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Air Pollution Emissions and Control Technology. Arctic Mining

Economic and Technical Review
Report EPS 3-AP-76-4

Air Pollution
Control Directorate

November 1976

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AIR POLLUTION EMISSIONS AND CONTROL TECHNOLOGY. ARCTIC MINING

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Air Pollution Control Directorate

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ABSTRACT

The possible contribution to air pollution by mining operations in the Canadian Arctic is evaluated. Estimated emissions from mines operating in the area during 1973 serve as a basis for the establishment of types, sources and magnitude of emissions and for definition of the best practicable technology for control of such emissions in order that guidelines, regulating all present and future mining operations, can be promulgated to minimize their impact on the arctic environment.

Areas considered are the Yukon Territory and the Northwest Territories consisting of the Districts of MacKenzie, Keewatin and Franklin, including the Arctic Islands and Baffin Island. Several mines are already in operation. Many ore bodies have been outlined, and more will be discovered in exploration programs. All of these may become subject to exploitation at some future date.

RÉSUMÉ

Cette étude estime l'apport possible à la pollution atmosphérique des exploitations minières de l'Arctique canadien. Elle établit d'abord la nature, les sources et l'ampleur des émissions minières de la région en 1973. Cela permet de définir des meilleurs techniques praticables pour enrayer les émissions, dont s'inspireront des lignes directrices qui pourront minimiser les répercussions sur l'environnement arctique des exploitations minières actuelles ou futures.

Les régions considérées sont le Yukon et les Territoires du Nord-Ouest, y compris les districts de Mackenzie, de Keewatin et de Franklin, les îles de l'Arctique et l'île Baffin. Plusieurs mines son déjà en exploitation. De nombreux gisements de minerais ont été repérés et d'autres le seront par suite des travaux d'exploration qui se poursuivent. Un grand nombre de ces gisements pourront éventuellement être exploités.

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1.1 Scope

It is important that the arctic environment be preserved from serious degradation of the type that has resulted from early, uncontrolled mining ventures elsewhere in Canada. This study pertains to air pollution control of mining operations in the Canadian Arctic. Size and location of mines, mineral products, and relative importance to the Canadian economy are discussed. The initial inventory is based on emission estimates but will be upgraded when actual operating data become available. Various types of equipment for pollution control are discussed and the best practicable technology is defined for present and future mining operations.

1.2 Purpose

The purpose of this report is to provide the technical information necessary for the establishment of effective emission guidelines for the regulation of mining operations in the Canadian Arctic.

A secondary purpose of this report is to provide information to assist in the development of federal briefs, state-of-the-art reviews and other documents related to air pollution from arctic mining operations.

1.3 Information Sources

A bibliography of air pollution in the Arctic was prepared by Western Research and Development Limited and copies of available original papers were provided. Because of the small number of active mining properties in the Canadian Arctic, personal contact with mine operators supplanted the normal questionnaire survey in obtaining detailed operational data. Other information was acquired through the reference section of the library of the Department of the Environment from articles in the most recent trade literature and from other government departments.

2 INDUSTRY DESCRIPTION

2.1 Size

There were six mines operating in the Yukon Territory in 1973, with a total mineral production valued at $145 594 000, up 37% over 1972 production. Minerals recovered were lead, zinc, silver, cadmium, nickel, copper, platinum, asbestos and coal, with lead and zinc accounting for 67% of total production.

Six mines also operated in the Northwest Territories in 1973 and had a total mineral production valued at $164 777 000, up 40% over 1972 production. Minerals recovered were lead, zinc, copper, gold, silver and tungsten, with lead and zinc accounting for 76% of total production. The sharp increase in the price of gold in 1973 resulted in an increase of 37% in value although production volume was 18% lower than that of 1972.

In addition to the producing mines, active exploration is underway at a great number of locations in the Yukon and the Northwest Territories. Work to date has resulted in discoveries that indicate the establishment of new operating mines in the near future. Production plans are well advanced for two companies, preliminary feasibility studies and metallurgical tests are being considered by others.

During 1973, a total of 9383 mining claims were recorded in the Yukon Territory, up 37% over the number recorded in 1972, and a total of 15 303 claims were recorded in the Northwest Territories, up 275% over 1972. This gives some indication of the increased activity that can be expected in the future.

2.2 Employment

The work force at producing mines during 1973 totalled 2499 : 1155 employees in the Yukon and 1344 in the Northwest Territories. The number of employees of companies and contractors engaged in exploration is not known.

2.3 Products

Minerals are usually recovered in the form of concentrates of zinc, lead, copper and tungsten, which are shipped to various locations for smelting and refining. Some contain varying amounts of silver, gold, cadmium, nickel and bismuth which may be recovered as by-products of the refining processes. Coal is mined in the Yukon but only in quantities sufficient to satisfy the requirements of affiliated companies in the area. Various grades of asbestos are also produced in the Yukon for direct sale to manufacturers of finished products. Some bullion is shipped to the mint from companies mining gold and silver ore.

Volume of production and value of minerals recovered is tabulated in Appendix I.

2.4 Geographic Distribution

The locations of producing mines operating in the Yukon and Northwest Territories in 1973 are illustrated in Figure 1. The areas which were under active exploration at that time are also indicated. Detailed information on the various producers is given in Table I.

3 OPERATIONS

3.1 Mining

Mining is carried out by open pit and underground methods with surface operations at four locations accounting for 80% of ore mined compared to only 20% for underground operations at eight other mines.

No consideration is given to the mining of asbestos in this report because it is covered in a separate study on the asbestos mining and milling industry, currently in preparation.

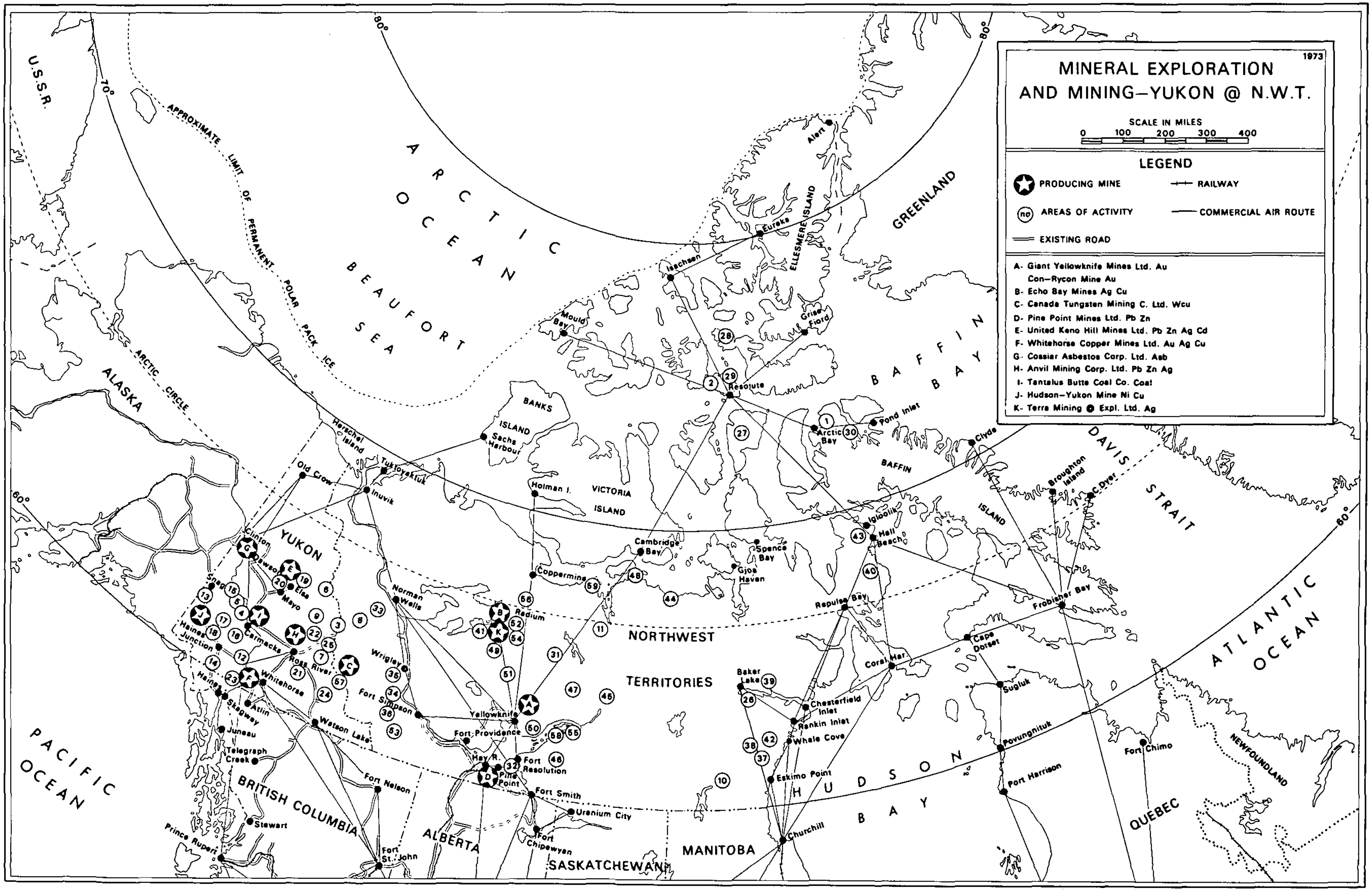

FIGURE 1 PRODUCING MINES IN THE YUKON AND NORTHWEST TERRITORIES, 1973 (1)

TABLE 1 PRODUCING MINES - YUKON AND NORTHWEST TERRITORIES, 1973 (1, 2)

Mine and Location	Type	Products	Rated capacity (TPD)	Operation %	Tons milled Per day	Total year	Number of employees	Remarks
YUKON								
Anvil Mined Corp. Faro	Open pit	Lead, Zinc, Silver, Gold	7 800	101.8	7 942	2 899 124	375	Increased to 10000 TPD 1973-1974
Cassiar Asbestos Corp. Clinton Creek	Open pit	Asbestos	5 300	91.3	4 838	1 247 154	228	
United Keno Hill Mines Ltd., Elsa	Underground	Silver, Lead Zinc, Cadmium	500	51.2	256	95 179	280	
Whitehorse Copper Mines Ltd., Whitehorse	Underground	Copper, Silver Gold	2 000	95.9	1 919	700 054	196	
Hudson-Yukon Mines Ltd., Quill Creek	Underground	Nickel, Copper	600	76.5	459	76 760	57	Closed Aug. 1973
Tantalus Butte Coal Mine, Carmacks	Underground	Coal	80	97:5	78	19 601	19	
NORTHWEST TERRITORIES								
Pine Point Mines Ltd. Pine Point	Open pit	Lead, Zinc	10 000	107.9	10 790	3 896 357	550	
Con-Rycon-Vol Mine Yellowknife	Underground	Gold	500	92.4	462	168 696	207	
Giant Yellowknife Gold Mine, Yellowknife	Underground	Gold	1 200	88.9	1 067	389 460	358	
Echo Bay Mines Ltd. Great Bear Lake	Underground	Silver, Copper	160	66.3	98	37 393	91	
Terra Mining & Exploration Ltd., Great Bear Lake	Underground	Silver, Copper Bismuth	200	56.5	113	38 787	53	
Can. Tungsten Min. Corp. Tungsten	Open pit	Tungsten	500	90.4	452	165 000	85	Developing underground

3.1.1 ***Surface.*** Recently, large, low-grade ore bodies have been brought into production using open pit mining methods. Large tonnages must be handled to make such operations viable. These ore bodies outcrop on the surface or are covered with a slight mantle of overburden and/or waste rock. Safe slopes must be maintained around the open pit so the waste/ore ratio becomes an important factor in determining the profitability of an operation and the daily tonnage of ore that must be processed. Overburden and waste rock removed in developing the open pit is hauled to a waste dump established nearby. The rock is drilled, using large rotary or percussion drills, boring widely spaced holes six to nine inches in diameter to a depth two or three feet below grade. Ore is blasted in benches 30 to 50 ft high. Broken waste rock is placed on the waste dump and blasted ore is hauled to the primary crusher. Loading is by electric shovels and/or front-end loaders of 8 to 15 yd^3 capacity. The rated capacity of off-highway trucks used on ore and waste hauls varies from 50 to 200 tons at different locations.

3.1.2 ***Underground.*** Several methods may be used for the underground mining of base metal ores depending upon the size and altitude of the ore bodies.

3.1.2.1 *Blasthole Method (Figure 2).* In preparing a blasthole stope, sublevels are established longitudinally along one or both walls of the ore body or stope. A slot stope is then mined across one end of the blasthole stope to the full height of the block to be mined, using regular shrinkage methods (see shrinkage stoping). All ore is removed from the slot stope to provide an open space to ease breaking rock in subsequent long-hole blasts. Drawpoints are established on the haulage level under the stope being developed. The tops of these drawpoints are connected and the stoping area is completely undercut. This could be progressive, as rings are blasted in the sublevel, to minimize loose rock conditions around the drawpoints. Rings of holes are drilled transversely across the ore body or stope at regularly spaced intervals from the sublevel drifts, using long-hole machines or diamond drills. Spacing of rings varies for different mines but averages about 7 ft. The bottoms of individual holes in each ring are also regularly spaced for ideal blasting to obtain optimum fragmentation. The ring nearest the slot stope is blasted first. Subsequent rings are blasted in sequence, as required, to satisfy broken ore requirements. This method is relatively cheap but can only be used where there are competent wall rocks, otherwise sluffing and excessive dilution result.

3.1.2.2 *Block Caving (Figure 3).* This is the cheapest of all underground mining methods but is only used at one base metal mine and two asbestos mines in Canada. It has, however, been used extensively at various base metal mines in the United States. Blocks are usually about 300 ft x 300 ft and 400 to 500 ft high. A vertical raise is put up at each corner to the full height of the block. Fringe drifts are driven around the block from the corner raises at regular sublevel intervals. This is to provide lines of weakness around the outer perimeter of the block. Further weakness can be created by drilling a line of vertical holes between sublevels and blasting alternate holes and/or blasting back stopes (Figure 4) along each sublevel drift. Broken ore from such back stopes is usually left in the fringe drifts. Drawpoints are established under the whole block to be caved. The tops of these drawpoints are all interconnected and the whole block is undercut at this elevation. Caving now commences and regulated drawing from different drawpoints will tend to 'rock' the block to set up further stresses for fragmentation and reduce the size of broken ore delivered to the drawpoints.

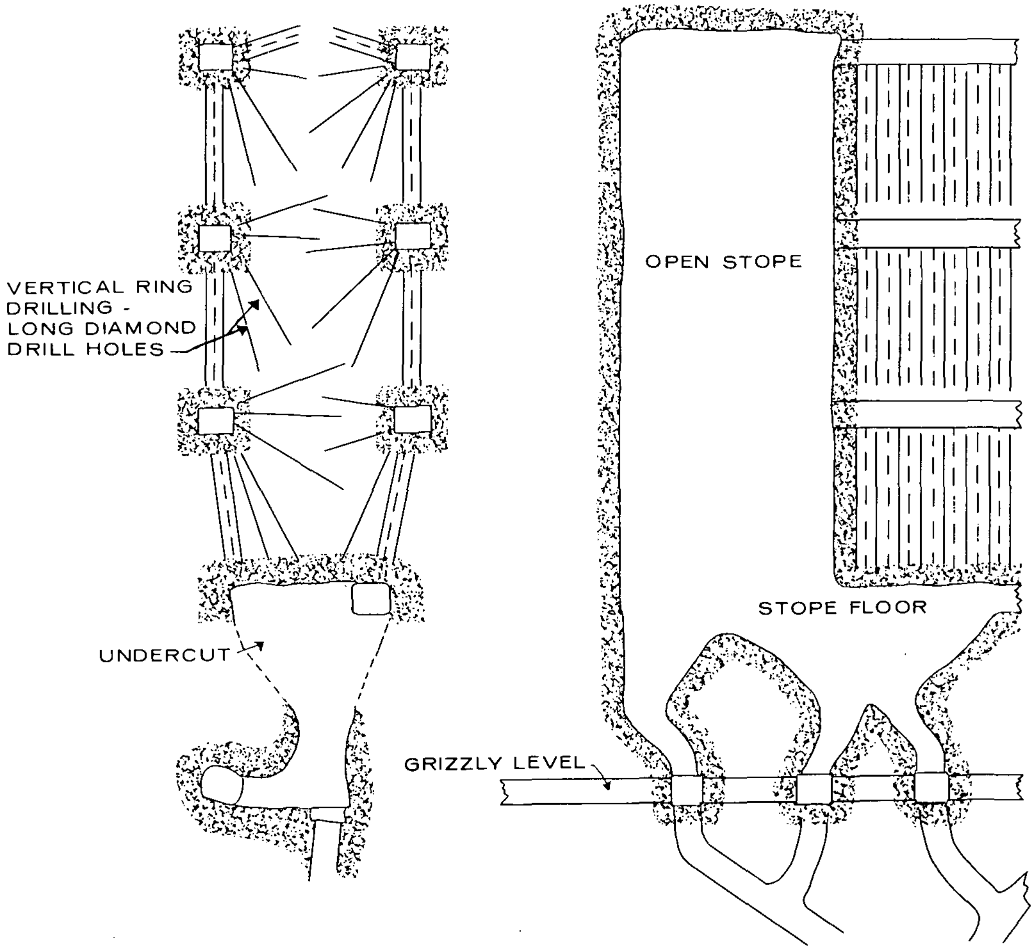

FIGURE 2 LONG-HOLE BLASTING

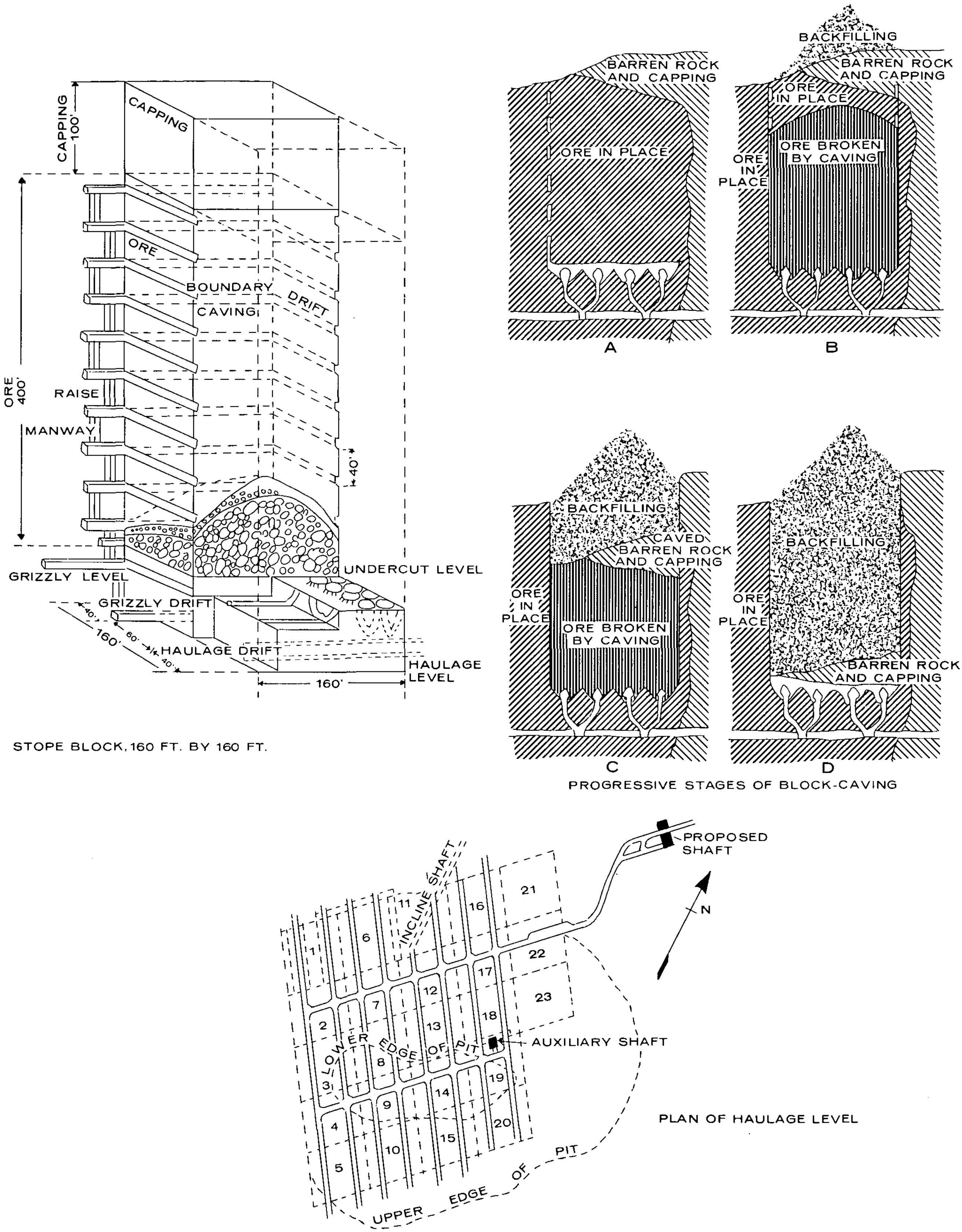

FIGURE 3 BLOCK CAVING

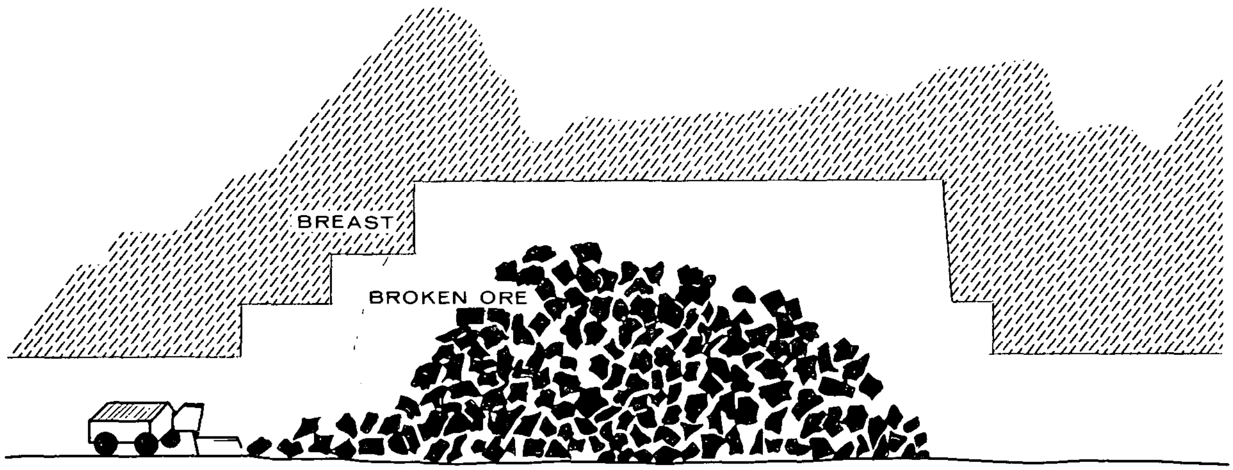

FIGURE 4 BACK STOPE

3.1.2.3 Shrinkage Stoping (Figure 5). This method is used on small, higher-grade ore bodies. It is not used where heavy ground conditions exist in the ore to be mined. It is also essential to have competent wall rocks to avoid excessive dilution. Drawpoints are established on a haulage level, along the length of the stope. The tops of these drawpoints are connected and the ore is mined out to the stope walls at this elevation. A raise is driven in the ore on an incline to the level above to provide additional ventilation and access to the working area. Breasts about 8 ft high are advanced from this raise to both ends of the stope. Only sufficient ore is drawn from the stope to provide working space on top of the broken ore. When mining has been completed to the level above, all broken ore is drawn from the stope.

3.1.2.4 Cut-and-Fill Stoping (Figure 6). This method is used where some wall support is necessary but should not be used where very heavy ground conditions exist in the ore to be mined. The walls of the drift are slashed out to the ore limits. Next, a backstope is mined to a height of about 25 ft above track elevation. All broken ore is removed. The stope is then timbered and combined chutes and manways are built at spaced intervals. The timber is then covered with plank flooring so that it is about 16 ft above the track elevation. A fill raise is then driven in to the ore to the level above and all the broken ore is removed. Breasts about 8 ft high are blasted in both directions from the raise. The broken ore is mucked off the plank floor and deposited in the chutes. Fill is then dumped down the raise and levelled off about 8 ft above the stope floor. A plank floor is laid and a fill chute is built under the raise. Planks are laid on the slope of this fill under the next breast which has been previously drilled. The breast is then blasted and the next breast is drilled off from a working place on top of the broken ore. The broken ore is mucked out, the planking on the slope removed, the fill advanced to the next breast and the procedure repeated. As filling progresses over a chute, the chute and manway are built up to the new fill level, using cribbed timber, and hardwood plank lining is installed in the chutes. When a cut has been completed for the full length of the stope, the fill chute is removed and a new cut started, as previously described. Some ground conditions may require the use of timber to provide temporary support for the back (roof) of the stope. Usual sets consists of two posts supporting a cap which is wedged to the back. In some instances, the occasional use of cribs is necessary. Fill may be waste rock, sand and/or the coarse tailing fraction from milling operations, in which case a different procedure for filling is required.

3.1.2.5 Square-Set Stoping (Figure 7). This method is used in mining narrow or wide ore bodies where extremely heavy ground conditions exist. The square-set system is a method of mine timbering in which heavy timbers are framed together in rectangular sets, 6 or 7 ft high and 4 to 6 ft square, in order to fill in space as the ore is removed by overhand stoping. The back and walls of the stope are supported at all times by square-sets along and across the stope. Chutes and manways are built in square-sets as they are raised to the mining floor. While the timber itself may provide sufficient support, fill is also regularly used and the square-sets are left in place in the fill.

3.1.2.6 Hoisting. Ore is transported from stopes to the orepass, crushed and then hoisted to the surface bin.

From this point on, ore is handled in a similar manner for both surface and underground mining.

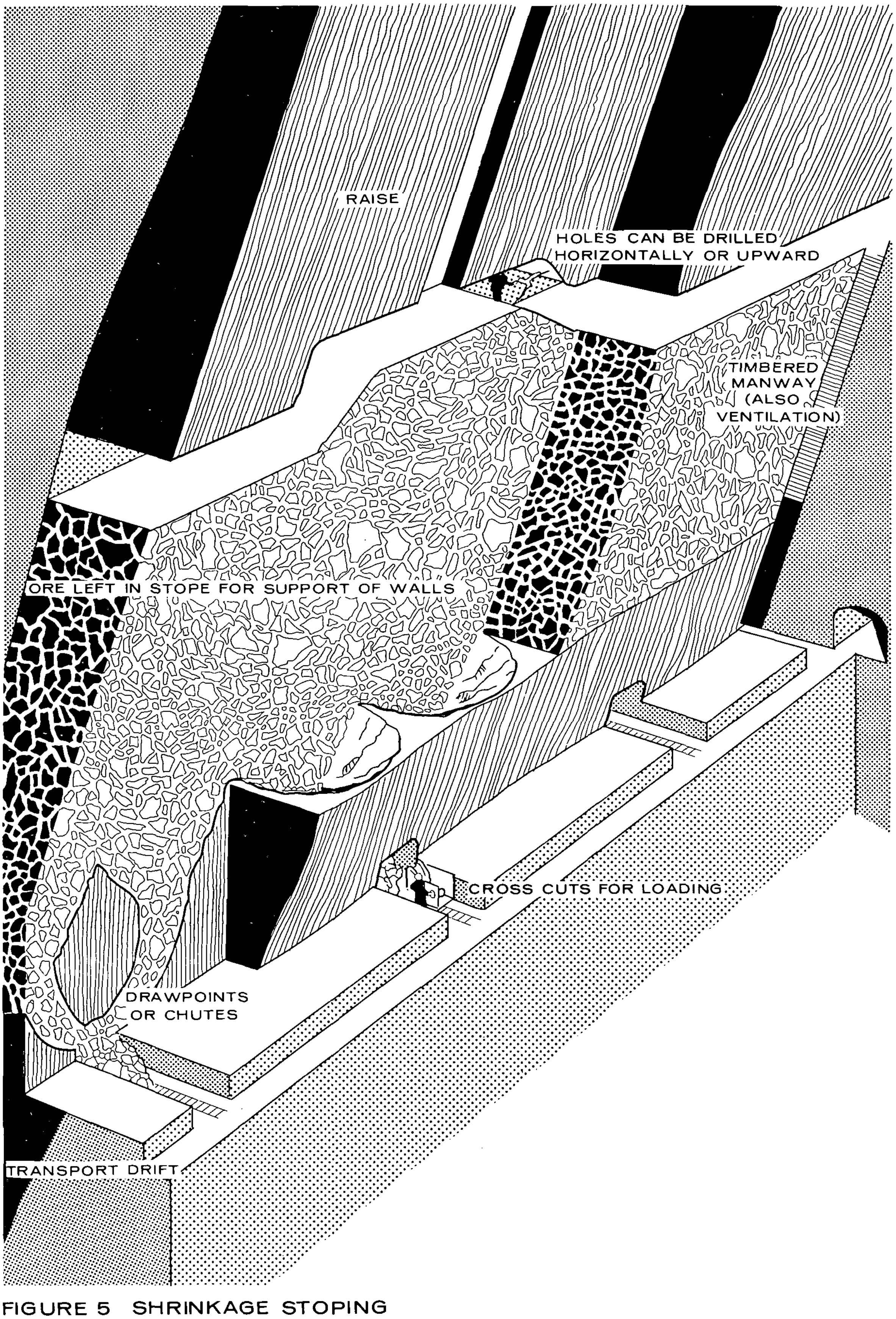

FIGURE 5 SHRINKAGE STOPING

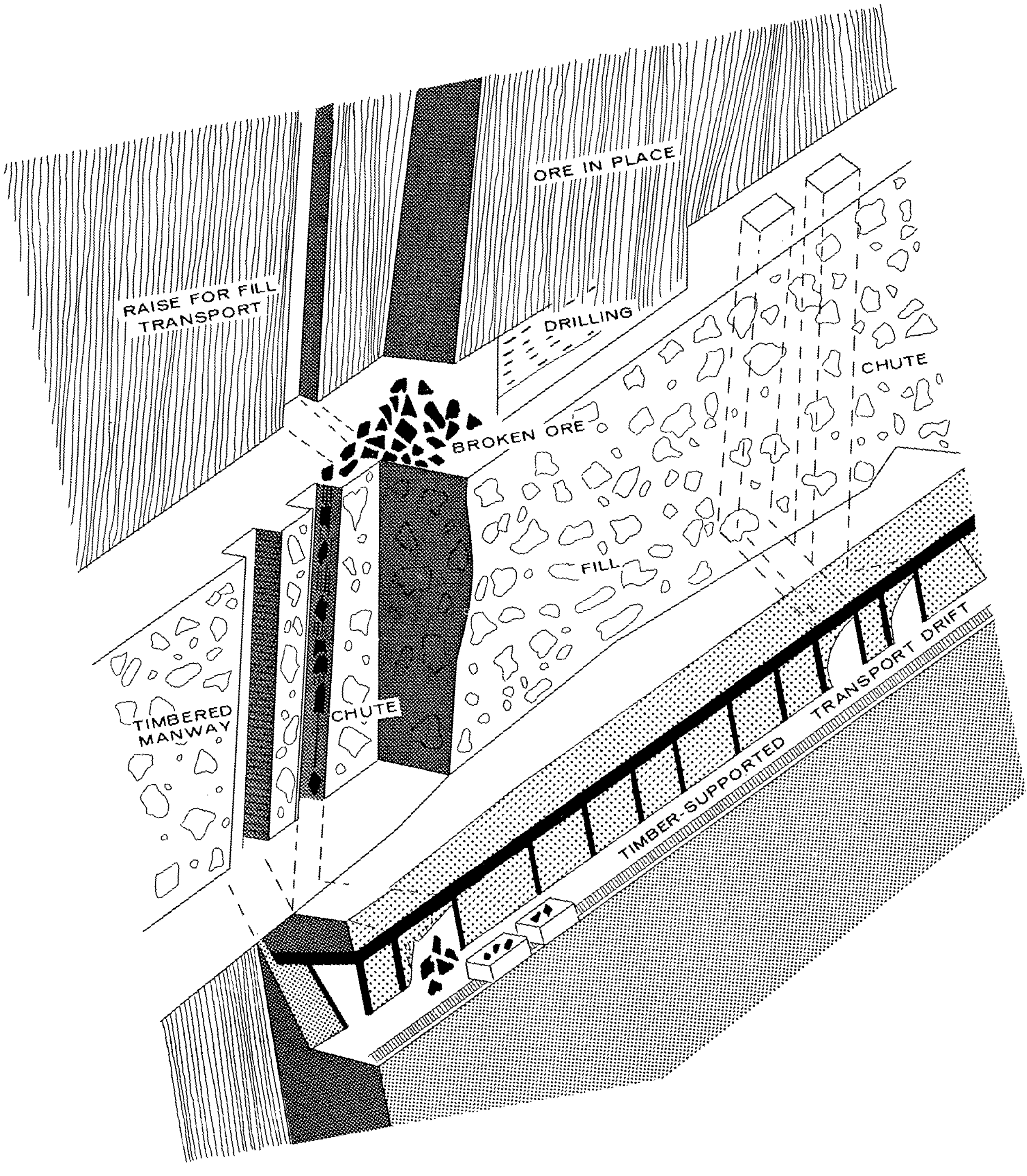

FIGURE 6 CUT-AND-FILL MINING

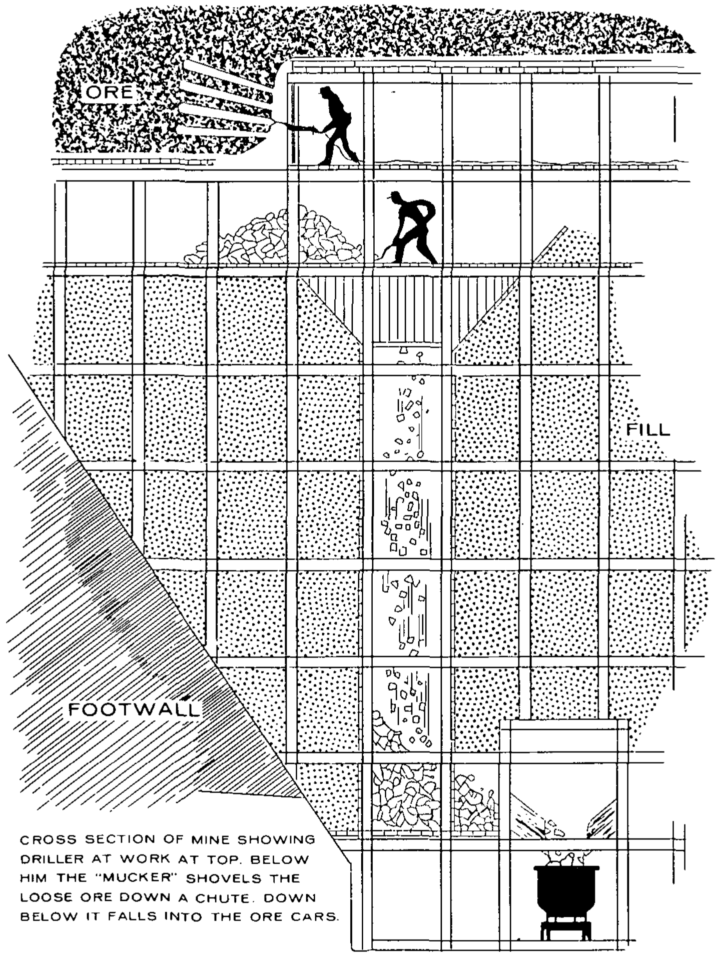

FIGURE 7 SQUARE-SET STOPE

3.2 Milling

3.2.1 Crushing and Screening. Primary crushers used at open pit mines are large jaw or gyratory crushers, capable of handling very big pieces of rock and crushing all ore to minus 6 to 8 in. without interrupting the flow through the crushing circuit.

At underground mines, the primary crusher, whether located on the surface or underground, tends to be somewhat smaller because of limitations in the size of broken rock that can be handled by equipment delivering ore to the orepass system and/or the primary crusher.

Ore from the primary crusher is screened and the oversize delivered to the secondary crushers where further reduction takes place. The one or more cone crushers used for this purpose are usually in closed circuit with fine screens. In most instances, tertiary crushing is required, using short-head or cone crushers at finer settings, in closed circuit with screens, to achieve reduction to the size necessary for ideal milling. Ore fed to the mill is usually about 100% minus 5/8 to 3/4 in. in size and is conveyed to the mill bins feeding the grinding circuit. Should autogenous mills be used in the first grinding circuit a proportion of the mill feed could be up to 4 in. in size.

3.2.2 Grinding. Ore is drawn from the mill bin and ground, in water suspension, to the fineness required for separation of minerals in the concentrator. All mills are large, heavy, rotating, horizontal steel cylinders with protective liners installed to prevent wear of the outer shell.

Primary grinding takes place in autogenous mills or ball mills. Ore is drawn from the mill bins at a fixed rate and fed to the primary mill circuit, along with enough water to give the required solution density. In autogenous mills coarser pieces of ore form the main grinding media. In some cases, a load of small steel balls is added to increase grinding efficiency. Where ball mills are used, finer ore is fed to the mill and steel balls are used to grind the ore in water suspension.

The initial ball load consists of various sizes up to about 4 in. in diameter. Large balls are occasionally added to replace those being gradually consumed in the grinding process. The discharge from primary grinding enters a classifying circuit. The fine fraction reports directly to the primary thickener and the oversize portion is fed to the secondary grinding circuit where final reduction takes place.

Secondary grinding is done in tube mills or rod mills. These are normally longer but smaller in diameter than the mills used in the primary circuit. Tube mills use a large load of small balls to regrind the ore; rod mills use large rods that are slightly shorter in length than the mill. These secondary mills are in closed circuit with classifiers to achieve the fineness required in the concentrator. Ground ore from the secondary circuit is pumped to the primary thickener to join the undersize material from the primary grinding circuit. The required particle size is normally determined by metallurgical tests, prior to mill construction and is usually about 60% minus 200 mesh or even finer. The slurry is thickened to about 65% solids and delivered to the concentrator. The water removed is recirculated to the primary grinding circuit with only enough make-up water added to replace that lost in the concentrator slurry.

3.3 Concentrating

Concentration of the various minerals to be recovered is achieved by selective flotation. The slurry from the primary thickener is pumped to conditioning tanks where it is agitated and flotation reagents are added. The flow is then directed to secondary conditioners where water is added to reduce the density of the slurry to about 25%, after which it is fed to the bank or banks of primary flotation cells. Flotation cells consist of tanks having vertical shafts, with impellers affixed to the lower end, rapidly revolving in a pipe throat and driven by an overhead motor. Slurry enters the throat of the tank around the rotating impeller by flowing down the outer feed well. Low pressure air is premixed with the slurry and is diffused throughout the cell by the intense action of the impeller. Certain reagents will depress unwanted minerals along with the gangue, while allowing the desired mineral or minerals to adhere to the frothy bubbles and rise to the surface of the cell where it is skimmed off as a concentrate. The froth is then delivered to cleaner cells where the action is repeated. The underflow goes to a secondary flotation circuit, the concentrate from which joins the feed to the cleaner cells and the underflow reports to the scavenging cells. The concentrate from the scavenging cells joins the feed to the rougher cells for upgrading. Concentrate from the cleaner cells is delivered to the concentrate thickener, or to other flotation circuits if more than one mineral is present and further separation is to be made. In some instances, the underflow of the scavenging cells may be subjected to further flotation stages to concentrate minerals depressed in the first stage. The underflow from the final scavenging cells is decanted and pumped to the disposal area. The recovered water is returned to process. In some instances, settling ponds at the tailings disposal area can also provide process water which is circulated to the plant to reduce pollution of surface watersheds by contaminated overflow.

At certain plants, combined concentrates of different minerals may be produced but efforts are usually directed towards producing clean concentrates of individual metals to avoid excessive smelter charges or penalties.

Each concentrate is delivered to a thickener where water, added to transport the frothy concentrate, is decanted. The overflow is delivered to the tailings pond. The thickened slurry goes to the filters where it is washed and then dewatered to about 17% moisture, after which it is delivered to the bin feeding the concentrate dryer. The filtrate is returned to the concentrate-thickener feed.

3.4 Roasting

Gold ores containing arsenopyrite are first treated by flotation to obtain a concentrate of metallic sulphides which is then roasted to drive off the arsenic as a fume before the gold is extracted by a wet cyanidation method. This results in the release of large quantities of arsenic and sulphur dioxide in the exhaust gases. These emissions and their control are the subject of additional studies which are currently underway.

3.5 Concentrate Drying

The dryer used on the concentrate filter-cake is usually a fluid-bed, multiple-hearth or rotary type. Some sulphur dioxide emissions occur from the fuel used as a heat source or from the minor breakdown of sulphides in the concentrate. Although it is not necessary to elevate the drying temperature to high levels to achieve the required moisture content, some tests have shown greater emissions of sulphur dioxide than could result from the fuel alone. Quantities of sulphur dioxide from the fuels being consumed can be calculated (0.5%S = 0.61 lb/million BTU); however, emissions of sulphur dioxide from the breakdown of sulphides in different concentrates are difficult to estimate because of the many variables involved. It is believed, under present operating practices, that the emissions are of a relatively minor nature. The exhaust gas should be passed through cyclone separators to remove coarse particulates, then passed through high-efficiency fabric filters to remove the finer fraction from the gas stream. Since all particulate matter removed consists solely of the concentrate, the dust collected may be added directly to the dried concentrate. If scrubbers are used instead of fabric filters, the particulate matter removed by the dry cyclone is still added to the dried concentrate but the slurry from the scrubber must be directed back to the concentrate thickener or to the concentrate-filter feed.

3.6 Concentrate Storage and Shipment

After drying to a moisture content of 4%-7% each concentrate is stored in a separate bin for shipment. Occasionally, operating conditions necessitate the use of open stockpiles of concentrate but this practice should be minimized to prevent pollution by wind and rain.

In recent years the trend in shipping has been towards shipment in containers or covered railway cars, to eliminate pollution and to lower loss by any cause for economic reasons. Bulk loading methods used by ships are continually being improved for the same reasons.

Gold is shipped to the mint in a semirefined state. Straight silver concentrates are also partially refined on site and shipped to the mint.

4 POLLUTION ASPECTS

Pollution problems at mines operating in the far north vary according to location, type of mining, and method of mineral recovery. Possible sources of emissions, listed in production sequence, are

1. Power generation and thermal plants
2. Open pit operations
    - a) Drilling
    - b) Blasting
    - c) Loading
    - d) Transporting ore to crusher or waste to dump
3. Underground operations
    - a) Exhausting ventilating air
4. Crushing operations
    - a) Unloading ore from open pit or underground (hoisting)
    - b) Crushing ore
    - c) Screening ore
    - d) Conveying ore to fine-ore bin

5. Roasting of flotation concentrates from milling of gold ores

6. Drying of concentrates for shipment

7. All transfer points

8. Fugitive dust from open pit operations.

5 ESTIMATED EMISSIONS FROM MINES OPERATING IN THE TERRITORIES, 1972

Particulate emission factors for various mining operations are given in Table 2. Estimated emissions of particulate matter from producing mines amounted to 83 352 tons during 1972. A breakdown of the estimated particulate emissions inventory for 1972 is shown in Table 3. This estimate of emissions from mining operations does not include any fugitive dust from ore stockpiles or tailings disposal areas. Little information was available, so estimates are based on the uncontrolled emission factors for different operations and on the percent control achieved by the equipment in use.

TABLE 2 PARTICULATE EMISSIONS FROM MINING OPERATIONS (3)

Operation	Uncontrolled emissions (lb/ton)	Estimated control (%)	Estimated emissions (lb/ton)
Open pit mining	5	60	2 (ore)
Handling and stockpiling of waste	5	–	5
Crushing and milling	25	60	10 (ore)
Roasting	45	99	0.45 (concentrate)
Concentrate drying	40	60	16 (concentrate)
Material handling and shipping	5	95	0.25 (concentrate)

TABLE 3 ESTIMATED PARTICULATE EMISSIONS INVENTORY - YUKON AND NORTHWEST TERRITORIES, 1972

Plant	Tons milled	Mineral concentrates produced (tons)	Tailings (tons)	Fugitive dust tail/stock (tons)	Estimated Emissions (tons per year)				
					Mining	Crushing and milling	Concentrate drying (roasting)	Material handling	Total
Anvil Mining Corp.00	2 906 000	443 000	2 423 891	6 060	2 906	14 530	3 464	54.00	20 954
Canada Tungsten	172 828	2 570	168 315	421	173	864	21	0.3	1 058
Cassiar Asbestos	1 011 183	104 626	892 388	2 231	1 101	5 055	4 853	13.00	11 022
Hudson Yukon	97 310	15 452	81 796	204	-	487	123	2.00	612
Tantalus Butte Coal	21 000	21 000	-	-	-	-	-	2.60	3
United Keno Hill	80 646	9 783	69 968	175	-	403	78	1.20	482
Con Mine	165 000	-	163 344	408	-	825	-	-	825
Echo Bay	36 800	3 961	32 445	81	-	184	32	0.5	217
Giant Yellowknife	401 272	(±)8.3	397 237	993	-	2 006	7	-	2 013
Lolar Mine	(71 422)	Included with Giant Yellowknife							
Supercrest	(65 736)	" " " "							
Pine Point Mines	3 810 000	510 000	3 280 441	8 201	3 810	142	84	64.00	4 100
Terra Mining & Exploration	40 264	1 840	38 007	95	-	201	15	0.23	216
Whitehorse Copper	10 707	693	9 896	25	-	54	6	0.09	60
TOTAL	8 753 010		7 557 728	18 894	7 990	24 751	8 683	138	41 562

6 CONTROL METHODS

Emissions of particulate matter from mining operations can be very well controlled by equipment that is in general use.

6.1 Open Pit Mining

In open pit mining operations, wet drilling is not recommended because of freezing conditions during cold weather and problems in loading. Dust from dry drilling is controlled by mounting collectors on the drills. The best control is achieved by the use of a small baghouse, although bags may occasionally cake due to excessive moisture when a wet hole is encountered. Emissions from blasting, are uncontrolled but because blasting is infrequent and of short duration, emissions are not usually significant, provided blasting is reasonably controlled. Dust generated while loading trucks and hauling ore to the crusher or waste to the dump is not controlled but is considered minor. Fugitive dust raised from roads is controlled by wetting the travel surface.

6.2 Underground Mining

Dust generated by underground drilling, blasting, loading, and crushing is well controlled and contained by conventional methods. Only a very minor emission results from exhausting the ventilating air from underground workings and is usually uncontrolled.

6.3 Crushing

Ore delivered to the crusher by truck from the open pit or hoisted from underground workings is reduced in size by crushing and stored in the fine-ore feed bin of the concentrator or mill. Dust generated in the crushing and screening of ore is best controlled by water sprays, high efficiency cyclones and/or bag filters.

6.4 Milling

Minerals are normally recovered by wet milling processes using selective flotation and/or cyanidation. Since these are wet operations no significant air pollution problems occur.

6.5 Roasting

At some gold mines gold-bearing sulphides, concentrated by flotation, contain arsenopyrite which interferes with the cyanide process for recovery of gold and silver. Concentrates are dewatered as mentioned previously, and roasted to drive off the arsenic. This also generates sulphur dioxide emissions and efficient control equipment must be used to remove these pollutants from the exhaust gases. Arsenic is removed by passing the hot exhaust gas through an electrostatic precipitator to remove the particulates and then through a bag collector after cooling by dilution with air to a point below that necessary for the sublimation of arsenic. The clean gases are then exhausted to the atmosphere. Scrubbers could be used as a sulphur dioxide abatement measure following arsenic removal.

6.6 Concentrate Drying

Ore concentrates at base metal mines are dried, prior to shipment, to reduce the moisture content to about 4% to 7%. This moisture is sufficient to minimize dusting, if shipment is made in open cars, but low enough to prevent freezing. Three types of dryers are presently in use; radiant heat, multiple hearth and the rotary dryer, the last being the most common. Emissions from this operation are particulate matter, consisting chiefly of the concentrate being dried and fly ash from the high-ash coal that is used in some instances to provide hot air. Some sulphur dioxide may result from the fuel used or from a minor breakdown of sulphides in the concentrate. Efficient control of emissions at this point can be affected by the use of bag filters or wet scrubbers. If bag collectors are used, the exhaust gases must be cooled but maintained above the dew point. Wet scrubbers are preferred for control of the emissions from drying operations because the solids in the slurry resulting from the scrubbing action are mostly concentrate and can be recycled to the milling circuit ahead of the filters.

6.7 Concentrate Storage, Handling, and Shipping

Emissions from concentrate storage can only be controlled by providing enclosed storage facilities. Open stockpiles of concentrate should be avoided whenever possible. Ideally concentrates should be handled by enclosed conveyors with well-controlled transfer points. Air conveying can be used when loading. Concentrates from mine sites should be shipped by closed containers or covered gondola railway cars to eliminate emissions.

6.8 Fugitive Dust

Fugitive dust from mine roads is controlled by wetting down the travel surface in dry weather. Another possible source of fugitive dust is improper disposal of dust collected in the plant. There is some concern regarding the possibility of blown dust from dried-out tailings disposal areas. Although tailings are placed in the tailings dam wet or in solution, dry weather and high winds could create problems especially after a mine is abandoned.

6.9 Evaluation of Control Technology

6.9.1 General. The degree of control of particulate emissions from crushing and conveying operations has been given as up to 70% for medium-efficiency cyclones and 85% to 90% for high-efficiency cyclones. If fabric filters are used, collector efficiency can be expected to exceed 99%.

Exhaust gases from concentrate dryers may be passed through medium-efficiency cyclone collectors to remove coarse particles, which are returned to the dried product. Control of fine particulates in the gas stream may be achieved by using low-energy scrubbers or fabric filters. When scrubbers are used, collection efficiency of 97% to 98% can be expected. Sludge and water can be recirculated to the wet concentrate stream, prior to filtration. If fabric filters are used on the concentrate dryer exhaust, the gases must be cooled by air dilution to prevent bag destruction. Care should be exercised to maintain an operating temperature above the dew point. Dust from the filter can be added directly to the dried concentrate.

6.9.2 ***Cost of Pollution Control.*** Cost of pollution control equipment for arctic mining plants will vary from property to property, depending upon the type and size of mining operations. Capital requirements should be less than 2% of total plant cost for many mining and milling plants.

6.9.3 ***Best Practicable Technology.*** Control of emissions of particulates from crushing and conveying is achieved by the use of high-efficiency cyclones or fabric filters. Control of emissions from concentrate dryers can be achieved using low-energy scrubbers or fabric filters.

The use of best practicable technology will control emissions of particulates from arctic mining operations to a low level. Sulphur dioxide emissions from concentrate drying, heating, or power generation can be limited by the selection of fuels with low sulphur contents.

It is estimated that the application of these technologies will reduce present particulate emissions by 80% and help prevent serious degradation of the delicate ecology of the arctic environment.

REFERENCES

1. Department of Indian and Northern Affairs, *North of 60 Mines and Mineral Activities 1973,* Mining Section, Oil and Mineral Division, Northern Natural Resources and Environment Branch (1974).

2. The Northern Miner, *1973 - 1974 Canadian Mines Handbook* (1974).

3. U.S. Environmental Protection Agency *Compilation of Air Pollution Factors, February 1972 and Suppl. # 1,* 2nd ed. (July 1973).

BIBLIOGRAPHY

''A Mine at Minto'', *Western Miner,* (Dec. 1973).

''Anvil Expansion: On time, on Budget'', *Western Miner* (May 1974).

'''Black Angel' in Production'', *Western Miner* (Nov. 1973).

Bostock, H.S. ''Physiography and Resources of the North Arctic'', *Canadian Geographical Journal, LX 111, (4)* (Oct. 1961).

British Columbia & Yukon Chamber of Mines, *List of Mines; Oil and Quarries - British Columbia, Yukon and Northwest Territories.*

Brown, C.H., ''Yukon Mines in the Making'' *Western Miner and Oil Review,* (Oct. 1963).

Buck, W.K., ''Metallic and Non-Metallic Minerals (The Place of the Mineral Industry in the Economy of Yukon and N.W.T.)'' *Proceedings of Second National Northern Development Conference,* (Sept. 1961).

Buck, W.K. ''Mineral Resources of the Canadian Northland'', *Proceedings of the Third National Northern Development Conference,* (Oct. 1964).

Christian, J.D. ''The Development of the Clinton Creek Asbestos and its Effect on the Yukon'', *Proceedings of the Second Annual Yukon Northern Resource Conference* (March 1966).

Collins, F.H., *The Yukon Territory* (Nov. 1955).

Department of Indian and Northern Affairs, *Mining in the North* (1973).

Ellerman, R., ''Operations of Canada Tungsten Mining Corporation Limited'', *Deco Trefoil,* Summer Issue, (1969).

Fenn, R.W., *Measurement of the Concentration and Size Distribution of Particulates on the Arctic Air of Greenland,* USASRDL Technical Report 2097 (Feb. 1960).

Hilker, R.G., ''Exploration Geo. Chemistry, Yukon Territory'', *Western Miner* (Oct. 1973).

''Industry and the Arctic Environment,'' *Transactions of the Royal Society of Canada, Series IV, VIII* (1970).

''International Engineering Effort in Greenland, *Engineering Digest* (April 1974).

Kay, Kingsley, ''A Look at the Future of Hazardous Contamination of the Circumpolar Environment,'' *Arch. Environmental Health, 17* (Oct. 1968).

Knutsen, W.G., ''Gold Potential: District of Mackenzie, N.W.T.,'' *Western Miner* (1974).

MacNeill, R.J., ''Far North Property Promising (Bathurst Norsemines Report),'' *Western Miner,* (Oct. 1973).

Marven, C. "Gold Mines Are With It," *Canadian Mining Journal* (Nov. 1963).

Pawson, H.E., "Giant Yellowknife's Milling Operation," *Canadian Mining Journal,* (June 1973).

Peyton, Harold R., "Arctic Engineering," *Journal of Petroleum Technology* (Sept. 1970).

"Polaris Mine in High Arctic Ships First Ore for Testing," *Western Miner* (Sept. 1973).

Ramseier, R.O., "Oil on Ice" *Environment 16, (4)* (May 1974).

Robertson, R.G. *The Northwest Territories* (Nov. 1955).

"Silver Standard - Asario Yukon Belt," *Western Miner* (Sept. 1973).

"The Anvil Project," *Transactions of the Third Northern Resource Conference,* (April 1969).

"The Mining Scene in B.C. and Yukon," *Western Miner* (Oct. 1973).

Trevor, B.J. "Recent Major Mining Developments North of 60°," *Canadian Mining Journal* (April 1969).

Western Research and Development Limited, *Literature Search and Air Pollution Sources in the Arctic* (May 10, 1974).

Yates, A.B. *Northern Activity Increases,* Western Miner (April 1973).

APPENDIX I - MINERAL PRODUCTION CHART - YUKON AND NORTHWEST TERRITORIES, 1964 - 1973 (1)

MINERAL PRODUCTION, 1964-1973

Mineral		1964	1965	1966	1967	1968	1969	1970	1971	1972	1973(a)	Cumulative totals (b)
NORTHWEST TERRITORIES												
Gold	$	15 586 182	17 071 580	15 990 133	14 356 476	13 285 459	12 381 240	12 168 776	10 897 934	17 713 250	24 262 000	344 195 413
	ozs.	412 879	452 479	424 029	380 304	352 306	328 502	332 844	308 339	307 479	252 000	
Silver	$	91 312	1 490 754	2 325 407	3 429 755	8 677 365	3 910 888	5 114 587	4 574 616	6 778 965	13 801 000	52 045 809
	ozs.	65 223	1 064 824	1 662 192	1 980 228	3 751 563	2 026 367	2 764 642	2 932 446	4 059 261	5 520 000	
Copper	$		354 342	672 065	538 077	833 169	643 761	766 578	727 595	577 416	1 064 000	7 602 952
	lbs.		942 400	1 496 805	1 131 126	1 732 160	1 251 723	1 320 502	1 378 021	1 133 767	1 669 000	
Nickel	$											12 850 205
	lbs.											
Lead	$	823 279	25 677 695	31 472 562	35 665 535	33 636 984	32 299 014	37 842 405	22 629 795	27 838 277	35 853 000	283 738 546
	lbs.	6 125 588	165 662 547	210 659 720	254 753 820	250 275 180	212 913 740	239 206 099	167 628 110	180 439 960	222 136 000	
Zinc	$	1 111 016	28 596 474	57 128 344	60 852 900	57 504 129	68 275 481	76 004 563	75 056 384	64 792 006	89 741 000	579 062 297
	lbs.	7 840 620	189 380 626	378 333 400	419 964 800	407 830 700	448 296 000	477 115 900	448 633 500	339 741 000	374 544 000	
Pitchblende	$											79 477 897
(c)	lbs.											
Cadmium	$		516 635	2 769 372	2 551 920	774 060	675 136	737 632	301 476	205 436	56 000	8 587 667
	lbs.		185 840	1 073 400	911 400	271 600	191 800	207 200	155 400	81 200	15 000	
Bismuth	$							3 072	41 149			44 221
	lbs.							490	7 578			
Tungsten	$											
	lbs.								3 288 400	3 174 120	3 700 000	
TOTAL	$	17 611 789	73 707 480	110 357 883	117 394 663	114 711 166	118 185 520	132 637 613	114 228 949	117 905 350	164 777 000	1 367 605 007

(a) Preliminary Figures

(b) Cumulative totals 1932 to December 31, 1973 (Figures for tungsten not available)

(c) Figures for years 1932, 1943 to 1953 not available.

MINERAL PRODUCTION, 1964–1973

Mineral		1964	1965	1966	1967	1968	1969	1970	1971	1972	1973(a)	Cumulative totals (b)
YUKON TERRITORY												
Gold	$	2 183 611	1 698 975	1 639 103	675 725	911 338	1 118 715	653 034	511 534	234 983	386 000	268 904 353
	ozs.	57 844	45 031	43 466	17 900	24 167	29 682	17 862	14 473	4 079	4 000	
Silver	$	7 894 196	6 462 393	5 868 217	6 701 756	4 806 384	5 182 166	7 845 312	8 966 417	8 331 575	15 391 000	178 771 234
	ozs.	5 638 712	4 615 995	4 194 580	3 869 374	2 077 987	2 685 060	4 240 709	5 747 703	4 988 967	6 156 000	
Lead	$	2 744 235	2 766 953	2 386 684	2 141 959	970 629	4 256 183	20 830 196	29 340 379	34 392 366	36 718 000	181 833 943
	lbs.	20 418 415	17 851 309	15 975 125	15 299 709	7 221 940	28 056 581	131 670 010	217 336 142	222 921 742	227 499 000	
Copper	$				3 409 779	5 097 157	7 645 623	9 148 995	2 709 696	890 286	13 771 000	45 774 319
	lbs.				7 167 919	10 597 000	14 866 077	15 760 000	5 132 000	1 748 093	21 587 000	
Coal	$	98 150	85 626	46 390	15 791							2 567 132
	tons	7 229	8 801	5 670	1 912		6 039	10 908	21 026		19 915	
Zinc	$	1 855 512	2 000 396	1 729 027	1 373 151	748 206	5 035 385	24 845 216	39 003 342	45 241 287	60 536 000	209 146 854
	lbs.	13 094 653	13 247 653	11 450 510	9 476 545	5 306 429	33 062 280	155 964 948	233 134 144	237 225 560	252 654 000	
Cadmium	$	428 399	386 192	306 336	265 997	147 716	239 965	261 528	114 654	82 759	55 000	6 353 517
	lbs.	132 222	138 918	118 735	94 999	51 830	68 172	73 463	59 100	32 711	15 000	
Asbestos	$				406 371	8 684 125	11 924 526	13 927 652	12 374 380	13 006 476	14 849 000	75 172 530
	tons				2 260	63 592	87 437	105 638	91 969	101 888	99 000	
Nickel	$									3 996 762	3 888 000	7 884 762
	lbs.									2 814 621	2 541 000	
Platinum	$									325 573		325 573
	ozs.									3 625		
TOTAL	$	15 204 103	13 400 535	11 975 757	14 990 529	21 365 555	35 402 563	77 511 933	93 020 402	106 502 067	145 594 000	976 734 217

(a) Preliminary Figures

(b) Cumulative totals 1886 to December 31, 1973

APPENDIX II – GLOSSARY OF MINING TERMS

In order that descriptions of various mining procedures can be better understood, the following definitions are given:

Adit	—	A nearly horizontal tunnel from the surface by which a mine is entered.
Back Stope	—	To mine a stope from below. No timber is used, the back or roof of a level is blasted directly on the floor, the broken ore is loaded and hauled to the shaft or primary crusher.
Boxhole	—	This is a short raise driven from a haulage level, which is belled out at the top to direct broken ore to the chute or draw point established at the level. A series of boxholes may be connected together at their tops to form a continuous undercut of an area to be mined and allow intimate control of broken ore removed from the stope.
Crosscut	—	A tunnel driven at approximately right angles to a main tunnel, or from a shaft or other opening across the formation to an objective point.
Chute	—	A control device built into a boxhole, raise or stope timber, constructed of wood planks or timber. This is used to load ore into mine cars and interrupt the flow of broken ore from above.
Drawpoint	—	This is a method of controlling the flow of ore from a stope. A stub drift is driven from a haulage way or scram drift. A short raise is driven up from it and belled out as a boxhole. Broken ore from stoping falls directly on the floor of the drawpoint, where it is loaded into cars by mucking machines. In the case of a scram drift, a slusher hoist is used to scrape the ore along the scram drift to a drop point or chute directing ore into mine cars on the haulage level below.
Drift	—	A horizontal passage underground, following the vein, as distinguished from a crosscut which intersects it.
Drive	—	To excavate a horizontal passage like a drift. A main drive would be a tunnel driven along the geological structure possibly parallel to but not necessarily following a vein.
Level	—	A horizontal tunnel in a mine. It is customary to work mines by levels spaced at regular intervals, numbered in their order below the adit or collar of a mine shaft.
Lode	—	Strictly, a fissure in the country rock filled with mineral. Sometimes, improperly, veins of ore occuring under different conditions.
Open pit	—	A working in which excavation is performed from the the surface, as in quarrying.
Ore	—	A mineral or mineral aggregate containing precious or useful metals, which occurs in such quantity, grade, and chemical combination as to make extraction commercially profitable.

Quarry — An open or surface working in rock, usually for the procurement of building-stone, such as slate, limestone, etc.

Raise — An inclined or vertical opening like a shaft, made in the roof of a level to reach the level above.

Scram drift — A drift, along which drawpoints are established on one or both sides. Ore is scraped along the drift bottom from drawpoints to a raise or a dump point which delivers the ore to cars on the haulage level.

Shaft — An excavation of a limited area compared with its depth, made for finding or mining ore, hoisting and lowering men and materials, or ventilating underground workings. The term is often specifically applied to vertical shafts, as distinguished from a decline, or an incline shaft.

Stope — An excavation from which the ore has been extracted either above or below a level, in a series of steps.

Sublevel — An intermediate level opened a short distance below a main level.

Vein — An occurence of ore, usually disseminated through a gangue.

Winze — A vertical or inclined opening connecting two levels in a mine but sunk underhand as opposed to a raise which is driven upwards.