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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

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MINES BRANCH INVESTIGATION REPORT IR 62-78

SEMI-AUTOGENOUS GRINDING OF A SAMPLE OF COPPER-ZINC ORE FROM MATTAGAMI LAKE MINES LIMITED MATTAGAMI AREA, QUEBEC

by

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MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

A pilot plant investigation showed that autogenous fine grinding to 95% -200 mesh, using screened lump ore as the grinding media, could be readily obtained with ore from Mattagami Lake Mines Limited.

Pebble consumption reached a minimum of 13.4% when the pebble mill was operating at near peak efficiency.

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* Head, Non-Ferrous Minerals Section, Mineral Processing Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

INTRODUCTION

Semi-autogenous grinding as described in this investigation report utilizes conventional rod mill primary grinding of the crushed ore to approximately 14 mesh followed by secondary pebble grinding to the desired degree of fineness, using a portion of the screened lump ore as the grinding media.

This modern concept of wet pebble grinding has won wide acceptance in Canada during the past ten years with the result that a number of plants have converted secondary grinding circuits to this method, and some new plants have been built incorporating semi-autogenous grinding.

Shipment

For this investigation, a shipment of 80 tons of lump ore was received from Mattagami Lake Mines Limited.

Location of Property

The property from which this shipment was received consists of 30 claims on a zinc-copper ore-body in Galinee township, in the Mattagami area of northwestern Quebec.

Purpose of Investigation

The flowsheet and the design of the proposed mill for the treatment of the Mattagami Lake ore is being supervised by a milling committee composed of:

Mr. H. A. Steane	-	Canadian Exploration Limited,
Mr. J. M. Carter	-	McIntyre Porcupine Mines Limited,
Mr. M.J.S. Bennett	-	Quemont Mining Corp. Ltd.,
Mr. H. L. Ames	-	Noranda Mines Limited (Chairman)

The purpose of this investigation was to demonstrate to the Mattagami Milling Committee the feasibility of pebble grinding Mattagami ore. The committee was particularly concerned as to whether or not a high sulphide ore (over 80% sulphides) would produce sulphide pebbles which would not disintegrate before they accomplished the fine grinding to 95% -200 mesh which was required.

The investigation was not directly concerned with any effect that autogenous grinding might have on the metallurgy of the ore.

Sampling and Analysis

Although the investigation was not concerned with chemical analysis of test products, a head sample was cut from the rod mill discharge to determine if the 80-ton shipment was fairly representative of the ore-body.

TABLE 1

Chemical Analysis* of Head Sample

Copper	(Cu)	-	0.54 %
Zinc	(Zn)	-	12.88 "
Iron	(Fe)	-	28.18 "
Sulphur	(S)	-	19.3 "
Silica	(SiO_2)	-	16.4 "

All other samples taken during the investigation were for screen analysis only.

GENERAL PROCEDURE

The general procedure for conducting this investigation was arrived at after consultation with Mr. Bunting S. Crocker, Vice-President, Kilborn Engineering (1954) Ltd.

Approximately 12 tons of -3 in. +1¼ in. material was screened from the ore, as received, and set aside as "rock feed"**, to produce the pebble load for the autogenous grinding mill. The remainder of the ore was crushed to approximately ½ in. to make up the feed to the primary grinding circuit.

The primary grinding was done in a 3 ft x 6 ft Marcy rod mill in closed circuit with an 8 mesh screen, to obtain a product which was all minus 8 mesh and approximately 80% -14 mesh. Because the capacity of the rod mill could not be adjusted to that of the pebble mill, it was necessary to filter and store the rod mill discharge. This resulted in some filtration difficulties caused by the sanding up of the filters and changes were made in the size of screen in the circuit as well as the number of rods in the mill.

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* From Internal Report MS-61-1018, by R. C. McAdam and H. Lauder.

** The term "rock feed" in this report means the screened ore fed to the pebble mill. The term "pebble" is not used until the rock feed has been in the mill long enough to become rounded.

Pebble grinding was done in a 36 in. x 44 in. Dominion mill. Two classifiers in series were used to close the fine grinding circuit. The two classifiers were put in as an insurance to give adequate classification capacity as a fairly heavy circulating load was anticipated.

DETAILS OF INVESTIGATION

Rod Mill Grinding

The ideal set-up for a pilot plant test such as this would have been to feed the rod mill discharge directly to the pebble mill. However, the capacity of the 3 ft x 6 ft rod mill was about 2 tons/hr; the capacity of the 36 in. x 44 in. Dominion mill, which was used as the pebble mill was unknown, but was not expected to exceed 1 ton/hr when operated at full capacity. It was, therefore, necessary to filter the final product from the primary grinding in the rod mill and set it aside to be used later as the feed to the pebble mill.

The rod mill was started up with a feed rate of 3500 lb/hr with approximately 2000 lb of rods. The rod mill discharge was put over an 8 mesh Sweco screen with the oversize returned to the mill. After experimenting with 8, 10, and 14 mesh screens at different feed rates, it was found that at a feed rate of 4300 lb/hr, and a rod charge of 2400 lb, the 8 mesh screen gave a product which was close to 80% -14 mesh.

A great deal of difficulty was experienced trying to filter the finished rod mill product. The problem was finally solved by placing a 20 mesh screen ahead of the filter. The +20 mesh material was mixed with the filter discharge.

The following table gives the results of screen analyses on composite samples of the final rod mill product taken during four days of rod milling.

TABLE 2

Screen Analyses on Rod Mill Product

Mesh Size											Remarks
% Wt Retained											
+10	+14	+20	+28	+35	+48	+65	+100	+150	+200	-200	
6.0	8.5	6.5	3.9	5.5	5.4	4.5	5.0	5.1	5.0	44.6	Feed rate - 3600 lb/hr Closed circuit screen, 8 mesh
1.8	6.7	7.9	5.4	6.5	4.9	5.2	5.8	6.2	7.7	41.9	Feed rate - 4500 lb/hr Closed circuit screen, 10 mesh
Nil	0.2	7.6	7.0	7.6	4.9	4.4	4.9	5.7	5.2	52.5	Feed rate - 4000 lb/hr Closed circuit screen, 14 mesh
12.7	13.5	9.7	5.2	5.6	3.4	3.0	3.4	2.9	3.8	36.8	Feed rate - 4600 lb/hr Closed circuit screen, 8 mesh
6.4	7.2	9.3	8.5	9.7	6.9	5.8	5.9	5.0	6.4	28.9	Feed rate - 4300 lb/hr Closed circuit screen, 8 mesh
2.2	2.9	3.9	5.1	8.4	6.8	6.0	7.4	7.0	6.5	43.8	Feed rate - 4300 lb/hr Closed circuit screen, 10 mesh

Because of the variation in the size of the product from rod milling, it was necessary to mix the rod mill discharge as much as possible to obtain a fairly uniformly sized feed to the pebble mill.

Pebble Mill Grinding

An important aspect of this autogenous grinding investigation was to determine the pebble consumption required to produce the desired fineness of grind. This would be determined from the amount of rock feed that was necessary to maintain a 50% pebble volume level in the mill when grinding at full capacity.

The power meter on the pebble mill was fitted with a fairly sensitive graphic recorder so that any change in the power demand of the mill could be readily noted. When the power demand remained constant it would mean that the pebble load was remaining fairly constant. A gradual decrease in the power demand would indicate that either the pebble load in the mill was decreasing or that the pebble load was increasing beyond the 50% volume level.

A bolt in the pebble mill was removed and replaced with a rubber plug so that the pebble level in the mill could be checked with a long wooden pole at any time.

Test 1

The pebble mill was loaded with 2000 lb of -3 in. + $1\frac{1}{4}$ in. rock feed. The mill was run for 20 min with the feed off to round the rocks into pebbles. The level had dropped 2 in. and 600 lb of rock was added to bring it up above the 50% volume level.

The mill was then run for 2 hours with a crude ore feed rate set at 1500 lb/hr and the rock feed of 150 lb/hr.

At "shut down" the pebble volume was down 7 in. and it took 1600 lb of rock to fill the mill to 2 in. above the 50% volume level.

Test 2

The pebble mill was run for 8 hours with the wet feed rate varying from 1500 lb/hr to 2400 lb/hr to build up the circulating load. Rock was added every 15 min at a feed rate which varied from 140 to 170 lb/hr to maintain the pebble load. The density of the pebble mill discharge was maintained at approximately 70% solids. The classifier sands continued to build up to close to 100% circulating load. Near the end of the days run, several samples of the final classifier overflow were taken for screen analyses.

Results of Test 2

	Density % Solids	Screen Analysis % -200m
Class o'flow	28	95.6
" "	26	98.0

At the end of the test the pebble load was down 6 in. It took 1300 lb of rock to bring the pebble level up to 50% volume.

Summary of Test 1 and 2

The first two tests were of a preliminary nature. The circuit had not become stabilized as the circulating load was still increasing. Pebble consumption appeared to be high but this may be partly due to the mill being underloaded with feed, with a result that there was excess pebble-on-pebble wear. The preliminary tests showed that the ore could be ground autogenously.

Test 3

The pebble mill was started up with a crude feed rate of 1500 lb/hr (wet wt). After 5 hr the feed was increased to 1700 lb/hr for 4 hr, and finally to 2000 lb/hr during the last 10 hours of the run. The rock feed varied from 200 to 320 lb/hr during the 19-hr run to maintain the pebble charge in the mill. Samples were taken throughout the run at 30 min intervals. The conditions and the results of Test 3, shown in the following tables, were for the last four hours of the run in which the circuit remained fairly steady.

TABLE 3

Results of Test 3

Product	Weight* lb/hr	Solids %
P.M. crude feed	1700	85.4
Rock feed (pebbles)	280	100.0
P.M. discharge	4840	72.0
Class. sands	2860	-
" o'flow	1980	21.0

* adjusted dry weight

TABLE 4

Results of Screen Analyses of Test 3

Mesh Size	Weight %			
	P.M. Crude Feed	P.M. Discharge	Classifier Sands	Classifier O'flow
+10	1.4	0.1	0.4	-
+14	2.6	0.2	0.6	-
+20	5.6	0.2	0.2	-
+28	7.1	0.3	0.3	-
+35	8.4	0.6	0.8	-
+48	8.8	0.9	1.2	-
+65	8.9	2.0	2.6	-
+100	8.6	5.1	7.1	-
+150	8.0	11.2	14.2	-
+200	8.8	23.5	28.4	3.5
-200	31.8	55.9	44.2	96.5
+325				15.6
-325				80.9
Total	100.0	100.0	100.0	100.0

During Test 3, the rock feed (pebbles) was added every 15 min. The rate of addition was increased or decreased several times during the test after checking the pebble level in the mill. The rate of rock feed shown in Table 3 gives a pebble consumption of 16.5%. During the entire test, 5195 lb of rock was added while feeding 29,240 lb of crude ore feed equivalent to a pebble consumption of 17.8%.

Test 4

The pebble mill was started up at a crude ore feed rate maintained at 2000 lb/hr (wet weight) for the first 5 hrs. The rate was then increased to 3000 lb/hr (wet weight) for the remaining 8½ hrs of the test. Tonnage samples taken during the two different periods are shown in Table 5.

Beginning an hour after the run started, samples for screen analyses were taken every ½ hr for 12 hrs and combined.

TABLE 5

Results of Test 4

Product	First Part of Run		Second Part of Run	
	Weight* lb/hr	Solids %	Weight* lb/hr	Solids %
P.M. crude feed	1690	88.6	2560	88.5
Rock feed (pebbles)	360	100.0	355	100.0
P.M. discharge	6770	73.0	8030	75.0
Class. sands	4720	-	5380	-
Class. o'flow	2050	20.0	2650	33.0

* adjusted dry weight

TABLE 6

Results of Screen Analyses of Test 4

Mesh Size	Weight %			
	P.M. Crude Feed	P.M. Discharge	Classifier Sands	Classifier O'flow
+10	0.5	0.1	0.1	-
+14	2.3	0.9	0.2	-
+20	5.1	0.1	0.2	-
+28	5.6	0.1	0.5	-
+35	11.7	0.8	1.3	-
+48	9.0	1.6	2.5	-
+65	7.8	3.9	5.7	-
+100	8.6	10.2	13.5	-
+150	7.6	17.6	20.6	-
+200	11.2	24.0	27.0	10.0
-200	30.6	40.7	28.4	90.0
+325				19.8
-325				70.2
Total	100.0	100.0	100.0	100.0

The volume level in the pebble mill had increased by 4 in. at the end of the run and it was not possible to adjust the weights of the tonnage samples taken during the second part of the run to balance the weight through-put within a 10% error limit.

Test 5

In this test the feed rate was held at 2000 lb/hr (wet weight). The rock feed was 320 lb/hr for the first 3 hrs; then rock feed was stopped for 2 hours to allow the pebble volume to get down to the 50% volume level. During the last 7 hours the feed rate was 240 lb/hr, giving an average rock feed rate during the 12-hour test of 212 lb/ton.

TABLE 7

Results of Test 5

Product	Weight* lb/hr	Solids %
P.M. crude feed	1790	89.3
Rock feed (pebbles)	212	100.0
P.M. discharge	5312	72.0
Class. sands	3310	-
Class. o'flow	2002	37.2

* adjusted dry weight

TABLE 8

Results of Screen Analyses of Test 5

Mesh Size	Weight %			
	P.M. Crude Feed	P.M. Discharge	Classifier Sands	Classifier O'flow
+10	7.0	0.1	0.4	-
+14	9.5	0.2	0.2	-
+20	8.5	0.2	0.4	-
+28	6.9	0.4	0.5	-
+35	7.3	1.1	1.2	-
+48	4.8	1.6	1.9	-
+65	4.4	3.2	3.9	-
+100	4.8	6.0	8.5	-
+150	4.6	9.3	14.1	-
+200	5.2	17.7	24.7	4.6
-200	37.0	60.2	44.2	95.4
Total	100.0	100.0	100.0	100.0

The results of Test 5 showed that at a feed rate of 1790 lb/hr, a grind of 95.4% -200m was produced. During the last 7 hrs of the run, a steady pebble load in the mill was maintained with a rock feed rate of 240 lb/hr.

Test 6

At the start of this test the pebble load was at the 50% volume mark. The crude ore feed was maintained at 2000 lb/hr which was the same rate used during the last 7 hrs of the previous test. During the 5½ hrs of this run the rock feed was added at 240 lb/hr.

TABLE 9

Results of Test 6

Product	Weight* lb/ hr	Solids %
P.M. crude feed	1800	90.1
Rock feed (pebbles)	240	100.0
P.M. discharge	5400	72.0
Class. sands	3360	-
Class. o'flow	2040	41.2

* adjusted dry weight

TABLE 10

Results of Screen Analyses of Test 6

Mesh Size	Weight %			
	P.M. Crude Feed	P.M. Discharge	Classifier Sands	Classifier Sands
+10	12.1	0.2	1.1	
+14	12.7	1.3	1.5	
+20	9.5	0.6	0.7	
+28	5.2	0.6	0.8	
+35	6.4	1.2	1.8	
+48	4.0	1.6	2.4	
+65	3.8	2.9	4.5	
+100	4.5	6.1	9.0	
+150	4.4	11.6	13.7	
+200	6.5	20.6	24.4	7.1
-200	30.9	53.3	40.1	92.9
+325				16.0
-325				76.9
Total	100.0	100.0	100.0	100.0

At the end of Test 6 the pebble load was still at the 50% volume level. The pebble consumption during this test was 13.3%.

In Tests 4, 5 and 6, 8,640 lb of rock (pebbles) was consumed while grinding 61,550 lb of crude feed, giving an average pebble consumption of 14.0% for these three tests.

Power Calculations

The following calculations were made using Bond's Work Index Formula(1) -

$$W = Wi\left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}}\right)$$

where W = Work done in grinding expressed in kWh/short ton
Wi = Work Index
P = 80% passing size of product in microns
F = 80% " " " feed " "

The work index, Wi, for Mattagami Lake ore had been determined by laboratory grinding tests[2] to be 13.0. This value for Wi was obtained by comparing the grinding characteristics of the Mattagami Lake ore with an ore whose work index was known.

From the size distribution curves from the pebble mill feed and discharge from Test 5, the 80% passing size of the feed, F, is 350 , the 80% passing size of the discharge, P, is 110 .

Substituting in the above formula results in -

$$W = 5.44 \text{ kWh/short ton of mill feed.}$$

Since the pebble mill feed in Test 5 was made up of 1 part crude feed to 1.8 parts of classifier sands, the power required to grind crude feed was -

$$W = 15.2 \text{ kWh/ton of crude mill feed.}$$

From power reading taken during Test 5, the power consumed in grinding crude feed was calculated to be -

$$W = 11.2 \text{ kWh/ton of crude mill feed.}$$

The only explanation for obtaining a lower actual power consumption rate than the theoretical value was that the work index used to calculate the theoretical value was too high.

If the work index is calculated from the actual power consumption value (W = 11.2 kWh/ton) using the values for P and F from Test 5, the work index for Mattagami Lake ore is -

$$Wi = 9.6 \text{ kWh/short ton.}$$

ROCK AND PEBBLE SIZING

The screened ore that was fed to the pebble mill to make up the pebble charge was sampled throughout the pilot plant tests. This sample was set aside for size distribution determination.

At the end of the mill run the pebble mill was emptied and the pebble charge, weighing 2747 lb, was coned and quartered and a sample set aside for size distribution determination.

The method used for sizing both the samples of the rock feed and the pebbles was one developed by Mr. B. S. Crocker[3].

Sizing Technique

The sample to be sized was roughly separated into sized groups visually, starting with the largest pieces first. The weight of the individual pieces were then checked on a balance to determine into which weight fraction each belonged (Figure 1).

After sizing into fractions as shown in Tables 11 and 12, the total weight of each fraction was obtained, the number of pieces in each fraction counted, and the average weight per piece calculated. The "weighted mean" of each fraction was obtained by multiplying the "% total weight" by the "weight per piece". The total of the "Weighted Mean" and in case of the rock, the total of the "Weighted Mean x 77%", are figures for describing the mean size of the pebbles in the pebble load which is doing the grinding.

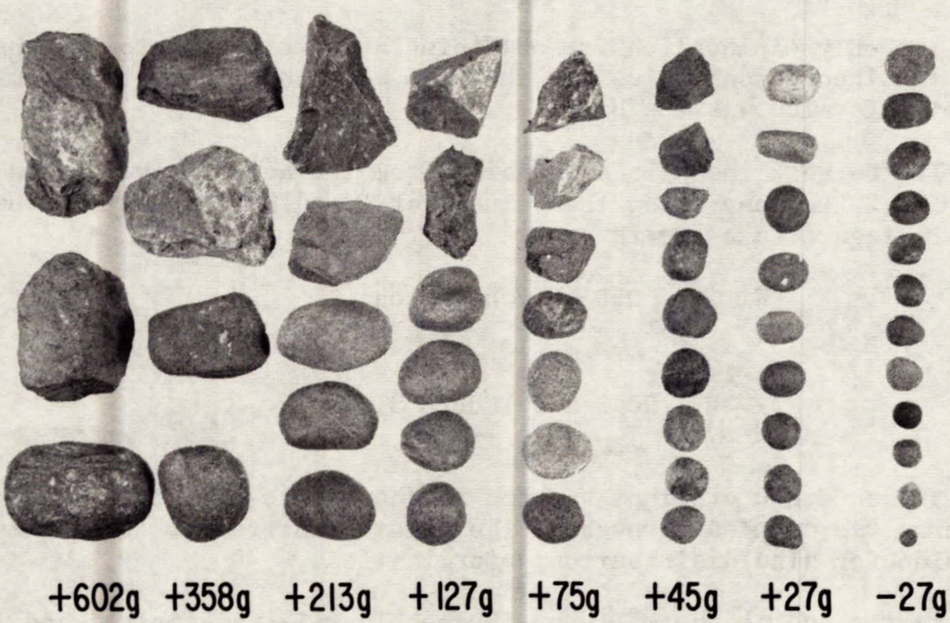

Figure 1 - Photograph of pieces of rock feed and pebbles from each of the sized fractions.

TABLE 11

Size Determination of a Sample of the Rock Feed

Size (in.)	Wt. (g)	Total Wt (g)	No. of Pieces	Av. Wt. per Piece	% Total Wt.	Weighted Mean	Weighted Mean x 77%*	Diam (In.) Pebble	Steel Ball
+2.97	+602	11,068	16	691.7	4.1	28.4	21.9		
+2.5	+358	48,082	107	449.4	17.9	80.4	61.9		
+2.1	+213	79,607	288	276.4	29.6	81.8	63.0		
+1.77	+127	65,545	417	157.2	24.4	38.4	29.6		
+1.48	+75	46,721	485	96.3	17.4	16.8	12.9		
+1.25	+45	16,783	270	62.2	6.2	3.8	2.9		
+1.05	+27	1,025	28	36.6	0.4	0.1	0.1		
-1.05	-27								
TOTAL		268,831				249.7	192.3	2.1	1.6

* Weight loss of the rock in rounding into pebbles is usually about 23%.

Sp. Gr. of Rock Feed - 3.75

TABLE 12

Size Determination of a Sample of the Pebble Load

Size (in.)	Wt. (g)	Total Wt (g)	No. of Pieces	Av. Wt per piece	% Total Wt.	Weighted Mean	Diam (in.) Pebble*	Steel Ball**
+2.97	+602	3,892	5	778.4	1.3	10.1	2.95	2.3
+2.5	+358	13,098	31	422.5	4.4	18.6	2.40	1.9
+2.1	+213	26,989	102	264.6	9.0	23.8	2.05	1.6
+1.77	+127	54,886	347	158.2	18.3	29.0	1.73	1.3
+1.48	+75	62,143	684	90.9	20.7	18.8	1.45	1.2
+1.25	+45	50,576	924	54.7	16.9	9.2	1.22	1.0
+1.05	+27	35,834	1056	33.9	11.9	4.0	1.03	0.8
-1.05	-27	52,345	5455	9.6	17.5	1.7	0.67	0.5
TOTAL		299,764			100.0	115.2	1.53	1.2

* From graph relating pebble weight to pebble diameter.

** Diameter of a steel ball having equivalent weight to a pebble of Sp. Gr. of 3.62.

Remarks

It was expected that the total of the "Weighted Mean x 77%" of the rock feed (Table 11) would be close to the total of the "Weighted Mean" of the pebble load (Table 12), but as can be seen, this is not the case. The number of pebbles in the coarse sizes (+2 in.) was only about one-third of the number of pieces of rock in this size range. If the sample of rock feed was representative, which it was believed to be, the only explanation for the reduced mean size of the pebbles was that many of the coarse pieces of rock broke up into two or more pieces before rounding into pebbles.

CONCLUSIONS

From the results of the investigation, autogenous pebble grinding of this ore, using screened lump ore as the grinding media, is feasible. A grind to 95% -200m (80% -325m) was readily obtained in a 36 in. x 44 in. pebble mill at a crude feed rate of 1800 lb/hr.

Pebble consumption varied from 16 to 18% during preliminary tests, but this high rate was attributed to excess pebble-on-pebble wear when the mill was underloaded. When the mill was operated at a feed rate of 1800 lb/hr with a full circulating load, the pebble consumption was 14%. During the last 12 hours of running time (Tests 5 and 6), in which the pebble volume remained steady at 50% volume, the pebble consumption was 13.4%.

The results of the size distribution analysis on the pebble load in the mill at the end of the investigation showed that a mean pebble size of 1.5 in. diameter ground the ore to the desired fineness. This pebble size is equivalent to a steel ball having a 1.2 in. diameter.

The power calculation results are rather inconclusive. More power consumption readings should have been taken during the investigation, but not too much time was spent on this phase of the investigation. Although very little reliance can be placed on the results from one test, the fact that the actual power consumption was lower than that obtained by calculation from the size distribution curves for Test 5, would indicate that during this test the pebble mill was operating at near peak efficiency.

Although the investigation was successful in showing that the ore can be ground to the desired fineness using semi-autogenous grinding, it is not known what effect comminution by this method would have on the subsequent metallurgy of the ore.

ACKNOWLEDGMENT

The writer wishes to acknowledge the excellent work done by the mill operators under the direction of Mr. A. J. Boisonnault, Mill Foreman, in helping to carry out this pilot plant investigation.

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