EXPERIENCE WITH PERMAFROST IN GOLD MINING

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The Giant Mine of Giant Yellowknife Mines Limited is located on the north shore of Great Slave Lake (60°30'N, 114°21'W), adjacent to the mouth of the Yellowknife River and approximately 4 miles north of the Town of Yellowknife. An all-weather highway and daily air services link the mine and the community of Yellowknife with the outside world.

The general relief of the Yellowknife area is typical of the Precambrian Shield. Although generally flat, the local relief is rugged with rock, hills and ridges rising abruptly from the innumerable lakes and muskegs. Almost continuous outcrop is present throughout the district, but stands of spruce, pine, birch and poplar in the valleys and on the sand plains tend to soften the overall landscape. The sand plains, eskers and other such surficial deposits were presumably left, following the intensive glaciation of Pleistocene times.

The regional climate, though naturally severe, is not unpleasant. The summers are short, but warm, and the days pleasantly long; temperatures occasionally reach the high 80's; August is the warmest month with a mean temperature of 60°F. The converse is true of the winter months, with January averaging -20°F. The mean annual air temperature at Yellowknife over the past 22 years is 24°F. Annual precipitation is low at slightly less than 12 inches per year, of which approximately 5 inches is rain.

Yellowknife is located in the discontinuous zone and permafrost is patchy and erratic in distribution. Although generally present beneath overburden, it appears to be absent beneath rock outcrops. Several authorities have suggested that the permafrost may have originated in late glacial times and has been preserved by the insulating cover of the overburden.

UNDERGROUND OPERATIONS

The Giant Mine commenced production in May 1948, and in the intervening years has produced over $140, 000, 000 of gold from approximately 6, 000, 000 tons of ore. The current milling rate is slightly in excess of 1, 000 tons/day at a grade of approximately 0. 65 oz./ton. The underground workings, with some 35 miles of tunnels, extend over a strike length of nearly 3 miles and to a maximum depth of 2, 100 feet. A variety of stoping methods have been used throughout the mine which include open stoping, shrinkage stoping and horizontal cut and fill; today due to changing physical conditions approximately 85 per cent of the ore is extracted by the latter method. These methods have been discussed in considerable detail in papers by McDonald (1953) and Smith (1961).

It will be appreciated that the choice of a mining method at any underground operation is influenced by many factors; however, permafrost conditions at Giant have in no way influenced or dictated the mining techniques to be used. This point is perhaps the most significant aspect of Giant's approach to mining in permafrost areas. Experience has shown that by providing adequate ventilation, which is a normal prerequisite for all stoping operations, temperatures can be maintained sufficiently above the freezing point in permafrost areas to ensure that broken muck piles and water lines do not freeze. Under such conditions mining can proceed in a normal manner.

PERMAFROST AREAS OF THE MINE

Underground rock temperatures at Giant vary from 28° to 32°F at the upper levels of the mine, to almost 50°F at the 2, 100 level; the geothermal gradient has been established at approximately 0.9°F per 100' vertical feet. Areas of permafrost are thus only encountered at the upper levels of the mine, with the limiting horizon at/or about the 250 foot level. Significantly, the areas of permafrost exposed by Giant all lie immediately below the valley of Baker Creek, which provides an insulating covering of 50 to 60 feet of clay and gravel. Numerous test drillings into this overburden have confirmed that it is perennially frozen. These permafrost areas are essentially dry, and they are characterized by the growth of ice crystals on the walls of underground openings if ventilation is kept to a minimum. This effect can be very striking if the crystals are allowed to grow for any length of time.

In sharp contrast to the severe permafrost conditions encountered in the ground below the Baker Creek valley, the upper levels in the B3 area of the mine have not as yet exposed frozen ground. This area is noticeably although only relatively wet; there is considerable rock outcropping and very little overburden in this area. Ice-filled fissures have occasionally been exposed in this area but these appear to be seasonal features. Generally, rock temperatures in the area are sufficiently above 32°F to maintain open drainage ditches and open water lines.

VENTILATION

As mentioned previously, before any mining can be successfully initiated underground adequate ventilation must be provided. At Giant, two parallel triple stage fans force 60, 000 cfm into the underground workings; during the winter months it is of course necessary to preheat the air to approximately 35°F. This primary supply of ventilating air is subsequently broken down in a number of splits to direct fresh air to all underground working areas.

This relatively warm air causes all signs of the permafrost to disappear rapidly and it recedes into the wall rock. There is no recorded data on the amount and rate of permafrost recession but it is known that the permafrost has returned relatively rapidly when the warm air ventilation was discontinued after completion of lengthy mining programmes.

MINING IN PERMAFROST

More than half a million tons of ore have been extracted from Giant's permafrost horizons, and this figure will probably approach the one million ton mark over the next decade. Stopes have varied in size from less than 10,000 tons to 100,000 tons, with most of the ore being extracted by the shrinkage stoping method. Open stoping and the more costly cut and fill methods have been used only when shrinkage stoping was not applicable. All three of these methods are acceptable, however, for selective underground mining operations throughout the world. Thus, Giant has developed no special techniques nor taken any special precautions for mining in its permafrost horizons. Similarly, conventional equipment has been used.

Using short hole drilling equipment and standard explosives, the breaking of frozen ground has presented no unusual problems. The driller must blow his holes dry when completed or they will be frozen at loading time. Because the ground in these areas was extremely competent in the first place, the gradual thawing and retreat of the permafrost has not led to any abnormal scaling conditions within the stopes. In fact, several stopes have remained open and dry for more than ten years with virtually no sign of wall deterioration during this period. Track bound mucking machines (and latterly rubber-tired LHD equipment) have been used for drawpoint loading, and have not been hampered by any freezing of the broken muck within the body of the stopes. For the physical comfort of the miner, the forced ventilation ensures an air temperature of about 35°F, which, although not warm, is suitable for steady physical labouring. Smoking breaks are kept to a minimum during the shift, however, and the meal period in a heated room is a virtual necessity.

UNDERGROUND ARSENIC STORAGE

Accompanying the gold production, Giant has also produced a considerable quantity of crude arsenic trioxide dust. This undesirable unmarketable waste by-product originates from the arsenopyrite in the ore from which it is released during the roasting of sulphide concentrates. As mill tonnage has increased over the years, the daily production of this dust has risen from approximately 10 to 12 tons in the early 1950's to almost 25 tons daily since 1958. The total to the present time is approximately 140,000 tons occupying a volume in excess of four million cubic feet.

To avoid the dangers of surface pollution, it would have been tremendously costly for Giant to store such large quantities of arsenic on the surface. Consequently, since 1951, Giant has been containing and storing arsenic dust in large underground chambers. Using shrinkage stoping methods, these chambers have been cut in the perennially frozen ground above the 250 foot horizon and are consequently completely dry. This condition is absolutely essential because of the solubility of arsenic in water. The chambers are accessible only from the ground surface and have been completely sealed off from the remainder of the underground workings by massive reinforced concrete bulkheads. Eventually surface access to these areas will also be sealed by bulkheads, leaving the arsenic dust permanently entrapped in the frozen ground for as long as necessary.

Arsenic dust is conveyed into these chambers through a 4 inch delivery line from the baghouse, low pressure compressed air being the conveying medium. The "spent" air is returned to the baghouse through a 6 inch exhaust line. The baghouse and chamber are essentially in closed circuit together preventing any possibility of arsenic contamination. Each chamber is provided with a sealed inspection point, and during drilling operations the storage capacity is measured frequently. Generally, Giant maintains a 2 to 3 year storage reserve because of the length of time required to prepare such areas.

Giant has prepared a total of seven arsenic disposal chambers, varying in size from 400,000 to 1,400,000 cubic feet. The first five chambers were all cut from waste ground with the waste being utilized for fill in cut and fill stopes on lower levels. By 1957, however, tailings fill had been introduced to the cut and fill operations and the need for waste fill was virtually eliminated. By this time too, a considerable quantity of ore had been mined from the permafrost areas, and several of the abandoned shrinkage stopes were suitable for arsenic disposal. Chambers 6 and 7 are, therefore, essentially old shrinkage stopes with suitably located isolating bulkheads. Considerable saving has been achieved by utilizing such areas as arsenic disposal chambers. They also have a definite physical advantage over the waste stopes in that ground conditions are known ahead of time, and similarly these areas have been known to be dry for several years.

This concept of utilizing abandoned stoping areas within the permafrost has been incorporated into long-range plans for future arsenic disposal; today's shrinkage stopes in these permafrost horizons will become the storage areas of tomorrow.

SUMMARY

Permafrost conditions at Giant have not necessitated any significant revisions to standard mining methods. Its presence in the upper horizons of the mine, however, has enabled Giant to dispose of its arsenic dust safely in underground chambers with minimal expense and maximum security.

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REFERENCES

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Discussion

Dr. L. W. Bliss remarked that storing the arsenic trioxide dust in the permafrost seemed like a good method of disposing of this waste by-product. He asked what would happen if the permafrost thaws and whether studies had been carried out to determine water flow patterns and potential routes of movement of the arsenic material. Mr. Espley replied that the arsenic chambers are inspected frequently to ascertain any recession of the permafrost. None has been observed to date and they hope that this situation will continue in the future. When arsenic trioxide is stored underground, the warm ventilating air is sealed off completely from these areas. During the cold winter months, cold air is blown into the arsenic chambers to enhance the return of the permafrost back into the areas that were mined. Dr. Bliss stated that this procedure would take care of the current situation but suppose the permafrost thaws several centuries in the future and can it be assumed that this will not happen? There are cases where isotopes were stored in rock caverns that were presumed to be impermeable but the isotopes leaked into adjacent lake basins in a few years. Is there any chance that the same problem might arise on a long-term basis if the permafrost thaws? Mr. Espley replied that this is an important consideration. It is known, however, that the permafrost at Yellowknife formed 10,000 to 12,000 years ago and there is no reason to assume that it will not remain for the next 10,000 to 12,000 years.