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CANADIAN BASE METAL MINING IN THE 1970'S

D.G.F. HEDLEY

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D.G.F. HEDLEY

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by

D.G.F. Hedley*

ABSTRACT

The Canadian base metal mining industry in the 1970's is examined to determine the source of production, mining method used, number and size of mines, employment figures, costs, and productivity.

Overall, the industry appears to be in a state of decline. Metal production in the latter half of the decade has been below the first half, and Canada's share of world markets has decreased steadily for most metals. The number of underground mines has decreased by 40% while paradoxically the percentage of base metal production from underground mines has increased in the last part of the decade and represents the major producing sector.

Although technical innovations have been made which have improved efficiency and productivity at the underground work place, this has not resulted in any noticeable increase in productivity on a mine or mine site basis, whereas productivity in open pit mining has increased.

An increasing percentage of the underground ore tonnage is being mined by cut-and-fill methods which are the most expensive and have low productivities.

Research and development could halt further decline in base metal production. Underground mining is considered to be most critical, particularly cut-and-fill and other methods are required, especially for ore below 1000 m.

A worthwhile area of research is to improve productivity. All aspects of mining will have to be examined to identify bottlenecks and to find out how existing technology can be applied to raise productivity on a mine-wide basis.

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L'EXPLOITATION MINIERE DES METAUX COMMUNS
AU CANADA DANS LES ANNEES '70

par

D.G.F. Hedley*

RESUME

L'industrie canadienne de l'exploitation des métaux communs dans les années '70 est étudiée afin de déterminer les sources de production, les méthodes d'exploitation, le nombre et la dimension des mines, les données sur la main d'oeuvre, les coûts et la productivité.

Dans l'ensemble, l'industrie semble être dans un état de déclin. La production des métaux est basse dans la deuxième moitié de cette décennie comparativement à la première; en conséquence, la part du marché qu'occupe le Canada décroît graduellement pour la plupart des métaux. Le nombre de mines souterraines a diminué de 40% mais, inversement, le pourcentage de la production des métaux communs provenant des mines souterraines a augmenté ces dernières années et consiste du plus important secteur de production.

Quoique plusieurs progrès techniques aient amélioré l'efficacité et la productivité du chantier souterrain, le rendement ne s'est pas accru d'une façon marquée; toutefois, la productivité des exploitations à ciel ouvert est à la hausse.

Un pourcentage grandissant du volume de minerais souterrains est exploité par des méthodes d'exploitation par chantiers individuels et remblayage qui sont plus dispendieuses et donnent un faible rendement.

La recherche et le développement peuvent freiner la détérioration de la production des métaux communs. L'exploitation souterraine est considérée comme un secteur critique et particulièrement les techniques d'exploitation par chantiers individuels et remblayage. D'autres méthodes seront requises pour l'exploitation des gisements des minerais situés à plus de 1000 m de profondeur.

Un autre domaine susceptible de profiter de la recherche serait la productivité. Tous les aspects de l'exploitation minière devraient être examinés afin d'identifier les endroits de congestion et trouver comment la technologie actuelle peut améliorer la productivité de la mine.

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Canada has a world-wide reputation as an efficient base metal producer and is perceived as being in the forefront of technical innovation, especially in underground mining with the development of new mining methods and extensive mechanization. Notwithstanding this reputation, Canada's position as a world supplier has deteriorated as richer deposits, mainly in the under-developed countries are brought on stream. To maintain even its present position in world markets will require further innovations which can only come from a significant research and development effort.

A wealth of information on the Canadian base metal mining industry is available from annual reports of the mining companies, the Canadian Mines Handbook of the Northern Miner, and the mineral surveys published by Energy, Mines and Resources Canada and Statistics Canada. However, this information does not provide the percentage of metals produced by underground mines or the extent to which the production of metals is interdependent. Such type of information contained under a single cover would give an overview of the industry, establish trends, and indicate where research and development would have the greatest benefit.

WORLD POSITION AND PRODUCTION LEVELS

Canada is an important producer of base metals: copper, lead, nickel and zinc. In 1977 production of these four metals was valued at about \$3.4 billion compared with about \$3.6 billion for the Soviet Union, \$2.9 billion for the United States and \$1.4 billion for Australia. In terms of individual metals, Canada is the leading producer of nickel and zinc and fourth in copper and lead.

Canadian production of these metals and its share of the world market between 1970 and 1977 is shown in Fig. 1. Although Canada is a leading producer it can be seen that only in the case of copper was production in 1977 greater than in 1970. Consequently, production of base metals during the 1970's could be characterized as stagnant.

Canada's share of the world market has also declined during the same period from 48.6% to 32.9% for nickel; from 22.7% to 16.8% for zinc; from 10.4% to 8.0% for lead; and marginally from 9.8% to 9.6% for copper.

METAL PRODUCTION BY TYPE OF DEPOSIT

Metalliferous deposits usually contain more than one recoverable product and hence production levels are interdependent. In Canada there are four main types of base metal deposits:

1. lead-zinc deposits as found in New Brunswick, Northwest Territories, Yukon Territory and British Columbia;
2. copper-zinc deposits in the Precambrian Shield of Quebec, Ontario, and Manitoba;
3. nickel-copper deposits at Sudbury, Ontario and Thompson, Manitoba;

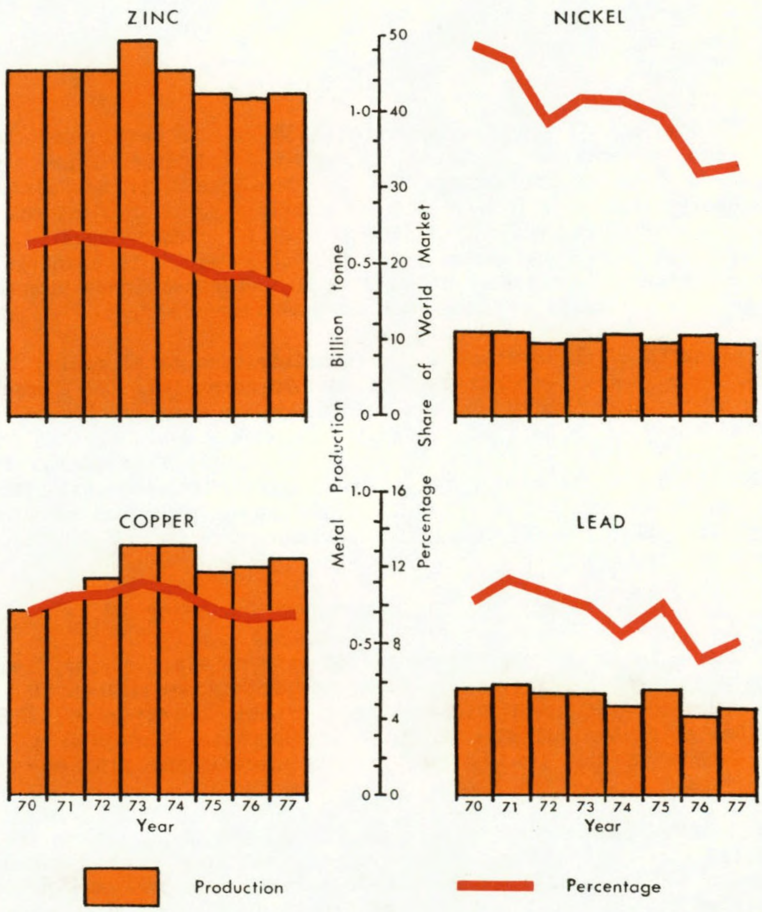

Fig. 1 - Shipments of Canadian base metals

4. copper deposits with either precious metals as byproducts, such as in the Precambrian Shield, or with molybdenum as a co-product, such as in British Columbia.

The proportion of metal production from each type of deposit in 1976 is given in Table 1. As indicated, almost all of the nickel and lead comes from nickel-copper and lead-zinc deposits respectively. Zinc production is split almost evenly between lead-zinc and copper-zinc deposits. In the case of copper, almost half the production comes from deposits where precious metals and molybdenum are byproducts and co-products, and almost a quarter of the production comes from both copper-zinc and nickel-copper deposits.

Table 1 - Distribution of base metal production in 1976 by type of deposit

Type of deposit	Cu	Pb	Ni	Zn
Pb - Zn	1.8%	95.2%	-	45.1%
Cu - Zn	27.0%	3.7%	-	50.3%
Ni - Cu	22.6%	-	98.6%	-
Cu (Au, Ag, Mo)	48.4%	-	-	-
Others	0.2%	1.1%	1.4%	4.6%

The only significant change in distribution of metal production between 1970 and 1976 was for copper. In 1970, production from nickel-copper deposits was higher at 32.6% of the total and from copper-precious metals - molybdenum deposits it was lower at 38.8%.

The percentages in Table 2 also indicate the degree of interdependence of metal production. For instance, to increase lead production by 10% would automatically increase zinc production by about 4.5% with little or no effect on copper or nickel production. Similarly, decreasing nickel production by 10% would reduce copper production by 2.3%.

UNDERGROUND VERSUS OPEN PIT PRODUCTION

Most mining companies release detailed information on tonnage and metal production on a mine by mine basis which is listed in the Annual Mineral Review and Forecast* and the Canadian Mines Handbook**. However, there are two important exceptions: Inco Limited and Falconbridge Nickel Mines Limited. These two companies which each operate a number of mines report only total tonnage and total nickel and copper deliveries, although Inco Limited also reports total nickel production. To estimate the relative output between open pit and underground mines for these companies, the tonnage and metal outputs of individual mines were prorated based on the daily capacities given in the Canadian Mines Handbook, disregarding differences in ore grade between mines.

Figure 2 shows the estimated percentage production of copper, lead, nickel and zinc from underground mines for the years 1970 to 1976. The ore tonnage and value, based on average yearly metal prices, are also given on a percentage basis.

Ore tonnage from underground base metal mines has declined from just over 60% in 1970 to 35% in 1973 and has remained at about that level ever since. Value of total underground metal production declined from 76% to 60% in 1974 but then increased to 69% in 1976.

Underground production of nickel has remained fairly constant around 90% and the trend is not expected to change.

*Published each year in the February issue of Canadian Mining Journal.
**Compiled each year by the Northern Miner.

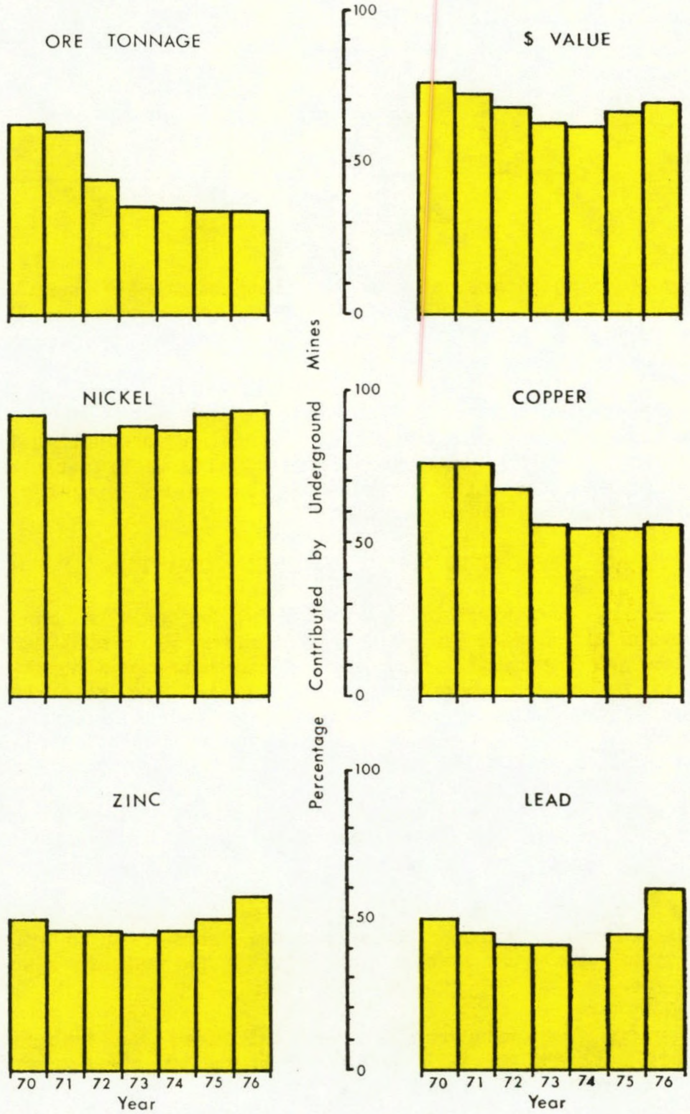

Fig. 2 - Distribution of base metal production between underground and open pit mines

Underground copper production declined from 76% in 1970 to 55% in 1973 and has been constant since then. The sharp decline in the early 1970's was mainly due to several open pits in British Columbia coming on stream, which as mentioned above also affected the tonnage figures.

Underground zinc production was fairly steady at just under 50% up to 1974. Since then it has climbed to 57% as the largest producer Texasgulf Canada Limited, converted from open pit to underground. With completion of this conversion in 1977, underground zinc production will climb to over 60% of total production.

The distribution between underground and open pit production of lead shows the largest fluctuation of any metal. Production is concentrated in a few mines and labour disputes have a significant effect on the figures. Generally, underground production varies from 40-50%. The low value of 36% in 1974 was due to labour disputes at the two largest underground producers, and the high value of 61% in 1976 was due to a labour dispute at an open pit mine.

In summary, underground mines are responsible for the major portion of base metal production. In the short-term the trend is more likely to be affected by mine closures rather than new mines coming on stream. It normally takes several years to bring a mine into production and at present very few base metal mines are in the development stage.

NUMBER AND SIZE OF MINES

The number of underground and open pit base metal mines in operation between 1970 and 1977 is given in Table 2. As can be seen, the number of underground mines declined, especially in 1972 and 1976. The number of open pit mines has remained fairly constant which masks the fact that during the period a number of small open pits were closed and replaced by several very large open pits. These statistics seem to be at variance with the general increase in underground metal production given in the last section. However, in general it has been the small and lower grade underground mines which have closed and the large new open pit copper mines opened in British Columbia are low-grade.

Table 2 - Number of underground and open pit base metal mines

Type of mine	1970	1971	1972	1973	1974	1975	1976	1977
Underground	97	94	80	83	85	84	66	60
Open Pit	22	21	21	24	26	22	22	24

The size distribution for underground and open pit mines is given in Table 3 for 1970 and 1976. For underground mines, the trend has been a reduction in the number of small and medium size mines producing less than 500,000 tonne/year and in the very large underground mines producing over 2,000,000 tonne/year. However, the trend in open pit mines is an increase in the number producing over 5,000,000 tonne/year.

Table 3 - Size distribution of underground and open pit base metal mines in 1970 and 1976

Size	No. of underground		Size	No. of open pits	
(,000 tonne)	1970	1976	(,000 tonne)	1970	1976
Less than 250	41	28	Less than 1000	11	8
250 - 500	30	8	1000 - 2500	6	5
500 - 1000	11	15	2500 - 5000	3	2
1000 - 2000	10	12	5000 - 10000	2	4
Over 2000	5	3	Over 10000	0	3

MINING METHODS AND COSTS

The tonnage mined by various underground mining methods is given in Fig. 3 for the years 1970 through to 1974; complete statistics have not been compiled since 1974. Average mining costs by different methods for the five-year period are related to the highest cost method, cut-and-fill, and are listed as relative costs. Open pit mining cost is also given for purposes of comparison.

In 1970, cut-and-fill and open stoping were the major underground mining methods followed by sub-level caving and shrinkage stoping. Room-and-pillar mining is specific to gently-dipping sedimentary deposits which are not common in Canada for base metals. By 1974, cut-and-fill methods were predominant, representing almost 50% of underground production, followed by open stoping and sub-level caving with conventional shrinkage stoping being almost eliminated.

In many respects the terms shrinkage stoping, cut-and-fill, and open stoping are obsolete. More realistic categories would be to differentiate between incremental mining with concurrent backfilling such as practiced in transverse, longitudinal and undercut-and-fill stoping, and bulk mining with delayed bulk filling.

Cut-and-fill is the most costly underground mining method. Costs of open stoping and sub-level caving are about 50% that of cut-and-fill, whereas open pit mining costs are much lower than any underground method. The predominant use of the highest cost mining method would imply that backfill is necessary in Canadian mines for controlling ground conditions and allow maximum recovery of ore.

EMPLOYMENT AND PRODUCTIVITY

Table 4 lists the number of employees working in base metal mines and the total employees, including administration and mill, at the mine sites for the years 1970 to 1975. Personnel working at smelters, refineries and head offices is not included in these statistics. Productivity figures were obtained by dividing the yearly ore tonnage mined from all underground and open pit base metal mines by the number of mine employees and total employees respectively, assuming that 240 shifts are worked per employee per year. As such the figures are approximate, subject to interpretation, and are useful only to indicate trends.

The number of mine employees has declined in the underground sector and increased in open pit mining between 1970 and 1974. In underground mining, about 66% of the work-force work in the mine compared with just under 50% in open pit mines. Total employment at mine sites for both underground and open pit has increased from about 37,600 in 1970 to 42,100 in 1974. Again complete statistics have not been compiled since 1974 which would reflect the effect of a number of underground mine closures in 1976 and layoffs in the nickel industry in 1977 and 1978.

Productivity on a mine and overall basis has not changed appreciably in underground mining but increased in open pit mining between 1970 and 1975. In open pit mining, the increased productivity coincided with several large copper mines coming on stream in British Columbia, utilizing large rock-moving equipment. The stagnancy in underground productivity is more difficult to explain as it occurred during a time of increased mechanization underground. However, it has been observed at individual mines that the introduction of such equipment as load-haul-dump units and multi-drill jumbos does not decrease the underground work-force. Instead there is a redistribution of work occupations with more mechanics and electricians and fewer involved with drilling and materials handling.

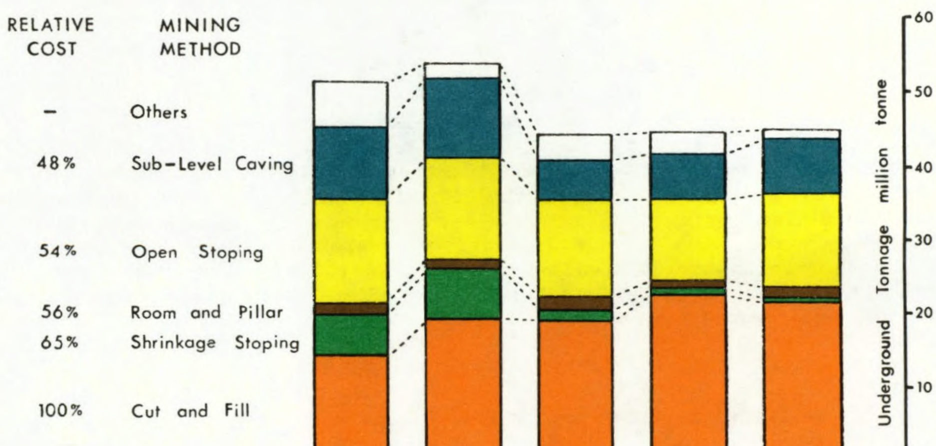

Fig. 3 - Mining methods and relative costs in Canadian base metal mines

Table 4 - Employment and productivity in base metal mines

Year	Type of mine	Employment		Tonnage (million tonne)	Productivity tonne/manshift	
		Mine	Total		Mine	Overall
1970	Underground	22380	32460	51.02	9.5	6.5
	Open pit	2320	5190	32.41	53.6	26.0
1971	Underground	23330	34830	53.22	9.5	6.4
	Open pit	2780	5820	35.04	52.5	25.1
1972	Underground	21930	31540	43.03	8.2	5.7
	Open pit	3530	7090	56.48	66.7	33.2
1973	Underground	20800	32740	44.18	8.8	5.6
	Open pit	5030	11100	85.58	70.9	32.1
1974	Underground	20790	32080	44.54	8.9	5.8
	Open pit	4470	10040	86.13	80.3	35.7
1975	Underground	*	*	44.59	9.5	5.8
	Open pit	4950	10830	87.62	73.8	33.7

*incomplete data.

Some mining companies give a breakdown of their underground labour force which is listed in the yearly Reference Manual and Buyer's Guide published by the Canadian Mining Journal. The productivity for different underground mining methods can be estimated by selecting mines which use predominantly one mining method. Productivity figures based on all underground employees for the three major underground mining methods are as follows:

1. incremental cut-and-fill methods - 8.5 tonne/man shift,
2. open stoping with delayed backfill - 17.6 tonne/man shift,
3. sub-level caving - 25.4 tonne/man shift.

The figures indicate that cut-and-fill methods provide approximately half the productivity of open stoping methods, which could be expected from the relative mining costs given in the last section. Although productivity of sub-level caving looks very attractive, considerable dilution can occur with this method which has limited its use in Canada. These figures are higher than those given in Table 4, but represent only a few selected mines rather than all underground base mines.

TECHNICAL INNOVATIONS IN MINING OVER THE LAST DECADE

As mentioned in the introduction, Canada has a reputation of being in the forefront of mining technology. Some examples of technical innovation are listed below:

1. Load-haul-dump (LHD) units were developed in the 1960's, but their widespread use occurred only in the 1970's. A recent survey estimated that 1250 LHD units ranging up to six cubic metres capacity were being used in Canadian mines. These units have increased mobility and capacity

in materials handling operations and to a great extent have eliminated the less efficient slushing operations. Mining methods and layout of development drifts have been altered to take advantage of this mobility. Inclined ramp systems are used at many mines to allow movement of LHD and other equipment from level to level. In some cases stopes are inter-connected so that the units are not captive and the number of ore-pass raises can be reduced.

2. Large hole drilling - 100 to 200 mm in diameter - using either rotary drills or in-the-hole drills was developed in the 1970's. These machines are capable of accurately drilling holes 60 m long. Sub-levels which were previously spaced at about 30-m intervals for long-hole ring drilling can now be spaced at 60-m intervals, eliminating the development of every second sub-level. Multi-drill jumbos are also being used to speed up the driving of development headings.
3. In conjunction with improved drilling techniques, blasting methods have improved with the introduction of slurry explosives. These can be handled in bulk, are safer to work with, and loading of the boreholes can be achieved in a shorter time.
4. In the early 1960's the average size of trucks used in open pit mines was 25 tonne and in 1978, 320-tonne capacity trucks are being manufactured. A corresponding increase in the size of loading equipment also occurred. These large materials handling units had a considerable impact on the economics of mining the low-grade copper deposits in British Columbia which required a large tonnage operation to be viable.
5. Post-pillar mining was developed by Falconbridge Nickel Mines Ltd. during the early 1970's. The mining method is basically a combination of room-and-pillar and overhand cut-and-fill mining; a checkerboard pattern of rooms and pillars is extended upwards by blasting down the roof of the rooms and backfill is poured around the pillars to prevent their disintegration and to provide a working floor. The advantage of this method is that about 85% of the orebody can be extracted by primary stoping which can be extensively mechanized. Pillar recovery operations by undercut-and-fill methods which are labour intensive and expensive are eliminated.
6. Another mining method developed to supersede undercut-and-fill pillar recovery operation is vertical retreat crater blasting which was developed by Canadian Industries Limited in conjunction with Inco Metals Company and Falconbridge Nickel Mines Limited. Rib pillars between backfilled transverse stopes are drilled off over a vertical distance of about 25 m using large holes. Horizontal slices about 4 m thick are blasted in sequence into the undercut slot drift. Sufficient broken ore is drawn off to allow space for blasting the next horizontal slice.

A number of pertinent factors emerge from these examples of technical innovations. In most cases, development of new mining equipment seems to have been the key to changes in methods and layout. Equipment development usually precedes changes in mining methods by several years. In other words, it takes a number of years before the benefits of new equipment, such as mobility of LHD units, are taken advantage of and new mining methods are designed around them. Most of this new equipment is designed outside Canada and the innovative aspects of Canadian base metal mining is in its application.

DISCUSSION

The preceding sections indicate that the Canadian base metal mining industry is in a state of decline in the 1970's. Metal production in the latter half of the decade is below that in the first half. The number of underground mines has decreased by about 40% while paradoxically the percentage of base metal production from underground mines has increased and represents the major producing sector. Although technical innovations have improved efficiency and productivity at the underground work place this has not resulted in any noticeable increase in productivity on a mine or mine site basis, whereas productivity in open pit mining has increased. An increasing percentage of the underground ore tonnage is being mined by cut-and-fill methods which have the highest operating costs. In addition, world metal markets for copper, nickel and zinc were weak during 1977 and 1978 and there was also a shortage of skilled labour when the mines were producing at more normal levels. All this presents a somewhat bleak picture for the future status of base metal mining in Canada in the 1980's.

It is unlikely that increased research and development could restore Canada to its former position as the leading world supplier of base metals. World metal markets, and federal and provincial regulatory and taxation policies are the major factors affecting the industry. On the technical side, discovery of high-grade, near surface deposits, could materially benefit production, but the last major discovery - Texasgulf's Kidd Creek deposit - was made 14 years ago so that prospects are by no means promising. However, research and development could prevent a further drop in base metal production. Such efforts should be directed at underground mining in particular, which is in the greatest need for improvement.

Cut-and-fill methods are used almost exclusively for mining deposits below 1000 m. As very few new mines are being developed, an increasing proportion of output will come from deeper levels at existing mines. Hence, increasing use of cut-and-fill methods would be expected, which as mentioned previously, are high cost mining methods and have the lowest productivity. Undercut-and-fill techniques for recovery operations have already become uneconomical at some mines and the industry has developed post-pillar mining and vertical retreat crater blasting methods to replace them. It is considered that conventional transverse and longitudinal cut-and-fill methods also have a limited life before they too become uneconomical. A common feature of these present mining methods is that they are incremental in nature. In other words, a relatively small volume of ore is drilled, blasted, has supports installed, is mucked out and then backfilled in a repetitive cycle. On the other hand, open stoping methods with delayed backfill usually consist of pre-drilling the whole stope, large tonnage blasting, installing supports only at the beginning of mining operations, continuous mucking, and bulk filling of the stope at the completion of mining. As such, these bulk mining techniques have about half the cost and double the productivity of cut-and-fill methods. However, their use below 1000 m is very limited because of the uncertainty of being able to control ground conditions. This is considered a worthwhile area for research and development.

Another promising area for research would be to raise productivity. The introduction of such new mining equipment as load-haul-dump units and large-hole drills has resulted in a significant increase in productivity at the work face, but statistics have indicated no noticeable increase in productivity on a mine basis. All aspects of mining operation from development to hoisting should be examined to identify bottlenecks and where existing equipment and technology can be applied to improve productivity.

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