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MINERALOGICAL AND IMAGE ANALYSIS
INVESTIGATION OF SAMPLES FROM THE TAILINGS OF
CURRAGH RESOURCES AT FARO, YUKON

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EXECUTIVE SUMMARY

A suite of pyrite-rich samples from the Curragh resources tailings site was studied by mineralogical and image analysis techniques in connection with a mineral processing investigation on recovering the zinc, lead and copper from the tailings. The samples contain 1.00 to 1.66 wt% Zn, 0.07 to 0.12 wt% Pb and 0.11 to 0.14 wt% Cu. The study involved identifying the minerals, determining mineral quantities, determining liberations of sphalerite and chalcopyrite, and determining distributions of liberated and unliberated sphalerite. The minerals in the samples do not show much evidence of weathering although all samples contain small amounts of an iron sulphate and goethite which are products of pyrite weathering. The presence of these secondary minerals suggests that special conditioning may be required for flotation.

Liberation analyses show high liberations for sphalerite and chalcopyrite in fractions that are finer grained than $75\ \mu\text{m}$ (-200 mesh). More than 40% of the sphalerite and chalcopyrite in the $-75\ \mu\text{m}$ (-200 mesh) fractions is totally liberated, and more than 60% of the sphalerite and chalcopyrite is in particles that contain > 75% of the mineral of interest. (Particles with > 75% sphalerite are invariably recovered in Zn concentrates containing 50% to 55% Zn produced from Faro type sphalerite).

Sphalerite distribution data show that most of the liberated sphalerite is in fractions which are finer-grained than $150\ \mu\text{m}$ (-100 mesh), and most of the unliberated sphalerite is in fractions which are coarser-grained than $75\ \mu\text{m}$ (+200 mesh).

It is interpreted that:

- (1) About 60% of the sphalerite and chalcopyrite in the $-75\ \mu\text{m}$ (-200 mesh) fractions of the tailings are liberated sufficiently to be recovered in saleable grade concentrates. This represents about 41% of the sphalerite in sample P1, 33% in sample P2, and 68% in sample P3. The minerals may not, however, be directly recoverable due to surface chemistry of the particles.
- (2) Flow streams containing unliberated mineral grains need to be reground to 80% minus $53\ \mu\text{m}$ (-270 mesh) to liberate most of large (potentially recoverable) sphalerite and chalcopyrite grains.

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INTRODUCTION

A suite of sieved fractions from three samples of tailings was received from Mr. T. Cienski, project leader, MSL Project 854, on December 1, 1992. Mr. Cienski requested that the samples be analyzed to determine mineral quantities and liberations of sphalerite, chalcopyrite, galena and combined base metals. The samples had been prepared by separating drill hole samples of Curragh tailings according to pH and combining fractions with a pH <5, 5 to 7, and >7. The samples were labelled P1, P2 and P3 respectively. The average pH for sample P1 is 3.64, for P2 is 5.90, and for P3 is 8.13. The samples were sieved, by the Mineral Processing Laboratory, into +48 mesh, 48 to 100 mesh, 100 to 200 mesh, 200 to 400 mesh, and -400 mesh fractions (Table 1) to provide suitable fractions for mineralogical and image analysis studies.

Table 1 - Sieve analysis of samples*

Size range (mesh)	Weight %			Cumulative wt%**		
	P1	P2	P3	P1	P2	P3
+48	3.6	5.0	1.0			
48 to 100	11.0	14.7	3.7	96.4	95.0	99.0
100 to 200	26.7	25.5	14.1	85.5	80.3	95.4
200 to 400	27.7	21.5	21.6	58.7	54.8	81.3
-400	31.1	33.3	59.7	31.1	33.3	59.7

* Data supplied by Mr. T. Cienski

** % passing

METHOD OF INVESTIGATION

Three sets of sub-fractions were taken from the sieved fractions. One set of sub-fractions was ground to -200 mesh and submitted for chemical assays for Zn, Cu and Pb (Table 2); another sub-fraction was submitted to X-ray diffraction analysis for identification of major and minor minerals; and polished sections were prepared from third set of sub-fractions. The polished sections were studied by optical microscopy,

electron microscopy, and image analysis to identify the minerals, determine mineral textures, determine mineral liberations, and determine distributions of liberated and unliberated sphalerite.

Table 2 - Chemical assays*

Sample	Weight %		
	Zn	Pb	Cu
P1 +48	0.72	0.40	0.04
P1 48 to 100	1.29	0.25	0.07
P1 100 to 200	1.35	0.05	0.10
P1 200 to 400	0.71	0.02	0.08
P1 -400	0.88	0.18	0.16
P1 Total**	1.00	0.12	0.11
P2 +48	2.91	0.86	0.12
P2 48 to 100	2.88	0.30	0.15
P2 100 to 200	1.75	0.02	0.14
P2 200 to 400	0.89	0.02	0.11
P2 -400	1.35	0.11	0.16
P2 Total**	1.66	0.13	0.14
P3 +48	0.69	0.22	0.05
P3 48 to 100	1.77	0.28	0.10
P3 100 to 200	1.36	0.06	0.12
P3 200 to 400	0.76	0.03	0.09
P3 -400	1.32	0.07	0.16
P3 Total**	1.22	0.07	0.14

* performed by R. McCorkell and R. Fortin

** calculated

RESULTS

MINERALOGY

The major minerals in the samples are pyrite and quartz; minor minerals are muscovite, biotite, K feldspar, barite, goethite, Fe sulphate, sphalerite, pyrrhotite and marcasite: trace minerals are chalcopyrite, galena, Fe-Al silicate (pyroxene or amphibole), chlorite and kaolinite. X-ray diffraction tracings show that all minerals are

present in all fractions. Mineral quantities, determined by image analysis, are given in Tables 3a, 3b and 3c. The values for siderite and Fe sulphate (identified as $\text{FeSO}_4(\text{OH})_7$ by X-ray diffraction analysis) are combined because they have the same grey level in the SEM electron backscattered image, and the image analysis procedure which separates them was not incorporated into the macro that was used to perform the analyses. It was qualitatively observed, however, that the Fe sulphate was the dominant phase in sample P1 and siderite the dominant phase in sample P3.

Table 3a - Mineral quantities in sieved fractions of Sample P1

Mineral	+48M	48 -100M	100 -200M	200 -400M	-400M	Combined
Pyrite*	2.0	39.5	68.6	69.2	60.1	60.6
Quartz	81.0	45.2	18.2	16.4	14.9	21.9
Muscovite and K feld.	13.2	4.0	2.1	2.5	2.6	3.0
Barite	tr.	2.1	3.7	4.1	8.1	4.9
Goethite	0.4	3.5	3.5	3.8	9.1	5.2
Fe sulphate and siderite**	1.6	2.3	0.8	1.5	2.1	1.6
Sphalerite	1.2	2.15	2.25	1.18	1.47	1.7
Pyrrhotite	tr.	0.7	0.5	1.0	0.8	0.7
Chalcopyrite	0.12	0.21	0.29	0.23	0.47	0.3
Galena	0.47	0.29	0.06	0.02	0.21	0.1
Kaolinite	tr.	tr.	tr.	tr.	tr.	tr.

* includes minor marcasite

** includes biotite, chlorite and FeAl silicate (pyroxene or amphibole).

Table 3b - Mineral quantities in sieved fractions of Sample P2

Mineral	+48M	48 -100M	100 -200M	200 -400M	-400M	Combined
Pyrite*	16.4	77.0	77.4	74.4	62.1	68.5
Quartz	63.1	7.7	7.2	9.3	16.2	13.5
Muscovite and K feld.	6.4	0.9	1.1	1.1	0.9	1.3
Barite	0.3	2.8	3.8	7.0	9.4	6.0
Goethite	4.3	3.9	4.8	4.2	2.4	3.7
Fe sulphate and siderite**	2.5	0.7	0.7	0.9	4.9	2.2
Sphalerite	4.85	4.8	2.92	1.48	2.25	2.8
Pyrrhotite	0.9	1.4	1.7	1.2	1.3	1.4
Chalcopyrite	0.35	0.44	0.41	0.32	0.47	0.4
Galena	1.0	0.35	0.02	0.02	0.13	0.2
Kaolinite	tr.	tr.	tr.	tr.	tr.	tr.

* includes minor marcasite

** includes biotite, chlorite and FeAl silicate (pyroxene or amphibole).

Table 3c - Mineral quantities in sieved fractions of Sample P3

Mineral	+48M	48 -100M	100 -200M	200 -400M	-400M	Combined
Pyrite*	8.4	59.4	74.2	65.3	61.2	63.4
Quartz	81.0	27.3	9.8	15.4	11.8	13.6
Muscovite and K feld.	6.3	1.9	1.5	1.6	2.4	2.1
Barite	0.02	1.5	5.3	4.5	13.8	10.0
Goethite	1.6	4.7	4.4	8.5	0.8	3.1
Siderite and Fe sulphate**	1.1	1.1	0.5	1.3	5.7	3.8
Sphalerite	1.15	2.95	2.27	1.27	2.20	2.0
Pyrrhotite	0.02	0.5	1.7	1.8	1.4	1.5
Chalcopyrite	0.15	0.29	0.35	0.26	0.47	0.4
Galena	0.26	0.33	0.07	0.03	0.08	0.1
Kaolinite	tr.	tr.	tr.	tr.	tr.	tr.

* includes minor marcasite

** includes biotite, chlorite and FeAl silicate (pyroxene or amphibole).

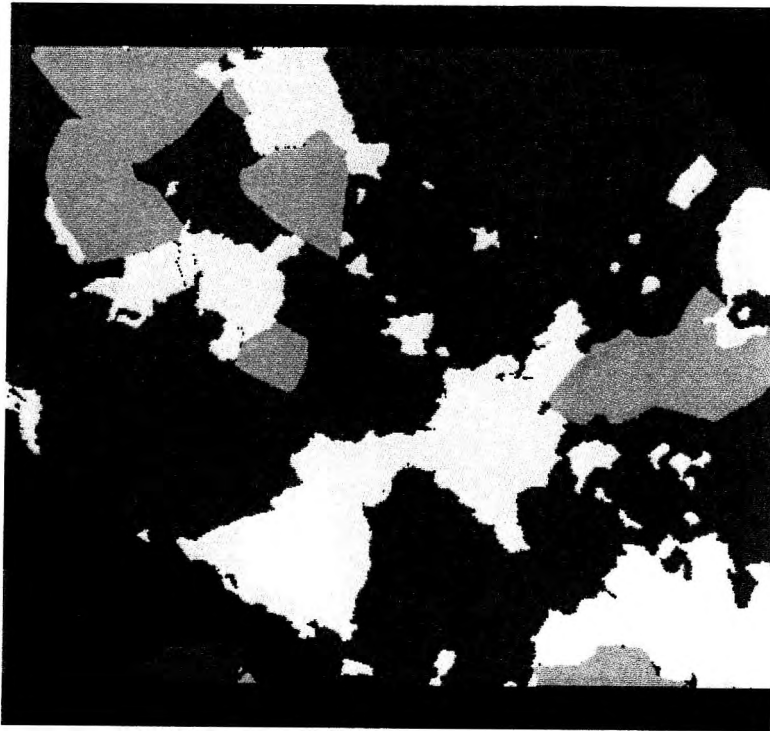
TEXTURES AND LIBERATIONS

The sphalerite, galena, and chalcopyrite in the +48 mesh fraction are generally locked in quartz and pyrite (Fig. 1). In contrast, the sphalerite and chalcopyrite in sieved fractions finer than 48 mesh occur as liberated particles and as inclusions in pyrite and quartz (Fig. 2). The galena in all fractions has a low liberation. Some of the goethite and Fe sulphate are associated with pyrite, and some are present as free grains.

PARTICLE CLASSIFICATION

Degrees of liberation were measured for sphalerite and chalcopyrite and the data were classified according to percent of mineral in the host particle.

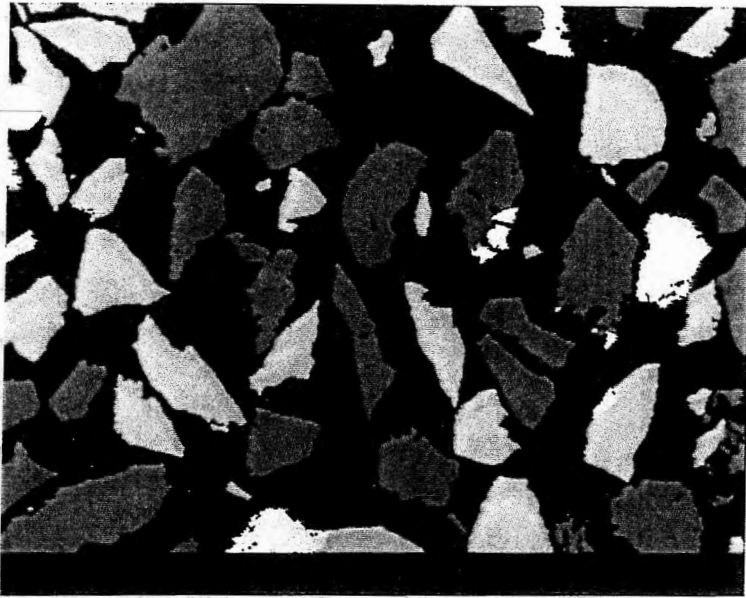
The scheme for classifying the liberation data was selected on the basis of an evaluation of products from a bench test that was conducted in 1988 (Petruk, 1990) on ore from the Faro deposit. In that bench test the ore was ground to 80% -56 μm . Recoveries with respect to particle sizes were nearly identical for particles containing free sphalerite, 90 to 99.9% sphalerite, and 70 to 90% sphalerite in the rougher concentrate grading 34 wt% Zn (Fig. 3A). The rougher concentrate was reground to



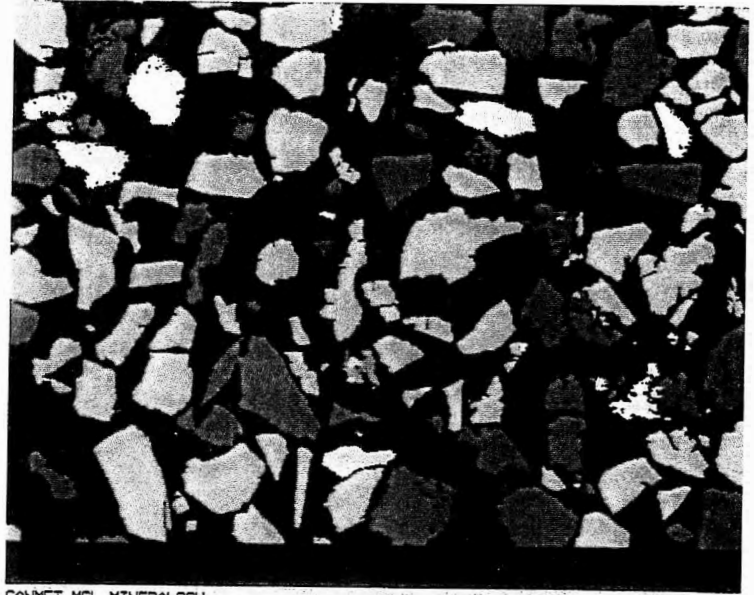
CANMET MSL MINERALOGY

Fig. 1 - Photomicrograph of BSE image of +48 mesh fraction of sample P3. The grey levels have been modified with image analyzer to enhance discrimination between minerals.

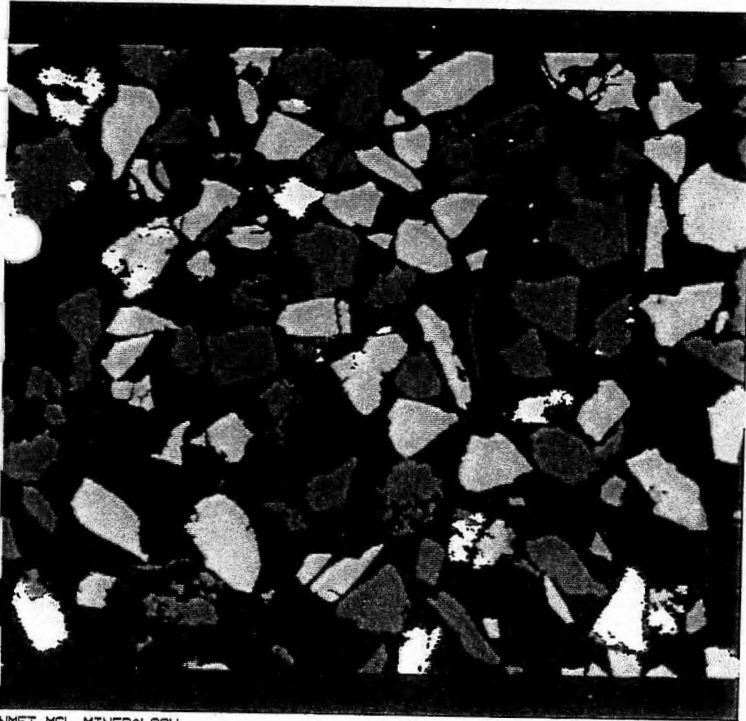
White = sphalerite + chalcopyrite + galena: **Light grey** = pyrite + minor marcasite: **dark grey** = silicates + barite + alteration products.



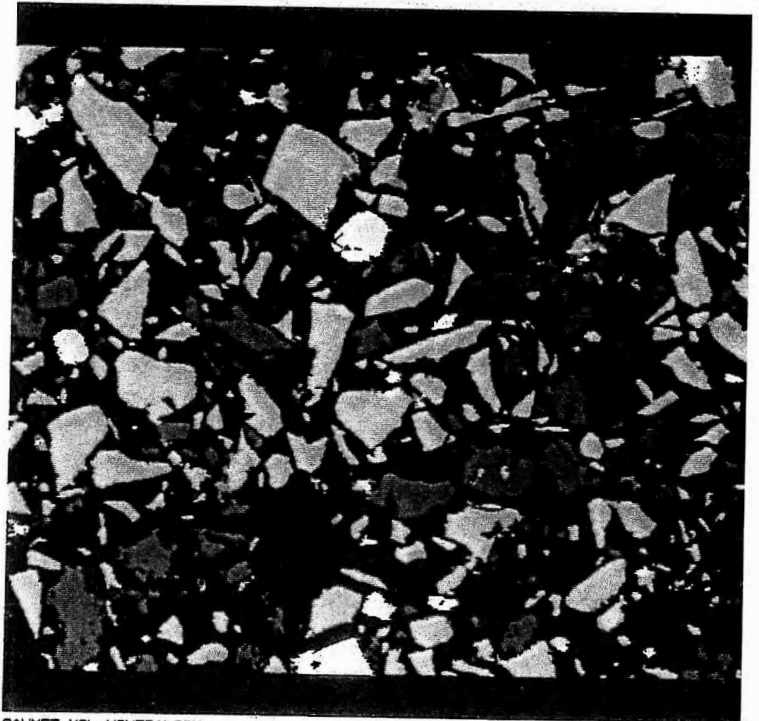
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Fig. 2 - Photomicrograph of BSE images of screened fractions of sample P3. The grey levels have been modified with image analyzer to enhance discrimination between minerals. (a) 48 to 100 mesh, (b) 100 to 200 mesh, (c) 200 to 400 mesh, (d) -400 mesh.

White = sphalerite + chalcopyrite + galena: **Light grey** = pyrite + minor marcasite: **dark grey** = silicates + barite + alteration products.

80% -39 μm and cleaned to produce a Zn concentrate grading 52.9 wt% Zn.

Recoveries in the Zinc concentrate were highest for 90 to 99.9% sphalerite particles (89%), and were nearly equal for free and for 70 to 90% sphalerite particles (68% and 66% respectively) (Fig. 3B). The recovery of free sphalerite was lower than for the 90 to 99.9% sphalerite because most of the slimed sphalerite (-6 μm) which was lost to tails was free. The recovery of 70 to 90% sphalerite is relatively high which indicates that 70 to 90% sphalerite particles were preferentially recovered in the zinc concentrate grading 52.9% Zn. The proportion of sphalerite present as 70 to 90% particles represented only 9.3% of the sphalerite in the Zn concentrate (Fig. 3C), and hence did not reduce the Zn concentrate grade. It is noteworthy that 3% of the zinc in the Zn concentrate grading 52.9% Zn was in particles that contained from 70% to 5% sphalerite.

The scheme for classifying the sphalerite and chalcopyrite, based on the above evaluation, was selected as:

- (1) particles containing 100% of mineral of interest (free),
- (2) > 75% [including free] (recoverable),
- (3) 25 to 75% (middlings), and
- (4) < 25% (unrecoverable middlings).

The recoverable category of >75% sphalerite is used because it is assumed that the Zn concentrate which will be produced from the Faro tailings will contain about 50 to 55 Wt% Zn. A recoverable category of more than 90% sphalerite would have to be used if Zn concentrates containing more than 55% Zn were required. Data on >90 sphalerite were automatically collected with the image analyzer, but for simplicity of presentation, were not included in this report. They can, however, be extrapolated from the free and >75% data.

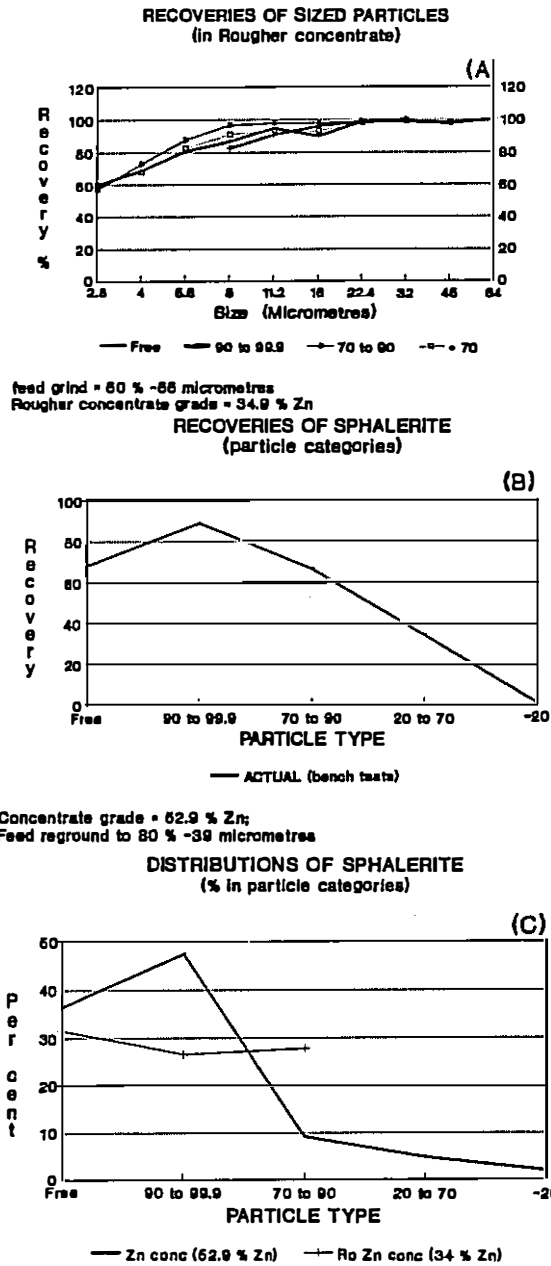


Fig. 3 - Graphs: (A) Recovery of sphalerite in a Zn rougher concentrate in different sized particles containing different amounts of sphalerite. (B) Recoveries of sphalerite as free grains, 90 to 99.9%, 70 to 90%, 20 to 70% and -20% sphalerite particles. (C) Proportions of sphalerite in different types of particles.

LIBERATION ANALYSIS

Results for free, recoverable (>75%), middlings (25 to 75%) and unrecoverable middlings (<25%) are plotted with respect to particle sizes (determined by sieving) in Figures 4 to 6 for sphalerite and chalcopyrite in samples P1, P2, and P3. The results show that liberations of recoverable sphalerite (>75%) are higher than 60% for particles that are finer grained than 200 mesh (75 μm), and higher than 40% for free sphalerite finer grained than 200 mesh. Liberation data are given in Tables 4a and 4b for sieved fractions of the samples.

DISTRIBUTION OF SPHALERITE

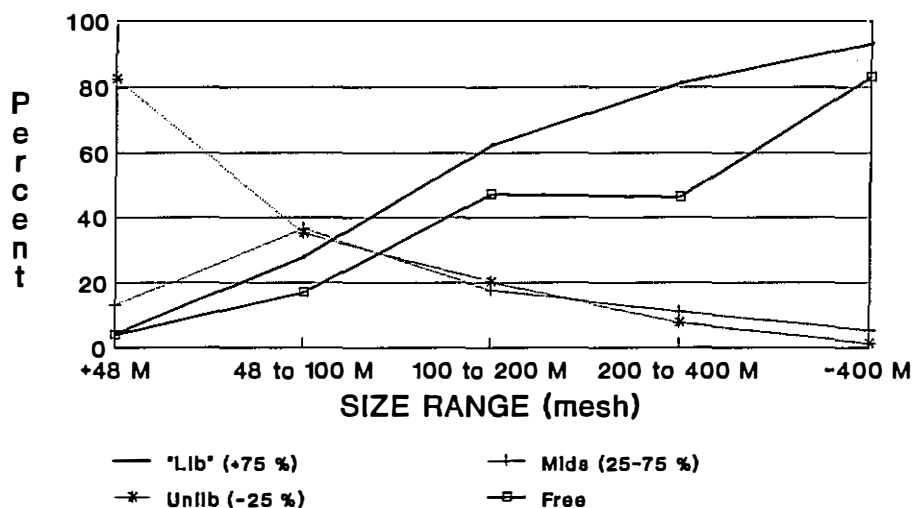
The distribution of free, recoverable, middling and unrecoverable sphalerite in each sample were calculated by using the sieve analysis data, Zn assays, and the liberation characteristics of the sphalerite in the sieved fractions. The results, given in Table 5, show that 39% to 51.2% of the sphalerite in samples P1, P2 and P3 is free, and 65% to 79.1% is recoverable (>75% sphalerite in particles). The table also shows that most of the free and recoverable sphalerite is in sieved fractions that are finer grained than 106 μm (100 mesh), and most of the unliberated sphalerite is in fractions coarser-grained than 75 μm (200 mesh).

CONCLUSIONS

The samples contain small amounts of secondary minerals, such as Fe sulphate and goethite, produced by weathering of pyrite. These minerals may interfere with flotation reagents, therefore appropriate conditioning should be performed prior to flotation to minimize their affect.

The liberation of sphalerite and chalcopyrite can be interpreted by using either the free or the recoverable ("liberated" >75) particles. In both instances the liberation data show relatively high liberations in fractions which are finer-grained than 75 μm (200 mesh). The percentages of sphalerite occurring as "liberated" grains, smaller than 75 μm , are 41%, 33% and 68% in samples P1, P2 and P3 respectively.

LIBERATION, SAMPLE P1 Sphalerite



LIBERATION, SAMPLE P1 Chalcopyrite

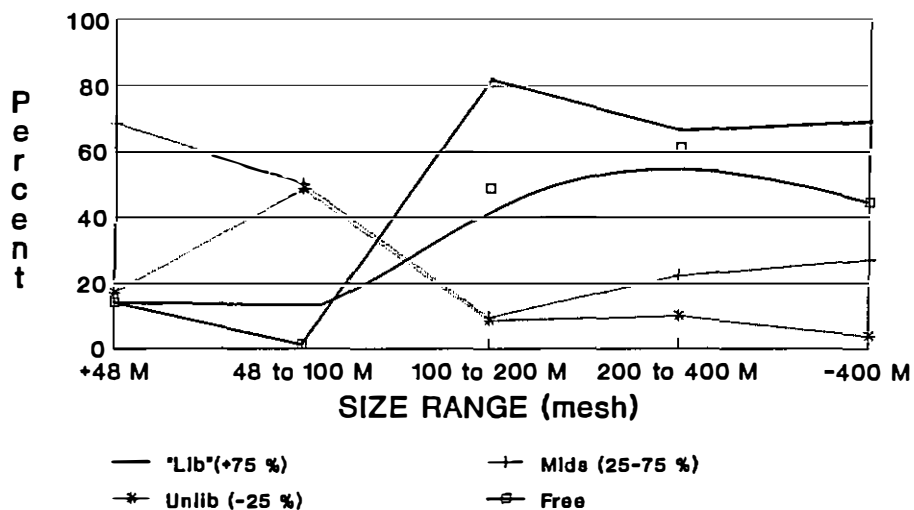
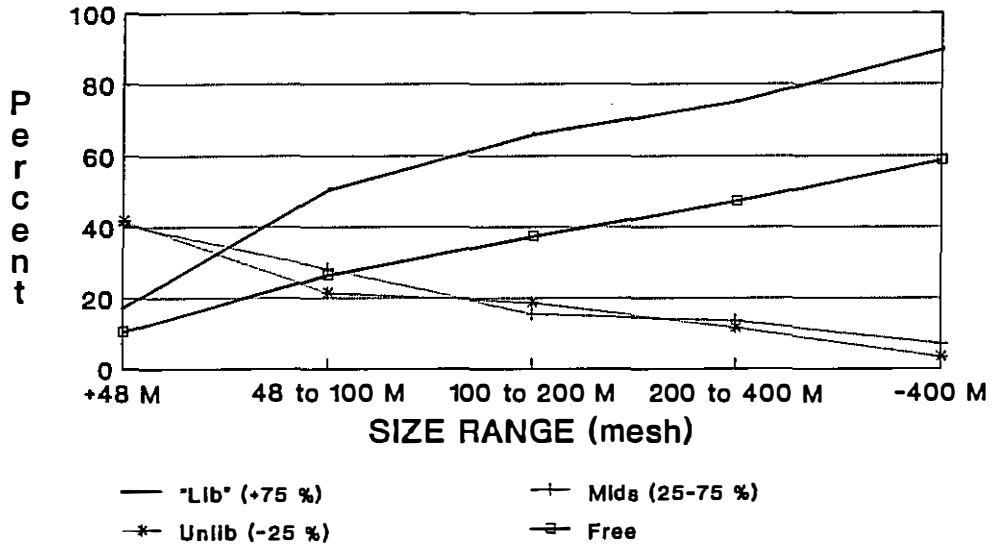


Fig. 4 - Graphs showing liberations of minerals with respect to particle sizes (determined by sieving) for: (a) Sphalerite, and (b) chalcopyrite. Sample P1.

LIBERATION, SAMPLE P2 Sphalerite



LIBERATION, SAMPLE P2 Chalcopyrite

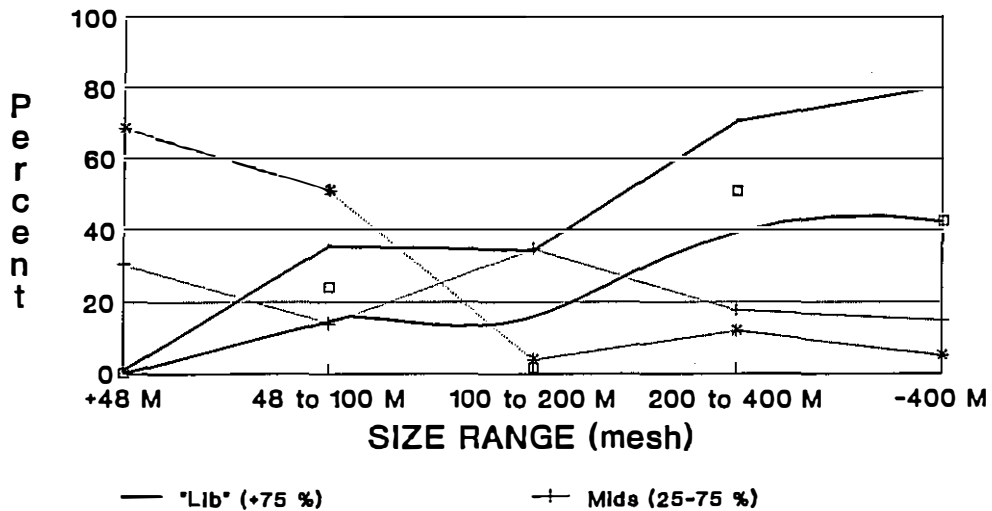
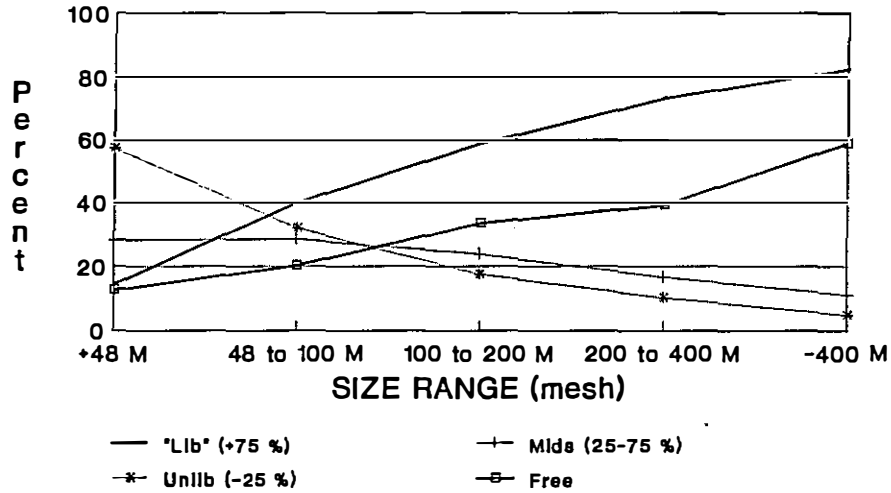


Fig. 5 - Graphs showing liberations of minerals with respect to particle sizes (determined by sieving) for: (a) Sphalerite, and (b) chalcopyrite. Sample P2.

LIBERATION, SAMPLE P3 Sphalerite



LIBERATION, SAMPLE P3 Chalcopyrite

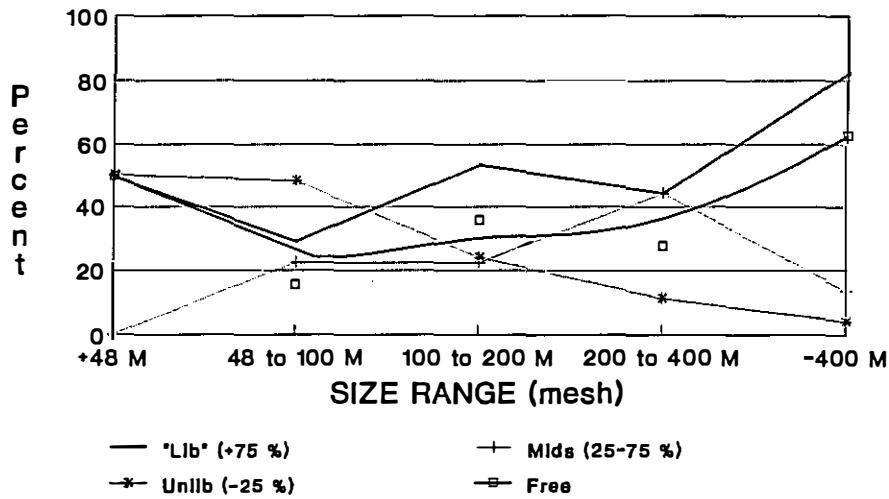


Fig. 6 - Graphs showing liberations of minerals with respect to particle sizes (determined by sieving) for: (a) Sphalerite, and (b) chalcopyrite. Sample P3.

Table 4a - Liberations for sphalerite

Sample	Size range (mesh)	Recoverable	Middling	Non-recoverable	Free
		> 75%*	25 to 75%*	< 25%*	100%*
P1	+48	4.3	13.2	82.4	3.9
P1	48-100	27.9	36.9	35.2	17.0
P1	100-200	62.2	17.7	20.2	47.2
P1	200-400	81.3	11.0	7.7	46.4
P1	-400	93.2	5.4	1.3	83.0
P2	+48	17.4	40.7	41.9	10.5
P2	48-100	50.4	28.2	21.4	26.4
P2	100-200	65.8	15.5	18.7	37.4
P2	200-400	74.9	13.5	11.6	47.2
P2	-400	89.6	7.1	3.3	58.7
P3	+48	14.4	28.3	57.3	12.7
P3	48-100	39.9	28.4	31.8	20.2
P3	100-200	58.6	23.8	17.5	33.5
P3	200-400	73.2	16.6	10.1	39.2
P3	-400	89.6	7.1	3.3	58.7

* = % sphalerite in particles

Table 4b - Liberations for chalcopyrite

Sample	Size range (mesh)	Recoverable	Middling	Non-recoverable	Free
		> 75%*	25 to 75%*	< 25%*	100%*
P1	+48	14.1	68.7	17.2	14.1
P1	48-100	1.3	50.0	48.7	1.3
P1	100-200	81.9	9.5	8.7	48.9
P1	200-400	66.6	22.4	10.0	61.1
P1	-400	69.2	27.1	3.7	44.5
P2	+48	1.1	30.5	68.4	0.1
P2	48-100	35.4	14.0	50.6	23.9
P2	100-200	34.4	34.7	30.9	1.5
P2	200-400	70.3	17.6	12.1	50.6
P2	-400	80.2	14.8	5.0	42.2
P3	+48	49.7	0	50.3	49.7
P3	48-100	29.1	22.6	48.3	15.6
P3	100-200	53.3	22.6	24.1	35.9
P3	200-400	44.3	44.4	11.2	27.9
P3	-400	82.3	13.6	4.1	62.6

* = % chalcopyrite in particles

Table 5 - Distribution of sphalerite in samples

Sample	Size range (mesh)	Recoverable	Middling	Non-recoverable	Free	Total
		>75%*	25 to 75%*	<25%*	100%*	
		P1	+48	0.1	0.4	
P1	48-100	3.9	5.2	4.9	2.4	14.0
P1	100-200	22.4	6.3	7.3	17.0	36.1
P1	200-400	16.3	2.2	1.5	9.3	20.0
P1	-400	25.1	1.5	0.4	22.4	27.0
Total		67.8	15.6	16.6	51.2	100.0
P2	+48	1.6	3.7	3.8	0.9	9.1
P2	48-100	12.8	7.1	5.4	6.7	25.3
P2	100-200	17.8	4.2	5.1	10.1	27.1
P2	200-400	8.6	1.5	1.3	5.4	11.4
P2	-400	24.3	1.9	0.9	15.9	27.1
Total		65.1	18.4	16.5	39.0	100.0
P3	+48	0.1	0.2	0.5	0.1	0.8
P3	48-100	2.3	1.6	1.8	1.2	5.7
P3	100-200	9.2	3.7	2.7	5.2	15.6
P3	200-400	9.6	2.2	1.3	5.1	13.1
P3	-400	58.0	4.6	2.2	38.0	64.8
Total		79.2	12.3	8.5	49.6	100.0

* = % chalcopyrite in particles

Liberations are low for galena in all sieved fractions, and for sphalerite and chalcopyrite in particles which are coarser-grained than 150 μm (100 mesh).

A regrind of 100% minus 75 μm (200 mesh) (or 80% minus 53 μm (-270 mesh)) is needed to liberate most of the large (> 10 μm) (potentially recoverable) sphalerite and chalcopyrite grains.

ACKNOWLEDGEMENTS

The author gratefully acknowledges J. Greer for preparing polished sections of the samples and P. Carrière for performing the XRD analysis.

REFERENCE

1. W. Petruk, 1990, Image analysis evaluation of mineral behaviour during a laboratory flotation test of the zinc-lead volcanogenic ore from the Faro deposit, Yukon; Process Mineralogy IX, AIME/TMS, Warrendale, PA, Edited by W. Petruk, R.D. Hagni, S. Pinolet-Brandom and D.M. Hausen, pp. 37-48.