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Signed

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A PRELIMINARY STUDY OF BASIC OPEN-HEARTH SLAG CHARACTERISTICS AND THE CORRELATION BETWEEN THEM AND THE CORRESPONDING BATHS

INTRODUCTION

It has long been recognized that the type and characteristics of a slag in metallurgical practice is probably the most important factor in determining the nature of the bath beneath it. This is particularly true in the case of steel making, which consists of the controlled elimination of such impurities as carbon, phosphorus, silicon, manganese, and any others which may be present in the ore or the pig iron or the scrap which is charged into the steel making furnace. As a heat progresses and this elimination proceeds, the composition of both the slag and bath are constantly changing and the impurities are transferred from the bath to the slag in which they are retained and by means of which they are finally removed.

In steel making, the removal of these impurities from the metal is accomplished by oxidation and the slag is an oxidized and oxidizing medium which contains these impurities and prevents them from reentering the bath. The active ingredient in both the slag and the metal by which this oxidation is accomplished is FeO which acts as a carrier for the oxygen and makes it available to the impurities in the bath.

Basic open-hearth steel slags vary over a wide range of composition and the result of this variation is a fairly wide range of variation in physical properties and general characteristics of the slag. In spite of these variations there are seven general conditions to which a basic open-hearth slag must conform, and the slag which most nearly meets these conditions and is yet within the range of economic feasability is the one which should be used.

The seven general conditions which a basic open-hearth slag must meet are as follows:

1. The slag must be sufficiently basic to prevent the dissociation of 3 $CaO-P_2O_5$ by carbon or by SiO_2 in the slag.
2. It must not be too silicious, otherwise the bottom will be attacked.
3. It must absorb and retain the impurities removed from the bath. Mn, P, and Si.
4. It must be sufficiently fluid to allow contact between metal and slag.
5. It must be sufficiently oxidizing to cause the chemical reactions to go to completion.
6. It must protect the bath from superoxidation from the flame.
7. It must conduct heat from the flame to the bath on the hearth of the furnace.

One of the important problems in open hearth steel making is the removal of sulfur, particularly with reference to the part played by manganese. This action is, at best, very problematical and uncertain, for in some heats considerable quantities of sulfur are removed, while in others there is practically no removal of sulfur. There is at present no means of estimating the amount of sulfur which will be removed in any given heat, and for this reason it is always desirable to use low sulfur materials in open hearth charges, both basic and acid.

Basic open hearth steel slags, with which this paper is concerned, are composed of SiO_2, P_2O_5, CaO, FeO, Fe, Fe_2O_3, MnO, MgO, and Al_2O_3, with varying, but for our purposes, insignificant amounts of minor impurities. The exact nature of the chemical tie-ups between

these various constituents in the slag is not definitely known, nor can it be easily determined. In addition to this fact the distribution of the various phases in each other is likewise very much a matter of conjecture.

It is the object of this paper to pave the way for a detailed study of the constitution of open-hearth slags and the correlation of them with the baths which they cover. No attempt has been made to settle the question or even to state definite conclusions with regard to these studies, but it is hoped that work herein outlined and the material accomplishments which have been made will stimulate interest in the subject and serve as a foundation upon which valuable work may subsequently be based.

METHODS USED IN THE EXAMINATION

This work consists of a study of four typical open-hearth heats. Two of these heats are from a western steel company, the Colorado Fuel & Iron Corporation at Pueblo, Colorado; and two are from a midwestern steel company, the South Chicago works of the Carnegie-Illinois Steel Corporation in South Chicago, Illinois.

Three samples were taken during the progress of each of these heats. The first in each case was taken at the flush off period and represents the flush off slag. The second sample in each of the heats was taken during the melting period and after most of the lime had come up as may be seen from the analyses. The third samples were taken at the end of the heat and represent the slag on the bath at the time of tapping the furnace. A sample of the metal bath was taken at the same time each of the slag samples was taken.

A portion of each of the twelve slag samples was ground down carefully in a disc pulverizer to -200 mesh for chemical analysis. The portion which was so ground was, as nearly as possible, just half of the original sample and was taken so as to be representative of the whole sample in the event there might be variations in composition of the sample. Chemical analyses were run on these samples for SiO_2, P_2O_5, CaO, Total Fe, FeO, Metallic and water soluble iron, MnO, MgO, and Al_2O_3. The percent Fe_2O_3 was calculated from the total iron by deduction of the FeO and the metallic iron.

A second portion of the samples were prepared as thin-sections for examination with a petrographic microscope. Two representative thin sections were prepared from each of the slags samples from the Carnegie Illinois Steel Works. These sections were taken from different parts of the sample to check for variations in composition and structure. Three sections were prepared from each of the samples from the Colorado Fuel & Iron Company, in the same way and for the reasons as before.

The remainder of each of the samples was retained and polished for examination with the metallographic microscope. In the metallographic examination both direct reflected and oblique lighting were used. Because of the relief caused by the polishing operation, the oblique lighting proved to be much more satisfactory than the direct reflected lighting.

The steel samples were drilled for analysis by first removing the outside layer of the sample to avoid contamination and then taking drillings made by slow drilling with a high-speed tool steel drill. The holes from which these drillings were collected

were evenly distributed over the sample to allow for segregation in the sample. The steels were analyzed for silicon, manganese, carbon, sulfur, and P_2O_5.

DESCRIPTION OF EXAMINATION AND FACILITIES USED

The chemical analyses of the slags are shown in tabulated form on page No. Sixteen. These analyses were performed at the Colorado School of Mines Experimental Plant laboratories and were carried out with as much care and precision as was possible. As may be noticed, the total in many cases is over 100%. The source of this error is not quite clear. It is possible that it is in the determination of either silica or alumina or possibly both, although the alumina was run by different methods for a check on this. The figure given in the table for Fe_2O_3 is the figure obtained by deducting the metalic iron and the FeO converted to metalic iron, from the total iron and then converting this in turn to Fe_2O_3 as was stated above. It is of interest to notice the much higher percentage of lime in the slags from the Colorado plant then in those from the Chicago plant.

The supplementary table of analyses following the one just mentioned gives the analyses sent by the plant chemist at the C.F.&I. plant. The discrepancy between these figures and those obtained in the school laboratory is significant but not alarming. These figures were used to check against when the samples were run and could not be duplicated. The more accurate figures are probably those in the first table.

The table on page 17 following the tables of analyses gives the calculations and figures for the lime distribution according to Herty's formulas in which it is assumed that the silica is present as di-

calcium silicate, $2CaO \cdot SiO_2$ and the P_2O_5 is present as tri-calcium phosphate $3CaO \cdot P_2O_5$. This method of determining the excess lime gives a relative number only since in many cases a negative basicity is obtained where ther has been reroval of phosphorus, hich is impossible except in the presence of free CaO. The reason for this apparent error is that the degree of dissociation of the $2CaO \cdot SiO_2$ could not be determined and thus it is possible to have a higher actual basicity than that indicated by the calculations on this basis. In addition to this the true absolute excess lime could not be determined unless the formation of lime iron oxide compounds, ferrates and ferrites, in the slag were taken into account. For these reasons the figures on excess lime as given should be used only as numbers indicating the relative basicity of the slags and not as absolute values.

The thin sections were prepared as stated above and studied with the petrographic microscope. Photographs were taken of representative fields with ordinary light and also with polarized light between crossed nicol prisms. These photographs are shown in each case as the second and third photographs on each of the pages of photographs.

The microscope used for this work is a Bausch and Lomb instrument loaned to the department for this work by Dr. Underhill of the Mining Department. The camera used is an old model put out by "Sauveur and Boylston." It consists of a heavy base with a clamp arrangement for mounting the microscope in an upright position under the bellows of a vertical camera. There is a track and clamp for holding the light source for the microscope. For this work a carbon arc was used and the rays concentrated and rendered parallel by passing them through a series of lenses. Alternating current at a voltage of 220 was used

for the arc between two six millimeter cored carbons. This arrangement gave a very steady and even light quite ideal for the examination and photographing of the thin section samples.

The microscope and camera were set to give a magnification of 130 diameters. This magnification was checked by means of a ruled scale of .01 and .1 millimeter divisions which was photographed and measured. To duplicate results with the same microscope the number 1 eyepiece and the 2/3 objective should be used and the bellows of the camera extended to the division marked "50" on the vertical scale. With the light as described on exposure of about 10 - 15 seconds on a "Hammer Ortho Dry" Plate (Exfast) is approximately right with most sections.

In making these photomicrographs exactly the same field was photographed with the ordinary and polarized light and these are mounted so that they may be easily compared. As may be noticed there is only one photograph for each of the first six samples. These are the samples from the Carnegie Illinois Steel Works and the field shown in each case except No. 4 is representative of the whole sample. In the photomicrographs of No. 4 the typical field is similar to that shown for number 1 and the one which is shown was taken to show a stringer of undissolved di-calcium silicate a number of which may be seen throughout the samples of both number 1 and number 4. These six slags are for the most part very uniform in structure and in this respect are quite different from the samples from the Colorado Fuel & Iron Company.

In order to show the variations in the structure of the western slags it was necessary to take several photomicrographs, of them showing various fields. Samples number 7 and number 10, marked "On

lime ends and middle", are quite uniform and as with the first six, required but one field to show the typical and average structure. With samples number 8 and number 11, marked, "Not Quite Clear", these show considerable variation throughout the samples and this is shown in the various photographs for these samples.

The first two photographs of sample number 8 and both of the photographs of sample number 11 show fields which represent approximately 50% of the sample in each case. The third photograph of sample number 8 shows an inclusion in the main part of the slag which is distinctly different from any of the rest. There are several of these areas and together they constitute about 5% of the total sample.

Samples number 9 and number 12 likewise are composed of two main structures each of which comprises approximately 50% of the sample. One of the three pictures in each case shows the distinct division between the two structures. Close examination of the second structure shown for sample 9 will reveal small inclusions of iron between, and in some cases, within, the rounded grains of the major slag constituent. In this particular constituent and within this particular structure is the only place where these inclusions of iron were found.

The third picture of each of the samples is one taken with oblique reflected light. In each case care was taken to obtain a field which corresponded as nearly as possible to the field photographed with the transmitted light. For those samples of which several photographs were taken from the thin section corresponding photographs were taken of the opaque specimen. The same magnification was used for these photographs as was used in photographing the thin sections.

The camera used for photographing the opaque specimens is a horizontally mounted Bausch and Lomb metallographic microscope and camera unit. The light used was furnished by a carbon arc as before with the exception that direct rather than alternating current was used and that the carbons were 6 and 8 millimeter cored carbons rather than just the six millimeter carbons.

To obtain the oblique lighting used in making these photographs the transparent illuminator was withdrawn from the tube and the offset prism illuminator used in its place. With this prism set at the proper angle a lighting was produced which gave a varying degree of obliquity across the field. As may be seen by examination of the photographs one side shows a very definite shadowed effect while the other side shows almost direct reflection. With the illuminator set in this manner the plates are quite uneven in density and require very uneven lighting in printing. This is quite inconvenient but the final result seems to be well worth the additional time and trouble it necessitates. In the photographs the relief caused by the polishing is very plainly evident and for this reason the relative hardnesses of the various constituents may be readily determined. This fact is of considerable importance and is of considerable value in determining the constituent of the slag, as well as in giving a clean distinction between the separate constituents, which is quite indistinct in direct reflected light or in transmitted light.

Very careful polishing is essential in the preparation of these opaque specimens as even very minute scratches which are completely invisible with direct reflected light are plainly evident when the sample is examined with this type of oblique lighting. The final polish

was made with powdered alumina rather than with the more conventional rouge. Because, while the rouge polish is easier to obtain with the absence of scratches it is not nearly as satisfactory for the type of examination as is the alumina polish. The chief difference seems to be that the rouge drags the surface more than the alumina does and for this reason leaves a much less distinct separation between the various constituents. In preparing the alumina polishing medium only the alumina which remained in suspension in the water in a liter graduated cylinder three inches or more from the accumulated solid after three minutes settling was used. This gave a very fine polishing medium and when used for the final polish gave the most effective relief obtained with any of the polishing media tried. As may be seen from the photographs there is practically no dragging effect of the polishing at all.

Another precaution which must be observed much more rigidly then in polishing for ordinary metallographic examination is that the sample must not remain on the wheel in the same position for any length of time, but must be constantly rotated so that the polishing action takes place in a constantly varying direction. Perhaps the easiest way of accomplishing this is to move the sample around the polishing wheel in a direction opposite to the rotations of the wheel. If the sample is moved in this manner at an even rate of speed the polishing will be completely even and dragging will be equal in all directions.

The polished samples of the three slags from each heat were mounted and photographed as a whole so that the physical appearance of the slags may be noted. These photographs with an accompanying description of the samples are included in this paper.

The steel samples were taken at the same time at which the slag samples were taken and represent the composition of the bath at the

various stages in the refinery operation corresponding to the various slag samples. As was noted so above, the outside surfaces of the samples were removed with the drill and discarded to avoid contamination by scale or by dirt. Drillings were made with a high speed tool steel drill run at low speed and without lubricant of any kind. The drill holes were so spaced throughout the sample as to give a representative sample in case there had been any segregation in the cooling process. Fairly large samples were drilled so as to further minimize the effect of any segregation which might have been drilled into. The steels were analyzed for carbon, phosphorous, sulphur, manganese, and silican, and the distribution of these various constituents between slag and bath is easily seen. The results of the analyses are shown in tabulated form on page 19.

SUMMARY

As may be seen by comparing the photomicrographs of the C. F. & I. slags and those from the Carnegie-Illinois steel corporation there is a distinct difference in the characters of the slags from these two plants. The slags from the eastern company show a much more advanced stage of maturity than those from the western plant. In other words the various constituents are in a much better state of solution in the eastern plant. In addition to this there is a marked difference in the uniformity of the two different groups of slags. The eastern slags were nearly uniform throughout and, for this reason it was necessary to take but one photomicrograph to obtain a field typical of the entire sample. This was not at all true with the western slags in which there are very marked segregation into two or three distinctly different structures, and it was necessary to photograph several fields to get a true picture

of the character of the slag.

In addition to this, and perhaps as a partial explanation for it, the western slags run definitely higher in CaO than do the eastern slags, although, in every case there is an appreciable excess of CaO over that required for the acids at the time of tapping.

These conditions may well be the reasons for much if not all of the trouble being experienced at the C. F. & I. plant in their steel-making at the present time.

It may also be noticed that as the lime increases in the slag there is at first an apparent decrease in FeO. This is not as would off-hand be expected since the total amount of FeO in the slag should increase as the lime comes up. As a matter of fact this is exactly the case and the decrease in percentage of FeO as the lime comes up is caused by the dilution effect of the lime as it enters the slag, thus causing the FeO to be dissolved in a larger quantity of slag.

RECOMMENDATIONS

Since the optical properties of many of the suspected compounds in these slags are not available and since they are necessary to determine the presence or absence of these compounds in the slags it is recommended that if further work is to be done on the subject pure slags be made up and studied to determine these properties.

A detailed petrographic study of the slag constituents which is beyond the scope of this paper should be undertaken and as many as possible of the constituents determined. Since the question of sulfur elimination is so uncertain it seems proper to suggest that work on the action of manganese in the bath and slag be also undertaken and the exact nature of the reactions and distribution of products involved be studied with the ultimate aim of determining the requirements for cer-

tain sulfur elimination in the basic open hearth.

Rate of cooling has a very decided effect upon the structure of slags and for this reason some experimentation on the difference in structure caused by different rates of cooling seems desirable. The slags examined for this paper were all cooled at very nearly the same rate and for this reason the relative differences in structure were quite probably maintained.

Another series of tests which were not attempted at all in this work and which would probably prove of value in subsequent work on the subject are tests to determine the physical properties of the metal at the various stages.

It is suggested that possibly a scheme of cooperation between the metallurgy department and the geology department be worked up whereby the petrographic and mineralogical work could be performed in the geology department and the correlation and analytical work could be performed in the metallurgy department.

Because of the scarcity of published or available information on the structure of slags and their correlation with the baths and because of the extreme importance of information on this subject it is a field which offers almost unlimited opportunity for future work.

TABULATED DATA

SAMPLES EXAMINED

1	Flush Off	223719
2	Melt Sample	223719
3	Tap Slag	223719
4	Flush Off	174282
5	Melt Sample	174282
6	Tap Slag	174282

7	8047-1	On Lime - End & Middle
8	8047-2	Not Quite Clear
9	8047-3	At Prelim
10	8049-1	On Lime - End & Middle
11	8049-2	Not Quite Clear
12	8049-3	At Prelim

Samples 1 - 6 From Carnegie Illinois Steel Co., Chicago, Illinois

Samples 7-12 From C. F. & I., Pueblo, Colorado

ANALYSES OF SAMPLES

SAMPLE	SiO_2	Al_2O_3	CaO	MgO	Fe	Fe	FeO	Fe_2O_3	MnO	P_2O_5	Total
1	17.0		15.2	4.6	34.6	3.4	37.6	2.86	13.7	3.10	
2	21.9		37.4	8.4	11.2	1.3	10.7	2.29	11.6	2.81	
3	15.8		36.3	7.8	18.6	2.2	19.3	2.00	7.9	1.94	
4	20.0	6.67	18.5	4.7	29.4	2.2	32.8	2.43	14.8	2.49	
5	22.1		38.3	9.3	11.1	1.6	11.6	.72	10.7	2.49	
6	15.1		42.9	7.6	17.2	1.8	18.3	1.72	7.6	1.96	
7	26.1	3.44	41.2	9.6	8.2	1.1	8.7	.43	9.8	2.32	
8	18.1		50.5	8.0	9.8	1.3	10.0	1.00	6.2	2.25	
9	14.1		51.4	7.5	13.3	1.2	13.3	2.43	5.9	1.75	
10	24.4		42.7	8.9	9.4	1.4	9.6	.77	7.7	2.76	
11	17.5		50.9	7.8	9.5	1.1	9.9	1.00	5.8	2.40	
12	14.5		52.5	7.2	11.8	1.2	12.2	1.57	5.7	2.08	

SLAG ASSAYS FROM C. F. & I.

SAMPLE		SiO_2	CaO	Fe
7	8047-1	24.1	36.4	7.3
8	8047-2	17.0	47.7	8.9
9	8047-3	14.2	46.6	11.6
10	8049-1	25.6	38.7	8.1
11	8049-2	17.2	51.2	8.8
12	8049-3	14.8	51.2	10.9

EXCESS CaO

SAMPLE	TOTAL CaO	CaO FOR SiO_2 1.86 x SiO_2	CaO FOR P_2O_5 1.19 x P_2O_5	CaO FOR ACIDS SiO_2 : P_2O_5	Excess CaO
1	15.2	31.6	3.69	35.3	20.1
2	37.4	40.7	3.35	44.1	6.7
3	36.3	29.4	2.31	31.7	4.6
4	18.5	37.2	2.97	40.2	21.7
5	38.3	41.1	2.97	44.1	5.8
6	42.9	28.1	2.33	30.4	12.5
7	41.2	48.5	2.76	51.3	10.1
8	50.5	33.6	2.68	36.3	14.2
9	51.4	26.2	2.08	28.3	23.1
10	42.7	45.4	3.29	48.7	6.0
11	50.9	32.5	2.86	35.4	15.5
12	52.5	27.0	2.48	29.5	23.0

ANALYSES OF STEELS

SAMPLE	Si	Mn	C	P_2O_5	Fe	S
1	.05	0.03	2.68			
2	.07	0.18	1.00			
3	.07	0.15	0.10			
4	.07	0.18	2.94			
5	.03	0.23	0.67			
6	.05	0.16	0.09			
7	.05	0.24	0.94			
8	.03	0.25	0.37			
9	.05	0.13	0.09			
10	.03	0.19	0.61			
11	.03	0.17	0.24			
12	.05	0.15	0.19			

SLAG APPEARANCE AND CHARACTERISTICS

No 1 - Flush Off 223719

This slag is very porous and spongy in appearance and is composed almost entirely of gas bubbles. It is a very dark redish brown color in thin section and black in mass. It is very brittle, quite hard, and not at all tough. The sample contains a considerable number of iron inclusions which, for the most part, have settled to near the bottom of the sample ladle. The fracture is quite vitreous and away from the gas bubbles.

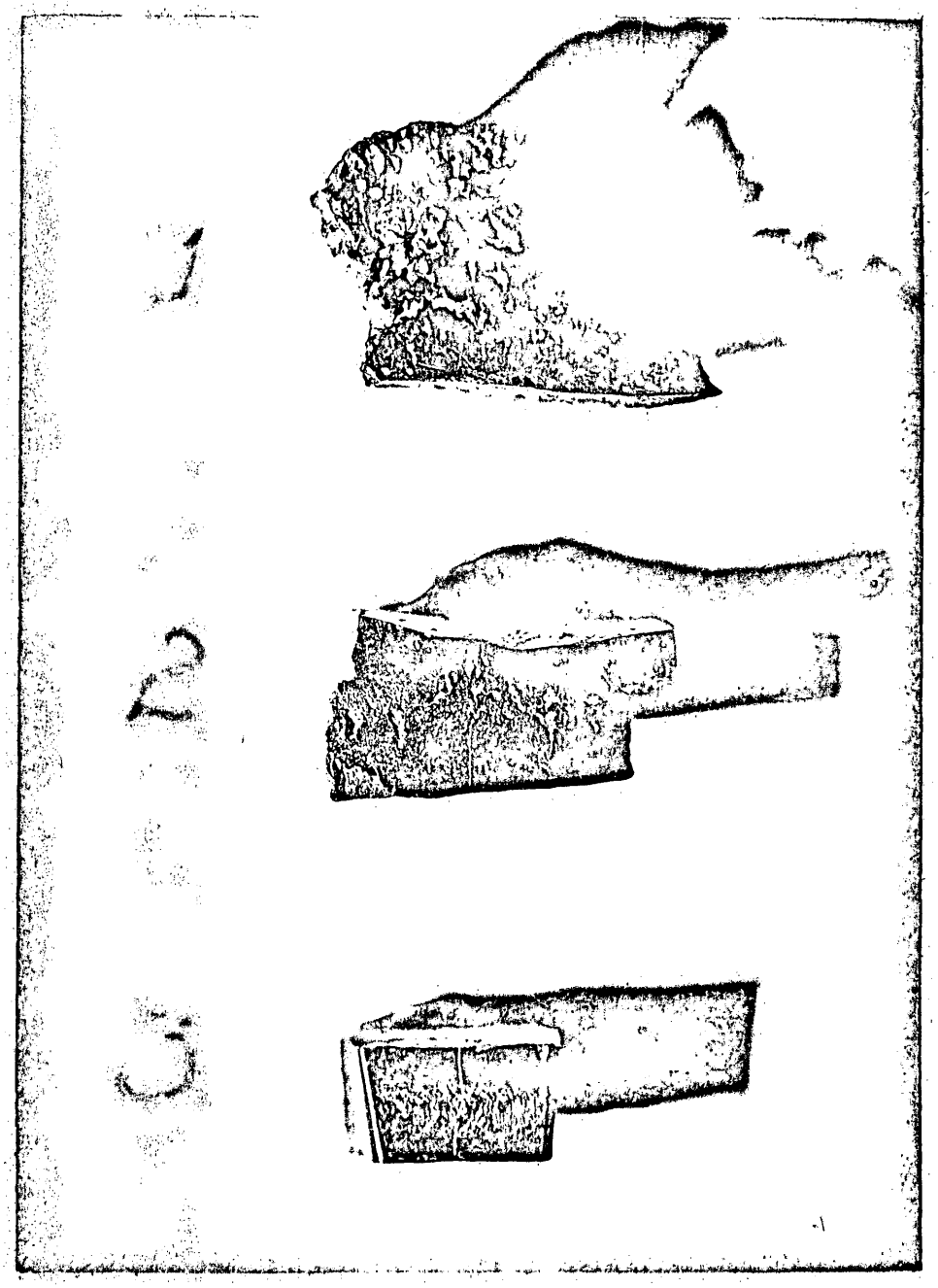
No 2 - Melt Sample 223719

This slag is much more dense and less spongy than the flush off but there are still a good many gas pockets near the cooling center of the cross section. This sample is quite hard though uniform. In color it is blacker than the flush samole and gives a dull sooty surface on fracture. There are a number of small inclusions of iron in the sample. There are not nearly as large or as abundant as in the case of the previous sample, and do not seem to have settled out of the slag to nearly the degree.

No 3 - Tap Sample 223719

This is a very dense, hard and tough slag. It is very finely crystalline, and shows some spongyness near the center of the sample. It is almost black in color in both thin section and mass. This fracture is dull rather than vitreous as in the case of the flush sample. There are a few very small inclusions of iron in the sample and these seem to be quite uniformily distributed throughout.

SLAG SAMPLES FROM HEAT 223719
CARNEGIE ILLINOIS STEEL CORPORATION



1. FLUSH OFF SLAG
2. MELT SAMPLE
3. TAP SLAG

No 4 - Flush Off 174282

This slag is not nearly so spongy as the flush off slag from heat 223719. The gas in the sample collected, rather, at the center of the sample and divided it quite clearly in two. In thin section the color of the slag is a reddish brown and in mass is jet black. The slag is quite dense, glassy, and very brittle, and not at all tough. No inclusions of iron are visible to the unaided eye.

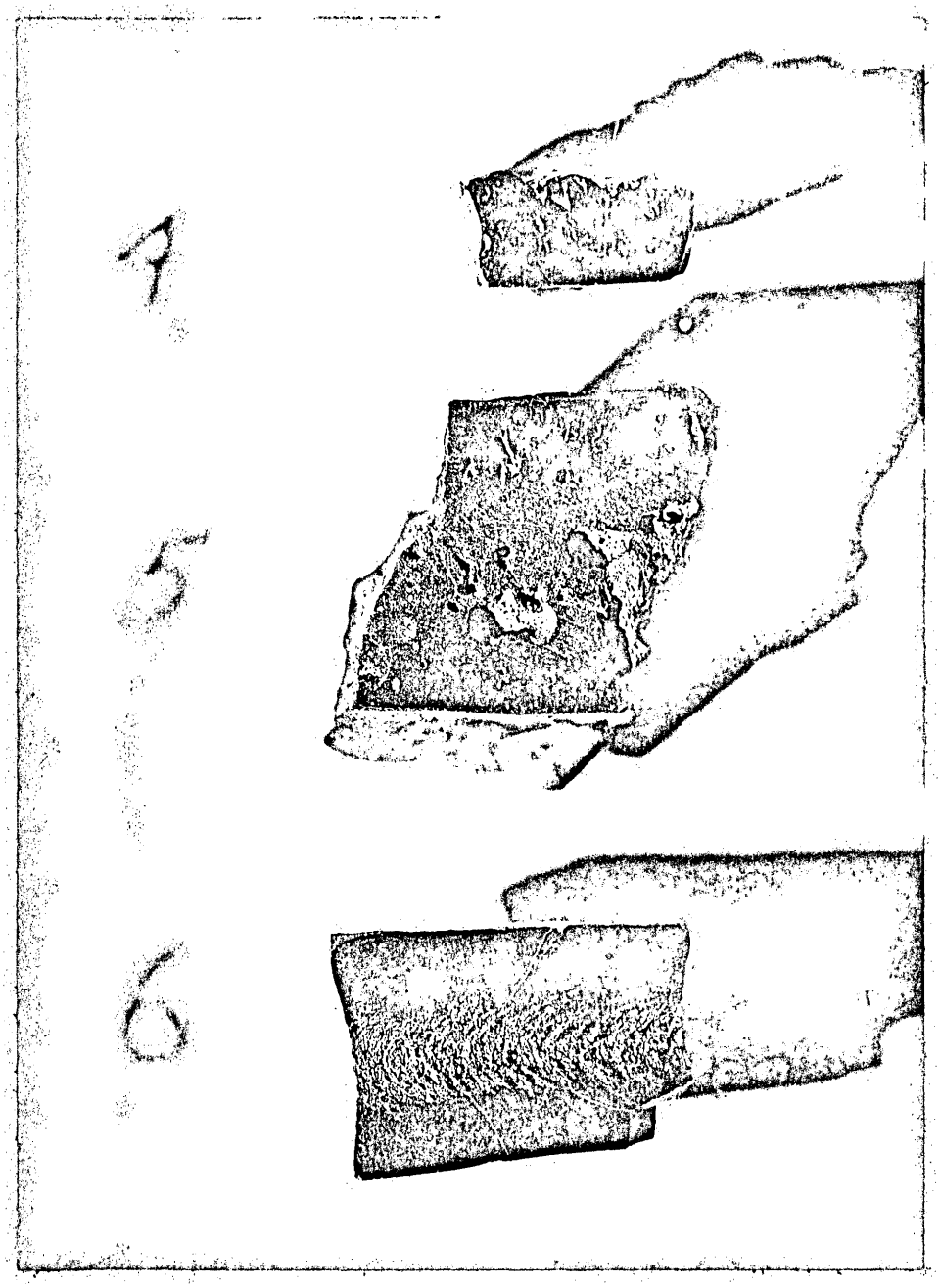
No 5 - Melt Sample 174 282

This slag is quite spongy in nature and contains many large gas pockets. It has a dull sooty fracture similar to the corresponding sample of heat 223719. The color in thin section is dark reddish brown and in mass a dull black, especially near the upper cooling surface. This slag contains a great deal of included iron. Many of the iron inclusions are quite large in size and, for the most part have settled to the bottom of the sample, probably indicating low slag viscosity. The slag is fairly hard but not very dense or very tough.

No 6 - Tap Sample 174282

This slag is very similar to the tap slag of heat 223719. It is quite black in both thin-section and in mass. It is very finely crystalline with a very narrow spongy layer at the center which almost completely divides the sample in two. There is very little or no included iron in the sample. The fracture is quite even giving a dull black surface.

SLAG SAMPLES FROM HEAT 174282
CARNEGIE ILLINOIS STEEL CORPORATION



4. FLUSH OFF SLAG

5. MELT SAMPLE

6. TAP SLAG

No 7 - 8047 - 1 On Lime Ends & Middle

This was a small sample and for this reason cooled in a thin section indicating, even with the rapid cooling the slag shows fairly coarse crystalline structure. It is quite spongy with some fairly large gas pockets near the upper surface. The bottom, however, is almost vitreous. This particular slag is very brittle and only small pieces remained intact for polishing. No inclusions of metalic iron are visible to the unaided eye. The color of the sample in thin section is a greenish gray and in mass is jet black.

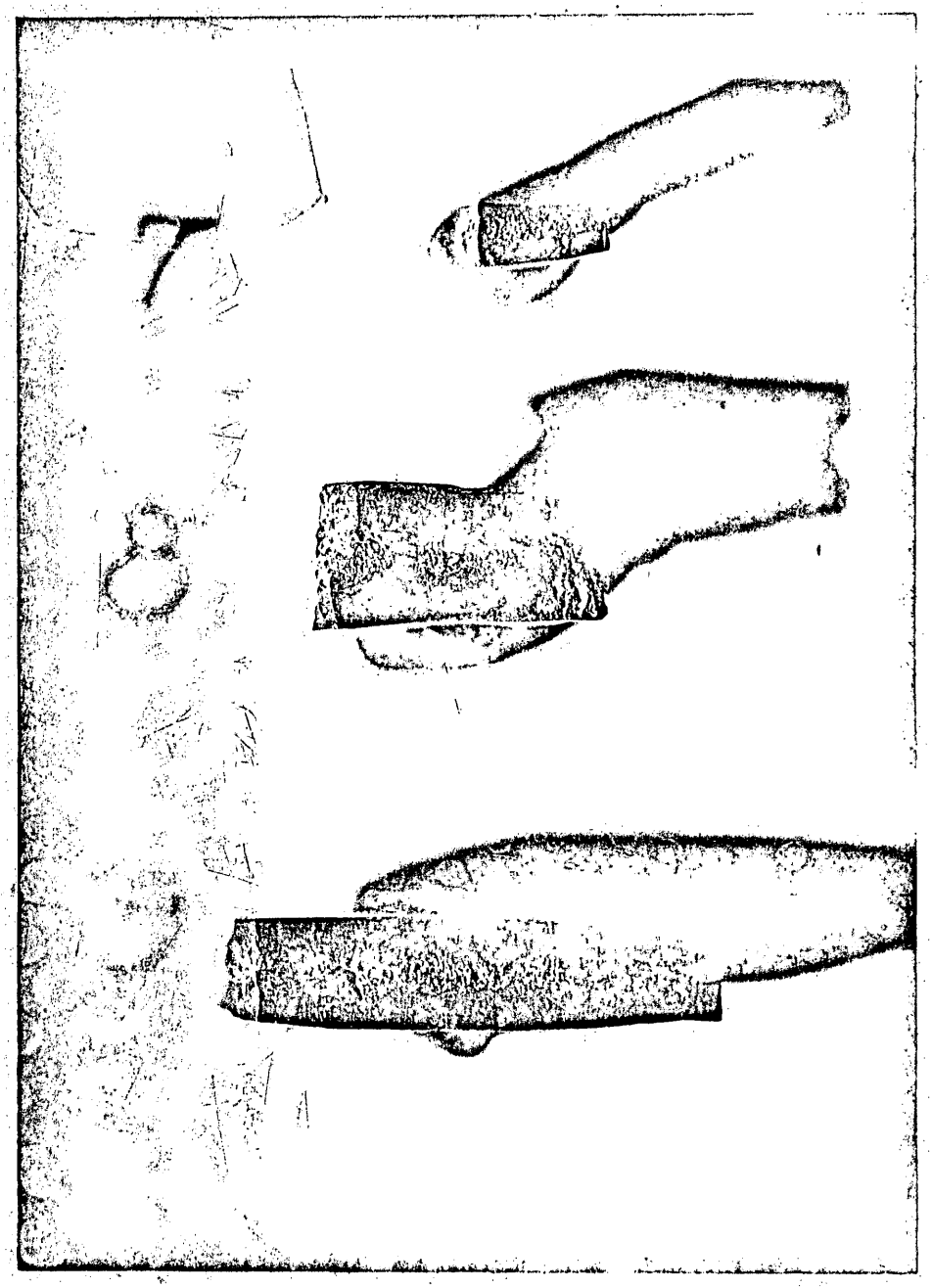
No 8 - 8047 - 2 Not Quite Clear

This sample is pale brown in color and somewhat translucent particularly near the bottom surface. It is finely crystalline in structure near the edges and somewhat coarser near the center. It is quite spongy at the center of the cross section and some of the gas pockets are quite large in size. There is very little mechanically included iron in the sample. This slag is hard fairly dense and quite tough.

No 9 - 8047 - 3 At Prelim

This slag is finely crystalline in nature. It is dense, hard and quite tough. There is a little spongyness near the center but there are very few gas pockets of any appreciable size. The slag is a greenish brown color with an almost metallic luster and a splintery fracture. There are almost no inclusions of iron in the sample.

SLAG SAMPLES FROM HEAT 8047
COLORADO FUEL & IRON CORPORATION



7. ON LIME - ENDS & MIDDLE

8. NOT QUITE CLEAR

9. AT PRELIM

No 10 - 8049 - 1 On Lime Ends & Middle

This is a very spongy slag and has a great number of large gas pockets in the center of the sample. It is finely crystalline in structure, quite brittle and not very tough. There are very few mechanical inclusions of iron in the sample. The color of the slag is black and the fracture away from the spongy center is splintery.

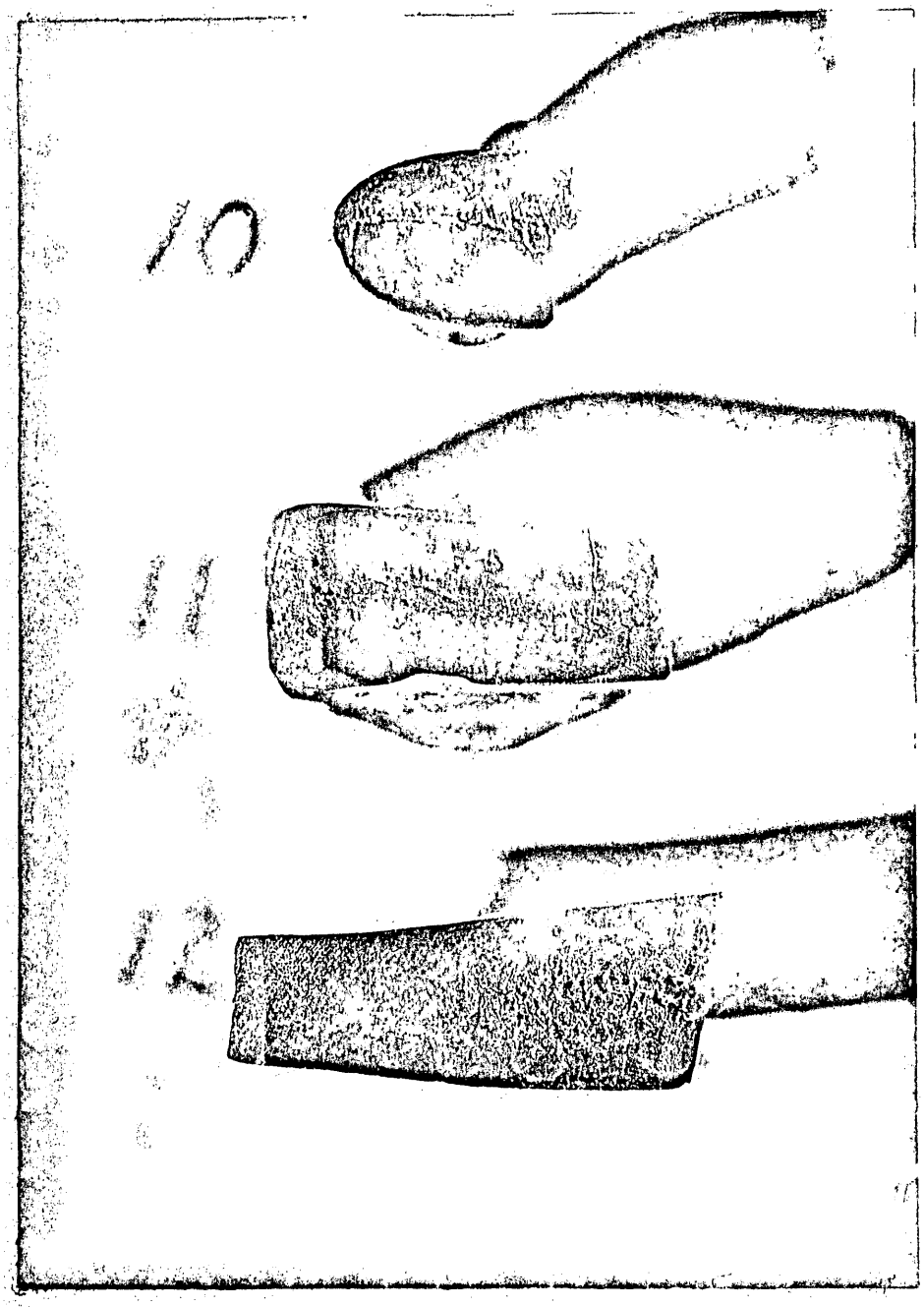
No 11 - 8049 - 2 Not Quite Clear

This sample like No 8 is brown in color and translucent near the bottom surface. It is hard compact and brittle. It is not very tough and near the center is quite ockety and spongy. There are a few inclusions of iron and these seem to have settled to near the bottom of the sample ladle. Some fairly large crystals are visible to the naked eye.

No 12 - 8049 - 3 At Prelim

This sample is finely crystalline, dense, compact, hard and quite tough. There is almost no spongyness at all and there are no gas pockets in the sample. No inclusions of iron are visible to the unaided eye. The color of the slag is sort of a redish brown rather than the green of sample 9 in the corresponding stage of heat 8047.

SLAG SAMPLES FROM HEAT 8049
COLORADO FUEL & IRON CORPORATION



10. ON LIME - ENDS & MIDDLE

11. NOT QUITE CLEAR

12. AT PRELIM

PHOTOMICROGRAPHS

SAMPLE NO 1 FLUSH OFF - 223719 - 120 X

Reflected Light

Oblique

Transmitted Light

Crossed Nicols

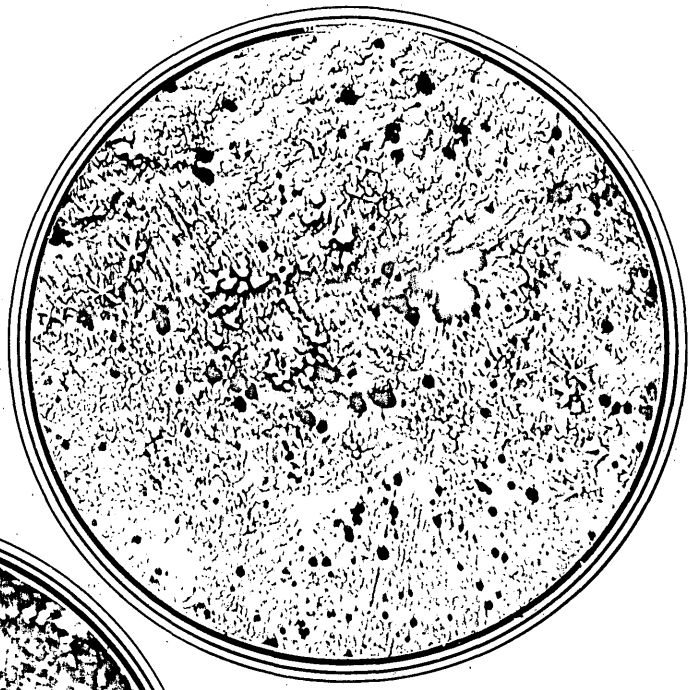
Transmitted Light

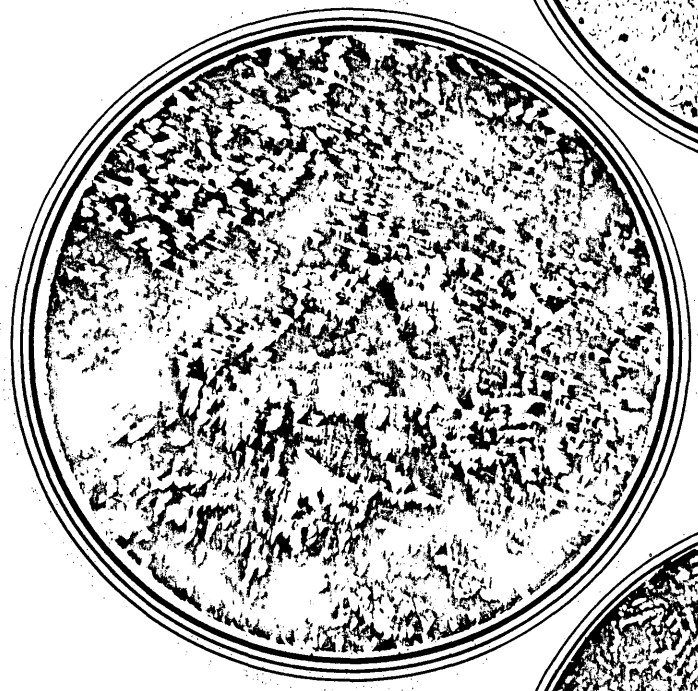
Ordinary

SAMPLE NO 2 MELT SAMPLE - 223719 - 120 X

Reflected Light

Oblique





Transmitted Light

Crossed Nicols

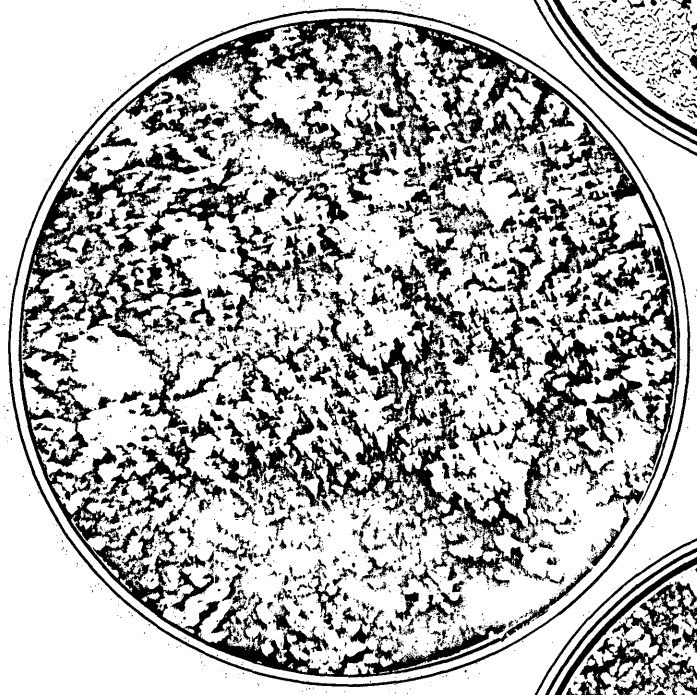
Transmitted Light

Ordinary

SAMPLE NO 3 TAP SLAG - 223719 - 120 X

Reflected Light

Oblique



Transmitted Light

Crossed Nicols

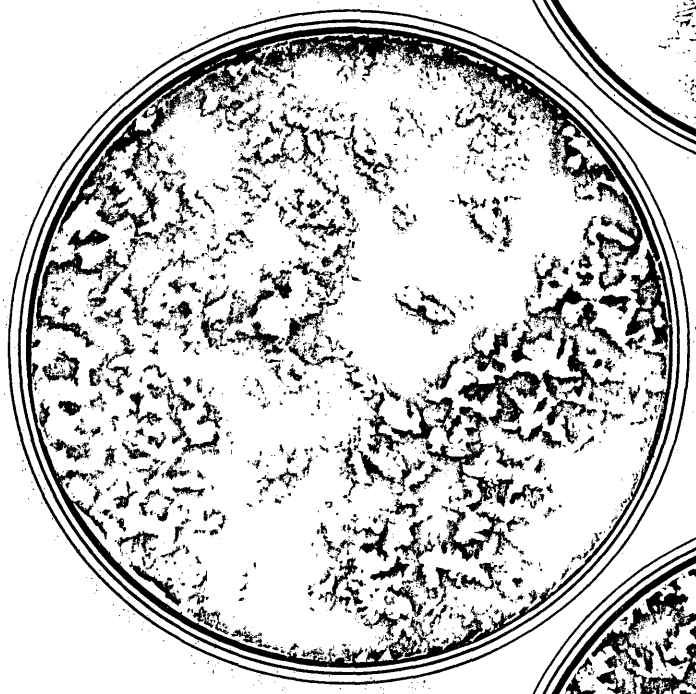
Transmitted Light

Ordinary

SAMPLE NO 4 FLUSH OFF - 174282 - 120 X

Reflected Light

Oblique



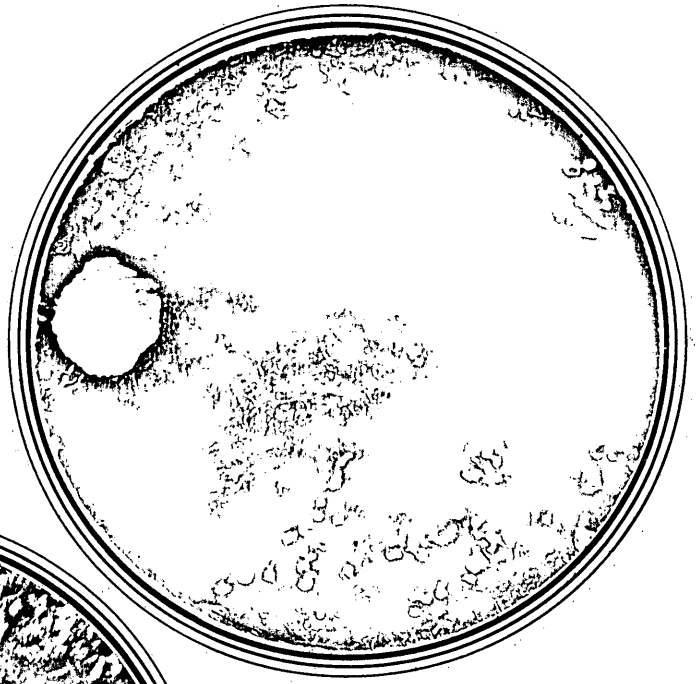
Transmitted Light

Crossed Nicols

Transmitted Light

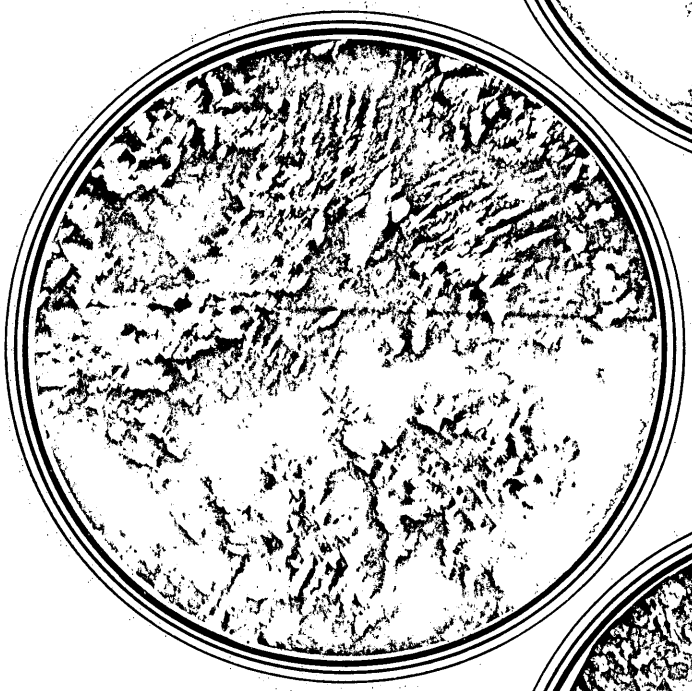
Ordinary

SAMPLE NO 5 MELT SAMPLE - 174282 - 120 X



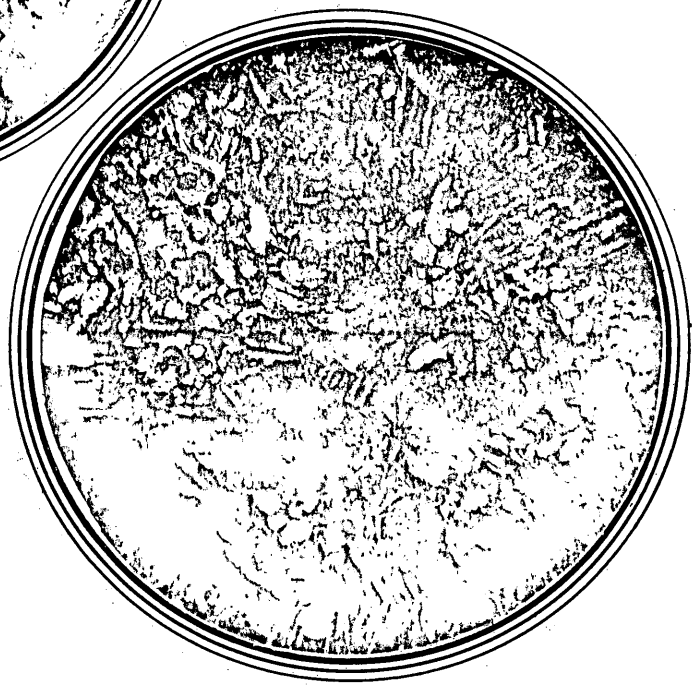
Reflected Light

Oblique



Transmitted Light

Crossed Nicols



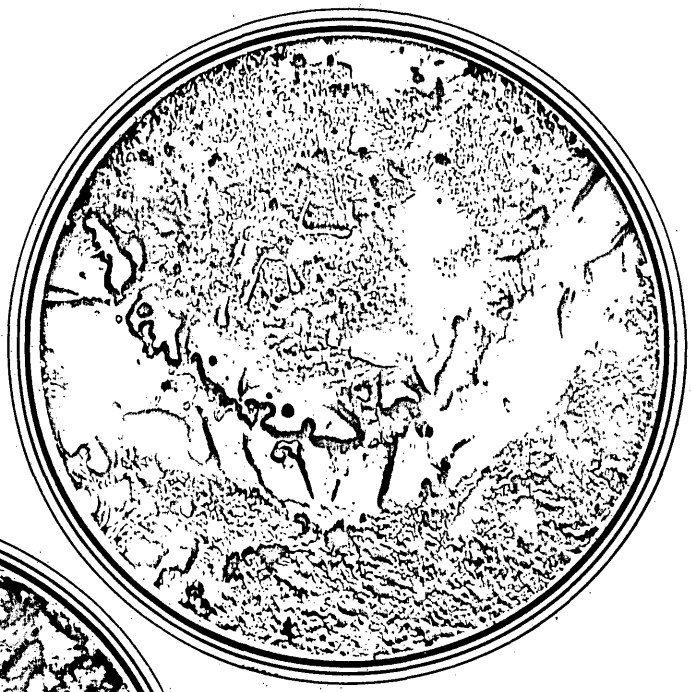
Transmitted Light

Ordinary

SAMPLE NO 6 TAP SLAG - 174282 - 120 X

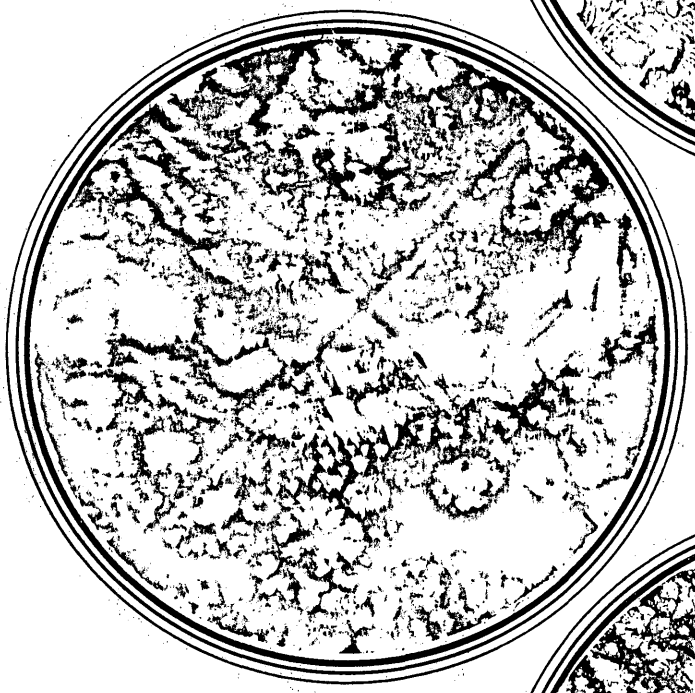
Reflected Light

Oblique



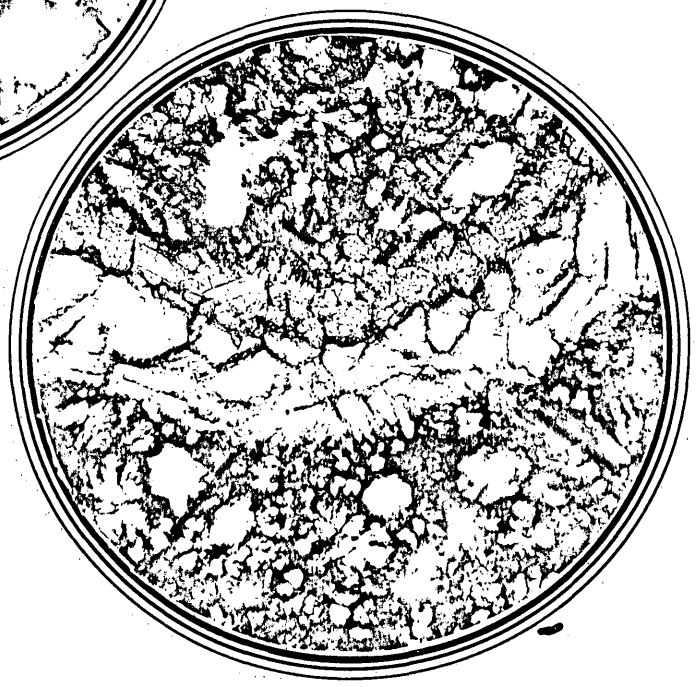
Transmitted Light

Crossed Nicols

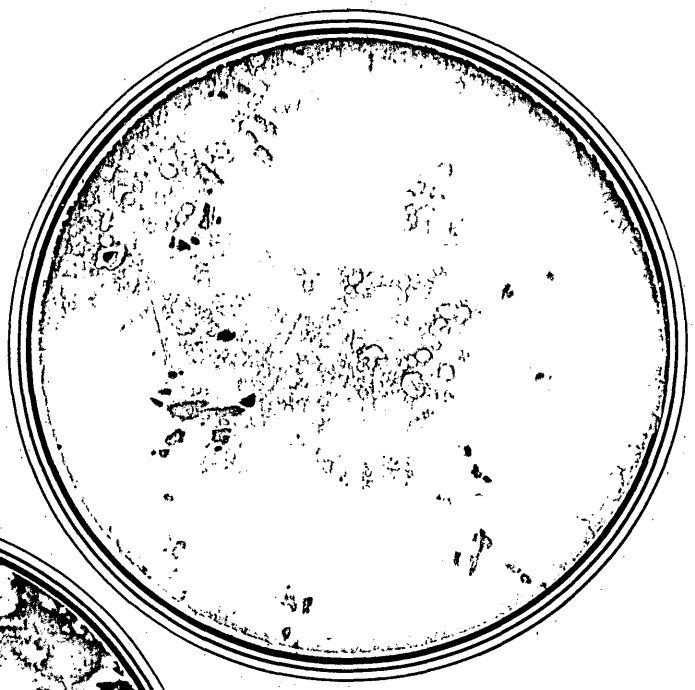


Transmitted Light

Ordinary

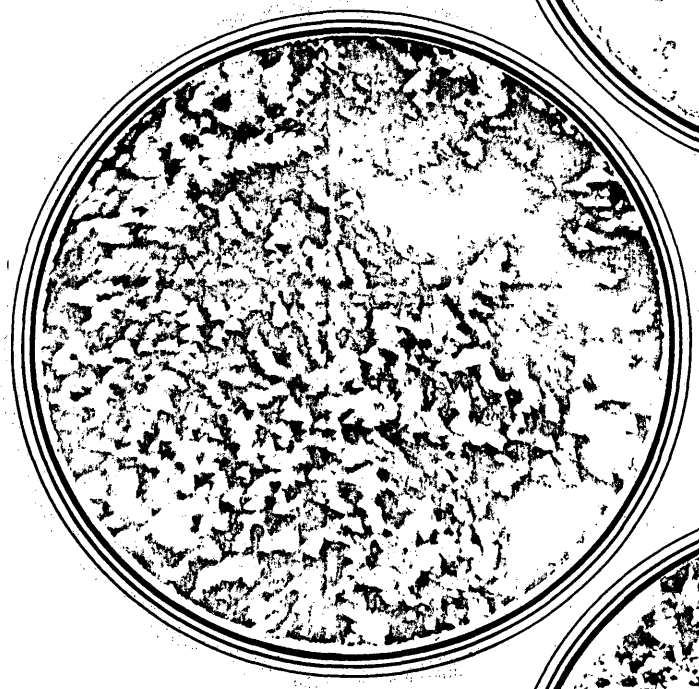


SAMPLE NO 7 ON LIME - ENDS & MIDDLE - 8047 -1 - 120 X



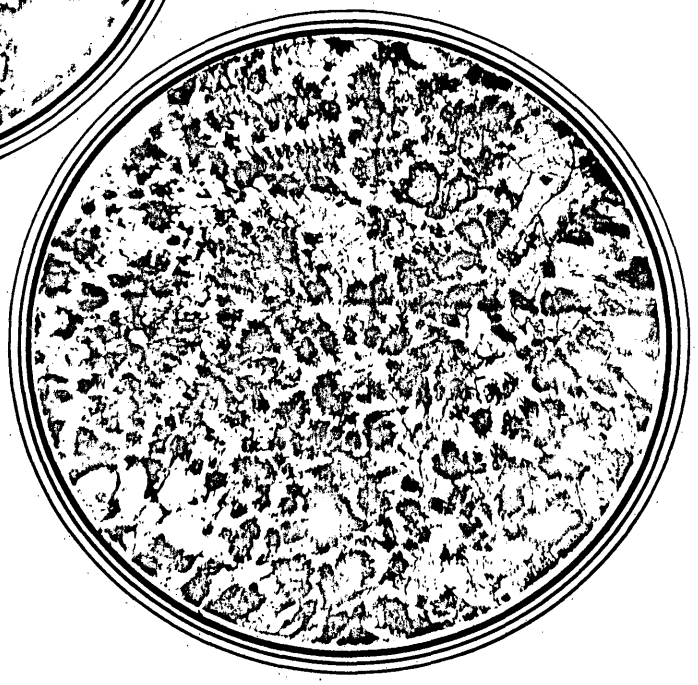
Reflected Light

Oblique



Transmitted Light

Crossed Nicols



Transmitted Light

Ordinary

SAMPLE NO 8 NOT QUITE CLEAR - 8047-2 - 120 X

Reflected Light

Oblique

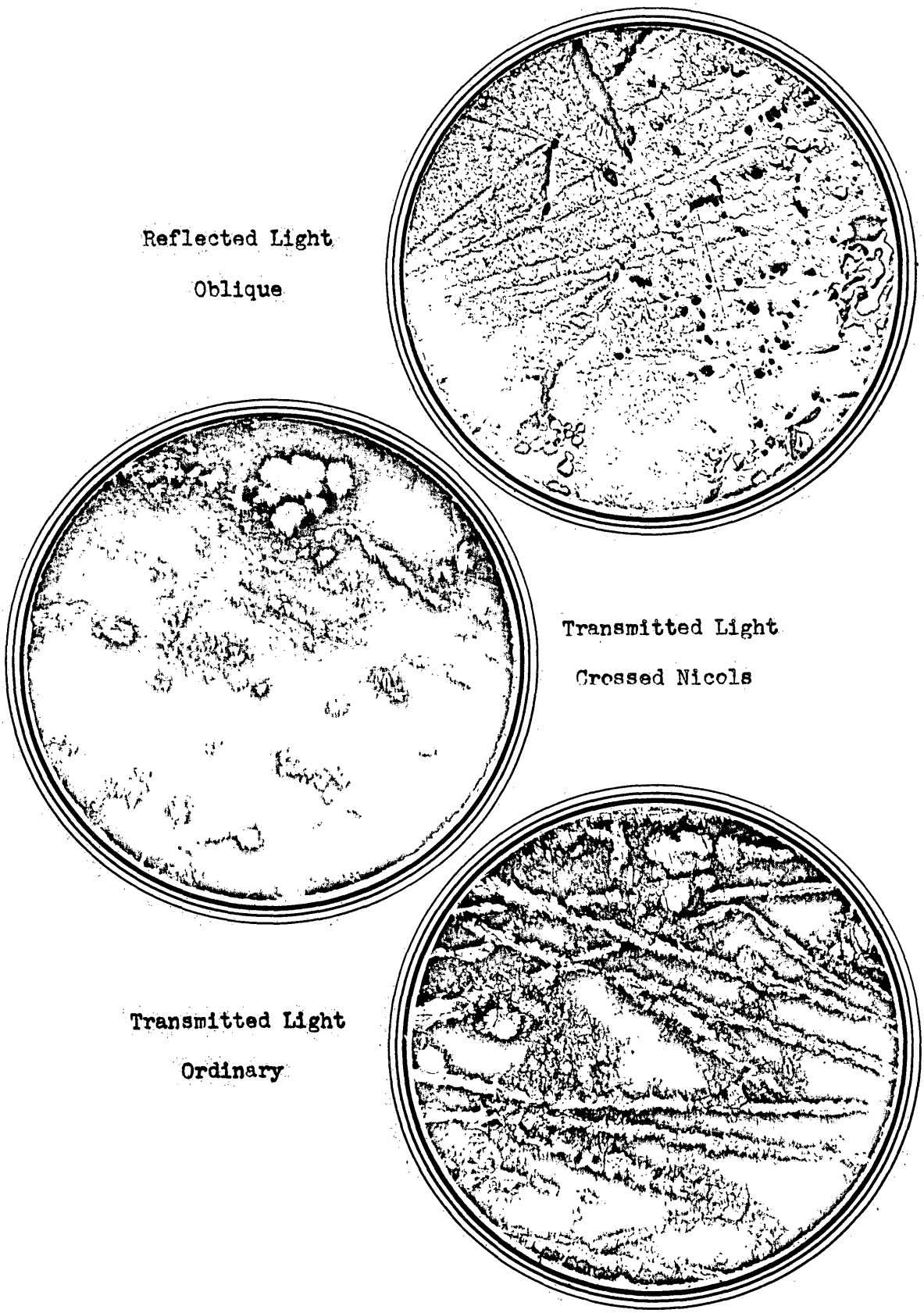
Transmitted Light

Crossed Nicols

Transmitted Light

Ordinary

SAMPLE NO 8 NOT QUITE CLEAR - 8047-2 - 120 X



Reflected Light

Oblique

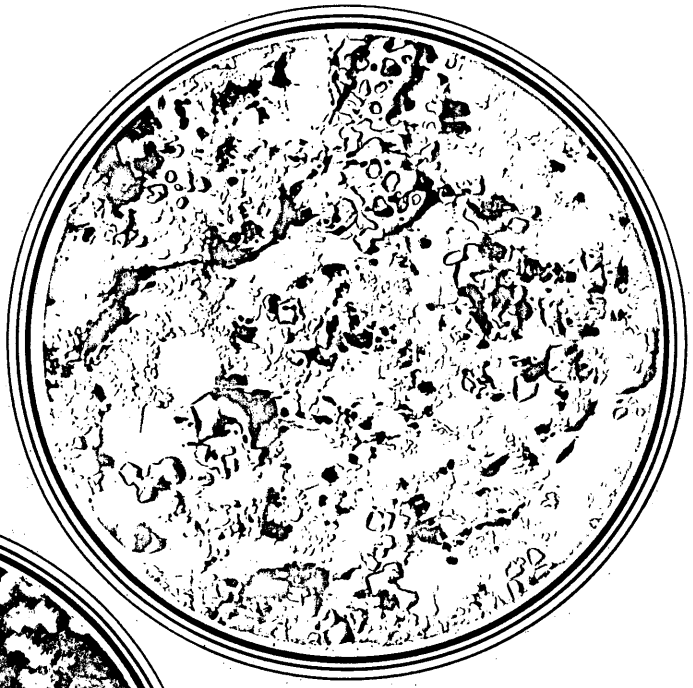
Transmitted Light

Crossed Nicols

Transmitted Light

Ordinary

SAMPLE NO 8 NOT QUITE CLEAR - 8047-2 - 120 X

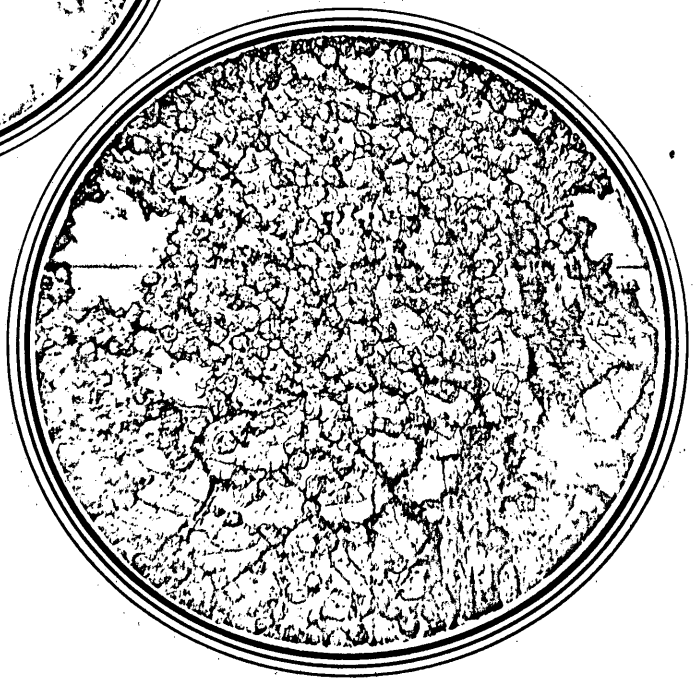


Reflected Light

Oblique

Transmitted Light

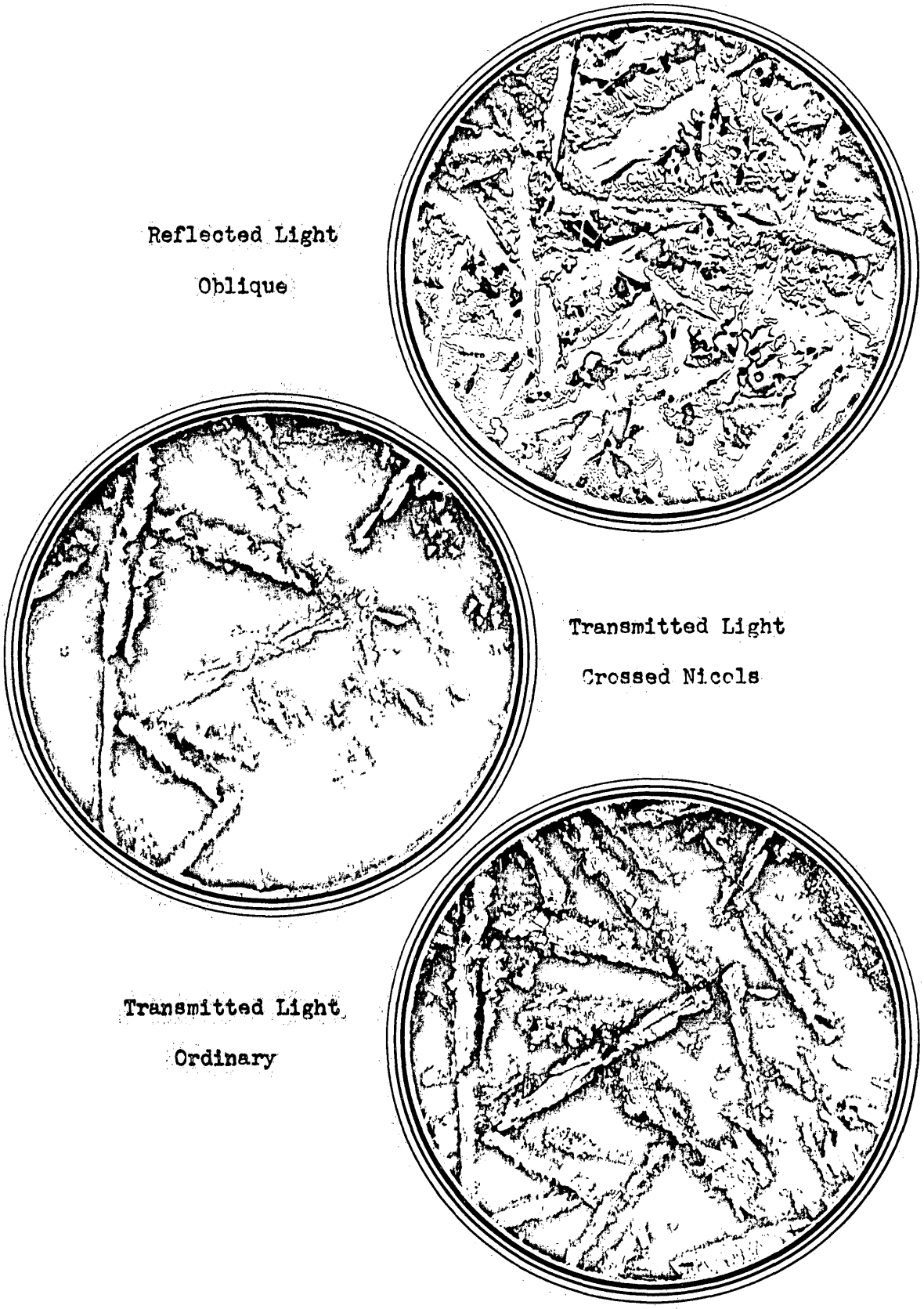
Crossed Nicols



Transmitted Light

Ordinary

SAMPLE NO 9 AT PRELIM - 8047-3 - 120 X



Reflected Light

Oblique

Transmitted Light

Crossed Nicols

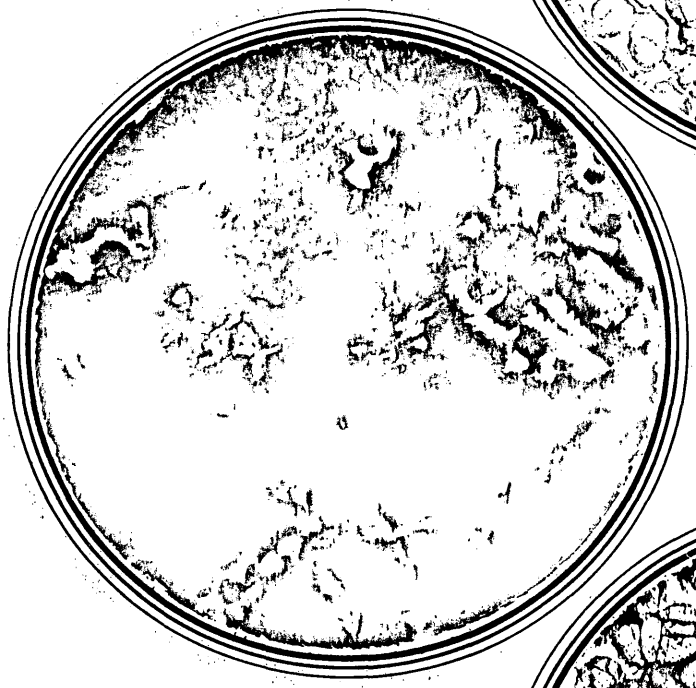
Transmitted Light

Ordinary

SAMPLE NO 9 AT PRELIM - 8047-3 - 120 X

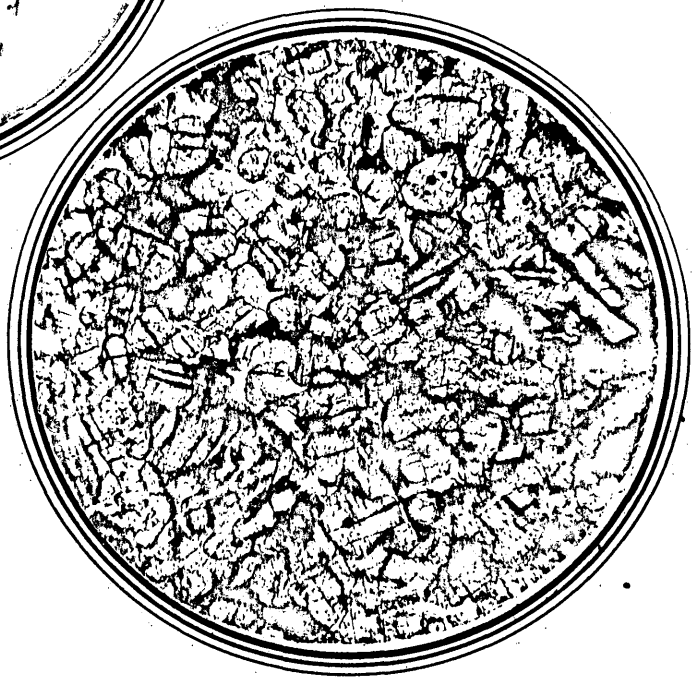
Reflected Light

Oblique



Transmitted Light

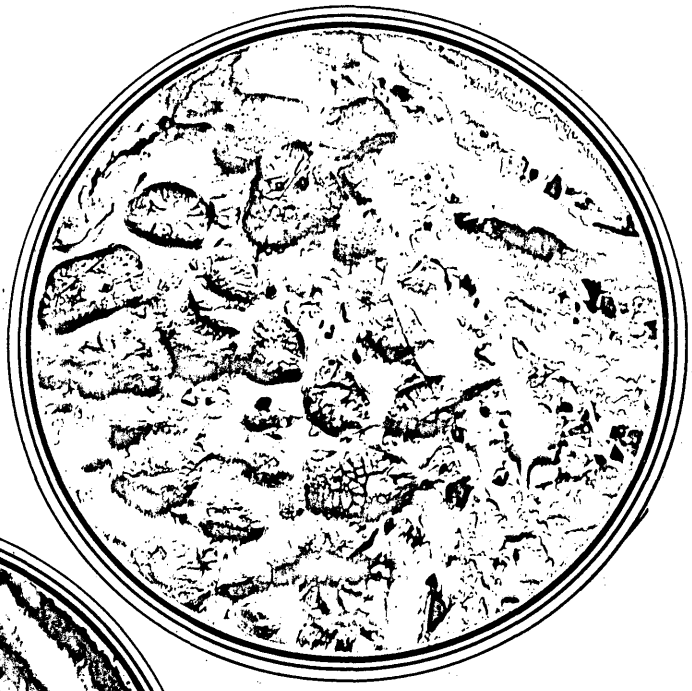
Crossed Nicols



Transmitted Light

Ordinary

SAMPLE NO 9 AT PRELIM - 8047-3 - 120 X



Reflected Light

Oblique

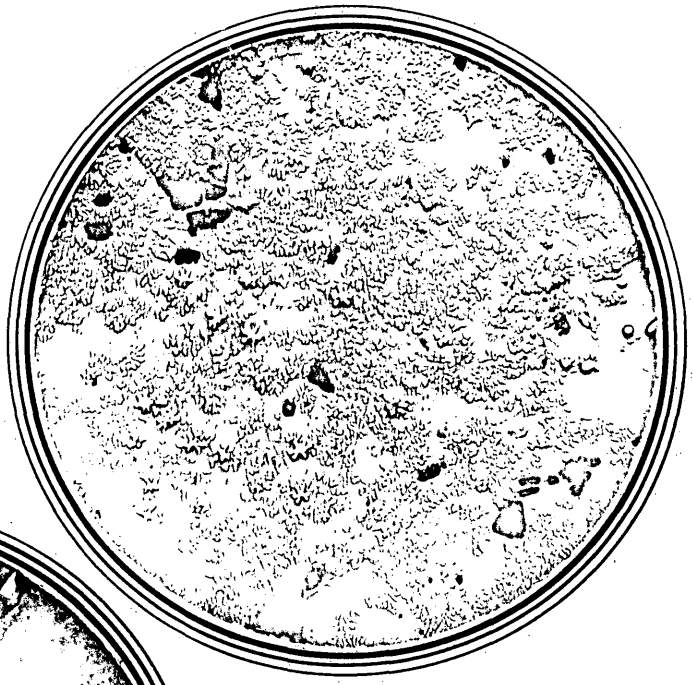
Transmitted Light

Crossed Nicols

Transmitted Light

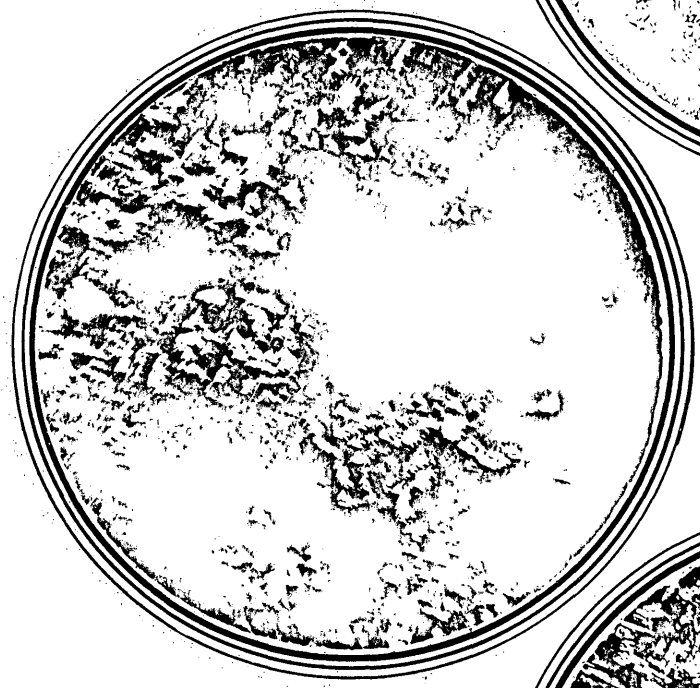
Ordinary

SAMPLE NO 10 ON LIME - ENDS & MIDDLE - 8049-1 - 120 X



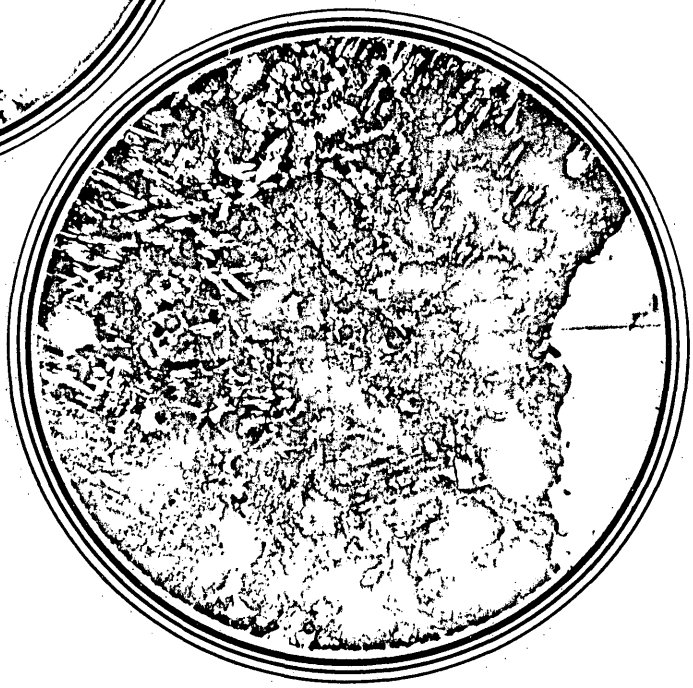
Reflected Light

Oblique



Transmitted Light

Crossed Nicols



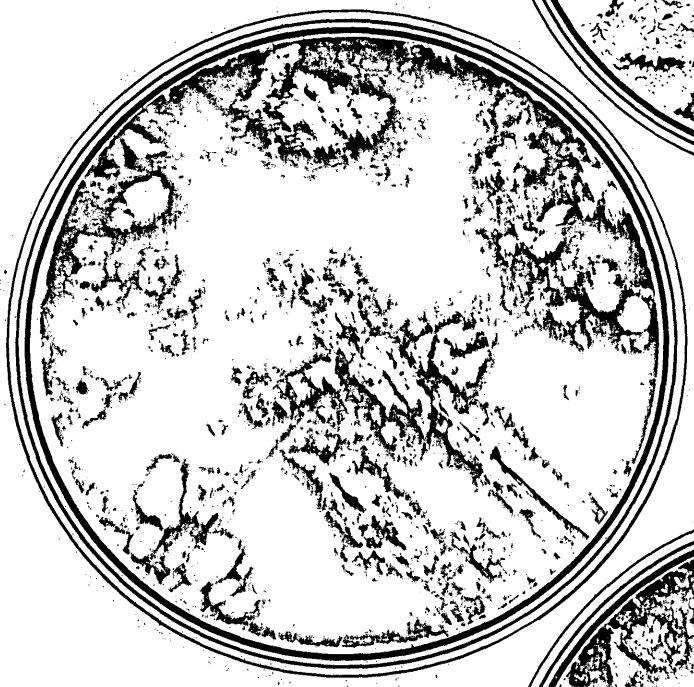
Transmitted Light

Ordinary

SAMPLE NO 11 NOT QUITE CLEAR - 8049-2 - 120 X

Reflected Light

Oblique



Transmitted Light

Crossed Nicols

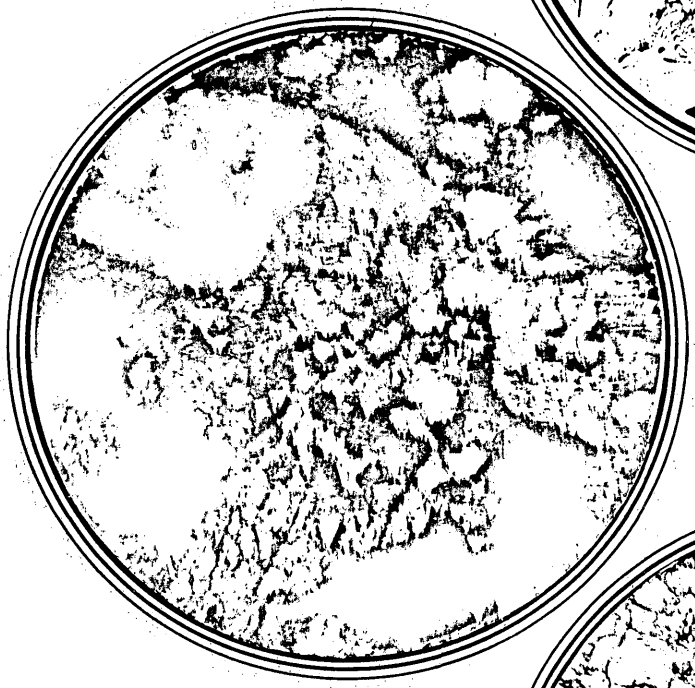
Transmitted Light

Ordinary

SAMPLE NO 11 NOT QUITE CLEAR - 8049-2 - 120 X

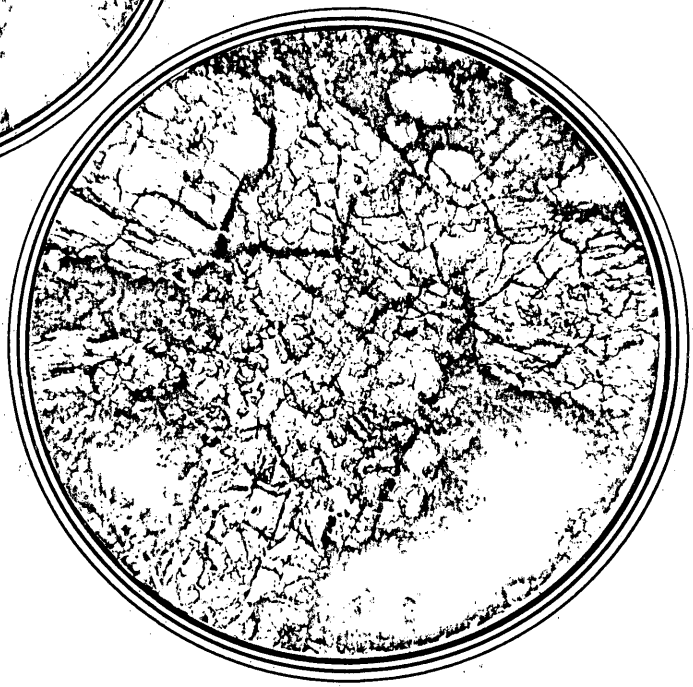
Reflected Light

Oblique



Transmitted Light

Crossed Nicols



Transmitted Light

Ordinary

SAMPLE NO 12 AT PRELIM - 8049-3 - 120 X

Reflected Light

Oblique

Transmitted Light

Crossed Nicols

Transmitted Light

Ordinary

SAMPLE NO 12 AT PRELIM - 8049-3 - 120 X

Reflected Light

Oblique

Transmitted Light

Crossed Nicols

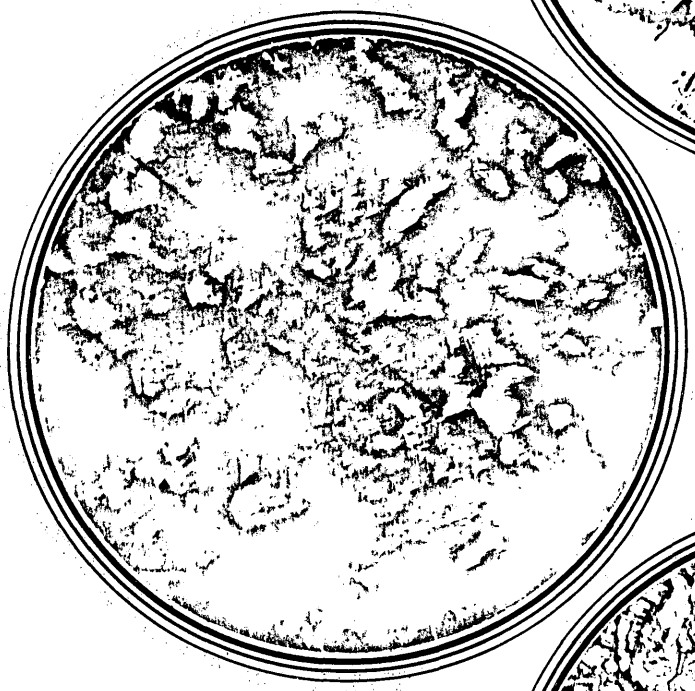
Transmitted Light

Ordinary

SAMPLE NO 12 AT PRELIM - 3049-3 - 120 X

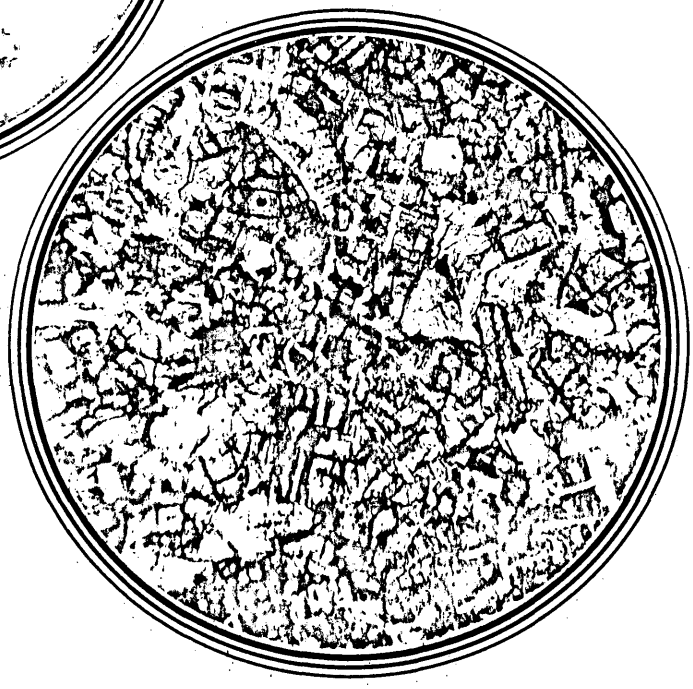
Reflected Light

Oblique



Transmitted Light

Crossed Nicols



Transmitted Light

Ordinary

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