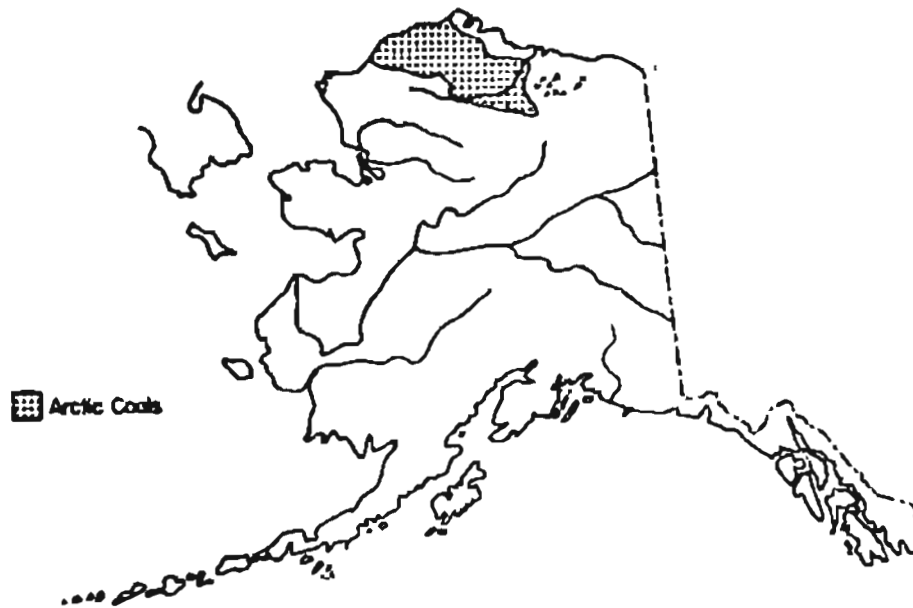




CONSTRAINTS ON THE DEVELOPMENT OF COAL MINING IN ARCTIC  
ALASKA BASED ON REVIEW OF EURASIAN ARCTIC PRACTICES



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## PREFACE

Arctic Alaska's enormous reserves of coal may be a significant future source of energy for the United States and for the Pacific Basin. Large coal reserves have been developed in the Arctic portions of Eurasia, where problems similar to those that might be encountered in Alaska have already been faced. To determine the nature of these problems, the Mineral Industry Research Laboratory of the University of Alaska, under contract S 0133057 with the U.S. Bureau of Mines, has conducted a literature review on Eurasian coal mining and visited mines in Svalbard, Norway; Carmacks, Y.T.; and Healy, Alaska. The purpose was to establish the most significant physical constraints which may apply to the eventual development of Northwestern Arctic Alaskan coal.

The report concludes that special conditions and circumstances exist in Arctic Alaska which may require modifications of standard U.S. mine regulations and practices, and cautions against an automatic transferral of existing practices and procedures from the "Lower Forty-eight" to Arctic Alaska. In addition, the report particularly stresses the need for a broad view of the trade-offs involved in establishing mine ventilation, dust suppression and water supply requirements, and suggests that no solution presently exists for the problem of dust suppression in waterless low humidity Arctic coal mines employing extremely high speed mining machinery. With this exception, however, coal mining on both a large and a small scale exists in the Eurasian Arctic under conditions similar to those found in Arctic Alaska, indicating that the technical problems involved

have been largely solved.

The report is short and presents the conclusions which are supported by the information given in the five appendices, each of which is designed to be read separately. Appendix A presents the relevant information obtained on Svalbard and Greenland including a report on the visit there in the summer of 1974. Appendix B presents data on northern coal mining in the USSR and summarizes what is known about the physical constraints encountered by the Russians in developing coal mines in Arctic Siberia. Appendix C provides the trip reports and other data obtained on the mining operations at Healy, Alaska, and Carmacks, Y.T.

Appendix D contains two translated bibliographies of Russian language materials and is designed for the reader who does not understand Russian but wishes to know the nature of the literature available. This appendix builds upon the information provided in the Summary Report of June, 1974.

Finally, Appendix E presents an analysis of the probable relationships that could exist between the environment and the development of large-scale Arctic coal mining. It is designed to provide some general guidelines for use in planning the future development of Arctic Alaskan coal.

The reader interested only in the conclusions may restrict himself to the Report and, if he desires more information, Appendix E. The reader concerned about the supporting materials used to reach the conclusions should consult Appendices A, B and C. The reader interested in the Russian language literature should review Appendix D.

The report was written by Dr. Donald F. Lynch, with support from Dr. Ernest N. Wolff and Dr. Nils I. Johansen. Appendix A was written by

Dr. Lynch with support from Dr. Chris Lambert, Jr., and Dr. Johansen. Appendix B was written by Dr. Lynch. Appendix C was written by Dr. Wolff with Dr. Lynch and Mr. John Wiebmer. Appendix D was written by Mr. Niall C. Lynch. Appendix E was written by Dr. Lynch with assistance from Dr. Johansen. Much of the literature search and some of the translations were done by Mr. Adadu Yemane and Mr. Sverre S. Pedersen.

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The Interaction of Large-Scale Alaskan Coal Mining and the  
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## INTRODUCTION

Coal mining in the Arctic faces some special conditions and circumstances which may require modification of standard U.S. mine practices and regulations. Practices normal in the "Lower Forty-eight" cannot be automatically transferred to Arctic Alaska without considerable risk. This conclusion was reached by study of Arctic coal mining experiences in Eurasia where problems similar to those in Alaska exist.

Eurasian Arctic coal mining has a long history, and coal has been produced on a large scale for at least forty years. The major producer is in the Pechora Basin, at the northern edge of the Ural Mountains. Smaller but still significant mines exist on the island of Vest Spitsbergen in the Svalbard Archipelago, near Noril'sk in the upper Yenisey Basin, in Yakutiya and Magadan, and elsewhere. Coal is also produced at Healy, near Fairbanks, Alaska, and at Carmacks in Canada's Yukon Territory. (See figures p. 5A, B, C)

The environmental constraints on Arctic coal mining derive from the cold climate, high winds, permanently frozen nature of the rocks, and remoteness from major centers of population. These physical factors can have a major influence on roof support, ventilation, mine openings, dust generation and suppression, coal washing, productivity and supplies. In addition, they also impact on surface works, transportation, and personnel.

Mining in permafrost, properly conducted, has some advantages, among them being the fact that the low temperatures assist in maintaining roof stability and that abandoned shafts can simply be flooded with water to prevent surface subsidence.

A critical problem area for large scale surface and underground mining



will be dust suppression in an essentially waterless mine. Under winter conditions, dust generation is significantly increased, while the use of water for dust suppression may be impractical.

Another problem area is ventilation. High ventilation requirements may increase dust generation, reduce worker comfort, and create difficulties in roof control and mine shaft stability.

The report presents major conclusions, while the appendices provide the supporting information. Each appendix is designed to be read separately. Appendix A discusses Svalbard, B - Siberia, C - Healy, Alaska, and Carmacks, Y.T.

Svalbard, located due North of Norway along the 78th parallel of latitude, has a history of coal mining going back to the beginning of this century. Coal has been mined by companies organized by Americans, Dutch interests, Swedes, Norwegians and Russians. At present the only coal mining operations are those of the Russians and the Norwegians, both of whom appear to be planning significant future expansion of underground mining.

Coal mining, while old in Siberia, began to be economically significant in the early 1930s with the development of the Pechora coal basin, located to the north of the Ural mountains. This basin today produces about 20 million tons of high grade coal used for metallurgical and thermal purposes in the energy deficient northern part of European Russia. Mining in Noril'sk near the mouth of the Yenisey River, has also been significant for support of the town and nickel mining and refining in this area. The Lena Basin, one of the greatest potential coal basins in the world, has been developed primarily for local use, but may have a significant future as a major producer of coal for eastern Siberia and the Soviet Far East.

Healy, Alaska, has been the site of coal mining for about fifty years, and today provides a significant portion of the energy consumed in the

electricity producing plants in Fairbanks, Alaska. Carmacks, Y.T., has been the site of coal mining since the Yukon river boat days when it served the vessels moving from Whitehorse to Dawson and farther downstream. Today it produces coal for use in the ore reduction plants at Faro.

The literature available in Russian, while extensive, focuses more on technical problems affecting specific mines rather than on the constraints affecting Arctic coal mining. Finding truly relevant information has not, therefore, been an easy task. The sources known are presented in Appendix D and in the Preliminary Report, June, 1974.

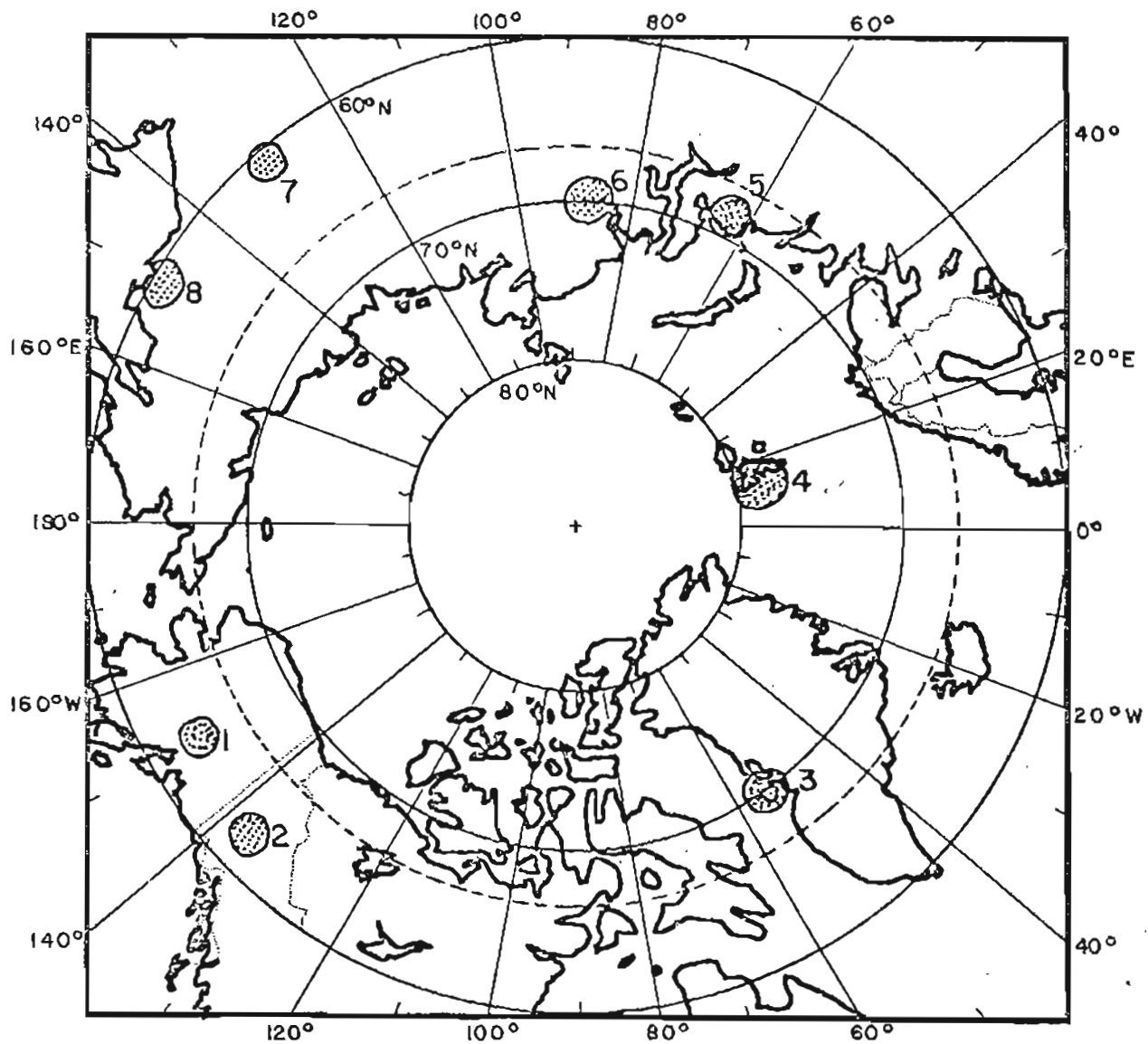
The future of Arctic Alaskan coal will depend upon a variety of factors, and these will include the relationship of mining to the local physical and human environment. Appendix E assesses this relationship in terms of the environment's impact on possible mining operations and the impact of mining on the environment. The relationships are assessed in terms of Eurasian Arctic experiences and knowledge of Alaska.

The study has stressed establishing those factors which make Arctic coal mining different from coal mining in other parts of the world. The Report and all the appendices focus on this problem rather than on a general description of the history and peculiarities of individual mining operations and national policies toward coal mining. Successful operations will consider these factors carefully in all stages of mine planning, development and operations. Failure to do so may cause costly mistakes. The low temperatures and humidities and deeply frozen ground of Arctic Alaska are special and unique phenomena not found in other American coal basins. Ignoring the constraints they represent on mining activities can cause extreme difficulties. Utilization of the positive aspects of cold and permafrost can, on the other hand, result in significant advantages both in mining operations and environmental protection.

Glossary of Some Norwegian and Russian Words

|               |   |
|---------------|---|
| Ǿ             | letter not found in the English alphabet (= aa) |
| Arktik        | Arctic  |
| A/S           | Inc.  |
| berg          | mountain  |
| bjørn         | bear  |
| bukta         | the bay   |
| by            | town  |
| byen          | the town  |
| dal           | valley  |
| dalen         | the valley                                      |
| Dkr.          | Danske kroner (1 Danish krone. = U.S. \$.18)    |
| fjord         | fjord   |
| fjorden       | the fjord                                       |
| grøn(n)       | green   |
| gruve         | mine  |
| gruven, gruva | the mine  |
| havn, hamn    | harbor  |
| hval          | whale   |
| kompani       | company   |
| kull (kul)    | coal  |
| neset         | the peninsula                                   |
| Nkr.          | Norske kroner (1 Norwegian krone = U.S. \$.20)  |
| ny            | new   |

|             |   |
|-------------|---|
| Ø, ø        | letter not found in the English alphabet (= oe) |
| øy          | island  |
| øya         | the island                                      |
| stor, store | great, greater                                  |
| sund        | sound (body of water)                           |
| talik       | unfrozen (thawed) area within permafrost        |
| våg         | the bay, the inlet                              |
| ugol'       | coal (Russian)                                  |



## LEGEND

- |  |                          |
|--|--------------------------|
| 1. Healy, Alaska, USA                                | 5. Pechora-Vorkuta, USSR |
| 2. Carmacks, Yukon Territory, Canada                 | 6. Noril'sk, USSR        |
| 3. Qutligssat, Disko Island, Greenland,<br>(Denmark) | 7. Lena-Yakutlya, USSR   |
| 4. Vest Spitsbergen, Svalbard, (Norway)              | 8. Magadan, USSR         |

FIGURE 1 LOCATION OF ARCTIC AND SUB-ARCTIC COAL MINING AREAS.



FIGURE 2  
SVALBARD

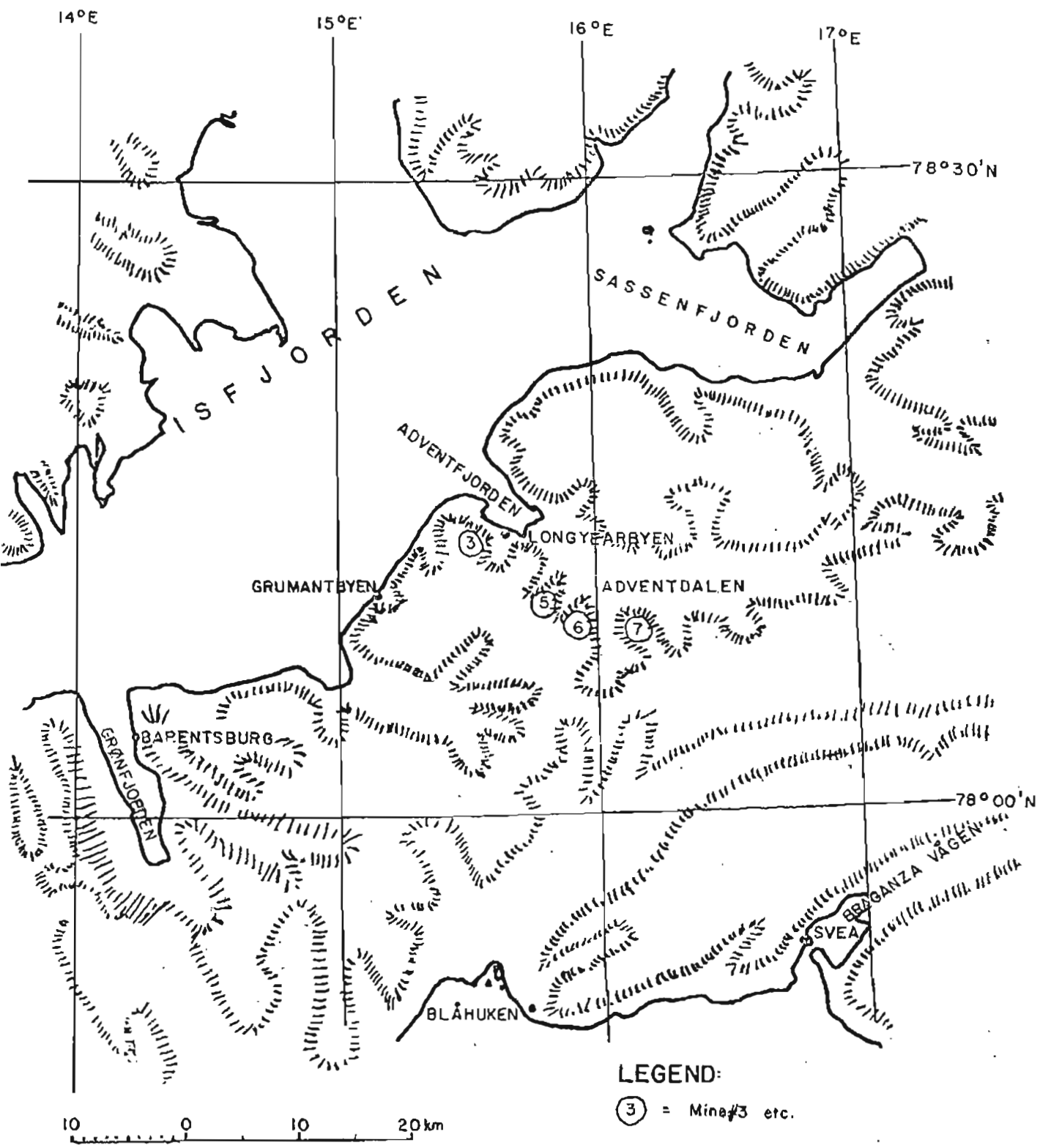


FIGURE 3 LONGYEARBYEN, BARENTSBURG AND SVEA

SUMMARY REPORT

CONSTRAINTS AFFECTING COAL MINE DEVELOPMENT IN ARCTIC  
ALASKA BASED ON REVIEW OF EURASIAN ARCTIC PRACTICES



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## 1.0 GENERAL

The Mineral Industry Research Laboratory of the University of Alaska, under contract S 0133057 with the U.S. Bureau of Mines, has completed a review of Eurasian Arctic mining practices to determine the constraints which may exist on coal mining in northwestern Arctic Alaska. This report summarizes the literature search and visits to coal mines in Svalbard, Norway; Healy, Alaska; and Carmacks, Y.T. The information developed through the literature search and visits is presented in Appendices A, B, C, and D, which support this report.

While the amount of information available on Eurasian coal mining is extensive, most of it is not relevant to establishing constraints on the development of Arctic Alaskan coal. Every mine, every mining operation and organization is so different from every other in terms of history, political environment, physical environment, economic factors, and geologic characteristics that isolating common factors has been difficult.

This report focuses on those factors which can be said to be unique to Arctic coal mining. It focuses on four major constraints: permafrost, frozen water, low ambient air temperature, and remoteness. It also addresses the question of environmental protection, the political and economic factors common to the mines studied, and presents conclusions and recommendations.

## 2.0 CONSTRAINTS ON MINING OF NORTHWESTERN ALASKAN COAL

The coal deposits of northwest Alaska lie in the western portions of the Arctic Coastal Plain and the foothills of the Brooks Range. The general area can be divided into three geographic regions: the west Arctic, the Colville Region, and the east Arctic. The west Arctic has permafrost extending to depths of 1,000 - 1,300 feet, mean annual precipitation of 10 - 20 inches, and a mean daily January temperature of approximately  $-17^{\circ}\text{F}$ .

The Colville region has permafrost about 1,000 feet in depth, a mean January daily temperature of  $-11^{\circ}\text{F}$ , and average annual precipitation of 4 to 8 inches.

The east Arctic has a similar environment, with a mean January daily temperature of  $-17^{\circ}\text{F}$ .

In this general area, summers are extremely short and cool (with extreme recorded highs of  $+75$  to  $+80^{\circ}\text{F}$ , and extreme winter lows of  $-57^{\circ}\text{F}$ ). Wind chill factors of  $-60^{\circ}\text{F}$  are frequent in winter.

The Arctic coastal plain is characterized by a water logged landscape with polygonal ground and thaw lakes. Periglacial phenomena are characteristic of the foothills of the Brooks Range.

Based on the information obtained on Eurasian Arctic coal mines, the principal physical constraints on coal mining in Northwest Alaska are the following:

- problems of mining in permanently frozen ground, including ice rich permafrost;
- problems of using water for dust suppression at temperatures below freezing;
- problems of operating in an environment with low external ambient air temperatures;
- problems of remoteness.

Most published information available concerns underground rather than surface mining. Surface mining problems for a small scale sub-Arctic operation appear to have been solved at the Usibelli Coal Mine near Healy, Alaska. Here dipping seams are being mined under permafrost conditions in a region of extremely low winter wind-chill.

Soviet and Norwegian experiences in underground Arctic coal mining demonstrate that the problems involved have been solved for mining techniques that do not employ extremely high speed machinery.

Coal has been transported by sea in the Arctic for commercial purposes since the beginning of this century. Long overland haulage of coal in significant quantities has been practiced in the Soviet Arctic since the early 1930's.

Significant future development of Arctic coal appears to be planned by both the Norwegians on Svalbard, and the Soviets, including particularly the Yakutsk - Lena Basin region.

Based on historical data and current realities there is no over-riding technical reason, except transportation, why Northwestern Alaskan coal could not be utilized at the present time with technologies and mining practices that are already known and in operation. According to all the information collected, these technologies and mining practices are without exception modifications of those employed in non-arctic environments.

### 3.0 CONSTRAINTS ASSOCIATED WITH PERMAFROST

The effect of permafrost on excavations is a function of temperature and ice content. Cold permafrost is considerably stronger than that with a temperature just below freezing. Ice-rich permafrost is more likely to cause difficulties than ice-free permafrost. Permafrost with temperatures near thawing is very liable to contain water and thawed areas and to be very weak. Some Russian sources have placed a rock temperature of  $-1.3^{\circ}\text{C}$  as a critical lower boundary at which thawing problems develop in coal mines.

#### 3.1 Roof Support

Air entering an opening, regardless of external ambient air temperature, attains the temperature of the surrounding rock after penetrating a distance of from 100 to 1,000 meters, depending on the ambient air temperature and volume of air. For this reason, the greatest difficulties in roof support are encountered near the opening. Various means of roof support near the

entries have been adopted. These include roof bolts and nets immediately after the mine is opened; extensive wood or concrete support for permanent openings; and drill holes alongside permanent vertical shafts to remove excess heat.

The problems are both short term and long term. The short term problems are sloughing, rock fall, and the possibility, in some rock types and conditions, of sudden rock falls due to spalling. At temperatures close to freezing, the interstitial water may be unfrozen or is easily thawed, resulting in the possibility of sudden roof collapse.

The long term problem is a continuation of the above and, in addition, damage and misalignment of permanent shafts due to ground deformation. Long term thawing may also introduce water into the shaft.

Beyond the limits of temperature change, roof support problems appear to be minimal. Retaining the rock temperature, particularly in the -2 to -10°C range, obviates the need in many workings for roof support.

### 3.2 Ventilation

No evidence was found of efforts to chill external air before its entry into coal mines. Instead, roof support is provided in areas where warm air is introduced, hence that are subject to thawing. In some Soviet coal mines incoming mine air is heated when the external ambient air temperature is -20°C or lower in order to improve worker comfort underground. Some mines evidently also maintain above freezing temperatures in winter to facilitate the use of water for dust control. The short term effect of this practice does not appear to cause undue roof support problems, however, the long term effect may be serious. In some Soviet Arctic coal mines, this practice may contribute to increasing the chances of spontaneous ignition of underground coal, sudden roof collapse, and shaft deformation and cracking.

The Soviet mines employ (or are considering employing) heating devices along the working faces in retreat long wall mining to improve worker comfort. Since in retreat longwall mining the roof is allowed to collapse, this practice would appear to have no short term effects on roof support. The long term effect would depend on the amount of total heat generated and its effect on rock temperature in the openings which would have comparatively long lives. It probably is minimal. Permafrost roofs are more difficult to collapse than non-frozen roofs in longwall mining.

Coal mine ventilation requirements depend on government mine safety codes, which take into account worker safety and comfort, gas content and dust content. For Arctic mining, particularly with high speed automatic equipment, the safety code regarding ventilation should take the following additional factors into consideration:

- substantial increases in dust generation in winter as compared to summer.
- changes in rock temperature in permanent or semi-permanent underground excavations.
- creation of wind-chill along the working face.
- tendency of high velocity ventilation to spread coal dust under winter, low humidity conditions.
- effect of high ventilation requirements on causing oxidation of mine rock which in turn can cause an increase in both rock temperature and the potential for spontaneous ignition.
- sublimation of ice in ice-bound rock or soil with associated disintegration.

None of the mines studied had a ventilation requirement along the working face sufficient to create serious wind-chill, but this could become a problem with higher requirements. The normal Eurasian Arctic practice appears to be a wind velocity across the face of  $\frac{1}{2}$  - 3 ft./sec.

### 3.3 Constraints Associated with Frozen Water

By definition rock temperatures in permafrost are below freezing. This fundamental fact indicates that water will freeze, and this in turn can cause extreme difficulties.

The use of large amounts of water for dust suppression will soak the coal which will then freeze. If it does not freeze underground, it will certainly freeze at the normal low winter temperatures encountered above ground. In addition, frozen water can create extremely unpleasant working conditions and even the hazard of frost bite. Ice can also clog nozzles, conveyors and other equipment. Some Soviet coal mines in the Arctic are provided with a circulating heated water supply system used both for dust suppression and for fire fighting. This appears, however, to be a relatively high cost manner of providing water. Sometimes a lanolin type solution or an electrolyte is added to heated water used to suppress dust. The water is sprayed through nozzles along the working face and at selected transfer points. However, it seems that the maximum amount of water which coal can accept without freezing into unworkable lumps is about 8%.

Water is usually not available in large amounts in permafrost coal mines, and where it does occur it is more likely to be a hazard rather than an asset. In some circumstances cracks or fissures may exist which can cause sudden inflows of water from the surface. Water is often available under the permafrost, so that mining below the permafrost level is similar to that in non-permafrost areas. However, employment of water in large quantities for dust suppression in sub-permafrost mines will lead to difficulties in coal transport and storage particularly above ground under winter conditions.

The Soviets employ large vacuum systems rather than water at underground coal transfer points in order to remove dust. Various vacuum systems are

also employed for drilling equipment. Mine safety regulations regarding water supply requirements for dust suppression in permafrost mining will have to recognize the serious difficulties involved in utilizing water. There is no known system for dust suppression in permafrost mines for high speed mining equipment, with the possible exception of air vacuums.

#### 3.4 Constraints Associated with Low Ambient Air Temperatures

The coal mining constraints associated with low external ambient air temperatures for surface works are essentially the same as those for any other Arctic operation. Vehicles utilized for hauling wet coal require some means of preventing the coal from freezing to the truck bed. Covering the bed with anti-freeze has been done, and another technique employed is to heat the bed of the truck with vehicle exhaust.

In the Arctic, even in areas with low snowfall, coal storage areas are bound to have snow. When the snow melts, it adds water to the coal which may freeze, particularly in the lower portions of the pile. The upper portion of the pile must be removed and the lower allowed to thaw in the summer, be re-classified, and then shipped.

Appropriate measures for preventing permafrost degradation under surface structures need to be taken, as well as measures for insuring vehicle operation. The latter may include providing heated warm-up sheds as well as low temperature lubrication. Soviet practice appears to include the utilization of thermo-pane windows, insulation, and double heaters in the vehicle cabs. Low winter temperatures increase the failure rate of rippers many fold in surface mines.

#### 3.5 Coal Washing

Frozen water and low air temperatures make wet coal washing impossible. The Norwegian Store Norske Spitsbergen Kulkompani A/S utilizes an air washing



plant at its mines in Longyearbyen, Svalbard. This plant separates coal from rock with a rising air current; poorly sorted coal is recycled. In addition, limited hand picking is utilized at the mine opening and special magnetic devices are used to remove metal objects from the coal entering the washing plant. A limited amount of coal is washed by water during the summer months at the Usibelli Mine, at Healy, Alaska. The Norwegian Kings Bay Kulkompani A/S built a water washing plant for summer time operation at their mine in Ny Aalesund, Svalbard. However, the plant was not operated for very long due to a catastrophe at the mine.

The literature consulted on the Soviet Arctic did not indicate that coal washing is practiced. There are references to coal beneficiation installations in Vorkuta, but the sources provide few details.

Conceptually, a water washing plant for winter operation in the Arctic is possible. The plant would need to be heated, and the coal dried after washing in order to prevent freezing in the coal storage piles. The Norwegian Store Norske Spitsbergen Kulkompani A/S may perhaps be planning such an installation at its proposed coal mine in Svea, Svalbard. However, no detailed studies of either a technical or economic nature were found regarding this possibility.

The trade-off between the cost of winter coal washing and transportation without washing appear to favour the latter as far as the Soviets are concerned, and the former as far as the Norwegians are concerned. ( See p. 50) A trade-off study on this problem for northwest Alaska would appear appropriate.

#### 4.0 CONSTRAINTS RELATED TO REMOTENESS

##### 4.1 Small Scale Local Mining

Low temperatures and remoteness are often cited as the major constraints on any type of operation in the North. While low temperatures can be

measured, remoteness exists basically in terms of transportation costs, locally available resources, and labor problems. These in turn are in large part a reflection of the objectives of the enterprise and the technology employed. A coal mine in the Arctic employing solely locally available resources including labor, and supplying a local market is not, therefore, remote. A mine which relies on external resources and ships to a distant market is, on the other hand, remote. Both types exist in the Arctic.

Qutdligssat in Greenland was a wet, underground coal mine employing relatively simple technology and native labor. It produced house heating coal for the settlements in Greenland. Supervisory personnel from Scotland were engaged as was a British consultant firm, under the overall management of an engineer in Copenhagen. The principal difficulties encountered were fires in the coal storage area caused by lack of safety consciousness on the part of some employees and underground drainage problems. The Danish government closed both the mine and the associated settlement in the early 1970's arguing that oil could be imported at less cost than local coal could be mined. Subsequent unanticipated increases in petroleum costs may, in retrospect, have made the coal mine more cost effective than it appeared at the time.

Small scale coal production for thermal uses has been undertaken in Yakutia, in the Lena Basin. According to the descriptive material available, these mines employ (or employed in the last decade) rather simple mining techniques and were justified on the basis of the high cost of importing fuel for small settlements.

The coal mine at Carmacks, Y.T., utilizes primarily native labor and relatively unsophisticated techniques, to produce coal for the concentrate

dryer at the Anvil Mine, 100 miles away on the backhaul for concentrate trucks. Immediate supply needs are evidently satisfied from available stores in Whitehorse, Y.T. although special inventory needs must come from southern Canada or the United States.

The Usibelli operation at Healy employs sophisticated surface equipment and appears able to obtain needed supplies from Fairbanks or Seattle without undue difficulty. This mine enjoys the advantage of utilizing an infrastructure (Alaska Railroad and Parks Highway and other services) whose costs are not borne by the mining company and also a secure market in supplying interior Alaska power plants.

In all of these cases, labor turnover appears not to be an overly serious problem. Some of the mines have the difficulty of high absentee rates among local employees. One solution to this difficulty has been to have large numbers of individuals on call able to fill in for someone who is absent.

The small coal mine, relying in large part on local labor, an available infrastructure, relatively simple mining technology, and a local market is still a characteristic of the North. The salient requirements for such an operation include:

- a secure, local market, in which the locally produced coal will be preferred either for economic or political reasons.
- an adequate and already available infrastructure.
- a reasonably stable local labor force.
- a salary or wage arrangement suitable to local conditions (e.g., in some cases an hourly rather than bonus rate of pay).
- a geologic situation which creates safe working conditions and is suitable to unsophisticated mining methods (e.g., low gas or no gas seams close to the surface, stable roofs, no need for coal washing, simple ventilation, low probabilities of rock burst, little or no water problem, etc.).

Whether or not these conditions may exist in Northwest Alaska is beyond the purvue of this study. They may be partially fulfilled in Northwest Alaska near the larger villages, where infrastructure might consist of a few miles of road and where a market might exist were the coal produced at a low cost.

#### 4.2 Large Scale Mining for Export

The main function of the coal mines in Svalbard and the Pechora Basin is the long distance export of coal for thermal or metallurgical purposes. The Pechora mines have an annual production in excess of 20,000,000 tons per year.

These mines are charged with most of the infrastructure costs associated with the development of transportation, surface facilities, worker settlements, safety, medical care, etc. The Soviet mines on Svalbard even print their own money. This circumstance is vastly different from that in more developed areas of the world where government organizations and not the mining operations are charged with the costs of maintaining settlements, human welfare, and a significant portion of building and maintaining an infrastructure.

Development and operation of these mines have been justified for political and strategic reasons. In addition, however, the argument is also made that in spite of higher costs due to remoteness, they remain competitive economically with alterative sources of supply. The economic attractiveness in turn is based upon superior coal and/or low real extraction costs due to favorable geology.

#### 4.3 Worker Morale

Both the Soviets and the Norwegians pay a premium to their coal miners in the North. This probably gives these miners an average wage rate 50 to 100% higher than in more developed areas. In addition, both appear to have a large labor turnover at the end of each working season. Evidently

the majority of miners leave after two years of work. The limited literature available is not adequate to determine whether or not this turnover has a serious effect on worker safety. The literature available on morale, absenteeism, alcoholism, and other symptoms of social or personal disorder due to employment in the remote Arctic is inadequate. The MIREL team that visited Svalbard found no evidence of any serious morale problems among the Norwegian miners there. No evidence regarding the Soviet miners has been found; evidently worker morale likewise is not a great problem with them.

On this point, the reader should be cautioned that a settlement in the north which is closed to much outside contact during a large portion of the year may have fewer social problems than one which is open. At least, this viewpoint was expressed by several Norwegians in Longyearbyen, Svalbard. With the opening of the new airport in Longyearbyen, which will permit air travel year around, one might anticipate an increase in worker morale problems.

#### 4.4 Productivity

While again no hard data are available, there would appear to be difficulties in training new workers especially for underground operations with a 100% turnover every two years. Also, there are indications that productivity declines during the onset of the summer vacation period and remains significantly lower in summer than in winter. Soviet practice appears to be to employ miners in the Arctic already experienced in other coal mines. This reduces on-site training time. High productivity resulting from mechanization can contribute substantially to the competitiveness of Arctic coal. This seems to be the approach taken by the Soviet coal mines in the Pechora Basin.

The social climate that would prevail in the development of northwestern Alaska coal would be significantly different from that on Svalbard or in

northern Eurasia, so that comparisons probably cannot be carried very far. Metal mines in the Yukon Territory appear to have significantly higher labor turnover rates than coal mines in Svalbard, the Soviet North, Healy and Carmacks. Large scale coal mining in northwest Alaska may have to develop a labor system which accepts either high labor turnover or frequent absenteeism or perhaps both. If a stable labor force is desired, then the factors involved should be clearly analyzed in advance.

#### 4.5 Supplies, Spare Parts Inventory

The mining situations studied are so different from one another that determining the additional requirements of an Arctic location as compared to a location in a developed region is difficult. The Soviet mines which are supplied by sea during the summer months carry a full year's supply of most items. There are no quantitative data on the Pechora basin supply pattern, but the Soviet custom is to maintain large supply inventories and to conduct major repair work at the mine site. Likewise both the Norwegians at Svalbard and the Alaskan mine at Healy maintain mechanics and a significant spare parts inventory for the repair of surface transport equipment.

For northwest Alaska, with its short shipping season, one would anticipate that most bulk cargo would need to be brought in during the summer. Storage facilities adequate for a year's bulk supplies would therefore be necessary. Standardization of equipment, including surface vehicles (the Norwegians on Svalbard use primarily Volkswagens), would ease the supply problem. In Alaska, however, air cargo service is available from Fairbanks to Anchorage. Neither the Norwegian nor the Soviet coal mines appear to rely on this mode of transportation to any significant degree. In Alaska, however, this mode is more traditional and the capabilities much greater.

#### 5.0 ENVIRONMENTAL PROTECTION

The question of environmental protection was not part of the study contract.

Information on this subject in the Soviet literature on coal mining is scarce. The Norwegians have recently begun enforcing a stringent environmental protection code for Svalbard which does not, however, appear as yet to have had a significant impact on coal mining operations.

Environmental degradation associated with Svalbard coal mining appears largely limited to:

- an old burning gob pile near Barentsburg;
- old wooden structures and mining timbers scattered about mined-out areas;
- some difficulties in the disposal of settlement trash.

Interestingly, the literature searched contained no reference to acid mine water drainage problems in the Soviet Arctic or in Svalbard. No acid mine water drainage was observed on Svalbard. While not studied, no water pollution problem associated with either the Russian or Norwegian coal mines was observed.

Surface collapse (subsidence) is not referenced as a problem in the literature. There is no evidence of subsidence on Svalbard. Underground mines in permafrost areas are not likely to collapse very quickly due to the frozen nature of the rock. A simple procedure for maintaining unused mine excavations in their original condition is to fill them with water which then freezes back. This happened in the old Swedish mine workings at Svea, where a mine fire in the late 1920's was suppressed with water. Subsequently the mines were closed. When the mine was opened again in the early 1970's, the frozen water was still in the tunnels, and according to verbal comments, the excavations were in their original form. The rock temperature was significantly higher than normal, due evidently to retained heat from the old fire and possibly to heat given off by the water during freezing. This same phenomenon of water freezing in mine openings is well known in old placer drift mines in Alaska, and in the Elsa-Keno area of the Yukon Territory.

The environmental effect of surface mining at Healy and, but to a much smaller degree, at Carmacks, is best studied by observation. The degree of damage certainly appears to be quite limited and, in the opinion of the research team, not to have any significant long-term effects. Although impossible to return the pits to the original contour at Healy, fertilizing and seeding have been successful in producing a stable, pleasing environment.

Environmental codes for coal mining in Northwest Alaska should take into consideration the behavior of the frozen ground, which could easily be an advantage as far as preventing long-term, environmental degradation. Although surface melting of ground ice may result in gullying, at least until the ice has all melted, subsidence due to underground workings can be minimized. In this connection, it should be noted that areas overlying old underground placer mines in Alaska often show subsidence. This could have been avoided if the drifts had been flooded.

The effect of large-scale surface coal mining in northwest Alaska would, of necessity, have to be the subject of a special study. The available Eurasian literature does not seem to provide much guidance. Conversations with individuals on this matter suggest certain somewhat obvious conclusions: surface mining will require the least labor and material input and be the most cost-effective mining technique, but the one which will cause the most environmental change. The damage would involve primarily the destruction of the surface vegetation and changes in the surficial configuration of the ground; acid water drainage will probably not be a factor in Alaska.

Underground mining would probably cause the least environmental changes. It has the advantage in the Arctic that surface collapse can be prevented or minimized quite easily, and that working conditions may be from a temperature standpoint more comfortable. However, underground mining is more expensive.



Future study of potential coal mining in northwest Alaska should not preclude underground mining. The trade-off between underground and surface mining should include environmental parameters. It is also probable that the first coal mine in Northwest Alaska will be a small one to provide fuel for a small village. An underground mine would obviate the operation of an open pit during the winter or the stockpiling of coal mined during a summer open pit operation. Studies should also include the utilization of low temperatures and frozen water in maintaining the natural environment. In addition, environmental protection requirements developed elsewhere should be carefully reviewed before being applied to Northwest Alaska, because in some cases they may not be serious problems in the Arctic, e.g., acid mine water drainage and surface collapse, while other requirements may need more consideration (melting ground ice, etc.).

#### 6.0 FACTORS COMMON TO THE MAJOR ARCTIC COAL MINES STUDIED

The major mining areas studied include the Vorkuta-Pechora Basin, the basins of Yakutia, and the Norwegian and Soviet mines on Vest Spitsbergen, Svalbard. Each of these operations has the following common characteristics.

- Each utilizes what is essentially "free" land. The Soviets are paying some fees for leasing mining lands, but these do not appear to be a high cost item. The Norwegian claims are extensive and do not involve significant financial expenditures. In the USSR, land is owned by the government and does not represent a financial cost item.
- Each is directly or indirectly supported by its government. Whether or not these mines are operating at an "economic" loss or gain is to a degree irrelevant, since they all rely on government financial support. Each argues that its operation is in fact cost-effective and profitable, and developing countervailing arguments would seem to be futile.
- Each has a major long-term, secure market for its product, one essentially guaranteed.
- Viewed from an American viewpoint, each also has a political justification. The Norwegian mines contribute substantially to economic development in Northern Norway, constitute the only significant coal mining in Norway, and establish and maintain a visible and politically significant presence in Svalbard. The same can be said for the Soviet mines on Svalbard. In addition, there would appear to be no significant

domestic alternative to them as suppliers of coal to Murmansk and Archangel. The Pechora basin produces a needed, high grade metallurgical coal for use in northwestern Russia and historically has been a major source of coal for this region. Its major competitor is coal from the Donbas, a basin with a large local market and one which is characterized by high cost deep underground mining. The Yakut mines (Lena Basin) are only now coming under significant development, primarily for a local market.

- The alternative fuel for thermal uses in each case would probably be petroleum. The alternative sources for metallurgical coals may in fact be more expensive and politically less reliable.
- Each is located in a permafrost region. However, many of the Soviet mines in Pechora (and one in Svalbard) have penetrated below the permafrost.
- Each is situated in a large coal basin with very substantial and available long range reserves.
- Each has been the object of significant, long-term capital investment in surface facilities, an investment which appears to be growing.
- Each has a cadre of engineers committed to the particular mining operation on a career basis.
- Each utilizes external consulting type organizations for major engineering design work.
- Each has made substantial investments in recreational and other service facilities for its employees.
- Each employs mining techniques and equipment originally developed outside of the Arctic.
- Each operates in a financial environment that involves the payment of extremely low personal income taxes.
- None has had to be concerned about the effect of its operations on an indigenous population.

The implications for large-scale coal development in northwest Alaska, based on these Eurasian experiences, are:

- a long term financial, economic, political and market commitment is necessary for successful development.
- a long term commitment of key engineering personnel may be highly desirable (if not crucial).

- adapting mining technologies, equipments, etc., from the non-Arctic regions is feasible. However, the effects of permafrost must be considered; techniques and practices cannot automatically be transferred.
- the influence of American political and economic values will be extremely significant.
- some form of government support may prove necessary.

The last point should be approached without bias. An operation involving people in a remote location is one that requires human services and an infrastructure. In developed areas, such services are normally provided by government and by non-mining sectors of the economy. It would seem only reasonable, therefore, that a remote mining operation receive some form of government assistance if it is required to bear an unusually large amount of the costs associated with providing government services and infrastructure.

Whether or not the United States of the State of Alaska has a long-term political or strategic need for the development of northwestern Alaskan coal is another question. The American and Alaskan "presence" in this area seems unquestioned, and it would be hard to foresee any strategic need in this area for coal mining. The national need for coal or its by-products would appear to be the overriding concern as far as the Federal government is concerned. Secondly, the Federal government may have to consider the long-range needs for coal in the Pacific Basin.

From the viewpoint of the State of Alaska, one would have to look not only at the long term economic needs of the State, but also at the needs and desires of the indigenous, native population.

## 7.0 CONCLUSIONS:

Based on the literature surveyed and the field trips conducted, the following conclusions can be reached regarding constraints on coal mining in northwest Alaska based on Eurasian Arctic experience.

1. Mine safety codes applied to Arctic Alaskan coal mining should take into account the effects of:

- (a) Ventilation requirements on:

- mine air temperature and its potential short and long range effects on ground stability and roof support;
- wind chill along working faces;
- dust generation under low temperature and low humidity conditions;
- roof support in the first 1,000 meters from the opening;
- deformation of openings;
- oxidation of rock and coal and associated temperature increases.

- (b) Dust suppression requirements involving water on:

- water supply problems in essentially dry mines at below freezing temperatures;
- coal storage and transportation problems of water soaked coal;
- effects on personnel and equipment of utilizing large amounts of water in below freezing temperatures.

2. Environmental protection requirements related to Arctic coal mining should consider:

- the utilization of permafrost conditions for the prevention of surface subsidence;
- the general absence of moving water which may inhibit problems associated with acid mine water drainage (coupled with the fact that the coals are low-sulfur).
- the use of water as permanent roof supports after mining operations cease.

3. Future research efforts may profitably focus on:
  - the unsolved problem of suppressing dust caused by high speed mining equipment in essentially waterless, frozen, low humidity underground mines;
  - the cost associated with cooling incoming mine air under summer conditions compared to the benefits in reduced roof support requirements;
  - the development of vacuum systems for dust removal in preference to water sprays;
  - the costs and benefits associated with the development of coal washing plants designed to operate in low temperature environments;
  - the necessity of making long-range commitments of reserves.
4. Future analyses of the potential for development of large-scale coal mining in northwest Alaska should include consideration of:
  - the trade-offs in terms of environmental impact of surface and underground mining;
  - the infrastructure and service cost burden that ought appropriately to be borne by government;
  - the social, political and economic trade-offs between a permanent and a transitory labor force and engineering staff;
  - the economic, political, and social impact of a commitment to coal mining that could stretch over half a century or more.
5. Future technical studies involving the development of mining plans should consider:
  - the benefits of maintaining a rock temperature of  $-10^{\circ}\text{C}$  ( $14^{\circ}\text{F}$ ) as a design objective;
  - the differences between the short term and long term effects of altering the temperature of the surrounding rocks and the coal seams;
  - the use of low temperatures to maintain roof stability;
  - the effects of air cargo transport on logistics, supply, and maintenance requirements;

- utilizing underground and surface equipments which have common component parts in order to reduce the range of supply and maintenance needs;
- the significant increase in dust generation associated with operating under low temperature and low humidity conditions;
- techniques of dust suppression other than the employment of water;
- possible long term deformation in permanent shafts and other openings due to thermal conductivity;
- effect of ventilation requirements on rock temperatures, wind chill, spreading coal dust, and oxidation;
- trade-off between the costs of coal washing at the mine versus transportation costs to market.

6. National decision making regarding the large-scale development of northwest Alaskan coal should include the following factors:

- the USSR and Norway have been mining coal in the Arctic on a large scale for forty years so that there may be a basis here for a significant interchange of knowledge and information.
- coal mining under the conditions found in northwest Alaska is fully feasible on technical grounds;
- both the short and long term environmental impact of underground mining on a large scale may be significantly less than that of surface mining under Arctic conditions;
- the national perspective on Alaskan Arctic coal development should extend fifty years into the future and should involve a long rather than short term commitment;
- transferring concepts and attitudes and regulations developed outside of the Arctic to Arctic coal mining may be both deceiving and counter-productive.

#### 8.0 RECOMMENDATION.

Northwestern Alaskan coal reserves are a significant national and Alaskan resource. Their potential should be the object of study and analysis focusing on both technical and non-technical areas. Studies might focus most profitably on the technical problems associated with dust control and suppression, ventilation,

the environmental impact of surface mining, and the applicability of American mine safety, environmental, lease, and labor protection laws on Arctic coal mining. Modification of these laws and regulations may prove necessary to satisfy Arctic mining conditions.

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APPENDIX A

INFORMATION ON SVALBARD AND GREENLAND COAL MINING

## APPENDIX A

### INFORMATION ON SVALBARD AND GREENLAND COAL MINING

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## 1.0 SVALBARD COAL MINING

### 1.1 General

The Svalbard Archipelago lies due north of Norway between latitudes  $76^{\circ}$  and  $80^{\circ}$  north. It has a total area somewhat in excess of 60,000 square kilometers divided among several islands, the largest of which is Vest Spitsbergen, with an ice-free western coast during a long period of the year. The pack ice in summer lies at about  $80^{\circ}$ N latitude along the coast of Vest Spitsbergen, whereas it reaches close to the northern shore of Alaska at  $71^{\circ}$ N during this same period.

Vest Spitsbergen consists in large part of a sedimentary syncline, with extensive coal deposits of Upper Cretaceous and Tertiary age. The main seams mined are of Tertiary age and consist of both energy and metallurgical grade coals.

Export coal mining began in the Isfjord area (about  $78^{\circ}$ N) in the latter part of the nineteenth century, with the first large scale mine developed in the Adventfjord area, a tributary fjord to Isfjord. This mine was established by an American, Mr. John Longyear, and the settlement has borne his name, Longyearbyen, ever since.

Prior to the early 1920s, no nation had sovereignty over Svalbard (often called Spitsbergen), but in a series of treaties that were ratified after World War I sovereignty was conferred upon Norway with certain major restrictions. These included restrictions on taxation, the maintenance of the rights of the signatory powers to conduct mineral exploration in the Archipelago, and strategic military neutralization. The Norwegians purchased Mr. Longyear's operation and have mined coal in Isfjord since World War I with an interruption during World War II. In

the early thirties, they also purchased a Swedish mining operation in Svea, located on Van Mijenfjord about 45 km southeast of Longyearbyen.

In the early 1930s, the Russians purchased Dutch mining operations at the towns of Grumant and Barentsburg located on Grønfjord, a tributary of Isfjord lying approximately 40 kilometers west-southwest of Longyearbyen. Later they acquired Pyramiden, a mine located on Billefjord, also a tributary of Isfjord, and situated about 50 km northeast of Longyearbyen. Russian mining has been continuous ever since except for the period of World War II. It is under the control of Arktik Ugol'.

The Grumant mine has been shut down, but both the Barentsburg and Pyramiden mines continue operations, producing together about 400,000 tons of unwashed coal per year which is shipped to Murmansk and Archangel for thermal power generation.

The Norwegian-owned Svea mine was opened after World War II, then closed down in the late 1940s. In recent years, exploration has revealed an extremely large coal seam in this area, and current plans are to develop this resource with an export target of one million tons of coal per year.

Current Norwegian production is approximately 400,000 tons per year, most of which is shipped to Norway as metallurgical grade coal for use in the ferro-silicon industry. Svalbard coal fulfilled approximately half of Norway's coal requirements in the early 1970s.

The Norwegian mines contribute substantially to the economic well-being of Northern Norway, a region largely devastated by World War II, and one in which the Norwegian government has pursued a policy of economic development focused on mineral resource utilization, the development of

an iron and steel complex, and subsidization of fishing and some forms of agriculture.

The Norwegian mines are owned and operated by a private company, the Store Norske Spitsbergen Kulkompani A/S (SNSK), with financial support by the Norwegian government. The Norwegian Kings Bay Kul Compani has also developed coal mines at Ny Aalesund on Kongsfjord about 79°N latitude. This settlement was known for years as the northernmost town on earth. An unfortunate mine fire in the early 1960s caused this operation to cease and led to the fall of the Norwegian government at the time.

Svalbard has tundra vegetation and an Arctic climate, characterized by extreme low winter temperatures of almost -50°C, a mean January temperature of -10.3°C and a mean July temperature of about +5 to +9°C. The western coastal area of Vest Spitsbergen, where the coal mining occurs, is a sharply dissected, sedimentary plateau, with the mountains appearing as spires (hence the name Spitsbergen), steep slopes, and extensive talus cones. The area has been (and in places still is) extensively glaciated, and signs of intensive valley glaciation can be seen everywhere. The permafrost in the mining areas appears to be dry permafrost with an active layer about 1 m thick and a total thickness of 300 m.

## 1.2 Longyearbyen

Longyearbyen is located at 78°15'N, 15°40'E, at the mouth of Adventdal near the eastern edge of Isfjorden. The settlement is located in Longyeardalen, which extends from north to south, and intersects with the east west trending Adventdal, both of which are glaciated valleys. Longyeardalen

is approximately 9 km long and 4 km wide with an active glacier and terminal moraine at its head. The valley sides consist of high, steep bluffs covered by alluvial cones and screes along their lower margins. The tops are plateaus with an elevation of approximately 1,000 m. The town consists basically of four sections: the old town, largely destroyed during World War II and subsequently rebuilt, with the church, government offices, maintenance sheds, storehouses, and coal loading facilities situated close to tidewater. The three other settlements are scattered up Longyeardalen and form residential communities for the approximately 2,000 inhabitants.

The coal seams are located approximately 300 m above the valley floor. Norwegian practice has been to mine a seam between two intersecting valleys and then to abandon the mine. At present, only one seam is being mined in Longyeardalen.

The same system has been applied along the Adventdalen where one mine in 1974 was under operation and another under development. The Adventdal mines are connected to Longyearbyen by a system of roads and an aerial tramway used to transport coal.

### 1.3 Svea

Svea lies at  $77^{\circ}55'N$ ,  $16^{\circ}40'E$  at the head of Van Mijenfjord which at its mouth is largely blocked by Axeløya. The head of the fjord is formed by two bays into which flow several glaciers. The area is heavily glaciated and shows signs of very recent glacial advance and retreat. The site of the area under development is approximately 10 km long by 5 km wide and consists of a coastal lowland (in part a pitted outwash plain)

about 1 km wide crossed by alluvial fans. Maximum elevations of about 1,000 m are reached within 4,000 meters of the coastline. Rock outcrops of sandstone form bluffs, while fractured shale forms steep, alluvial fans and screes showing signs of recent flooding, land slip and gullying. The coastal areas and fans contain large amounts of clay which also characterize the muddy coastal waters. The active permafrost layer is about 1.5 m deep with the permafrost having a horizontal depth into the hillsides and a vertical depth from the surface of approximately 300 m. Vegetation is very sparse, the soils appear well drained, and there are few signs in the lowland of ice-rich permafrost.

In 1974, the mine site was under construction with plans for developing a coal production rate of up to one million tons per year. A settlement of several hundred people is planned, with the objective of maintaining a stable family oriented highly trained labor force capable of operating high speed, modern mining machinery.

#### 1.4 Barentsburg

Barentsburg, located at 78°5'N, 14°10'E, has a population of 1,100 which includes 281 women. The town, situated on the east side of Grønfjord, is highly compact and has grown up a slope. In appearance it consists of three sections. The lowest section, at dock side, has older buildings and is covered with a patina of coal dust. Above it is a newer section with more modern Soviet architecture, and above it is a very recent development containing large, brick buildings on piling to prevent permafrost degradation.

The town supports 18 cows, about 200 pigs, 1,000 chickens, and one



horse, which is used for hauling small loads around town. There are few (if any) private vehicles and some heavy trucks. The settlement is sufficiently compact that all points are located at convenient walking distance from each other.

The coal seams are deep underground in this area and the present mines are under the permafrost. Methane content is extremely high (over 20 m<sup>3</sup>/ton) and therefore the mine is considered dangerous. Two seams are being mined: they are separated by about 20 m of rock, mostly sandstone. A water supply system is used in the mine for dust suppression and fire control. The pipes are insulated and heated by an electrical cable to keep water from freezing.

Coal has been mined here since the early 1930s, and with recent leasing of coal-bearing areas adjacent to the mine, production will continue into the future. Annual production is approximately 250,000 tons per year.

### 1.5 Pyramiden

Pyramiden is located at 78°40'N, 16°25'E at the northwestern head of Billefjord and on the northern shore of Mimerdalen. The settlement, with 750 inhabitants, has a port on Billefjord, but is concentrated at the foot of the 934 m high mountain Pyramiden along a coastal plain adjacent to Mimerdalen. Directly to the east of the town, across Billefjorden one can see the spectacular terminus of the Nordenskiöld glacier. The port area is connected to the town by a gravel road and to the mine opening by a railroad which is covered with wood. The town itself is more dispersed than Barentsburg, with smaller buildings, and in general is quite picturesque.

The newer buildings are large brick structures on pilings. The settlement has an extensive above ground network of wood covered utilidoors which also serve as sidewalks (a very sensible arrangement).

The mine opening is about half-way up Mount Pyramiden and is connected to the coastal plain by a cable car and tram for personnel, supplies and coal. Mining is conducted completely within permafrost. Reversible ventilation fans and heaters for mine air are located in a large, two story concrete structure located on the northwest slope of Mount Pyramiden at an elevation of approximately 600 m.

The ventilation system heats inflow air when the ambient air temperature reaches  $-20^{\circ}\text{C}$ . This system ensures that incoming air will reach the temperature of the surrounding rock ( $-4^{\circ}\text{C}$ ) within one kilometer after entering the mine. The mine is equipped with a circulating water supply system employed for fire prevention and dust suppression. Water is heated to a temperature of  $+35^{\circ}\text{C}$  before entering the system. At this initial temperature, the water will not freeze when used in dust suppressing sprinklers. At a lower initial temperature, such freezing is possible.

Sprinklers, with a lanolin type solution (called DB) added, are used at the main working faces and at the transfer point from the working face to the main haulage way. This additive may be the chemical wetting agent described in Appendix 3, p. 19, of the Coal Industry of the USSR, Part 2, a study by the U.K. National Coal Board, London, 1957 (available from Colorado School of Mines, TN808/R9G7). Another system of dust suppression is used at the point where the main conveyor belt system joins the cable tram system. The coal is dumped from the conveyors (or from underground rail cars) into a huge storage hopper, from which it is loaded

onto the cable trams. The dump point is covered and is under vacuum to remove the coal dust. The worker controlling the dumping system is situated in a metal and glass covered booth with its own exhaust system.

Mine production appears to be about 160,000 tons per year of uncleaned coal.

#### 1.6 Ny Aalesund

Ny Aalesund is located at 78°55'N, 11°58'E on a raised beach stretching along the southwest shore of Kongsfjorden. The fjord contains drift ice in the summer which comes from glaciers at its head. The mines here were deep underground and very gaseous. The settlement consists of two parts, a port area with the unused water coal washing plant, pier and loading facilities, and a washing plant (unused), and a new and very attractive town with predominately single family residences, located to the southeast. (This is within walking distance of the airship tower used to launch Nobile's dirigible on his trans-polar flight.) To the northwest of the town, on a second raised beach, is situated an ESRO tracking station (scheduled to close down the summer of 1974). This station is a companion to the one located near Fairbanks, Alaska. To the south of the town, the Norwegians maintain a facility for scientific studies related to glaciology and geology.

The total population which was supposed to winter over in Ny Aalesund during 1974-1975 was reported to be only seven persons. The surface area near the mines shows extensive debris, primarily old wooden structures and timbers, and railroad ties, left from the mining period. Visually, no other environmental damage due to coal mining or to the mine

explosion in 1962 could be detected.

### 1.7 Sources

The basic written materials used in preparing this section on Spitsbergen are:

Hoel, Adolf, Svalbard Svalbards historie 1596-1965, Sverre Kildahls Boktrykkeri, Oslo, 1966, three volumes, which relies heavily on Norwegian government reports regarding coal mining in Svalbard.

Government of Norway, Industridepartmentet, Energiforsyning i Norge in fremtiden, St. meld. nr. 100 (1973-74).

Various publications from the Norwegian Institute of Technology in Trondheim.

Various unpublished documents by the Store Norske Spitsbergen Kulkompani A/S.

The Spitsbergen Mines, A summary translation of Shakty na Shpitsbergene (NEDRA, Moscow, 1964), translated at MIRL.

In addition, extensive interviews were conducted in Norway and Svalbard during the summer of 1974. Individuals consulted include representatives of the Norwegian Ministry of Industry, Department of Justice, Svalbard Administration, Store Norske Spitsbergen Kulkompani A/S, Norwegian Institute of Technology, Arktik Ugol', and others. The mine engineers, foremen and workers in Longyearbyen, Svea, Barentsburg, and Pyramiden were extremely courteous, kind, and helpful, and answered questions without reservation.

For additional information on the literature consulted see Preliminary Report, Constraints on the Development of Coal Mining in Arctic Alaska, MIRL, June, 1974.

2.0 REPORT ON A VISIT TO VEST SPITSBERGEN SVALBARD COAL MINES,  
AUGUST, 1974

2.1 General

The information presented here results from a trip to Scandinavia and Svalbard in the period 11 July to 23 August, 1974, by Professors Chris Lambert, Jr., Donald F. Lynch and Nils I. Johansen of the Mineral Industry Research Laboratory, University of Alaska. Prof. Johansen obtained information within Norway, coordinated the agenda and acted as an interpreter. Prof. Lynch obtained information within Norway and Denmark and visited Svalbard as interpreter. Prof. Lambert, leader of the study team, collected information in Norway and Svalbard and assessed the technical aspects of the information obtained.

Mining and government offices were visited in Copenhagen, Bergen, Trondheim, Tromsø and Longyearbyen. Mines visited at Svalbard were the Norwegian operations by Store Norske Spitsbergen Kulkompani A/S in Longyeardalen and Svea, and the Russian operations by Arktik Ugol' at Barentsburg and Pyramiden. The abandoned operations at Ny Aalesund (Kings Bay Kul Company A/S) and the Russian works at Grumantbyen were also observed.

Representatives of the Norwegian Ministry of Industry, Store Norske Spitsbergen Kulkompani A/S, Arktik Ugol', the Norwegian Institute of Technology, the Norwegian Foreign Ministry, Sysselmann and Bergmester (the Governor and the Norwegian Government Mining Engineer at Svalbard) A/S Norsk Polar Navigasjon, and others were all extremely helpful and courteous in arranging the trip. Engineers of the Store Norske Spitsbergen Kulkompani were extremely hospitable and kind not only in answering numerous questions, but also in providing transportation, accommodations

and recreation during the three week stay on Svalbard.

Data on the closed Danish Mine at Qutdligssat, Disko Island, Greenland, were collected from the Greenland Technical Organization and the Greenland Geological Survey in Copenhagen.

In the Longyearbyen area, located on Adventfjorden, Vest Spitsbergen, the team visited the surface area of Mine #3 and the underground works of Mine #6, both of which are in production, and Mine #7 which is under development. The Svea Mine in the Braganzavagen area was also visited. This mine is under exploration and development and mining is expected to take place in the near future. Visits were also made to the two operating Russian mines, Barentsburg on Grönfjorden and Pyramiden on Billefjorden.

As was to be expected, each mine has its own geologic and engineering peculiarities which have led to significant differences in mining plans, mining techniques and equipment. In general, retreat long-wall mining is most commonly practiced. The Greenland mine at Qutdligssat on the north-east coast of Disko Island evidently lay in the thaw bowl of Vaigat Fjord and therefore had fewer permafrost problems. The Barentsburg mine is working two seams several hundred meters below the permafrost table. The active Norwegian mines and the Russian mine at Pyramiden are all within the permafrost, whereas one of the two exploratory headings for the Norwegian operated Svea mine has penetrated below the permafrost. While the differences between the mines are significant, there are some common features which may be broadly applicable to the problems of coal mining in the Arctic.

## 2.2 Mine Roof Stability

Roof stability is better in permafrost than in thawed ground. This could be seen dramatically in the case of Mine #7 in Adventdalen when one passed from the thawed portion of the drift into the permanently frozen area. Roof support is more effective and less costly where the rock remains frozen. It is the opinion of Russian engineers and operators, substantiated by observation, that in recently opened mines mine air will acquire the temperature of the permafrost at a distance of approximately 1,000 m or less into a mine opening. In the main entry of Mine #7 the moisture froze at 600 m, and at 900 m the rock was dry and frozen. When the air temperature is above  $-20^{\circ}\text{C}$ , experience has indicated that the distance is somewhat greater. The critical problem area is thus roof support near the mine entry. Thawing is, however, only part of the problem; the entry of warm, moist air in summer permits water to penetrate into rock fractures and this moisture causes significant and cumulative spalling. Further, thawing can occur along jointing planes, causing sudden and massive rock falls. Extensive props or other support systems are necessary in the mine entry, whereas elsewhere roof bolting and nets (and in some cases nothing at all) is sufficient. Below the permafrost, roof support problems are again encountered as well as sub-permafrost water in sufficient quantities to require drainage. Summer thawing in the entry, followed by winter freezing may lead to a slow inward movement of the area thawed in the summer.

## 2.3 Wind Chill Ventilation

Ventilation requirements are in part a function of gas conditions.

In the low gas Norwegian mines, an air velocity of less than 0.65 m/sec is maintained so that dust is not blown about. Larger amounts of air are required in the highly gaseous Barentsburg mine, but velocity is still kept low by using large openings. In none of the mines did wind chill seem perceptible. Pyramiden had air velocity 1.25 - 1.14 m/sec with a permissible maximum of 4 m/sec.

The Norwegian mines encounter a methane gas content of less than 1 m<sup>3</sup> per ton in all locations. Consequently, air volumes are minimal. As an example, Mine #7 draws approximately 300 m<sup>3</sup>/min through the last open cross cut in the development heading. The heading is in a 2 m thick coal seam with widths of approximately 5 m. The Russian mine at Barentsburg is highly gaseous, with a methane content of 17.5 m<sup>3</sup>/ton. In this case approximately 500 m<sup>3</sup>/min of air entered the longwall face. Here again the wide openings in the longwall section prevented any high air velocities on blown coal dust.

#### 2.4 Control of Mine Temperature

The Russians felt that incoming air should be warmed to a temperature of -20°C when the external ambient air temperature is below -20°C. In this way, the cold air will be warmed to rock temperature within 1,000 m or less of the opening. This warming of the air is designed to improve worker comfort. No one has investigated the possibility of refrigerating the summer air to prevent thaw-induced coal spalling. The Russians commented that this would be inappropriate in Svalbard where summer temperatures are low, but might be suitable in those parts of Siberia with very high summer temperatures.



### 2.5 Ventilation and Dust Control

Rock dust is obtained from the United Kingdom by the Norwegians and from the Urals by the Russians. In the Russian mines, very stringent regulations pertain to the application of rock dust because of fire danger.

Underground air temperatures are approximately  $-4^{\circ}\text{C}$  in permafrost. With the U.S. requirements of higher air volumes together with lesser amounts of bottom or top rock taken for haulage ways, wind chill and blown dust could be a problem not found in the mines visited. Chill would be most pronounced on man trips in and out of the mine, and by men working in air courses or in the more sedentary occupations in the mines. The Russians solved this problem by dressing warmly with wool undergarments as well as wool outer garments. In addition, padded garments, footwear and headgear were common underground. Yet the Russians were still concerned with miners' comfort, and were considering conveying warm air in insulated pipe to the longwall face for personal warmth on the theory that substantial damage could not result in a working face that was advancing at the rate of 2 m per day.

### 2.6 Wind Effect on Norwegian Aerial Tramway

Coal is conveyed from Mine #6 to an aerial tramway capable of transporting 120 ton/hour. Gale wind can severely damage trams as they pass through the bents. To prevent damage and resulting spillage, the aerial tramway automatically ceases operating at wind speeds of 20 m/min or more. It is apparent that there have been very few spills since the tramway has been in operation, because any spills would be plainly visible in the arctic terrain.

## 2.7 Dust Suppression Problem

The mining systems employed at Barentsburg, Pyramiden and in the Adventdalen area did not involve the use of high speed cutting machinery in close proximity to workers. The workers were either downwind from the cutting equipment or a distance from it. In any case, the equipments utilized were not the high speed equipment employed in the U.S. mines. Future plans for Mine #7 and Svea mine envisage the employment of such equipment and the creation thereby of a dust control problem. Approaches being discussed include the use of moisture and other additives for dust suppression.

Visible dust was nowhere observed at locations where men were working. The dust created by the scraper operation in the Norwegian mines was dissipated by the time it reached working locations. However, it is highly unlikely that the observed conditions would meet U.S. specifications of 3 mg of respirable dust per m<sup>3</sup>. It was a practice at the longwall face in Russian mines to work upwind of longwall rippers or loading conveyors. The Norwegian management was concerned about the dust problem as they converted from scraper mining to more sophisticated loading methods, but as yet do not have a solution to the problem. In permafrost areas, water in the quantities common in the U.S. coal mines cannot be used to suppress dust. Not only would coal freeze underground, but would instantly convert to a solid block at the surface in the wintertime. Two practices were observed that could have merit. In Barentsburg, water up to a pressure of 200 atmospheres was injected into the auger holes. At around 120 atmospheres there was a definite break. The coal fragmented and was definitely damp without visible water. Another practice at Pyramiden was to add

water with a solution of a lanoline-like substance in limited quantities. Currently the target is to have not more than 8% total moisture in the coal. The Russian managers believe they can cope with coal with this amount of moisture under winter conditions on the surface. It is conjectural as to how successful this practice would be in meeting the specifications of U.S. coal mining law.

### 2.8 Water Supply

Mines in permafrost normally contain little water. Some melting occurs near the mine openings as does moisture condensation. Fissures may conduct water into the mine, but this does not seem to be a significant problem in Svalbard. Water does exist below the permafrost, however, and pumping has been necessary in both Svea and Barentsburg. The use of electrically heated, insulated pipes or a continually circulating water supply system is necessary to keep this water from freezing when it is pumped through the permafrost for disposal on the surface or for use in dust suppression and fire control. In general, it seems that the problem in permafrost is the difficulty of using water for dust control, while below the permafrost level there may be difficulties in removing water through the permafrost zone to the surface. No indication was found of acid mine water drainage problems.

### 2.9 Surface Construction

Little difference was observed in surface construction techniques from those practiced in northern Alaska. The active layer in lowland areas is about one meter thick, and modern structures are built above ground on pillars anchored one or more meters into the permafrost. New

roads are built on 6 foot fills to provide an exposed surface so that snow is blown off the roads and in the expectation that the permafrost will rise into the road bed and provide stability. A small, earth dam for a reservoir in Svea is also designed with the same expectation that the permafrost horizon will rise into the dam and decrease permeability. The permafrost appears to lack significant amounts of ice, i.e. dry permafrost.

#### 2.10 Environmental Considerations

The older mines, some dating back to the 1920s and long since closed, show no signs of significant surface subsidence, water pollution, or other adverse effects. Alteration of the surface consists primarily of the rock debris near the mine portals or entrances which in some ways looks like the natural talus slopes. In some cases, old mine surface structures remain and are either eye-sores or historical monuments, depending upon the viewer's attitudes. Slopes near mines affected by underground fires are colored red. Exploratory headings into the Svea coal seam produced large coal piles which have subsequently been eroded by water so that very small beaches of fine coal can be seen along the shoreline, but the water itself appears to be unaffected. The coal storage and dock areas of Barentsburg appear to have a film of coal dust, and several Russian rock piles are burning. The experience of the past suggests that with proper precautions and clean-up there is no significant environmental damage above ground from underground coal mining in Longyearbyen and Svea. The major area of future concern here may be wind blown coal dust, disposal of mine coal dust produced by high speed mining machinery, and dust from any future water washing plant.

## 2.11 Coal Cleaning

The Russian mines employ some hand-picking and coal crushing, but otherwise the coal is shipped without cleaning. SNSK installed an air powered washing plant in 1964. The plant separates rock from coal with an air flotation mechanism. In addition, limited hand picking is done at the mine mouths. The total amount of rock removed is about 10%. In the future, consideration is being given to a water washing plant at Svea. The water will probably be heated and the coal dried before being stock-piled. The Russians said they are planning an air washing plant for Pyramiden similar to that in Longyearbyen.

The Longyearbyen coal cleaning plant is of an air suspension type manufactured by Westphalia Dennendahl Groppel A.G. West Germany. Coal is crushed and segregated into three sizes: -50 mm to +18 mm, -18mm to +10mm, and -10 mm. Each size is processed differently. The coal is fed onto vibrating perforated plates 97 cm by 140 cm in dimension with 2 mm perforations. The plates are arranged on a slope so that coal flows down them. Air is forced through the perforations and the coal is agitated and kept in semi-suspension with the rock particles dropping to the bottom. The separation of the rock from the coal in this fluid bed is regulated by the height of a cutting knife across the flow of coal. The flow of air in each of the plates can be adjusted so that the rock removed from each plate is consistent with that withdrawn in total from all three plates. The rate of feed is adjusted in anticipation of the amount of rock expected in the coal from mine reports and samples. This process is not in accordance with recommendations of the manufacturer, but the foremen stated that it works much better than complicated adjustments required by

any other method. The quantity of air varies with the size of coal. The smaller size coal requires 300 m<sup>3</sup> per min through the three plates. The middle size requires 520 m<sup>3</sup> per min and the coarse size requires 830 m<sup>3</sup> per min. The efficiency of the process varies with the size of coal but is best in the middle size which goes to the ferro-silicon industry and is less efficient in the finer size which goes to coking coal and the coarser size, some of which goes to steam coal.

The Kings Bay Kul Compani A/S at Ny Aalesund built a coal washing plant just prior to the mine explosion so that the plant operated for only a short while. It was designed to operate in summer and employ water. The objective was to wash one year's production and ship it during the summer navigation season. The plant buildings and associated power plant were observed in Ny Aalesund. The plant apparently experienced difficulty crushing and screening coal to a size compatible with the washing process.

#### 2.12 Affects of Remoteness on Labor Force

Both the Russians and Norwegians provide significant financial inducements to attract a labor force. The Norwegians employed on Svalbard pay only a 4% income tax on their income and an additional 6% for welfare, which is significantly lower than income taxes in Norway, which may go anywhere from 40-90%. In addition, room and board are subsidized and vacation generous for both Russians and Norwegians. The Russians receive double the normal wage for their work and a cumulative 10% base wage bonus for every six months they remain in Svalbard, while paying the standard, low Soviet income tax. Even with these inducements, however, labor

turnover is high. SNSK employs about 145 new men each year, or about half of the total underground labor for each year. The normal time an employee remains in Longyearbyen is slightly more than two years. The Russian workers have only a two year contract, which suggests a 50% labor turnover. Norwegian labor is generally untrained and is taught mining largely on-the-job. Russian workers, on the other hand, are skilled miners from the Donbas and occasionally from the Moscow Basin. The low retention rate for the Norwegians is said in large part to be due to the shortage of family housing in Longyearbyen. SNSK is building more family housing and hopes to increase the retention rate in the future since the use of high speed (and expensive) mining machinery will require a more stable and skilled force. The Russians are making a substantial investment in new housing and social clubs in Barentsburg, but do not expect a higher retention rate due to the severity of the climate. Both mines have a marked decline in production during the summer due to extended vacations and labor turnover.

The Greenland mine at Qutdligssat employed Greenland labor which was resident in the area and had its own housing. The difficulties here involved a high absentee rate, especially during summer and during hunting season. In addition, the local labor appeared to have had little safety consciousness. The absentee rate in Longyearbyen is quite low during the winter, but appears to increase with the approach of summer. In part this is due to the relatively untrained nature of much of the labor force. The Russian mines appear to place great emphasis on mine safety and safety awareness. In both cases, the most dangerous work was said to be moving roof supports in retreat longwall mining. The Norwegians are planning to use a system of hydraulic moveable roof supports in mines to alleviate

this problem in the future. The American team was surprised to note the absence of safety shoes in the Russian mines.

### 2.13 Mining Techniques

All mining in Svalbard is some form of the retreat longwall method at the present time. However, there are considerable differences in the methods at the individual mines. All mining in the Longyearbyen area is in the permafrost. Norwegian practice at present is to refrain from mining below the 300 m thick permafrost layer.

Mine #6 in the Longyearbyen area uses a highly developed and productive scraper mining system. The coal seam is approximately 0.75 m thick. A crew of nine men will drill, shoot, timber, and load out a longwall face in a twenty-four hour period. Production averages 7.1 tons per man shift. The scraper is of a unique three sectional construction in tandem and will gather a little over two tons of coal each scraper pass which will load exactly one mine car.

A refined and modified scraper system is to be initially installed in the two meter thick coal seam in Mine #7 which is now under development with the use of Joy loaders and shuttle cars. Here the scraper will be of larger construction and will be pulled by a 110 h.p. double drum hoist. The hoist is a shop modification of a basic Russian design. Crew size will remain the same as at Mine #6, with a possible reduction by one loading operator.

Mine #7 will also use some type of plough or other longwall mining tool yet to be determined. Also, hydraulic jacks for roof supports are under investigation to cope with the higher coal seam. Many of the



innovations which are successful in Mine #7 will be applicable in the Svea Mine now under development where the coal seam reaches 5 m in thickness.

The Russian mine at Barentsburg has been in operation since the year 1932. The coal is moderately dipping rather than flat as at Longyearbyen. Mining has progressed to sufficient depths to be under the permafrost. The active mining area is under approximately 650 m of cover and about 330 m below sea level. Because of the long period of operation, the mine entrances subject to seasonal thaw have deteriorated severely. A good portion of the slope entrance has been concreted and elaborate, closely spaced timbering is maintained throughout the slope and the underground haulage connecting the belt transportation system to the underground pocket.

It is obvious that the Russian management is making a great effort in mine safety. All walkways, haulage ways, and work areas were scrupulously clean by mining standards. Safety posters of a type almost identical to those found in American mines were distributed throughout. All equipment was of permissible construction, with provisions for periodic inspections and recording of inspection results at the site. The belt haulage system and the rail haulage system were monitored and under the control of a dispatcher on the surface. In addition, methane detectors were in scattered locations throughout the mine which automatically recorded the methane content and provided for an automatic shutdown of electrical equipment in the event that methane content exceeded two percent. One percent methane was the point at which operations ceased and corrective action was taken. No figures were made available as to the frequency or severity of injuries.

Roof conditions in the unfrozen ground at 650 m depth were good. Usually minimal roof bolting was sufficient and in some cases no roof bolting was required and the top was sound.

In the longwall areas, roof jacks were used in a coal seam of less than 1 m in thickness. Much larger jacks were used, however, than in the Norwegian mines. One closely spaced row of jacks was capable of holding 200 tons per jack. There were two producing longwall faces. One was a ripper type operation in which the ripper which was jacked against the 200 m longwall face with sufficient pressure to dislodge the coal from the face without undercutting or blasting. It produced 300 tons per 24 hours. The Russian engineers were quite emphatic in describing the operation as a "plane" much like the operation of a carpenter plane. They definitely did not accept the word "plough" which describes a common German machine. The cutting instrument consists of five sets of removable, double acting cutting teeth which will cut in either direction. The top and bottom set are splayed upward and downward in such a manner to cut a face wider than the cutting instrument itself. The instrument will take a 10-15 cm of coal per cut and advance along the face at 1.5 - 2.0 m/sec.

Coal is discharged onto flight conveyors which in turn discharge onto a conveyor belt. Coal is eventually transferred to mine cars of 1.25 tons capacity.

The second operating section was a longwall operation about 150 m long with a coal height of 1.25 m in which a "combine" was used. The combine consisted of a movable, rotary type cutting face which travelled along and loaded onto flight conveyors much like a shear loader except that the coal was ripped from the face in sizeable widths of approximately one meter

for each pass. The combine produced 500 tons/24 hours. When in operation, it was most effective and care had to be exercised to prevent overloading the flight conveyor in the heading. Prior to the cutting operation, the coal was broken hydraulically as described elsewhere. The reason for the hydraulic breaking was to prevent rock burst, but had the secondary effect of shattering the coal.

The Pyramiden mine was opened in 1956 and is situated approximately 300 m above sea level, entering into Mt. Pyramid at a distance of 1,300 m. It is completely within permafrost. The room and pillar method is used in areas with extensive faulting. The main seam being worked at present is approximately 4.6 m thick. It is worked in two sections. The upper 1.40 m is mined first, and then the area is left for one year. Afterwards the bottom 1.83 m seam is mined, leaving 1 m of coal as a roof. Ventilation is by an intake rather than exhaust fan with a capacity of 3,595 m<sup>3</sup>/min. The air is heated when the ambient air temperature drops to -20°C. In the retreat longwall face visited, the Russians were using a "combine", a machine with two rotating heads cutting coal at a rate of 0.6 - 2.5 m/min in either direction. The combine moves along the 200 m longwall. The coal is loaded onto a flight conveyor and then to a belt conveyor along the haulage way. The section operates three 6-hour shifts plus a maintenance shift each 24 hours. Each operating crew consists of 9 men, including a roof support crew, to produce 550 tons of coal per 24 hours. The mine is provided with a 12 km long heated water pipe which contains water at a temperature of +20°C. The water with an additive very much like a lanolin soap is used for dust suppression.

#### 2.14 Logistics and Supplies

Both the Norwegian and Russian mines are basically "company towns", with almost all consumer goods imported and distributed by the companies. Families procure their goods through the company store. Goods are imported in the summer and stockpiled in accordance with statistics from previous years. Both maintain vehicles and equipment repair facilities and spare parts inventories. The Norwegians have limited air transportation on a winter airfield in winter. A new permanent airfield was completed in Longyearbyen in 1975. Support for Svea is by ship in summer, and with aircraft and snow cat train from Longyearbyen in winter.

The Russians maintain a large greenhouse and some livestock that consume imported hay, and chickens for a local supply of milk, vegetables and eggs. The Norwegians create their own recombined milk and preserve eggs by waxing the exteriors.

The inventory level of spare parts and critical items is almost double that of a mine in populated sections of the United States. The Norwegian workers are charged Nkr. 510 per month for room and board, which is estimated to cover only half the cost of board. Many workers are gone a full 3-4 months in summer, but absenteeism is extremely low during winter. Insurance rates rather than actual ice conditions control the length of the shipping season. Diesel fuel is also used by Norwegians as an alternate power source, whereas the Russians use coal. The new airfield at Longyearbyen is designed primarily as an auxiliary field for polar commercial flights rather than to satisfy the needs of Longyearbyen.

### 2.15 Future Prospects

The Norwegians are considering a possible investment of some 100 million dollars to construct a town for about 400 people and develop a capacity for producing one million tons of coal per year from Svea. The coal seam here reaches 5 m in thickness and reserves are estimated at 10-20 million tons. In addition, they are planning to develop Mine #7 at an estimated cost of 8 million dollars to replace production from Mines #3 and #6 as these are depleted.

The Russians plan to develop coal mining properties adjacent to Barentsburg. These properties have been leased from SNSK.

Norwegian production is of metallurgical grade coal used to produce coke and for reduction of ferro-silicon. In time, all Norwegian coal requirements will be supplied from Svalbard.

Russian coal is used to supply thermal electric power plants and a cellulose factory in Murmansk and Archangel. The Russians stated that Svalbard coal was less costly for these purposes than coal from the Pechora Basin.

The area northeast of Disko Island in Greenland is estimated to contain some 30 million tons of mineable coal which, in view of the current European coal shortage, could be developed in the future for use in thermal electric plants.

Amax, Inc. had a team of geologists based at Ottonset in Rindersbukta searching for coal, and planned to send another geological reconnaissance team to Spitsbergen the summer of 1975.

With declining or stagnating West European coal production and increasing coal prices, especially for metallurgical coal, there appear to

be considerable grounds for optimism regarding the future of coal mining in Svalbard. In any case, both the Norwegians and Russians have committed themselves to maintaining settlements in Svalbard based on coal mining for the foreseeable future, and have plans for significant new investments in this activity. Denmark appears more cautious about coal mining in Greenland.

#### 2.16 Exploratory Drilling

Diamond drills require constant lubrication. In permafrost the drill can freeze causing the drill to seize. This has occurred at a depth of 10 m in some parts of western Greenland. Three solutions have been used in Svalbard: keeping the mud circulating; using sea water, adding salt if necessary; and heating the water. A/S Norsk Polar Navigasjon found that using salted sea water was adequate, while SNSK prefers to heat the drilling water.

#### 2.17 Management Personnel and Social Amenities

The Greenland coal mine was managed by a group of engineers and foremen from Scotland under a Danish supervisor. The arrangement appeared to work well.

Both the Norwegians and Russians provide family housing and better amenities for management personnel and foremen than for the labor force, in the expectation that the retention rate will be higher. This seems to have worked out in practice, and the retention of a relatively stable engineering and management staff seems to be a significant factor in maintaining production. Both the Norwegian and the Russians provide recreational opportunities for workers. It appears that worker participation

in community affairs is low, and that the primary motivation for being in Svalbard is the opportunity to acquire substantial savings and return home. In view of the physical labor involved in the underground mining techniques employed, a large number of relatively young and strong workers is required. Increased mechanization, particularly the use of movable hydraulic roof supports, may change this in the future. The Greenland mine was said to have needed more mechanization underground as the solution to difficulties in retaining labor.

SNSK trains new miners through 14 hours of formal presentations and on-the-job training. Formal training was found not to be particularly successful in Greenland. The Russians employ only experienced miners and so do not have a training problem. Both the Russians and Norwegians use contracting and consulting organizations to perform significant design and planning tasks, and SNSK also contracts out much of its construction work.

### 2.18 Mine Safety

The Norwegian mines have only about  $0.5 \text{ m}^3$  of gas/24 hr/ton of coal, and in Svea no gas emissions have yet been measured. Rock dusting and rock dust barriers are used in the mines and a cadre of miners has been trained in mine rescue and fire-fighting. A fire station is maintained in Longyearbyen. Mine safety is taught in special lectures and considerable data are collected on accident rates.

The Barentsburg mines are 650 m under the surface and about 350 m below sea level. The coal generates  $17.5 - 20 \text{ m}^3$ /ton/24 hrs of gas and is subject to rock bursts. The Russians maintain a remotely controlled system of gas monitors which automatically disconnect electrical systems when gas

content is dangerous. The haulage ways are equipped with rock dust and water barriers and water fire hydrants and hoses, and working crews have telephone communication with the surface. A standing, permanent, trained mine rescue team was said to be on duty at all times.

The Russian emergency rescuer carried by miners is said to be adequate for 5-6 hours, but is quite heavy and cumbersome. The Norwegian self-rescuer is much smaller, lasts for only 1-2 hours, but is easier to carry. Reserve self-rescuers were said to be kept near the working faces in the Norwegian mines.

The Russians and Norwegians follow the general mine safety regulations for their respective countries. The lack of water under permafrost conditions means that other measures for fire suppression are necessary. In the past, mine fires in the older mines at Longyearen and Svea started at the mine entrances and worked backward. The Svea fire of 1926 is now extinguished, but the rocks still retain a temperature about 8°C above normal. The fire melted ice from the permafrost and water accumulated, which now forms ice lenses in the old mine headings. The fire at Mine #1 in Longyearbyen which started in the early 1920s is now believed to be extinguished, perhaps because the available coal has been consumed. The absence of fires in recent years suggests that the safety measures are adequate. As a final note, several Norwegian mining engineers indicated that the gas release from frozen coal was slower compared to coal with a more moderate temperature.



### 2.19 Productivity

Mine productivity is a function of the nature of the coal seam, geology, mining plan, equipment, safety requirements and labor skills. No particular influence of climate or arctic conditions on underground productivity was noted. In terms of labor expended per ton of coal produced, it seems that the Norwegian mines are at least twice as productive as those of the Russians. Plans for Svea envisage quadrupling production per man by employing more effective machinery. At Barentsburg the Russians are mining two longwall faces with a combined production of 800 tons/24 hrs and 200,000 tons per year. At Pyramiden their annual production was said to be about 250,000 tons per year. Total Norwegian production is about 450,000 tons per year from about 10 working faces in Mines #3 and #6, with a daily production of about 2,500 tons. The Greenland mine produced approximately 30,000 tons per year. Longyearbyen has a total population of about 1,000, while Barentsburg has about 1,100 people and Qutdligssat (Greenland) has about this same number. Pyramiden was said to have a population of about 750. The Norwegians employ a total of about 300-360 men underground and the Russians were said to have about 380 at Barentsburg providing about half as much coal. Future plans for Mine #7 and Svea envisage a significant increase in the amount of coal produced per man because of greater seam thickness and the use of movable hydraulic props and high speed cutting machinery.

The labor force for the Norwegian mines is described below.

MANNING TABLE FOR THE STORE NORSKE SPITSBERGEN KULKOMPANI A/S  
MINES IN LONGYEARBYEN, SVALBARD, 1 APRIL 1974

Underground Workers:

|         |            |
|---------|------------|
| Mine #3 | 103        |
| Mine #6 | 183        |
| Mine #7 | 39         |
|         | <hr/>      |
| Total:  | <u>325</u> |

Maintenance Workers Underground:  
(repair of locomotives, shuttle cars,  
drilling machinery, electrical  
equipment, etc.)

|                 |       |
|-----------------|-------|
| Mines #3 and #6 | 40    |
| Mine #7         | 7     |
|                 | <hr/> |

Total Underground: 372

Above-ground Maintenance, including  
operation of the power plant 60

Workers on Aerial Tramway, Coal Washing  
Plant, Transportation Department 86

GRAND TOTAL 518

Support Personnel

Warehouse, Dining Hall, Personnel Department, 170 (about)  
Stores, School, Hospital, Administration,  
Accounting Department

Total number of employees: 688 (about)

MINE PRODUCTIVITY

For a total of 372 workers underground, the average productivity during the period 1 April 1973 - 31 March 1974 was 7.1 tons per manshift of run of the mine coal. This is equivalent to 5.7 tons of clean coal per manshift.

MANAGEMENT STAFF NOT IN SVALBARD

3 employees located in Harstad, primarily for recruiting workers.

About 25 at company headquarters in Bergen

## 2.20 Coal Storage

Spontaneous ignition has not been a problem at Longyearbyen. As long as the coal pile is no higher than 20 m, spontaneous ignition does not occur. Water from rainfall and snow melt drains to the bottom of the pile where it freezes. In summer, after the coal from a pile is shipped, the frozen coal thaws and is removed by a bulldozer. It is screened, the frozen lumps of coal are crushed, and the coal shipped. The lumps are soft and easily broken. High wind speeds, particularly in winter, were said to blow considerable amounts of coal dust around the storage area and may create visibility problems at the new airport located near the coal storage area.

No information was obtained on Russian coal storage. However, the Barentsburg coal has an ash content of 17% and contains about 20% stone. At Svea, the coal was said to have about 10% rock, 2% moisture, 5% ash, 1% sulfur, 40% volatiles, and 7,800 kcal/kg. Norwegian practice is to handpick rock; the Russians do not do so. Spontaneous or other forms of ignition has occurred in conically stacked waste piles at Barentsburg and Grumant as can be seen from the sea. Evidently, there have been tripple fires at Longyearbyen in the past. In Greenland, the coal stock pile was ignited by workmen throwing hot ashes from a stove onto the pile.

Coal at all the mines is stockpiled in winter and shipped during the summer. Vessels of up to 20,000 tons are loaded at Longyearbyen; plans are for Svea to have a capability to load 40-60,000 ton vessels.

## 2.21 Cost Data

This trip was not concerned with collecting cost data. However, it appears that coal is produced in the Longyearbyen area for perhaps \$25.00 per ton, which includes about \$2.50 for amortization of capital investment. The cost for investment at Svea will probably be about \$5.00 per ton. With European prices for metallurgical grade coal said to be about \$45.00 per ton, the economic future for SNSK coal should be promising. However, officials said that coal production is committed first to the Norwegian steel and ferro-silicon industry at below world market prices, and only the surplus will be sold elsewhere.

The large labor force involved in the Russian mines and the obviously greater investment in roof support, safety, and underground transportation suggests that the real costs of mining must be significantly greater than those of the Norwegian mines. In addition, the Russian coal is used for power production rather than metallurgical purposes, and certainly has a lower market value. However, it is committed to markets in Murmansk and Archangel and is not likely to enter world trade.

The Greenland mine produced coal for home heating. Oil gradually replaced coal, and the decision was made to close the mine and the town, which was done in 1972. The subsequent increase in oil prices and the social effects of disbanding a community of over 1,000 people which had lasted for 50 years casts doubt on the wisdom of this decision. Reconnaissance of coal outcrops in the peninsula northwest of Disko Island indicates reserves of 30 million tons of coal with a calorific value of about 6,000 Kcal/kg, moisture content of 10-30%, and an ash content of 5-18%. This coal might possibly be mined for use in Danish thermal electric

plants at some time in the future. The Norwegian, Russian and Greenland mines have all received significant financial support from their respective governments. The Svalbard mines are subject to a tax at 1% on the value of coal exported and in addition SNSK pays a total income and welfare tax of about 10%. According to the treaty governing Svalbard, the only taxes imposed are a 4% income tax and a 1% export tax, the funds from which must be used on Svalbard. In addition, a 6% welfare tax is imposed by Norway for medical, retirement and other social benefits. Thus, the mines enjoy a significant tax advantage which is guaranteed by international treaty. Evidently, the same provisions would apply to petroleum development, making the area attractive from a tax standpoint.

Average hourly wages for SNSK workers appear to be approximately \$5.00 per hour. Fringe benefits and other costs apparently add about 60% to this figure giving an average cost of \$8.00 per hour. The fees and costs for maintaining existing mining claims are minimal. SNSK and the Russian mines do spend considerable sums on employee housing, food, recreational and educational activities, road construction and repair, and employee transportation to and from Norway as well as transportation to and from work while on Svalbard, and four weeks paid vacation per year, and salary while in travel status. These factors make comparison with probable mining costs in Alaska somewhat difficult.

## 2.22 Permafrost Conditions

In those areas being mined in Vest Spitsbergen, the active layer appears to be from 1 to 1.5 m deep. However, on the hillsides where the Norwegian mine openings exist, the depth may be somewhat less. Rock

temperatures appear to be approximately  $-4^{\circ}\text{C}$ . Norsk Polar Navigasjon in oil drilling outside the coal bearing areas has found the level of zero amplitude to be at a depth of about 15 m with a temperature of  $-8^{\circ}\text{C}$ . The bottom of the permafrost is generally at a depth of 300 m from the surface. The interior of hillsides at a horizontal distance of 300 m from the slopes and a vertical distance of 300 m from the surface is free from permafrost. The Norwegian mines are driven into the hillsides less than 300 m from the plateau surface and so are almost completely within the permafrost zone. Examination of recent excavations, and interviews, suggest that the ice content of the unconsolidated surficial layers of permafrost is low. In Longyear valley, the active layer is 1 m deep and if it is removed in summer the ground will thaw 0.5 m within approximately one week. Vegetation is sparse and consists of mosses, lichens and very small plants. Hillsides are very steep, largely unvegetated, and covered with talus slopes which exhibit active top layers overlying permafrost. The most common rocks are sandstones, shales, black shales, some conglomerate, claystone and coal. The valley bottoms and river courses contain large amounts of gravel and clays. The minimum rock temperatures encountered in the mines appear to be  $-4^{\circ}\text{C}$  and the maximum about  $+1^{\circ}\text{C}$ .

### 2.23 Svalbard Environmental Controls

The international treaties governing the archipelago of Svalbard provide for Norwegian sovereignty, but specifically prohibit the extension of Norwegian laws automatically to the archipelago. Only those passed by the Norwegian parliament with specific reference to Svalbard can be applied, and these only when they do not conflict with the terms of the international treaties.

Various departments of the Norwegian government have responsibilities for Svalbard. The main responsibility for governmental administration rests with the Department of Justice which acts through its representative in Svalbard, a Commissioner (Sysselmann) situated in Longyearbyen. The Department of Industry is responsible for supervising mineral development and works with current and prospective organizations interested in Svalbard. The Norwegian Foreign Ministry is responsible for all matters regarding the treaties governing Svalbard and the powers signatory to those treaties. The Department of Environmental Protection is responsible for environmental protection.

An official program of environmental protection is relatively new in Svalbard.<sup>1</sup> The Norwegian government has promulgated a series of resolutions creating three national parks, two natural reserves, and 15 bird sanctuaries on Svalbard, all of which are closed to mining. Overland vehicular movement and the development of airfields are prohibited without permission from the Norwegian government through the Commissioner for Svalbard. The Commissioner is also responsible for working with the Tromsø museum for protecting historic sites, buildings, etc., particularly those dating from before the year 1900. Hunting of all forms is closely regulated.

The primary motivation behind the development in recent years of regulations for the protection of Svalbard's environment appears to have been oil exploration. Svalbard may contain oil reserves, and with the favorable tax structure existing, development could be financially very profitable. Unfortunately, oil exploration in the past has damaged the environment.<sup>2</sup>

The existing mining activities, both Norwegian and Russian, do not



appear to have suffered from environmental controls. Both the Norwegians and the Russians appear to have made a substantial effort in recent years to utilize better methods of garbage and other waste disposal, but neither appeared subject to the type of controls which exist in Alaska.

There appears to be no significant problem involved in controlling hunting or other activities by individuals which might be harmful to the natural environment.

The major problem concerning environmental protection seems to be a political one, whether or not the Norwegian government can in fact enforce its own environmental regulations on the activities of foreign nationals exercising their rights under international treaties. There is, for example, some doubt as to whether or not the Russians can be obliged to follow Norwegian regulations concerning the environment in their mining and mineral and petroleum exploration activities.<sup>3</sup>

<sup>1</sup> Miljøverndepartementet, Miljøvernforskrifter for Svalbard, 1974.

<sup>2</sup> This was visually observed at the old Caltex site at Blaahuken on the northern shore of Van Mijenfjord.

<sup>3</sup> Based on conversations with Norwegians in Svalbard.

#### 2.24 Concluding Observations

Excepting World War II, SNSK has mined coal continuously in Svalbard since 1916 and Arktik Ugol' since 1934. Both are motivated in part by a political desire on the part of their respective governments to maintain a physical presence on Svalbard and to utilize Spitsbergen coal to supply a limited number of domestic consumers who would otherwise be forced to obtain coal elsewhere. Future plans clearly indicate that both the Russians

and Norwegians intend to continue coal mining and improve their present settlements. The Norwegian investment in supporting activities, and particularly the new airfield, is impressive. Problems exist because of permafrost, cold weather, a short shipping season, and remoteness, but these all seem to have been solved. The experience indicates that with a long term commitment, financial support, and a secure market base, coal mining in the Arctic is fully practical. The environmental hazards associated with underground mining appear minimal and subject to control. Settlements consisting largely of short-term residents can also become permanent, as demonstrated by the life span of both Longyearbyen and Barentsburg. Given the political significance of Svalbard, the question of whether coal mining is economically viable under changing world market conditions is perhaps not too important. However, the future economic prospects for the Norwegian coal mines do appear at present to be quite promising.

### 3.0 GREENLAND<sup>1</sup>

Coal has been mined for local use in Greenland since the latter part of the eighteenth century. In the early nineteenth century, various attempts were made to establish mining as a commercial activity. These failed, however, due to lack of investment and competition from lower cost and higher quality English coals. In the early part of the twentieth century coal mining became established on the northern side of the Nugssuak Peninsula. In 1924, this mine was closed down and a new one opened at Qutdligssat, located on the northeastern edge of Disko Island along Vaigat Strait (70°7'N, 53°W).

In an economy move the mine was phased out between 1968 and 1973. The town of 1,200 people which was supported by the mine was closed down, the people sent to other settlements, and the entire town was sold off for scrap. The reasons for closure appear to have been largely economic in nature. The coal was used primarily for home heating and cooking and was no longer competitive with lower cost imported oil. In addition, the oil was more convenient. The port was awkward and maintenance of the mine probably would have involved increased investment in mining machinery.

Production appears to have peaked at about 40,000 tons per year in 1963. The basic mining system employed was underground advance short wall mining with coal pillars for support. Coal was handloaded onto conveyors (or underground railroads) for haulage to the surface where it was stored during the winter and shipped during the summer. The labor force was exclusively native except for a management staff of individuals from Scotland supported by Powell Duffryn Technical Services Ltd. as consultants.

Judging from some newspaper articles consulted and limited interviews in Copenhagen, it appears that not everyone was pleased with the decision to close both the mine and the town, particularly in view of the social disruption caused among the relocated families and the subsequent and rather dramatic increases in the cost of imported oil.

The extensive outcroppings of coal on the Nuqssuak Peninsula are being studied and may represent a significant future source of energy.

In the late 1960's, the mine shafts reached a maximum depth of 100 m below ground. A coal seam as thick as 1.5 m was mined by the advance short wall system. A total labor force of about 100 was utilized, 85 of

whom worked underground. A significant absenteeism problem existed, especially during the summer months, and to compensate for this a larger number of workers was actually carried on the rolls (see Tontatus Butte Mine). Mine development work occurred during the summer, when labor was short, and most mining occurred during the winter, with coal stored and then shipped during the summer. Supplies came from Copenhagen by ship.

Coal mined at the face was manually moved onto conveyors. With this system productivity averaged 4.25 tons per manshift. The mine evidently was not within permafrost, or at least permafrost did not appear to be a significant problem. There was considerable seepage from the surface resulting in an extremely wet mine. The wet mine characteristic was the reason for employing engineers from Scotland who have experience in this form of coal mining.

Because of the wetness, coal dust generation appears not to have been a problem. The coal did not produce measurable gas. The inclines were abandoned when they reached a distance of about 3,000 feet.

Winter temperatures created some problems. Temperatures as low as  $-35^{\circ}\text{C}$  were measured in air entering the mine. This caused some freezing and breaking of pipes. The consultant recommended that mining machinery which is stored above ground be kept heated and covered during the winter while not in use. The reason given was that the low temperatures would cause contraction in the steel and could cause difficulties with the bearings in the machinery.

Room and pillar mining was also employed evidently because it was a better means of maintaining roof stability. Wood props were used, but these proved to be quite expensive, and a gradual transition was made to

hydraulic supports and steel props.

The mine did not employ sophisticated technology and was used to provide coal for local consumption. The coal mine, with its 100 man labor force, was the principal economic activity in a settlement of 1,200 people.

Had the mine remained in operation, it appears probable that investments would have been made in more modern equipment in order to reduce the labor force. This was necessary not only because of the increasing cost of labor, but also because of labor difficulties particularly over the question of absenteeism. Reported direct labor costs per ton were 30 Dkr in 1969.

Note on source. Interviews with Mr. Elmar J. Schiener, Greenland Geological Survey, Copenhagen, and with Mr. Erick Dockner of the Greenland Technical Organization. Selected reports produced for the GTO by Powell Duffryn Technical Services, Ltd., were consulted. A survey of newspaper articles from Danish newspapers in the University of Alaska Library was also made. On early mining, see: P. P. Sveistrup, Det Danske Styre af Grønland, Meddelelser om Grønland, Bd. 145, Nr. 1, 1945.

4.0 ABSTRACTS FROM: HOEL, ADOLF, SVALBARD SVALBARDS HISTORIE, 1596-1965, SVERRE KILDAHLS BOKTRYKKERI, OSLO, 1966, Volumes I and II.

Spitsbergen is an Arctic island group lying in the Arctic Ocean between 76°26' and 80°50' north latitude and 10°30' and 23°10' east longitude. The group includes the following islands: Vest Spitsbergen (39,500 km<sup>2</sup>), Edgeøya (5,150 km<sup>2</sup>), Barentsøya (1,300 km<sup>2</sup>), and Prins Karls Forland (650 km<sup>2</sup>). Including the smaller islands Spitsbergen has an area of 61,600 km<sup>2</sup>.

Kvitøya (250 km<sup>2</sup>), Kong Karls Land (311 km<sup>2</sup>), Hopen (46 km<sup>2</sup>) and Bjørnøya (178 km<sup>2</sup>) do not belong to the Spitsbergen archipelago. Together with this island group they form the Svalbard Archipelago which has a total area of 62,405 km<sup>2</sup> (p. 17). Spitsbergen Treaty of 9 February 1920 gave Norway full sovereignty; acceptance took place on 14 August 1925 (p. 17).

Climatic data, shown on the table, indicate that a very large temperature increase has occurred in the winter months from the period 1912-1930 until the period 1951-1960 (p. 24). March is the coldest month of the year, July the warmest. Temperatures down to -30°C can occur in winter and temperatures up to +16°C in summer. There is a large variation in winter temperatures. For example, the average temperature in January 1947 was -1.8°C and in January 1959 -15.6°C. (In Grønfjord temperatures have been measured down to -49.5°C.) Precipitation is greatest in fall and least in spring. The average annual precipitation is over 300 mm. Precipitation can occur as snow in every month, but is relatively infrequent in July. Sky cover is usually least in April and highest in July and August. The dominant wind is from NNE and E, that is out Isfjorden, practically the whole year. Only in July and August is the wind from the south strongest (p. 25). Wind velocity is often high in winter. In the months November through March, 50% of the days have an average maximum wind speed of 6 on the Beaufort scale (p. 26). Along Vest Spitsbergen lie the youngest rock formations, i.e., rocks from the Tertiary period, in a trough-like structure which stretches from Kongsfjord southward to Storfjord. On both sides of these Tertiary deposits are found Triassic, Jurassic, and Cretaceous rocks. These in turn are surrounded by rocks

## CLIMATIC DATA ON SVALBARD

(Developed by Thor Werner Johannessen)

|                                    | Jan   | Feb   | Mar   | Apr   | May  | Jun | Jul  | Aug | Sep | Oct  | Nov  | Dec   |
|------------------------------------|-------|-------|-------|-------|------|-----|------|-----|-----|------|------|-------|
| Average Temp. °C<br>(1951-1960)    | -10.3 | -9.9  | -11.9 | -8.2  | 2.7  | 2.1 | 5.0  | 4.5 | 1.3 | -2.4 | -5.3 | -7.9  |
| Precipitation(mm)                  | 22    | 31    | 31    | 16    | 21   | 26  | 32   | 36  | 36  | 44   | 23   | 36    |
| Average Cloud<br>Cover (scale 0-8) | 5.2   | 5.6   | 5.4   | 4.8   | 5.4  | 6.2 | 6.5  | 6.6 | 6.3 | 6.2  | 5.8  | 5.2   |
| Average Number of<br>Days with Fog | --    | 0.4   | 0.7   | 0.1   | 1.1  | 5.3 | 10.0 | 5.3 | 2.2 | 1.7  | 0.3  | --    |
| Normal Temp. °C<br>1912-1930       | -13.8 | -14.0 | -15.7 | -11.8 | -4.7 | 2.2 | 4.4  | 4.3 | 0.6 | -5.2 | -9.6 | -11.1 |

from the Carboniferous and Permian periods. Farthest out west along all of Vest Spitsbergen rocks have been strongly metamorphosed due to folding. These are called the Hecla Hoek rocks.

The Hecla Hoek formation evidently consists of Pre-Cambrian and younger rocks up to Ordovician and Silurian ages. The Hecla Hoek formation weathers into mountains with peaks which inspired Barents to name the island group Spitsbergen. Younger sedimentary formations have formed the mountain plateaus which are most characteristic in the inner portion of Isfjord (p. 30).

Fossils from the Carboniferous show that there must have been a very rich vegetation on Svalbard 300-380 million years ago (p. 32). Coal is found in the upper Cretaceous and lower Tertiary. It is the Tertiary coals that are being mined today. The coal-bearing area with thick seams is spread over the central and southeastern parts of Vest Spitsbergen and includes coals from the Carboniferous up to and including the Tertiary periods. The most important deposits under exploitation were formed in the Tertiary period.

The Norwegian mines at Longyearbyen drift into nearby horizontal beds up to the mountain sides. In the mines at Ny-Aalesund the work was in an area with large faults which made the mine conditions difficult. At Barentsburg in Grønfjord, the Russians mine along horizontal deposits at low level. Deep in Billefjord is Pyramiden, the other Russian mine. The coal mined here is from a deposit from the lower Carboniferous (p. 32).

Iron is found in many places but is of no economic value. The same can be said of copper which has been found in St. Jonsfjord and other places in the Hecla Hoek formation. Lead and zinc have been found in the



area between Isfjord and Bellsund. Marble has been mined on the Blomstrand Peninsula in Kongsfjorden, but it was not profitable because of the peninsula's tectonics and frost influence on the marble. A small deposit of asbestos was found in Recherchefjorden, but the quality was low. Gypsum is found in Billefjord but turned out to be not mineable. Gypsum is a bulk commodity and probably not worth mining (p. 33). Phosphates are found, but in too thin layers to be worth mining; also there are some iron carbonates but not sufficiently pure to be of economic value (p. 34).

During the Ice Ages the land was pushed down by the ice sheet and was 300 m lower than it is today. Later the land rose, resulting in terraces. Today two thirds of Svalbard is covered with ice and snow. Glaciers entering the sea often lie on the sea bottom; can lie up to 100 m deep in the sea. Ice bergs result from glacier calving in summer (p. 34). Permafrost in Svalbard has an average depth of 300 m. On grass-covered flat lands the surface melts on the average only 50 cm, and on well drained gravels up to 2 m. Permafrost causes the surface to be extremely wet. Frost action causes sorting of the ground material as the larger deeper materials is shoved up to the surface.

According to Icelandic Landnamabok (p. 37), Svalbard was discovered by Vikings from Iceland in 1194, and rediscovered by Dutch in 1596 (p. 37). The Dutch explorers were searching for a route to the east in competition with the British who opened trade with the White Sea in 1553. The Portuguese rounded Cape of Good Hope in 1497, and the Hanseatic League had control over trade in Northern Europe (p. 37-39). The Barents party proceeded to the northern tip of Novaya Zemlya where they overwintered,

lost their vessel, and returned by boat to the mouth of Pechora, and Kola Peninsula, and were found by Dutch merchantmen. Barents himself died of scurvy (p. 39-40).

Seas west of Spitsbergen and around Bjørnøya had walrus and Greenland whales; walrus were hunted and killed on land. Henry Hudson explored Spitsbergen in 1607 and called it Kongsfjord Hvalbukta because of the large number of whales he found there (p. 41). The first whaling off Spitsbergen began in 1611 by Englishmen (p. 42). Little is heard of English whaling in Spitsbergen after 1660, but the Dutch continued strong (p. 46). Whales began leaving the fjords in about 1650; Englishmen quit, but the Dutch went into Pelagic whaling (p. 46).

Jan Mayen was discovered by the Dutch in 1614, and was used as a shore based whaling station (p. 46). Smeerenburg's decline began in about 1647 and by 1690 was empty (p. 47). The last Dutch whaler came to Spitsbergen in 1864. The first Russian hunters came to Spitsbergen sometime between 1715 and 1720, although it has been stated that they came earlier, in the 16th century. At the beginning of the 18th century, Russians in large numbers were found along the coast of North Norway where they were called "pomorer". Russians hunted walrus, white fish, seal, reindeer, and fur animals. In the beginning, Russians remained on Edgeøya. They left the White Sea in July in "Lodj" carrying up to 24 men; remained in Spitsbergen until following summer (p. 55). Russians gradually spread over Spitsbergen in search for new hunting grounds; reached to Bellsund and Grønfjorden in Kongsfjord and to other fjords along the west coast (p. 56). Most Russian hunting expeditions were sent in the century from 1730 to 1830. In 1804 the Russian White Sea Company was given boundaries

for its operational area by Alexander I. "This would include not only the White Sea but also the Gruman Islands (Grumant was the Russians' name for Svalbard), Novaya Zemlya, Kolguyev, and the Northeast Sea and the Arctic waters" (p. 56). Russian hunting began to decrease in the early 19th century, in part because of Norwegian competition (p. 56-57).

Norwegians from Hammerfest, Tromsø and later Trondheim began hunting in Spitsbergen in the early 19th century. They were mainly interested in the large walrus herds. In the 1870s, herring schools appeared off the west coast of Spitsbergen, but left in 1883, and were fished in the intervening years (p. 58-59). The first shipment of coal from Spitsbergen was made by Søren Zachariassen in the summer of 1899. The coal was sold in north Norway (p. 65) and this led to coal mining claims. In 1904 Trondhjem Spitsbergen Kulkompani sold its claims on Adventfjord to John M. Longyear who with Frederick Ayer from Boston, founded the Arctic Coal Company in Boston in 1906 (p. 66). Norway took sovereignty over Svalbard only after the U.S.S.R. in 1924 acknowledged Norwegian sovereignty (p. 77). In 1935, U.S.S.R. signed the treaty with Svalbard (p. 77). World War I caused a halt to mining of belligerents in Spitsbergen (p. 71). A Norwegian syndicate bought Arctic Coal Company and the lands of Norwegian companies lying nearby and soon became the Store Norske Spitsbergen Kulkompani.

Arktik Ugol' opened mines at Grumant east of Coles Bay and at Barentsburg on the east side of Grønfjord in 1931 and 1932 (p. 111). Musk oxen were brought from Greenland to Adventfjord area (Moskushavn) (p. 169). The Svalbard og Ishavsundersøkelser organization has been supported by the Norwegian government since 1927 (p. 269). In the period

1907-1939, Norwegian scientific expeditions went to Svalbard; mapped 18,653 sq. km; took 65,000 aerial photographs and mapped 92,166.8 sq. km of ocean area (p. 177).

Just prior to World War II, total Russian and Norwegian coal production reached nearly 700,000 tons annually and about 150 ships arrived annually to haul coal (p. 179). A Russian company, based in St. Petersburg and named A/S De Russiske Kulfelder Green Harbour, bought land between Barentsburg and Colesbukta between 1913 and July 1918, from Norwegian interests (p. 247). Bibliographical note: Sir Martin Conway, No Man's Land, published in 1906, concerns the history of Spitsbergen whaling (p. 274).

In the summer of 1910 a large German expedition led by Graf von Zeppelin and Prince Heinrich of Prussia, went to Spitsbergen to study the use of air ships in Arctic areas (p. 275). At the same time the Germans "occupied" land in Krossfjord, Kingsfjord, Magdalenafjord and Raudfjord, all along the northwest coast of Vest Spitsbergen from Ny-Aalesund northward (p. 285). In 1920, a Dutch company bought out the Russian company owning fields along Green Harbour. The Dutch planned to mine 500,000 tons of coal annually and founded the town of Barentsburg (p. 310-312). They produced 48,000 tons of coal in 1924-1925 and made preparations for producing 250,000 per annum (p. 314). A Russian expedition came to Barentsburg in the summer of 1931 which resulted in the purchase of Dutch mines which have shipping facilities to load up to 350,000 tons of coal per annum (p. 325, 326).

It was in the years just before the first World War that the Russians first showed interest in Svalbard. This undoubtedly occurred because of

the discovery of the rich coal deposits on the archipelago and an understanding of the meaning they could have for Russia. After leading an expedition to Spitsbergen in the summer of 1913, mining engineer, Rudolf L. Samoilovitsj, wrote a report about the coal deposits in Spitsbergen. It was stated that the coal deposits were highly significant for Russia, according to a translation of an extract available at Svalbardadvokatens archives.

The utilization of large deposits of coal with a quality nearly as good as English coal, and under realistic maritime conditions, are of especially great significance for the Russian Navy. When one takes into consideration the fact that the Baltic fleet's vessels use English coal and that in case of a conflict with England they will be threatened. It must be admitted that the fact that the Spitsbergen coal is only two days from North Russia can be of significance for the State. Vladimir Alexandrovich Rusanov, a Russian geologist, was sent to Spitsbergen by a group of merchants from Archangel. A report entitled: "The Island of Spitsbergen and the first Russian Scientific and Industrial Expedition" was published in the year 1913 in Archangel. The expedition had 14 members and arrived at Bellsund on 3 July 1912 (p. 333). They went overland and explored Green Sound and Colesbukta. They claimed a small area near Colesbukta (p. 334). On the 16th of March 1913, Rusanov's backers established the Handelshuset Grumant A/S to develop minerals in Svalbard and began coal mining in 1913 (p. 336). N. H. Dole, America in Spitsbergen, Vol. II, cites that the Russians had a disagreement with Longyear over mining properties (p. 338). The Russians mined in Colesbukta in the summer of 1913 (p. 341). Additional exploration was conducted in Colesbukta

in the summer of 1914 and the summer of 1915 (p. 342).

In 1920 the Anglo Russian Grumant Company was established in London to use Russian properties. The Russians commenced mining at Grumant (p. 355) and at Barentsburg (p. 356) mines were taken over by 'Arktik Ugol' in 1933 (p. 361). In the winter of 1933-1934 Russians had 1,261 people in Barentsburg, including 100 children.

In 1934, they produced 180,312 tons of coal, of which 10% was used locally and about 149,000 tons were shipped (p. 363). The Russians attempted in 1934-1935 to utilize water for dust suppression, but the water froze in the mines, and instead they removed the dust once per working week and used rock dust to control the coal dust. Production in 1935-1936 reached 1,300 tons per day with 700 men working in the Barentsburg mine (p. 367). The gas content was very small. They mined 400,134 tons of coal in 1936 of which 342,216 tons were shipped during the year. A 50 m wide pillar had been left separating the shaft from the ocean where it was under sea level (p. 368) in the Grumant mine which in 1936 produced 75,131 tons of coal, of which 63,909 was shipped (p. 368). The mines were evacuated in 1941; Germans shelled and destroyed the buildings in 1943. Reconstruction of Russian mines began in 1946 (p. 380-382). In 1954 Barentsburg delivered 161,080 tons of coal, Grumant 120,459 tons. During 1954, 211,616 tons of coal were shipped out (p. 401). In 1965, a total of 400,000 tons of coal were to be produced. In Barentsburg, coal was to have 7,400 Kcal/kg and an ash content of 30%, reduced to 24-25% by "sjeiding" (p. 415). From April 1965 a new mine was in operation in Barentsburg. The bottom of the shaft lies 1,200 m down from the surface, but at the time the lowest operating level was 800 m. Retreat

longwall mining was used; water spray was used at cutter machines to reduce coal dust (p. 416). Daily production at Barentsburg was 600 to 700 tons in 1965. A fire hose system exists in the mine, which brings sea water from the sea down to the coal faces for use in case of fire; rock dust barriers and rock dust are used for dust suppression. They have a relay in the ventilation system to cut off all electricity in the mine in the event the methane gas content in the return air reaches 0.5%, but this has never occurred (p. 416). Coal production from the Russian mines according to Norwegian data on coal shipped out of Spitsbergen: 1933 - 149,000, 1935 - 318,868, 1939 - 313,246; reached 310,133 by 1955; from 1956 through 1963 coal shipments varied from 366,800 (1962) to 480,395 in 1960.

An English company developed a marble quarry in Kongsfjord by 1913; it was thought that the marble to be of very high quality (p. 439). Research in 1916 showed that the good marble was at the surface only and quarrying would be worthless (p. 446). The British also sought to develop what they thought was high grade iron ore in Recherchefjorden in 1918 (p. 450-451). Pages 450-462 discuss some minor discoveries of copper, lead, zinc and iron ore deposits made in 1919. Most proved uneconomical by 1921 (p. 466).

The Svalbard Treaty was signed in Paris on 9 February 1920 (p. 468). The above discoveries and explorations were made by an English company, the Northern Exploration Company, which went out of business by 1929 (p. 482).

Noel, Adolf, Svalbard, Svalbards historie 1596-1965, Vol. II, Sverre Kildahl's Boktrykkeri, Oslo, 1966.

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Swedish organization laid first claim to coal seams in the Pyramid area in 1910 for the purpose of securing coal for Swedish steel production (p. 500-503).

At about this time (1910-1916) the Swedes also obtained coal properties at Sveagruva (p. 514). Development of Sveagruva began in 1919 (p. 517). From September 19 through June 30, 1920, Sveagruva produced 27,097 tons of coal (p. 520). In 1920 it shipped 38,000 tons of coal, of which 34,500 tons went to Swedish railroads in Narvik and Trondheim; the rest was sold or used at the mine (p. 520). A small exploration tunnel was driven in Pyramiden. In 1921 the Swedish mines reorganized as Svenska Stenkolsaktiebolaget Spetsbergen (p. 524). From July 1, 1923 through June 30, 1924, Sveagruva produced 98,260 tons of coal (p. 533). The coal was shipped to Narvik railroad and the Swedish railroad in Hommelvik, Göteborg, Malmö, Stockholm, and for other uses (p. 534).

On May 12, 1925, a fire broke out in Sveagruva. Fire started in a locomotive "stall" located in the main tunnel 40 meters from the mine opening probably when a gasoline tank was ignited during the cleaning of a gasoline driven locomotive (p. 535). Gas moved to Shaft 1 from Shaft 11 where the fire was and made it necessary to close both shafts. By September the fire was out due to pumping of water into the mine. Then the mine was closed to prevent air entering the mine and starting the fire anew (p. 536). In 1926, due to falling coal prices, the Swedish government stopped its subsidies for coal mining in Spitsbergen (p. 540). The fire appears to have been put out without extensive damage to the mine,



but falling coal prices, absence of government subsidies, led to liquidation of the company (p. 539-641) in 1926. The Swedish government changed its mind in 1927 due to British coal strike of 1926 which cut off coal imports except from the U.S. (p. 540-543). However, in March 1927, there were three explosions which caused a new fire in the mine (p. 543). The fire was put out by flooding (p. 544).

In 1926, Swedish rights to Pyramid were sold to the Russians (p. 545-546). In 1934, Store Norske Spitsbergen Kulkompani purchased Sveagruva (p. 548-549).

The Spitsbergen Coal and Trading Company was founded in the United Kingdom in 1904 to develop coal. It laid claim in 1901 to Adventfjord (p. 555-557). The Spitsbergen Coal and Trading Company encountered labor difficulties in 1906 and ceased operations in 1908 (p. 566). Advent Bay was named after Adventure Bay, a British whaling vessel named Adventure which stopped in Isfjord in 1656 (p. 571). A Norwegian group bought the company's rights to Advent Bay in 1915 (p. 572). A Norwegian company founded in Bergen, named A/S De Norske Kulfelter Spitsbergen (p. 573). Musk oxen were brought to Advent Bay in 1929, landed at a place which was therefore named Moskushamn (p. 574). The company produced and sold 8,000 tons of coal from Advent Bay in 1920 (p. 577). The company went bankrupt in 1922, unable to raise capital. It had borrowed money from the Norwegian government which refused further subsidization (p. 578). The area was redeveloped by a new company, Norske Kulfelter A/S, beginning in 1937. It basically went out of business in 1940 (p. 584), and the company liquidated in 1953 (p. 584). Longyear was interested in Spitsbergen coal for use in making iron and steel from the iron deposits in

Sør Varanger, discovered in 1901, since Andoya coal was unsuitable for coking (p. 590-593). SNSK bought out Norwegian rights from the Trondheim-Spitsbergen Company which had done a little mining in Adventfjord in 1903-1904 (p. 593). The Arctic Coal Company claimed land from Grønfjord to the west side of Adventfjord and three quarters of the way south to Van Mijenfjord (p. 599), and also land on the south part of Sassenfjord (p. 599) in 1905 (p. 599). The Longyear Company had difficulties in asserting its claims against others, especially in Grønfjord; had labor difficulties with Norwegian laborers. It produced about 30,000 tons of coal per annum (p. 599-664). In the winter of 1914-1915 Adventfjord mine produced 44,000 tons of coal (p. 673). Operations stopped in 1916 due to wartime restrictions on shipments of supplies (p. 676-677). N. H. Dole, in America in Spitsbergen, discusses Longyear. They invested about \$1 million in the mine (p. 678). The Russians were interested in buying the mines to obtain coal for the Murmansk railroad; the Norwegians were interested for coal for Norwegian railroads. Longyear was anxious to sell (p. 682-684). The Swedes then became interested as coal prices increased and the Swedes wanted to become independent of English coal (p. 689). The Norwegians purchased the mine, in part because they did not want the Swedes or the Russians to have the mine (p. 689-690). In 1916 (p. 690) this situation led to the founding of Store Norske Spitsbergen Kulkompani A/S (p. 690). A French vessel "Recherche" took the French scientific expedition to Spitsbergen in 1838; Recherchefjord in Bellsund was named later after this vessel (p. 715).

Kings Bay Kul Compani A/S was founded in 1916 by businessmen from

Aalesund who had been blacklisted by the British and refused coal because they continued to trade with Germany. They bought property from other Norwegians (p. 734-735). In 1916 Store Norske Spitsbergen Kulkompani A/S bought out other Norwegian claimants to coal land in Grønfjord (p. 757). The Norwegians and the English, in conflict with each other, mined asbestos in Recherchefjord in the early 1920s (p. 770-772). The asbestos field is still owned by A/S Kulspids (p. 773).

APPENDIX B

;  
CONSTRAINTS ON COAL MINING  
IN THE SOVIET NORTH

## APPENDIX B

### CONSTRAINTS ON COAL MINING IN THE SOVIET NORTH

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## 1.0 GENERAL

This appendix summarizes the information obtained from the search of Russian language literature on coal mining in the Soviet North. Three major Siberian coal basins are discussed: Pechora (Vorkuta), Lena (Yakutia), and the Noril'sk. Additional information is provided on coal mining in Magadan. The basic source utilized for sections 3.0, 4.0, and 5.0 is V. K. Kurenchanin, Mining of the Coal Deposits of the North-eastern USSR, Moscow, 1971.

The information extracted relates to the period 1955-1970 and is organized around Arctic problems encountered in different coal mines.

Siberian coals, while mined to a limited degree in the eighteenth and nineteenth centuries, owe their modern development to the period after 1931 when the Soviet government began an intensive program for developing the mineral resources of Siberia. The Vorkuta coals were developed to provide needed energy and metallurgical grade coals for the northern part of European Russia, a region deficient in energy resources. The domestic alternative to the Vorkuta coals was and is the deep coal seams of the Donbas in the Ukraine. The Donbas was lost to the Germans during World War II, and since that time has been oriented toward supplying the needs of the Ukraine's heavy iron and steel industries. The Vorkuta area, thus, provides a much needed alternative energy resource.

The Noril'sk coal was developed basically to provide for the needs of the Noril'sk nickel mines and metallurgical plants. Coal mining there appears to have become less significant in recent years due to the availability of local supplies of natural gas.



The coals of the Lena and Magadan region have historically been used as a local energy resource. In the future, however, they may be exploited as a resource for the industrialization of eastern Siberia and perhaps the Soviet Far East.

A major change in Soviet policy toward Siberia occurred in the late 1950s and early 1960s with the implementation of a long range program of large scale investment in energy and mineral resource development. This program led to changes in coal mining technology and an increase in investments in Siberian coal. The literature reflects this with substantial increases in investment, marked improvements in workers salaries and fringe benefits, and significant changes in coal mining equipment and research beginning in the early to mid 1960s.

#### 1.1 Pechora-Vorkuta

The Vorkuta basin (about 69°N, 65°E) is located in a wet, Arctic climatic zone near the northern edge of the Ural mountains. Coal is shipped long distances overland to markets in northern European Russia. The physical environment is characterized by wet, ice rich, fractured permafrost, which has created drainage and mine opening difficulties. Current mines are below the permafrost and produce some 20,000,000 tons per year.

#### 1.2 Noril'sk

The Noril'sk basin (about 69°N, 89°E) is located near the mouth of the Yenisey River. The region has a cold, arctic climate. The permafrost here is cold and the mines have suffered from a history of underground

fires caused by spontaneous ignition. Evidently, mining operations caused an increase in rock temperatures which, when coupled with improper ventilation, led to oxidation of the coals, and in time to the generation of sufficient heat to cause spontaneous ignition.

### 1.3 Lena-Yakutiya

The Lena basin, centered more or less around the settlement of Yakutsk (about 61°N, 130°E), lies in a zone with a very severe continental climate. Winter temperatures are extremely low, while summer temperatures are quite high. The temperature range is somewhat greater than that in interior Alaska, while the permafrost is considerably colder. The literature surveyed suggests that maintenance of normal rock temperatures is beneficial to mining. One critical problem, as yet unsolved in these mines, is that of suppressing coal dust during the winter period when coal dust generation is much greater than in the summer.

### 1.4 Magadan

While there is less information directly on the coal mines in the Magadan area (the area north of 60°N, 150°E), the literature surveyed contains a variety of recommendations for coal mining. These revolve around maintaining existing thermal properties, modifying mine safety regulations for Arctic conditions, and developing special design requirements for Arctic coal mining, particularly concerning pillar sizes, ventilation and dust suppression.

Northwestern Alaska is not from a geographic point of view truly compatible with any of these areas. The permafrost is similar to that in the Lena Basin, but the climate more closely approximates that of the

Vorkuta area. Whether or not underground coal mining in northwestern Alaska would encounter the underground mine fire problem of the Noril'sk area is unknown.

The Soviet system of costing and of presenting productivity data is quite different from that used in the United States. For this reason, direct comparisons should be made with caution. The fact is that the government of the USSR has made a substantial investment in Siberian coal mining, an investment that has increased substantially during the last decade.

## 2.0 THE PECHORA COAL BASIN (VORKUTA AND INTA COAL MINES)

### 2.1 Summary

This chapter summarizes the most significant information on the physical constraints on Arctic coal mining obtained from the literature regarding the Pechora Coal Basin.

Soviet experience in this maritime Arctic region located at the same latitude as Fairbanks, Alaska, and characterized by discontinuous permafrost shows that there are definite trade-offs involved in developing coal mines. These particularly are found in the relationships among mine ventilation, coal gas and dust content, water inflow and permafrost. Inadequate attention to this inter-relationship under similar conditions could result in costly delays in opening a new mine, long-term deterioration of permanent shafts, and difficulties with sudden inflows of water.

The thermal changes occurring in an underground coal mine in permafrost are a function of the (1) velocity and volume of heat entering the mine through ventilation, (2) that entering the mine and the surrounding

rock from inflow of ground water, and (3) heat from chemical oxidation of the rock and the coal. The excavation of mine openings can greatly increase the introduction of heat from all three of these sources.

First there is a brief description of the Pechora basin. This is followed by the Soviet economic argument that Pechora coal is cost competitive in northern European Russia with alternative sources of domestic coal. A discussion of equipment problems shows that Arctic conditions reduce the service life of mining equipment by 50%. The following sections mention labor turnover, which appears to be high but not excessive, and discuss some major problems in opening new shafts in the 1950s. Thawing can occur very quickly in new mine openings and actually prevent their completion. The answer adopted by the Russians was to ventilate and cool the area external to the entries.

The next section indicates that blasting under the conditions of the Pechora basin can increase the rate of water inflow into the mines by fracturing the roof. Then follows some employment data. These data are probably more a reflection of Soviet practices than they are of the influence of the Arctic on labor requirements.

The final section focuses on mine ventilation problems which are related to gas, dust, and permafrost degradation. The Russians maintain a large scientific research staff in Pechora and have faced some serious water control problems in the Pechora Mines. These problems involve the inter-relationship between underground mining and the natural ground water systems, a factor which could apply to those parts of arctic Alaska with ice rich permafrost.

## 2.2 General Characteristics

The Pechora coal basin lies at the northern extremity of the Ural Mountains in the Komi ASSR of the USSR. It is part of the northwestern USSR and lies between 67°10' and 68°30' North latitude and 63°20' and 65° East longitude. Topographically, the area consists of a plateau with maximum elevations of 100-260 m above sea level, cut by broad lake and bog studded river valleys. Geologically, the area consists of a folded sedimentary basin of Permian age overlain by Quarternary glacio-fluvial deposits and recent alluvium. Permafrost varies from 45 to 132 m in thickness and has an average temperature slightly below freezing. The permafrost has a large ice content, many unfrozen areas, and a large number of cracks or fissures through which water penetrates from the surface.

The region has a maritime Arctic climate, with a mean annual temperature of -5.7°C, a mean high temperature of +11.4°C (July) and a mean low of -19°C (January). June through September is characterized by above freezing temperatures, while the remainder of the year is below freezing. Mean annual precipitation is 620 mm, of which 61% occurs as snowfall. The snow cover forms in the first part of December and melts in the beginning of June, with a maximum snow depth of 65 to 100 cm occurring in March and April. Blizzards are very frequent during the winter, with wind occurring 84% of all days during the year. The mean winter wind is from the southwest and the average summer wind is from the northeast. Maximum winter wind speeds reach 40 m/sec (approximately 80 miles per hour).<sup>1</sup>

The Pechora coal basin produces approximately 20,000,000 tons of

coal per year from underground mines, most of which are below the permafrost. The basin was first developed in the early 1930s, with production increasing during World War II, and a major program of capital investment beginning in the late 1960s. There are two primary basins: Vorkuta, containing the principal settlement, and Inta. Vorkuta produces high grade coking coal used to produce what is supposed to be the best pig iron in the USSR at the Cherepovets steel mill. Inta produces energy coals used in the northern part of the European USSR.

The European portion of the USSR is deficient in coal, having only one major coal district, the Donets, in the Ukraine. The northwestern portion of the USSR is an energy deficient region, and the Pechora basin, tied to the Northwestern USSR by the 2,000 km long Vorkuta-Kotlas Railroad, is viewed as a major supplier of energy and metallurgical coals. The use of Pechora coals will increase in the future.<sup>2</sup>

This energy deficiency was the basis for a significant increase in investments in the Pechora Coal Basin. The use of modern mechanized mining systems began in 1967. In the late 1960s, mines were consolidated, the number of working faces reduced, new mines brought into operation, and other measures carried out to both increase total production and labor productivity. As of 1 January 1968, the coal reserves were estimated at 214 billion tons. The coking coals have less than 1% sulfur, an ash content of 16-17%, almost complete absence of phosphorus, and good coking qualities and hardness. The average seam thickness is 2-3 meters, and the beds are relatively flat lying, most at a dip of less than 45 degrees. New mines are being developed to depths of 400 m.<sup>3</sup>

As a developed coal basin undergoing major technological changes, the Pechora Basin has experienced many difficulties associated with the north: high precipitation, discontinuous permafrost, and excessive surface and underground drainage problems. In addition, the coal mining organizations have had to present arguments justifying the high costs of operation in the Arctic.

### 2.3 Economic Arguments in Favor of Arctic Coal

The arguments, in addition to the simple fact that northern European Russia is deficient in coal, rest on comparisons with the other major basin of European Russia, the Donets in the Ukraine. Here the Pechora Basin is viewed as being more favorable geologically and having coking coal of higher quality, leading to lower real extraction costs and higher net benefits. The following table compares the two basins.<sup>4</sup>

|  | <u>Donets</u> | <u>Pechora</u> |
|--|---------------|----------------|
| Average Seam Thickness (meters)            | 1.04          | 1.79           |
| Average Thickness of Seams Worked (meters) | 0.92          | 1.82           |
| Depth of Mines (meters)                    | 453           | 409            |
| Loading per face (tons/24 hrs)             | 295           | 553            |
| Loading per shaft (tons/24 hrs)            | 1,380         | 2,631          |
| Productivity (tons/month/miner)            | 36.9          | 54.8           |

The actual cost, however, of Pechora coal (excluding transportation) has been 10 to 12% higher than that of Donets coal, but this in large part is explained by the fact that the Pechora coal mines bear costs

which in the Ukraine are not charged against the mines. These include the costs of social and cultural overhead, fire protection for settlements, operation of surface railroads, some costs for road maintenance. Were these costs to be removed, then, so the argument runs, Pechora coal would actually be less expensive at the mine than Donets coal.<sup>5</sup>

Underground coal mining is a labor intensive operation. Labor costs account for 59.6% of total mining costs in the Pechora Basin, which is somewhat higher than the national average for coal mines in the USSR (53.2%). In addition, Pechora wage rates, with the special bonuses for working in the Arctic, are 1.5 to 3 times higher than the national average. However, mechanization has led to a reduction in the total amount of labor required by 36.5% during the last decade. From 1960, coal production increased by 20%, but the total number of employees decreased by 5.4%. The high cost of labor in the Arctic is compensated by greater productivity, with the Pechora Basin having labor productivity rates 45 to 50% higher than those of the Donets. More than half of the coal mined in the Pechora Basin is produced at a lower cost than in the Donets Basin.<sup>6</sup>

#### 2.4 Equipment and Maintenance Problems

The severe climate, and the failure to design equipment specifically for Arctic conditions, has resulted in an equipment service life significantly shorter than normal. On the average in the coal industry of the USSR, equipment has a life service span of 6.62 years, but in the Pechora Basin the average is 5.23 years. Equipment used by the Vorkutaugol' combine, the organization operating the Vorkuta Basin coal mines, has a life of only 4.83 years. Some equipment wears out so quickly that its



utilization rate is only 30 to 40% of normal. The basin has three large repair shops capable of performing major overhauls. The cost, however, is 50% or more of the cost of new equipment, while the productivity of the repaired equipment is lower and its operational costs are significantly higher.<sup>7</sup>

The Pechora basin lies in the Komi ASSR which has a population of approximately one million people. The coal mine organizations strive to utilize local resources to supply immediate needs, such as wood and metal mine props, certain types of spare parts, etc. The Komi ASSR is richly endowed with petroleum, natural gas, salt, titanium and bauxite ores, so that the possibility exists for the development of primary manufacturing, particularly of chemicals.<sup>8</sup>

#### 2.5 Coal Mining Vs. Forestry

The mining of coal is viewed as a more productive use of land than forestry. On the average in this region, one hectare of forested area produces 400 tons of timber (apparently per crop), whereas mining a seam only one meter thick over the same hectare will produce 14-16,000 tons of coal.<sup>9</sup>

#### 2.6 Labor Turnover

Labor turnover in the Vorkuta and Inta coal mines dropped from 33-35% in 1964 to 20-25% in 1970, making it lower than the average for the coal industry of the RSFSR. In the Komi ASSR as a whole, however, it appears that there is a net out-migration of labor, and that many critical specialties can only be filled by importing labor from other regions. The rate of natural population increase dropped from 24.5 per 1,000 in

1966 to 10.5 in 1970. Whether or not this suggests labor supply difficulties in the coal mines is not evident, since only 16% of the total population of the Pechora basin is employed in the mines.<sup>10</sup>

### 2.7 Problems of Opening Mines in Permafrost

The following section is taken from an article published in 1958 which describes problems encountered under Arctic conditions.<sup>11</sup>

The basic difficulties involved in mining in permafrost in the Pechora basin are those related to thawing of the discontinuous permafrost which has a temperature close to freezing. In addition, roofs have a tendency to come down slowly unless special measures are taken to promote roof collapse, important in long wall mining.

The development and maintenance of permafrost underground works is hindered by the thawing of permafrost, which, inter alia, is caused by the high rates of infiltration of underground waters. The excavations increase water flow and thereby increase the amount of heat brought into the mines, causing thawing in the permanent openings.

Thawing of the permafrost causes settling under surface structures and deformation of the main shafts and surface works. The answer to this problem is the utilization of special techniques to isolate the excavations and surface works from the permafrost. This is made difficult by the fact that the regulations governing coal and oil shale mines, issued by the Ministry of Coal Industry, do not contain special regulations regarding mining in permafrost. The planning organization basically responsible for planning development in the Pechora Basin, Lengiproshakht, has not taken the special conditions of permafrost and hydrology charac-

teristic of the Pechora Basin into consideration in designing mines. The result has been in some cases the creation of dangerous conditions in the mines.

A particular problem was encountered in sinking new shafts. In one case, preliminary borings indicated the existence of frozen sands cut by a water bearing horizon 7 to 8 meters thick. The technique adopted assumed that water would be a problem only in that horizon. However, the water entered the shaft and quickly thawed the frozen sands, resulting in considerable collapse, and the size of the water bearing stratum rapidly increased due to thawing from 7 to 20 meters. Pumping the water caused settling in the sands which in turn caused supports to fail. Work could not be renewed until the sediments were frozen by artificial means. This required a construction delay of two years and a cost increase of more than six million rubles in Mine No. 25.

In another shaft similar problems were encountered. Quarternary sands, clays and ground moraine had a temperature of  $-0.3^{\circ}\text{C}$  at a depth of 25 meters, and an active layer about 10-14 meters thick. The normal methods of shaft sinking were employed, with work occurring in the summer, resulting in rapid thawing of the clays. The temporary wooden props were deformed by the increased pressure, while a large depression formed on the surface due to collapse of the clays. The surface waters rapidly drained into the depression causing an even greater rate of thawing of the permafrost.

The solution to this problem was to drill special cooling and ventilation holes by means of which the shaft was frozen from December to May. During this period temperature measurements were made. During two and a half months, the following results were observed:

| <u>Distance from the Wall</u> | <u>Rock Temperature</u> |
|-------------------------------|-------------------------|
| 0.5 m                         | -9.3°C                  |
| 1.0 m                         | -2.2°C                  |
| 1.5 m                         | -0.2°C                  |

Temperature measurements within the shaft during the middle of January showed that with a surface temperature of approximately -12.5°C, the temperature 70 meters down the shaft was -6.3 to -6.9°C.

Other mines also utilized cooling to freeze the Quarternary sediments. Here it was found that reducing temperature to -5 to -7°C sharply reduced the viscosity of the clays, which in turn considerably improved the rate of excavating. The greatest difficulties in tunneling occurred with gravels and sandy gravels, particularly frozen ones. The difficulties increased with increase in ice content. The relationship is as follows:

| <u>Material</u>              | <u>Work Expended</u> |
|------------------------------|----------------------|
| Thawed loams                 | 1                    |
| Frozen loam                  | 1.8                  |
| Large grained sands          | 2.5 - 3.2            |
| Sandy gravels                | 4                    |
| Heavy gravels (temp. -1.5°C) | 4.8                  |

Difficulties are especially encountered in drilling operations. Mechanical drilling loses effectiveness in permafrost, so that heat is often utilized. In view of these difficulties, experiments were conducted to thaw permafrost by electrodes, which were able to thaw 10-20 cm of ground in 2½ hours. Another experiment was the use of bore holes into which water was poured and heated to the boiling point. The heating element

was removed and excavation commenced when the thaw bowl reached a diameter of 2.5 - 3.0 meters.

At the present time, the greatest danger in the openings of mines in the Pechora Basin is thawing outward from the mine openings, which results in flooding. The thawing rate is a function of shaft ventilation. As thawing continues over time, with an ever expanding thaw bowl, increased water not only enters the mine but also penetrates into the coal. As a consequence the coal freezes when it reaches the surface, which complicates surface work during the winter months.

Deformation of vertical shafts destroys the concrete supports. Bulges form at certain depths. Horizontal openings have even greater problems due to the heat exchange caused by circulating ground water, heated ventilation air, and the underground network of steam pipes. The result of thawing is a significant increase in rock pressure which causes roof collapse and prop failure. At the present time (1958), approximately half of the active shafts in the Pechora basin suffer from deformation. The answer to this problem is to maintain the rock temperature to prevent thawing and to control the surface and ground water.

Shaft 27 was designed with inclined drill holes to introduce cold air along the sides of the shaft and remove heat, particularly the heat penetrating the shaft walls from the heated ventilation air. In this fashion the rock around the shaft is cooled in winter, and then the holes are blocked in summer to prevent incursion of warm summer air. In addition, in those places where compaction due to water loss occurs, cement grout is introduced into the rocks to maintain their previous volume. This system was effective in some areas, but proved less valuable in water

bearing horizons.<sup>11</sup>

Permafrost introduces another problem unrelated to thawing. Because of the inherent stability of the frozen material, the roof behind an advancing or retreating longwall operation does not cave properly.<sup>14</sup>

## 2.8 Blasting

In the Pechora area, the permafrost is fractured and cut by vertically oriented thawed zones through which water enters the mines. Blasting has the effect of increasing the fractures and thus the inflow of water and consequent increase in heat. The result of blasting, therefore, is to increase the amount of thawing over time.<sup>13</sup>

## 2.9 Employment

No direct data regarding employment figures were obtained. One article, however, describes the reconstruction of Mine No. 1 in the Inta area. Mine Number 1 began in 1941 as a development mine producing 100,000 tons of coal per year. Capacity increased to 300,000 tons per year in 1946. Between 1959 and 1963 the mine was rebuilt, and by 1969 capacity reached 910,000 tons per year. The improvements included replacing underground electric locomotives for coal haulage with a conveyor system. Between 1967 and 1970, the number of workers employed on the faces dropped from 361 to 200, while productivity increased from 160.3 tons per man month to 359.3 tons per man month. In 1970, the number of workers involved in underground coal transportation was 126, with another 144 working on roof support (perekrepleniye). Total employment in the mine equalled 1,394 people.<sup>13</sup>

## 2.10 Mine Ventilation Problems

The introduction of external air can cause a net inflow of heat into the mines which in turn can cause long-term thawing and deformation of permanent works. In addition, however, the air can cause oxidation in both the coal and the surrounding rock. In the Pechora basin, oxidation results in coal sometimes having a significantly higher temperature than the surrounding rock.<sup>12</sup>

Most (if not all) of the active coal mines in the Pechora Basin exploit seams from 500 to 700 m underground. The depth of the working faces increased from an average of 208 m in 1958 to 500 m in 1959. The methane content in the Vorkuta coals reached 50 m<sup>3</sup> per ton. The Inta coal seams have a lower gas content, from 1 to 8 m<sup>3</sup> per ton. The Inta seams being worked are at depths of 160 to 300 m (the upper seam) and 630 to 800 m (lower seam). The mine is considered dangerous because of dust, and the deeper mines have problems with rock and coal bursts, and some of the Vorkuta coals are subject to spontaneous ignition underground. In addition, the roofs are difficult to collapse, an important factor in long wall mining.<sup>14</sup>

There is an obvious difficulty here in determining the proper trade-offs between the velocity of air necessary for gas control and the contribution of ventilation air to the generation and spread of coal dust, thawing, and oxidation of the coal. With some coals, oxidation can cause increases in temperature sufficient to create underground mine fires through spontaneous ignition.<sup>15</sup>

To further complicate the matter, it appears that policy requires the heating of incoming ventilation air so as to maintain mine air temperatures of plus 2°C. This practice should prevent freezing of water in the shafts,

a distinct advantage, but at the cost of further increasing the amount of heat exchange and its attendant problems.<sup>16</sup>

### 2.11 Scientific Research

The literature search indicates that the Pechora coal mines obtain research support from many organizations in the USSR, including specifically the V. A. Obruchev Institute for Permafrost Studies. In addition, mine plans and designs are developed in Leningrad. For more parochial problems, the Pechora Basin also has its own Scientific Research Coal Institute (Pechor NIUI), which was founded in 1957. This institute is divided into six sections, maintains fourteen laboratories, has 148 scientists and 15 candidates of sciences, and has published some 400 articles and 45 books and brochures. The Institute has worked on the problem of designing plants for improving the quality of coking coals and also on various technical and economic problems.<sup>17</sup>

### 2.12 Surface and Mine Water Problems<sup>18</sup>

The surface of the Pechora Basin is covered with Quarternary alluvium and glacio-fluvial deposits. Much of the surface area is thawed (up to 50% in some areas) with an extensive network of thaw lakes, bogs, streams, and flows of ground water below the stream beds. The permafrost extends to a depth of 50 to 170 m. The rocks underlying Recent deposits are a sequence of sandstones, argillites, and claystones of Permian age. The permafrost is cut through by vertical thaw zones, and contains extensive areas of thaw (taliks).

The hydrology of the area consists of three water systems: the surface, permafrost, and subpermafrost, each of which has a different chemical



composition. The surficial water consists of both surface and ground waters, including flows under stream channels and infiltration from rivers.

The permafrost waters consist of inflows from the surface along the vertical thaw zones, and flows through the Permian sandstones which are highly permeable and act as aquifers.

Mine excavations can interfere with these systems. Excavations in the thawed layer above permafrost (from 4-6 to as much as 30-40 m) cut into the surficial waters, particularly the ground waters flowing through unconsolidated sands, gravels, and clays. Mine openings in the permafrost cut across horizontal and vertical thawed zones, receive infiltration from the surface, and also cut across the water bearing sandstones. Below the permafrost, the two upper systems join with the subpermafrost waters.

Shaft sinking causes an increase in the velocity of ground water flow, and because there is an influx of heat through ventilation, an expansion in the size of the water bearing horizons. Pumping water out of the mines and emptying it on the surface can result in this same water re-entering the shafts through the vertically thawed zones. In addition, shafts can increase the rate of infiltration of stream and stream bed water into the ground water.

In the areas studied, the normal velocity of ground water flow was 1.5 liters/sec/km<sup>2</sup>. The result of shaft construction was to increase the velocity of flow to 4.5 liters/sec/km<sup>2</sup>, or a threefold increase.

The average rate of water inflow in the coal mines varies from 75 to 150 m<sup>3</sup>/hour. However, mines near rivers have inflows as high as 300 to 500 m<sup>3</sup>/hour, because of the high volumes of water flowing under the rivers as ground water.

In some cases, roof collapse can increase the porosity of the rocks 20 to 30 fold and cause the rate of water infiltration to increase tremendously to as high as 1,500 m<sup>3</sup>/hour. Due to the hydrology of the region, as summarized above, very significant variations in rates of mine water inflow occur, resulting in substantial requirements for pumping and other dewatering facilities and installations, e.g. reservoirs.

One proposed solution to the mine water problem is to drain the surface area that will be in the depression cone around the shafts. This should be done by drainage ditches with impervious bottoms to prevent downward infiltration. Similarly, the river channels in the area affected could be lined with impervious materials.

There is a relationship between permafrost thawing, shaft degradation, and both the volume and velocity of water inflow. As mining progresses, the rate of water inflow increases, thus increasing the amount of heat brought into and around the mine openings, causing thawing and tunnel deformation. At some point, however, it appears that the mine water inflow stabilizes.

The literature search did not indicate any consideration of the possible environmental impact of draining a large surface area in order to decrease water infiltration into the underground mines. Were this practice to be necessary in northwest Alaska, the environmental considerations could be very real and must be considered. Another factor to be considered would be the effect of underground mining on surface, intra-permafrost, and sub-permafrost water, flows, and the possible impact of these effects on streams and lakes.

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### 3.0 NORIL'SK DEPOSIT<sup>1</sup>

#### 3.1 General

The coal mines of the Noril'sk Metallurgical Combine are the principal energy source of one of the largest enterprises in the USSR. From 1971, however, the main source of energy will become natural gas, and the consequent decrease in coal production will significantly decrease the investment in coal mining. The Noril'sk coal region lies on the Taymyr peninsula and is part of the Tunguska basin. The area has 28 coal seams with reserves of tens of billions of tons. There are twelve seams being worked, divided into three sections: Noril'sk, Karayelakhsk, and Imangdinsk.

The Noril'sk deposit is situated 300 km north of the Arctic Circle and has a mean annual temperature of  $-8.5^{\circ}\text{C}$ . The number of frost free days ranges from 40 to 110 per year, with 80 being the average. The mean annual wind speed is 5.9 m/sec, with the maximum being 50 m/sec. Mean annual precipitation equals 500-600 mm. The depth of permafrost ranges from 0 to

3 m in the valley of the Norilka River to 370 m in highland areas.

In vertical cross section, the permafrost can be divided into three zones. These are the active zone, the zone of accumulation, and the zone of constant temperature. The active zone is the depth of thaw during the period from July 15 through September 15th, and varies according to morphology, relief and aspect.

The accumulation zone has been poorly studied. In general it varies in depth from 12 to 17 m. Below this is the zone of constant temperature which is not influenced by variations of atmospheric temperature.

For many years the mines operated without the use of heating devices, but from 1953 to 1961 such devices were installed in all mines. Without heating devices, the mine air temperatures in winter at the working faces ranged from  $-2^{\circ}\text{C}$  to  $-8^{\circ}\text{C}$  and the temperatures of the surrounding rocks and coal varied from  $-3^{\circ}\text{C}$  to  $-6^{\circ}\text{C}$ . After the installation of mine air heating devices, the air temperatures of the mine atmosphere ranged from  $+4$  to  $+8^{\circ}\text{C}$ . At a distance of 0.5 m from the mine works, the temperature in the coal and in the rocks ranged from  $-1.5^{\circ}\text{C}$  to  $-3^{\circ}\text{C}$ . Seasonal variations in the temperature regime along the ventilation ways showed little change except near the mine opening.

### 3.2 The Deposit of Smith and Hope Mountains (gor Shmidta i Nadezhdy)

The deposit is cut by numerous fractures along which air reaches to significant depths causing oxidation of coal which thereby increases the danger of spontaneous ignition when the coal is mined. One of the seams in this deposit contains metallurgical grade coal which has for a long time completely satisfied the needs of the metallurgical combine for this product.

There are seven underground and two surface coal mines in the Noril'sk Metallurgical Combine. The Kayerkansk deposit is worked by one active surface mine and a second surface mine is under development. The Mount Smith and Hope deposit is worked by five underground mines all of which are dangerous because of gas. The mines all use the suction system of ventilation. The opinion has long existed that the gas content of the coal increases with depth and that gas release is greater in thawed rocks. The maximum gas generation was measured in November, 1963, when the ventilation air exiting a mine showed up to 68 m<sup>3</sup>/ton of methane.

There has been more than thirty years of experience in coal mining in the Noril'sk deposit. For a long time the room and pillar system was employed. The room and pillar system, while quite effective, increases the potential danger from endogenous fires. Roof collapse in this system occurs after 6 to 12 days. The effectiveness of the room and pillar system employed in Noril'sk is no lower than in other areas of the USSR and in some cases is higher. The system is particularly appropriate where roofs are weak. The weaknesses lie in the large amount of coal left underground, the increased danger to the workers, incomplete ventilation of the working areas, the low level of mechanization in coal loading, and the large amount of labor used for placing wooden props.

Roof bolting has been employed in place of using wooden props. However, there is not yet a common system for drilling into roofs, and there have been cases of sudden roof collapse over large areas after roof bolting.

A system has been utilized in which the roof directly over the working area is not supported. Here the coal is removed by scrapers and taken to the haulage way, so that there are no people right at the working face.

This system has not been widely utilized because there are limited reserves of suitable coal.

### 3.3 Endogenous Fires

The only coal mines in permafrost in the USSR characterized by endogenous fires are those of Noril'sk. When plans were formulated for developing the Noril'sk coal deposit, the coals were assessed as not being subject to spontaneous ignition. The first underground endogenous fire was discovered on July 2, 1949. From then until 1966, there have been many fires. Four occurred in the period 1949-1951 and for the following five years there were no fires, but in 1956 there were two fires simultaneously. Subsequently fires occurred almost every year. The fires have continued to burn for many years, and as of January 1, 1966, there were eleven endogenous fires still burning, which has resulted in significant losses of coal and increased operational costs for fire suppression and prevention.

Data on the gas content of mine air just prior to the fires gave no indication that a fire was imminent. Similarly, there were no visual signs that a fire was about to break out. Plans were made in 1957 to attempt to put out the fires by pumping liquid clay into the mines to form barriers.

Analyses of coal samples made in 1937 indicated that the Noril'sk coals were not subject significantly to spontaneous ignition.

More recent analyses have shown that the capacity of coal to absorb oxygen is a function of temperature. As temperature increases, so does the capacity of coal to absorb oxygen, which in turn means that chemical activity also increases. Analyses of chemical activity showed that Noril'sk



coals have a lower level of activity than coals from other parts of the USSR.

During the first years in which the field was mined, few precautions against fire were utilized and the mined areas were not isolated from the haulage ways. Extremely large amounts of air with an oxygen content above 20% entered the mined area. The temperature of the mine air reached 5°C and higher as a consequence of the heat generated by mining operations and poor ventilation of excavations near the working faces.

These conditions exist in both seams one and two, and yet only seam two has had endogenous fires. The reason appears to be that the heat generated in seam one does not accumulate but, due to the favorable geologic conditions, is lost to the mine air. In seam two, however, the velocity of the ventilation air leaving the worked out areas is significantly less than in seam one. The result is the accumulation of heat which, with oxidation of the coal, results in endogenous fires. The lower air velocity through the waste coal (the room and pillar system is employed) results from the presence of clay and sand layers within the coal seam. It appears that the most likely places in which spontaneous ignition will occur are in waste coal pillars at a distance of 5-7 meters from the entry along which moves the fresh ventilation air stream. Pulling the pillars in such a way as to create large fissures in the coal increases air movement and thereby prevents the accumulation of heat.

Experiments were conducted underground to determine the relationship between temperature and chemical activity in Noril'sk coal. The results suggest that if the natural thermal regime is maintained there will be little probability of spontaneous ignition.

Experiments also showed that moving air heated to  $+7^{\circ}\text{C}$  through a small coal pile caused an increase in coal temperature to  $+11^{\circ}\text{C}$  initially, but later the temperature dropped to  $7^{\circ}\text{C}$ , showing that the heat generated was adequately dissipated. Thus, there is little danger of spontaneous ignition if the heat generated by chemical action is dissipated.

Experiments also showed that moving air heated to  $+7^{\circ}\text{C}$  through a large coal pile caused a temperature increase first to  $+11^{\circ}\text{C}$  and subsequently to  $+26^{\circ}\text{C}$ . Subsequently, the pile was isolated from incoming air, and this caused the temperature to drop back to  $+11^{\circ}\text{C}$ . The results indicate that the movement of mine air with a temperature of  $+7^{\circ}\text{C}$  through a large coal pile creates the highest danger of endogenous fires. The center of the fire is at the center of the coal pile.

An additional experiment involved moving air with the same temperature as that of the surrounding rock through a large coal pile. No increases in coal temperatures were noted.

The experiments indicate that even a small increase in mine air temperature, on the order of 3 to  $4^{\circ}\text{C}$ , can initiate a significant increase in chemical activity in coal and thereby increase the risk of spontaneous ignition under permafrost conditions.

The most significant conclusion reached is that maintaining temperatures equal to those of the surrounding rock will maintain the natural thermal conductivity. This enables adequate dissipation of heat generated in the coal by chemical action, and thereby prevents spontaneous ignition of coal mined by means of the room and pillar system under permafrost conditions.

Measurements of the heat exchange in a dead end room with temperatures held at those of the surrounding rock show the following:

|                                |         |           |
|--------------------------------|---------|-----------|
| Heat Generated                 | 0.00896 | cal/ml·hr |
| Coal Heating                   | 0.00180 | "         |
| Heat Lost to the Air           | 0.00003 | "         |
| Heat Loss to Surrounding Rocks | 0.00713 | "         |

The last figure, heat loss to rocks, can only be explained by the low temperature of the permanently frozen rocks. Almost all the generated heat is consumed in heating the coal of the coal pile or, is removed by thermal conductivity. This accounts for 99.6% of the generated heat. By calculating the time, it can be determined that the amount of heat retained would be sufficient, under a below freezing temperature regime, to cause spontaneous ignition of coal after approximately 17 years.

Measurements of the heat exchange under conditions of good ventilation in which the air has a temperature of 7°C above freezing show different results, as follows:

|                 |          |           |
|-----------------|----------|-----------|
| Heat Generated  | 0.01046  | cal/ml·hr |
| Coal Heating    | 0.00036  | "         |
| Lost to the Air | -0.00222 | "         |
| Other Heat Loss | 00.01233 | "         |

The negative sign in front of the number for heat lost to the air reflects the effect of warm air on rocks with below freezing temperatures, and indicates that heat is gained from the air.

By calculating the time, it appears that under these conditions

(temperature of the air being at  $+7^{\circ}\text{C}$ ) the point of spontaneous ignition will be reached after six months, which is reasonably close to the actual history of the underground fires studied.

Under permafrost conditions, the thermal conductivity of the rock is about  $0.01 \text{ cal/ml}\cdot\text{hr}\cdot\text{degree C}$ , whereas in the Kuzbas it is equal to  $0.00285$ . Probably this difference stems from the influence of ice in the rock and the low rock temperatures.

### 3.4 Permeability of Ventilation Shafts<sup>3</sup>

There are special difficulties encountered in the development of main and secondary ventilation shafts. The below freezing temperatures of the atmosphere and a wind speed of  $3\text{--}6 \text{ m/sec}$  prevents the use of water and other freezable liquids and damages structures. Near the entry ways, the temperature difference between the winter incoming air ( $-50^{\circ}\text{C}$ ) and the rock temperature, and the pressure differential between the rock and the tunnels cause difficulties. The ventilation ways are composed of concrete, and fractures develop over time causing a loss of ventilation air as high as ten percent. The fractures are gradually widened through the removal of concrete due to the pressure differential between the inside and the outside of the concrete walls.

Similar problems are encountered with the construction of blocking walls for isolating areas. The designs and techniques for building such walls cannot be automatically transferred from other areas but must take permafrost conditions into account.

"As is known, the Safety Regulations for Coal and oil shale mines, adopted in 1963, did not take into account the specific conditions of work

under permafrost conditions, and only in recent years has this situation been partially corrected."

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## 4.0 COAL MINES OF THE LENA BASIN (YAKUTIYA)

### 4.1 General Characteristics

The basin of the middle and lower Lena River, including the basins of its tributaries, the Aldan and Vilyuy Rivers, is estimated to contain 30% of the total coal reserves in the USSR. The estimated reserves in 1969 in this Mesozoic province were 3,000 billion tons.<sup>1</sup>

The coal basins lie in a region of predominately continuous permafrost lying between about 56° and 72°N latitude and 100° and 140°E longitude. In this large region there is, generally speaking, an increase in the thickness of the permafrost from south to north, although factors other than latitude are involved in permafrost distribution. The active layer varies in depth from less than 1 meter at the lowest (northernmost) part of the river Lena to more than 2 to 3 meters in the southern part of Yakutia, the area of Aldan and Chul'man. In the basin of the Vilyuy River, a major left bank tributary of the Lena, the active layer is two to three meters thick. The lower Lena area has permafrost reaching to a depth of 500 meters and more, while the central Lena has a depth of 200

to 400 meters. The southernmost area, the Aldan Chul'man region, has permafrost to a depth of 200 meters (the same depth of permafrost is also found in the Laptev Sea offshore from the mouth of the Lena).<sup>2</sup>

In this region, the most promising area for coal development appears to be the Southern Yakut Basin (latitude 57°N latitude, 122°-126°E longitude) which can supply coking coals to the metallurgical industry east of Lake Baikal. Prior to 1959, coal from this basin was utilized only for local needs.

The oldest coal mine in the Lena basin is situated at Sangara near the confluence of the Vilyuy and Lena Rivers (64°N, 128°E). It produced 187,000 tons in 1954 primarily for the Northern Sea Route vessels and for the Lena gold industry. The Dzhebariki-Khaya deposit on the middle Aldan (62°N, 136°E) produced 108,300 tons in 1954 for use along the Aldan and upper Lena Rivers. The Kangalassk (Surgutsk) deposit (62½°N, 129°E) situated on the left bank of the Lena about 45 km northeast of Yakutsk produced about 60,900 tons of coal in 1954. This coal can be transported and stored for long periods of time when frozen, but quickly disintegrates and is subject to spontaneous ignition when thawed. Very high quality coal exists at Sogo (Sogo-Khaya), an island at the mouth of the Vilyuy, which has been mined on a small scale in the past and which, due to its high quality and location, may be significant in the future. The Soginsk deposit situated along the coast of the Laptev Sea 14 km from the port of Tiksi (71½°N, 129°E) produced 57,500 tons of coal in 1954 primarily for power plants at Tiksi and at various fishing factories in the lower Lena. The Zyryansk deposit (66°N, 150°E) on the Kolyma River produced 136,000

tons in 1954 principally for the Kolyma River fleet and to supply the polar stations at Chukotka and Wrangel Island. This deposit contains high grade coking coals and is a low cost producer.<sup>3</sup>

The first exploration of Yakut coal occurred in 1736 with study of the Kangalassk deposit near Yakutsk. Coal was first mined here near the end of the eighteenth century for use by the Billings expedition. During the following century this coal was used by gold mining organizations in the area. The Sangar deposit was first tested and explored in 1913. The Sangara and Kangalassk deposits were studied and developed in 1928 and 1930, and the Chul'makansk deposit in Southern Yakutia and the Zyryansk basin were developed in the late 1930s. The first coal was mined in the Dzhebariki-Khaya in 1940. At present about 800 coal deposits are known in Yakutsk.

The coal mining organization Yakutugol' formed in 1966 controls four underground mines, Sangara, Dzhebariki-Khaya, Chu'l'mansk, Sogo, and three surface mines, Zyryansk, Kangalasskiy, and Neryungrinskiy. Each mine supports a closed, small industrial region containing electrical power stations, vehicle parks, river vessels, suitable agricultural undertakings, construction sections, timber industries, etc. In the underground mines, seams 1.7-3.5 m thick are worked, and in the open pit mines seams 3.5-49 m thick are worked. The gas content of the seams being worked is insignificant. The region is tectonically quiet. The Sogo underground mine and the Kangalasskiy and Zyryansk surface mines are worked only from October to May. During the summer the mines are improved, repair work undertaken, and coal shipped. The capacity of the underground mines is 80,000 to 400,000 tons per year and that of the surface mines is 120,000 to 450,000

tons per year. Coal production increased from 923,000 tons in 1960 to 1,589,000 in 1971.<sup>4</sup>

With the special bonuses for Arctic work, labor costs amount to 64.6% of total costs for coal. In 1971 the average cost per ton of coal mined by Yakutugol<sup>1</sup> was 7.66 rubles, with underground coal costing 10.52 rubles and surface mined coal 4.80 rubles per ton. The use of improved technology has increased monthly productivity per miner from 83.4 tons in 1965 to 100.7 tons in 1971, which includes an increase in underground productivity from 63.3 to 69.6 tons per man month. At the same time the percentage of coal obtained from surface mines increased from 39.6% to 49.4%.<sup>5</sup>

Yakutia lies approximately in the heart of Eurasia and is surrounded on the east, west, and south by mountain ranges. Except along the Arctic coasts, its climate is continental in the extreme. Mean minimum ambient air temperatures in the coal mining areas range from  $-49$  to  $-64^{\circ}\text{C}$ , with absolute extremes as low as  $-69^{\circ}\text{C}$ . The average length of the frost free period ranges from 45 to 103 days, and precipitation is small, ranging from 90 to 350 mm per year, occurring primarily as summer rainstorms. With the exception of the area containing the Sogo deposit, wind speeds are generally low. Relative humidities are high, averaging between 70% and 80% throughout the year, so that equipment should be designed with a view toward operation in a wet atmosphere. Sheet ice is also a problem, particularly for surface mining.<sup>6</sup>

The coal mines are situated in permafrost, which ranges in temperature from  $-11^{\circ}\text{C}$  (Sogo) to  $+0.5^{\circ}\text{C}$  in the Chul'mansk mine. Permafrost in itself is not a difficulty for surface mining except during summer when



special measures must be followed to maintain the stability of slopes, tailing piles, and roads under thaw conditions. However, frozen ground does create special conditions for underground mining which affect blasting, loading, transportation, ventilation, and utilization of automated equipment. Small changes in temperature can cause significant alterations in roof stability and cause sudden roof collapse.<sup>7</sup> Heat exchange between the mine atmosphere and the surrounding rocks influences dust generation, particularly during winter when dust generation can exceed 2,200 mg/m<sup>3</sup>. In addition, underground fires can be caused by oxidation in the coal seams resulting from mine ventilation.<sup>8</sup>

#### 4.2 Sangara Deposit (64°N, 128°E)<sup>9</sup>

The deposit is situated near the settlement of Angar which has a population of 6,000 people. The mean annual temperature of this area is -10.1°C, with a mean annual precipitation of 265 mm. High winds occur in summer. The area is served by river transportation along the Lena and by aircraft and by winter roads. The coal is consumed along the Lena and is also transhipped via Tiksi to the basin of the Yana River, where, due to high transportation costs, it is sold for up to 108 rubles per ton. The sale price at the Sangara mine is set at 12.85R per ton for coal with an average ash content of 15%.

The mine which is worked from five shallow shafts is dangerous because of gas and has had several gas explosions. The coal mined occurs in dry permafrost with an active layer 1.5 - 3 m thick and an inactive layer reaching as deep as 200 m. Permafrost temperatures vary from -0.9°C to -3.2°C. There appear to be no water bearing formations in the mine in

spite of its proximity to the Lena River. It is assumed that ground water exists below the permafrost, and should coal below permafrost be worked there would be a need for pumps. The problem then would be how to pump water out of a mine and dispose of it at temperatures as low as  $-55^{\circ}\text{C}$ .

Ventilation is aided in winter by the air pressure, but is hindered in the summer. Ventilation velocity is 0.3 - 0.7 m/sec in development areas and is on the average 0.7 m/sec along working faces. The mining plan was adopted from practice in other areas with seams of the same thickness. This caused difficulties. Particularly under conditions of below freezing temperature, the method of isolating mined areas did not work, the norm for ten meter pillars was inadequate, the pillars collapsed, and thawing occurred along the roofs of the haulage ways. The incoming ventilation air is not heated, so during the lowest winter temperatures, the mine air temperature ranged from  $-3^{\circ}\text{C}$  to  $-9^{\circ}\text{C}$  at a distance of 800-900 m from the mine opening along the incline and from  $-2^{\circ}\text{C}$  to  $-4^{\circ}\text{C}$  at the working face. Summer temperature along the working face was near  $0^{\circ}\text{C}$ , while thawing occurred along the haulage ways.

During the winter of 1968-69, there was an attempt to heat the incoming ventilation air, but the heating system was not completed. At the same time, an effort was made to increase the humidity of the mine air by introducing steam into the fresh air stream 15-20 m from the mine opening. The result was moisture condensation, ice formation, over a distance of 200 m. Humidity was not measured, but there was no visual indication of any reduction in dust formation.

Dust is suppressed by the use of filters in the ventilation system, by clean-up and removal, by rock dusting, by removal of dust from working places by air, and by utilization of respirators. The Ural 2M combine (continuous miner) was first employed in 1968, but without the use of water for dust suppression. The maximum measured dust concentration occurred 3 meters behind (downstream) of the combine and reached  $244.6 \text{ mg/m}^3$  at a relative humidity of 74.1%, a temperature of  $-1.2^\circ\text{C}$ , and a ventilation air speed of 0.5 m/sec. Data show that dust generation exceeds health standards, but, even so, is lower than that created by this same machine without dust suppression in other mines. The use of the combine reduced coal extraction costs and eliminated blasting, the most dangerous part of underground work. Without blasting, the stability of the roof improved which in turn reduced both the accident rate and also the costs for wooden roof supports. In comparison with the drilling-blasting method, the combine increased worker productivity from 9.26 tons to 16.68 tons and reduced costs per ton from 0.72 rubles to 0.44 rubles.

Coal cleaning is done only by hand picking manually at the face and along the conveyors at the loading point. Annual production during the 1960s varied from 237,500 tons to 263,600 tons, with no major changes in technical or economic indicators of productivity.

#### 4.3 The Dzhebariki-Khaya Deposit ( $62^\circ\text{N}$ , $136^\circ\text{E}$ )<sup>10</sup>

The name Dzhebariki-Khaya means "Black Mountain". It is located on the shores of the Aldan River 60 km south of Khandyga and is connected with other settlements by light aircraft, river vessels, and winter roads. The coal is utilized by settlements along the Aldan River, river vessels

along the Lena, industrial centers along the Lena, and gold and other mining organizations along the Aldan.

The region's climate is extremely continental, with average winter temperatures ranging from  $-25^{\circ}\text{C}$  to  $-42.5^{\circ}\text{C}$  (January) and summer temperatures reaching to  $+30^{\circ}\text{C}$  in July and August. Relative humidity ranges from 62 to 80 percent; the 250 mm of annual precipitation occurs principally as summer rainfall.

Permafrost reaches to depths of 420 to 500 m and has a relatively constant temperature between  $-3.7^{\circ}\text{C}$  and  $-5.5^{\circ}\text{C}$ . In summer, heating occurs due to incoming air, and temperature changes can be noticed to a distance of 900 m along the ventilation way. Thawing occurs to distances as great as 35 cm in the roof and foot wall, resulting in the formation of mud along the foot wall and dropping of coal from the roof along preparatory works. Summer heat reaching the working faces causes intensive thawing of roofs leading to sudden roof collapse, thereby increasing the danger of mining.

The coal is not subject to spontaneous ignition. However, there has been a series of fires in the storage areas. Each fire has resulted from the same circumstances. Newly mined coal which is placed on top of coal from the previous year which was not shipped out during the summer shipping season ignites after intensive rainstorms and when air temperatures reach  $+25^{\circ}\text{C}$  (July, August).

The mining plan employs coal pillars with a width of 5 to 8 m for roof supports, and these have remained for many years. In all the development works, coal of up to 1.4 m thick is left in the roof. In some excavations, after 3-5 years the combined effects of thawing and rock

pressure cause this layer of coal to collapse. The basic roof, composed of sandstone, is not subject to collapse.

The mine is dangerous because of gas and dust. The mine ventilation system produces an air flow of 0.45 m/sec along the working face, 0.85 m/sec in the development works, and elsewhere between 0.9 and 1.4 m/sec. While rock temperatures remain more or less constant throughout the year, the temperature of mine air varies from  $-1^{\circ}\text{C}$  in summer to  $-6^{\circ}\text{C}$  in winter at a distance of 600 m from the mine opening.

From 1962 to 1969, the volume of air entering the mine was increased from about  $600\text{ m}^3/\text{min}$  to  $1,350\text{ m}^3/\text{min}$ . With a summer temperature of  $+20^{\circ}\text{C}$  at the mine opening, this resulted in an increase in the entry of heat into the shaft from 144 kcal/hour to more than 300 kcal/hour. This change altered significantly the rate and extent of thawing which resulted in the degradation of barriers isolating mined out areas.

Dust generation has been a problem especially in areas where coal is transferred from one conveyor to another. Here measured dust concentrations are as high as  $400\text{ mg}/\text{m}^3$ . Dust generation in winter is more than 100 times as great as in summer, with attendant deterioration of working conditions. There appears, however, to be a correlation between the mine air temperature and dust generation, with higher temperatures producing significantly less dust. Dust is removed by vacuum from the mine air and deposited on the surface through special pipes. The use of suction to remove dust combined with manual clean up and rock dusting is the most effective method of dust suppression under below freezing conditions.

Until 1962 underground coal haulage was by electric locomotives hauling one ton cars. After 1962 a conveyor system was installed.

#### 4.4 The Soginsk Deposit (Gulf of Tiksi) (71½°N, 129°E)<sup>11</sup>

The deposit is located on the right bank of the Sogo River about 14 km south of Tiksi on the gulf of Sogo. The mine is connected to Tiksi by telephone, by light vessels between July and September, and over the ice of the Gulf of Sogo in winter. The average annual temperature here is -13.6°C, with up to 70 days per year having temperatures below -40°C. Sixty-two days of the year have wind speeds above 30 m/sec, with maximum speeds of 52 m/sec. Blizzards occur for 10 to 15 days at a time. Mean annual precipitation is about 240 mm. The coal is used for the town of Tiksi and also in nearby settlements for fishermen and geologists. The coal is not transportable because of its characteristics.

The coal is a brown coal with a high moisture content, and when stored at above freezing temperatures breaks down into a dust which from a practical point of view can not be transported. Experiments have shown that the coal could be made into briquets. Production has been a function of the needs of the local markets and ranged from 74,500 to 97,000 tons per year during the 1960s. The mine is much more productive than other mines of Yakutiya because of a greater level of mechanization and the use of pillars for roof support instead of props.

The future of this mine is dependent upon the course of an underground coal fire which started on August 8, 1958, because of breaking of an electrical power cable in Mine 1. The affected area was isolated and holes drilled from the surface to measure underground temperatures and gas content. Analysis shows that the fire is moving northward along the seam in the direction where the seam outcrops on the surface.

Continuation of the fire may force the mine to be closed down as

reserves are adequate for only 5-6 years. Possible solutions include surface mining which has demonstrated its practicality in Noril'sk. However, in view of the extreme low temperatures and high winds of winter, this method may prove very costly.

The coal mine is not gaseous, but is dangerous because of coal dust, which is explosive. The temperature of the rocks is about  $-10^{\circ}\text{C}$ . The seam is 18.5 - 20 m thick, has a simple structure, and is cut through by a large number of fractures of up to 30 cm in width, each filled with ice. The seam also contains ice lenses up to 2.5 m in thickness and 6 m in length.

#### 4.5 Chul'mankansk Deposit ( $57^{\circ}\text{N}$ , $126^{\circ}\text{E}$ )<sup>12</sup>

The Chul'mankansk deposit lies in Southern Yakutia 20 km to the north of Chul'man. The region is in the permafrost zone and has a severe continental climate. The average annual temperature is  $-11^{\circ}\text{C}$ , 50-60 days out of the year have temperatures below  $-40^{\circ}\text{C}$ , and has sporadic permafrost.

The mine was opened in 1965-1966 and produced about 100,000 tons per year by the end of the 1960s. The roof is highly fractured. The fractures have smooth surfaces and are sometimes filled with ice. Sudden rock falls are common. Fractures in the surrounding rock allow water to enter the mine at a rate of about  $600\text{ m}^3$  per twenty-four hour period.

The mine is not gaseous but is dangerous because of coal dust explosions. The basic means of dust control are rock dusting, clean-up and removal of dust in boxes, and removal of dust by the ventilation system. Dust generation is significantly higher in winter than in summer.

The mine is only 10-15 cm below the surface, and the coal produced is high in coking qualities and is highly oxidized.

#### 4.6 Neryungrinsk Surface Mine (57°N, 125°E)<sup>13</sup>

The Neryungrinsk deposit is situated 40 km to the southwest of the town of Chul'man at the mouth of the river Neryungry. The climate is extremely continental with an eight-month winter, maximum temperatures reaching 35°C in July and August, and high winds with abundant snowfall occurring at the end of February and the beginning of March.

The bowl-shaped deposit was opened in 1968 for surface mining with the entire output destined for use by the thermal electric plant in Chul'man. Bulldozers remove the overburden from May through October and scrapers are utilized to remove the coal. In 1967 the mine produced 160,735 tons of coal at a cost of 2.94R per ton, and in 1968 produced 122,022 tons at a cost of 3.79R per ton.

#### 4.7 Zyryansk Surface Mine (66°N, 150°E)<sup>14</sup>

"The Zyryansk deposit has been known since 1936 and consists of two sections - the Eroziionnyy, located on the left bank of the Zyryanka river, and the Buor-Kemyuskiy, - on its right bank. Some geologists consider these sections to be distinct deposits. In structure, the deposit is a monocline, the coal bearing deposits of which dip to the west-southwest at an angle of 35-40°."<sup>15</sup>

The deposit could be worked by either surface or underground methods. The coals are low in sulfur and have a small mineral content. The coking characteristics of the coals vary, but small amounts of adequate coke have been obtained. During the 1940s a few thousand tons of coal were mined manually by Dal'stroy and made into adequate coke.

The Eroziionnyy section was first worked underground beginning in 1935, a task eased by the size of the seams (3-6 m), their 25-30° dip and the



strength of the frozen sandstones and shales forming the roofs and foot-walls, which have a temperature ranging from  $-3^{\circ}\text{C}$  to  $-6^{\circ}\text{C}$ . The shortage of underground machinery led to the changeover to surface mining. The technique involved blasting the coal and removal downhill by bulldozer. The surface is stripped for 150 m along the seam in the summertime. Stripping is made easier by melting and thawing of the overburden. Bulldozers were used exclusively through 1967, and then excavating machinery was introduced in 1968. The coal is transported to a storage area on the banks of the Kolyma River by truck-trailers during the winter and then shipped during the summer. During coal loading and while working the face at temperatures below  $-40^{\circ}\text{C}$ , large amounts of coal dust are generated, which reduces visibility and causes other difficulties. However, no measures have been taken to reduce dust generation or to improve visibility.

Coal loaded from the open pits totaled 79,100 tons in 1960, 141,600 tons in 1966, 115,900 in 1967, and 102,200 in 1968. The average ash content of the coal mined is about 12%. Productivity ranged from 71.6 tons/man-month in 1960 to 102.6 tons/man-month in 1966, with costs per ton of coal ranging from 5.47 rubles in 1966 to 8.33 rubles per ton in 1968. In 1950, coal cost 12 rubles per ton. Low productivity and high costs are evidence of an inadequate level of technology. The selling cost per ton of Zyryansk coal was established at 7.45 rubles with an ash content of 12% in the year 1967.

Surface mining of the Eroziionnyy section started in the early 1960s. The coal mined is subject to weathering and has an average caloric content of about 4,500 kcal per kg. It is difficult to transport, and is frequently

transshipped on its way to consumers, sometimes as many as ten times, which has resulted in enormous losses and the generation of much dust. The coal is planned to be the main energy source for the Kolyma Basin and specifically for the industrial centers of Peveksk and Bilibinsk. Total coal costs, showing the impact of transportation, delivered at the port of Pevek are: 6.83 R for mining, 8.45 R for truck transport, and 45.29 R per ton for water transportation. The total cost per ton of coal delivered at Pevek amounts, therefore, to 60.57 rubles.

Underground mining would be more expensive, but the quality of the coal would be much better, averaging 6,300 kcal/kg. The costs for underground mining are 9.7 rubles/ton for mining, 8.45 rubles for truck transportation, 45.29 rubles for water transportation, for a total cost of 63.44 rubles per ton. However, if the quality of the coal is taken into consideration, the cost picture is quite different. The cost of one ton of "basic fuel" delivered at Pevek is 94.4 rubles per ton mined by surface methods, but only 70.5 rubles per ton mined underground. The cost estimates for underground mining are based on the actual costs of underground mining for the first quarter of 1963 in the Arkagalinskiy mine administration.

At the present time the Dal'stroyproyekt Institute at Magadan is developing a plan for underground mining of the Buor-Kemyuskiy section with working designs being developed by the Vostsibgiproshakht Institute in Irkutsk. The mine is to have a planned capacity of 450,000 tons per year which should supply the needs of the Kolyma basin as well as the consumers along the coast of the Arctic Ocean. In the meantime, the

Vostsibgiproshakt Institute completed a plan for rebuilding the existing Erozinnyy section facilities in order to supply the needs of consumers in the Kolyma basin and Magadan oblast'.

#### 4.8 The Kangalassk Surface Mine (62½°N, 129°E)<sup>16</sup>

The Kangalasskoye deposit is located on the left bank of the Lena River 45 km below Yakutsk. The section being mined is situated 4 km from the Lena. The climate is extremely continental, with an average summer temperature of 16.4°C and an extreme high of 37.9°C. The winter extreme low is -65°C. The average snow depth equals 37.1 cm. The river Lena in the Yakutsk area breaks up near the end of May and freezes in the middle of October, with the river having about 155 ice free days. Permafrost reaches 200 m in depth. The deposit is connected to Yakutsk with dirt roads which cannot be driven by heavy trucks during the rainy season and which in some years are covered by flood waters.

The river route to Yakutsk is used for not more than four months of the year, and coal transport is complicated by the fact that the river near the coal storage area is shallow. Until 1964 the coal mine had its own steam turbine for electricity. Later a diesel installation was supplied, and then the mine was supplied with electricity from the Yakutsk central electrical station.

The Kangalasskoye brown coal deposit is in the Lena-Vilyuy lowland and is of Mesozoic age. The coal seams are cut by ice filled fractures. Freshly mined coal has a complex structure and in storage quickly loses moisture and breaks up into irregularly shaped small pieces. The coal turns into dust if stored for periods of up to two years. The coal is

subject to spontaneous ignition and catches fire if stored more than four months in piles higher than three meters. The coal is good energy coal and reserves are estimated at 6,385,600,000 tons.

The Rudnyy seam has been mined since 1929. Formerly the room and pillar system was used, and from 1950 to 1962 retreat long wall mining was employed. The coal was transported to the main haulage way by conveyors.

Electric locomotives pulling 3-ton coal cars were used to move the coal to a receiving bunker with a capacity of 50 tons, from which the coal was moved to the storage area on the bank of the Lena by means of a conveyor. Wooden props, locally made, were used for roof support.

As a result of an underground fire in 1961, all underground mining ceased in 1962. Coal production underground was 2,400 tons in 1930, 22,500 tons in 1941, 31,700 tons in 1946, 40,300 tons in 1950, 84,100 tons in 1956, and 57,600 tons in 1960. Production from surface mining was 114,000 tons in 1960, 262,200 tons in 1963, and 449,400 tons in 1967.

Surface mining is by means of a system of trenches. Excavators mine the coal which is transported by dump trucks. The frozen rock overburden is broken by blasting. Two excavators are used for mining, each with a bucket capacity of 2.5 m<sup>3</sup>. Another diesel excavator and three bulldozers are used for emergencies and for other work. The mine is worked year around by three shifts.

During summer, dust is suppressed by use of a special watering machine. In any case, the amount of coal dust in the air during the summer is small. The quantity of dust in the air during the winter has not been measured.

Mining during winter is difficult because the coal dust reduces visibility to 3-5 m. At a temperature of  $-40^{\circ}\text{C}$ , a fog forms which together with the coal dust makes an impenetrable environment. The causes of this fog and coal dust formation have not been studied.

#### 4.9 General Comments

With the steady growth in population and dwindling wood supplies near settlements, coal mining will increase. In those areas where coal is now picked up manually, mines will develop. In the past many mistakes have been made in planning mines because the factors of permafrost and low temperature were ignored. The advantage of permafrost lies primarily in reduced roof support costs and lessened water problems. Measurements in the Sangara deposit show that the bearing strength of rocks is 35 to 40% higher at a temperature between  $-5$  and  $-10^{\circ}\text{C}$  than it is at a warmer temperature.<sup>17</sup>

In spite of the introduction of advanced technology the accident rate for underground work does not appear to have changed significantly between 1965 and 1968. Most accidents occur in the Sangara mine which utilizes more manual labor than the other mines.<sup>18</sup>

#### 4.10 Sources

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## 5.0 COAL MINING IN PERMAFROST IN THE NORTHEASTERN USSR (MAGADAN OBLAST')

### 5.1 Kadykchansk Mine<sup>1</sup>

Coal in the Magadan oblast' is used for energy production in the area with some being exported to the upper reaches of the Indigirka River basin. The Arkagalinsk coal basin lies in the center of Magadan oblast' on the left bank of the upper Kolyma River in a region with an extremely continental climate. The mean annual air temperature is  $-13.2^{\circ}\text{C}$ , with temperatures dipping to  $-58^{\circ}\text{C}$  in December and January and rising to  $26^{\circ}\text{C}$  in June and July. Mean annual wind speeds equal 2.6 m/sec and north and northwest winds predominate. Relative humidity varies between 61% and 78%.

Coal from the Arkagalinsk basin is the fuel for the central portions of the oblast' and is shipped to Magadan. It is the main energy source in the region. The Kadykchansk area of the Arkagalinsk coal basin is worked with five inclines for ventilation, movement of materials, movement of workers, and the removal of rock and coal. The main incline has a length of 225 meters with a cross section of  $10\text{ m}^2$  at the maximum, and is equipped with a 900 mm gauge railroad and two LKU-250 conveyors. The seams have an irregular dip ranging from 0 to  $50^{\circ}$  and the mine is assigned to category II in terms of gas and the danger of coal dust explosion. Coal is mined by the drilling-explosion method, using electric drills. Two types of room and pillar methods are utilized. The principal economic

indicators are: room length, up to 80 m; coal recovered, 26%; coal lost in the area, 23%; productivity of labor, 28 tons/shift at the working face; and 9.2 tons/shift in the working area. The operating cost (evidently underground) is 1.14 rubles per ton.

This is one of the first mines to employ a mine air heating system. The ventilation system involves suction with an air flow of more than 3,500 m<sup>3</sup>/minute. The air entering the mine comes from fractures and from the entries and has a speed of up to 1 m/sec and during the winter contains more than 300 mg of coal dust per m<sup>3</sup>. The coal dust content of the mine air varies according to the type of operation. The dust concentration ranges from 20 - 1,100 mg/m<sup>3</sup> at conveyor transfer points, from 45 - 1,200 at the tipple, 20 - 400 in scraping operations, and 50 - 150 mg/m<sup>3</sup> in drilling.

Dust suppression is carried out by means of cleaning up dust in particularly bad areas and transporting it to the surface in closed bags, dusting roofs, walls and floors with inert dust, removal by suction through fractures to the surface and through small filters, removal by the mine ventilation air, and the use of individual respirators.

In the future, coal will be mined in this area in the zone of transition between the permafrost and the unfrozen area below the permafrost. From a practical point of view, the transition zone can be defined as that area with a temperature of -1.3°C. Based on experience elsewhere, a temperature of 0°C will be reached in various places within a rock layer when the general temperature of the rock reaches -1.3°C during the winter period. This is without heat being added to the air which enters the mine.



In a zone containing talik, one can visually observe ice melting in small cracks in the rock when the temperature reaches  $-1.1^{\circ}\text{C}$ . Under these conditions, the roof will begin to crack and spall throughout its entire length. The result can be sudden roof collapse. This occurrence is associated in the Chul'makansk deposit with an increase in humidity. As a result, evidently, of mineralization of the water, water flow changes from migration to active filtration, which causes numerous sudden incidents of roof collapse in the preparatory and working excavations. Rock pressures also increase as a result of the weakening of the cement in the various rock layers.

## 5.2 Anadyr Deposit<sup>2</sup>

The Anadyr deposit is located in the Anadyr rayon of the Chukotsk National Circle. At present, the Ugol'nyy section is worked. It is located on the coast of the Gulf of Anadyr 6 km from the city of Anadyr' near the mouth of the river Ugol'naya. The region, being close to the sea, has a moderate climate for its latitude. The mean annual air temperature is  $-7.7^{\circ}\text{C}$  and the relative humidity is 75-86%. Temperatures reach  $12^{\circ}\text{C}$  in July and August and drop to  $-33^{\circ}\text{C}$  in December and January. Winter is characterized by high winds and blizzards. The deposit has been worked continuously since 1923. Permafrost in some areas has a thickness of more than 100 m. Rock temperatures vary between  $-3^{\circ}\text{C}$  and  $0.5^{\circ}\text{C}$ . The lower limit of permafrost is at a depth of about 95 m.

The room and pillar mining system is employed. The preparatory works are developed with the aid of drilling and explosives and coal is mined in the same way. Coal is transported by conveyors. Coal loss averages

about 60%. The mine ventilation is by fan, with the ventilation rate up to 550 m<sup>3</sup>/min. Gas has not been noted in the mine, but the mine is considered dangerous because of coal dust. The dust content in the mine atmosphere is small and in the places of dust generation does not exceed 150-170 mg/m<sup>3</sup>. Relatively good working conditions result from favorable geologic conditions, the shallow pitch of the seams, the high quality of the roof and walls, and the high moisture content of the atmosphere.

#### 5.4 Coal Gulf Deposit (Bukhta Ugol'naya)<sup>3</sup>

Near the settlement of Nagornyy on the coast of the Anadyr Gulf is a coal mine of the Bering Mine Administration which has been in operation since 1940. The climate is influenced by the sea, with a mean annual air temperature of -4.2°C and a January temperature range of 13°C. The lowest mean temperature occurs in February and is -23°C. Winter is characterized by blizzards with wind speeds above 40 m/sec. Summers are cool, and in July temperatures very seldom rise above 12°C.

All existing mine excavations are within the 200 m thick layer of permafrost which is cut by a mass of fractures with a width of up to 30 cm, some of which do not contain ice.

Mining is underground. Mine entrances and above ground works are composed of concrete, while underground roofs are supported by timbers or left unsupported.

Measurements indicate that the mine atmosphere has above freezing temperatures in summer and below freezing temperatures in winter. In August the roofs thaw to a distance of 1.5 m and the footwalls 0.5 m, which is almost three times the depth of thaw of other mines in permafrost.

Coal dust in the mine exceeds health norms and in winter is twice as great as in summer. Dust suppression techniques include clean up and removal of dust to the surface, removal by the active flow of ventilation air, utilization of inert dust and the utilization of individual respirators. The below freezing temperatures of the mine atmosphere and the rock prevent the utilization of water for dust suppression, which would involve significant costs.

#### 5.4 The Thermal Regime and Dust Generation<sup>4</sup>

At the present time the economic practicability of mining the extremely rich and abundant mineral wealth of the northeastern part of the country depends on the scientific resolution of the questions of conducting industry in the North, and first and foremost the conduct of mining. Thus, for 1967, in the Yakutsk ASSR more than 70% of the capital investment was in mining enterprises and industries and in related services. The gross production of mining enterprises for the same period amounted to more than 80% of the total production.

Numerous researchers on the mines of the North have demonstrated the great influence of the thermal regime on the effectiveness of mining. The thermal regime influences the processes of mass thermal exchange between the mine atmosphere and the rocks, which determines the stability of the roofs, the processes of dust generation, the health and sanitary conditions in the mines, the distribution of air in the mine, and the leakage of the ventilation structures, i.e. on all factors which determine the economic effectiveness of mining.

Only the mines of the Noril'sk Mining Metallurgical Combine are equipped

with mine air heating equipment, that is, have a regulated thermal regime. All the other mines in the northeastern part of the country utilize the natural thermal regime of the rocks.

The characteristics of the natural thermal regime are as follows. The temperature of the mine air along the length of the ventilation way is determined by the surface air temperature. Within the first 1800 m along the ventilation entry the temperature variation may be as high as  $60^{\circ}\text{C}$ . Thus in the excavations of the mines of Dzhebariki-Khaya (Yakutia) during the winter the incoming air has a temperature of as low as  $-62^{\circ}\text{C}$ , while at the exit from a longwall face it had a temperature of  $-2^{\circ}\text{C}$  in January 1968. The temperature of the mine air varies sharply along the first 200 m of the ventilation entry. In Haulage Entry 13 of the Eastern Mine (Noril'sk Combine) the temperature of the mine air increased from  $-37^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$  between 105 and 205 m within the shaft. Along the haulage entry of the Western Coke Mine (Noril'sk Combine) in July, 1963, the temperature of the mine air along the first 100 m decreased from  $28^{\circ}\text{C}$  to  $14^{\circ}\text{C}$ .

The temperature of the mine air along the ventilation way further in than 1,800 m from the mouth is close to the temperature of the surrounding rock and varies from it no more than  $1.5^{\circ}\text{C}$ .

The heating of rocks to above freezing temperatures is noted along the entries in summer from a distance of 500 to 1,200 m from the mouth. The limit of melting moves farther in from the portal each year.

Dust content is inversely related to air temperature. In winter, dust concentration in the air is ten times greater than in summer.

Roof stability in areas with a temperature below  $-5^{\circ}\text{C}$  is up to twice

as great as roof stability under a temperature above 2°C.

The naturally warm temperatures of mine openings during the summer period, and the operation of ventilation air heaters during the winter time, causes significantly increased expenditures for maintenance.

The thermal mass exchange between the mine air and the rocks has a regular cyclic character during the course of the year. Thus in the winter and in the summer periods the heat flow changes its direction from the rocks to the air and vice versa. The process of thermal mass exchange determines the mechanism of dust suppression under the conditions of the natural thermal regime.

The natural thermal regime works to prevent spontaneous ignition since most of the working faces are at a distance of 700 m or more from the mine mouth, where the coal remains frozen and oxidation is slow. The thermal regime may be regulated by having the air entering the mine heated during the winter or cooled in summer. The problems of regulating the thermal regime have been most thoroughly studied by the scientific workers of the Leningrad Mining Institute under the leadership of Doctor of Technical Sciences, Professor Yu. D. Dyad'kin.

The main sources of dust generation are drilling and blasting; coal mining and development of preparatory work; all forms of loading and transporting coal on conveyors; and transferring coal from conveyors into coal cars.

The most effective methods of dust control under the natural thermal regime is to remove it through the use of a suction mine air ventilation system. Low pressure is created in the mine air by a suction device which passes the coal dust through filters or removes it to the surface.

The removal of dust in mine air, cleaning up coal dust and placing it in special boxes or sacks for removal to the surface, and rock dusting are quite effective.

In the mines of the Noril'sk Combine, where the temperature is regulated during the entire year, dust is suppressed by sprinklers along the entire length of the transportation entries.

Any discussion of the mine dust problem should note that in general dust generation in the mines of Yakutia and Magadan oblast' is significantly lower than in the mines of other basins of the country including the mines of the Noril'sk deposit. The general lower level of dust is explained by the higher moisture content of the coals and by their ice content. Thus, in the Sogo mine the moisture content of the coal exceeds 40%. In the coal of the Shtol'nevo seam of the Chul'mankansk deposit there exists a year around water circulation with a flow of up to 800 m<sup>3</sup> per twenty-four hour period.

There are several explanations for the increase in dust content in winter. One is suggested by the behavior of the tensile strength of the surrounding rock. Thus, the tensile breaking point of the Arkagalinsk sandstones in the unfrozen condition with a moisture content of 4% is about 17 kg/cm<sup>2</sup>, whereas under a temperature of -15°C and with the same moisture content, it rises to 31 kg/cm<sup>2</sup>. The compressive breaking point does not change, but the rock becomes twice as brittle. Consequently, under the same mechanical influences on coal, dust generation will increase many times, which corresponds to observation.

Another explanation has to do with the mechanism of condensation processes. Thus, during the winter period when the air entering the mine

has a temperature significantly lower than that of the rocks, and a very low absolute humidity, the air is warmed and takes moisture from the rocks. As a result of the absorption of moisture by the air, moisture, which up to this point held the particles of dust together and prevented their breakup is taken from the rocks. The sublimation of ice contributes to this process.

During the summer, the reverse occurs. Then the air entering the mine has a high temperature and moisture content and is cooled, so that condensation occurs. The condensation of moisture occurs first around the coal dust particles which are in a suspended condition. These precipitate out of the mine air and collect along the walls and the floor. The dust content in the air is sharply reduced, while at the same time the process of dust formation is slowed down. Both the tensile strength and the brittleness of rock decreases with increasing temperature which results in a lowered intensity of dust formation. [Ed. note: While brittleness certainly contributes to dust formation, the effect of increasing tensile strength is debateable. The ultimate cause, of course, is shrinking due to dehydration. Beyond that the mechanical properties of the coal take over.]

Other researchers (Kudryashov, Voronina, 1969) explain the seasonal variation in dust concentration in a suspended condition by the increased capacity of moisture particles to adhere to a frozen object as the temperature of the object increases and approaches the freezing (or thawing) point. The general utilization of electrolytes for the battle with dust is recommended. It is stated that their utilization will increase the adherence capacity of particles under below freezing conditions. In this

regard, the dust suppression effort under below freezing temperature conditions should stress the use of water dust control systems in all their modifications (for example, salt water), with other measures, including the regulation of mass exchange processes, playing a subordinate role.

Water dust suppression systems have been tested under permafrost conditions, and can be utilized in mining, taking into consideration the reduced moisture absorption capacity of coal dust under low temperature conditions. However, in spite of the effectiveness of many methods, from a practical point of view only one is used: watering coal on the conveyors, and this only in the mines of the Noril'sk Combine and on the island of Spitsbergen. Any of the systems of using water for dust suppression lead to such high economic costs that installing them in the low production mines of Yakutiya and Magadan oblast' would involve extreme difficulties. Dust suppression water systems along the haulage way and dust suppression under the regulated thermal regime in mines can be undertaken only by using a closed circulating pipe with water heated to 35°C at the point where it enters the mine. In general the utilization of water systems results in a significant reduction in dust. In May 1963 in the Noril'sk Combine mines, measurements of dust content and of the effectiveness of utilizing the moistening additives OP-7 were undertaken. In the Eastern mine the dust content of the air at the loading point in the inclined cross cut decreased 46 times (to 5 mg/m<sup>3</sup>); on hoist 2 of Seam IV it dropped four times, but still remained high (61 mg/m<sup>3</sup>). In the Central mine the dust content was lowered two to three times.



In the Central and Eastern mines industrial experiments were undertaken with the moistening additive OP-7, the utility of which under permafrost conditions was shown by the work of the Leningrad Mining Institute. The utilization of the additive reduced the dust of the mine excavations two to four times, but the technical equipment for utilizing the additive, the heated box and the pipes, was inadequate. Because of this, utilization of the additive increased the cost of one ton of coal by 4 kopeks.

#### 5.5 Mechanical Characteristics of Permafrost, the Thermal Regime of Mining Excavations and Dust Generation

The repeated freezing and thawing of rocks, and the deep penetration of water, alter the physical and mechanical properties of permanently frozen rocks. Many years of experience in mining in permafrost composed of different rock types confirms the fact that the physical and mechanical properties of rocks are to a large extent determined by rock temperature, under the influence of which the moisture contained within the rocks and the level of cementing of the rocks is changed. Under these conditions, the cementing material in the rock, the material which determines strength, is water. As is known, not all water molecules are changed to the frozen state under a temperature below freezing. Therefore, the lowering of temperature leads both to an increase in cohesiveness as a result of the freezing of the water molecules and also to a reduction in the thickness of the water layer surrounding the larger particles of rock, which changes the forces of molecular adhesion.

Frozen sands, clays, and alluvial deposits can have the same strength and characteristics as sedimentary rocks underground, but completely dis-

integrate when brought to the surface and thawed.

Measurements indicate that strength of ice is a function of temperature. However, the results vary from one experiment to another probably because of the influence of the chemical content of the ice, and length of time it has been frozen, and other factors. Both experiments and experience indicate that the environmental temperature has little effect on the compressive strength of ice but a significant effect on its tensile strength. Lowering of temperature increases the tensile strength and mining experience indicates that the roof rocks are stronger when the temperature is low.

#### 5.6 Ice Strength in Coal Mines

[Ed. The data below are as given in the text. Evidently Compression and Tensile should be reversed.]

#### The Dependence of Ice Strength on Temperature<sup>6</sup>

| Author                  | Form of Experiment | Breaking Point, kg/cm <sup>2</sup> at temperature in Centigrade |     |      |      |
|-------------------------|--------------------|---|-----|------|------|
|                         |                    | -2°   | -5° | -10° | -20° |
| V. N. Pinegin           | Compression        | 19  | 22  | 25   | 42   |
| K. N. Korzhavin         | "                  | 7   | 19  | 45   | -    |
| V. N. Arnol'd-Alyab'yev | "                  | 35  | 47  | 56   | -    |
| V. N. Pinegin           | Tensile            | 10  | 11  | 12   | 13   |
| B. D. Kartashkin        | "                  | 9   | 11  | -    | -    |
| B. P. Vasenko           | "                  | -   | 11  | 18   | -    |

"With results regarding absolute quantities being so diverse, it is hardly possible to utilize these data in calculating the sizes of pillars

or the unsupported roof area. Probably the breaking characteristic of ice is influenced by the chemical content of the water, freezing conditions, length of time the water has been frozen, and other factors."

"The elastic characteristics of samples was determined in the unfrozen and in the frozen condition. Numerous experiments show differences only in absolute magnitude. As a result of the experiments conducted, it is possible to reach the following conclusions:

1. The environmental temperature has little effect on the breaking point under compression. Lowering of temperature increases the breaking point under tension (stretching)."

#### 5.7 Sources

1. Kurenchanin, op. cit., pp. 111-118.
2. Kurenchanin, op. cit., pp. 118-122.
3. Kurenchanin, op. cit., pp. 122-125.
4. Kurenchanin, op. cit., pp. 181-188.
5. Kurenchanin, op. cit., pp. 179-178.
6. Kurenchanin, op. cit., p. 177.

APPENDIX C

INFORMATION ON TANTALUS BUTTE MINE (CARMACKS, Y.T.)

and

USIBELLI COAL MINE (HEALY, ALASKA)

APPENDIX C  
INFORMATION ON TANTALUS BUTTE MINE (CARMACKS, Y.T.)  
and  
USIBELLI COAL MINE (HEALY, ALASKA)

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## 1.0 TANTALUS BUTTE COAL MINE

### 1.1 Location and History

The Tantalus Butte Coal Mine is located three miles northeast of the town of Carmacks, Y.T., in the Carmacks District. The mine site lies on the north bank of the Lewes River at 62 degrees, 08 minutes north latitude and 136 degrees, 15 minutes west longitude.

The coal seam near Carmacks has supported five mining operations since development began in 1905 with the Tantalus Mine. Coal from this operation supplied fuel for steamboats that ran from Whitehorse to Dawson, but the mine was phased out in 1922 due to the high cost of transporting the coal up and down the river to fueling points. Another mine in the area caught fire in the early 1920's and is still burning. Of the five mines begun in the area, only the Tantalus Butte Coal Mine is still in operation. Started in 1923 to replace the Tantalus Mine, it produced from 300 to 600 tons a year, most of which was used for domestic heating in Dawson. For a period of time the Tantalus Butte Coal Mine was owned by United Keno Hill Mines, Ltd. At present the mine is owned by the Cyprus Anvil Mining Corp. One hundred tons of bituminous coal are being produced per day, all of which is transported 100 miles by truck to the Anvil Mine in Faro where it is used to dry ore and heat buildings. An insignificant amount of four tons per year is produced for domestic sales.

The Tantalus Butte Coal Mine is located at the south end of Tantalus Butte, which rises 500 feet above the Lewes River Valley. The butte is composed of conglomerate, sandstone, shale, and coal seams of the Tantalus formation. The strata strike almost due north and dip at an angle of approximately 50 degrees to the west. The area lies in the physiographic

province of the Yukon Plateau, but is characterized by small mountain groups and individual peaks. The Lewes River meanders extensively near Carmacks.

The climate is of moderate extremes with a mean annual temperature of about 30°F. An extreme of -70°F was recorded in January, 1975. Freezing conditions persist from mid-September until early May. Snowfall accounts for one-half of the mean annual precipitation of 15 inches and the maximum snowfall cover ranges up to 50 inches in late March.

White spruce is the predominant tree in the region and is the chief source of timber and firewood. The area is covered by grasses and plants characteristic of rather arid, northern interior climates.

The town of Carmacks has a population of 480 people, mostly native Indians. The townsite is on the south bank of the Lewes River, 110 miles by gravel and paved road northwest of Whitehorse and 100 miles by gravel road west of Faro. Service buildings in the town include one grocery store, two gas stations, two motels, one school, two taverns, and one government building. A native village is situated directly across the river.

## 1.2 Geology

The Tantalus formation is a clastic assemblage of Jurassic or early Cretaceous age. It underlies an area of approximately 14 square miles and outcrops on both sides of the Lewes River just east of Carmacks. The formation consists largely of conglomerate composed of cherty slate and quartzite in a matrix of finer particles of the same material. The conglomerate beds are 3 to 6 feet thick and are separated by beds of sandstone 3 to 12 inches thick. Shales comprise a very small percentage of the formation and the coal seams are associated with these shales.

The bituminous coal is non-coking, with 8 percent ash and low sulfur content. Heat content varies from 11,000 to 13,500 BTU as mined. No cleaning of the coal is done either at the mine site or before it is burned at the Faro Anvil Mine.

The coal seam strikes almost due north and dips at an angle of 60 degrees towards the west. It varies in thickness from a few inches to 50 feet and is found from the surface down to a depth of 500 feet. Because the seam has been folded and faulted it is naturally drained; consequently the mine is dry and gasless. Reserves have been calculated as 100 years at the present mining rate.

### 1.3 Mine Operations

The overall impression carried away from the Tantalus Butte Coal Mine was that of a safe mine and economically sound operation. Although it is a small production mine, the importance of the coal supply can be measured by the dependence of the Faro Anvil Mine upon it.

The mining technique is mainly a room and pillar system, but some strip mining has recently been begun. The mine does not lend itself to mechanization due to the steep dip of the seam. Thus the recovery is characterized by simple and efficient operation. Seven to eight miners work underground; four working places are available, but rarely are more than two places ever worked at one time. A crew consists of one miner and one miner's helper. They are responsible for pulling previously blasted coal away from the face and drilling a new round consisting of 12 to 14 holes. The mine foreman then loads the round with a low velocity permissible, primed by millisecond detonators, and does the blasting himself. The crew waits for the fumes to dissipate, then returns to pull loose coal and again drills a new round. This cycle is usually repeated twice a day at each working place. A crew



produces a maximum of 25 tons per day. The local labor force does not want to do development work; Canadian Mine Services contracts for the hard rock mining involved in improving headings and development work.

Because of the excellent natural mine ventilation and the small amount of blasting done, no problems are encountered with gas fumes or coal dust. No fan or dust suppression systems have been installed in the mine. The main entry serves as the air intake and raises to the surface at the top of the butte acts as the exhaust. Although no air velocity measurements have been made, an appreciable movement of air throughout the mine was apparent. Brattice curtain is available but is not in use.

The safety factors in the mine were impressive. Nine raises lead out of the workings, providing an escape route from each working place. Only one shaft is open through to the surface, although there are others, unuseable, that will pass air. There was very little evidence of roof collapse. The roof is composed of sandstone, with little shale, and timbering is set only where it is needed, usually in large rooms. The crews work without supervision and decide for themselves when roof support is necessary. A mine inspector visits once each month.

The coal that is pulled from the working place is dropped by gravity down chutes and loaded on twelve electrically driven railroad cars for haulage out of the mine. The locomotive is a battery powered, 72-volt Swedish model. Each of the twelve wooden cars has a capacity of one and one-half tons. Outside the mine the train load of coal is dropped into a 100 ton bunker. Anvil Mine trucks returning empty from Whitehorse haul the coal to Faro. Five to six trucks are loaded per day, each with an 18 ton coal capacity. Anvil Mine maintains a 12,000 ton stockpile near Faro.

The mining method is geared to easily accessible coal where few problems are encountered. Only a 16 foot width is mined because of the steep dip and when a rock lens is encountered the seam is worked on either side around it. Recovery is 60 percent with no plans for secondary recovery. When coal shortages occur during the winter, mine production is stepped up by robbing the pillars of easily accessible coal. The results of this practice are readily observable. In places the roof and headings were abnormally high, but this did not seem to affect the strength of the natural support.

Because of the geology of Tantalus butte and the nature of the mining practice, the entire operation is simple, efficient, and effective. As mentioned before, no gas or water drainage problems are manifest due to the natural draining of the folded seam. Ventilation is excellent and coal dust and blasting fumes are minimal because the operation is small. This could become a problem if more miners were to be employed underground. Mine temperatures do reach the freezing point, but never become cold enough so as to require a heating system. Electricity is not used in the mine; cap lamps provide illumination. Drills and picks are powered by compressed air. The safety record is excellent, averaging one accident per year. There have been no mine fires, although the miners' locker and shower building, situated 2 miles from the mine, burned to the ground in early 1975.

The strip mining operation is located on top of the south end of Tantalus butte. The seam is 50 feet wide in this area. The work was contracted out to a heavy equipment operator who used a scraper to produce 12,000 tons of coal in two weeks. This coal, which assures one year's supply for the Anvil Mine, is stockpiled one mile from the open pit operation. No further open pit production is planned in the near future. The coal is dirtier than that

produced in the underground mine, but no problems are encountered in burning it at the Anvil Mine. Although this operation is more economical than the room and pillar system, the underground mine will not be phased out in favor of it. Rather, emphasis will be placed upon underground development since the pressure of production has been removed.

#### 1.4 Labor Force

The labor force is predominantly native. Twenty-five employees are on the payroll, but rarely do more than ten men ever appear for work on any given day. The miners work on the buddy system; if a miner does not plan to work, he is expected to find a replacement for his job. Superficially, this appears to be quite haphazard and inefficient labor management, but the system works well and production is not hampered by the casual attitude towards work. The mine superintendant, mine foreman, and one experienced miner work the total five days per week and together form the backbone of the operation; most other employees work two to three days per week.

It is estimated that 20 percent of the 480 people in Carmacks derive economic support from the mine payroll. Living costs are low because the Indian Brotherhood provides housing for which the natives pay only what they can afford. The miners do not belong to a union since the Indian Brotherhood provides many similar benefits. Hourly wages are paid rather than using a bonus system. This is an important factor in the mine's excellent safety record--the day wage system is a low pressure type of work, while the bonus system encourages miners to rush, thus promoting more accidents. The native laborers work at their own pace without supervision. They set timbering only when they feel it is needed and, thus far, no problems have arisen from this self-management mining technique.

Wages at the time of the visit were \$6.55 per hour for miners, \$6.21 per hour for miner's helpers, and \$5.98 per hour for laborers. Maintenance costs are kept to a minimum through the ability of the mine superintendent to install and maintain most mining equipment himself. Because the local labor force does not want to do hard rock development, the added expense of contracting a private drilling company must be absorbed.

The total cost, as set down at the Faro Anvil Mine, is \$17.00 per ton. At this price it is a little more economical for the Anvil Mine to burn coal rather than oil, for drying ore and heating buildings. The strip mining operation produces coal for \$4.00 per ton, but this does not include the cost of transportation to Faro. The Tantalus Butte Coal Mine does not ship its own coal. Transportation is provided by Anvil Mine trucks backhauling from Whitehorse to Faro.

#### 1.5 Characteristics Due to Northern Location

The operational problems at the Tantalus Butte Coal Mine are typical of those encountered in any mine in the northern latitudes. Cold weather during the winter months creates many surface problems. When the temperature in January, 1975, dipped to  $-70^{\circ}\text{F}$ , mercury lamps stopped operating and hoses froze. Production was hampered by the adverse conditions in handling coal outside the mine. These production problems occur at a time when coal demand is highest, thus necessitating the robbing of pillars for easily accessible coal. The availability of coal from the strip mining operation could alleviate these problems in the future. One characteristic that plagues all northern coal mines is low humidity in cold weather. As mentioned, during the cold weather of January 1975, the locker and shower building burned. Low humidity and almost complete impossibility of fighting fire in such weather make fire a special hazard in high latitudes.

The remoteness of the mine location is of little importance from the standpoint of transportation costs. In fact, the mine site is in a near ideal location, since trucks backhauling from Whitehorse must pass through Carmacks on their way to Faro. This low cost transportation is an important factor in keeping the price of coal competitive to oil. The supply of materials and services does present a problem at the mine. Materials supplied from the Faro Anvil Mine or from Whitehorse are slow in arriving, so the mine superintendent must make frequent trips to Whitehorse to pick up purchases himself. Services from outside sources are extremely expensive due to the remote location, thus the burden of maintenance lies mainly with mine personnel.

Although the mine is within 300 miles of the Arctic Circle, there has been no permafrost found in the mine development. The mine is normally dry except during spring run-off. When water accumulates, it is removed by a bucket-to-barrel method. A small pump is sometimes used but must be taken out of the workings at night to prevent it from freezing. Water in the mine presents a problem when it covers the rail and freezes, thus preventing the haulage train from operating. Some water is pumped into the mine for the hard rock drilling and pneumatic mining equipment, but no attempt is made to remove this water from the workings.

The operation of this mine is not politically motivated in the sense that mines on Svalbard in part reflect national aspirations. However, the mine provides employment for the largely native population of Carmacks, and so plays an important social-economic-political role.

## 2.0 USIBELLI COAL MINE, NEAR HEALY, ALASKA

### 2.1 Introduction

Two representatives of the Mineral Industry Research Laboratory of the University of Alaska visited the coal mines owned and operated by Usibelli

Coal Mine, Inc., near Healy, Alaska, on May 2, 1975. The M.I.R.L. team spoke with the mine superintendent and the safety supervisor, and visited both active and closed mining areas. The mining operations are efficient and effective in the use of excavation and hauling equipment for surface mining of thick, sub-bituminous, dipping coal seams. Potential for expansion in production seems excellent.

The Healy area (63°52'N, 149°W) lies in the northern foothills of the Alaska Range, a short distance north of Mount McKinley National Park, about 120 road miles southwest of Fairbanks, and about 240 road miles north of Anchorage. The coal mines are situated only some 7 miles from the Alaska Railroad and the Anchorage-to-Fairbanks highway. The area has a markedly sub-Arctic continental climate with extreme temperatures ranging downward to -65°F in winter, relatively ice-free permafrost, and spruce forests in the lowlands, and Alpine tundra on the uplands. High velocity down valley winds are common and create extremely low chill factors. The area is a breeding ground for Dall sheep and contains other game animals. The land in the general area is mostly State selected, patented or State tentatively approved lands.

The Healy and Lignite river valleys, in which the large reserves lie, are eastern tributaries of the northward flowing Nenana River which meets the Tanana River at the town of Nenana. The Healy and Lignite Rivers have cut deep, V-shaped valleys into the coal bearing formations. Relative relief is about 2200 feet.

The coals are part of the Tertiary Coal Bearing Group, which is overlain by the poorly consolidated Pliocene Nenana gravels, which in turn are unconformably overlain by glaciofluvial gravels that form terraces of the Nenana River. The Coal Bearing Group consists of poorly consolidated

sandstone, conglomerate, siltstones and clays, and of course, coals. Thirteen coal seams have been recognized, at least five of which are clearly visible in the Healy Valley and along the Nenana River. The estimated coal resources of the Nenana coal field, of which Healy is a part, are stated to be approximately seven billion tons (to a depth of 3,000 feet).

Coal has been mined in the Healy River area since 1913. The initial mining was underground, and related to the construction and operation of the Alaska Railroad and the needs of Fairbanks for coal as a substitute for wood in home heating, electrical generation, and dredging operations. The Usibelli Coal Mine was started in 1943; the company purchased the Suntrana Mine in 1952 and the Vitro Mine in 1970 to become the largest and finally the only coal mining operation in Alaska. Smaller mines, such as Black Diamond, have gone out of business, while the Usibelli operation now has leases on Lignite Creek, just to the north of Healy River, sufficient to maintain current production rates for another 40 years.

The current major coal users are the electric generating and heating plants located at Clear A.F.B., Fort Wainwright, Eielson A.F.B., the City of Fairbanks (Municipal Utilities System), Healy, (Golden Valley Electric Association), and the University of Alaska at College. Total production is about 750,000 tons per year, with productivity ranging from 32 to 35 tons per man day.

The coal being mined is sub-bituminous "C" in rank with approximately 20% - 25% moisture, 8% - 15% ash, and a BTU content of 7500-9000 as received. The coal slacks easily, has no gas, and contains some admixture of bone. The coal has a very low sulfur content (about 0.1%) which makes it, in common with most Alaskan coals, a clean coal environmentally. Between 75,000 and 120,000 tons per year are washed in a small sink-float plant

during the summer months, primarily for limited domestic use and for coal that does not meet required power plant specifications. Most of the coal is shipped as mine run, with only occasional hand-picking. A sink-float washing plant operates during the summer months for stockpiled coal too dirty to ship.

In the past five years, coal prices have increased about 50% to more than \$10 per ton exclusive of shipping. Wage rates are about \$10 per hour with the average five day work week consisting of 50 hours. Purchase prices for heavy equipment appear to have increased 250% in the last decade. In spite of increasing costs, however, coal prices at Healy appear to be low and with increased petroleum prices will probably remain competitive with oil in Interior Alaska for the foreseeable future.

## 2.2 Cold Weather Problems

There seem to be few serious personnel problems associated with cold weather. The basic work force has been employed at the mine for more than five years, and the more experienced men guide the newcomers so that frostbite problems are few. Labor turnover was low until recently when jobs became available on the construction of the trans-Alaska pipeline. About 75% of employees are married and all live in the immediate Healy area, which has a total population of about 450 people (including employees at the local elementary school, Golden Valley Electric Co. power plant, and the Alaska Railroad).

Winter employment averages about 50-55 men, most either operating heavy equipment or working as mechanics. The cabs of the equipment are heated, providing protection against the cold. The experience of the labor force in cold weather and the heated equipment would explain the absence of serious problems.



Heavy equipment is kept inside warm-up shelters when not in use, and there seem to be few difficulties with the heavy trucks which are kept constantly in motion and warm. With the roads frozen in winter and covered with snow and ice, there is significantly less tire wear than in summer. Tracked equipment, however, has difficulties in the cold; steel turns brittle and rippers are easily broken. Unless absolutely necessary, no bulldozers are used if the temperature is lower than  $-45^{\circ}\text{F}$ . Frozen gravel is more difficult to drill than unfrozen, and wears the bits rapidly. A fixed tooth drag type bit has been found best for sandstone.

Stripping occurs mainly in summer, increasing employment to about 80 men. Bulldozers and rippers are used to remove overburden, and at present little blasting is done. Until 1964, overburden was removed hydraulically. The ground, after removal of vegetation and loose gravel, thaws at a rate of about one foot per day when exposed to the sun, but will freeze back in winter. The frozen ground is ripped, piled with bulldozers, and loaded into trucks with loaders. It is then hauled to a disposal area, generally being used to fill previously mined areas.

Stripping takes place in summer, and the trucks are equipped with dump boxes to handle rock. These rock boxes are removed and larger coal boxes are installed on the trucks in winter. The coal boxes have double floors through which vehicle exhaust is piped to keep the truck bed warm so as to prevent the coal from freezing to the bed. When the boxes are up, in dumping position, the exhaust gases vent directly to the outside. On occasion, coal fires can be started if the bed temperature is too high. A simple device that has proved effective is a chain welded to each corner of the dump box. The chain swings and rattles, removing loose material during dumping, so that it does not freeze to the bed.

Due to the high moisture content of the coal, it tends to slack and produce excessive dust upon drying. This dust generation occurs at transfer points, especially in the tipple. During summer, water is used to suppress dust, but so far it appears that no effective solution has been found to dust suppression in winter. Rock dust is employed if welding must be performed at the tipple in winter. No welding is performed in the tipple unless absolutely necessary, and a 24 hour fire watch is maintained after any welding. The combination of high moisture content in the coal and extremely low humidity in winter produces a dust and fire situation that ranks among the most serious of the cold weather problems.

The foregoing discussion is not meant to discount the effects of cold and extremely cold weather. The winter environment offers certain advantages, and can be characterized as cold, dry, and hard. Tires last longer, equipment does not bog down, but no operations using water, e.g., at the washing plant, can be done, and expenses skyrocket as heating requirements go up.

### 2.3 Mining System

The coal seams that are mined dip from 10 to 30 degrees with clay in the footwall and poorly consolidated sandstone and conglomerate in the highwall. The surface is stripped of vegetation and loose gravel, laying bare the coal seams, and then the highwall is removed. Coal is mined as deep as 200 feet, but mining on federal leases must cease within five feet of the creek water level due to federal regulations. Water above pit level is drained by submersible dewatering pumps in drill holes. Winter freezing and permafrost in the footwall and highwall, are considered advantageous. Slippage along the footwall (promoted by the clay) can degrade the coal and can cause spontaneous ignition. Due to ancient coal fires, the clay in places is baked. Some of the clay is of ceramic quality.

After stripping, the surface of the coal seam is cleaned both with scrapers and washed down in summer. Formerly the seam was hand swept. Gravels falling from the highwall can lower coal quality, and must be removed. The coal is blasted using ANFO in drill holes, loaded with front end loaders into 45-50 ton trucks and hauled to the GVEA plant or the railroad tippie. Coal can be ripped, but this creates much dust in winter. Mining continues year-round.

#### 2.4 Remoteness Problems

Remoteness is a relative problem. Proximity to markets and sources of supplies coupled with adequate surface transportation, have made the Healy area much less remote than formerly. The mine maintains a larger inventory of spare parts than would be necessary further south and is currently installing a small computer capable of inventorying and ordering parts when necessary. Parts are priced 15% above the Seattle price plus shipping and are obtained through Fairbanks. The mine maintains a road watering truck which is also equipped as a fire truck and also has a locally available medic. The town of Healy has organized a volunteer fire department, and the nearby town of Cantwell maintains an ambulance. The mine has a small air strip, and there is a larger one at Healy. All serious medical cases are taken to Fairbanks.

There is a small store at the mine, and otherwise people use mail order catalogs and shop in Fairbanks which is about a three hour drive on a paved road to the northeast. Cost of living is about 30% higher than on the west coast. The area is not so remote that a camp must be maintained. Twenty to twenty-five percent of the men live in bachelor quarters. The absence of locally available entertainment facilities does not appear to cause personnel problems. No special explosives handling problem seems to exist.

## 2.5 Labor Utilization

In summer, the mine employs approximately 80 men. Stripping operations involve two ten-hour shifts five days per week, while coal mining and maintenance involve only one ten hour day, five days per week. Four men work the tibble, three manage the boilers in winter, twenty-five are mechanics, and the remainder are truck drivers, cat skimmers, and front end loader operators. The mine has one supervisor, a day shift group foreman and shop foreman, a night shift foreman for stripping, a "lead man" in the repair shop, and a small office staff. The major component of the labor force is equipment operators and repair personnel. The workers belong to the United Mine Workers and are employed on contract, hourly wage basis with no incentives. Most employees are locally hired with only an occasional specialist brought in from the "Outside". The mine employs no geological or engineering staff, but relies on consultants for such services. Accident rates were reported to be low, absenteeism and alcoholism are not problems. Historically, labor turnover has been low, but has increased since the trans-Alaska pipeline construction project began. The mine superintendent did not foresee any difficulties in recruiting workers should this be necessary.

## 2.6 Future Prospects

AMAX Corporation had an option to purchase the Usibelli holdings and conducted an extensive drilling program last year. Usibelli Coal Corporation has sufficient reserves in the Healy area to last for four years or so at current production rates. With leases in the Lignite area, reserves are believed to be adequate for forty years. There is considerable thought being given to the possibility of exporting coal from the Healy-Lignite area to Portland, Oregon or other west coast cities for thermal electricity production. This could involve a three-fold increase over current production.

The possibility of exporting coal led AMAX Corporation to option the Usibelli mine and do extensive drilling. Although AMAX dropped the option, the possibility or probability remains that the operation, either under present ownership or a successor, might be expanded to produce coal for export. Most certainly the local market will require additional output, perhaps raising the annual production to one million tons within a short time.

## 2.7 Environmental Considerations

While not covered within the scope of the contract, a word or two about the Healy environment and the effects of coal mining may be appropriate. There is surprisingly little evidence of mining in the area, in spite of a mining history that goes back almost sixty years. The coal does not produce acid mine water and the streams, at least visually, show no signs of any changes caused by coal mining. Stripping and surface mining do remove the vegetation. However, an aerial grass seeding program, utilizing fertilizer mixed with the seed, has proven successful, and the area is occupied by a herd of Dall sheep who seem unaffected by the mining operations. Sheep were observed near the mine, and an area in which they had bedded down for the night within a very short distance from operating stripping equipment was seen. The machinery and the consequent noise levels and disturbances appear not to bother the sheep. Wolves and moose are common in the area, and it would be hard to prove that mining has had an adverse effect on them. With older mined out areas being filled with the waste from new mines, the amount of change in the surficial topography would appear to be minimal although it is impossible to completely fill all pits. The main environmental difficulties which the visitor notices are those associated with the disposal of used equipment. As is common in Alaska, used equipment is merely thrown aside rather than removed to a disposal area, presumably awaiting the time

when it may be needed again. The Healy area, however, does not seem overly encumbered with such debris.

Paranthetically, one might note that the visit to coal mines in Svalbard during the summer of 1974 led to similar observations. There the caribou, Arctic foxes and birds seem to be undisturbed in their habits by the mining operations, and the rivers also seemed unaffected by mine runoff. The principal environmental damage observed were the old, run-down structures, which are either "eye sores" or "historical monuments," depending upon the observers bias.

## 2.8 Conclusions

The Healy area enjoys certain advantages due to its location. It is served by railroad and highway and has an assured market in the power plants of the Fairbanks region. The coal beds, while dipping, are thick and can be mined with a stripping ratio of less than 4:1. Perhaps of equal significance is the fact that the Healy coal is the only developed source of energy in Interior Alaska. Cold weather appears to be both advantageous and disadvantageous. Frozen, snow covered roads reduce tire wear and permafrost and low temperatures increase the competence of the hanging and footwalls and hence contribute to pit stability. On the other hand, excavation equipment incurs higher maintenance costs, and the absence of available water complicates the problem of dust suppression and prevents winter washing of coal. Unlike the other northern coal mines visited, however, Healy does not seem to have serious personnel problems due to its location. In fact, although extremely cold temperatures and wind chill factors occur in winter, the Usibelli operation bears a remarkable resemblance to operations further south.

The Alaska Railroad has about 350 coal hopper cars and plans to add an additional 150 cars this year. There is also the possibility that the military power plants in Anchorage may convert back to coal and utilize coal from Healy. In spite of a cost-of-living differential of about 30 percent above the west coast, the simplicity of the mining system and the availability of coal may make the Nenana field competitive on the West Coast market in the near future.

APPENDIX D

BIBLIOGRAPHIES OF RUSSIAN LANGUAGE SOURCES



APPENDIX D: BIBLIOGRAPHIES OF RUSSIAN LANGUAGE SOURCES

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## 1.0 MAJOR ORGANIZATIONS INVOLVING IN EURASIAN ARCTIC COAL DEVELOPMENT

The Mineral Industry Research Laboratory (M.I.R.L.) was asked to perform a literature search on Arctic coal mining and to prepare abstracts of selected sources. Selected abstracts and references were submitted in the Preliminary Report of June, 1974. Information from the Russian materials acquired is referenced in Appendix B. As part of the data acquisition task, M.I.R.L. obtained a bibliography of Russian materials from the Library of the Academy of Sciences of the USSR, Leningrad. The original was submitted with the Preliminary Report.

This Appendix, prepared by Mr. Niall C. D. Lynch, under the direction of Dr. Donald F. Lynch, is a translation of the Russian language bibliographic materials and is designed for the reader who wishes to know the nature of the information available. The first section presents the basic sources used and the second is a translation of a Russian language bibliography obtained from Leningrad. The translations follow the original Russian as closely as possible to facilitate obtaining the sources from libraries should this be desired.

Should there be future interest in developing contacts within the USSR on Arctic coal mining problems, the bibliographic references suggest that the most useful relationships would be with scientific organizations in Leningrad, Vorkuta, Syktyvkar, Moscow, Krasnoyarsk, Novosibirsk, Irkutsk, Yakutsk, and probably Magadan. The major organizations referenced are: Vorkutaugol', Yakutugol', A. A. Skochinskiy Mining Institute, Lengiproshakt, G. V. Plekhanov Mining Institute, Pechora Scientific Coal Research Institute, G. V. Plekhanov Mining Institute, S. M. Kirov Mining and Metallurgical Institute, V. A. Obruchev Institute of Permafrost Study, and Arktik Ugol'. From the point of view of

reaching organizations which have faced problems similar to those likely to be encountered in Arctic Alaska, the most useful contacts would probably be in Syktyvkar, Vorkuta, and Yakutsk. The most significant mining planning and design organizations referenced are the Pechora Research Coal Institute (Vorkuta), Vostsibgiproshakt (Irkutsk), Leningrad Mining Institute (Professor Yu. D. Dyad'kin) and Lengiproshakt (Leningrad). The study team found that attempting to make direct contacts with Soviet specialists on Arctic coal mining, either by correspondence or through the Soviet Embassy or the Soviet Ministry of Coal Industry was very difficult. Contact with Arktik Ugol' and Mr. N. D. Gusev in Svalbard was arranged through Norwegian officials. Bibliographic references were obtained from the U.S.S.R. Academy of Sciences' libraries in Leningrad and Novosibirsk on the basis of their receiving reports produced by the Mineral Industry Research Laboratory. Most of the Russian sources used were obtained from the Suzallo Library of the University of Washington.

On the Scandinavian side, the most useful contacts would be with the Store Norske Spitsbergen Kulkomani A/S, with main offices in Bergen, Norges Tekniske Høyskole (Norwegian Institute of Technology) in Trondheim, and the Norwegian Ministry of Industry, Oslo (Mr. Hans Im. Ross). Of particular significance would be following closely the development of mining operations in Svea at Svalbard. Norwegians from all organizations involved in Svalbard were extremely helpful to the study team and provided much unpublished information. A good magazine on mineral development in Scandinavia is "Bergverks-Nytt," published by Mr. Odd Valmot, Post Box 1438, 7001 Trondheim, Norway.

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APPENDIX E

THE INTERACTION OF LARGE-SCALE ARCTIC  
ALASKAN COAL MINING AND THE ENVIRONMENT

## APPENDIX E

### THE INTERACTION OF LARGE-SCALE ARCTIC ALASKAN COAL MINING AND THE ENVIRONMENT

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## 1.0 GENERAL

Planning for the future possible development of Arctic Alaska's tremendous coal reserves will need to consider a wide variety of environmental factors many of which are peculiar to the Arctic and some of which are unique to Alaska. This appendix presents a conceptual framework for use in assessing the impact of the environment on large-scale mining, and, to a lesser degree, the impact of mining on the environment.

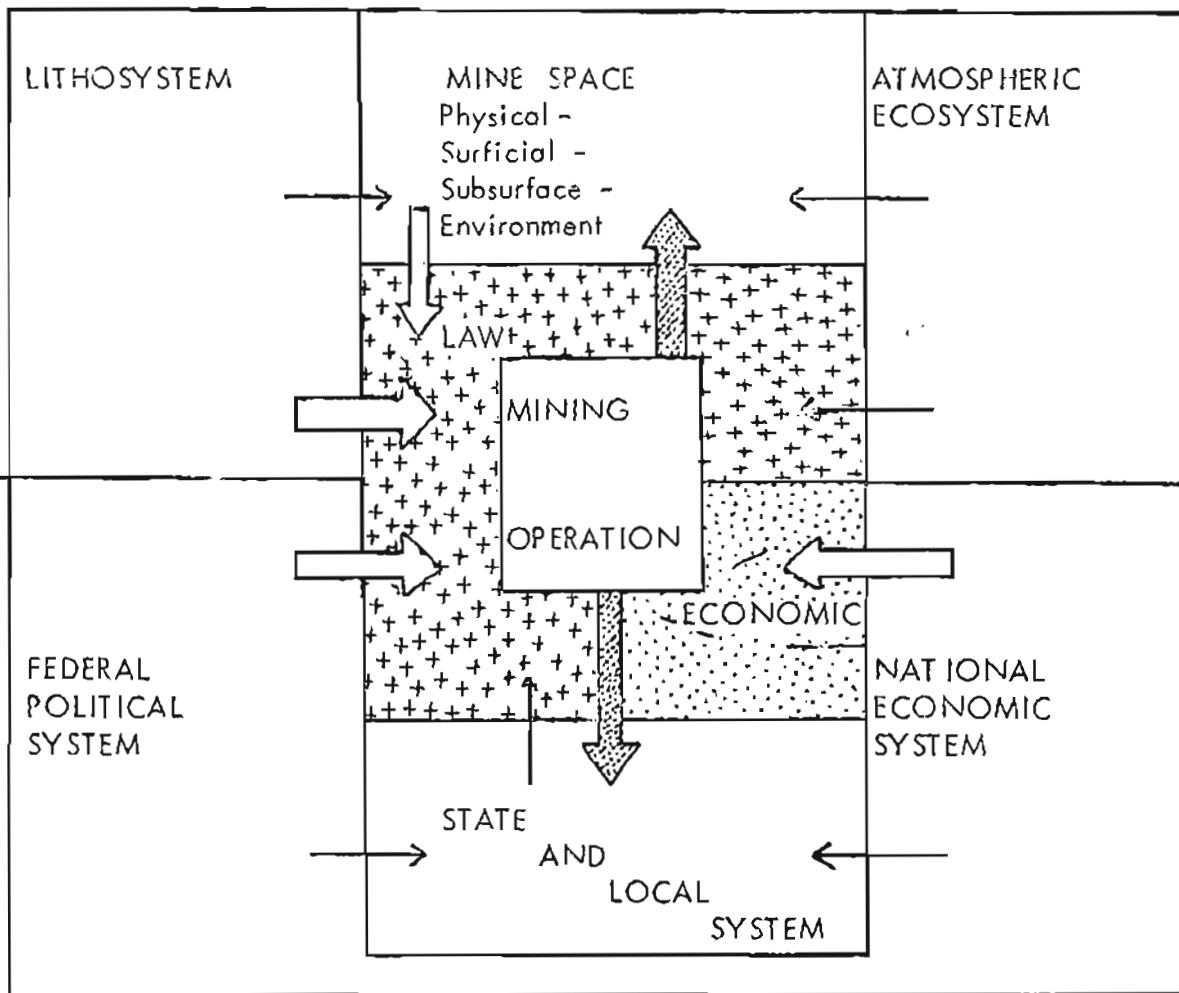
The general relationships are shown in Figures 1 and 2, while specific relations are portrayed in Figures 3, 4 and 5. Figure 6, a matrix, highlights the important mining/environment interactions and is provided as a summary document.

Analysis of the relationships becomes complicated because various elements of mine planning interact on each other and also on the environment. Similarly, various elements in the environment interact with each other and also with mining. Figure 2 depicts these relationships in the form of a systems flow diagram.

The relationships shown and discussed are based on the literature search and field trips discussed in Appendixes A, B, and C, the basic factors emphasized in the report, and on the study team's knowledge of Alaska. This analysis should be considered general rather than specific, as the actual relationships that may exist will be very dependent upon the timing of the mining operation, the technology utilized, the mine method and plan, and the specific locational and site characteristics of the area selected.

The major factors that will influence the large-scale development of Arctic Alaskan coal will be the specific characteristics of the coals,

PHYSICAL SYSTEMS



SOCIO-POLITICAL ECONOMIC SYSTEMS





- LEGEND:
-  Zone of Economic Impact on Mining
  -  Zone of Legal/Regulatory Impact on Mining
  -  Major Environmental Impact on Mining
  -  Major Impact of Mining on the Environment  
(Width of Arrows shows Magnitude of Inter-Action)

FIGURE 1. ALASKAN ARCTIC MINING/ENVIRONMENTAL INTERACTION



economic incentives, market conditions and the national interests involved in utilizing this resource. These factors are outside the purview of the analysis.

## 2.0 ALASKAN ARCTIC MINING/ENVIRONMENT INTERACTION

Figure 1 portrays the general relationship of an Arctic mining operation to the physical and socio-political systems within which it will exist and interact. The physical systems basically consist of two parts: the lithosystem and the atmospheric-ecosystem. The former consists of those geological forces which have created the basic structures and rock types. This system impacts directly on coal mining since it produces the mineable coal and the geologic environment in which the coal would be exploited.

The atmospheric-ecosystem is largely the result of macroclimatic forces and topography which create the local and micro-climates and the vegetative and animal environments of the surface. This system and the lithosystem acting together create that surface and subsurface environment in which mining occurs. This might be considered the mine's environmental space and is the area that has the greatest physical impact on mining operations. It is also the area of greatest concern for environmental protection.

For the Alaskan Arctic, the mine environmental space is characterized by extremely low winter chill factors (to  $-60^{\circ}\text{F}$ ), cool mean summer temperatures (a maximum of  $+50^{\circ}\text{F}$ ), the widespread distribution of deep, ice rich permafrost, a shallow active zone, extensive thaw and other lake formations in lowland areas, and sedimentary, coal bearing rock formations. The interaction between a mining operation and the mine space is a physical relationship which is increasingly controlled by government laws and regulations.

The mine operation is also affected by federal political and national economic systems. For Arctic Alaska, this relationship is critical as far as development is concerned. The Federal Government controls the bulk of the coal bearing land and also the major potential transportation corridors. The government establishes the rules and regulations which control mining operations (safety, environmental control, taxation, leasing, health), and has a major influence over the establishment of communities, communications, and human amenities. The national economic system will determine both the feasibility and the financial support to be provided for the development of large-scale mining, and it will also be this system which will determine the markets and together with the federal political system the transportation corridors to be used to move the coal to its ultimate destination.

The mine operation, while heavily influenced by these systems, has its greatest impact on the local and state socio-political system. Local cultural, social and political values and institutions will be the ones most affected by mining, and it is local legal, economic, and human land-use patterns which are most likely to impinge directly on mining operations. From a practical point of view, it is the local Native Corporations which will be the most affected, and, depending on the locations, may control part or all of the lands needed for mining and/or transportation.

The size of the arrows on Figure 1 suggests the magnitude of the various interactions. The lithosystem and the federal political and national economic systems are the ones with the greatest impact on the development of coal mining. However, the coal mine operation has its major effects on the local and state systems and on the immediate physical environment, which can be thought of as the mine space. Over the long term, these latter relationships may become politically more important than they are at present.

### 3.0 MINE DEVELOPMENT PLANNING PHASES

Planning for the development of coal mining in Arctic Alaska involves proceeding through a series of logical phases. These can be expressed in many ways. For the purposes of this analysis the following sequence has been formulated. The flow of this sequence and the critical environmental relationships are shown in Figure 2.

#### 1. Objectives:

The mining operation must work toward certain defined objectives before it is even worth considering. The objectives certainly under the American system would include an operation which would meet economically valid and financially profitable long term needs. In addition, however, the objectives might include such factors as establishing a basic industry able to provide employment, tax revenues, infra-structure and services, and a stable economic base in a region which is sparsely populated and underdeveloped. The argument that the economic future of the North should rest on mineral resource development can not be overlooked.

#### 2. Mining Laws:

The laws and regulations governing access to and utilization of mineral resources constitute an important constraint in the development of Arctic Alaskan mines, support services, and transportation corridors. It would hardly make sense to plan for the development of a mining operation in an area that may not be accessible due to restrictive land-use policies or in which mining claims or leases may not be obtainable.

#### 3. Resource/Land Availability:

Given the objectives and the applicable laws, this phase involves determining whether the resources and the necessary land are or can be made available under adequate conditions.

#### 4. Transportation:

This variable may be the key to the development of Arctic Alaskan coal as it may represent not only the highest cost but also the one requiring the longest lead time and the greatest amount of governmental support. The issue could be as complicated as that of the haul road from the Yukon to Prudhoe Bay, if a market outside of Alaska is needed to satisfy the objectives. The selection of modes and routes may involve some complex trade-offs.

#### 5. Technology:

Based on Eurasian experience, it is unlikely that special mining equipment specifically designed around Arctic Alaskan environmental requirements will be developed. Assessment of technological capabilities will

involve, therefore, equipment already developed or easily modified. Once installed, however, this equipment is very likely to remain in operation for many decades, so that the initial selection is a critical parameter. The technology employed is also likely to have the greatest effect on the surficial environment, the mine space, and on the local human environment. It will also have to be compatible with the transportation system, while the support requirements for the selected technology will dictate in large part the infrastructure and labor force requirements.

6. Mine Method:

The mining method will basically be a choice between surface and underground mining and between a large scale and small scale operation. The selection will be a function of the previous phases and will be a critical variable in assessing local environmental and human effects. If underground mining is followed, then care must be taken in performing trade-offs between ventilation requirements as a function of gas content and the impact of ventilation on roof and shaft stability, worker comfort, equipment icing, and thermal exchanges. Surface mining will have to face the problems of operation under conditions of extremely low wind chill factors and the impact of large scale operations on the local physical and human environments.

7. Labor:

The labor requirements will be a derivative of the above. The proper mix between locally available labor and imported labor will be important in assessing the local environmental impact. In terms of community design, this factor will also affect the requirements for amenities, infrastructure, and other human needs. In addition, Eurasian experience suggests that the maintenance of a permanent, career engineering staff may be highly significant for Arctic operations.

8. Mine Operation:

With the previous stages completed, the next phase would be the construction and operation of the mine itself. This is the point at which the mine begins to have a long term impact on the local environment.

9. Beneficiation:

Beneficiation is a separate phase and the selection of the most suitable system will be a function of objectives, technology, transportation, and the physical surficial environment. Effective, low cost water washing of coal will prove difficult in a cold climate.

10. Support:

Support requirements are a derivative of all of the above.

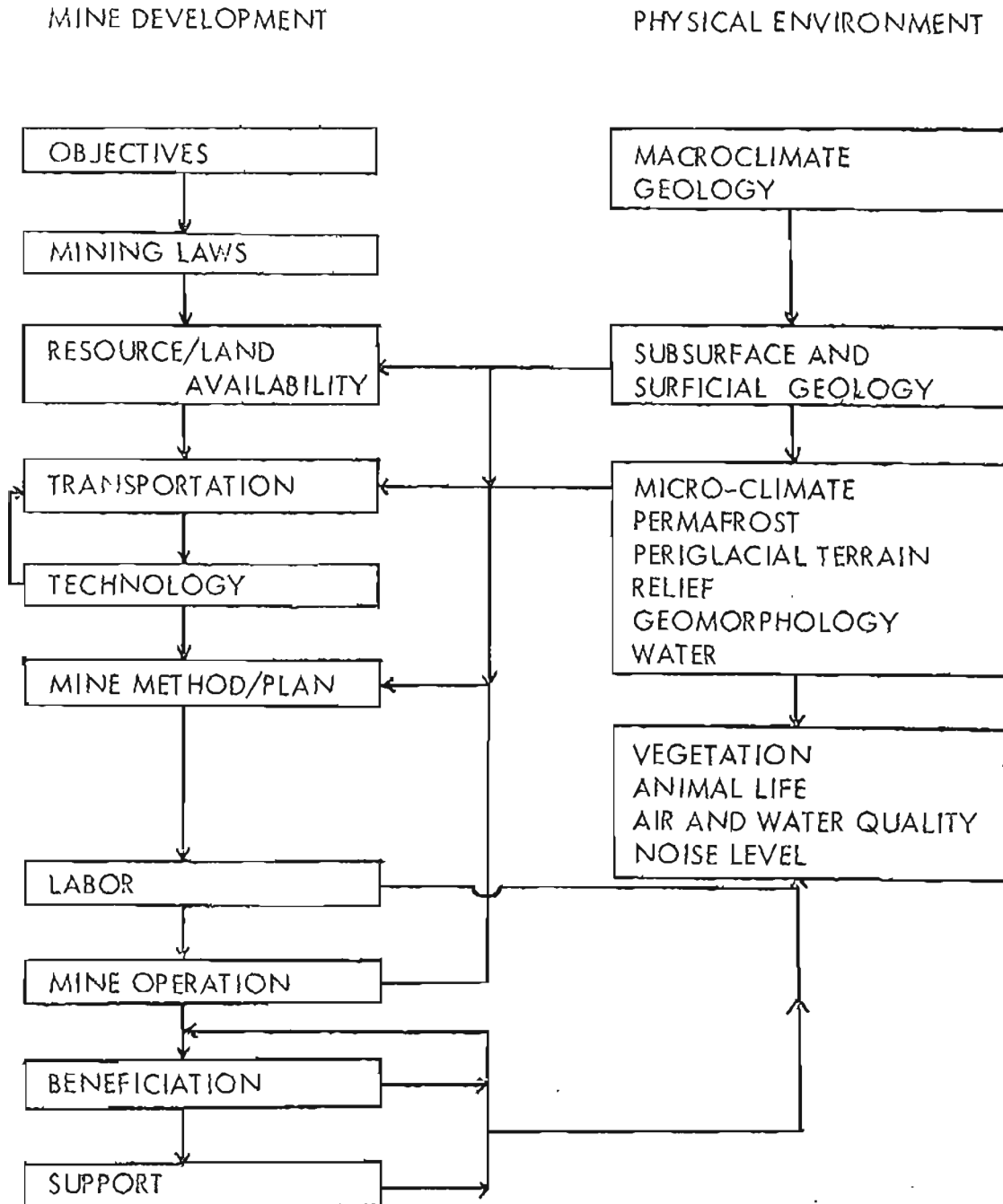


FIGURE 3. ARCTIC COAL MINING/PHYSICAL ENVIRONMENT INTERACTION

#### 4.0 ARCTIC MINING/PHYSICAL ENVIRONMENT INTERACTION

Figure 3 portrays the interaction between the physical environment and Arctic Alaskan coal mining. As can be seen, the number of environmental factors which affect mine development increases as planning progresses through the various phases.

Macroclimate and geology affect resource availability, while microclimates, water, permafrost and surficial features affect transportation and subsequent phases. Microclimates can be measured in terms of temperature, precipitation, relative humidity, and wind speed. From a design point of view, for winter operations on the surface one should consider mean and extreme low temperatures and chill factors. Underground, the temperature regime will remain fairly constant 1,000 yards or so from the opening (Appendix A, 2.2). The range of temperatures to be encountered will be from 24 to 32°F, so that all equipment can be configured to operate in this narrow thermal envelope. Relative and absolute humidities may show drastic changes from season to season, resulting in special precautions against dust generation and perhaps electrical malfunctions during the winter period. Surface water may penetrate through cracks and fissures into underground works, particularly if the thermal regime of the rock structures is altered. This has been a particular problem in the Vorkuta region of the USSR, and could also be a problem in those parts of Arctic Alaska characterized by thaw lakes, ice wedge polygons, and surface and subsurface stream flows. Intra-permafrost water is also likely to be encountered, possibly as sudden inflows. The mining method should assess the effects of excavations on the total hydrogeological space to be effected (Appendix B, 2.7). In some cases, surface water may have to be drained. Particular attention should be paid

to removal of mine water on to the surface, as this could result in increasing the volume of water that cycles through the mine area. This creates not only a water control problem, but perhaps in the long run a more significant thermal exchange problem that can lead to shaft misalignment, roof collapse, and other forms of deformation. Planning on water control should be undertaken long before the mine excavations enter the region below the permafrost. The lower section of permafrost has a temperature close to freezing and can be a difficult region for mining (Appendix B, 5.1). The water supply and control system should take into account the effects of water on the thermal regime of the mine, especially in areas of permafrost with a temperature close to thawing.

Wind speed and surface pressure may have an effect on altering the pressure gradient between the surface and the mine workings, thus affecting the ventilation system (Appendix B, 4.2). A reversible ventilation system may be worth considering. Wind speed can also affect surface coal storage areas, surface transportation systems, and areas of snow accumulation. Proper designs, correct orientation of structures in relation to wind direction, proper positioning of vehicle parks and the use of raised road beds are factors to be considered. Wind direction and speed should be considered in the location of coal storage areas to minimize snow accumulation on the coal (and subsequent thawing and freezing of the coal) and to prevent wind blown dust.

Permafrost has different characteristics depending upon its depth, nature of its constituents, ice content and history. For coal mining, there are different problems on the surface and deeper underground. Surficial permafrost deposits are likely to consist of alluvium and the products of

mass wasting. Openings through this unconsolidated material must be stronger to avoid structural deformation as the material freezes and thaws. Once into the rock this problem is considerably simplified (Appendix A, 2.2). Unconsolidated materials not subject to annual thawing and at temperatures lower than 28°F are frozen together and have great strength (Appendix B, 5.4). Conceivably they could be mistaken for rocks, and if this happens, subsequent thawing induced by mine operations can cause roof support and shaft alignment difficulties (Appendix B, 4.1-5.5). Sandstones, claystones, shales, and other sedimentary rocks normally associated with coal seams often contain interstitial moisture which, when thawed or removed by sublimation, can cause rock spalling and sudden rock falls. Coal that is hard when frozen underground may break into small particles when thawed. One Russian source states that coal pillar dimensions for underground mining in permafrost should be different from those for other climates (Sangara deposit). It appears that freezing below 28°F increases tensile strength very significantly but has little effect on compressive strength (Appendix B, 5.5). With proper precautions, particularly regarding thermal exchange, it may be possible to use only limited amounts of roof support material within permafrost. However, this same characteristic may complicate adequate roof collapse in retreat long wall mining.

Calculation of the thermal changes likely to occur within the permafrost over time as a result of the mining operation is necessary in the planning stages (Appendix B, 5.4). Permafrost, if maintained, has the great advantage that it deforms only slowly. For this reason, abandoned excavations can be filled with water which, when frozen, will provide adequate, long term roof support and prevent surface subsidence. Ice is not



particularly difficult to remove at a later date should the excavations need to be reopened.

Introduction of ventilation air and mine water can cause a change in the thermal regime and a gradual increase in rock and coal temperatures. This in turn can result in an increase<sup>1</sup> rate of chemical oxidation which causes heat. Under special circumstances in the Vorkuta area, this process appears to have contributed to spontaneous ignition and extensive underground fires (Appendix B, 3.3). There may, therefore, be value in testing the susceptibility of Arctic Alaskan coals to spontaneous ignition under a range of temperature and ventilation conditions.

Surface mining will also be affected by permafrost. Slope stability in unconsolidated sediments will be a continuous summer problem as the banks thaw and erode. Thawing at the base of the excavation will also occur. The mine is likely to receive water inflow during the summer from both surface water and water from thawing permafrost. Inflow in winter is also possible when thawed aquifers are encountered. Surface mining should, therefore, assess the hydrogeological environment in which the operation is to be conducted.

Coal dust generation is likely to be extremely high in large scale surface mining under winter conditions. One Soviet report on the Kangalassk and Zyryansk surface mines describes such an operation as creating so much dust that visibility was near zero for equipment operators (Appendix B, 4.7, 4.8). The susceptibility of the mined coal to dust generation under a variety of low temperature and humidity conditions might profitably be determined in advance of mining. (At the Usibelli Mine in Alaska, coal is blasted rather than ripped, partly to avoid dust).

The entrance of water (or snow) into the excavation may cause the coal to become frozen in large lumps either during transport or storage. The design of the excavation to minimize snow drifting, water inflows, and the affects of wind on blowing coal dust would seem to be appropriate.

If the excavation is subsequently abandoned, there will be some significant choices regarding restoration. If the space is to be left as is, the slopes will likely continue to erode as they thaw until some form of stable slope is restored. If filled with water, the resulting lake will freeze only to a depth of less than ten feet. The remainder of the water will remain unfrozen throughout the year and creat a thawbowl around its edges and below. Depending upon the depth and local microclimatic and ecological conditions, the lake may in time fill in with vegetation. If it is affected by a strong dominant or prevailing wind, it may migrate across the landscape. Whether or not the creation of such a lake would be an advantage or a disadvantage environmentally might be a significant question.

If the excavation is backfilled with thawed materials, the result could be the creation of a hollow due to the absence of the previously existing ice. This would depend upon the type of backfill used. An unfrozen, dry area can be a significant economic asset in a region of waterlogged, ice rich permafrost. Properly utilized, it could become an excellent town site. Natural revegetation will probably occur at a much more rapid rate than in ice rich permafrost areas.

In the case of both surface mining and underground mining with high speed equipment, the problem of dust suppression under winter conditions remains unsolved (Appendix A, 2.7). Possible approaches to this problem include respirators for equipment operators, the utilization of special additives to water spray to reduce drastically the amount of water utilized

for dust suppression, the construction of special vacuum systems to remove dust along the working faces, haulage ways, and at coal transfer points, and artificially increasing the relative humidity of the mine atmosphere. These have all been tried by the Soviets, but not with (as far as is known) really high speed mining equipment. The reported results appear not to satisfy the stringent requirements of U.S. mining codes.

The effects of mining operations on vegetation, animal life, water quality and noise levels are significant not only from an environmental point of view, but also from a legal and human standpoint. Underground mining, properly conducted, appears to have limited effect on the local ecology under Eurasian Arctic conditions, primarily because of the stability of permafrost, the general absence of acid mine water drainage, and strict regulation of hunting and other activities by people, that might damage the environment (Appendix A, 2.10). Whether or not this same situation would pertain in Arctic Alaska is another question. Here the mining organization would have to take into consideration not only the applicable laws, but also the needs, interests, and cultural values of the local population and of the State of Alaska. In addition, Eurasia lacks the migratory herds of caribou that characterize Arctic Alaska, a factor that would have to be considered in mine site selection, development and operation.

Mining operations are quite likely to create a local ice fog condition, and if situated in a valley with a winter temperature inversion, they may cause a wintertime air pollution problem. Measures to combat this might include the limited utilization of gasoline and diesel powered surface vehicles, the removal of moisture from smokestacks, and the provision of heating systems that produce only minimal air pollutants and moisture.

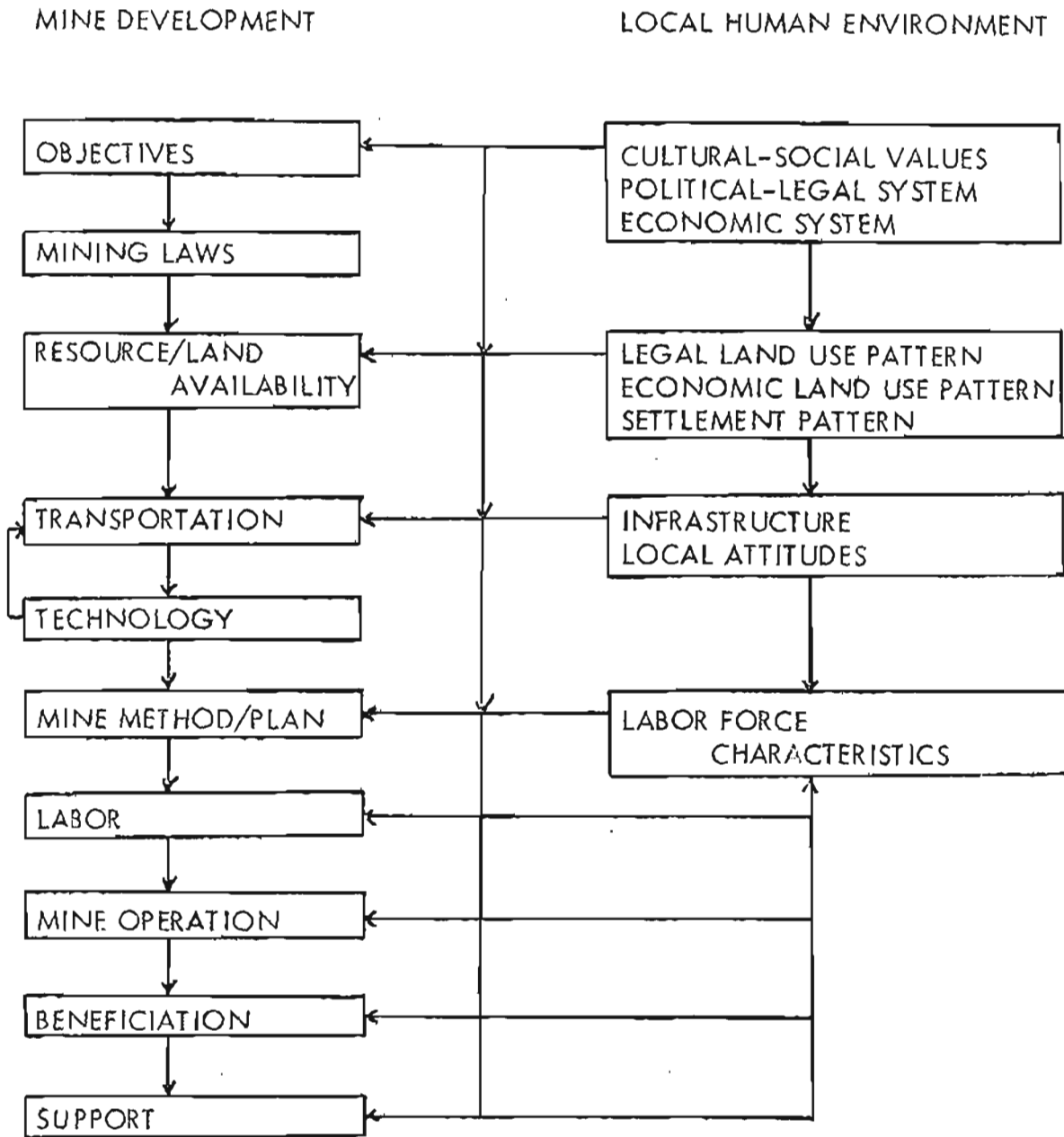


FIGURE 4. ARCTIC COAL MINING/LOCAL HUMAN ENVIRONMENT INTERACTION

Without proper precautions, and under the right microclimatic conditions, a deep surface mine could conceivably create its own ice fog which in conjunction with extremely low temperatures and a high rate of dust generation could develop a very unpleasant working environment. One rather obvious answer to this problem would be to close down operations under ice fog producing conditions, which are likely to exist for only a small portion of the year anyway. In interior Alaska, however, these are the very times when coal is needed most.

#### 5.0 ARCTIC MINING/LOCAL HUMAN ENVIRONMENT INTERACTION

The relationship between coal mine development and the local human environment is very likely to be quite different in Alaska than it has been in Eurasia, particularly if the operation is to be a large-scale one designed for a distant market. From a locational point of view, it is possible that Arctic Alaskan coal could be developed in an area that has only a sparse or indeed no local population. However, the indigenous population of Arctic Alaska has a tradition of utilizing large areas for subsistence hunting and fishing, and it is quite unlikely that a large mining operation, particularly a surface mine, can be so located as not to intrude to at least some degree into areas used by people.

The transportation corridor and the support systems will undoubtedly affect native Alaska, and at least a portion of the labor force may be drawn from native Alaskans.

These factors, as suggested in Figure 4, might perhaps most appropriately be considered in establishing the objectives of the mining operation and in determining the resource and land availability, facets of mine development that must be considered early in planning.

This approach at least would meet the problems early, before a large investment is made, and perhaps even enlist local support for the mine development, a factor of no small significance in today's political environment in Alaska.

From a planning point of view, one would have to assess the existing and possible future local land use pattern. This has three distinct aspects. The first is the current and possible future legal status of the land itself, since the final selections of native, state and federal lands have not yet been completed. Then, the actual economic land-use pattern should be assessed. This pattern is a function of the season of the year, subsistence hunting, and animal migration patterns, and is not identical with legal land ownership. Finally, the settlement pattern itself should be addressed, as it may affect the transportation, support and infrastructure requirements of the mine operation, and in turn may be affected by these. The settlement pattern historically in Arctic Alaska has also included temporary settlements established around seasonal hunting and fishing sites.

The cultural values, settlement patterns, and seasonal land-use patterns will affect significantly the attitudes of the indigenous population and the local labor force. Absenteeism has been a problem in coal mines elsewhere in the north using local labor. In Alaska a significant percentage of the population is accustomed to seasonal construction work. Hunting season can be the cause of significant absenteeism (e.g., moose and caribou seasons in interior and northern Alaska), and this is a factor which should be taken into account in assessing labor force requirements.

Total reliance on an outside labor force carries with it certain other problems. Alaska is probably better provided with air travel capabilities than any other coal basin in the Arctic, so that employees from the outside

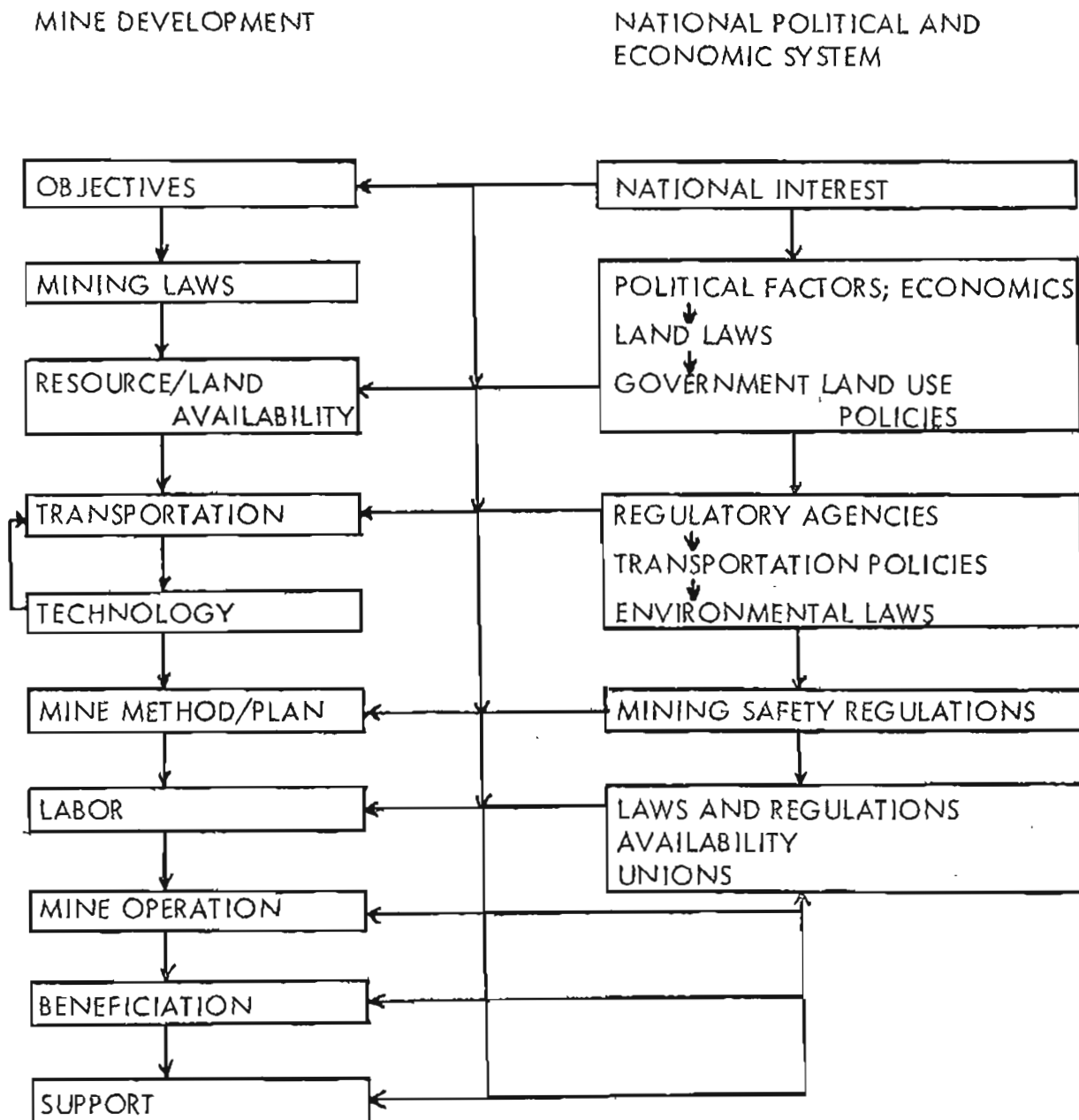


FIGURE 5. ARCTIC COAL MINING/NATION INTERACTION.

may not feel committed to remaining at a particular Arctic location.

These labor force characteristics and requirements need to be considered in developing transportation plans, selecting technology, and formulating the mine method and plan. The mine operation, depending on its size, location, site, and duration may also have a significant effect on labor force characteristics, local attitudes and the infra-structure pattern.

## 6.0 ARCTIC MINING AND THE NATION

Mine development in Arctic Alaska will be more affected by national political and economic systems than is true in most other states of the Union. Most of Arctic Alaska's coal resources are located in areas controlled by the Federal Government and the development of transportation facilities to export this coal will undoubtedly require government approval. It is not inconceivable that large scale coal development in Arctic Alaska might require literally an Act of Congress.

The development of a substantial export market will depend both upon the economic situation, the capability of the economic system to make and sustain long term commitments of both markets and financial resources, and also on political factors.

As portrayed in Figure 5, government policies at the federal, state and local level will also impact on resource and land availability, the commitment of long term coal reserves, on transportation, and on the selection of technology, mining method and plan, and mine operations.

From a technical point of view, the literature search on Eurasia suggests that modifications may be necessary in existing mine regulations particularly regarding ventilation and the use of water for dust suppression if Arctic coal mining is to be successful. Ventilation in Arctic underground coal mines affects not only the gas content of the mine atmosphere, but



may also affect the degree of dust generation, worker comfort (wind chill underground), roof stability, pillar strength, shaft deformation and alignment, permafrost degradation, the possibility of spontaneous ignition, and mine atmosphere humidity. High ventilation air volumes and velocities do dissipate gas more effectively than low air volumes and velocities, but they may do so at the cost of creating other problems that could be just as serious.

High requirements for the use of water for dust suppression may not only increase operational costs, but also cause worker discomfort, equipment failures, coal freezing, permafrost degradation, roof instability, and deformation of openings.

These two examples clearly suggest that the applicable mining codes may have to be carefully examined for their suitability to Arctic coal mining operations.

While undoubtedly controversial, it may also be that the laws and regulations governing the environmental impact of coal mining may not in all respects be suitable for Arctic Alaska. These laws and regulations were developed for a temperate, humid to subhumid, non-permafrost environment, and their unmodified application to a cold, frozen, Arctic environment may create difficulties. For example, a requirement to completely restore the natural environment after deep surface coal mining would logically require recreating an ice-rich permafrost environment, whereas several alternative environments might be equally acceptable.

Because of the magnitude of the resources and the significant role of the Federal government in the development of Arctic coal mining, the factors that set the Arctic Alaskan deposits apart from other deposits deserve further study.

## 7.0 ENVIRONMENTAL FACTORS MATRIX

Figure 6 is a matrix developed in order to summarize the significant possible impact of the local environment on Arctic coal mining. While not exhaustive, it does present a check list of factors against which future proposals for mine development and study of Alaskan Arctic coal may be assessed.

The vertical column lists the major factors involved in developing an Arctic coal mine. The horizontal row lists those local environmental factors considered most significant in the planning phase. The intersects can be used for placing quantitative or qualitative estimates of the impact on mining on the environment and vice-versa. The most important probable impacts of the environment on coal mining are marked with an X.

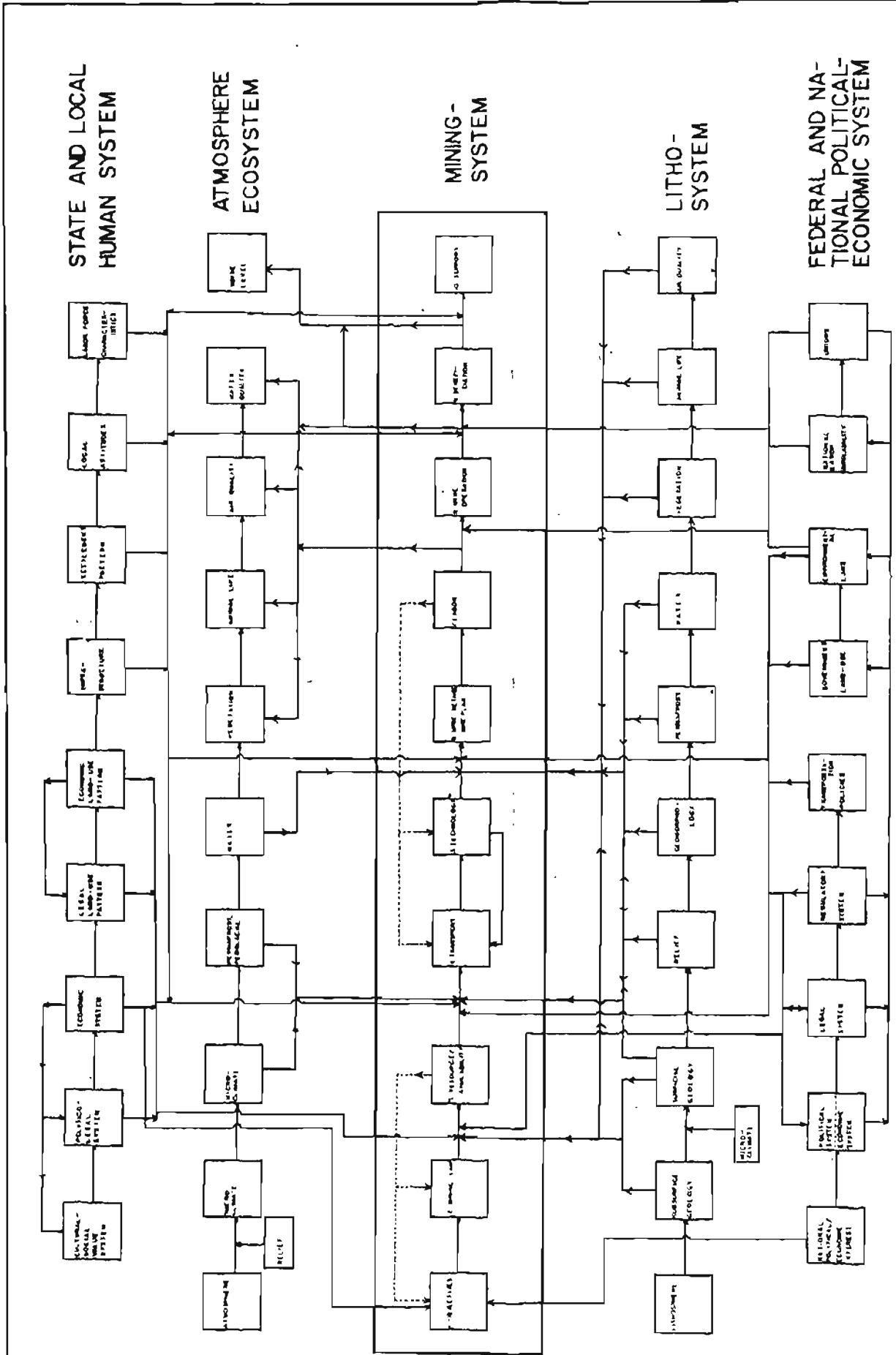


FIGURE 2. FLOW CHART OF ENVIRONMENT / COAL MINING INTERACTION

| LOCAL ENVIRONMENT<br>COAL MINE DEVELOPMENT | PHYSICAL & CLIMATE   | GEOLOGY  | LOCAL TOWN  | PERMANENT   | URGENT   | LOCAL ENVIRONMENT  |
|--|--|--|---|---|--|--|
|  | Temperature<br>Wind<br>Precipitation<br>Humidity<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects<br>Dust<br>Noise<br>Vibration<br>Odor<br>Light<br>Sound<br>Temperature<br>Humidity<br>Precipitation<br>Wind<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects | Stratigraphy<br>Structure<br>Faulting<br>Seismicity<br>Dust<br>Noise<br>Vibration<br>Odor<br>Light<br>Sound<br>Temperature<br>Humidity<br>Precipitation<br>Wind<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects | Population<br>Density<br>Economic<br>Activity<br>Social<br>Cultural<br>Historical<br>Archaeological<br>Landscape<br>Visual<br>Noise<br>Vibration<br>Odor<br>Light<br>Sound<br>Temperature<br>Humidity<br>Precipitation<br>Wind<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects | Permanence<br>Duration<br>Frequency<br>Intensity<br>Area<br>Volume<br>Weight<br>Temperature<br>Humidity<br>Precipitation<br>Wind<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects | Urgency<br>Priority<br>Frequency<br>Intensity<br>Area<br>Volume<br>Weight<br>Temperature<br>Humidity<br>Precipitation<br>Wind<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects | Local Environment<br>Impact<br>Frequency<br>Intensity<br>Area<br>Volume<br>Weight<br>Temperature<br>Humidity<br>Precipitation<br>Wind<br>Fog<br>Thunder<br>Lightning<br>Snow<br>Ice<br>Permafrost<br>Soil<br>Vegetation<br>Wildlife<br>Fish<br>Insects |
| OBJECTIVES                                 |  |  |   |   |  |  |
| RESOURCE / LAND                            |  |  |   |   |  |  |
| TRANSPORTATION                             |  |  |   |   |  |  |
| MINING TECHNOLOGY                          |  |  |   |   |  |  |
| MINING METHOD / PLAN                       |  |  |   |   |  |  |
| LABOR FORCE                                |  |  |   |   |  |  |
| SAFETY WORKER CONTROL                      |  |  |   |   |  |  |
| HOOR SUPPORT                               |  |  |   |   |  |  |
| VENTILATION                                |  |  |   |   |  |  |
| DUST SUPPRESSION                           |  |  |   |   |  |  |
| WATER SUPPLY                               |  |  |   |   |  |  |
| REHABILITATION                             |  |  |   |   |  |  |
| SUPPORT SERVICES                           |  |  |   |   |  |  |

FIGURE 6. IMPACT OF LOCAL ENVIRONMENT ON ARCTIC ALASKAN COAL MINE DEVELOPMENT