

FLOTATION OF SOME CARBONATE MINERALS  
WITH  
SPECIAL REFERENCE TO INORGANIC SOL DEPRESSANTS

By

SIDDHI NATH MUKHERJI

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A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master Engineer of Metallurgy.

Signed

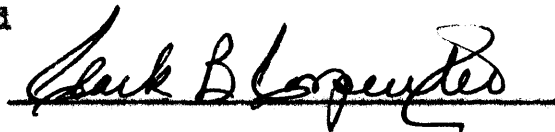


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FLOTATION OF SOME CARBONATE MINERALS  
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Introduction

Flotation as a technique has been defined as the means or process of separation of two or more minerals if they differ from each other in such a way that one contains a substantial amount of a particular metallic element or acid ion which is absent in the other. At present differential flotation of sulphides has been substantially controlled, but this is not so in the region of non-sulphide group. The selective flotation of non-sulphide minerals depends largely upon the floatability of the associated gangue minerals, whereas often in non-sulphide flotation, it makes little difference which minerals are floated and which are depressed; generally only a separation is sought.

The carbonate minerals as a class form a distinct group of non-sulphide minerals. In certain cases they have been floated individually from the silicate gangue without any trouble, but in combination with other carbonates, they behave more or less in the same way towards the ordinary flotation reagents; therefore, their separation becomes extremely difficult.

As more and more complex ores are coming into the mar-

ket, and heavy metal carbonates, in some cases, are becoming the potential ore reserves of certain metals, the knowledge of the relative floatability of carbonate minerals is becoming more and more important from the point of future economy. On the other hand, existence of a combination of two carbonates may completely ruin the ore value of one carbonate unless it is separated efficiently from the other. The existence of calcite as a gangue is a common occurrence in non-sulphide minerals, but the removal of it is a difficult problem when calcite exists in combination with other carbonate ores.

This thesis presents the results of tests carried out to determine the differences in floatability of different carbonate minerals and also to study their behavior with respect to the heavy metal oxide sols like aluminum sol in comparison with the other conventional depressants.

The carbonate minerals in general can be divided into two groups on the basis of their inherent chemical characteristics: (1) heavy-metal carbonates like cerussite, siderite, etc., and (2) alkaline-earth carbonates. Generally heavy-metal carbonates behave much as heavy-metal oxides do and so require careful treatment for effective separation. The fundamental difficulty is considered to be in producing ions of the metal at the particle surface. The alkaline-earth metal group is mainly important among industrial minerals in the cement, paint, refractory and allied industries. The flotation of the members of this

group is universally affected by soap or fatty acid reagents. The whole problem of carbonate flotation can be looked upon from two standpoints, viz., the first connected with pure beneficiation of a particular carbonate from a mixture and the second to find out a method of control by which they could be selectively depressed.

### Developments in Flotation Practice

According to Taggart (17), all dissolved reagents, which in flotation pulps, either by action on the to-be-floated or on the not-to-be-floated particles, affect their floatability, function by reason of chemical reactions of well recognized types between the reagent and the particle affected.

Wark and Cox (20) have tried to explain the principle of collection and activation in the light of adsorption phenomenon of the molecular species at the interface without giving much consideration to the stoichiometric relation of the reacting substances.

Dean and co-workers (3) postulate a detergent theory of Flotation. According to them surface-active reagents preserve, enhance, create and sometimes destroy water-repellant film, thereby influencing the flotation behavior of a particular mineral.

Sun's work (15) on cataphoresis has shown that the activation and floatability of minerals can be interpreted to some extent by means of the zeta-coefficient.

Speaking about the mechanism of collection, Taggart (18) considers that collection involves bringing about a precipitation reaction between the collector and the mineral. The function of the activators is to react with the

mineral to be floated, in such a way that the resultant salt, forming the modified surface, will react with the collector to form an adherent water-repellant film. In case of depression, the nature of the collector should be such that either it must not react with the mineral in question or any reaction product of it, or, even if there is any reaction with one of the ions of the particle, it must produce a reaction product that is not a substantially insoluble compound. Another way of achieving the desired result is to allow a third substance to form a compound with the particle surface less soluble than the reaction product of the collector with the unaltered particle surface.

Rogers (14) defines activators with respect to any particular collector as inorganic anions or cations that so alter the surface of a mineral that it can be floated more readily by that collector. The action of these ions on the mineral is not dependent upon collector's being present, and they are generally absorbed upon the surface of the minerals. From the experiment on quartz, Rogers has shown that there must be more than a certain amount of activator on the mineral surface before the latter will respond, if at all, to a given collector. The adsorption of metallic ion on quartz has been found to be by partial replacement of already adsorbed hydrogen ion.

### Progress in Carbonate Flotation

Gaudin (5) in his book on flotation has said that it has been found impossible to separate cerussite from the carbonate of the alkaline earth, manganese or iron by the use of fatty acids or soaps. When xanthates are used as collectors, the floatability of the carbonate of lead, copper, and zinc decreases in the order named. Though individually different carbonates display different reaction to flotation with soaps, the flotation behavior of a mixture results in their simultaneous flotation.

The conditions for the separation of one carbonate from another are: (a) the collector to be used must form a much less soluble compound with the metal ion in one carbonate than with that in the other, and (b) separation can proceed only at a  $p_H$  that involves no substantial solution of either carbonate. The great importance of  $p_H$  change on the flotation of calcite and also on the flotation of most polar non-metallics is evidenced by the fact that any increase in  $p_H$  value will necessitate an increase of the fatty anions for successful separation. Too great an alkalinity will inhibit calcite flotation with soap.

With lower fatty acid, the tendency of calcite to float is less. The flotation property of rhodochrosite being similar to that of calcite,  $p_H$  value has great effect, and the most favorable range is considered to be 7.5 to 9.

Chromates and phosphates are said to form insoluble coatings at the surface of cerussite and to a lesser extent at the surface of malachite. There are possibilities of using these reagents for inhibiting the lead carbonate flotation. Certain other salts which form colloidal hydroxides, can bring depression of calcite in fatty acid flotation.

Hergt, Rogers, and Sutherland (8) report that the depressant action of ferric salt has been realized in the flotation of cassiterite at  $p_H$  value between 3 and 8, and the probable explanation is considered to be the existence of colloidal hydroxide.

### Colloidal Depression

The non-selective properties of the fatty acid collectors have forced the use of selective depressors for separation of non-sulphide minerals. Colloidal substances constitute the most widely known class of depressors. They function in flotation in two ways: (1) forming watery surface coatings which prevent the flotation of the mineral particles and (2) causing dispersion of the mineral particles by attaching to their surfaces electric charges

of like polarity. Colloid substances may act as either unchanged surface coatings or electrically charged dispersing agents. This class includes metal-silicate gels, tannin or tannic acid, metal-hydroxide sols, starch, and sodium silicate.

Considering the behavior of certain metal-hydroxide sols in flotation, the following facts are worth noting. It is generally known that substances which have an extremely low solubility can easily form a stable colloidal system. The existence of a colloidal system is also highly supported by electrokinetics. Usually in the range of so-called electrical neutrality, a colloidal system becomes unstable. All stable lyophobic systems contain particles which possess some electrical charges. The charges may arise either (a) by the capture of an ion or (b) by direct ionization.

Most organic materials form negatively charged colloids with water as the dispersion medium. The complex bases and metallic oxides generally form positively charged sols in water. The nature of the positively charged micelles has been illustrated by Gartner (7) with the example of ferric hydroxide. The composition of the parti-

cle may be either  $\text{Fe(OH)}_3$  <sub>Y</sub>  $\text{Fe(OH)}_2$  <sub>X</sub> OH or  $\text{Fe(OH)}_3$  <sub>Y</sub>  $\text{Fe(Cl)}_2$  <sub>X</sub> Cl, where X and Y may represent continuous numerical series, varying over relatively wide range, i.e., not in stoichiometric units. In the first

form, the charge is by direct ionization, but in the second case it is due to the ionization of the ferric chloride which has been absorbed by the ferric hydroxide.

According to Weiser (21) alumina or ferric hydroxide sol particles maintain their charge by the help of the so-called double layer of ionic bond. Now as opposite electrical charges neutralize each other, positively charged colloid systems are flocculated by the addition of negatively charged colloid systems. The effect which is observed upon the addition of an electrolyte is the joint effect of stabilization, brought about by the like charged ions, and flocculation produced by the ions of unlike charge. Weiser has tried to show that the mechanism of a coagulation in these cases is purely an adsorption phenomenon. In this respect, he has found that there is a great similarity in the behavior of alumina sol and ferric oxide sol, when subjected to the action of neutral electrolyte.

Now, as in the case of positively charged sols, flocculation is mainly controlled by anions; the selective property can only be realized, if at all, by the proper selection of the salt with desirable qualities. Experiments carried out by Weiser on aluminum hydroxide have shown that the coagulating powers of the anions are in the decreasing order of citrate, sulphate, oxalate, acetate, and nitrate.

When dealing with a mixture of carbonates of differ-

ant metals in a flotation pulp, the formation of a depressing sol coating is somewhat like a slime coating, and the possibilities of realizing a selective property by the influence of metallic ions, as in peptization, is not very clear. On the other hand, as all the carbonate minerals do not react in the same way with heavy metal salts, selective property may be realized from the consideration of the solubility of the different reaction products. Another possibility is that when a singular carbonate is present in a mineral, it can be floated through sol coating by flocculation with suitable anions. Considering the inherent non-floatability of the carbonate minerals, there may be some way of floating one of them by the use of pure frother, taking account of the fact that the mineral in question can be flocculated, if it happens to form a preferential sol coating. The final selection, of course, will depend upon the efficiency and cheapness of the reagents in comparison with the conventional metal-silicate-sol depressants.

Minerals	Specific Gravity	Solubility in 100.	Crystal Property	
			Structure	Axial Ratio
Calcite $\text{CaCO}_3$	2.710	0.10618°	Rhombohe- dral	c-0.8543
Dolomite $\text{CaMg}(\text{CO}_3)_2$	2.8-2.9	0.03218°	Tri-rhombo- hedral	c-0.8322
Magnesite $\text{MgCO}_3$	3.0-3.12	0.0106	Rhombohe- dral	c-0.8112
Rhodochro- site $\text{MnCO}_3$	3.45-3.6	0.006505°	Rhombohe- dral	c-0.8184
Strontian- ite $\text{SrCO}_3$	3.68-3.71	0.001118°	Orthorom- bic	a:b:c .609:1:1.7239
Siderite $\text{FeCO}_3$	3.83-3.88	0.07218°	Rhombohe- dral	c-0.8134
Witherite $\text{BaCO}_3$	4.27-4.35	0.02218°	Orthorom- bic	a:b:c .604:1:1.730
Cerussite $\text{PbCO}_3$	6.46-4.57	0.0001120°	Orthorom- bic	a:b:c .6099:1:1.723

TABLE A.

Some Physical Properties of the Minerals Tested.

### Experimental Procedure

The minerals tested were cerussite, siderite, rhodochrosite, magnesite, dolomite, and witherite. Some of their physical properties are given in Table A. Some tests were also conducted on Washington magnesite sample, and also on a synthetic mixture of fluorspar and calcite, to find out the commercial possibilities of such separation.

All the samples, except rhodochrosite, were mineralogically pure and crystalline. Synthetic mixtures were made from separately ground pure minerals. Siderite, dolomite, cerussite, and witherite samples were obtained from Ward's Natural Science Establishment, Inc., Rochester, N. Y. Calcite used was from Riverside, California, and the magnesite from Luning, Nevada. Rhodochrosite supply was from Emma Mine, Butte, Montana. Some strontianite sample for wettability test was obtained from the Geology Department of the Colorado School of Mines.

All minerals used in the flotation work were dry ground in a disc pulverizer to pass through 65-mesh screen size. It was suggested by the staff of the Experimental Plant that it has been experimentally verified that in case of oxide minerals dry grinding is equivalent to wet grinding. All flotation tests were done on 500-gram samples in a laboratory-type Denver Sub-A flotation machine.

The principal reagents used throughout the tests, either alone or in combination, were naphthenic acid as

collector and frother and a commercial grade of technical aluminum sulphate as inorganic depressant. Selection of these reagents was based on the successful practice of Basic Magnesium, Inc., at their plant in Luning, Nevada. There naphthenic acid, in combination with aluminum sulphate, was found to be a very useful reagent in the selective flotation of magnesite from dolomite. The function of the aluminum salt was considered to be the same as the depressing action of ferric sol. As regards the selection of other reagents, it was mostly done to show the difference in behavior and results between aluminum sulphate and other conventional depressing agents like quebracho, silicic acid, and the like.

Whenever possible, influence of  $p_H$  variation was recorded to show the effect of such variation with respect to some particular reagent. The effect of each test was determined by chemical analysis, and a metallurgical balance was made up to check the analysis with the head sample of the mixture.

As the tests were carried out to demonstrate trends in the field of carbonate flotation rather than specific possibilities of commercial application, no recleaning of products was done. Another reason for following this procedure was the limited time available.

#### Determining Floatability

The relative floatability of the different carbonates

was obtained from the flotation test results carried out on synthetic mixtures with naphthenic acid alone as a collector and frother. The results in each case show the natural tendency of one mineral to float ahead of the other. As most of the flotation tests were carried out on synthetic mixtures having calcite or dolomite as one of the constituents, some wettability tests were conducted on dry mineral samples to bring out any possible link between the floatability of a mineral and its other physical properties. These tests were carried out as suggested by Mr. Patek (12) in his test on silicate minerals.

When wettability is expressed in terms of contact angle  $\theta$ , which represents the tendency of a particular liquid at a particular mineral surface to cohere or contract, the lesser the value of  $\theta$ , the greater becomes the wettability. In the case of silicate or oxide minerals, which are considered normally wettable, it is very difficult to measure the contact angles by means of bubble attachment tests, as suggested by Taggart. One of the simplest ways of comparing their wettability has been found to be by taking contact angle readings with drops of the liquid on dry, clean, flat, and ground but unpolished mineral surfaces in the presence of air. Though many arguments have been put forward against the exposure of the mineral surface to the air during the test, most of the reasonings are worth noting only in case of sulphide minerals.

The method adopted to measure the wettability was as

follows: Minerals were ground wet on a sandstone wheel to produce a smooth surface. They were then cleaned, first with distilled water and next with ether, and dried. A drop of water was placed on the flat dry mineral surface, shaken to equilibrium, and photographed after 2 minutes. Pictures are shown in Plates 1 to 3. The angles were measured from the photograph with a protractor. The final value was taken from the mean of the angles measured at both ends of the drop. The values of the different angles obtained for different minerals, together with the results obtained by flotation tests, are recorded in Table B in the decreasing order of floatability.

Another series of tests as suggested by Mudd and Mudd (9) was conducted to determine the relative wettability of mineral particles. This method suggested the use of mineral particles suspended in water and placed on a microscopic slide. A drop of oil was placed near the water drop, and the movement of the oil-water boundary was studied under a microscope in dark-field illumination after placing a cover slip over the combination. The progress of the oil-water interface through the particles, with or without distortion, and the existence of the particles inside the oil phase, with or without any water film attached to them, gave a sound idea of the wettability of the minerals, consistent with the results obtained by the other method.

Minerals	Contact Angle Measured	Average Contact Angle	Floatability According to Float Test
Magnesite	63,65°	64°	Magnesite
Rhodochrosite	58,62°	60°	Rhodochrosite
Calcite	54,56°	55°	Dolomite
Siderite	55,57°	56°	Siderite
Witherite	51,49°	50°	Calcite
Strontianite	49,51°	50°	Witherite
Dolomite	46,48°	47°	Strontianite
Cerussite	28,30°	29°	Cerussite

TABLE B.  
Relative Floatability.

### Flotation Tests and Results

As the whole idea of using naphthenic acid as the flotation reagent in carbonate flotation originated from the practice of Basic Magnesium, Inc., on Nevada magnesite, the first series of tests was carried out on a sample of Washington magnesite. The only difference in the experimental conditions in this case was the presence of a certain amount of talc in the sample. This was removed by floating it ahead of magnesite by the use of alcohol. Test results are recorded in Table 1. Results of this test definitely proved the usefulness of naphthenic acid in carbonate flotation and also the depressing action of aluminum sulphate on calcite.

Tests on Magnesite-Calcite Mixture.--A synthetic mixture was made of pure magnesite from Luning, Nevada, with calcite from Riverside, California, in the proportion of 5:1. In all tests, before any other flotation reagents were added, test pulp was conditioned with aluminum sulphate for five minutes, except in case of Test 1, which was used to determine the natural floatability of the minerals with respect to pure naphthenic acid alone. The pH readings were made colorimetrically. Experimental results are reported in Table 2. It was quite apparent from the test results that normally, with naphthenic acid, there was a natural tendency of the magnesite to float ahead of calcite. This tendency has been found to be accentuated by the addition of calcite depressants like aluminum sul-

phate. As regards the influence of  $p_H$  control, lowering of  $p_H$  by the addition of sulphuric acid helped to produce a better grade of concentrate.

Tests on Magnesite-Dolomite Mixture.--A synthetic mixture was made of the pure Nevada magnesite with white crystalline dolomite. Five minutes conditioning time was allowed in each case as before, except in case of Test 1.  $p_H$  readings were taken as usual. Results are reported in Table 3. From the experimental results, it was found that under experimental conditions dolomite behaved more or less in the same way as calcite with respect to magnesite, but the depression of dolomite was a little more difficult than that of calcite. In another group of tests with dolomite-calcite mixture, it was found extremely difficult to separate dolomite from calcite by flotation.

Tests on Witherite-Dolomite Mixture.--A synthetic mixture was made of the pure crystalline witherite with dolomite sample. Conditioning time was 5 minutes as before. Test W1 was made with naphthenic acid alone. Test W2 was made with ferric chloride to bring out any possible differences in its depression action as compared to that of aluminum sulphate. Test results are recorded in Table 4. Quite contrary to expectation, dolomite floated ahead of witherite even with pure naphthenic acid. This tendency was also found to be increased by the use of either ferric chloride or aluminum sulphate. Experimental results have

also shown that, so far as the depression of witherite is concerned, ferric chloride is a comparatively weaker reagent than aluminum sulphate. High insolubility of barium sulphate might have some influence on bringing out this type of result.

Tests on Cerussite-Calcite Mixture.--A synthetic mixture was made of pure cerussite sample with crystalline calcite in the proportion of 1:4. Flotation was first tried with naphthenic acid and then with a combination of both naphthenic acid and aluminum sulphate, but in both cases there was practically no flotation of cerussite. Even calcite, except for a certain amount of slime, could not be floated from this mixture. Other reagents, like oleic acid, have also been tried, but with no success. Tests C2 and C3 were carried out by the process of sulphidization, using sodium sulphide and xanthate as the flotation reagents, in presence of either naphthenic acid or a pure frother like cresylic acid. Results are recorded in Table 5. From the experimental results, it was quite apparent that, under the experimental conditions, cerussite was totally inert towards normal fatty acid reagents. Sulphidizing was found to be the only means for the successful separation of cerussite from calcite.

Tests on Rhodochrosite-Calcite Mixture.--A synthetic mixture was made of rhodochrosite sample from Emma Mine, Butte, Montana, with crystalline calcite in the proportion

of 1:2. This rhodochrosite sample contained about 10 per cent insoluble material. Some tests were carried out with the rhodochrosite sample alone, and it was found that rhodochrosite was very easily floatable with naphthenic acid. Results are recorded in Tables 6 and 6A. With the mixture, Test R1' was conducted using quebracho and sodium silicate as depressants, to compare the results with those of Test R2', in which aluminum sulphate was used as depressant. Experimental results definitely proved the efficiency of aluminum sulphate. It was also found from the other group of tests that aluminum sulphate acted quite efficiently, like other silicate depressants, with respect to the insoluble materials present in the sample. The depressing power of aluminum sulphate was decreased when sodium citrate was added to bring about the flocculation of the aluminum sol.

Tests on Siderite-Calcite Mixture.--A synthetic mixture was made of the pure crystalline siderite with calcite, in the proportion of 3:1. In this particular mixture, even 65-mesh grinding produced considerable slime trouble. Experimental results are recorded in Table 7. It was apparent from the results of Test S1 with pure naphthenic acid that the relative floatabilities of siderite and calcite were nearly the same. The use of aluminum sulphate was quite effective in floating the siderite ahead of calcite, but a high-grade product could not be produced

from the mixture. By the use of other electrolytes, like lead nitrate or copper sulphate, it was possible to reverse this tendency and float calcite ahead of siderite.

Tests on Fluorspar-Calcite Mixture.--These tests, though not within the narrow scope of the original problem, were carried out to investigate the possibility of the practical application of aluminum sulphate to depress calcite. Pure crystalline fluorspar and calcite were mixed in the proportion of 5:1. Results are recorded in Table 8. The results show that aluminum sulphate is superior to other depressing agents like quebracho or sodium silicate.

### Conclusion

From the results obtained by the preceding investigations, it may be concluded that, with naphthenic acid as the flotation reagent, there is a definite individual flotation characteristic of each carbonate mineral. Some are easily floatable, and some do not respond to fatty-acid flotation at all. Dolomite, being a complex carbonate, behaves somewhat differently than other carbonates, as regards its wetting property. No relation whatsoever has been found between the floatability and the density or solubility of the different carbonates. It is quite apparent from the experimental results that the eight minerals tested could be arranged in the order of increasing floatability as follows: cerussite, strontianite, witherite, calcite, siderite, dolomite, rhodochrosite, and magnesite. This gives a rough idea of the probability of effectively separating one mineral from the other, when the two are widely apart in the series. It is possible that on specific ores or mineral combinations other promoters, such as oleic acid, linseed oil, and fish oil soap used in combination with aluminum sulphate, might give improved results. Investigation of these variables did not fall within the scope of the present investigation.

Comparing the role of inorganic sols, like aluminum and iron in carbonate depression, it is to be said that, under experimental conditions, aluminum sol has been found

to be more effective than iron sol. The flotation of rhodochrosite from a mixture of rhodochrosite and calcite has been found to be feasible, when aluminum sulphate, together with naphthenic acid, are used as reagents. Comparative results with other depressants like tannic acid or sodium silicate, have shown that, in all cases, aluminum sulphate is more useful from the point of view of overall efficiency. There is, however, one disadvantage in the use of inorganic sols; that is, these being positively charged are usually not influenced by ordinary electrolytes. As an experimental verification of flocculating phenomenon, sodium citrate was used in one case, and the result obtained was as expected.

Another interesting correlation has been found in connection with the depressing action of aluminum sulphate, between the flotation of a certain carbonate, in the presence of aluminum sulphate, and the solubility of the sulphate of that metal, assuming the reaction product in all cases to be a sulphate. When the sulphates of different metals, whose carbonates have been tested, are arranged in order of increasing solubilities, they are barium, lead, strontium, iron, calcium, manganese, and magnesium. These, except barium and dolomite, are in close agreement with the series predicted by the experimental results, the metals forming the more soluble sulphates being less influenced by the depressing action of aluminum sulphate.

The results of tests on rhodochrosite from Emma Mine,

and fluorspar-calcite mixture, were very encouraging from the standpoint of successful depression of carbonates as well as silicate gangue mineral by means of aluminum sulphate.

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### Summary

1. Naphthenic acid has been found to be a good collector, comparable to oleic acid in carbonate flotation.
2. Aluminum sol behaves more or less in the same way as iron sol, in depressing carbonates. In some cases, however, aluminum sol has been found to be more useful.
3. Compared with other common organic depressants, aluminum sol is more effective for good recovery.
4. Cerussite could not be floated with naphthenic acid.
5. In presence of naphthenic acid, each carbonate shows individual preferential flotation characteristic. When arranged in order of decreasing floatability, they are magnesite, rhodochrosite, dolomite, siderite, calcite, witherite, strontianite, and cerussite.
6. The preferential action of aluminum sol in depressing carbonates, in most cases, has been found to be controlled by the solubilities of the sulphates formed, if it is assumed that the reaction between aluminum sulphate and the various carbonates is a simple chemical reaction.
7. Certain electrolytes (lead and copper salts) have shown the property of reversing the natural floatability order of certain carbonates when added in the flotation circuit, as observed in the case of siderite-calcite mixtures.

Table I. - Tests on Washington Magnesite Sample

Test No.	Product	Metallurgical Results (Per cent)					PH	Talc Float from Raw Feed
		Weight	Insol R <sub>2</sub> O <sub>3</sub>	MgO	CaO	Recovery MgO		
	Raw feed	100.0	6.02	40.2	5.22			
1.	Concen- trate	68.5	4.96	43.2	2.36	73.60	8.2	7%
	Tailing	24.5	6.68	38.9	9.93	23.45		
2.	Concen- trate	68.3	4.50	43.6	2.39	74.00	8.0	7%
	Tailing	24.7	6.36	37.24	8.62	22.60		
3.	Concen- trate	68.0	4.70	42.2	3.72	71.30	8.0	7%
	Tailing	25.0	5.08	40.03	6.06	24.90		
4.	Concen- trate	70.0	3.72	43.9	2.16	76.40	8.1	7%
	Tailing	23.0	7.64	36.45	9.08	20.60		
5.	Concen- trate	64.0	4.46	43.1	2.77	68.00	8.2	-
	Tailing	36.0	8.48	35.8	9.20	32.00		

## Reagents Consumption, Lbs. per ton

Test No.	Naph- thenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Tetra-sodium Pyro-phosphate	Starch	Silicic Acid	PH
1.	0.62	10.0	-	-	-	8.2
2.	0.45	10.0	-	0.8	-	8.2
3.	0.70	-	-	0.8	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> - 10.0	8.0
4.	0.45	10.0	1.0	0.8	1.5	8.0
5.	0.80	10.0	1.0	0.8	H <sub>2</sub> SO <sub>4</sub> -2.0, 1.5	7.8

Table II. - Tests on Magnesite-Calcite Mixture

Test No.	Product	Metallurgical Results (Per cent)				Reagents, Lb. per ton Feed				
		Weight	MGO	CaO	Recov. MGO	PH	Naph-thenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	NaOH	Other
	Raw feed	100.0	40.10	9.15	100.0					
M1	Concen- trate	68.0	43.30	5.30	73.6					
	Tailing	32.0	32.5	17.90	26.0	10.0	0.45	-	-	-
M2	Concen- trate	62.0	44.5	3.90	69.0					
	Tailing	38.0	32.3	18.25	30.6	8.2	0.45	10	-	-
M3	Concen- trate	65.6	45.7	2.40	75.0					
	Tailing	34.4	30.7	20.10	25.4	7.1	0.53	10	-	H <sub>2</sub> SO <sub>4</sub> 2
M4	Concen- trate	63.7	44.7	3.65	71.0					
	Tailing	36.3	32.0	18.60	28.8	9.8	0.36	10	2	-

Table III - Tests on Magnesite-Dolomite Mixture

Test No.	Product	Metallurgical Results				PH	Reagents, Lb. per ton			
		Weight	MGO	CaO	Recov. MGO		Naphthenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	NaOH	Other
	Raw feed	100.0	41.40	7.55	100.0					
MD1	Concen- trate	63.2	43.40	5.25	67.7	9.4	0.25	-	-	
	Tailing	36.8	34.6	15.50	30.7					
MD2	Concen- trate	68.0	44.0	4.50	72.4	8.2	0.25	10.0	-	
	Tailing	32.0	35.8	14.00	27.6					
MD3	Concen- trate	55.6	44.5	3.90	60.0	9.3	0.25	10.0	4	
	Tailing	44.4	37.1	12.50	39.9					

Table IV - Tests on Witherite-Dolomite Mixture

Test No.	Product	Metallurgical Results (Per cent)				PH	Reagents, Lb. per ton Feed			
		Weight	BaO	MgO-CaO	Recov. BaO		Naphthenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	NaOH	Other
	Raw feed	100.0	36.54	25.36	100.0					
W1	Concen- trate	70.0	33.19	29.10	63.6	9.2	0.25	-	-	
	Tailing	30.0	44.10	22.50	36.2					
W2	Concen- trate	62.5	28.59	32.30	49.0	8.0	0.45	-	FeCl <sub>3</sub>	
	Tailing	37.5	49.27	15.98	50.2				8	
W3	Concen- trate	64.3	25.91	33.00	45.7	8:1	0.36	8	-	
	Tailing	35.7	55.23	12.68	54.0					

Table V - Tests on Cerussite-Calcite Mixture

Test Products No.	Metallurgical Results (Per cent)				Reagents, Lb. per ton feed		
	Weight	Pb	CaO	Pb Recovery	Naph-thenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Others
Raw feed	100.0	10.6	37.40	100.0			
C1* Concntrate	-	-	-	-	0.8	-	-
C1* Tailing	-	-	-	-			
C2 Concntrate	22.0	34.46	27.15	71.5	-	-	Z <sub>6</sub> -0.4
C2 Tailing	88.0	3.40	40.35	28.2			Na <sub>2</sub> S-1.5 Cresalyc Acid- 0.5
C3 Concntrate	65.0	16.21	35.05	99.4	0.25	15	Z <sub>6</sub> - 0.4
C3 Tailing	35.0	1.48	42.40	0.05			Na <sub>2</sub> S - 1.5

\* In this particular case, it was found to be impossible to float PbCO<sub>3</sub>, even in minute quantities. Other reagents like oleic acid and sodium oleate were also tried, but in every case the floated mineral was fine calcite.

Table VI - Tests on Rhodochrosite, Emma Mine, Butte, Montana

Test No.	Metallurgical Results (Per cent)				Reagents, lb. per ton feed		
	Weight	Mn	Insol	Mn Recovery	Naphthenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Others
	Raw feed	100.00	38.42	10.50	100.0		
R1	Concen- trate	41.0	40.47	5.07	43.0	1.35	Silicic acid - 2 lb./ton
	Tailing	59.0	37.14	14.00	57.0		
R2	Concen- trate	70.0	41.45	3.27	75.5	0.95	Silicic acid - 1 lb./ton
	Tailing	30.0	31.26	26.72	24.4		
R3	Concen- trate	59.0	41.65	2.82	63.96	0.70	Silicic acid -1 lb/ton Al(NO <sub>3</sub> ) <sub>3</sub> - 8 lbs/ton
	Tailing	41.0	33.38	22.22	35.60		
R4	Concen- trate	37.0	40.78	4.18	39.27	1.35	Sodium citrate - 4 lb/ton
	Tailing	63.0	36.46	15.56	59.78		

Table VIA - Tests on Rhodochrosite (Impure)-Calcite Mixture

Test No.	Metallurgical Results (Per cent)					Reagents, lb. per ton Feed		
	Weight	Mn	Insol	CaO	Mn Redovery nlc Acid	Naphthe- Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Others	
	Raw feed	100.00	32.06	7.64	4.82	100.0		
R1	Concen- trate	38.00	38.32	3.56	3.20	45.42		Quebracho - 1 lb./ton
	Tailing	62.00	28.23	9.22	9.30	54.58	1.35	Na <sub>2</sub> SiO <sub>3</sub> - 2 lb./ton
R2	Concen- trate	44.00	40.43	1.68	1.20	55.48		
	Tailing	56.00	25.48	13.42	13.60	44.50	0.70	10

Table VII - Tests on Siderite-Calcite Mixture

Test No.	Metallurgical Results (Per cent)				Reagents, lb. per ton Feed			
	Weight	FeO	CaO	FeO Recovery*	PH	Naphthenic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Others
	Raw feed	100.00	38.29	11.25	100.0			
S1	Concentrate	47.6	38.45	10.25	47.8			
	Tailing	52.4	36.65	12.20	50.0	9.3	0.45	
S2	Concentrate	70.0	39.98	9.30	73.1	9.4	0.45	NaOH - 2 lb/ton
	Tailing	30.0	34.34	14.75	26.9			
S3	Concentrate	39.8	36.91	11.10	38.1	9.3	0.55	PbNO <sub>3</sub> - 8 lb/ton
	Tailing	60.2	39.28	10.90	61.7			
S4	Concentrate	40.0	37.04	12.45	38.7	9.1	0.45	CuSO <sub>4</sub> - 6 lb/ton
	Tailing	60.0	38.45	10.50	60.3			

\* Even in 65-mesh grinding, there was too much slime trouble. Hence, desliming was carried out to some extent.

Table VIII - Tests on Fluorspar-Calcite Mixture

Test No.	Products	Metallurgical Results (Per cent)				Reagents, lb. per ton Feed		
		Weight CaF <sub>2</sub>	CaO	CaF <sub>2</sub> Recovery	PH	Nephthelic Acid	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Others
	Raw feed	100.00	84.14	8.88	100.0			
F1	Concntrate	70.0	90.44	5.35	75.32		10	
	Tailing	30.0	68.30	17.19	24.68	8.0	0.55	
F2	Concntrate	38.4	92.25	4.34	42.10	7.8	1.10	Quebracho-- 1 lb/ton
	Tailing	61.6	79.00	11.76	57.83			
F3	Concntrate	56.0	89.74	5.74	59.72	9.0	0.85	Sodium silicate 1 lb/ton
	Tailing	44.0	76.69	13.05	40.15			
F4	Concntrate	58.0	90.60	5.26	62.45	7.8	0.45	CaCl <sub>2</sub> - 2 lb/ton
	Tailing	42.0	75.24	13.86	37.55			

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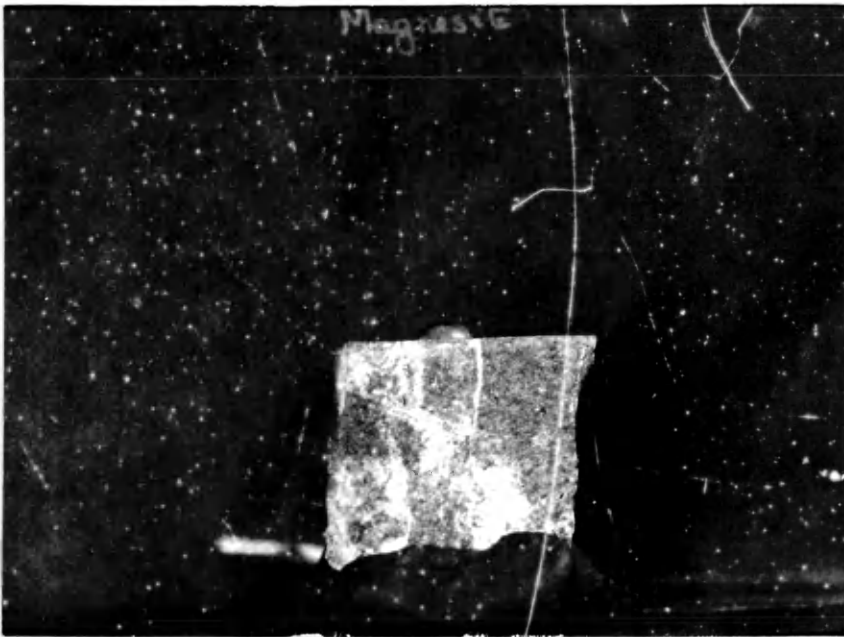


Plate I - Showing the shape of a water drop on the magnesite sample

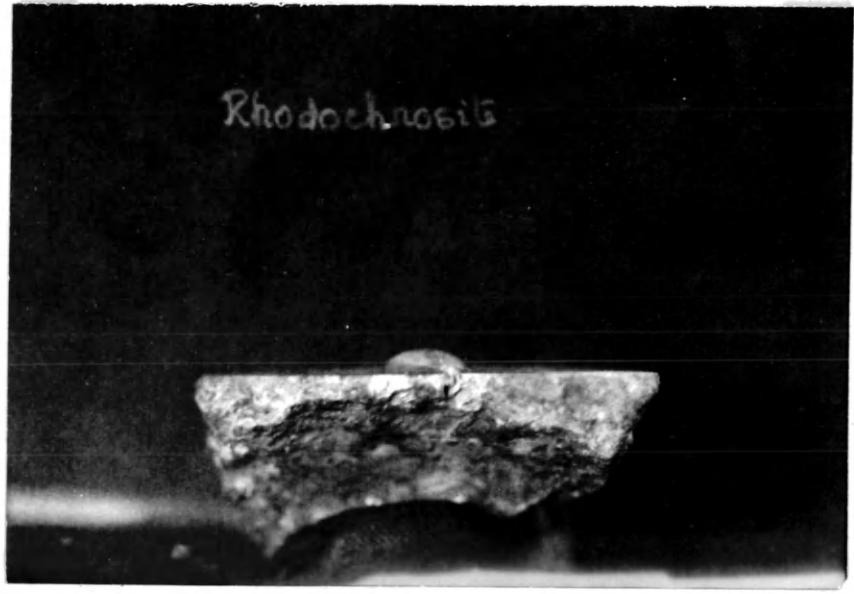


Plate II - Showing the shape of a water drop on the rhodochrosite sample

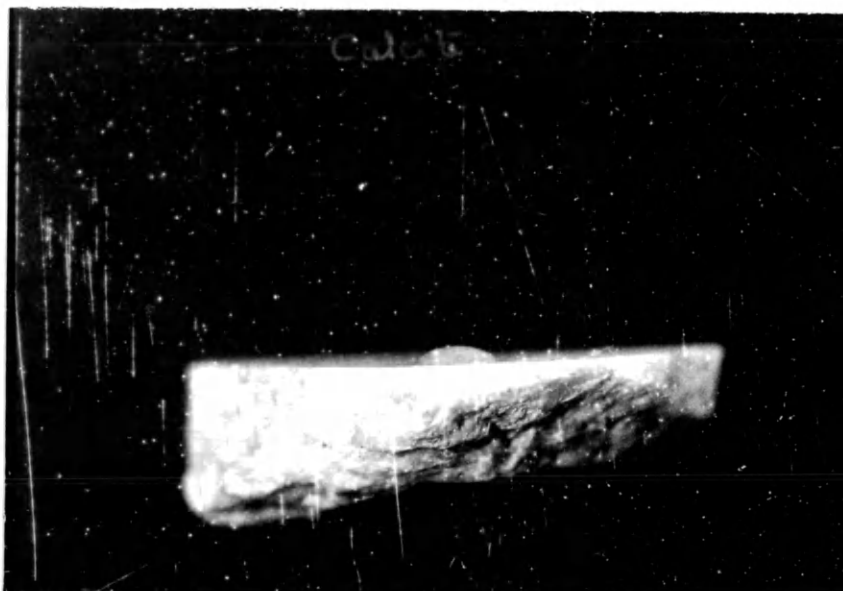


Plate III - Showing the shape of a water drop on the calcite sample.

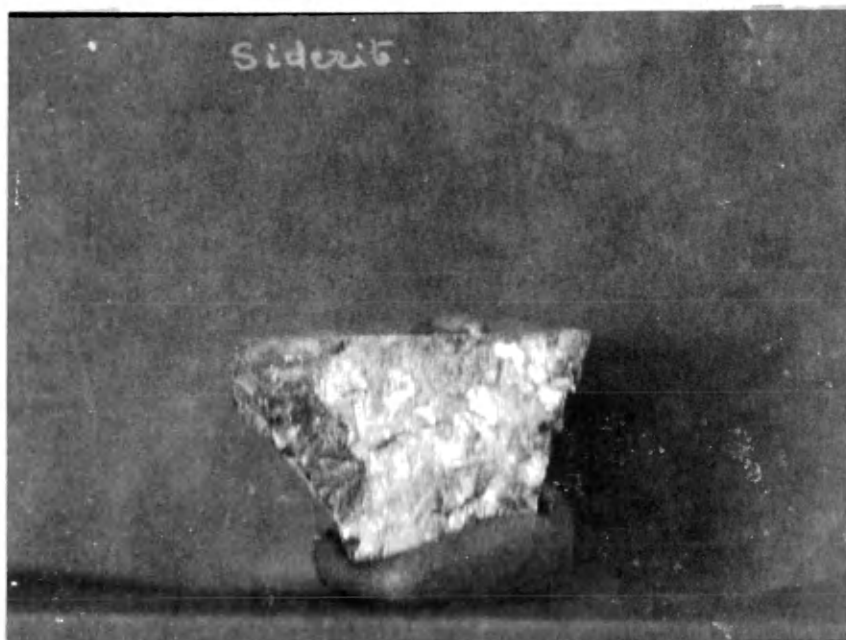


Plate IV - Showing the shape of a water drop on the siderite sample

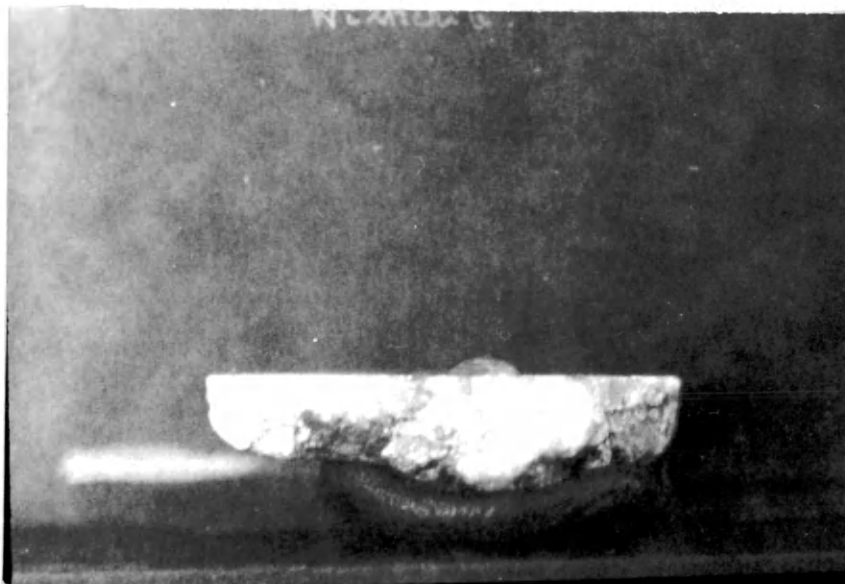


Plate V - Showing the shape of a water drop on the witherite sample

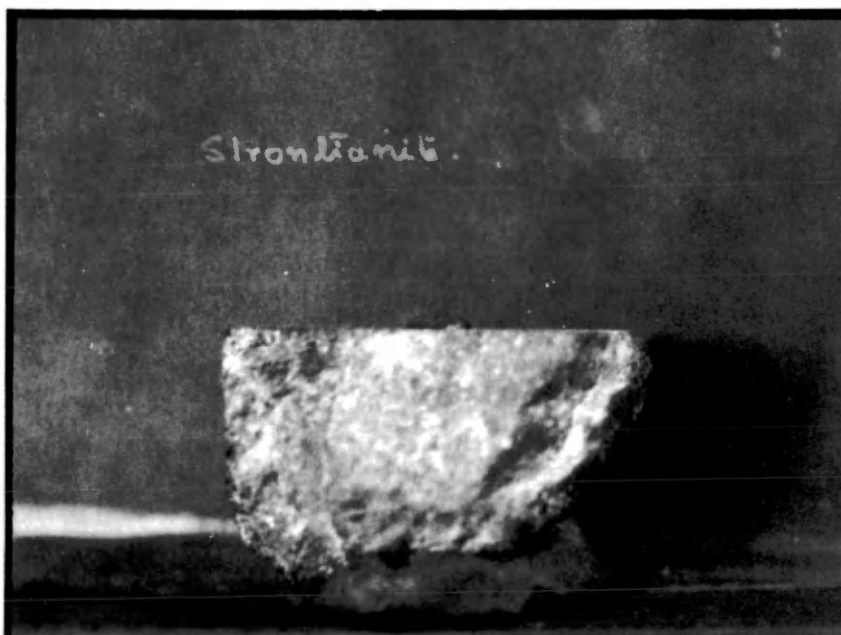


Plate VI - Showing the shape of a water drop on the strontianite sample

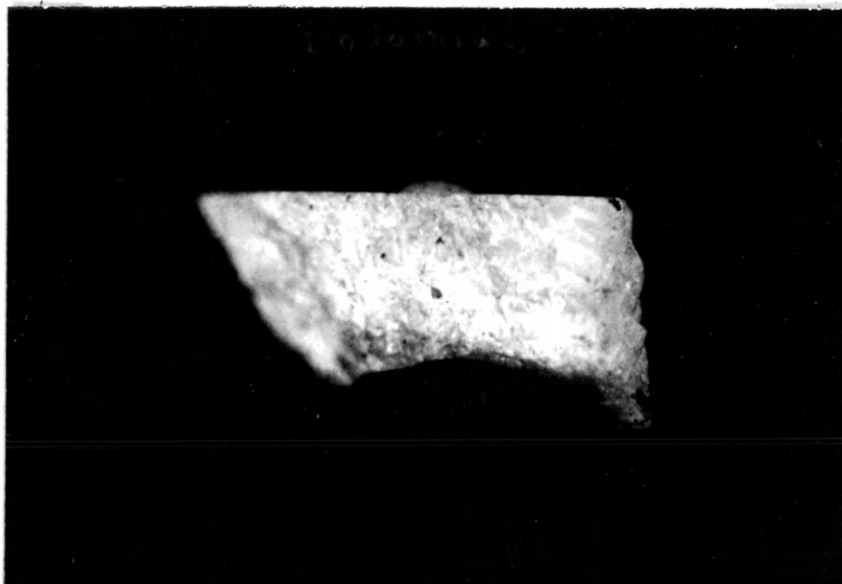


Plate VII - Showing the shape of a water drop on the dolomite sample



Plate VIII - Showing the shape of a water drop on the cerussite sample

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