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OF MINING

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Dear Sir,

The Graduating Thesis of J. Z. Hall
in the Department of Mining and Metallurgy
entitled

Recovery of Cobalt
from
Concentrates supplied by
Kelowna Exploration Co. Ltd.

is approved by the Department

Head of Dept.

RECOVERY OF COBALT
from
Concentrates Supplied by Kelowna Exploration Co. Ltd.
by
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The Requirements for the Degree of
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INTRODUCTION

The Kelowna Exploration Concentrate consists principally of a mixture of Arsenopyrite (FeAsS) and pyrrhotite ($\text{FeS}_{\frac{1}{2}}$) containing from 5 % to 10 % of gangue (SiO_2). In addition the concentrate contains the following elements.

Au ----- 1.1 oz/ton (approx)

Ag ----- 0.25 oz/ton "

Cu ----- 0.6 - 1.4 %

Co ----- 0.6 - 0.8 %

Now the gross value of this concentrate is:

Au ----- 1.1 oz @ 35.00 -----	38.50	
Co ----- 0.6 % - 12#/ton @ 1.50 -----	18.00	
Cu ----- 0.6 % - 12#/ton @ .12 -----	<u>1.50</u>	
	58.00 -----	<u>58.00</u>

Returns when shipping the concentrate to Tacoma:

Gross Value of Au plus Cu -----	40.00	
Freight, Treatment, etc -----	<u>16.00</u>	
Net Return -----	24.00 -----	24.00

Now Gross value including Cobalt ----- 58.00

Present Net Return ----- 24.00

Therefore, value available for Treatment 34.00 ----- 34.00

58.00

Thus in considering a treatment method, it's cost including Au and Co losses, overhead, amortization, etc., should be kept down to about \$25.00 per ton if a reasonable and certain profit is to be shown.

This research on the concentrates was undertaken with the following objects in view.

- (1) to determine whether the Cobalt could be profitably extracted in a marketable form.
- (2) to determine whether a suitable recovery of the Au content could be obtained in the course of the Cobalt extraction.

The values contained in silver and copper are of secondary importance and their recovery was considered as likely to parallel that of the other metals.

TREATMENT OF RAW CONCENTRATES WITH SULPHURIC ACID

Preliminary work carried out in the ore dressing and metallurgical laboratories of the Department of Mines and Resources in Ottawa during July and August 1940, under the supervision of Mr. F.A. Forward, indicated that treatment of the concentrate directly with hot strong sulphuric acid might offer a suitable solution to the problem of recovering both cobalt and gold from the concentrates. The first five (5) tests were devoted to this method of treatment and their general procedure and reasons are as follows:

- (1) Concentrate added to strong boiling H_2SO_4

REASON: to convert cobalt, copper to water soluble sulphates; at the same time freeing the gold so that it may be cyanided. In attaining this result iron was converted to an undesirable water soluble sulphate.

- (2) Filter the "Quiescent Mixture" while hot.

REASON: Arsenic interferes with the recovery of cobalt and this serves as one simple method of eliminating the arsenic because Arsenious Oxide (As_2O_3) is soluble in hot acid. Moreover the acid is easily freed of the As_2O_3 because it settles out on cooling.

(3) The Precipitate is given an oxidizing roast below 725°C .

REASON: The undesirable water soluble iron sulphate is converted to insoluble iron oxide (Fe_2O_3) between $600 - 725^\circ\text{C}$. whereas the water soluble cobalt and copper sulphates remain unchanged.

The best recovery from this series of tests was 93 % recovery of cobalt. Further work on sulphating raw concentrates was discontinued because an experiment on roasted calcines performed by Mr. Alfred G. Lyle proved sufficiently attractive to warrant further investigation.

PRELIMINARY ROASTING

(A) Low Sulphur, Low Arsenic.

Low sulphur and low arsenic calcines were obtained by an oxidizing roast of the concentrates. These roasts were carried out under two different conditions. The first by placing the concentrates in a moderately hot furnace ($500-550^\circ\text{C}$.) and gradually raising the temperature up to between 750 and 850°C . The second by placing the concentrates directly into the furnace at $750-850^\circ\text{C}$. It was found the gradual raising of the temperature adversely affected the elimination of arsenic. These roasts were continued at the higher temperatures until completely roasted.

(B) High Sulphur, Low Arsenic.

High sulphur and low arsenic calcines were obtained by a reducing roast of the concentrates. These roasts were obtained by placing the concentrates directly into a hot furnace (750-850C.) and cutting short the roasting time; stopping when the arsenic flame died and cooling in a confined atmosphere. This type of roast may be properly described as a "reducing roast" because during the arsenic elimination the concentrates are enveloped by an atmosphere of arsenic vapor. For a comparison of the resulting calcines from this type of roast to the foregoing oxidizing roast note the following chart.

(C) COMPARISON OF CALCINES

Test No.	Original Wt	Final Wt	% Red.Wt.	Initial Temp.	Final Temp.	Time Hrs. Min.	As	Assays SO ₄ -S	S-S	Remarks
12	1000	565	43.5	750	820	1 - 0	0.64	1.08	0.86	
14	2000	1155	42.2	550	800		2.64	0.72	0.25	
18A	1000	606	39.4	500	700		5.6	0.8	0.10	550-650 for 3 hours.
19A	1000	570	43.0	800	825	1 - 0	1.06	1.0	2.43	
20A	2000	1135	43.3	800	830	2 - 0	0.56			Total S 1.18%
21A	3000	1683	43.8	750	750	1 - 15	0.36	1.87	0.19	
30A	2000	1207	39.7	800	800	0 - 40	1.95	0.86	11.3) Stopped when As flame died- Air cooled
34A	2000	1270	36.5	750	750			0.61	12.57	
40A	2000	1165	41.7	800	810	0 - 35	0.56	0.18	21.32	Stopped when As flame died-
41A	2000	1465	26.8	750	750	1 - 05		0.06	21.04	cooled in con- fined atmosph.
42A	2000	1180	41.0	775	775	0 - 55		0.11	19.39	"
43A	2000	1155	42.3	800	800	1 - 10		0.11	17.09	"
44A	2000	1180	41.0	825	825	0 - 30		0.12	20.98	"

(C) Comparison of calcines.

- (1) Slowly oxidizing dead roasts, started at low temperature and finished at high temperature. These roasts gave moderately high arsenic and low sulphide sulphur. See Tests 14 and 18A.
- (2) Rapid oxidizing dead roasts entirely carried out at high temperatures. These roasts gave very low arsenic and low sulphide sulphurs.
- (3) Reducing roasts carried out at high temperature and cooled in open atmosphere. These roasts gave low arsenics and moderately high sulphide sulphures (12%). See Tests 30A and 34A.
- (4) Reducing roasts carried out at high temperatures and cooled in confined atmosphere. These roasts gave low arsenic and high sulphide sulphur (21%). See tests 40A to 44A inclusive.

TREATMENT OF LOW SULPHUR, LOW ARSENIC CALCINES

(A) MAINLY WITH SALT AND SULPHURIC ACID

This treatment in general was conducted as follows:

- (1) Mixed the preliminary calcine with varying percentages of salt and sufficient sulphuric acid to thoroughly wet all the calcine.
- (2) Roasted this mixture at a moderate temperature (500-550°C.) to allow the sulphuric acid and salt time to react and form primary sulphates.
- (3) Ground these primary sulphates to pass through an 80 mesh screen and gave them an oxidizing roast at temperatures varying from 600 - 700°C. This would break up water soluble iron sulphate into water insoluble iron oxide (Fe_2O_3).

For further details of this treatment method see the following tests:

No. 8	No. 9G2	No. 14C	No. 14I	No. 16C	No. 18B
9C	9G3	14D	14J	16H	19B
9D	10C	14E	14N	16J	20C
9E	10G	14F	14O	17A	22C
9F	13	14H	16B	17B	

At first these treatments embodied the use of small percentages of carbon which were thought to help in the elimination of arsenic by reducing the stable arsenic compounds to the more volatile arsenious compounds. However there was not sufficient advantages gained by its use and so its addition was discontinued in later treatments. Tests 14B, 14C, 14D, 14E, 14F and 14M show that good recoveries may be

obtained by this treatment. For example in Test 14C the use of 5 % salt and 80 % strong sulphuric acid and roasted not above 650° C. gave 92 % water soluble cobalt. It should be noted that heating the primary sulphates from 550 to 650° C. decomposed the water soluble iron sulphate. This decomposition released sulphur trioxide which had a mild sulphating action; increasing the recovery of the cobalt and copper by forming additional water soluble sulphates of these metals.

(B) MAINLY WITH SULPHURIC ACID

This treatment method was carried out in general, as follows:

- (1) Added sufficient sulphuric acid to thoroughly moisten the preliminary calcine.
- (2) Roasted the mixture at a moderate temperature (500 - 550° C.) to allow formation of primary sulphates.
- (3) Ground these primary sulphates to minus 80 mesh and gave them an oxidizing roast to break up iron sulphate to water insoluble iron oxide (Fe_2O_3).

For details and results see tests:

No. 10B	No. 14B
10D	14G
10E	20D
10F	

The best recovery that was obtained by this method was 82 % of the cobalt in Test No. 20D.

(C) MAINLY WITH SALT

This treatment method in general was simply a chloridizing roast. The tests were carried out at varying temperatures from 350° C. up to 650° C. For results and details see tests:

No. 6	No. 21D
9B	22B

The best recovery obtained by this method was 72 % in Test No. 21D. Where the chloridizing roasts were carried out at temperatures exceeding 450° C. the recovery was very poor because the cobalt chloride was broken down to water insoluble cobalt oxide.

(D) MAINLY WITH HYDROCHLORIC ACID

This treatment in general was carried out as follows:

- (1) Calcine was mixed with sufficient hydrochloric acid to moisten it thoroughly.
- (2) This mixture was slowly dried at a low temperature and roasted below 450° C. At this temperature any water soluble iron chloride formed is broken down to water insoluble iron oxide (Fe_2O_3) while water soluble cobalt and copper remain unchanged.

For results and details see tests:

No. 21B	No. 22N	No. 31B
21C	24A	31C
21M	24B	31D
22G	24C	32B

This treatment gave fair recoveries of copper and cobalt especially in Test No. 24A, where only 10 % hydrochloric acid was used, gave a 72 % recovery of cobalt. This treatment is particularly attractive because of its simplicity and the low temperatures involved.

TREATMENT OF HIGH SULPHUR, LOW ARSENIC CALCINES

(A) MAINLY BY SULPHATIZING ROAST AIDED BY SULPHURIC ACID

This treatment in general was a sulphatizing roast making use of the high sulphide sulphur content of the calcines augmented by sulphuric acid. These roasts were carried out at moderately low temperatures (350 - 450° C.) When sulphating action was complete the temperature was raised to 650° C. to break up any water soluble iron sulphate.

For details and results see tests:

No. 40D No. 40G

40E 40K

It should be noted that the final roasting at the higher temperature to break up soluble iron sulphate resulted in higher cobalt recoveries as experienced in the treatment of low sulphur, low arsenic calcines with salt and sulphuric acid. See page 6.

The best recovery was Test No. 40E which gave 74 % water soluble cobalt.

(B) MAINLY BY SULPHATIZING ROAST AIDED BY SALT

This treatment in general was as follows:

- (1) Calcine mixed with small percentage of salt.
- (2) Calcine given a sulphatizing¹² roast at low temperatures
350 - 450°C.
- (3) Calcine given an oxidizing roast at higher temperature
(625°C.) to decrease soluble iron and increase soluble
cobalt.

For details and results see tests:

No. 30C	No. 41B	No. 44C	No. 45F
40H	42B	44D	45G
40N	43B	44E	45B

The best recovery was in test 40N which gave 90 % recovery of the cobalt with but little interfering water soluble iron.

(C) MAINLY BY SULPHATIZING ROAST AIDED BY HYDROCHLORIC ACID

This treatment in general was carried out as in foregoing sulphatizing roast aided with salt excepting that salt is replaced by Hydrochloric Acid. For summary of results and details see tests: 30B, 34C, 34D.

The best recovery was obtained in Test No. 30B which gave 82 % recovery of the cobalt. However an excessive amount of hydrochloric acid was required to attain this high recovery.

(D) MAINLY BY SULPHATIZING

This treatment involved only the use of the high sulphide sulphur content of the preliminary calcines to effect a sulphating roast. This roast was carried out at a low temperature ($350^{\circ}\text{C}.$) under a closely controlled atmosphere. When the sulphating action is complete the temp. is raised ($625^{\circ}\text{C}.$) to effect the decomposition of water soluble iron sulphate, taking advantage of the released sulphur trioxide to give a "secondary sulphating" action. For details and results see tests:

No. 40B	No. 40F	No. 45K
40C	45E	

The best test, 45K, gave 68 % recovery of the cobalt.

PRECIPITATION OF COBALT FROM LEACH SOLUTION

The recovery of cobalt from the water leach solutions is easily obtained by standard practise. In evidence of this tests No. 23, 23B, 23C were run and gave in the order of 98 % recovery of the cobalt as cobalt carbonate. This is easily converted into a marketable cobalt oxide product by calcⁱⁿing. There is nothing to indicate that this phase of the work will present any difficulties.

SUMMARY OF RESULTS

- (1) Although good recoveries were indicated by treatment of raw concentrates with excess sulphuric acid, the complexity of this operation in comparison to the simplicity of treatment of roasted concentrates made this method very unattractive.
- (2) In the treatment of low sulphur, low arsenic calcines, the best recoveries were obtained by the use of salt and sulphuric acid. However, in spite of the lower recoveries obtained by the use of hydrochloric acid alone, this treatment was more attractive than the salt and sulphuric acid treatment because of its comparative simplicity.
- (3) In the treatment of high sulphur low arsenic calcines the best recovery was obtained by the use of salt in aiding the sulphating action. However, in spite of the lower recoveries, ~~obtained by~~ sulphating the calcines with the omission of any reagents, is favored, because:
 - (A) Simplified treatment.
 - (B) Elimination of gold loss by chloridization.
- (4) The best treatment of the high sulphur low arsenic calcines by sulphating action alone, is preferred to the best treatment of the low sulphur low arsenic calcines with hydrochloric acid because:
 - (1) Simplified treatment.
 - (2) Elimination of gold loss by chloridization.

- (5) Recovery of the cobalt from the leach solutions is standard practise and will offer no difficulties as shown by test No. 23.
- (6) Preliminary work on cyanidation of leached residues, indicated that no difficulty will be encountered in obtaining good gold recoveries.

CONCLUSION

From an analysis of the results embodied in this research, it may be concluded that by a combination of reducing and sulphatizing roasts a practical and simple method of extracting the cobalt from the concentrates, at the same time freeing the gold so that it is amenable to cyanidation, is possible.

TESTING PROCEDURES

Pictured below is a 13 K.W. electric resistance furnace which has automatic temperature control. Nearly all the roasting both

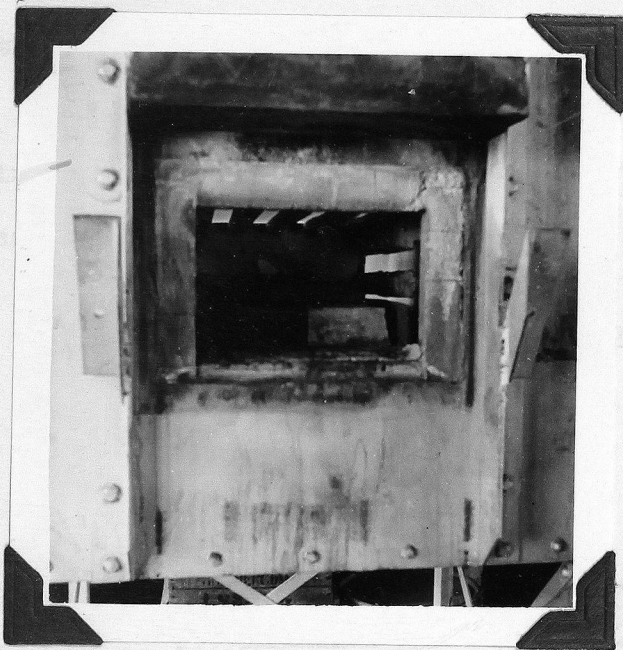
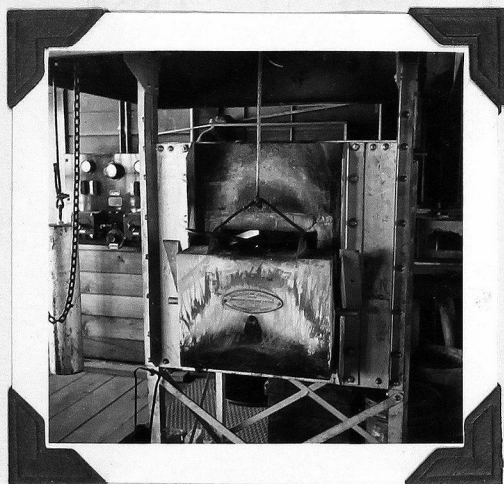


Exhibit No. 1

preliminary and sulphatizing was carried out in this furnace. Note the hole in the back of the furnace through which the pyrometer is introduced.

The silica tray commonly used is sitting on top of bricks but unfortunately both are difficult to distinguish in this picture.



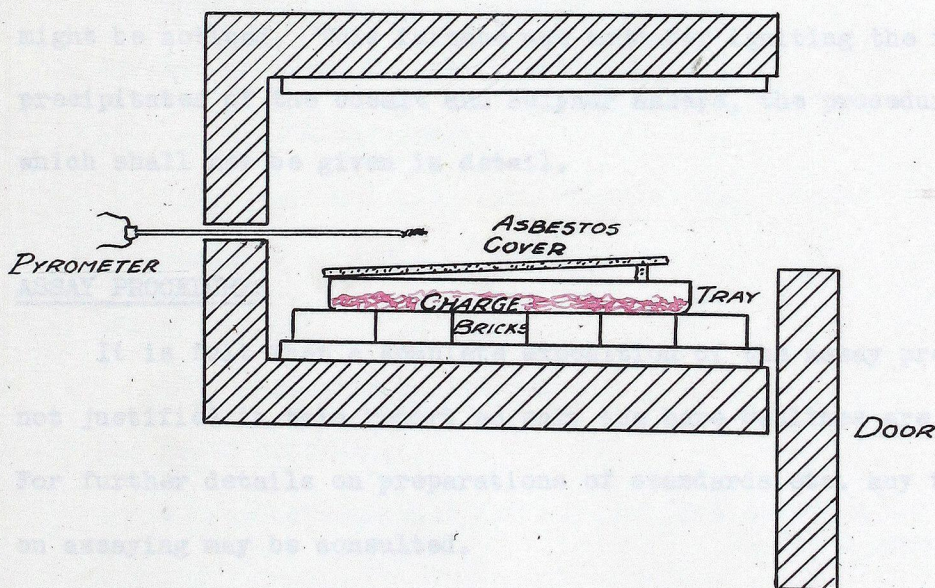
The picture to the left shows the usual position of the door when either preliminary or sulphatizing roasting was being carried on.

Exhibit No. 2

The high sulphur low arsenic roasts were usually carried out in an open silica tray placed in the furnace as per sketch below. The tray was immediately covered with an asbestos board when withdrawn from the furnace. This gave the so-called "confined-atmosphere" to the cooling calcine.

Sulphatizing roasts on the calcines were latterly carried out in a silica tray which was partially covered by an asbestos board as shown below in the sketch.

Cross Section of Furnace



The leaching of calcines was carried out in a beaker as pictured in the left of Exhibit No. 3. Note the heater that the beaker is setting on and the mechanical stirrer used for agitation of the pulp.



No 3.

Conditions employed for leaching were:

Dilution - 1-3 gms cobalt per litre of solution.

Time - 20-30 minutes.

Temperature - 80-90 C.

The electric furnace pictured to the right in Exhibit No. 3 might be noticed. This furnace was used for igniting the final precipitates of the cobalt and sulphur assays, the procedures of which shall now be given in detail.

ASSAY PROCEDURES

It is felt that a complete exposition of the assay procedures is not justified in this report so only the bare outlines are included. For further details on preparations of standards etc. any textbook on assaying may be consulted.

There is in many textbooks on assaying an alternative electrolytic method for the assay of cobalt. It might be worthy of note that this method was tried, but because of the interfering effect of manganese, it was found unsatisfactory.

COBALT

Weigh out 1 or 2 gms Ore or calcine.

Add 10-15 c.c. HCl - digest until oxides in solution.

Add 3-5 c.c. chlorate mixture, slowly evaporate to dryness and bake.

Add 3-5 c.c. HCl, again take to dryness and bake.

Add 1-3 c.c. HCl.

Add 100 c.c. H₂O.

⚡ Gas with H₂O for 5-10 minutes.

Bring just to boil.

Gas again with H₂S for 3-5 minutes.

Filter - Precipitate to copper assay.

Boil filtrate to eliminate H₂S gas.

Add 10-15 c.c. 3 % H₂O₂.

Pour into 500 c.c. volumetric flask.

Add ZnO emulsion to precipitate iron - cool.

Add H₂O to 500 c.c. mark.

Filter off 250 c.c. into 250 c.c. vol. flask.

Transfer to 400 c.c. beaker.

Add 6 c.c. HCl.

Boil until all O₂ expelled.

Add 25-50 c.c. HAc.

Add Nitrosobetanaphthol (10 c.c. of 10 % solution for every
25 Mg Co present).

Filter - Ignite precipitate (700-900 C.)

Weigh as Co₃O₄

Weight x 0.734 = weight of cobalt.

(Nitrosobetanaphthol solution must be freshly prepared by
dissolving the right amount of Nitrosobetanaphthol in glacial
acetic acid.)

WATER SOLUBLE COBALT (W.S. Co)

Weigh out 5 gms calcine.

Add 100 c.c. H_2O and boil 10 minutes and filter

Add 3-5 c.c. HCl to filtrate

Gas with H_2S gas etc.

Proceed as in Cobalt assay of ores. See α .

ACID SOLUBLE COBALT (A.S. Co)

Weigh out 5 gms calcine.

Add 100 c.c. H_2O

Add 1 c.c. conc. H_2SO_4 - Boil 10 minutes

Filter

Add 3-5 c.c. HCl to filtrate

Gas with H_2S gas etc.

Proceed as in Cobalt assay of ores. See α .

COPPER

Wash copper precipitate from cobalt assay into beaker using as little water as possible.

Add 5-10 c.c. HNO_3

Add 3-5 c.c. Bromine water

Evaporate mixture down to a volume of 2-4 c.c.

Add 25 c.c. H_2O .

Add NH_4OH until just neutral

Boil off excess NH_4OH

Add 1 c.c. HAc

Add 1 gm (approx.) KI

Titrate with standard sodium theosulphate solution.

SULPHIDE SULPHUR (S-S)

Weigh out $\frac{1}{4}$ to 1 gm of ore or calcine

Add 5-10 c.c. HCl - digest until oxides in solution

Add 3-5 c.c. nitric chlorate mixture, evaporate to dryness and bake.

Add 3-5 c.c. HCl - evaporate to dryness and bake.

Add 3-5 c.c. HCl

Add 25-50 c.c. H_2O

Filter and wash precipitate well.

★ Dilute filtrate to 300 or 400 c.c. - boil.

Add sufficient boiling $BaCl_2$ to precipitate all the sulphur.

Allow to set on warm plate. Filter and wash precipitate

3 or 4 times with hot 5 % HCl solution and finally 2 or 3 times with hot water.

Ignite - Cool - Weigh as $BaSO_4$

Weight $BaSO_4 \times 0.1313$ = weight of sulphur

SULPHATE SULPHUR (SO_4 -S)

Weigh out 1-2 gms calcine

Add 50-100 c.c. H_2O - boil, filter and wash precipitate well.

Proceed as in Sulphide Sulphur. See ★ .

IRON

Weigh out $\frac{1}{4}$ to $\frac{1}{2}$ gm of calcine or ore.

Add 5-10 c.c. HCl - digest until oxides in solution.

Add 3-5 c.c. nitric chlorate mixture, take to dryness and bake.

Add 3-5 c.c. HCl, take to dryness and bake.

Add 15-20 c.c. HCl and heat.

★ Add Stannous chloride solution drop by drop until all iron reduced and one drop in excess. Dilute to 400 c.c. volume.

Add 10-15 c.c. Mercuric Chloride solution

Add 10 c.c. Titrating solution ★

Titrate with standard permanganate solution.

★ Titrating solution consists of:

80 gms MnSO_4

165 c.c. H_3PO_4

160 c.c. H_2SO_4

850 c.c. H_2O

WATER SOLUBLE OR ACID-SOLUBLE IRON (W.S. Fe or A.S. Fe)

Weigh out 5 gms calcine

Add 100 c.c. water

Add 1 c.c. H_2SO_4 (only for A.S. Fe)

Boil for 10 minutes - Filter

Evaporate to almost dryness

Add 10-15 c.c. HCl

Add Stannous chloride solution drop by drop

Proceed as in Iron assay. See ★ .

ARSENIC

Weigh out 4 gms calcine ($\frac{1}{2}$ gm ore)

Add 5-10 c.c. HCl - digest until oxides in solution

Add 3-5 c.c. nitric chlorate mixture - evaporate to dryness and bake

Add 3-5 c.c. HCl - evaporate to dryness and bake

Add 3-5 c.c. HCl and warm until dissolved. Transfer to a pyrex

flask with the aid of HCl. Add $\frac{1}{2}$ gm of NaBr and $\frac{1}{2}$ gm

hydrazine sulphate. Connect flask with a distillation column.

Have a thistle tube entering into, and continuing to the bottom of, the flask; through which 25-50 c.c. of HCl may now be added.

Distill - catching distillate in a 250 c.c. beaker $\frac{1}{3}$ full of cold water with tip of condenser just below surface of water.

When volume in the flask has been evaporated down to about 20 c.c. add 25 c.c. more HCl and continue distillation until volume in flask is again about 20 c.c. Wash out condenser into beaker. Transfer contents of beaker to a 500 c.c. flask.

Add a few drops of methyl orange

Add NH_4OH until just alkaline

Add HCl until just acid - cool completely

Add 5-10 gms NaHCO_3

Add 10 c.c. starch indicator solution.

Titrate to standard color end point with standard iodine solution.

TESTSTEST No. 1

150 gms conc. were added to an excess of strong boiling sulphuric acid to convert everything to sulphates. The mixture was filtered hot. The precipitate was roasted at 600 C. to 650 C. until all action seemed complete. The resulting calcine weighed 97 gms.

Co in calcine ----- = 0.5 %

Co in water leach residue ----- = 0.11 %

Result:

78 % Cobalt, water soluble.

TEST No. 2

90 gms conc. were added to boiling H_2SO_4 left over from Test No. 1 (The hot acid from Test No. 1 was cooled and the resulting precipitate of As_2O_3 filtered off.) The mixture was filtered hot. The precipitate was roasted at 650 C. to yield 104 gms calcine.

Total Co (Cal.) ----- - 0.76 %

Co in water leach residue ----- - 0.082 %

Result:

89 % Cobalt, water soluble.

TEST No. 3

2000 gms conc. were added to sufficient boiling strong H_2SO_4 to convert everything into sulphates. The hot mixture was filtered. The residue was split into three parts, each part roasted separately until all action seemed complete; as follows:

CALCINE	1	2	3
Temp. of roast -----	700 C. ----	665 C. ----	665 C. ----
Total Co -----	0.46 % ----	0.33 % ----	0.30 % (Cal) ----
W.S. Co -----	0.15 % ----	0.22 % ----	0.18 % ----
A.S. Co -----	0.20 % ----	0.24 % ----	0.19 % ----
Co in tails -----	0.24 % ----	0.09 % ----	0.11 % ----
Max. Co recovery -----	43 % ----	73 % ----	63 % ----

A 200 gms portion of No. 1 calcine was mixed with 80 gms salt and given a chloridizing roast.

Total Co -----	0.55 %
W.S. Co -----	0.24 %
A.S. Co -----	0.30 %
Co in tails -----	0.26 %

Result:

54 % Cobalt, acid soluble.

TEST No. 4

1350 gms conc. were added to an excess of strong boiling H_2SO_4 to convert everything into sulphates. The mixture was filtered hot. 470 gms of the precipitate plus 25 gms salt (NaCl) were roasted at 650 C. A 52 gm sample was cut from calcine and called A. The balance was mixed with an additional 25 gms of salt and given a further chloridizing roast to yield 405 gms calcine B.

CALCINE	A	B
Total Co -----	0.60 % -----	0.70 %
W. S. Co -----	0.56 % -----	0.63 %
Total Fe -----	22.3 % -----	27.2 %
W.S. Fe -----	5.1 % -----	4.1 %
Insols -----	3.5 % -----	3.5 %
Total Cu -----	0.48 % -----	0.48 %
Total As -----	3.5 % -----	3.4 %
Cobalt recovery -----	93 % -----	93 %

TEST No. 5

1800 gms conc. were added to a large excess of boiling strong H_2SO_4 to convert everything into sulphates. The hot mixture was filtered and the precipitate assayed as follows:

Co -----	.34 %	As -----	0.3 %
Cu -----	.36 %	S - S -----	2.0 %
Fe -----	24.1 %	SO_4 -S -----	22.0 %
W.S. Fe ---	20.4 %		

No further work was done on this test.

TEST No. 6

416 gms conc. were given a preliminary roast in a tray at an initial temp. of 550 C. and final temp. of 850 C. and yielded 250 gms calcine. The 250 gms plus 30 gms of salt plus 12 gms pyrite were roasted for two hours at 600 C. Final weight = 290 gms

Result:

Trace Cobalt, water soluble.

TEST No. 7

Some sulphated concentrate from Test No. 5 was roasted with 5 % carbon and again with 5 % carbon at 650 C. It was then given a chloridizing roast with 3 % salt at 650 C.

Result:

75 % Cobalt, water soluble.

TEST No. 8

100 gms of conc. were given a preliminary roast at an initial temp. of 550 C. and final temp. of 822 C. to yield 63 gms calcine. 50 gms of this calcine plus 25 c.c. strong H_2SO_4 plus 1 gm carbon plus 1 gm salt roasted at 650 C.

Result:

80 % Cobalt, water soluble.

TEST No. 9

2000 gms conc. were given a preliminary roast at an initial temp. of 550 C. and final temp. of 800 C. and yielded 1190 gms calcine (9A).

Result:

Co(Cal.) ----- 1.48 %

TEST No. 9B

250 gms 9A plus 30 gms salt plus 12 gms pyrite roasted at 625 C. and yielded 290 gms calcine (9B).

Result:

Trace Cobalt, water soluble.

TEST No. 9C

100 gms 9A plus 5 gms plus 2 gms carbon plus 50 c.c. strong H_2SO_4 roasted at 650 C. and yielded 124 gms calcine 9C..

Result:

90 % Cobalt, water soluble.

TEST No. 9D

100 gms 9A plus 5 gms salt plus 2 gms carbon roasted at 650 C. Calcine cooled, screened, mixed with 50 c.c. strong H_2SO_4 and re-roasted at 625 C.

Result:

93 % Cobalt, water soluble.

TEST No. 9E

100 gms 9A plus 5 gms salt plus 5 gms carbon plus 50 c.c. H_2SO_4 roasted for $2\frac{1}{2}$ hours at 625 C. to yield 127 gms calcine 9E.

Result:

90 % Cobalt, water soluble.

TEST No. 9F

100 gms 9A plus 5 gms salt plus 25 c.c. H_2SO_4 plus 2 gms C, roasted for 2 hours at 640 C. to yield 109 gms Calcine 9F.

Result:

62 % Cobalt, water soluble.

TEST No. 9G1

100 gms Calcine 9A plus 2 gms carbon plus 50 c.c. H_2SO_4 , roasted for 6 minutes at 530 C. to yield 148 gms.

Total Co -----	1.15 %	Total Fe -----	32 %
W.S. Co -----	1.06 %	W.S. Fe -----	6.7%

Result:

92 % Cobalt, water soluble.

TEST No. 9G2

140 gms 9G1 plus 5 gms salt, roasted for 15 minutes at 630 C.
to yield 140.5 gms calcine.

Total Co -----	1.15 %	Total Fe -----	33 %
W.S. Co -----	1.15 %	W.S. Fe -----	5.5%

Result:

100 % Cobalt, water soluble.

TEST No. 9G3

130 gms 9G2, roasted at 640-650 C. to yield 92 gms calcine 9G3.

Total Co -----	1.46 %	W.S. Co -----	0.99 %
" Fe -----	47.7 %	A.S. Co -----	1.31 %
" As -----	1.3 %	W.S. Fe -----	Tr.
" Cu -----	0.69 %		

Result:

67 % Cobalt, water soluble.

90 % Cobalt, acid soluble.

TEST No. 10

1000 gms conc. were given a preliminary roast at an initial temp.
of 550 C. and final temp. of 625 C. to yield 616 gms calcine 10A.

Total Co(Cal.) -----	1.36 %
" Fe -----	51.4 %

TEST No. 10B

100 gms 10A plus 50 c.c. H_2SO_4 roasted at 625 C.

Total Co(Cal.) ---	1.32 %	W.S. Co. ----	0.65 %
" Fe -----	49.8 %	A.S. Co ----	0.73 %
" Cu -----	1.02 %	W.S. Cu ----	0.28 %
A.S. Cu -----	0.40 %		

Result:

50 % Cobalt, water or acid soluble.

TEST No. 10C

100 gms of 10A plus 50 c.c. H_2SO_4 plus 5 gms salt, roasted for $1\frac{1}{2}$ hours at 625 C.

Total Co(Cal.) ---	1.09 %	A.S. Co ----	0.66 %
" Fe -----	43.1 %	W.S. Cu ----	0.10 %
W.S. Co -----	0.25 %	A.S. Cu ----	0.40 %

Results:

23 % Cobalt, water soluble.

60 % Cobalt, acid soluble.

TEST No. 10D

100 gms 10A plus 10 c.c. H_2SO_4 plus 25 c.c. H_2O , roasted at 650 C.

Total Co(Cal.) ---	1.34 %	A.S. Co ----	0.37 %
" Fe -----	50.7 %	W.S. Cu ----	0.02 %
W.S. Co -----	0.04 %	A.S. Cu ----	0.31 %

Result:

27 % Cobalt, acid soluble.

TEST No. 10E

100 gms of 10A plus 40 c.c. H_2SO_4 , roasted at 650 C.

Total Co(Cal.) ---	1.08 %	W.S. Co ----	0.82 %
" Fe -----	40.8 %	A.S. Co ----	0.86 %
" As -----	4.7 %	W.S. Fe ----	6.6 %
W.S. Cu -----	0.48 %	A.S. Cu ----	0.56 %

Results:

76 % Cobalt, water soluble.

80 % Cobalt, acid soluble.

TEST No. 10F

100 gms of 10A plus 40 c.c. strong H_2SO_4 were mixed and allowed to react at room temperature until they formed a hard cake.

Total Co(Cal.) ---	0.75 %
" Fe -----	28.3 %
W.S. Co -----	0.56 %

Result:

75 % Cobalt, water soluble.

TEST No. 10G

50 gms 10A plus 25 c.c. H_2SO_4 plus 1 gm of carbon plus 1 gm of salt, roasted at 650 C.

Total Co(Cal.) ---	1.13 %	W.S. Co ----	0.91 %
" Fe -----	42.8 %	A.S. Co (?) -	0.81 %
" As -----	3.0 %	W.S. Fe ----	4.0 %
A.S. Cu -----	0.61 %	W.S. Cu ----	0.49 %

Result:

80 % Cobalt, water soluble.

TEST No. 11A

1000 gms conc. were given a preliminary roast at 750 C. to yield 600 gms of 11A.

TEST No. 11B

100 gms 11A plus 10 gms carbon plus 10 gms salt plus 10 gms pyrite, roasted at 700 C., cooled and 50 c.c. H_2SO_4 added and further roasted at 725 C. to yield 120 gms.

Result:

90 % Cobalt, water soluble.

TEST No. 12

1000 gms of conc. were given a preliminary roast at 750 C.-820 C. for one hour. Weight of calcine 565 gms.

Total Fe -----	54.8 %	S - S -----	0.86 %
Total As -----	0.64 %	SO ₄ - S -----	1.08 %

TEST No. 13

400 gms calcine from test 12 plus 8 gms carbon plus 200 c.c. H_2SO_4 , roasted at 600 C. for 10 minutes. Sulphates weighed 595 gms. Sulphates ground through 20 mesh plus 20 gms salt, roasted at 640 C. for $1\frac{3}{4}$ hours to yield 537 gms calcine.

Result:

80 % Cobalt, water soluble.

TEST No. 14

2000 gms of conc. were given a preliminary roast at initial temp. of 550 C. and final temp. of 800 C. to yield 1155 gms calcine 14A.

Total Co -----	1.50	%	SO ₄ -S -----	0.72	%
" Fe -----	54.9	%	S - S -----	0.25	%
" As -----	2.64	%	Au(Cal.) -----	1.83	oz/ton
" Cu -----	1.40	%			

TEST No. 14B

100 gms 14A plus 2 gms carbon plus 40 c.c. H₂SO₄, roasted at 550 C. for 15 minutes. Weight of calcine 150 gms.

Total Co -----	1.06	%	W.S. Co -----	0.98	%
" Fe -----	37.2	%	A.S. Co -----	1.03	%
" As -----	1.33	%	W.S. Fe -----	7.4	%
" Cu -----	0.69	%	A.S. Fe -----	13.2	%
SO ₄ -S -----	12.40	%	W.S. Cu -----	0.62	%
S-S -----	0.2	%	A.S. Cu -----	0.65	%

Result:

87 % Cobalt, water soluble.

89 % Cobalt, acid soluble.

TEST No. 14C

100 gms 14B plus 5 gms salt, roasted at 650 C. for 15 minutes.

Weight of calcine = 96 gms.

Total Co -----	1.06 %	W.S. Co -----	0.98 %
" Fe -----	37.2 %	A.S. Co -----	1.03 %
" As -----	1.33 %	W.S. Fe -----	7.4 %
" Cu -----	0.69 %	A.S. Fe -----	13.2 %
SO ₄ -S -----	12.40 %	W.S. Cu -----	0.62 %
S-S -----	0.60 %	A.S. Cu -----	0.65 %

Results:

92 % Cobalt, water soluble.

97 % Cobalt, acid soluble.

TEST No. 14D

50 gms of 14 C., roasted at 680 C. for $1\frac{1}{2}$ hours to yield 36 gms calcine.

Total Co -----	1.45 %	W.S. Co -----	0.84 %
" Fe -----	49.5 %	A.S. Co -----	0.83 %
" As -----	1.74 %	W.S. Fe -----	Trace
" Cu -----	0.92 %	A.S. Fe -----	0.80 %
SO ₄ -S -----	4.0 %	W.S. Cu -----	0.45 %
S-S -----	0.1 %	A.S. Cu -----	0.80 %

Result:

58 % Cobalt, water or acid soluble.

TEST No. 14E

100 gms 14A plus 2 gms carbon plus $7\frac{1}{2}$ gms salt plus 40 c.c.

H_2SO_4 , roasted at 650 C. for 15 minutes to yield 149 gms sulphates.

Total Co -----	1.12 %	W.S. Co -----	1.01 %
" Fe -----	36.6 %	A.S. Co -----	1.01 %
" As -----	1.26 %	W.S. Fe -----	8.8 %
" Cu -----	0.67 %	A.S. Fe -----	13.1 %
SO ₄ -S -----	12.70 %	W.S. Cu -----	0.64 %
S-S -----	0.40 %	A.S. Cu -----	0.66 %

Result:

90% Cobalt, water and acid soluble.

TEST No. 14F

100 gms of 14E, roasted for $1\frac{1}{2}$ hours at 688 C. to yield 73 gms.

Total Co -----	1.43 %	W.S. Co -----	0.88 %
" Fe -----	49.0 %	A.S. Co -----	1.23 %
" As -----	1.68 %	W.S. Fe -----	Trace
" Cu -----	0.94 %	A.S. Fe -----	0.7 %
SO ₄ -S -----	4.1 %	W.S. Cu -----	0.51 %
S-S -----	NIL	A.S. Cu -----	0.91 %

Results:

61 % Cobalt, water soluble.

85 % Cobalt, acid soluble.

TEST No. 14G.

600 gms 14A plus 12 gms carbon plus 240 c.c. H_2SO_4 , roasted at 550 C. for 15 minutes. Weight of sulphates = 895 gms.

Total Co (Cal.) -----	1.02 %
A.S. Co -----	0.81 %
Au -----	1.19 oz./ton
Au (Cal.) -----	1.23 oz./ton

Results:

80 % Cobalt, acid soluble.

37 % Gold loss.

TEST No. 14H

823 gms of 14G plus 41 gms salt, roasted at 650 C. for 15 minutes. Weight of calcine = 837 gms.

Total Co (Cal.) -----	1.0 %
A.S. Co -----	0.86 %
Au (Cal.) -----	1.21 oz./ton
Au -----	1.08 oz./ton

Result:

86 % Cobalt water soluble.

10 % Gold loss

TEST No. 14 I

77 3 gms of 14H, roasted at 680 C. for $1\frac{3}{4}$ hours to yield 660 gms.

Total Co (Cal.) -----	1.18 %
A.S. Co -----	1.02 %
Au (Cal.) -----	1.41 oz./ton
Au -----	1.20 oz./ton

Result:

85 % Cobalt water soluble.

14 % Gold Loss.

TEST No. 14J

596 gms 14I, roasted for 2 hours at 680 C. to yield 530 gms.

Total Co.(Est.) ---	1.40 %	W.S. Co ---	1.21 %
Total Fe -----	47.5 %	A.S. Co ---	1.26 %
Total Cu -----	0.90 %	W.S. Fe ---	Trace
W.S. Cu -----	0.65 %	A.S. Fe ---	1.15 %
A.S. Cu -----	0.69 %	Au -----	1.37 oz/ton
Au (Cal.) -----	1.59 oz./ton		

Result:

86 % Cobalt, water soluble.

14 % Gold loss.

TEST No. 14K

200 gms of 14J were water leached. Approximately 10 gm sample cut from water leach tails.

Au ----- 1.60 oz./ton

TEST No. 14L

Water leach tails from 14K were cyanided in approx. 0.05 percent cyanide solution with protective alkalinity kept at 0.04 % CaO. Period of agitation was 43 hours. Cyanide tails weighed 142 gms.

Au = 0.25 oz./ton

Result:

84 % Gold recovery.

TEST No. 14M

100 gms 14A plus 2 gms carbon plus 40 c.c. H_2SO_4 , roasted at 550 C. for 15 minutes. Cooled, screened and further roasted for $1\frac{1}{2}$ hours at 680 C. and yielded 100 gms.

Total Co (Cal.)	---	1.50 %	W.S. Co	----	1.15 %
W.S. Fe	-----	0.10 %	A.S. Co	----	1.26 %
A.S. Fe	-----	2.9 %			

Result:

76 % Cobalt, water soluble.

84 % Cobalt, acid soluble.

TEST No. 14N

40 gms calcine 14M plus 3 gms salt, roasted at 620 C. for 15 minutes to yield 42 gms calcine.

Total Co(Cal.)	---	1.43 %	W.S. Co	----	0.17 %
W.S. Fe	-----	Trace	A.S. Co	----	1.19 %
A.S. Fe	-----	1.70 %			

Result:

12 % Cobalt, water soluble.

83 % Cobalt, acid soluble.

TEST No. 14O

40 gms 14M plus 3 gms salt plus 2 gms primary sulphates 14B, roasted at 620 C. for 15 minutes to yield 44 gms.

Total Co(Cal.)	---	1.41 %	W.S. Co	----	0.33 %
W.S. Fe	-----	Trace	A.S. Co	----	1.17 %
A.S. Fe	-----	1.4 %			

Result:

23 % Cobalt, water soluble.

83 % Cobalt, acid soluble.

TEST No. 16

2000 gms conc., roasted at 750 C. to yield 1202 gms calcine 16A.

Total Co(Cal.) -----	1.46	%
" As -----	4.7	%
" S -----	1.3	%

TEST No. 16B

600 gms 16A plus 300 c.c. H_2SO_4 , roasted for 15 minutes at 550 C. to yield 900 gms of sulphates. These sulphates plus 90 gms salt were ground - 28 mesh and roasted at 600 C. for 25 minutes. Final weight equal 935 gms.

Total Co -----	0.96	%	W.S. Co -----	0.79	%
" Fe -----	33.6	%	A.S. Co -----	0.79	%
" Cu -----	0.70	%	W.S. Fe -----	6.7	%
W.S. Cu -----	0.64	%	A.S. Fe -----	12.9	%
A.S. Cu -----	0.65	%			

Result:

82 % Cobalt, water or acid soluble.

TEST No. 16C

875 gms 16B, roasted at 640 C. for two hours to yield 827 gms calcine.

Total Co -----	1.00	%	W.S. Co -----	0.90	%
" Fe -----	35.4	%	A.S. Co -----	0.90	%
" Cu -----	0.66	%	W.S. Fe -----	4.7	%
W.S. Cu -----	0.60	%	A.S. Fe -----	10.9	%
A.S. Cu -----	0.63	%			

Result:

90 % Cobalt, acid or water soluble.

TEST No. 16D

250 gms of 16C leached with 1000 c.c. of 3.50 % H_2SO_4 solution for one hour at 80 C. Residue weighed 111 gms.

Total Co ----- 1.00 %

A.S. Co ----- 0.72 %

Result:

72 % Cobalt, acid soluble.

TEST No. 16E

250 gms 16C ground in a pebble mill for $\frac{1}{2}$ hour at 50 % solids. Pulp acid leached with 1000 c.c. of 3.5 % solution H_2SO_4 for $1\frac{1}{2}$ hours at 76 C. Residue weighed 115 gms.

Total Co ----- 1.00 %

A.S. Co ----- 0.72 %

Result:

72 % Cobalt, acid soluble.

TEST No. 16F

227 gms 16C roasted for four hours at 640 C. to yield 185 gms calcine.

Total Co ----- 1.20 % W.S. Co ----- 1.03 %

" Fe ----- 42.5 % A.S. Co ----- 1.04 %

" Cu ----- 0.79 % W.S. Fe ----- 0.10 %

" As ----- 2.1 % A.S. Fe ----- 1.9 %

W.S. Cu ----- 0.64 % SO_4 -S ----- 6.7 %

A.S. Cu ----- 0.68 % S-S ----- 0.1 %

Result:

86 % Cobalt, water or acid soluble.

TEST No. 16G

125 gms 16F leached with 600 c.c. of 3.5 % H_2SO_4 solution for one hour at 84 C. Residue weighed 90 gms.

Total Co ----- 1.20 %

A.S. Co ----- 0.81 %

Result:

67 % Cobalt, water soluble.

TEST No. 16H

500 gms calcine 16A plus 10 gms carbon plus 225 c.c. H_2SO_4 roasted at 550 C. for 15 minutes. Cooled, ground - 100 mesh plus $37\frac{1}{2}$ gms salt, reroasted for five hours at 630 C. Final weight = 670 gms.

Total Co ----- 1.09 % W.S. Co ----- 0.93 %

" Fe ----- 37.3 % A.S. Co ----- 0.94 %

" Cu ----- 0.70 % W.S. Fe ----- 4.1 %

W.S. Cu ----- 0.61 % A.S. Fe ----- 11.8 %

A.S. Cu ----- 0.65 % S-S ----- 0.8 %

SO_4 -S ----- 11.3 %

Result:

85 % Cobalt, acid or water soluble.

TEST No. 16J

348 gms 16H, reroasted at 680 C. to yield 282 gms calcine.

Total Co ----- 1.28 % W.S. Co ----- 1.04 %

" Fe ----- 45.6 % A.S. Co ----- 1.04 %

" Cu ----- 0.84 % W.S. Fe ----- 2.9 % ?

W.S. Cu ----- 0.68 % A.S. Fe ----- 0.20 %

A.S. Cu ----- 0.60 %

Result:

81 % Cobalt, water or acid soluble.

TEST No. 17A

2000 gms conc., roasted at 850 C. for one hour. Cooled, somewhat, added 30 gms of carbon and reroasted at 850 C. for 15 minutes. Cooled added 57 gms salt and 750 c.c. H_2SO_4 and roasted for six hours at 680 C. Final weight = 1345 gms.

Total Co(Cal.) ----- 1.31 %

TEST No. 17B

500 gms 17A, reroasted at 680 C. for two hours to yield 450 gms calcine 17B. 250 gms 17B leached for one hour at 800.

Total Co (Cal.) ----- 1.45 %

" Cu ----- 0.93 %

W.S. Co ----- 1.30 %

W.S. Cu ----- 0.76 %

W.S. Fe ----- 0.07 %

Result:

90 % Cobalt, water soluble.

TEST No. 18A

1000 gms conc., roasted at 500 to 550 for three hours. Then temp. raised to 650 C. for $\frac{1}{2}$ hour and finally to 700 C. for 15 minutes. Final weight = 606 gms.

Total Co(Cal.) ----- 1.45 % S-S ----- 0.1 %

" As ----- 5.6 % W.S. As -- 0.08 %

SO_4 -S ----- 0.8 % A.S. As -- 1.42 %

TEST No. 18B

100 gms 18A plus 6 gms salt plus 50 c.c. H_2SO_4 roasted for 20 minutes at 330 C. 10 minutes at 550 C. and finally 4 hours at 690 - 700 C. Final weight = 108 gms.

Total Co ----- 1.44 %

W.S. Co ----- 0.22 %

Result:

15 % Cobalt, water soluble.

TEST No. 19A

1000 gms conc. roasted at (800-825 C.) for one hour and yielded 570 gms calcine 19A.

Total Co(Cal.) ---- 1.54 % S-S ----- 2.43 %

" As ----- 1.06 % W.S. As-- 0.05 %

SO_4 -S ----- 1.0 % A.S. As-- 0.60 %

TEST No. 19B

100 gms of 19A were treated exactly the same and at the same time as 100 gms 18A were treated in Test No. 18B. Final weight = 112 gms.

Total Co(Cal.) ----- 1.37 %

W.S. Co ----- 1.21 %

Result:

88 % Cobalt, water soluble.

TEST No. 19C

100 gms 19A plus 45 c.c. HCl, roasted gently for one hour and finished at 350 C. for one hour. Final weight = 100 gms.

Total Co(Cal.) ----- 1.54 %

W.S. Co ----- 0.65 %

Result:

42 % Cobalt, water soluble.

TEST No. 20A

2000 gms conc., roasted at 800 C. for $\frac{1}{2}$ hour and at 830 C. for $1\frac{1}{2}$ hours. Weight of calcine = 1135 gms.

Total Co(Cal.) -----	1.55 %
" As -----	0.56 %
Ferrous Fe -----	2.5 %

TEST No. 20B

900 gms calcine 20A, roasted at 830 C. for 20 minutes and at 850 C. for 10 minutes. Final weight = 888 gms.

Total Co(Cal.) -----	1.57 %
" As -----	0.58 %
" S -----	1.18 %
Ferrous Fe -----	0.20 %

TEST No. 20C

300 gms of calcine 20B ground dry for 15 minutes plus 150 c.c. H_2SO_4 plus 15 gms salt plus 10 gms carbon, roasted at 550 C. for 10 minutes. Final weight = 480 gms.

Total Co.(Est.) ----	1.36 %	W.S. Co ----	1.26 %
" Fe -----	49.5 %	A.S. Co ----	1.23 %
" Cu -----	0.98 %	W.S. Fe ----	0.15 %
" As -----	0.43 %	A.S. Fe ----	1.14 %
W.S. Cu -----	0.90 %	A.S. Cu ----	0.95 %

Result:

91 % Cobalt, acid or water soluble.

TEST No. 20D

300 gms 20B ground dry for 15 minutes plus 150 c.c. H_2SO_4 , roasted at 550 C. and finally at 700 C. for $1\frac{1}{4}$ hours. Final weight = 306 gms.

Total Co ----	1.35 %	W.S. Co ----	1.10 %
" Cu ----	0.98 %	W.S. Cu ----	0.59 %
" Fe ----	53.6 %	W.S. Fe ----	0.03 %
" As ----	0.43 %		

Result:

82 % Cobalt, water soluble.

TEST No. 21A

3000 gms conc. roasted at 750 C. on floor of furnace for $1\frac{1}{4}$ hours to yield 1683 gms.

Total Co(Cal.) -----	1.57 %
" As -----	0.36 %
" S -----	2.06 %

TEST No. 21B

100 gms calcine 21A plus 5 gms pyrite plus 15 c.c. HCl plus 15 c.c. H_2O , roasted at 350 C. for $\frac{3}{4}$ hour. Weight calcine = 10.4 gms.

Total Co(Cal.) -----	1.51 %
W.S. Co -----	1.11 %

Result:

74 % Cobalt, water soluble.

TEST No. 21C

52 gms of calcine 21B heated in beaker at 350 C. for one hour to yield 52 gms.

Total Co(Cal.) ----- 1.51 %

W.S. Co ----- 1.05 %

Result:

70 % Cobalt, water soluble.

TEST No. 21D

100 gms calcine 21A plus 5 gms pyrite plus 15 gms salt, roasted at 350 C. for $1\frac{1}{2}$ hours. Weight of calcine = 119 gms.

Total Co(Cal.) ----- 1.27 %

W.S. Co ----- 0.94 %

Result:

74 % Cobalt, water soluble.

TEST No. 21L

400 gms 21A, roasted for one hour to yield 381 gms.

Total Co(Cal.) ----- 1.65 %

" As ----- 0.40 %

" S ----- 1.13 %

TEST No. 21M

100 gms 21L plus 10 gms pyrite plus 15 c.c. H_2O plus 15 c.c. HCl, roasted at 400 C. for one hour. Final weight = 114 gms.

Total Co(Cal.) ----- 1.45 %

W.S. Co ----- 0.85 %

Result:

58 % Cobalt, water soluble.

TEST 21P

100 gms 21A, ground dry and leached for one hour with 5 % sulphuric acid solution.

Total Co(Cal.) ----- 1.57 %

A.S. Co ----- 1.0 %

Result:

64 % Cobalt, acid soluble.

TEST No. 22A

4000 gms conc., roasted at 750 C. for one hour and five minutes on furnace floor with pyrometer in the calcine. Final weight = 2284 gms.

Total Co(Cal.) ----- 1.54 %

TEST No. 22B

500 gms 22A ground dry plus 50 gms salt, roasted for one hour at 590-600 C. to yield 538 gms calcine.

Total Co(Cal.) ---- 1.43 % A.S. Co ---- 0.25 %

" As ----- 0.41 % W.S. Cu ---- 0.48 %

W.S. Co ----- 0.15 % A.S. Cu ---- 0.80 %

Result:

10 % Cobalt, water soluble.

17 % Cobalt, acid soluble.

TEST No. 22C

100 gms 22A plus 40 c.c. solution roasted at 450-500 C. for 2 hours. Final Weight = 110 gms (solution: 35 c.c. water plus 6 c.c. H_2SO_4 plus 5 gms salt).

Total Co(Cal.) ----	1.40 %	W.S. Co ----	1.00 %
W.S. Fe -----	2.39 %	A.S. Co ----	0.77 %
Total Fe -----	49.0 %	A.S. Cu ----	0.62 %

Result:

72 % Cobalt, water soluble.

TEST No. 22G

100 gms 22A plus 40 c.c. of solution and evaporate to dryness at 350 C. plus 20 c.c. more solution and roast for 2 hours at 350 C. (solution: 4 c.c. HCl plus 2 c.c. H_2SO_4 plus 52 c.c. H_2O to last 18 c.c. portion added 2 c.c. more H_2SO_4 .) Final weight = 104 gms.

Total Co(Cal.) ----	1.48 %	A.S. Co ----	0.92 %
Total Fe -----	52.0 %	A.S. Fe ----	4.3 %

Result:

62 % Cobalt, acid soluble.

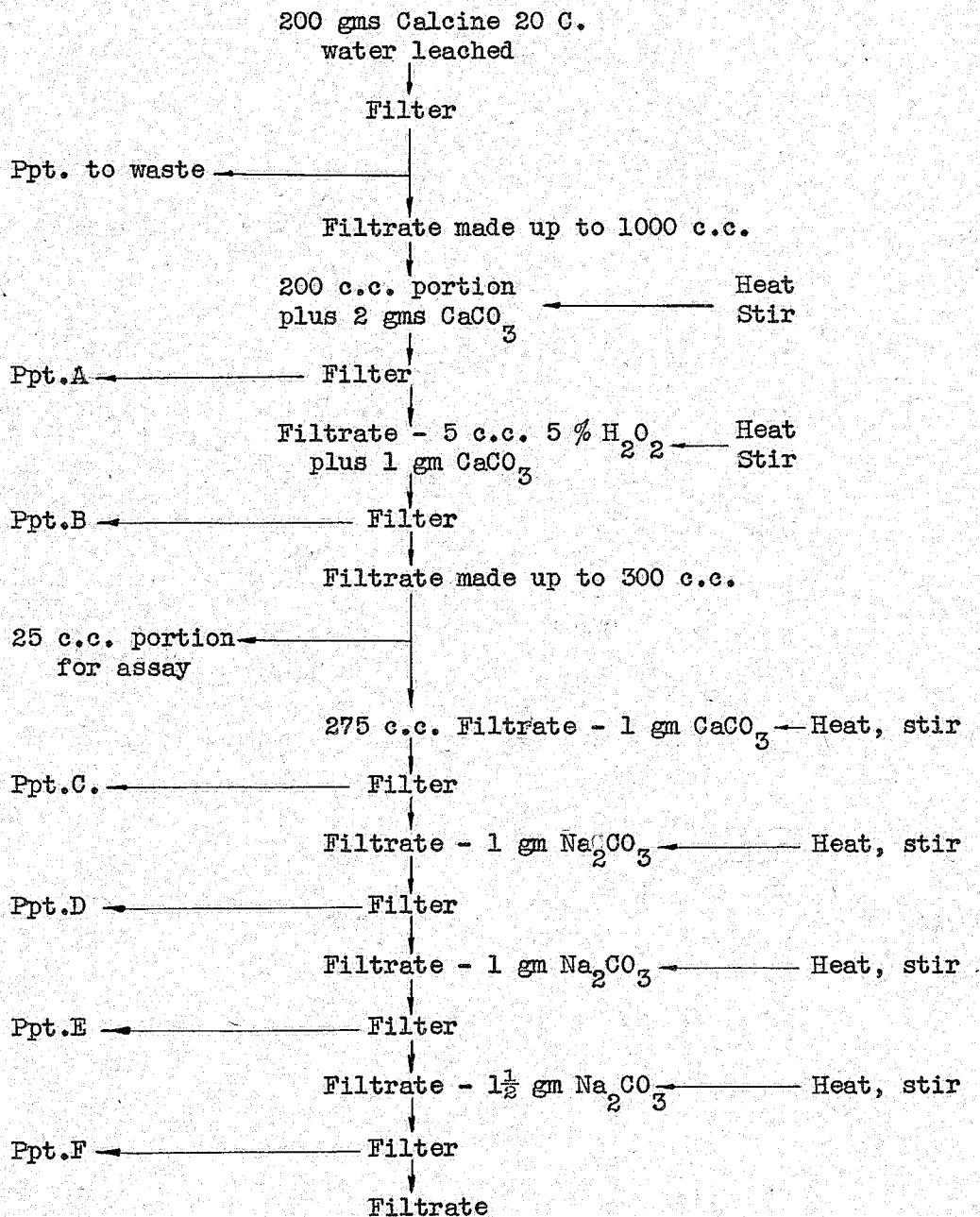
TEST No. 22N

100 gms 22A plus 50 c.c. HCl, roasted for 2 hours.

Total Co(Cal.) -----	1.54 %
W.S. Co -----	1.01 %
A.S. Co -----	1.00 %

Result:

65 % Cobalt, water or acid soluble.

TEST No. 23

Product	Additions	Co	Assays	
			Cu	Fe
Heads	---	1.26	0.90	0.15
Ppt.A	2 gm CaCO_3	---	0.27	0.07?
Ppt.B	1 gm CaCO_3	---	0.39	Tr.
Heads	---	1.25	0.24	---
Ppt.C	1 gm CaCO_3	---	0.19	---
Ppt.D	1 gm Na_2CO_3	0.87	Tr.	---
Ppt.E	1 gm Na_2CO_3	0.37	---	---
Ppt.F	1.5 gm Na_2CO_3	Tr.	---	---
Filtrate	---	---	---	---

Results:

98.5 % Cobalt recoverable from leach solutions.

1 gm Na_2CO_3 will ppt. 2.0 gms Cobalt.

TEST No. 23B

20 C

200 c.c. portion of leached, treated similar to Test No. 23 with the exception of additions which are shown below.

Product	Additions	Assays		
		Co	Cu	Fe
Heads	----	1.26	0.90	0.15
Ppt.A	1 gm CaCO_3	---	0.06	0.48?
" B	$3\frac{1}{2}$ gm CaCO_3	---	0.90	---
" C	2 gm Na_2CO_3	1.26	Tr.	---
Filtrate	----	---	---	---

Result:

100 % Cobalt recoverable from leach solution.

TEST No. 23C

50 gms of calcine 17B were treated similarly to test No.23 with the exception of the additions which are shown below.

Product	Additions	Assays		
		Co	Cu	Fe
Heads	----	1.30	0.76	0.07
Ppt.A	3 gm CaCO_3	---	0.72	Tr.
" B	2 gm Na_2CO_3	1.26	0.08	---
Filtrate	----	Tr.	---	---

Result:

98 % Cobalt recoverable from leach solution.

TEST No. 24A

100 gms calcine 22A plus 9 c.c. HCl plus 30 c.c. H_2O , roasted at 450 for 1 hour to yield 100 gms calcine.

Total Co(Cal.)	-----	1.54	%
" Fe	-----	54.0	%
W.S. Fe	-----	0.5	%
W.S. Co	-----	1.11	%

Result:

72 % Cobalt, water soluble

TEST No. 24B

50 gms of 24A plus 23 c.c. H_2O plus 2 c.c. HCl, roasted at 350 C. to yield 50 gms. final calcine.

Total Co(Cal.)	-----	1.54	%
A.S. Co	-----	1.07	%
A.S Fe	-----	1.11	%

Result:

69 % Cobalt, acid soluble.

TEST No. 24C

100 gms calcine 22A plus 6 c.c. HCl plus $2\frac{1}{2}$ c.c. H_2SO_4 , roasted at 350 C. for $\frac{1}{2}$ hour to yield 104 gms calcine.

Total Co(Cal.)	-----	1.48	%
W.S. Co	-----	1.01	%

Result:

68 % Cobalt, water soluble.

TEST No. 30A

2000 gms conc., roasted at 800 C. for 40 minutes to yield
1207 gms calcine.

Total Co(Cal.)	-----	1.45	%
" Fe	-----	62.0	%
" As	-----	1.95	%
" S	-----	12.2	%

TEST No. 30B

100 gms 30A plus 30 c.c. strong HCl roasted at 350 C. for
1 hour. Final Weight = 103 gms.

Total Co(Cal.)	-----	1.48	%
W.S. Co	-----	1.17	%

Result:
82 % Cobalt, water soluble.

TEST No. 30C

100 gms 30A plus 15 gms salt (added in aqueous solution)
roasted at 550-600 C. for $1\frac{1}{2}$ hours.

Total Co(Est.)	-----	1.27	%
W.S. Co	-----	0.94	%

Result:
74 % Cobalt, water soluble.

TEST NO. 31A

400 gms 30A roasted at 650 C. for $\frac{1}{2}$ hour. Final weight = 380 gms.

Total Co(Cal.) ---- 1.55 % Total S ---- 2.62 %

W.S. Co ----- 0.31 % $\text{SO}_4\text{-S}$ ----- 1.05 %

W.S. Cu ----- 0.18 %

Result:

20 % Cobalt, water soluble.

TEST No. 31B

100 gms calcine 31A plus 30 c.c. HCl, dried slowly and roasted at 350 C. for $\frac{1}{2}$ hour. Final weight = 102 gms.

Total Co(Cal.) ----- 1.52 %

W.S. Co ----- 0.75 %

Result:

50 % Cobalt, water soluble.

TEST No. 31C

100 gms 31A plus 15 c.c. H_2O plus 15 c.c. HCl roasted on hot plate at 350 C. for $\frac{1}{2}$ hour. Final weight = 101 gms.

Total Co(Cal.) ----- 1.54 %

W.S. Co ----- 0.64 %

Result:

41 % Cobalt, water soluble.

TEST No. 31D

Same as test 31C except roasted in furnace instead of on hot plate. Final weight - 101 gms.

Total Co(Cal.) ----- 1.53 %

W.S. Co ----- 0.92 %

Result:

60 % of Cobalt, water soluble.

TEST No. 32A

110 gms calcine 30A, roasted at 600 C. for 6 minutes. Final weight = 105 gms.

TEST No. 32B

90 gms of 32A plus 15 c.c. HCl plus 15 c.c. H₂O, roasted for one hour at 400C. Final weight = 92 gms.

Total Co(Cal.) -----	1.51 %
W.S. Co -----	0.88 %
A.S. Co -----	0.94 %
Brine Sol. Co -----	0.91 %

Result:

60 % Cobalt, water, or acid, or brine soluble.

TEST No. 34A

2000 gms conc., roasted at 750 C. Roast stopped shortly after arsenic flame died down. Final weight = 1270 gms.

Total Co -----	1.39 %
Total S -----	13.18 %
SO ₄ -S -----	0.61 %

TEST No. 34B

500 gms 34A roasted at 650 C. for 15 minutes to yield 480 gms calcine 34B.

TEST No. 34C

100 gms 34A plus 15 c.c. HCl plus 15 c.c. H₂O, roasted at 350 C. for one hour. Final weight = 99 gms.

Total Co(Cal.) -----	1.40 %
W.S. Co -----	0.89 %

Result:

63 % Cobalt, water soluble.

TEST No. 34D

50 gms 34B plus 7.5 HCl plus 7.5 c.c. H_2O , roasted at 350 C.
for 35 minutes. Final weight = 50 gms.

Total Co(Cal.) ----- 1.44 %

W.S. Co ----- 0.77 %

Result:

53 % Cobalt, water soluble.

TEST No. 35A

2000 gms conc. roasted at 825 C for one hour and a further two
hours at 750 C. Final weight = 1126 gms.

A.S. Co ----- Nil

TEST No. 37A

300 gms conc., roasted at 750 C on furnace floor until arsenic
flame died. Approx. 30 minutes.

TEST No. 40A

2000 gms conc., roasted at 810 C for 35 minutes - removed and
cooled away from open air. Final weight = 1165 gms.

Total Co(Cal.) ---- 1.51 % S-S ----- 21.32 %

Total As ----- 0.56 % SO_4 -S ----- 0.18 %

TEST No. 40B

200 gms 40A, roasted in open tray at 450 C for 30 minutes.
Final weight = 190 gms.

Total Co(Cal.) ----- 1.59 %

W.S. Co ----- 0.62 %

Result:

39 % Cobalt, water soluble.

TEST No. 40C

100 gms of 40A, roasted in partially covered tray at 450 C.
for one hour. Final weight = 97 gms.

Total Co(Cal.) ----- 1.56 %

W.S. Co ----- 0.88 %

Result:

54 % Cobalt, water soluble.

TEST No. 40D

100 gms 40A plus 5 c.c. H_2SO_4 plus 10 c.c. H_2O dried at 250 C.
for one hour and roasted in partially covered tray at 450 C. for
one hour. Final weight = 105 gms.

Total Co(Cal.) ----- 1.44 %

W.S. Co ----- 0.94 %

Result:

65 % Cobalt, water soluble.

TEST No. 40E

90 gms 40D reroasted at 650 C. for 40 minutes in open tray.
Final weight = 87 gms.

Total Co(Cal.) ----- 1.51 %

W.S. Co ----- 1.11 %

Result:

73 % Cobalt, water soluble.

TEST No. 40F

100 gms 40B reroasted at 625 C. for 40 minutes in open tray.

Final weight = 98 gms.

Total Co(Cal.) ----- 1.62 %

W.S. Co ----- 0.82 %

Result:

50 % Cobalt, water soluble.

TEST No. 40G

100 gms 40A plus 15 c.c. H_2SO_4 plus 5 gms H_2O , roasted at 450 C. for $1\frac{1}{2}$ hours in covered tray. Final weight = 113 gms.

Total Co(Cal.) ----- 1.34 %

W.S. Co ----- 0.60 %

Result:

45 % Cobalt, water soluble.

TEST No. 40H

100 gms 40A plus 15 gms salt, roasted at 450 C. for $1\frac{3}{4}$ hours in covered tray. Final weight = 122 gms.

Total Co(Cal.) ----- 1.24 %

W.S. Co ----- 1.00 %

Total S ----- 6.86 %

$\text{SO}_4\text{-S}$ ----- 6.54 %

Result:

81 % Cobalt, water soluble.

TEST No. 40I

100 gms 40A plus 40 gms pyrite roasted for 2 hours at 450 C.

Final weight = 110 gms.

Total Co(Cal.) ----- 1.37 %

W.S. Co ----- 0.83 %

Result:

60 % Cobalt, water soluble.

TEST No. 40J

100 gms 40A plus 5 gms Na_2SO_4 , roasted at 450 C. for $1\frac{1}{2}$ hours.

Final weight = 103 gms.

Total Co(Cal.) ----- 1.47 %

W.S. Co ----- 0.95 %

Result:

65 % Cobalt, water soluble.

TEST No. 40K

50 gms of 40G, reroasted at 625 C. for 40 minutes. Final weight = 43 gms.

Total Co(Cal.) ----- 1.56 %

W.S. Co ----- 1.12 %

SO_4 -S ----- 3.09 %

S-S ----- 0.32 %

Result:

72 % Cobalt, water soluble.

TEST No. 40L

50 gms of 40I reroasted at 625 C. for 40 minutes. Final weight = 48 gms.

Total Co(Cal.)	----	1.43 %	SO ₄ -S	----	1.21 %
W.S. Co	-----	0.86 %	S-S	-----	0.15 %

Result:

60 % Cobalt, water soluble.

TEST No. 40M

50 gms 40J reroasted at 625 C. for 45 minutes. Final weight = 48 gms.

Total Co(Cal.)	----	1.52 %	SO ₄ -S	----	2.64 %
W.S. Co	-----	1.13 %	S-S	-----	0.30 %

Result:

74 % Cobalt, water soluble.

TEST No. 40N

50 gms 40H reroasted at 625 C. for 45 minutes. Final weight = 48 gms.

Total Co(Cal.)	-----	1.29 %
W.S. Co	-----	1.16 %
SO ₄ -S	-----	6.14 %
S-S	-----	0.00 %
Total As	-----	0.40 %

Result:

90 % Cobalt, water soluble.

TEST No. 41A

2000 gms of conc., roasted in the tray at 750 C. for 65 minutes.

Final weight = 1465 gms.

SO₄-S ----- 0.06 %

S-S ----- 21.04 %

TEST No. 41B

100 gms 41A plus 15 gms salt, roasted at 450 C. for one hour and 20 minutes. Final weight = 102 gms.

Total Co(Cal.) ----- 1.18 % SO₄-S ----- 3.57 %

W.S. Co ----- 0.18 % S-S ----- 0.47 %

Result:

15 % Cobalt, water soluble.

TEST No. 42A

2000 gms of conc., roasted at 775 C. for 55 minutes. Final weight = 1180 gms.

SO₄-S ----- 0.11 %

S-S ----- 19.39 %

TEST No. 42B

100 gms 42A plus 15 gms salt, roasted for 1 $\frac{1}{4}$ hours at 450 C.

Final weight = 120 gms.

Total Co(Cal.) ---- 1.24 % SO₄-S ---- 6.00 %

W.S. Co ----- 0.91 % S-S ----- 0.32 %

Result:

73 % Cobalt, water soluble.

TEST No. 43A

2000 gms conc., roasted at 800 C. for 70 minutes. Final weight = 1155 gms.

SO₄-S ----- 0.11 %

S-S ----- 17.09 %

TEST No. 43B

100 gms 43A plus 15 gms salt, roasted for 80 minutes at 450 C. Final weight = 121 gms.

Total Co(Cal.) ---- 1.26 % SO₄-S ---- 5.90 %

W.S. Co ----- 0.91 % S-S ----- 0.25 %

Result:

72 % Cobalt, water soluble.

TEST No. 44A

2000 gms conc., roasted on furnace floor at 825 C. for 30 minutes. Final weight = 1180 gms.

SO₄-S ----- 0.12 %

S-S ----- 20.98 %

TEST No. 44B

500 gms 44A, roasted at 450 C. for 80 minutes.

Total Co(Est.) ---- 1.29 % SO₄-S ---- 3.98 %

W.S. Co ----- 0.88 % S-S ----- 0.17 %

Result:

68 % Cobalt, water soluble.

TEST No. 44C

500 gms 44B plus 25 gms salt, roasted for 60 minutes at 450 C.
and for a further 2 hours at 725 C.

Total Co(Cal.)	----	1.25	%	SO ₄ -S	----	4.20	%
W.S. Co	-----	Trace		S-S	-----	0.27	%

TEST No. 44D

500 gms 44A plus 25 gms salt, roasted in muffle for 2 hours.
Final weight = 580 gms.

Total Co(Cal.)	----	1.29	%	SO ₄ -S	----	5.21	%
W.S. Co	-----	0.97	%	S-S	-----	0.03	%

Result:
75 % Cobalt, water soluble.

TEST No. 44E

400 gms 44D, roasted at 600 C. for 50 minutes. Weight of
calcine = 387 gms.

Result:
43 % Cobalt, water soluble.

TEST No. 45A

4000 gms conc., roasted at 800 C. for 35 minutes. Weight of
calcine = 2370 gms.

TEST No. 45B

400 gms 45A plus 60 gms salt, roasted in partially covered tray
for 1½ hours at 350 C. and 1½ hours at 400 C. Weight of calcine =
524 gms.

Result:
41 % Cobalt, water soluble.

TEST No. 45C

400 gms 45A plus 53 gms Na_2CO_3 , roasted in partially covered tray at 350 C. for 3 hours. Weight of calcine = 483 gms.

Result:

18.5 % Cobalt, water soluble.

51 % Cobalt, acid soluble.

TEST No. 45D

400 gms. 45A plus 71 gms $\text{Na}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$, roasted in partially covered tray for 3 hours at 350 C. Weight of calcine = 462 gms.

Result:

24 % Cobalt, water soluble.

46 % Cobalt, acid soluble.

TEST No. 45E

400 gms 45A, roasted in partially covered tray for $2\frac{1}{2}$ hours at 350 C. Weight of calcine = 400 gms.

Result:

49.3 % Cobalt, water soluble.

TEST No. 45F

100 gms 45B, roasted at 620 C. for 45 minutes. Weight of calcine = 90 gms.

Result:

89 % Cobalt, water soluble.

TEST No. 45G

375 gms 45B, roasted at 625 C. for 45 minutes. Weight of calcine = 332 gms.

Result:

86 % Cobalt, water soluble.

TEST No. 45H

400 gms 45C, roasted at 600 C. for 50 minutes. Weight of calcine = 397 gms.

Result:

85 % Cobalt, water soluble.

TEST No. 45J

400 gms 45 D, roasted at 600 C. for 50 minutes. Weight of calcine = 392 gms.

Result:

86 % Cobalt, water soluble.

TEST No. 45K

350 gms 45E, roasted at 600 C. for 50 minutes. Weight of calcine - 330 gms.

Result:

68 % Cobalt, water soluble.

BIBLIOGRAPHY

Hayward, Carle R. - "An Outline of Metallurgical Practise".
D. Van Nostrand, 1940.

Schnabel, Dr. Carl, - Louis, Henry. - "Handbook of Metallurgy".
Second Edition - McMillan
and Co., 1907.

Liddell, Donald M. - "Handbook of Non-Ferrous Metallurgy".
McGraw Hill, 1926.

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