha)	DRIFT TYPE
1	1.5 to 3	15,000 to 30,000	Till
3	1.5 to 15	15,000 to 150,000	Till and peat in northern half; sand and gravel in southern half.
4	1.5 to 4.5	15,000 to 45,000	Till; sand and gravel on north and east sides.
5	1.5 to 3	15,000 to 30,000	Till and peat.
6	1.5 to 6	15,000 to 60,000	Till and peat; possible sand on NW margin.
7	6 to 30	60,000 to 300,000	Till and peat.

[a] See map, Figure 14.



MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 14

RESOURCE ZONES

also offers a method of tailing and hazardous waste disposal that does not require surface area which would be exposed to natural transport processes and therefore pose a potential pollution problem.

Compared to ground support measures utilizing timber or waste rock fill, hydraulic backfilling offers the following advantages:

1) Improved ground control over other methods

2) More rapid overall extraction of material as sandfill techniques are easier and quicker than other methods of ground support

3) More complete ore extraction due to improved support

4) Improved ventilation control

5) Decreased fire hazard compared to timber support

6) Utilization of part of the processing waste which reduces the need for surface tailing disposal

However, several principal support problems and other disadvantages remain unsolved. Among the important drawbacks are the following:

1) Large volumes of water used to pump backfill to the mine at 50-70% solids must be removed.

2) Haulage ways and drainage ditches may be clogged with fines that drain from filled stopes with the transport water.

3) Other spillage of fill from stopes due to imperfect sealing, high hydrostatic head or failure of the hydraulic system may create additional maintenance problems.

4) Some dilution of the ore by fill may occur, adding that load to the material flow system with no benefit of recoverable metal.

5) Coarse sand requirements for backfill may exceed the excess available from tailing dam construction, thereby causing a trade-off situation.

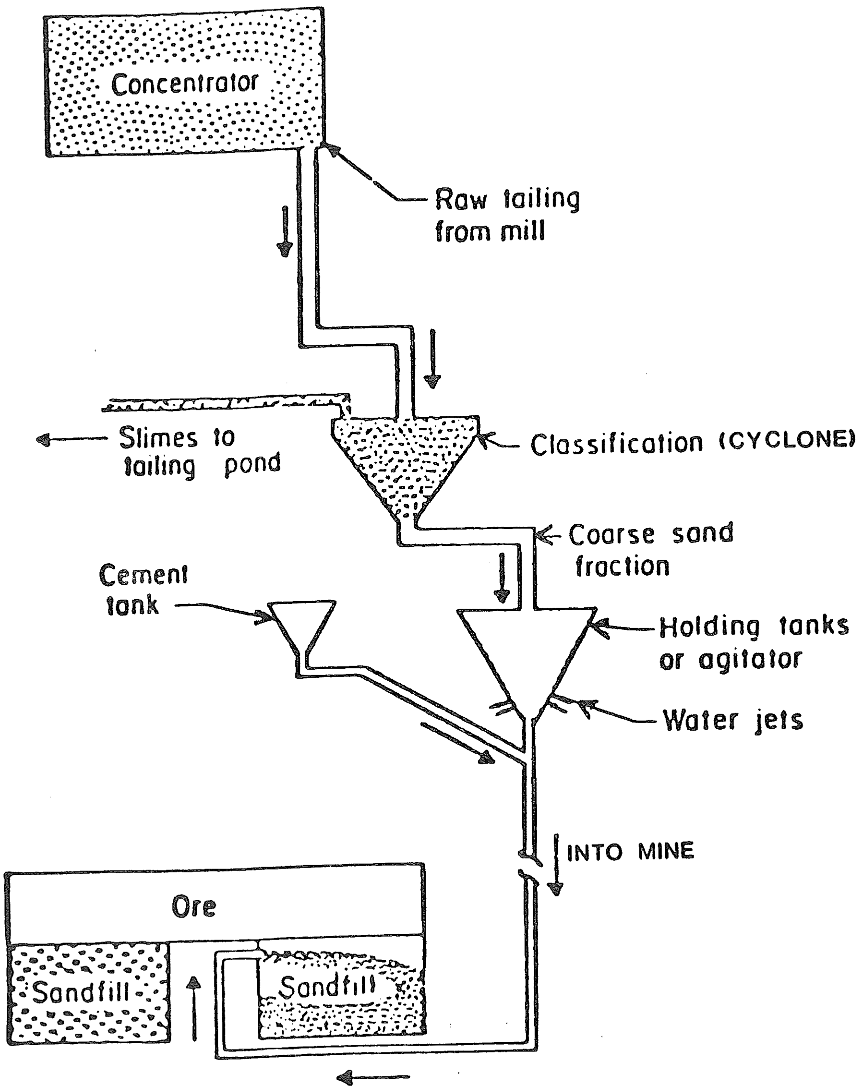
A typical flow diagram of a hydraulic backfill system is shown in Figure 15. As shown on the diagram, the hydraulic sandfill system begins at the point where the raw tailing is separated from the ore concentrate at the processing plant. The tailing is pumped to a primary classification unit (usually a cyclone) where the coarser size fraction of the tailing is separated from the finer size fraction (200 mesh is generally the dividing size). The coarse fraction is transported to holding tanks; the finer fraction is sent to surface tailing basins.

Figure 15

The coarse fraction is stored in holding tanks until required underground. Upon demand, this sand is mixed with a predetermined quantity of water (cement, additive, or other modifier may be combined with the sand-water mixture to give a stronger fill and to hasten consolidation) and the hydraulic fill is pumped to the underground mining area.

When the stopes are filled hydraulically, it is necessary to close off all abandoned stope accesses. Bulkheads must be capable of sustaining hydrostatic heads equal to the full height of the stope to be filled. Concrete or heavy timber bulkheads are preferred and they should be valved to bleed off liquids from the fill.

FIGURE 15 FLOW DIAGRAM OF A HYDRAULIC SANDFILL SYSTEM



NOT TO SCALE

Stopes drain by percolation, decantation, or both. Drains are of various designs but all serve the primary function of providing a pathway through which excess water can be removed from the stope.

It must be stressed that even with competent rock and cemented backfill (tailing sands with cement added), roof closure can occur due to local unique conditions, with surface subsidence being a possible consequence.

Mine filling costs vary from operation to operation, depending upon type and source of fill, transport distance, cost of sand walls and drainage system, and labor costs. Construction costs for placing burlap sand walls or fences have averaged \$0.46/ft^2; costs for concrete bulkheads would be substantially higher. Placement of classified tailing has generally cost less than quarried sand and/or gravel. Other mines have placed smelter slag with the sand fill. Hydraulic sandfill costs have ranged from \$0.56 to \$4.49 per ton of sand.

2.7 UPSET CONDITIONS

In any mining operation, conditions which cause delays in the scheduled production may be considered upset conditions. For example, these conditions may be slope failures in open pit mining which cause an area to be unsafe for production, or unsafe ground conditions in underground mining which prevent operations in a section of the mine. Both conditions are preventable, or at least can be remedied to allow full operations, but prevention is the safest and surest route.

Surface and underground mining upset conditions can be prevented to the extent possible by:

1) Proper engineering and design of the mine plan to minimize the risk of ground failure.

2) Handling and storage of flammable liquids and explosives by accepted safety methods.

3) Insistance on complete safety instruction of all employees (fire, accidents, etc.).

4) Establishment of preventive maintenance procedures which must be followed on all equipment subject to failure.

5) Insistance on a complete clean-up of all areas at frequent intervals.

6) Providing sufficient equipment to remove water in case of flooding conditions due to ground water inflows.

7) Providing an emergency power supply in case of failure of the main system.

8) Institution of regular inspection of all mine areas and monitoring of suspect areas to detect possible ground failures before they occur.

Most upset conditions can be prevented by good, common sense operations. However, when they do occur unexpectedly, employees must be trained to handle the situation safely and to restore full operations as soon as possible. Federal, state, and local officials must also be familiar with and trained to deal with upset conditions in Minnesota copper-nickel operations.

2.8 POLLUTION CONTROL TECHNOLOGY

The principal sources of potential pollution as a result of emissions to the environment from mining activities are dust, water, and noise. Dust generation in open pit mining is primarily due to vehicle travel on roadways and is usually controlled by watering or similar methods of dust suppression. In underground mining, dust control measures are primarily water sprays and ventilation.

The major particulate air pollution source in open pit mining operations is thought to be lift-off from mine roads. This can be controlled by watering or a combination of chemicals and water, but excessive treatment develops slippery conditions which would be hazardous to vehicle travel. Other alternatives would include rail or conveyor haulage, and fewer large trucks to move the ore, waste rock, lean ore, and overburden. Hard surfacing of the roadways is not practical due to the loaded weight of transport vehicles and the need to relocate roads at frequent intervals.

Although water is listed as a source of potential pollution, it is not expected to be significant, as little water is expected from mines in the Study Area (see Volume 3-Chapter 4). As much as possible, all mine water would be removed and discharged to the overall water management system (i.e. tailing basin, processing make-up water, or water storage area).

Noise control can, to a limited extent, be effected by proper design, engineering and installation of equipment, which is responsible for disturbing noise levels. A good measure of noise control for workers can be accomplished by ear protection for all employees in areas subject to high noise levels.

Tables 12 and 13 list potential pollution sources, mitigating measures, and effectiveness of these measures for both open pit and underground mines.

Tables 12 and 13

2.9 RECLAMATION (to be added at a later date)

Table 12. Open pit mining: pollution sources and controls.

OPERATION	POLLUTANT EMITTED	CONTROL TECHNOLOGY	EFFECTIVENESS OF MITIGATION MEASURES[a]
Drilling	Equipment noise	Workers wear ear protectors	1
		Use quiet type of equipment	2
	Dust	Use wet drilling	1
Blasting	Noise and ground shock	Select proper blast design and evacuate blast area	2
	Dust	Blast only under favorable atmospheric conditions	2
Loading	Equipment noise	Workers wear ear protectors	1
		Use quiet type of equipment	2
	Dust	Spray working face before loading	3
Transporting	Equipment noise	Workers wear ear protectors	1
		Use quiet type of equipment	2
	Dust generated by trucks traveling on unpaved haulage roads	Spray the haulage roads with water, use other transportation methods	1-2
Mine Dewatering	Contaminated water	Collect and treat discharge	1
Waste Rock/ Lean Ore Storage	Dust	Cover and revegetate piles	1
	Visual	Obscure view	3
	Water pollution from leaching	Isolate piles from rain or groundwater	unknown
		Collect and treat runoff	unknown
Abandoned Open Pit	Visual	Obscure view	3
	Contaminated water in mine	Prevent seepage of pit water into regional groundwater	3

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[a] 1: Good-proven effective control technology exists and is known to operate reliably in many installations.

2: Fair-proven effective control technology exists or is in the demonstration stage at one or more installations.

3: Poor-proven effective control technology has not been developed or is not yet ready for full-scale operation.

Table 13. Underground Mining: pollution sources and controls.

OPERATION	POLLUTANT EMITTED	CONTROL TECHNOLOGY	EFFECTIVENESS OF MITIGATION MEASURES[a]
Drilling	Noise	Workers wear ear protectors	1
		Use quiet type of equipment	2
	Dust	Wet drilling and ventilation	1
		Workers wear breathing masks	
Blasting	Noise	Evacuate blast area	1
	Dust	Ventilation and water sprays	1
		Workers wear breathing masks	
Loading	Noise	Workers wear ear protectors	1
		Use quiet type of equipment	2
	Dust	Water sprays and ventilation	1
Transporting	Noise	Workers wear ear protectors	1
		Use quiet type of equipment	2
	Dust	Water sprays and ventilation	1
		Workers wear breathing masks	
Crushing	Noise	Workers wear ear protectors	1
	Dust	Dust collectors, water sprays	
Hoisting	Noise	Use quiet type of equipment	1
Ventilation	Noise	Use quiet type of equipment	2
		Install passive sound absorbers and barriers	
	Dust	Dust collectors	1
Mine Dewatering	Contaminated Water	Collect and control discharge	1
Abandoned Underground Mine	Surface disturbance from subsidence	Proper mine design	1
	Contaminated water in mine	Properly seal mine prior to abandonment	1

[a] 1: Good-proven effective control technology exists and is known to operate reliably in many installations.

2: Fair-proven effective control technology exists or is in the demonstration stage at one or more installations.

3: Poor-proven effective control technology has not been developed or is not yet ready for full-scale operation.

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