Metal Mining in Antarctica

INTRODUCTION

Commercial mining in Antarctica, if ever allowed, would face not only the continent's harsh climate and remoteness, but also uncertainties about the geology, environment technology, legal regime, and commodity markets. The high costs of mining under these conditions would limit commercial interest to ''world class' deposits containing large amounts of very high grade ore and mineable with proven technologies. They would also probably have to be in the more accessible and/or hospitable areas of the continent.

The geology of Antarctica suggests that viable ore bodies may exist, although none have been discovered so far. So it will be some time before mining occurs, It typically takes nearly a decade or longer to find, delineate, and develop mineral deposits and meet permitting requirements. Even if exploration were to begin immediately, mining is unlikely before the next century. Given economic and political constraints, production is not expected to occur for at least two to three decades.

This appendix examines the technical and economic considerations for future Antarctic mines.[1] It assumes that the Convention will allow mining and that metals commodity prices will remain within their historic ranges. It also assumes that innovation in mining and processing technologies will continue to be evolutionary, not revolutionary. The analysis begins with a review of mining technologies now used in the Arctic, and then looks at the possibility of adapting these to Antarctica.

THE ARCTIC

Mines have been operated in severe winter climates near or north of the Arctic Circle for more than 30 years. Copper, lead, zinc, gold, silver, iron, coal, and other minerals are currently produced in the northern regions of North America, Greenland, Scandinavia, and the Soviet Union (see table B-l).

The conditions at each site differ, but all Arctic mines face low temperatures and high winds. Some mines must also contend with ice conditions that make production and transportation difficult. The weather can be so severe that roads and ports become impassable and mines and processing facilities are occasionally inoperable. Extended shut down periods (i.e., partial year operating schedules) are common. None but the richest deposits are economically attractive under these conditions. These climatic conditions require special approaches to design, operation, and maintenance in mining, processing, tailings disposal, and infrastructure support.

Mining

Open pit and underground mines, both of which exist in the Arctic, use similar approaches to the problems of cold, wind, and ice. For example, where the ground is permafrost buildings and other surface facilities are elevated or kept at subfreezing temperatures to prevent melting the ice.

Technologies used at Arctic mines have evolved to operate at -40" F and lower and in winds of 80 miles an hour and more.[2] Machinery is constructed of special steel alloys and rubber compounds, and uses special lubricants designed for cold weather use. Mobile equipment such as drills, trucks, shovels, loaders, bulldozers, and scrapers, are all furnished with heating systems and kept running continuously to prevent freezing during the severe periods of the winter. Equipment is shut down only for maintenance. Diesel fuel contains additives to permit continuous flow at low temperatures and to prevent waxing in engines. Hydraulic and electrical lines employ specially designed tubing or coatings that maintain their flexibility at low temperatures. Drilling, if necessary, is generally done dry or with a brine solution. Explosives must be designed to perform at low temperatures.

Underground Mines

Underground mining methods have been used in the Arctic for the past 100 years. Finland, Norway, and Sweden were the first to use these methods; Canada has followed in the last 10 to 15 years. Notable examples of underground mines are the Black Angel mine in Greenland and the Polaris (see box B-1), Lupin, and Nanisivik mines in the Northwest Territories of Canada.[3]

Underground mining methods generally are used for deep ore bodies where the costs of overburden removal would exceed those of developing and maintaining the required below ground facilities. In the Arctic, an additional consideration is that underground mines are for the most part protected from the wind and blowing snow.

[1] The geological factors that affect Antarctic minerals potential were discussed m ch. 4. The envir onmental impacts that could occur from mining operations are discussed in ch. 5. Political factors related to the adoption of the minerals convention, and the rights and assurances it affords to commercial operators and investors, are discussed us ch. 3.

[2] Magee Geological Consulting, ''Assessment of Mining and Process Technology for Antarctic Mineral Development, ' OTA contractor report, November 1988.

[3] COMINCO, ''Polaris Mine: ProductSon Success m the Rugged Arctic, ' *Mining Engineering*, October 1984, pp 1401-1406. J.K. Gowans, "Producing Lead and Zinc in Canada's High Arctic,'' *AIME Preprint 84-90* (Los *Angeles*, CA: March 1984).

Table B=l-Arctic Nonfuel Mineral Facilities

Name	Location	Commodity	Company	Operation	Latitude	Status
Arctic Camp	Alaska	Cu,Pb,Zn,Ag	Bear Creek Mining Co.	SUR/MILL	N67	Exp. Prospect
Bornite	Alaska	Cu	Bear Creek Mining Co.	UG/MILL	N67	Exp. Prospect
Red Dog	Alaska	Zn,Pb,Ag	Nana Regional Corp. & COMINCO Alaska	SUR/MILL	N68	Devel. Deposit
Lik	Alaska	Zn,Pb,Ag	General Cande, Houston Div.	SUR/MILL	N68	Exp. Prospect
Lupin	Canada	Au,Ag	Echo Bay Mines Ltd.	UG/MILL	N66	Producer
Terra Operations	Canada	Ag	Terra Mines Ltd.	UG/MILL	N66	Temp. Shutdown
Coppermine River	Canada	Cu,Ag	Coppermine River Ltd.	SUR/MILL	N67	Exp. Prospect
Izok Lake	Canada	Zn,Cu,Ag,Pb	Texasgulf Inc.	SUR/MILL	N67	Devel. Deposit
Hackett River	Canada	Zn,Ag,Pb	Bathurst Norse Mines Ltd. & COMINCO Ltd.	UG/MILL	N66	Exp. Prospect
High Lake	Canada	Cu,Zn	Kennco Explorations (Canada) Ltd.	UG/MILL	N67	Exp. Prospect
Raglan Nickel Deposit	Canada	Ni	New Quebec Raglan Mines Ltd. & Others	UG/MINE	N74	Exp. Prospect
Nanisivik	Canada	Zn,Pb,Ag	Nanisivik Mines Ltd.	UG/MILL	N73	Producer
Polaris	Canada	Zn,Pb	COMINCO Ltd./Bankeno Mines Ltd.	UG/MILL	N75	Producer
Kemi	Finland	Cr	Outokumpu Oy	SUR/MILL	N66	Producer
Sokoli	Finland	Phosphate	Kemira Oy	SUR/MILL	N68	Devel. Deposit
Black Angel	Greenland	Pb,Zn,Ag	Boliden Mineral Ab & Others	UG/MILL	N71	Producer
Kirkenes	Norway	Fe	Sydvaranger A/S	PELLET PLT	N70	Producer
Mo I Rana	Norway	Fe	Norsk Jenverks A/S	PELLET PLT	N66	Producer
Bleikvassli	Norway	S	Bidjovagge Gruber A/S	MINE/MILL	N66	Temp. Shutdown
Mosjoen	Norway	Al	Mosal Aluminum	SMELTER	N66	Producer
Sulitjelma	Norway	S	Norwegian Federal Gov.	UG/MILL	N67	Producer
Skaland	Norway	Graphite	A/S Skaland Grafitverks for Atlan.Rich.	UG/MILL	N69	Temp. Shutdown
Bjornevatin	Norway	Fe	Sydvaranger A/S	SUR/MILL	N70	Producer
Svappavarra	Sweden	Fe	Luossavaara Kirunavarra (LKAB)	PELLET PLT	N68	Producer
Svappavaara	Sweden	Fe	Luossavaara Kirunavarra (LKAB)	SUR/MILL	N68	PAST Producer
Kirunavaara	Sweden	Fe	Luossavaara Kirunavarra (LKAB)	UG/MILL	N68	Producer
Viscaria	Sweden	Cu	Outokumpu Oy	UG/MILL	N68	Producer
Kiruna	Sweden	Fe	Luossavaara Kirunavarra (LKAB)	PELLET PLT	N68	Producer
Malmberget	Sweden	Fe	Luossavaara Kirunavarra (LKAB)	UG/MILL	N67	Producer
Malmberget	Sweden	Fe	Luossavaara Kirunavarra (LKAB)	PELLET PLT	N67	Producer
Aitik	Sweden	Cu,Ag	Boliden Mineral AB	SUR/MILL	N67	Producer
Laisvall	Sweden	Pb,Zn,Ag	Boliden Mineral AB	UG/MILL	N66	Producer

SOURCE: U.S. Bureau of Mines, PC-ADIT data system.

Drilling, blasting, loading, hauling, shaft or ramp haulage to surface, and ventilation systems are usually all enclosed and operate at temperatures from -20°F to near freezing. Support facilities may also be located underground for protection from the weather. Transportation permitting, yealr-round operations are usually possible.

Permafrost in the Arctic can be up to 2,000 feet thick, and ice layers can be found in the rock. However, miners have developed techniques to cope with these problems. Two examples of underground mining in which ice and mixed ice-rock is encountered are the Nanisivik and Polaris lead-zinc mines.[4]

Shaft sinking technology has improved such that it can be performed in subfreezing conditions in the Arctic with the same efficiency as elsewhere. However, special approaches may be required where ground thawing is a threat (see box B-l).

Open Pit Mines

There are few open pit mines in the Arctic. Examples are Cyprus Anvil (Fare) in the Yukon, Aitik in Sweden, and Red Dog (see box B-2), currently under development in Alaska,[5] Most open pit mines operate through the severe winter conditions. A few operations, however, are seasonal and may shut down for 3 to 4 months of the winter. This is done more because of the workers' limited ability to function at the sustained low temperatures than the equipments' performance under these conditions.

Open pit mines are, by definition, exposed to the weather, so they must contend with very low temperatures in the Arctic. Of major importance is the ability of

[4] S. Dayton, ''Bolidcn Takes a Qua-tying Concept Underground at One of Europe's Larger Lead Mines,'' *E&MJ*, February 1981, pp. 67-73. R. Fish, ''The Place Where People Find Things—Nanisivik Mines in Canada's High Arctic,' *Canadian Mining Journal, September 1978,* pp. *344 Shaf*

[5] J.C. Hopkins, ''Galvanizing the Anvil," *Canadian Mining Journal,* August 1986, pp. 17-18. L. White, "Copper from the Swedish Arctic," *E&MJ*, February 19S4, pp. 29-33. H.M. Giegerich, ''Progress Repot-I on COMINCO's Red Dog Project in Alaska, Second Largest Zinc Deposit Ever Discovered,'' *Mining Engineering*, December 1986, pp. 1097-1101.

Box B-1—Polaris: An Arctic Underground Mine[1]

The Polaris lead-zinc mine (75° N. latitude) is located on Little Cornwallis Island, Northwest Territories, Canada near the settlement of Resolute Bay. It is owned and operated by Vancouver-based COMINCO, Ltd. and is the western world's most northerly base metal-mine.

had-zinc mineralization was discovered on Little Cornwallis Island in 1960. In 1972, following 10 years of exploration and several years of core drilling, the sizable ore body was confirmed. The ore assays at 12 percent zinc and 3 percent lead (compared with an average of 5.9 percent zinc and 2.4 percent lead at zinc mines worldwide).[2] In 1979, after 5 years of engineering and environmental feasibility studies, COMINCO announced it would proceed with development of the mine. Construction began in 1980 and was completed by 1982 at a cost of about $125 million and roughly $35 million in working capital.[3] It has operated continuously and profitably since.

Temperature extremes range from a winter low of -58° F to a high of 59°F in August. Continuous darkness prevails from November through February, and continuous daylight exists from April to August. Freeze-up begins in September. Offshore, ice thickness increases from 1 foot in October to 7 feet in May. The permafrost extends to a depth of approximately 1,400 feet. Only the top few inches thaw in the summer.

The major feature of mining at Polaris is the absolute necessity of preventing thawing. Because the entire ore body is located in permafrost, the ore is porous and the voids contain ice. If allowed to thaw, the stability of the mine openings would severely deteriorate. To ensure freezing conditions, four refrigeration units are used in the summer to cool the ventilation air. In the winter, the natural -25°F ventilation compensates for the heat generated by the mining equipment. Inhibiting thawing also extends to the backfilling operation. In many underground mines, the backfill material is mill tailings combined with cement, Mill tailings would add too much heat to the Polaris mine, so shale mined at the surface is used instead. A small amount of fresh water is added to this fill to freeze it in place for stability.

Polaris is located on the coast, so the need for roads was limited to those at the mine site. The mill was constructed on a barge in southern Canada and towed to the mine site. At high tide, the barge was floated into a prepared lagoon and berthed. The lagoon was then backilled. The 100 foot by 400 foot multilevel barge houses the concentrator, power generator, maintenance shops, offices, assay lab, warehouse, and fuel oil storage.

The concentrates are stored in an unheated building with a capacity for 220,000 tons of concentrates. The shipping season at Polaris is normally 6 weeks long, from mid-August to the end of September. During this period, the year's production of concentrates must be shipped out, and all supplies except perishable foods must be received. The concentrates are shipped primarily to Europe for smelting and refining. Air service via Resolute Bay is available for personnel and food.

Mill tailings are disposed in Garron Lake. They are pumped 1.6 miles to the lake, where they are thickened and pumped deep below the lake surface. Garron Lake provides an acceptable environment for depositing the tailings due to its meromictic character (no vertical circulation of the water). Below 66 feet, there exists a zone with three times the salinity of seawater that contains naturally occurring hydrogen sulfide. This precipitates any soluble heavy metals in the tailings slurry.

COMINCO has engineered a system which captures 93 percent of the energy value of the fuel oil burned to generate power. Waste heat from the electric generator is used to dry the concentrates and provide space heating. The accommodations for the 200 workers are designed to provide as attractive an environment as possible. There are four living modules plus modules for administration, dining, recreation, and service. The modules are positioned 5 feet off the ground to prevent thawing of permafrost. The recreation facility includes numerous indoor sports facilities, including a swimming pool. The southern (non- Inuit) personnel work continuously for 10 weeks and then have 2 or 3 weeks off. Most are flown to their homes in Montreal, Toronto, Edmonton, Yellowknife, or elsewhere across Canada.

[1]Taken primarily from "ASSaSXIIa[of Mining and Process Technology for Antarctic Mineral Development, ' November 1988, contractor report prepared for OTA by Magee Geological Consulting.

[2]*An Appraisal of Minerals Availability for* 34 *Commodities*, Bulletin 692, Bureau of Mines, U.S. Department of the Interior (Washington, DC 1987).

[3]Maarten J, de Wit, *Minerals and Mining* 01 *Antarctica, Science and Technology, Economics and Politics* (Oxford: Clarendon Press, 1985)

personnel to function efficiently at the sustained low temperatures that are encountered. Many operations, such al drilling, loading explosives, and blasting must be performed with personnel exposed to severe cold. Surveying, sample handling, secondary blasting, and other functions typically have to be performed outdoors.

Dredging

Dredging is another mining technology used occasionallv in the Arctic. Alluvial deposits in shaIlow water are dredged during the summer in Alaska and the Yukon. One large gold dredge operates off the coast of arctic Alaska near Nome for about 5 months of the year,

Photo credit: COMINCO Ltd.

The Polaris Mine at 75" N. latitude in the Canadian Arctic.

Processing

After an ore is mined, various processing steps are used to extract the valuable metals or minerals it contains. Depending on the mineral, some combination of crushing, grinding, beneficiation, smelting, refining, or hydrometallurgical processing are needed. Part of the processing is normally done at the mine site, the remainder is done elsewhere. The extent of mine-site processing depends on the costs of transporting products and raw materials and those of constructing and operating a processing facility. For an easily processed ore, such as gold, all processing may be performed at the mine site. Arctic gold mines commonly have small furnaces and make gold bars. Base metal mines in the Arctic, however, include only a mill (crushing, grinding, classification, and concentration). The concentrates are shipped elsewhere for smelting, refining, or hydrometallurgical processing. This particular configuration is chosen because:

- transporting ore that is of low value per ton to distant mills is prohibitively expensive;
- smelting economies-of-scale are such that few mines are large enough to support a competitive smelter
- transporting processing fuel oil, fluxes, and other supplies to the mine site is costly and further strains the already short shipping season; and
- there are no proven hydrometallurgical processes for nonferrous metals which are economically viable on a small scale.

Common forms of beneficiation have been used in the Arctic for copper, zinc, lead, and platinum group metals.[6] The important feature in designing crushing circuits is to keep ore from thawing and refreezing. For example, at the Polaris mine, primary crushing takes place underground at below freezing temperatures. Most Arctic grinding circuits are located in a heated building. Flotation and other concentration circuits are always located in heated buildings.

Tailings Disposal and Water Treatment[7]

The selection of a disposal method for mill tailings is a very site-specific decision. All Arctic mills have had to meet stringent environmental limitations, and in the case of newer operations ''zero discharge' is the goal. Red Dog uses a tailings dam and discharged water is treated to remove heavy metals. Mill tailings at the Polaris mine are discharged into a lake where the high salinity coupled with the naturally occurring hydrogen sulfide precipitates the soluble heavy metals contained in the tailings pulp. At Black Angel, where the tailings are discharged to the bottom of a fjord, the original disposal system resulted in lead contamination of the local marine life to the extent that certain mussels were not suitable for consumption. Black Angel has since adjusted its milling process to reduce the heavy metal content (dissolution) of its mill waste, and increased the thoroughness of its *tailings* treatment operations. The technical aspects of land-based tailings disposal can be resolved, as shown by the methods used at Lupin and proposed for Red Dog. However, because of the need for earthen darns and additional water treatment capacity, disposal on land is expected to become more expensive than ocean disposal.

Infrastructure Support

Mining requires a great deal of supporting infrastructure, including power, water, roads, and sometimes railroad and shipping facilities. In addition, airfields and personnel accommodations are required at remote mines. Most of the mining camps developed in the Arctic of Norway, Sweden, and Finland had some nearby manpower, roads, port facilities, and power available within 100 miles. Because North American Arctic mines are more remote, more infrastructure had to be constructed specifically for them. In general, governments have been supportive of mine development in the far north, and have at times assisted with infrastructure financing (e.g., Nanisivik in Canada).

Power at most Arctic mines is generated by diesel fuel. This requires large amounts of fuel (on the order 4 million

[6] Platinum group metals include platinum, palladium, rhodium, ruthenium, iridium, and osmium.

[7] Magee @-@K@ Consulting, op. cit., footnote 2.

Box B-2—Red Dog: An Arctic Open Pit Mine[1]

The Red Dog deposit (68° N latitude) is located in northwest Alaska near the Kotzebue Sound and the Chukchi Sea. The deposit contains 85 million tons of ore assaying 17.1 percent zinc, 5 percent lead, and 2.4 troy oz./ton silver. COMINCO, Ltd. is developing the mine, which will be the world's largest zinc producer when it starts production. The 6,000 short ton/day project is being built at a cost of $300 million, plus an additional $175 million for a port and the access road from the port to the mine.[2] Production is scheduled to begin in late 1989.

The operation will consist of an open pit mine, a mill, concentrate storage buildings, tailings disposal facilities, maintenance shop, a power facility, road and port facilities, and accommodations and recreation facilities for 300 people.

The mine will be a conventional open pit mine with 10-cubic-yard loaders and 50-to 85-ton haul trucks. Due to the minimum amount of waste which overlays the deposit, preproduction stripping is limited to several million tons; the life-of-mme strip ratio should be very low (1.0 or less).[3] A key element in the design of the pit is the placement of the waste rock. Weathering of the deposit outcrop has caused heavy metals to enter Red Dog Creek. The mine plan calls for positioning the waste dumps to minimize the potential for additional natural leaching of heavy metals from this weathered outcrop material, which will not be processed initially.

The mill will incorporate the latest technology in order to minimize space requirements, maximize energy efficiency, and improve recovery. The basic unit operations of the mill will be primary crushers; semi-autogenous (SAG), ball, and tower mills; Maxwell and column flotation cells; and pressure filters. The SAG mills are used to eliminate fine crushing with its inherent material-handling problems for wet or frozen ore. The concentrates will be filtered using pressure filters, thus making it unnecessary to further dry the concentrates.

The mill tailings will be disposed behind a tailings dam constructed from material excavated from the mill site. The dam will be raised in stages over the life of the mine. Excess water and run-off water will be treated for removal of heavy metals prior to discharge to Red Dog Creek.

Power will be generated onsite, and the waste heat will be used to heat the process buildings, accommodation building, and incoming water. Those surface facilities which do not house process equipment will be pre-engineered buildings erected on site. The main mill facility and the accommodation building will be constructed of modules that have been preassembled in the United States or Asia. These modules, weighing up to 1,500 tons will then be transported by barge to the Red Dog port and hauled to the mine site.

The Red Dog mine is inland, so ground transportation has to be available. A 52-mile all-weather road (including 10 bridges) from the port to the mine is being built at a cost of $2 million per mile. Concentrates out of, and supplies into, the mine will be transported with 150-ton trucks.

The Red Dog shipping season is estimated to be 100 days. The port facilities are limited by shallow water. Self-unloading barges will be required to transport the concentrates to offshore ships. The concentrates will be shipped to North America. Japan, South Korea and Europe for smelting and refining.

IT&m primarily from ''Aaseaamcmt of Mining and Process Technology for Antarctic Mineral Development,' November 1988, report prepared for OTA by Magee Geological Consulting.

[2] The port and road are to be financed by the State of Alaska. COMINCO will pay a toll fee of $17 per ton to transport the concentrates

[3] Strip ratio is the tonnage of waste rock that must be removed for every ton of ore extracted. Since waste removal is costly, low strip ratios enhance the viability of mines.

gallons per year at Polaris) to be transported north. The fuel is brought by truck or ship. Fuel transport by ship is seasonally limited at the coastal Polaris and Black Angel mines and can require the use of ice breakers or reinforced cargo vessels.

Road construction has been a major cost in some Arctic areas. The Lupin mine in the Northwest Territories has a winter road built on snow and lake ice. Supplies can move along this road only during the winter months. This road is 360 miles long, including 330 miles of ice roads across frozen lakes. The road can be used for about 3 months of the year, during which time essentially all fuel and supplies for the next 9 months are transported. The Red Dog mine in Alaska is presently under construction, and a 52-mile access road to a port facility has been built across permafrost at a cost of $2 million per mile.

Materials handling at the mine, mill, storage, and port facilities is another important consideration in Arctic mining operations. Special consideration during cold weather is required to prevent inappropriate freezing of ores, waste, tailings, slurry lines, conveyors, and concentrates.

Air transport is essential for rapid movement of personnel and related perishable food and emergency supplies. It is also essential during the construction phase to reduce construction time and costs. Each site must have a maintained airfield. Year-round operations must have an airfield designed for severe weather conditions.

Building construction in the Arctic is most often modular. Building and equipment modules are built in more temperate regions and transported to the mine site for final assembly. Module construction for infrastructure was done at Polaris and Lupin and is underway for the Red Dog mine in Alaska. In a unique design for Polaris, the entire processing plant was built on a barge, towed to a dredged basin at the site, and permanently moored in place.[8]

Accommodations for personnel are required at the remote Arctic mines. These quarters include recreational and communications facilities for the workers. Waste heat from the generator systems is used for surface facility and plant heating in the Arctic.

Economics

The technology developed by the mining industry has proved functional in severe Arctic conditions. The costs associated with the special approaches to mining, processing, tailings disposal, and infrastructure support are greater than in lower latitudes, but the mines have been economic because of their higher grade ores. The ore at Polaris averages 12 percent zinc, whereas ore grades at zinc mines worldwide average 5.9 pecent.[9] Coproduct values may also be important. For example, the ore in the Red Dog deposit not only assays 17.1 percent zinc, but also contains 5 percent lead and 2.4 troy oz./ton silver.

Table B-2 shows the difference in ore grade and operating costs for selected Arctic and southern mines. For the mines listed in the table, the average operating costs of both underground and open pit mines in the Arctic are more than twice as high as comparable mines further south. Ore grades are also significantly higher than for southern mines. Arctic deposits typically contain in situ ore valued at more than $200 per ton.[10] The risks inherent in Arctic mining lead companies to require a return on their Arctic investments of 20 percent or more, compared with a 15 percent hurdle rate elsewhere.

Another consideration affecting the economics of Arctic mines is the size of the deposits. Because of the large capital costs involved, a deposit must be very large and have suitable production to recover the investment. For example, the Red Dog mine, with 85 million tons of ore, will be the largest zinc mining operation in the world when it reaches production. The capital cost is estimated at $300 million not including the port and 52-mile access road to the mine, which are being built by the State of Alaska for $175 million. At full capacity, the mine is designed to operate at a rate of 6,000 tons of ore per day.

Location is another economic consideration, particularly with regard to transportation infrastructure. Occasionally, a deposit which may not be quite rich enough or large enough to be developed independently may, through fortuitous location, become more economically attractive by utilizing nearby infrastructure developed for another deposit. For example, the Lik deposit, 12 miles northwest of the Red Dog deposit may not have been as economically attractive on its own as it is with the nearby Red Dog deposit being developed. Thus far, the Lik deposit has drilled reserves of approximately 24 million tons assaying 9 percent zinc, 3 percent lead, and 1.4 troy oz./ton silver.

ANTARCTICA

Environment

The Antarctic environment is perhaps the first factor that would affect the viability of a mining venture. Antarctica is the coldest, highest, windiest, and most isolated continent on Earth. In addition, it has a cover of ice that limits rock exposure to about 100,000 square miles, or one-fiftieth of the total area of the continent. The Antarctic Peninsula reaches within 500 miles of the tip of South America, but in other sectors the closest land is some 1,400 miles distant.[11]

The isolation and ice cover create an environment more severe than that in the Arctic, and mines would need to be designed to withstand low temperatures, high winds, and harsh storms. The mean temperatures in the coastal areas range from about +32°F (in the warm months) to 0°F to -20°F (in the cold months). The interior, high polar plateau, is much colder, with mean temperatures of about -40°F in the warm months and as low as -90°F in the cold months. The northwestern part of the Antarctic Peninsula is milder because of its maritime climate; winter mean temperatures are +15 “F, and winds over its central part are persistent but not fierce.

[8] J.K. @wi n, ''The Polaris Process Barge, ' *CIM Bulletin*, April 1983, pp. 93-97.

[9] *An Appraisal of Minerals Availability for 34 Co mmodities*, Bulletin 692, Bureau of Mines, U.S. Department of the Interior (Washington, DC: 1987).

[10] In situ ore value (measured in $/ton) equals the amount of metal(s) contained in a ton of ore multiplied by the price of the metal(s). This value must be sufficient to cover all the operating costs and depreciated capital costs of recovering the metal(s) and getting it to market.

[11] D.H. Elliot, Director, *A Framew ork for Assessing Environmental Impacts of Possible Antarctic Mineral Development* (Institute of Polar Studies, The Ohio State University, 1987).

Table B-2—Lead/Zinc Producer Comparisons

Name	Mine type	Ore grade (%) Zinc	Lead	Estimated operating costs[a] ($/ton)
Northern:				
Red Dog	Open pit	17	5	27
Polaris	Underground	12	3	27
Nanisivik	Underground	12	1	30
Southern:				
Buick	Underground	1.6	5.9	12
Mount Isa	Underground	6.5	6.4	19
Elmwood	Underground	3.0	0.0	11

[a]Costs are estimates based on past surveys of lead/zinc producers. Though not current, they illustrate the differences between northern and southern mines.

SOURCE: Magee Geological Consulting, "Assessment of Mining and Process Technology for Antarctic Mineral Development," OTA contractor report, November 1988.

Storms are frequent, even in the milder coastal areas. Stormy conditions result from either surface flow of air from the continental interior (katabatic winds that are exceptionally violent in some coastal areas) or the passage of low pressure systems. Depressions are generated frequently in a circum-Antarctic belt between *70°* and *60°* latitude South, and strong westerly winds occur on the northern flank of this belt. Individual depressions may form in less than a day and as many as six depressions in various stages of growth and decay may occur at any one time around the continent. These centers may follow one another with greater frequency than is experienced in the Northern Hemisphere belt of westerlies, and there is little assurance of calm conditions between successive centers. The southern parts of the depressions frequently penetrate the coastal regions of Antarctica and bring strong winds, blizzards, and heavy snowfall.

An Antarctic mine may have more difficulty accommodating the moving glacier ice than coping with the weather. The ice sheet presents a formidable challenge to designing a mining system. It forms a slow-moving carapace whose thickness in places exceeds 13,000 feet.[12] The ice cover restricts rock exposures to coastal regions and to the summits of isolated peaks (e.g., in the Transantarctic and Ellsworth Mountains). At present no system to mine through this ice is considered economically feasible, It will also be prudent to avoid building a port and road system on moving ice. Resupply may also be a serious problem in Antarctica-many thousands of tons of fuel and other supplies must be brought to a mining operation. Interior areas would be the most difficult to resupply.

Logistical support for an Antarctic mine would be hampered by the coastal ice shelves. Moreover, Antarctica is physically isolated by a pack ice belt that seasonally extends 900 miles from the continent in some locations. The minimum sea ice cover occurs in March, but by September sea ice cover has grown to nearly 8 million square miles. The sea ice consists of individual floes 30 to 300 feet across and up to 10 feet thick. In spring and summer, however, the sea ice drifts northward and melts, and open water is encountered along many coastal areas.

Mineralization

Moderate climate, accessibility, and available knowledge about mineral deposits suggest that the most promising area for mining is the Antarctic Peninsula. The Peninsula has received the most attention from geologists, in part because theories point to possible deposits there and because sampling is easier there than elsewhere. Because parts of the Peninsula are accessible and more moderate in climate, they may be promising enough for initial minerals prospecting.[13]

Mining

A mine in Antarctica's interior (for instance on the Dufek Massif) would face much greater isolation and probably a harsher climate than is experienced at Arctic mines. Such conditions would probably require substantial improvements in existing technologies, if not completely new technologies, and would likely require extraordinarily high valued ore. In the coastal regions, however—especially the Antarctic Peninsula—environmental conditions are similar to those of existing mining operations in the Arctic. An Antarctic mine in

[12]The ice flows out toward the coast, calving as glaciers into the sea or becoming part of the floating ice shelves such as the Ross Ice Shelf. The ice shelves are the source of the large tabular icebergs.

[13]OTA Workshop on Antarctic Mining Technology and Economics, Dec. 13, 1988.

these areas would probably use similar technology and operating techniques.

The Antarctic Continent offers some special conditions not found in areas near mines of the Arctic. About 98 percent of the continent is covered by ice (which makes it similar to northern Greenland), so mines must be located in exposed or nearly exposed areas. Mine construction would have to start in an exposed area but may extend under ice cover. It would be impractical initially to locate mine shafts on ice and to sink shafts and declines through the ice to a deposit below. Shafts, ramp declines, or other underground mine access points, including ventilation raises, initially would have to be located on solid ground. Similarly all plant sites and support facilities would have to be located on the ground or underground. A plan for dealing with ice and for siting the surface plant and infrastructure must be addressed at the time of mine design. Temporary buildings may be located on ice, but if the ice is moving, even this is not practical. Land areas suitable for mine locations will be difficult to find. It will be necessary to drill and blast to establish level surface areas for mine access and plant and infrastructure construction in rugged areas such as the Dufek Massif and the Copper Nunatak in the Antarctic Peninsula. Alternatively, some of these facilities could be located in underground excavations.

Underground Mining

The conditions for underground mining in Antarctica may be similar to those in the Arctic. However, rock temperatures and permafrost depths may differ. Nonetheless, several underground mining methods that have been used in the Arctic might be applicable in Antarctica. For example, a room and pillar method might be used for a flat lying platinum deposit (a possibility in the Dufek igneous complex).

Open Pit Mining

The open pit mining method may be suitable in selected areas of Antarctica, the most likely being the northern Antarctic Peninsula and the Dry Valleys near McMurdo Station. It may be used in select areas where ice cover is less than 500 to 600 feet thick. Mining an ore deposit through thicker ice cannot be done by conventional methods, and open pit mining of a deposit below the ice is highly unlikely. There are no examples in the northern latitudes of open pit mining through a glacier or ice field. Ice accumulations have been mined in Canada in and around open pit mines, but nothing comparable to mining extensive ice areas. More research and investigation will be needed before any system to undertake open pit mining beneath the Antarctic ice cap can be contemplated. However, it does appear possible to remove some ice over an ore deposit by open pit mining methods.

Dredging

Dredging operations would be infeasible in much of Antarctica because of ice conditions. Some areas, though, have conditions suitable for at least seasonal dredging. One such area is the northern part of the Antarctic Peninsula. However, it is not certain what mineral resources exist there.

Processing

Processing in Antarctica would probably face the same problems and constraints as those encountered in the Arctic. Most likely, milling would be performed at the mine site, and the concentrates would be shipped to a northern smelter or hydrometallurgy plant. Energy efficiency in the milling process would take on added importance, because of costliness of bringing in fuel oil. Solar energy may have application because of 24-hour daylight in summer.

Tailings Disposal

Tailings from mill processing of ores would likely be contained on land surface areas, but if land surface is in short supply, tailings may be disposed on the ice. This material would freeze and, assuming no thawing of the ice, should present no future problem, Excess water could be recycled from the tailings. This is only one of a variety of possible methods for tailing disposal. All have some drawbacks, either technical or economic, and the disposal of tailings probably poses one of the most serious environmental problems in a mining operation (see ch. 5).

Infrastructure Support

Constructing the infrastructure for Antarctic mining would be more difficult and costly than in the Arctic given the longer distances from major staging areas and the moving ice. Transportation of fuel and concentrates as well as personnel and supplies would be perhaps the most difficult and costly task. New or modified transport technologies may have to be developed. Mining and processing initially may be seasonal operations for lack of year-round infrastructure,

The transportation of fuel and concentrates for a base metal operation would probably require ships. A port that is at least seasonally ice-free would be needed,[14] but port facilities would be expensive and difficult to locate. Arctic mining projects have used ice-reinforced ships and barges as well as newly built, dedicated port facilities. Ice-free periods are one to a few months' duration so

[14] Water transportation may not be required for high value, low volume products such as gold and platinum. These products may possibly be shipped by air.

product stockpiles need to be built up for use during the winter season, Port conditions in Antarctica may be similar to those in the Arctic but with the added difficulty of longer transits to a supply base, much stormier weather, and locally higher occurrences of icebergs in the open water.

Overland transportation of fuel, supplies, and product would be one of the major costs of an inland mining operation. A site at the Dufek Massif may require about 330 miles of ice ''road' across the Ronne Ice Shelf to the site. Any discovery in Antarctica inland from the coast would require the construction of an ice road for access, except perhaps in the islands near the Northern Antarctic Peninsula and the Northern Peninsula itself. Such construction and maintenance may well be a major and costly task. Maintaining winter access along such a road may be impossible where high winds and blowing snow could make passage unsafe.

Fuel may be transported by pipeline, but with subfreezing temperatures prevailing, a pipeline would have to be suspended and heated. Since a road would have to be maintained for other supplies, a pipeline for fuel may not be a justifiable added cost.

Air transportation would be required for personnel, small supplies, and possibly product shipment in the case of gold or platinum. Environmental conditions affecting air service to Antarctic regions near the coast may be similar to the Arctic, but inland, they may be much more severe. Extreme cold temperatures, high winds, and blowing snow in inland Antarctic regions could severely restrict aircraft operations, and this could affect the ability of a mine to operate year-round. Large, wheeled aircraft have made numerous landings on unprepared blue-ice patches in interior parts of the continent, suggesting that use of such aircraft may be viable in some areas during the austral summer.

Accommodations for personnel can be designed in a manner similar to those in the Arctic examples cited and should be satisfactory, but should be designed to withstand the high winds anticipated. If a year-round operation is planned, crew transfers from the site by air during much of the year will be needed. Air service in all conditions is probably not possible. This means that an airfield must be constructed that can function during almost all weather conditions, a very difficult task in most areas of Antarctica.

Economics

Several studies and a number of speculations have focused on the feasibility of mining platinum from the Dufek Massif.[15] The many technical problems encountered at this site in Antarctica's interior appear insurmountable to some experts, The studies speculate that mining may occur in this and other Antarctic sites if agreements are reached to encourage such development and if high-grade deposits are located. OTA finds that past studies that concluded mining platinum from the Dufek Massif was practical underestimated the costs and difficulties involved.[16]

OTA investigated the relative levels of difficulty of mining in the Arctic and Antarctic. **Mining in Antarctica would not only be more expensive than that in the Arctic, but the enhanced risks would require even greater financial returns to the investors. Antarctic mining might require an estimated 30 percent return, compared with 20 percent in the Arctic, and 15 percent elsewhere.** The in situ value of the Arctic Red Dog and Polaris ores are **$290** and **$200** per ton, respectively.[17] Deposits in Antarctica must have at least this value for mining to be economic. OTA concludes that to cover these costs, ore values would need to be about $200 to $400 per ton for a commercial Antarctic Peninsula mine, and about $300 to $600 per ton for a Dufek Massif mine. These values (at today prices) mean that a Peninsula gold deposit would need to contain an ore with between 1/2 and 1 ounce of gold per ton and a Dufek platinum deposit would need to contain the same grades of platinum per ton.[18] Ores of these high grades are rare and any lesser grade ores would probably not be developed. Though this conclusion is highly speculative, it appears reasonable given the limited state of current knowledge.

SUMMARY

OTA has not developed a separate, complete scenario for a hypothetical Antarctic mine because large numbers of variables make any detailed technical or economic approach impractical. Instead, the foregoing discussion presents possible general approaches. It indicates that certain high-grade mineral deposits could probably be mined economically in Antarctica if they were located in reasonably accessible areas. Mining on the coast or on the Peninsula might be done with the technologies currently used in the Arctic. Technology would not be a significant

[15] See, for example, M.J. de Wit, *Minerals and Mining in Antarctica Science and Technology, Economics and Politics* (Oxford: Clarendon Press, 1985). See also, The Institute of Polar Studies, *A Framework for Assessing Environmental impacts of Possible Antarctic Mineral Development*, Ohio State University, 1977.

[16] Magee Geological Consulting, op. cit., footnote 2.

[17] supra note 15

[18] A grade of approximately four times the grade of the example in the de Wit study.

deterrent to minerals development in these ice-free, accessible locations with ''Arctic-like' environments. Economics, however, could be a major deterrent. The deposit would have to be of "world class" value to cover the high costs of the facility and its infrastructure and the large financial returns needed to compensate the investors for the additional risks.

The situation is different for a mine in the Antarctic interior (including the Dufek Massif). Here, the climate, ice, and remoteness may require substantial improvements in existing technologies, if not completely new technologies. Considering the other risks in developing an Antarctic mine, mining firms and their financial backers would be hesitant to adopt unconventional mining and metallurgical processes. Initially only proven processes are likely to be acceptable. Therefore, mining in Antarctica's interior is not expected soon, if ever.

Most U.S. mining industry representatives have not given much, if any, attention to Antarctic minerals. Those that have paid some attention consider the political and institutional risks to be the principal deterrent to future Antarctic minerals development.[19] They are pessimistic about operating under the regulatory framework of the Minerals Convention and the uncertainties of jurisdiction, taxation, permitting procedures, environmental rules, etc.[20] Further discussion of industry views on the acceptability and workability of the Convention are covered in chapter 3.

[19]OTA Workshop, Dec. 13, *1988;* Keith R. Knoblock, Vice President, American Mining Congress, personal communication, Dec. 15, 1988,

[20]Simon D. Strauss, Consultant on Metal Markets, personal communication, Apr. 13, 1989.