

Problems of ore density determinations at Nanisivik mines

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Abstract

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One of the difficulties of ore reserve calculations is the determination of the factor to convert a volume to be mined into a tonnage to feed the mill. This factor is normally referred to as 'tonnage factor', 'density' or 'specific gravity'.

At Nanisivik, a zinc-lead mine located in Canada's High Arctic problems occurred with the tonnage factor when, 2½ years after start-up, a stockpile of 91 000 tonnes of ore had accumulated on paper, while actually only 11 000 tonnes could be identified. These stockpile differences indicated that the ore density of 4.4 t/m³ was probably no longer appropriate.

The influence of survey errors in measuring were evaluated. Density calculations were carried out on 345 samples taken underground. The moisture content of the ore in the millfeed was used to calculate the density for two periods of about one year.

Ultimately it was concluded that the actual density was around 4.0. This figure was then adopted and ore reserves were adjusted accordingly.

1. Introduction

Nanisivik is located in the Canadian High Arctic on the South shore of Strathcona Sound, a deep water fjord on the Northern Extremity of Baffin Island (Northwest Territories). The latitude is about 73° North, the distance to Toronto is 3300 km, see Fig. 1.

Although zinc-lead mineralization in the Strathcona Sound area was first reported in 1911 by a prospector and crew member of an expedition that spent the winter in Arctic Bay, it took until the sixties before a variety of exploration work was carried out by Texas Gulf Sulphur, including

diamond drilling and drifting. In 1972 the property was acquired by Mineral Resources International (MRI) and additional exploration work was conducted.

A feasibility study indicated that a profitable mining operation of the 6-7 million tonnes of ore, grading 14.1% zinc, 1.4% lead and 55 g of silver/tonne, should be possible. A new company was founded, Nanisivik Mines Ltd. Shares are held by MRI (53.0%), the Canadian Government (18%), Metallgesellschaft AG (11.25%), Billiton International Metals B.V. (11.25%) and Kidd Creek Mines (6.5%).

Strathcona Mineral Services of Toronto has been



Fig. 1. Map showing the northerly location of Nanisivik mine.

managing the project since construction of the townsite and mill started in 1974. The mine came into production in the fall of 1976. Nanisivik was the first major base metal mine North of the Arctic Circle in Canada.

The ore body is located less than 4 kilometers from the Sound, where a marine terminal has been constructed. Between July and November ore carriers and cargo ships are serving Nanisivik. Airservice is twice a week by Boeing 737 from Montreal.

The massive sulphide deposits at Nanisivik are hosted in the late Proterozoic (Helikian) Society Cliffs Formation, which consists of dense, laminated algal dolomite. Mineralisation consists of massive sulphides. Zinc occurs as sphalerite, lead as galena. The sphalerite contains some silver. Sparry dolomite is the main gangue mineral. Ice filled vugs are found frequently.

The orebody is about 3000 m long, 100 m wide, up to 20 m thick, and lies at a depth of about 100 m. It is flat with a rather regular hanging wall. The mining method used is room and pillar. First the top 5 m is mined followed by benching the deeper ore. Mining is completely mechanized resulting in a high productivity of 70 tonnes per manshift. Drill jumbos are used for both drifting and slashing. Benching takes place with either drilling horizontal holes using a jumbo or vertical holes using an airtrack drill.

The entire mine is in permafrost with rock temperatures of -9°C , which makes the use of plain water impossible for flushing the drillholes. Because of this, drilling is done dry with dust collectors mounted on the jumbos.

For ore mucking and hauling scooptrams, front-end loaders and trucks are used. The ore is crushed underground and transported on a conveyor belt to the concentrator. Annual concentrate production is about 120 000 t of zinc concentrate of 56% and 10 000 t of lead concentrate of 70%.

The boundaries of the Nanisivik deposit are reasonably well defined and minelife depends entirely on the reserves of the existing orebody. A few years after start-up the zinc market declined and the grade of the ore mined appeared to be a few percentage points lower than predicted in the feasibility study. It then became evident that the size of the ore reserve would be very important for the economical survival of the mine. This emphasized the importance of an accurate tonnage factor.

2. Pre production testwork

In 1970 Texas Gulf Inc. (now Kidd Creek Mines), who owned the property until 1973, planned to mine the ore by open pit during the summer. A density of $0.125 \text{ short ton/ft}^3 (= 4.009 \text{ t/m}^3)$ was used, based on testwork.

Watts Griffis and McQuat, who carried out the feasibility study for the Nanisivik project, calculated a density from 20 samples taken at random intervals along the strike of the orebody. These consisted of 12 core samples and 8 hand specimens. The average apparent density was $0.129 \text{ short ton/ft}^3$. A density of 0.125 was used in the feasibility study, allowing for some voids, which do not show up in small samples.

Investigations on samples of Nanisivik ore by Lakefield Research of Canada Ltd. in 1973 gave a density of 4.12 t/m^3 . Samples with a lead content of over 10% were not taken into account.

3. Tonnage factor used

From start-up in October 1976 until March 1977 a density of 4.0 t/m^3 was used to convert measured mined volume (m^3) underground into tonnes of ore milled. In 1977 there were indications that more tonnes were actually milled than calculated by survey measurements and that the density might be higher.

Tests were carried out by the Engineering Department on the rod mill discharge (-20 mesh size). The samples gave an average density of 4.38. It was then decided to use 4.4 as the density and the ore reserves were adjusted.

Theoretically the difference between tonnes mined and tonnes milled should be equal to the amount of ore at the stockpile. By 1979 this difference had accumulated to 91 000 t of ore (using 4.4 as the density factor), which should theoretically be the amount of ore on the stockpile. At that time the underground stockpile was estimated at only 11 000 tonnes. In January 1979 the volume of ore mined since start-up in 1976 was $301\,100 \text{ m}^3$, while 1 244 200 tonnes were milled, giving an average density of 4.13 t/m^3 . Changing to a lower factor than 4.4 would mean a reduction of the ore reserves and consequently a reduction in the life of the mine, which needed justification by further studies and testwork.

4. Measurement errors

Errors can occur in measuring the tonnage milled and in measuring the volume mined.

The conveyor belt feeding the rod mill has a weightometer which measures the mill feed. This meter is calibrated regularly. The shipped concentrate is weighed as well and once a year after the last shipment, the total tonnes of ore and concentrate are compared. Differences between measured-tonnes and calculated tonnes of mill feed have been less than one per cent in the past.

At the end of each month the volumes of ore and waste mined during the month are calculated from the survey results. Errors in surveying and calculating techniques are estimated to be within plus or

minus one per cent and should even out over a longer period.

A systematic error may occur because of the choice of the survey points underground. These points are mostly at the wall about 1.5 m from the floor. When the walls are not completely vertical an error can occur, accumulating if the slope of the wall has the same direction each time. This happens at the benches where the width tends to be less near the floor than at the top. The surveyed volume will then be consistently lower than the volume actually mined, thus giving a conversion factor to tonnage milled which will be higher than the actual density.

The total volume mined from the start of the mine consists of the accumulation of the monthly volumes and is not obtained from a recalculation using the ultimate outline of the mined area. This could result in yet another systematic error.

5. Density calculations

The implications of a different ore density on ore reserves and minelife required further investigations.

First the density was calculated from 345 samples collected throughout the mine. In this case the porosity was measured in the laboratory.

Secondly the reported moisture content of the mill feed was used as an indication for the minimum porosity. Subsequently a maximum density was calculated.

5.1 Density calculations from tests on lumps

A total of 345 samples were collected underground by various people from 31 locations in the mine, 17 from the West Zone and 14 from the Central Zone. The East Zone was not developed up till 1980. The samples were about 0.1 m. They were dried for 15 hours at 110°C . From the weight before and after drying the moisture content was calculated for each location. The density tests were carried out.

The samples were coated with paraffin to seal the pores in the rock. The paraffin was melted in a

beaker and kept at a temperature between 62°C and 65°C in a water bath. The sample is weighed before and after coating. The volume of the sample is determined by weighing it submerged and is equal to the weight difference before and after submerging it in water.

The density can then be calculated as follows:

$$D_s = \frac{W}{(W_p - W_s) - (W_p - W_s)/0.89} \text{ where}$$

D_s = Density of the sample

W = Weight of the sample, in air

W_p = Weight of the sample + paraffin, in air

W_s = Weight of the sample + paraffin, submerged

0.89 = Density of paraffin, accurate to ± 0.02

The samples were put in a deepfreezer for several hours after the tests in order to be able to peel off the paraffin. Hereafter they were assayed. The original mineral composition and theoretical density was calculated from the zinc, lead and iron analyses, see Table 1, and paragraph 5.2.1.).

The lower theoretical density of the tested ore results from a higher average zinc content and lower iron. The porosity of 7.6 vol. % refers only to the small voids and pores of the samples and is a minimum porosity, because the paraffin penetrates into some of the pores.

5.2 Density calculation from the mill feed

First the theoretical density of the mill feed is calculated from the mineral composition, without taking any porosity into account - see 5.2.1. The 'actual' density is then calculated using the moisture content of the mill feed as an indication for the porosity of the ore (5.2.2.).

It should be noted that the figures obtained using this method of calculation correspond to the minimum porosity and thus the maximum density because:

1. Only small voids and pores are measured in the relatively small samples (minus 25 mm). In the

Table 1. Summary of density calculations from tests on 345 samples.

	West zone	Central zone	Mined Average 1977/1979	
% Zn	15.32	17.61	16.35	13.14
% Pb	2.51	0.06	1.40	1.64
% Fe	30.67	28.55	29.71	32.15
% Sphalerite	25.04	28.79	26.73	21.48
% Galena	2.90	0.07	1.63	1.89
% Pyrite	62.75	57.74	60.48	66.36
% Dolomite	9.31	13.40	11.16	10.28
Percent moisture	1.70	1.70	1.70	1.62
Theoretical density	4.45	4.26	4.36	4.44
Measured density D_s	4.09	3.98	4.03	
Measured % porosity	8.50	6.60	7.64	

mine ice-filled cavities are frequently observed in a few occasions having a volume of several cubic metres.

2. Part of the ice may have disappeared before the ore reaches the mill due to sublimation.
3. Not necessarily 100% of the voids are filled with moisture.

5.2.1 Theoretical density calculation

The daily zinc, lead and iron assays were used to calculate the percentage of sphalerite (67% Zn), galena (86.6% Pb) and pyrite (46.6% Fe) in the ore. The remainder is considered to be dolomite.

Sphalerite contains an amount of iron varying between 0 and 11.42%. The assumption has been made that the sphalerite contains the average amount of iron (5.71% Fe). A correction of 1.02 is used in the sphalerite formula for the density of iron.

The following is an example of the computations:

From the daily mill figures over a 12 months period (April 1977 until March 1978) the weighed average of the assays was calculated giving 13.39% zinc, 2.02% lead and 31.62% iron. Using these figures

the mineral composition in weight per cent is calculated as follows:

$$\% \text{ Sphalerite} = \frac{\% \text{ Zn}}{(67.0 - (5.71 \times 1.02))} \times 100 = 21.89\%$$

$$\% \text{ Galena} = \frac{\% \text{ Pb}}{86.6} \times 100 = 2.33\%$$

$$\% \text{ Pyrite} = \frac{\% \text{ Fe} - (5.71 \times \% \text{ Sphalerite})}{46.6} \times 100 = 65.17\%$$

$$\% \text{ Dolomite} = 100\% - (\% \text{ Sphalerite} + \% \text{ Galena} + \% \text{ Pyrite}) = 10.61\%$$

The theoretical density (D) of the ore milled over this period can be calculated from the weight percentage of the minerals and their specific gravities:

Sphalerite : 4.03 t/m³ (for 5.71% Fe)

Galena : 7.50 t/m³

Pyrite : 5.00 t/m³

Dolomite : 2.80 t/m³

$$D = \frac{100}{(21.89/4.03) + (2.33/7.50) + (65.17/5.00) + (10.61/2.80)} = 4.43 \text{ t/m}^3$$

5.2.2 Actual density calculations

The actual density can be calculated from the theoretical density and the moisture content of the mill feed, which is measured daily, assuming that all pores are filled with water. The average water content over the twelve months period was 1.41 weight percent. Density calculations are made as follows:

Assume 100 gram of sample with 1.41 weight % water,

$$\begin{array}{lcl} 1.41 \text{ gram water} & = & 1.41 \text{ cm}^3 \\ (100-1.41) \text{ gram ore} & = & (100-1.41)/D \text{ cm}^3 \\ \hline 100-1.41 \text{ gram dried ore} & = & 1.41 + (100-1.41)/D \text{ cm}^3 \end{array}$$

$$\text{Actual density (D}^*) = \frac{100 - 1.41}{1.41 + (100-1.41)/D} = 4.17 \text{ g/cm}^3$$

The minimum porosity (in volume %) can be

calculated from the theoretical and actual densities:

$$\text{Porosity} = (1 - \frac{D^*}{D}) \times 100 = 5.87\%$$

Table 2 compares the calculated densities and porosities over two one year periods.

Table 2. Density calculations from moisture content for different periods.

	1977/1978	1978/1979	Average
% Zn	13.39	12.87	13.14
% Pb	2.02	1.22	1.654
% Fe	31.62	32.71	32.15
% Sphalerite	21.89	21.03	21.48
% Galena	2.33	1.41	1.89
% Pyrite	65.17	67.62	66.36
% Dolomite	10.60	9.94	10.28
Moisture content	1.41	1.83	1.62
Theor. density (D)	4.43	4.45	4.44
Actual density (D*)	4.17	4.11	4.14
Porosity	5.87	7.64	6.76

6. Conclusion

The results derived from density determinations on u.g. lump ore and on mill feed have both indicated a maximum density between 4.03 and 4.14. A downside adjustment to 4.0 was made to allow for larger voids, up to several cubic metres, not occurring in small samples used with the tests.

Between 1979 and 1981 four stockpile inventories were made and the density was recalculated. The resulting figure varied between 3.94 and 4.07 t/m³. Until now it was decided to continue using a density of 4.00 for all practical purposes.

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