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Testing of Missouri shales for light weight aggregate production

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TESTING OF MISSOURI SHALES

FOR

LIGHT WEIGHT AGGREGATE PRODUCTION

A

THESIS

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Approved by: Paul G. Herold

Chairman, Department of Ceramic Engineering

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The author wishes to acknowledge his indebtedness to Dr. P. G. Herold, under whose direction and supervision this project was carried out. The kind assistance and help of Dr. E. L. Clark, and the interest and suggestions of Dr. T. J. Planje are gratefully acknowledged.

This project started as a twin project with the work being preformed by Mr. Peter Kurtz, and Mr. Robert J. Scrivner; however, as Mr. Scrivner was called to the Armed forces in September 1952, the author assumed his part of the work, and wishes to acknowledge the work Mr. Scrivner completed.

Mr. Kurtz designed a rotary batch kiln, this kiln was constructed during the summer of 1953 by Mr. Kurtz, and Mr. Wallace T. Harper. The author is also indebted to Mr. W. C. Lo who ably assisted in the operation of the rotary kiln and the testing of the compression samples.

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INTRODUCTION

The original objective of this investigation was to determine by testing those clays, shales, and loesses occuring in Missouri in large deposits (over 15 feet in thickness with little overburden), which would be suitable for the production of light weight aggregate. The second objective was to investigate the mechanism of bloating as related to the physical and chemical properties of the above materials, and by using these relationships cause clays which do not naturally bloat, to bloat using some addition. The use of additives would permit the economical use of material closer to the market in many instances.

After the work of testing was well under way Dr. E. L. Clark, after conferences with light weight aggregate consumers and potential producers suggested that we determine the physical properties of the aggregate produced in the above test. The important information needed was the compression strength as compared to aggregates already in production. Light weight aggregate is of major economic importance when it is realized that in the building industry the use of light weight building blocks is perhaps the biggest development in recent years.

The equipment for production of aggregate from clay or shale is expensive, therefore potential investors are hesitant to invest in any particular location without assurance of the proper raw materials being available. This study is to report those materials which are available and the quality of the aggregate produced from several of them.

In this work, standard firing behavior tests were conducted, and the data and results while not conclusive for aggregate production are indicative of the results which can be expected. The results of these firing behavior tests are included as they will be of use to any structural clay products industry which might seek to locate in this State.

Quantities of seven shale samples were collected and pilot plant quantities of aggregate were produced in the batch type rotary kiln. After production of sufficient material, compression tests were made of six samples to give a relative measure of their strengths.

REVIEW OF PREVIOUS WORK

T. E. Jackson[1] in 1903, without published data, theorized that the problem of bloating of clays (encountered in the production of structural clay products) was caused by the evolution of oxygen liberated by the dissociation of ferric oxide.

Orton and Staley[2] did not accept the view proposed by Jackson, and pointed to two facts; one, many clays which contain iron do not bloat, two, if the ferric oxide reduction were the cause, all clays would bloat at the same temperature, in contrast to the experimental evidence that clay bloating temperature ranges from 1,100 to 1,700° C. They suggested that iron sulfide was not dissociated in ceramic bodies, but dissolved in the glassy phase, then as more silica was dissolved into this glassy phase, the melt became more acid causing the sulfur to be driven from the solution as sulfur dioxide, thereby causing bloating.

Seger[3] supported the position of Orton and Staley. He reported dissolving ferric oxide in glass with no apparent evolution of gas.

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(1) Jackson, T. E., p 43, discussion of the paper ''Changes in Color of Clays on Ignition in Clayware Kilns,'' by Arthur Hopwood, Trans. Ceram. Soc. (Engl.), 1903, pp 37-43.

(2) Orton, E., and Staley, H. F., Status of C, Fe, and S in clays During Various Stages of Burning; 3rd. Report, National Brick Manufacturers Association, Indianapolis, Indiana, 1908.

(3) Seger, H., Collected Writings of Herman Seger, 1037.

Matson[4] came to the conclusion that ferruginous clays burned to vitrification in an oxidizing atmosphere did not have the iron present in a ferrous form.

Bleininger and Montgomery[5] said that if at any time after vitrification began gases were evolved to produce a pressure within the clay body, then bloating would occur. They recognized as factors affecting bloating, initial structure, rate of heating, kiln atmosphere, and others.

Work done by the Emergency Fleet Corporation[6] in 1919 indicated clays should be high in compounds of metallic oxides, carbon, sulphur, sodium, potassium, or other equivalent oxides which are fluxes or decompose giving off a gas.

Jackson [7] mixed various impurities with pure kaolinite and fired to high temperatures in an effort to determine the cause of bloating.

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(4) Matson, G. C., Clayworker (Engl.), 1904.

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(5) Bleininger, A. V., and Montgomery, E. T., ''Effect of Overfiring Upon the Structure of Clays,'' Trans. Am. Ceram. Soc., 15, 71-85 (1913).

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(6) History and Properties of Light-Weight Aggregates, Eng. News. Rec., 82, 802, (1919).

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(7) Jackson, F. G., ''Oxidation of Ceramic Ware During Firing: 2, Decomposition of Various Compounds of Iron with Sulphur Under Simulated Kiln Conditions.'' J. Am. Ceram. Soc., 7 (4) 223-37 (1924).

He attributed bloating to sulphur, the sulphur retained above 900° C. formed a complex with the iron present. His work found sulphur could not be retained above 900° C. without the presence of iron oxide, this complex was designated ferrosulphosilicate.

Wilson[8] listed the gases responsible for bloating as; entrapped air, water, sulphur dioxide, carbon monoxide, oxygen, and hydrocarbons. Also he believed bloating resulted from two factors: (1) incomplete oxidation below the vitrification temperature, and (2) decomposition of compounds and evolution of gases above the vitrification temperature. Calcium sulfate was given as the principle example of the second factor.

Austin, Numes, and Sullivan[9] developed and used a tube furnace (equipped with gas absorption train to quantitatively determine gases evolved) to measure gases evolved with variation in heating rate, air flow, and different atmospheres.

The gases evolved were CO_2, SO_3, H_2O. The rate of heating inversely affected the total quantity of any gas given off, and high rates of heating caused the gases to be evolved at higher temperatures. Also the greater the air flow the greater the amount of gas given off.

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(8) Wilson, Hewitt, Ceramics-Clay Technology, McGraw-Hill Book Co., Inc., New York, 1927, 296.

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(9) Austin, C. R., Numes, J. L., and Sullivan, J. D., ''Basic Factors Involved in the Bloating of Clays,'' Am. Inst. Mining & Met. Engrs., Tech. Pub. No. 1486; Mining Technol., (4) 11 pp., (1942).

They also determined that CO_2 was not formed by the reaction of atmospheric oxygen with the surface of the heated clay, this fact was determined by heating the clays in a nitrogen atmosphere, and they bloated as well as, or just a bit better than in air. The SO_3 gas was believed to result from the decomposition of the sulfates, and the source of the water was not determined, but they did not believe it could be water held in the clay mineral as the temperature was too high.

They also recognized the role played by the glassy phase, and noted the effect that CaO would play in reducing the viscosity of the glass formed, and the affect this would have on the formation of irregular pores.

Sullivan, Austin, and Rogers[10] produced in the laboratory, large blocks of bloated material to be used for building blocks. They noted that the length of bloating range, was inversely a function of the amount of CaO present. In an effort to improve bloating, and to reduce over-bloating they tried (successfully) calcining the raw material to drive off the gas at low temperatures.

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[10] Sullivan, J. D., Austin, C. R., and Rogers, E. J., ''Expanded Clay Products'', Am. Inst. Mining & Met. Engrs., Tech. Pub. No. 1485; Mining Technology., 7., 3-10, (1942).

Conley, Wilson, and Klinefelter[11] conducted a very intensive, and extensive study of clays, shales, and slates to determine their bloating properties. Their research on the causes of bloating tried to correlate chemical composition to bloating, but they were unable to establish any relationship. They did note that the mean values of CaO, MgO, K_2O, and Na_2O for bloaters was 6.19% and with the addition of the Fe_2O_3 the total fluxes rose to 12.58% with a pH of 6.6, this in contrast to the non-bloaters with values as follows; 2.6%, 7.1%, and a pH of 4.4 However, it was noted that clays with values in the order of the mean of one group could be bloaters, or non-bloaters, thus they were not rules, but guides to the bloating.

Conley, et al[11] conducted a study of additives, and found that with the additions of sulfates, carbonates, flowers of sulphur, hydroxides, coke, and coal they could produce bloating in different clays, but again they could not establish a definite relationship. They decided that the additives must be based upon trial and error, and each and every clay was a different problem. Also considerable work was done on the engineering properties of the aggregates produced, and a study of the economics of production was made.

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[11] Conley, J. E., Wilson, H., Klinefelter, T. A., ''Production of Lightweight Aggregates from Clays, Shales, Slates and Other Materials,'' U. S. Bur. Mines Repts. Invest., No. 4401, 121 pp., (1948).

Riley,[12] by chemical analysis of a large number of bloating, and non-bloating clays and igneous rocks, was able to define an area on a triaxel diagram, which he labeled the ''Area of Bloating''. The diagram was a composition diagram with Al_2O_3, SiO_2, and flux as the three end members. (The flux was the sum of all fluxes present). By additions of any of the three end components he was able to shift clays into or out of the area of bloating, resulting in the material either bloating or not depending upon the point upon the diagram it occupied. To demonstrate that the clay minerals were not at all important he found that igneous rocks of the proper composition, when ground and formed into blocks, and fired also bloated when in the area of bloating. He believed the reduction of hematite and the formation of SO_2 from pyrite caused the bloating to occur.

Larson[13] collected and studied twelve shale and clay samples from different locations in Missouri to determine their value as ceramic raw materials. He fired small blocks in a muffle kiln until they bloated or melted down, seven of these twelve samples were found to be good bloaters, five were retested in this work.

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(12) Riley, C. M., ''Relation of Chemical Properties to the Bloating of Clays.'' J. Am. Ceram. Soc., 34 (4) 121-28 (1951).

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(13) Larson, L. N., ''Ceramic Possibilities of some Missouri Clays and Shales,'' Thesis 753, Missouri School of Mines and Metallurgy, Rolla, Missouri.

Kurtz[14] in conjunction with this project ran the firing behavior tests, which are recorded in this study. In an effort to submit as many results as quickly as possible he published a summary of the bloating tests of all samples, a copy of this list is included in this report in appendix ''A''.

In addition he conducted research into the relation of chemical composition and bloating characteristics. The two fundamental facts were restated: (1) that a gas must be formed and evolved during firing, (2) enough glass of the proper viscosity must be formed to trap the gas to result in the expansion.

Also he found that Riley's[12] ''Area of Bloating'' had considerable merit, but the main difficulty was that the fluxes form glasses of different viscosity, and with all fluxes lumped into one group this can lead to error. By differential thermal analysis methods he found that organic carbon was not burned out at low temperatures, the carbon reacted with the oxygen given off by the reduction of Fe_2O_3 to FeO forming CO and CO_2, which were the bloating gases. The role of carbon was related to bloating by operating the furnace at both reducing and oxidizing conditions for the same sample. Fe_2O_3 was found to be the best flux to add to a shale as an additive to promote bloating.

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(14) Kurtz, P. Jr., ''The Bloating of Missouri Shales,'' Masters Thesis Missouri School of Mines & Metallurgy, (1953)

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(12) Riley, C. M., Op. Cit., pp 8.

COLLECTION OF SAMPLES
and
PREPARATION FOR TESTS

The original planning work done by Dr. E. L. Clark gave consideration to the areas close to the Kansas City and St. Louis areas, as they constituted the largest market for light weight aggregates. Light weight aggregates are rather bulky for their unit value; therefore, freight costs soon reduce the value of any given deposit. As many samples as possible of different materials were located near these two large centers of population, but samples were collected in twenty five different counties of the state.

Mr. W. R. Higgs collected all the samples and his report (Appendix B) contains the exact location of the site of each sample. Mr. Higgs has also given the geologic description of the outcrops for each sample.

A hundred pound sample was taken from each bed of shale tested. A channel was dug vertically across the exposed face of the deposit and the sample was taken of the un-weathered material. A total of fifty five samples were taken in all.

Each sample was air dried, crushed in the jaw and the roll crusher, then further divided by a hammermill. Each sample was quartered until about a five pound sample remained, this material was passed through a twenty mesh (U.S. Standard) sieve. Mixed with sufficient water to make the clay plastic, small bars were formed, marked, and dried at 110° C. in preparation for the standard firing behavior test.

FIRING BEHAVIOR TEST

In the complete study of bloating two types of firing tests were conducted, and a general description of the results was published by Kurtz[14]. These descriptions of the results are published again in this report in Appendix (A). The firing behavior tests were performed by this writer, and the data for the results is included in this report in graphical form. These graphs are not of much value in light weight aggregate production, but their value is to provide information for any future structural clay products industry.

The standard firing behavior test was performed by forming 18 one inch cubes of each sample; upon each cube was printed the sample number and the pyrometric cone to which the particular cube was to be fired. Two cubes were withdrawn at each of the following cone numbers 06, 04, 02, 1, 3, 5, 7, 9, and 11. The pyrometric cones are roughly equivalent to the following temperatures 1,005°, 1,050°, 1,125°, 1,145°, 1,180°, 1,210°, 1,250°, and 1,285°C. The reason for using pyrometric cones instead of direct temperature readings was based upon the fact that cones are a measure of heat treatment as well as temperature. The amount of heat treatment is of importance in the bloating of shales, and clays which point has been stressed in several different papers.

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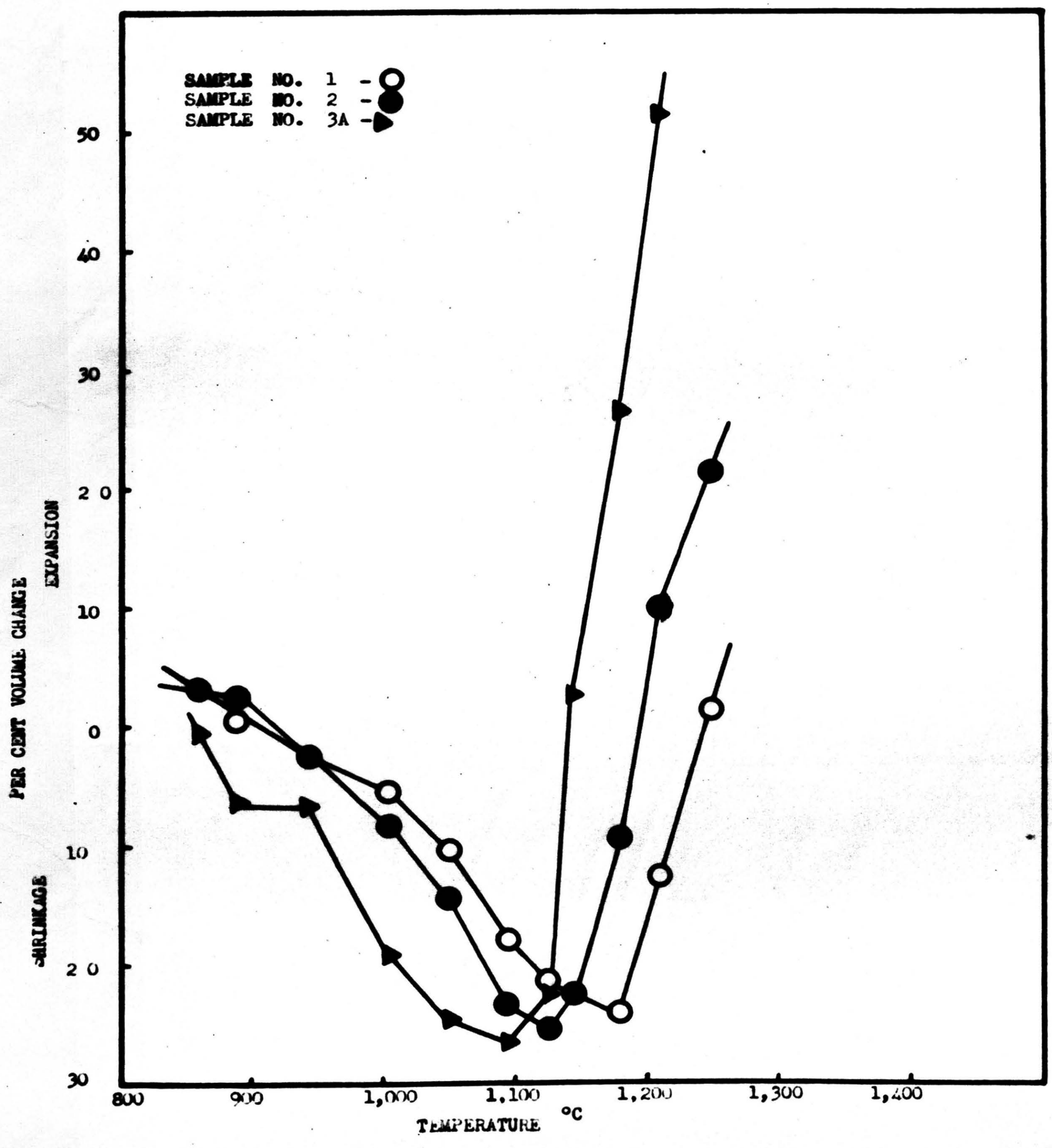
(14) Kurtz, P. Op. Cit., pp 9.

Volumes and weights of the dried cubes were taken and recorded, after which the cubes were mounted on a ''Standard Mullfrax'' split upon which was dusted fine silica sand to prevent the cubes from sticking to the split upon fusion. On each split were mounted ten cubes representing five samples, and in front of the cubes was set the cone plaque.

The furnace used for the firing was an upright electric glowbar furnace heated by six bars, the rate of heating was controlled by a Micromax temperature indicating program controller. For the first 1,050°C. the rate of heating was 60°C. per hour, thereafter 20°C. per hour. Sample splits were removed when the cone tips touched the plaques. The withdrawn splits were placed in pans of fire brick grog, and covered over with more grog to prevent thermal shock breakage.

The fired pieces were carefully dusted and then weighed and their volumes were taken, this being done to an accuracy of one hundredth of a gram and one hundredth of a cubic centimeter. The balance used was a Roller Smith Precision Balance No. 296225, and the volumeter was a mercury device made by the Missouri School of Mines Ceramic Department.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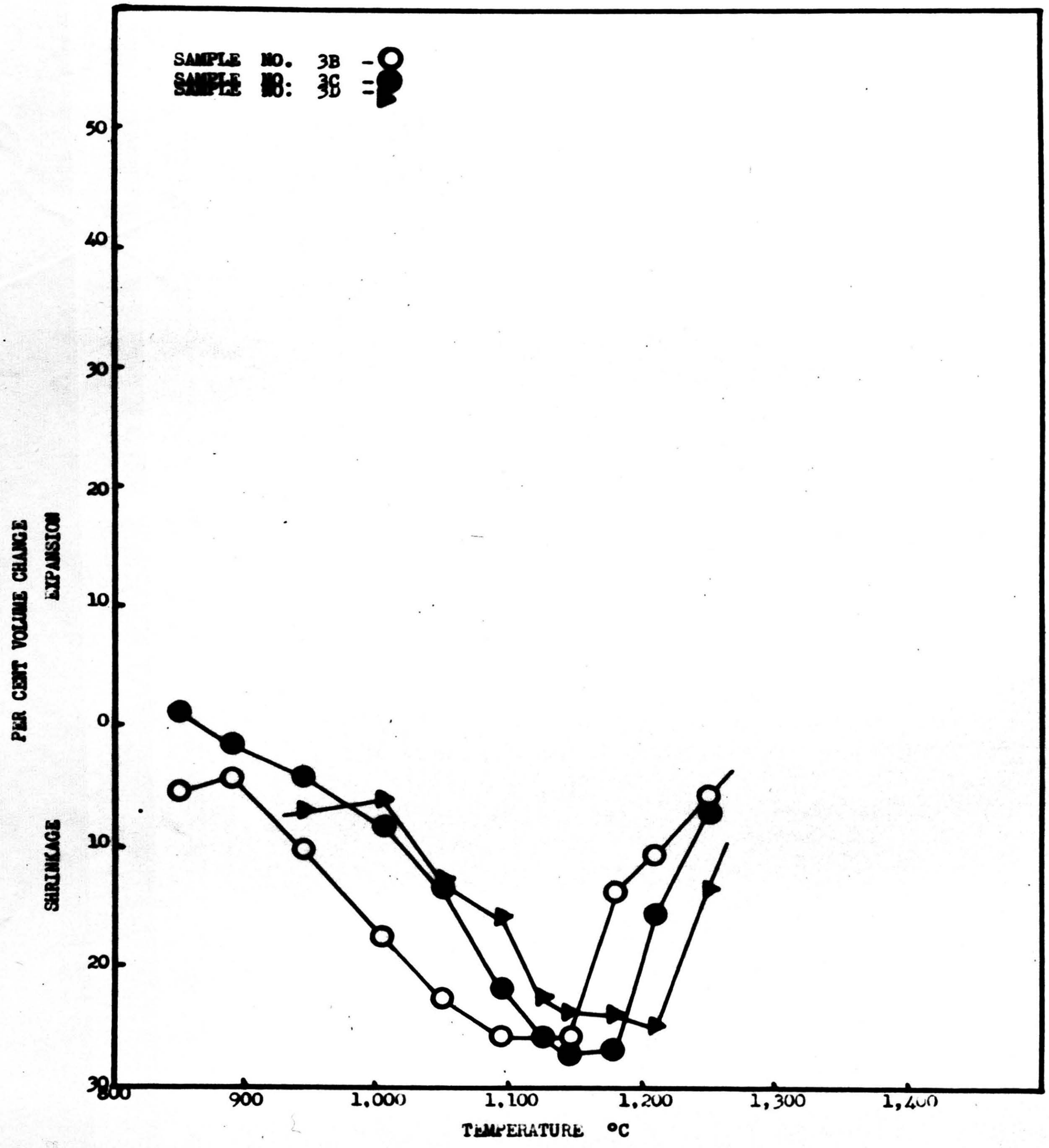
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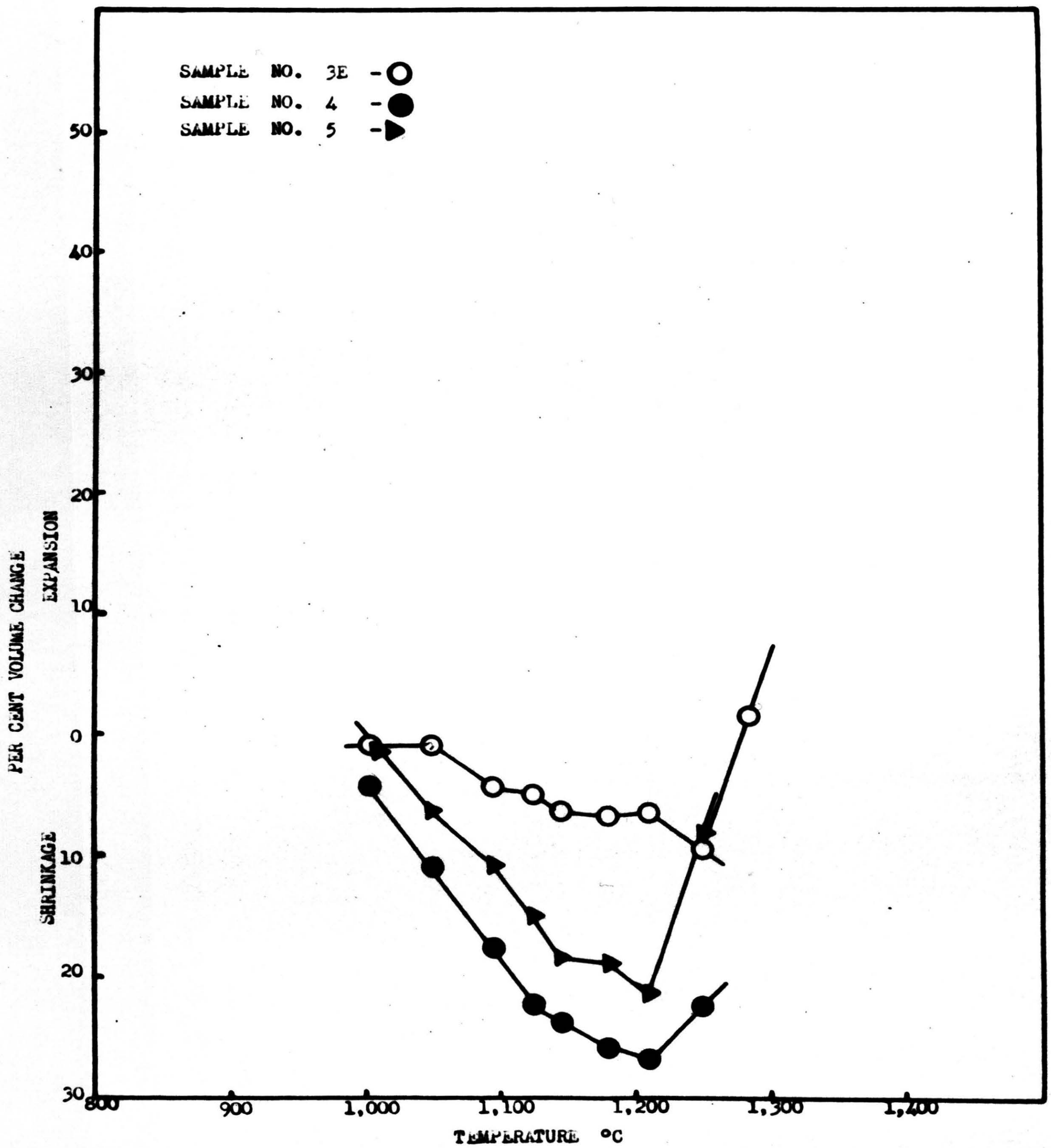

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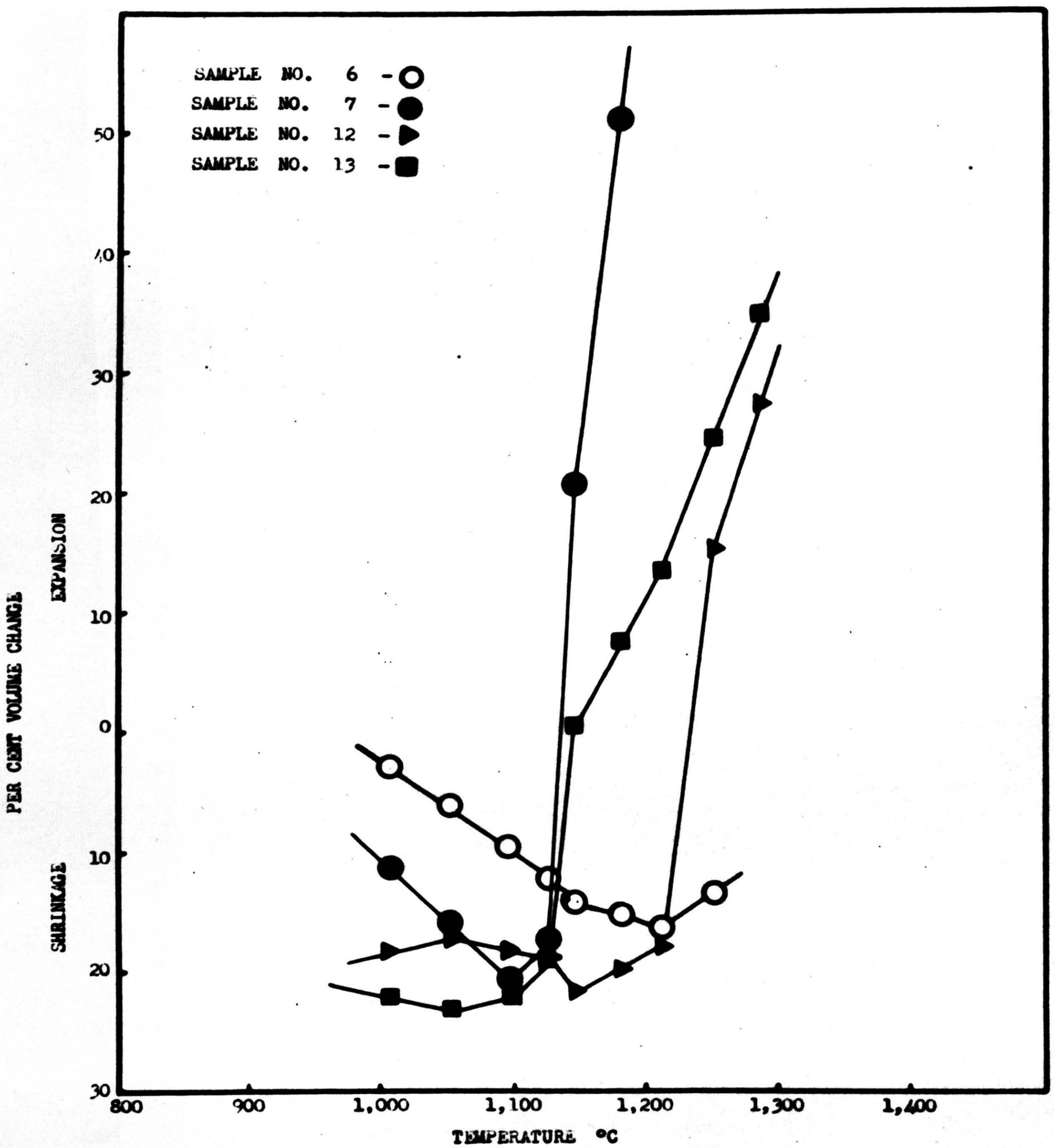

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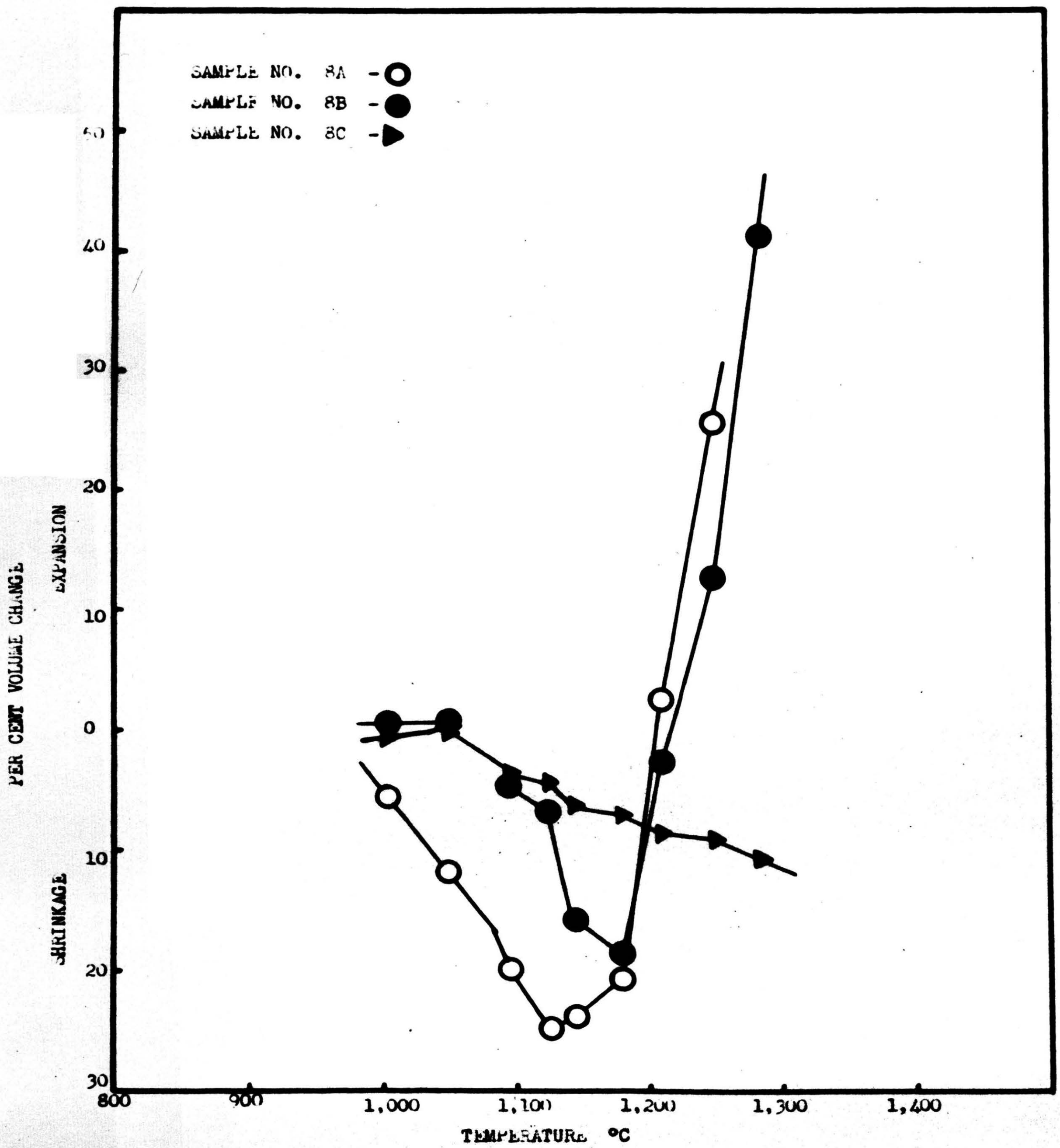
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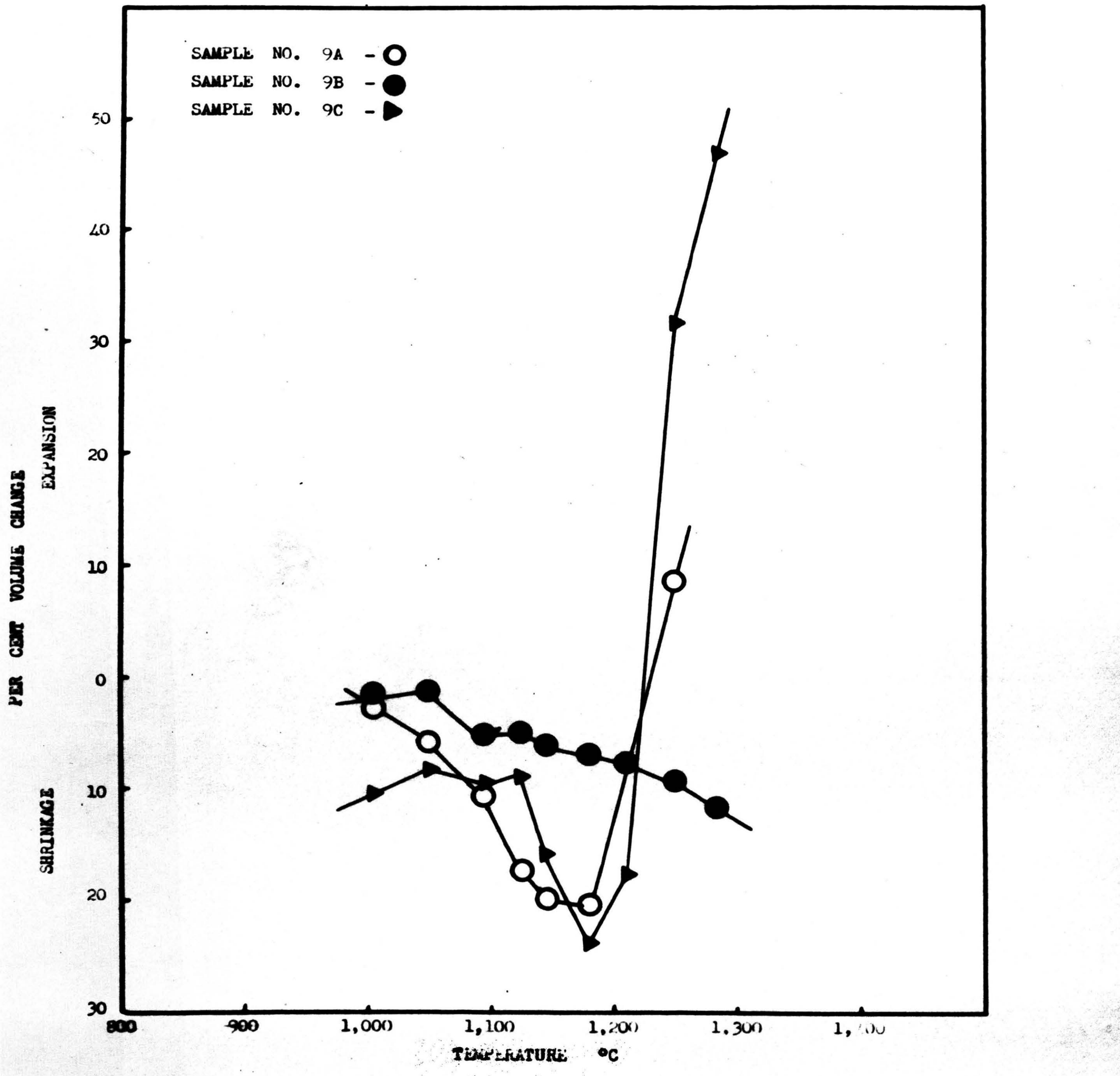

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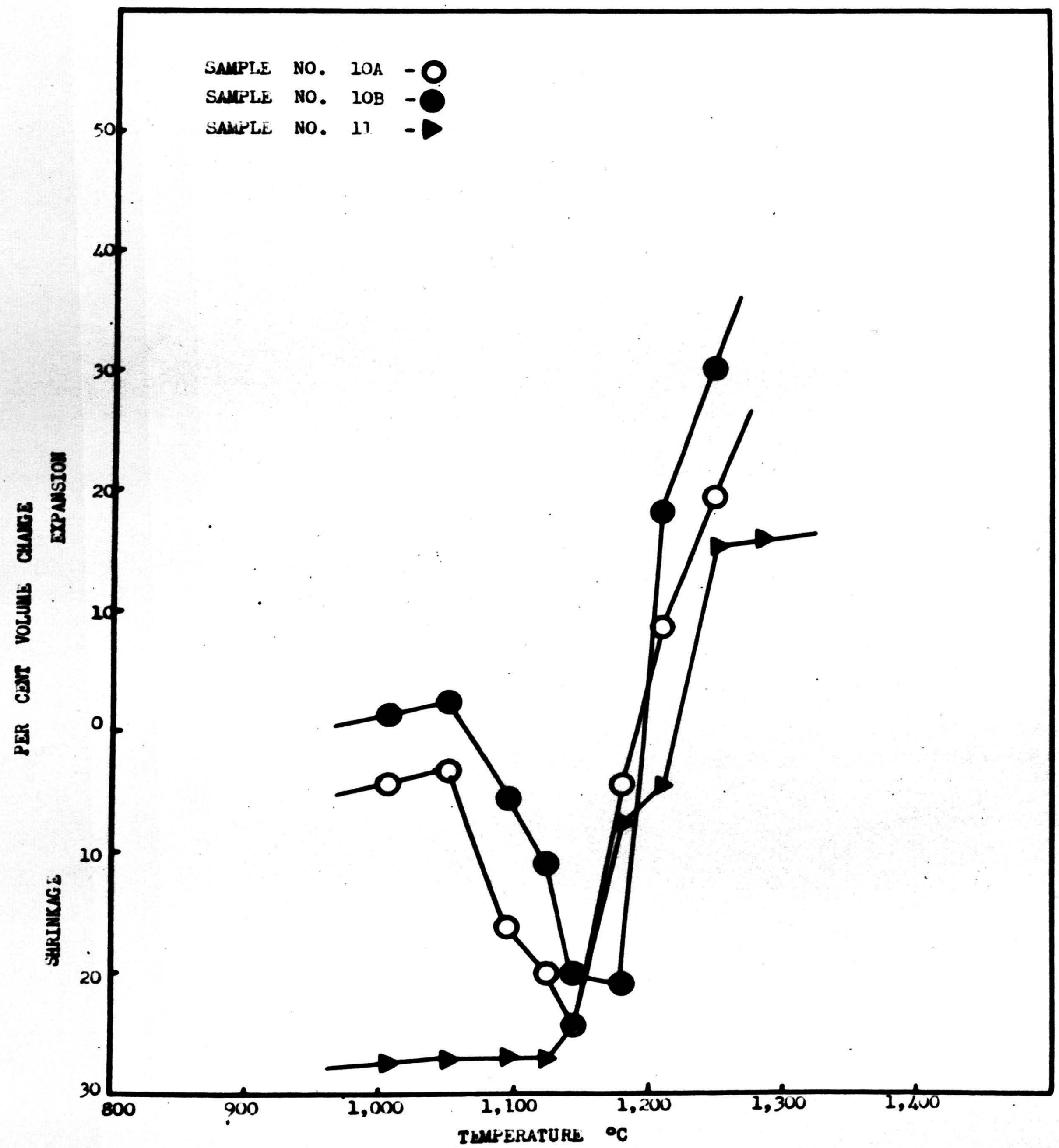
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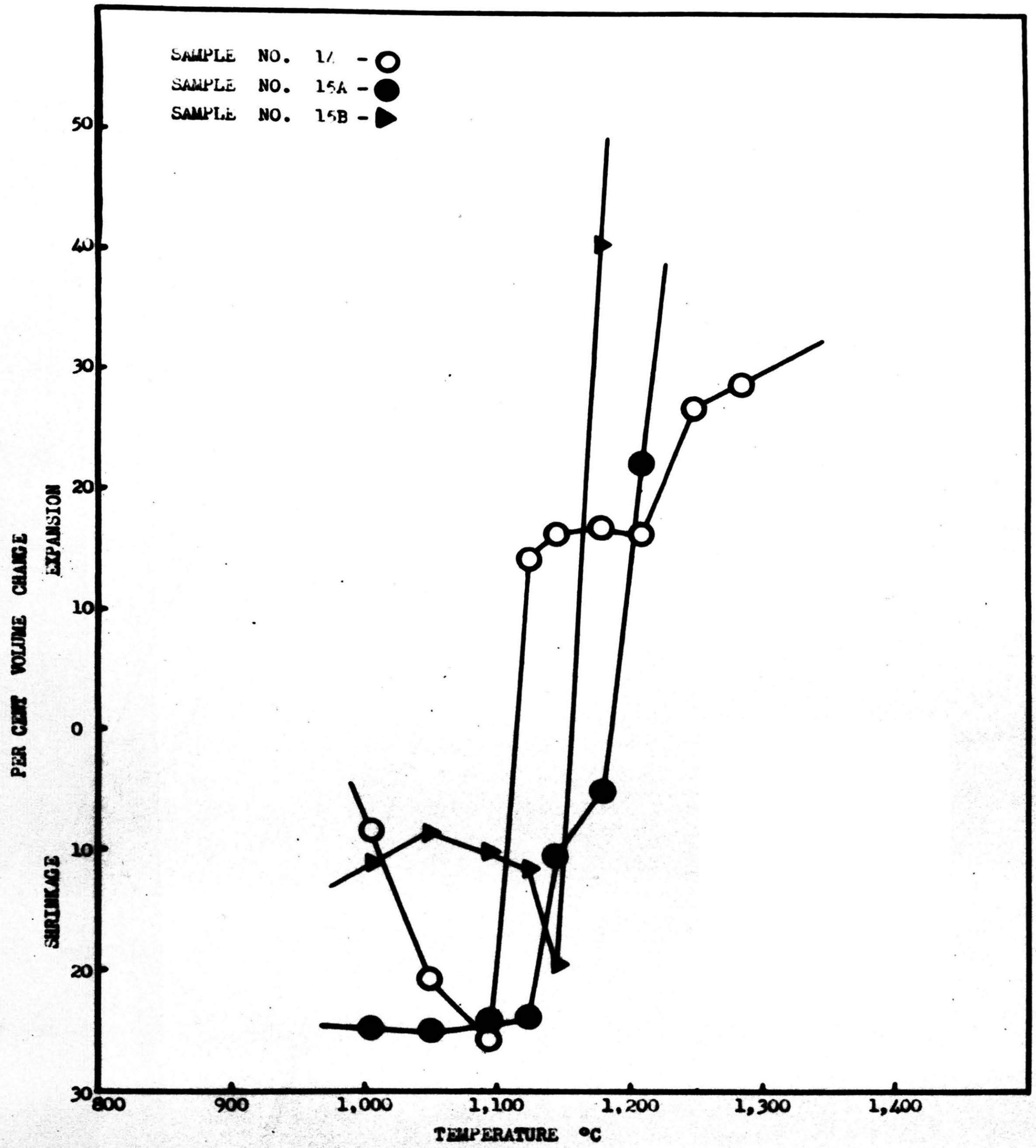
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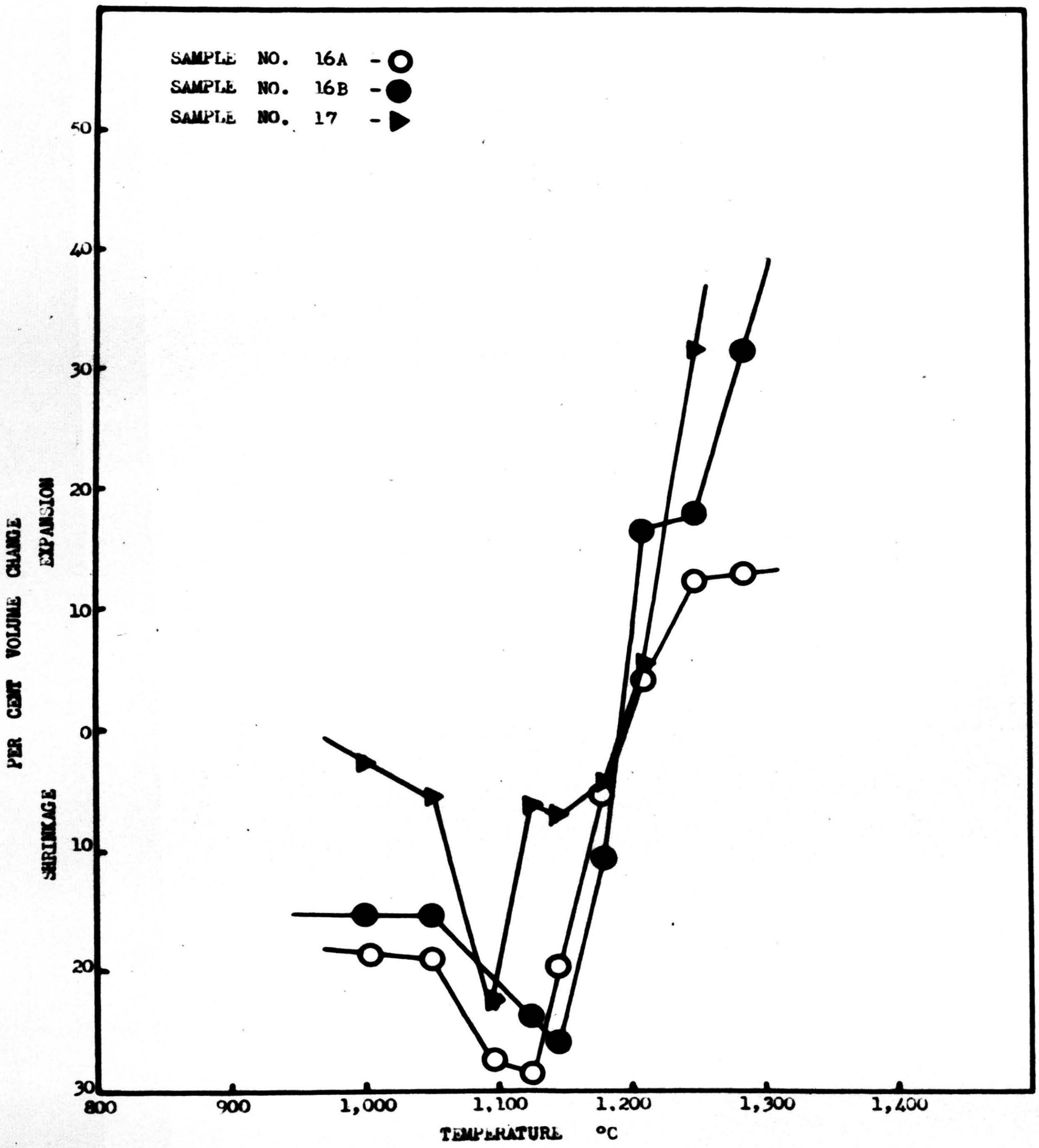

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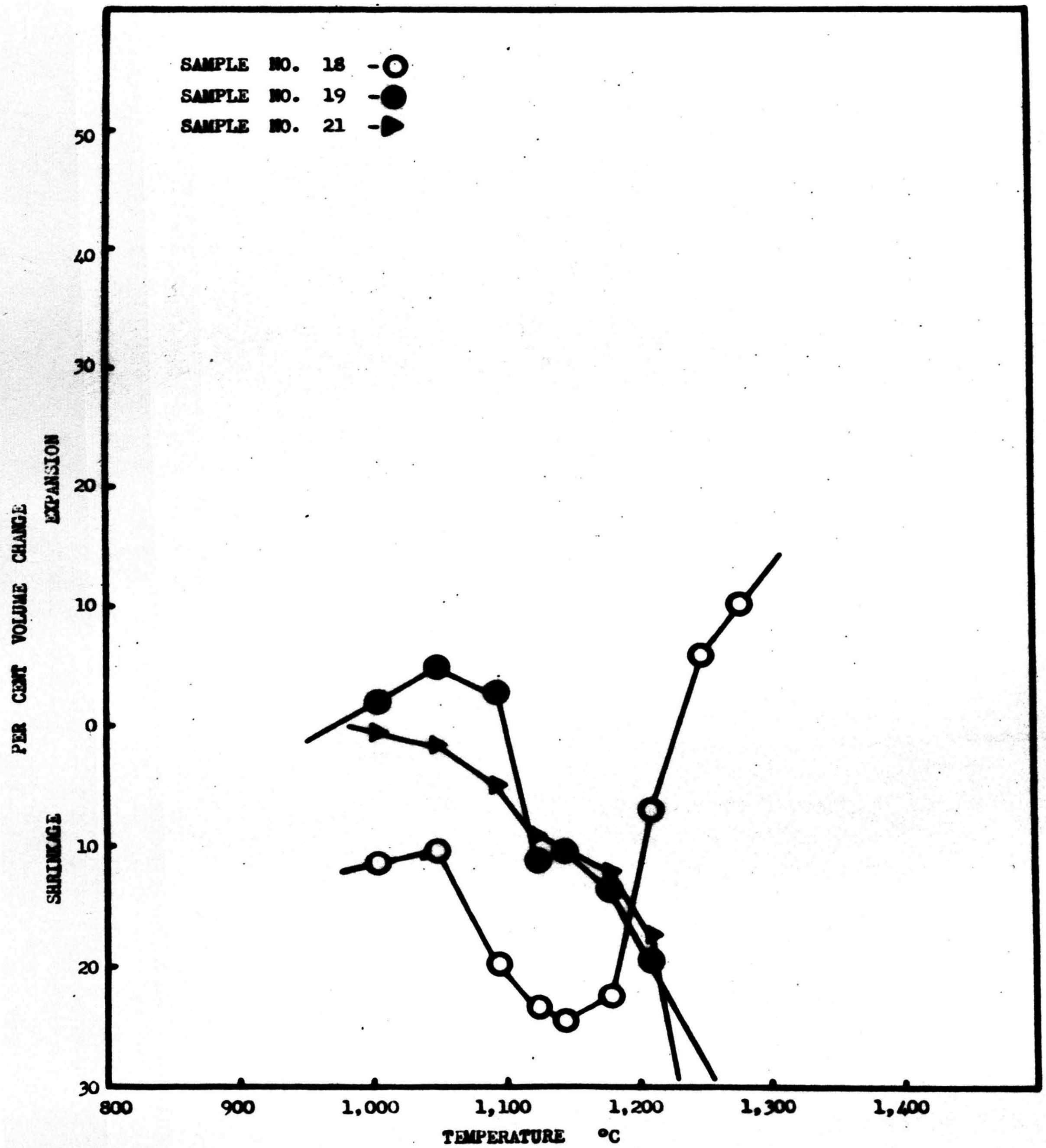
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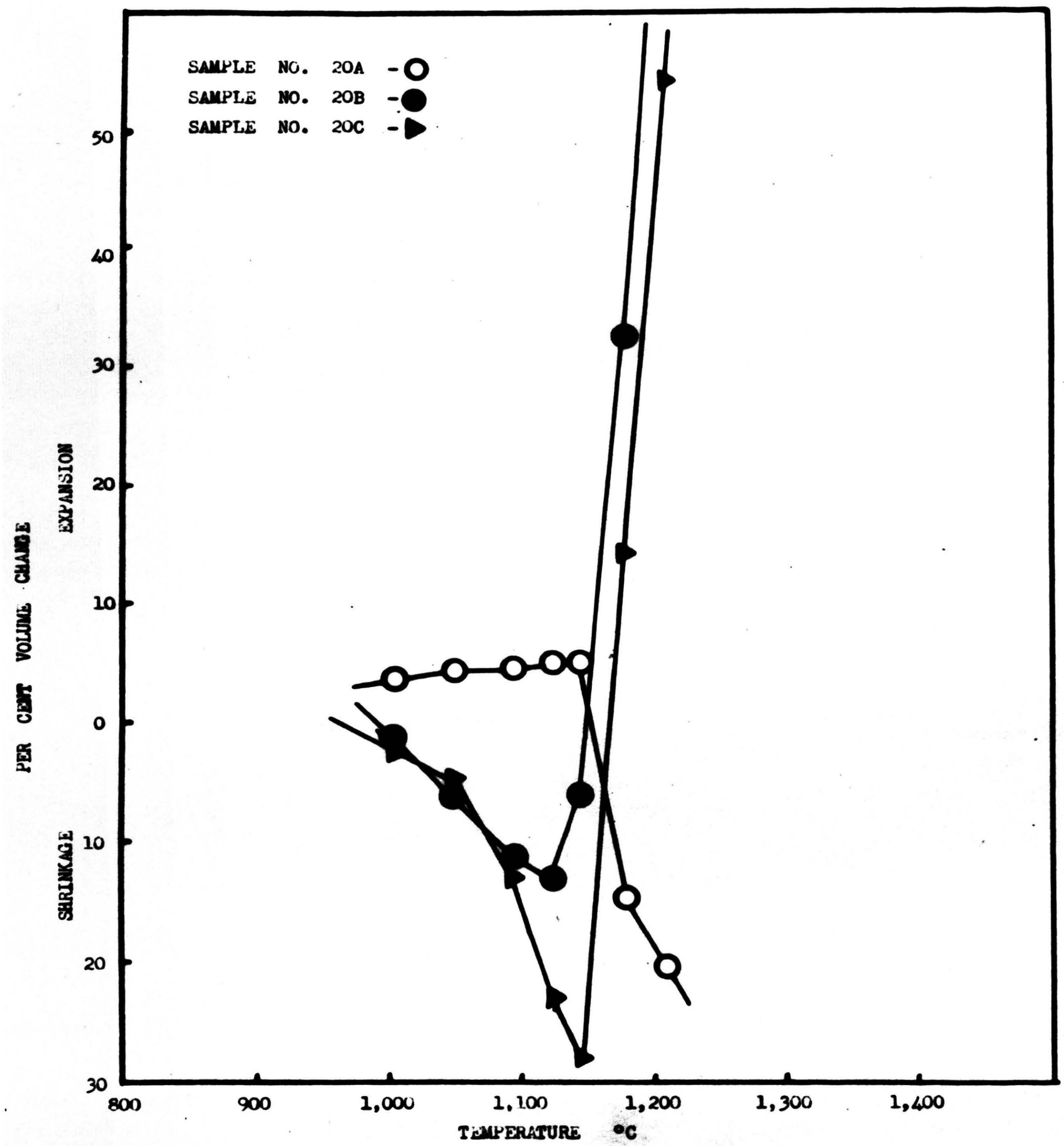
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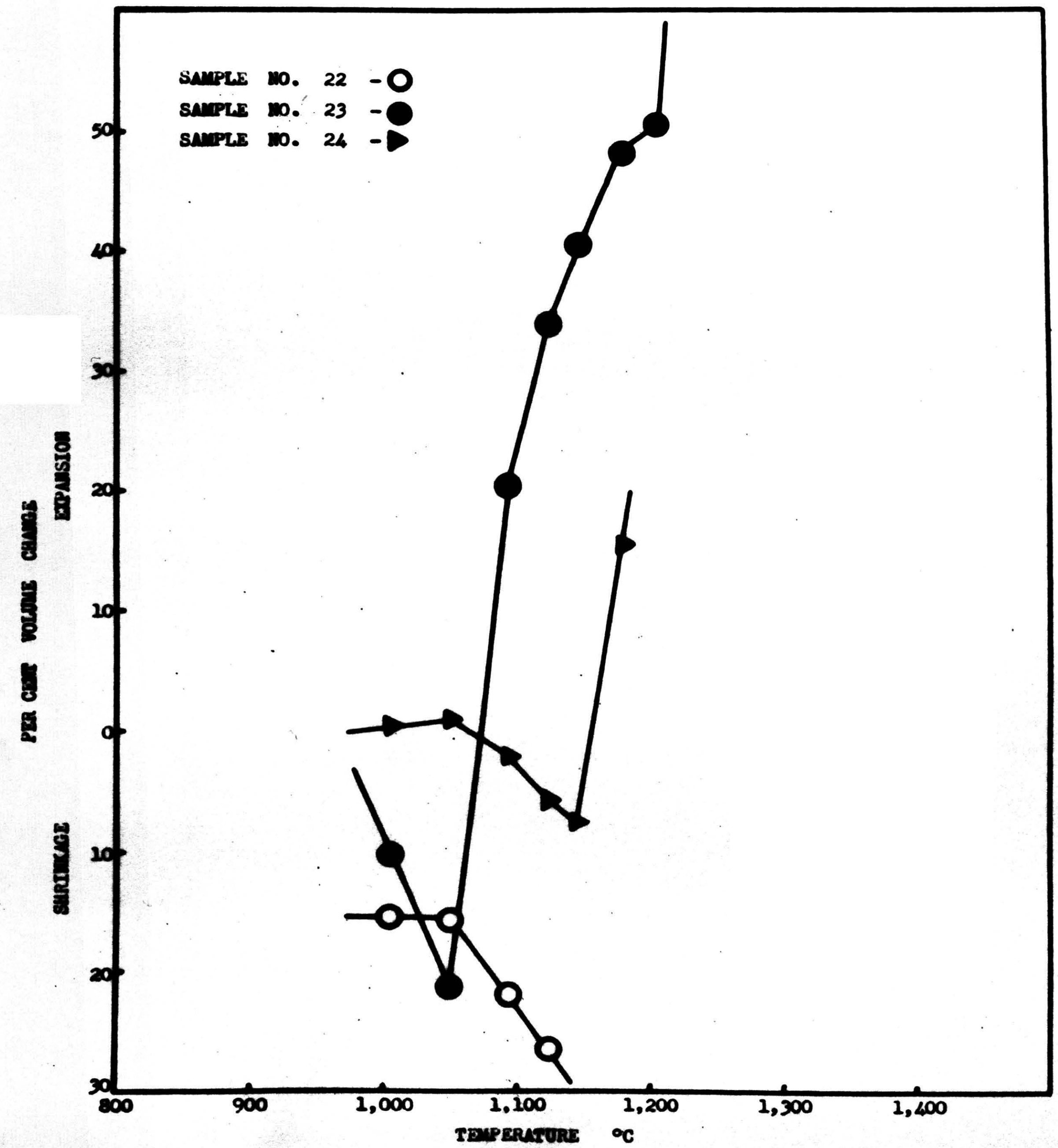
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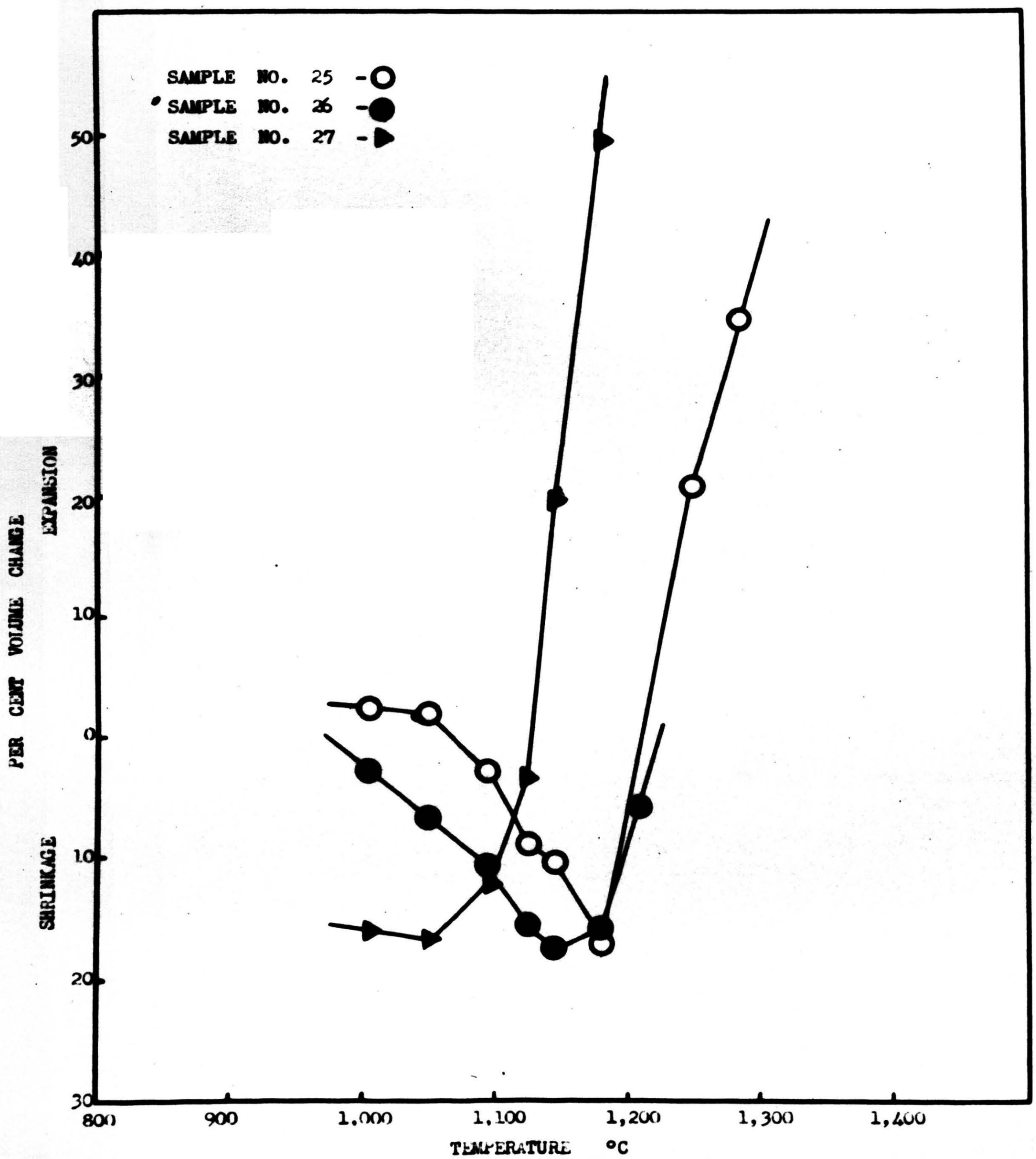
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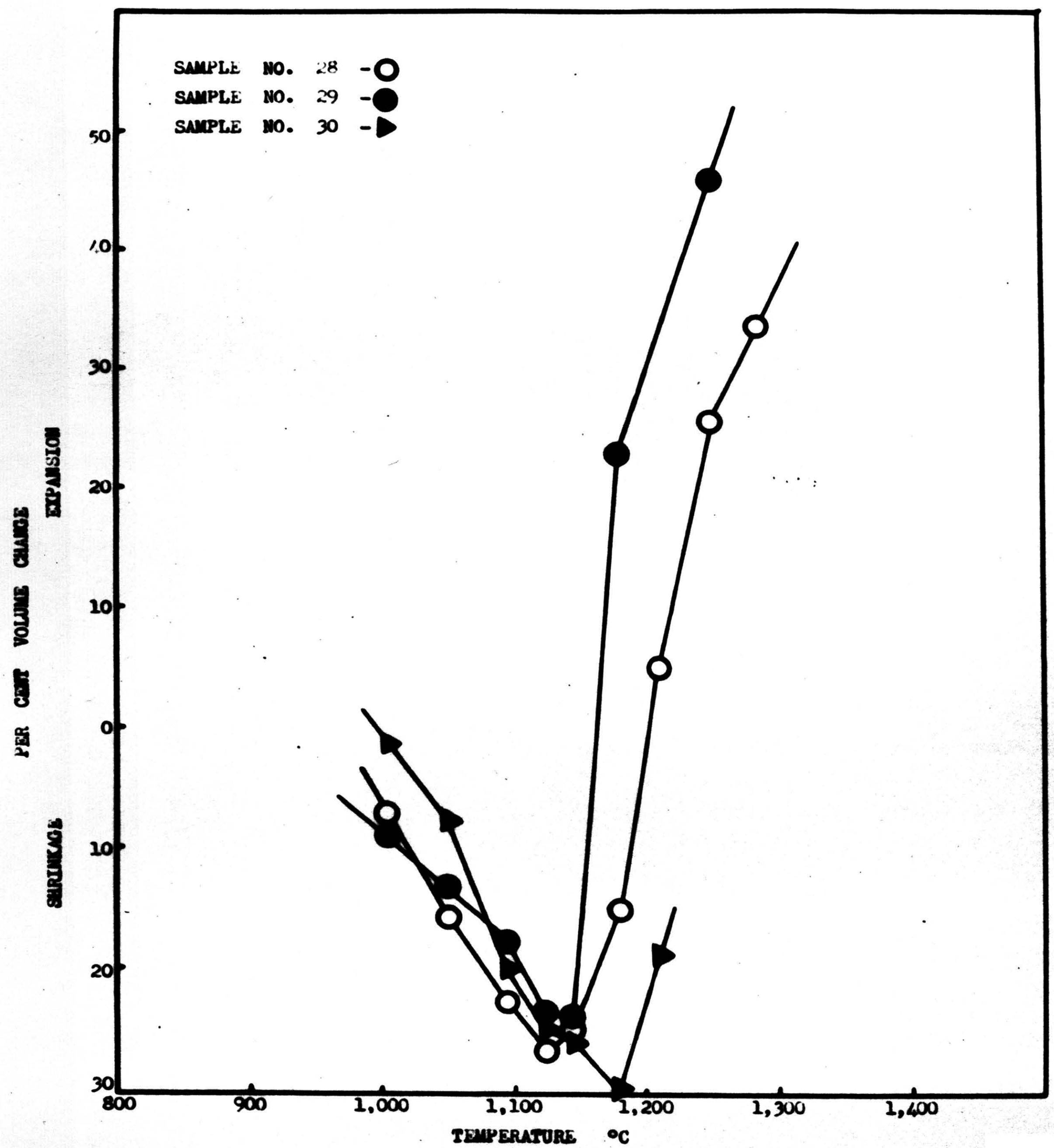
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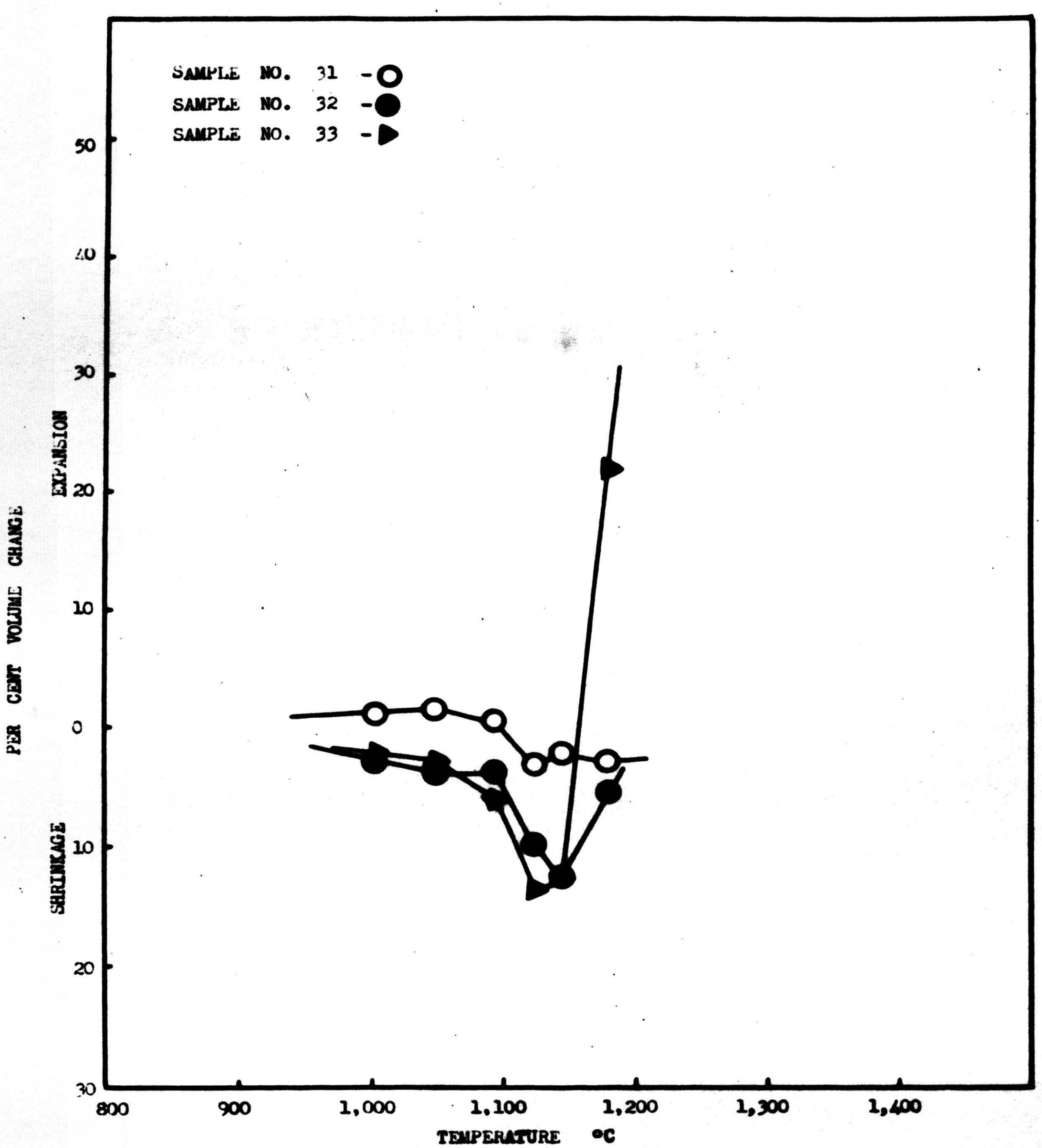
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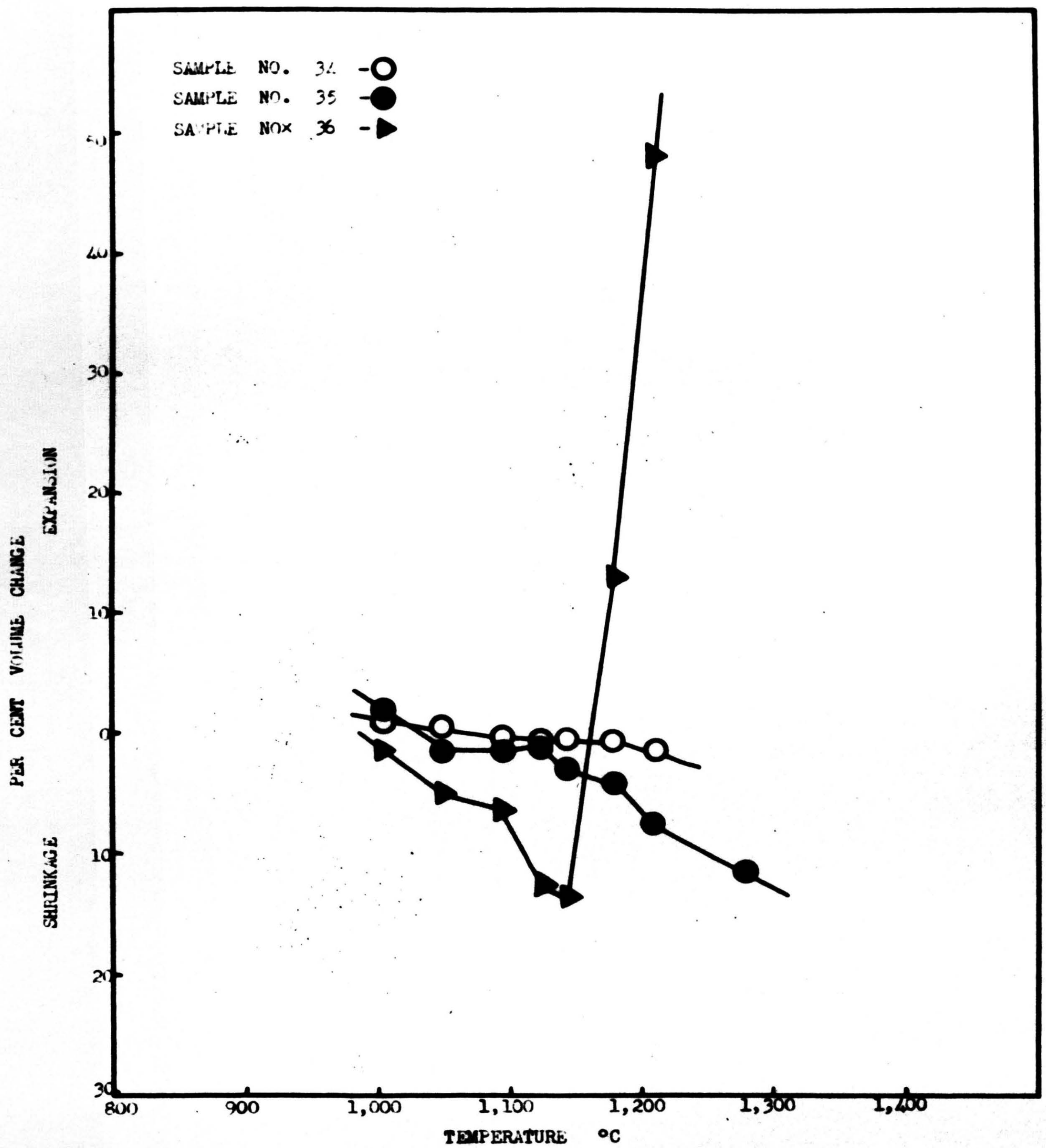

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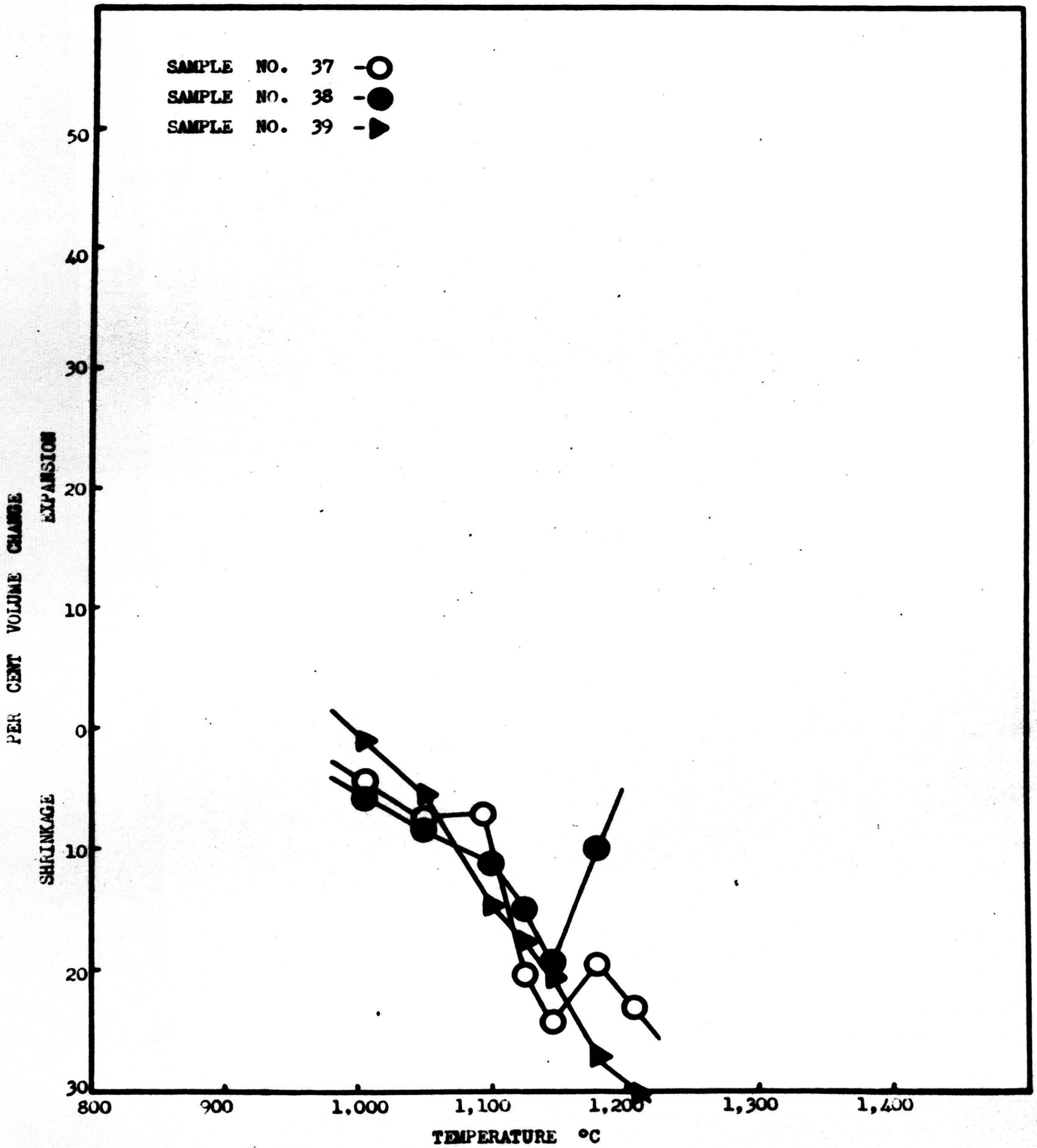

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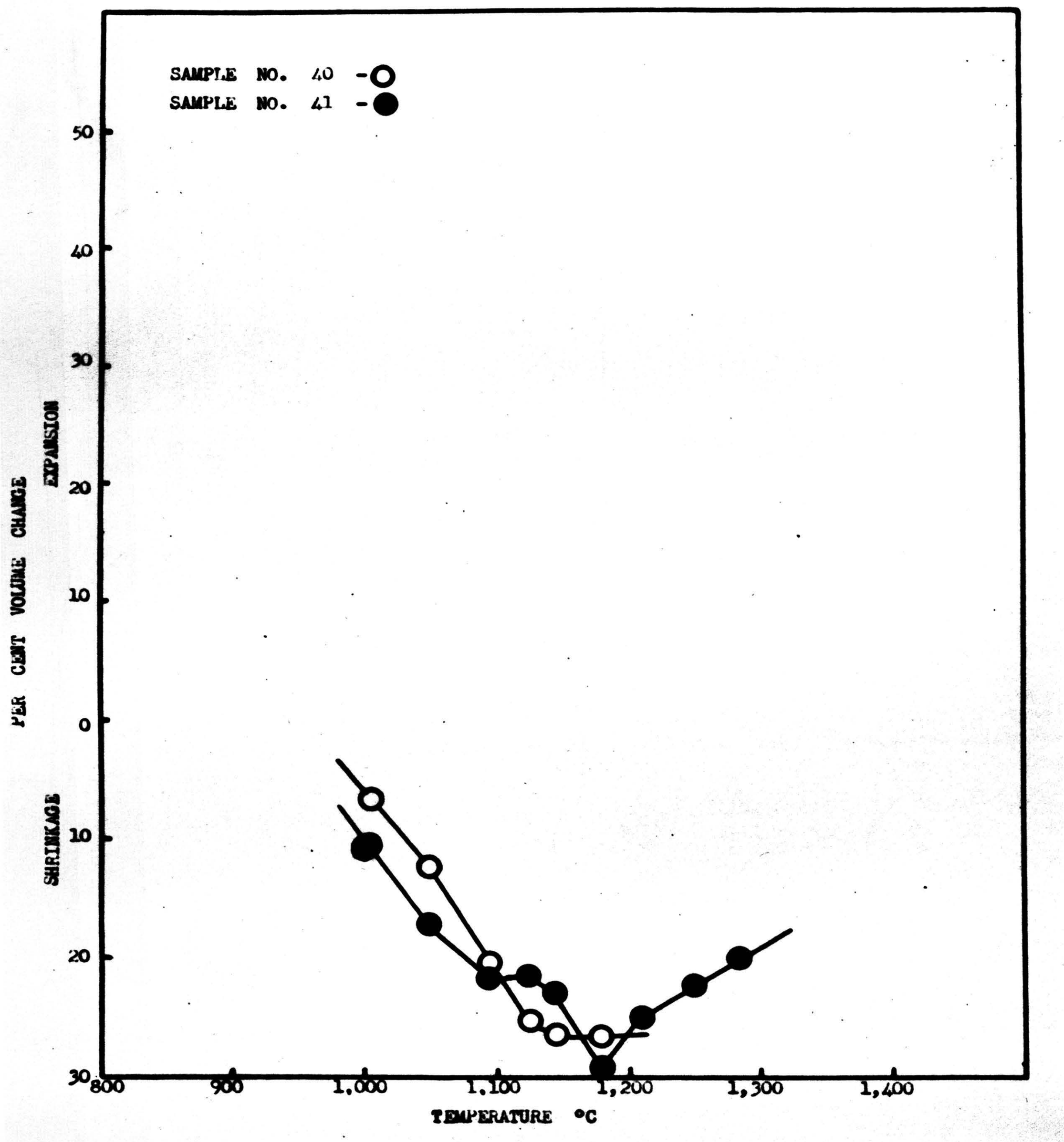
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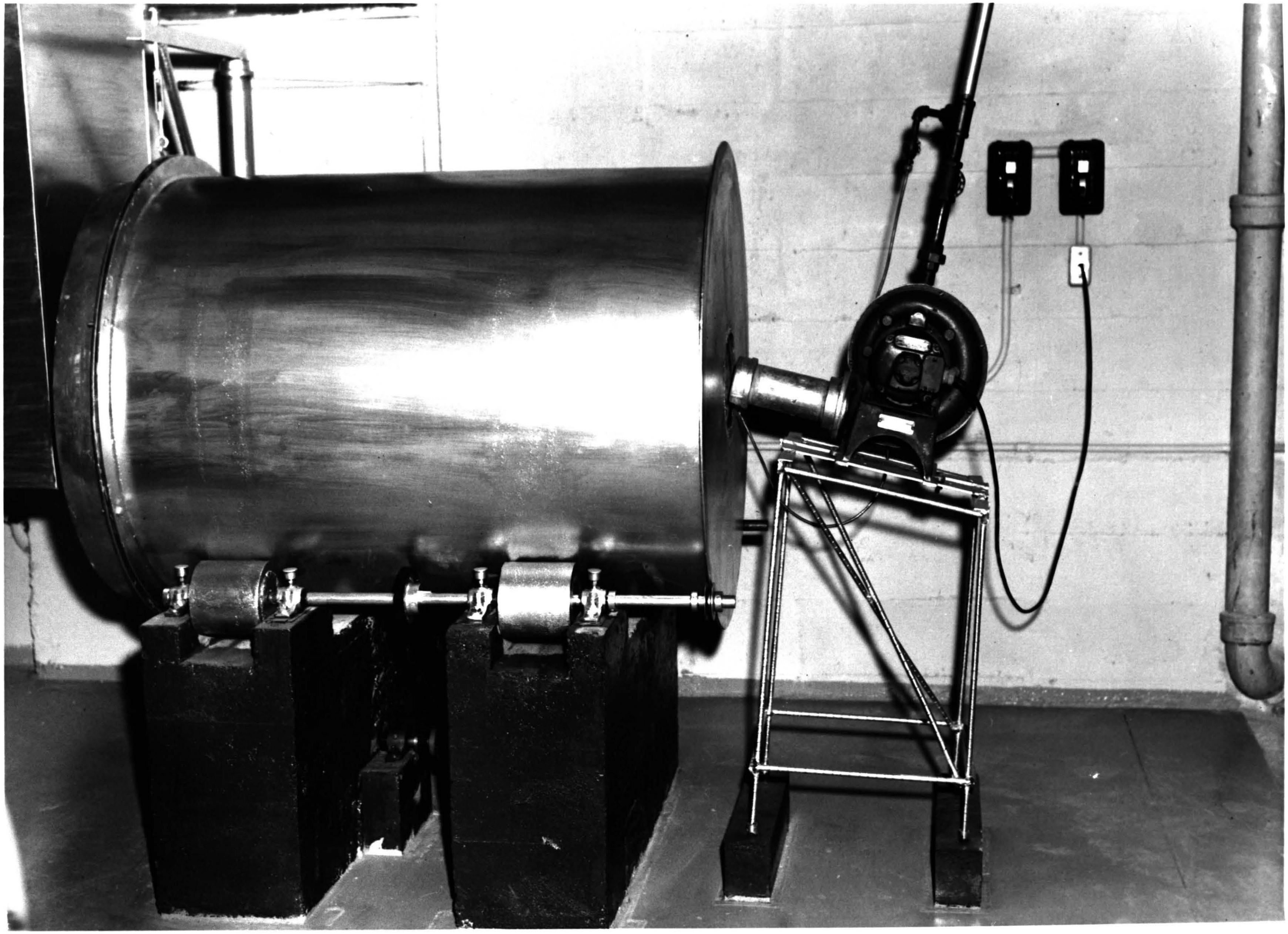
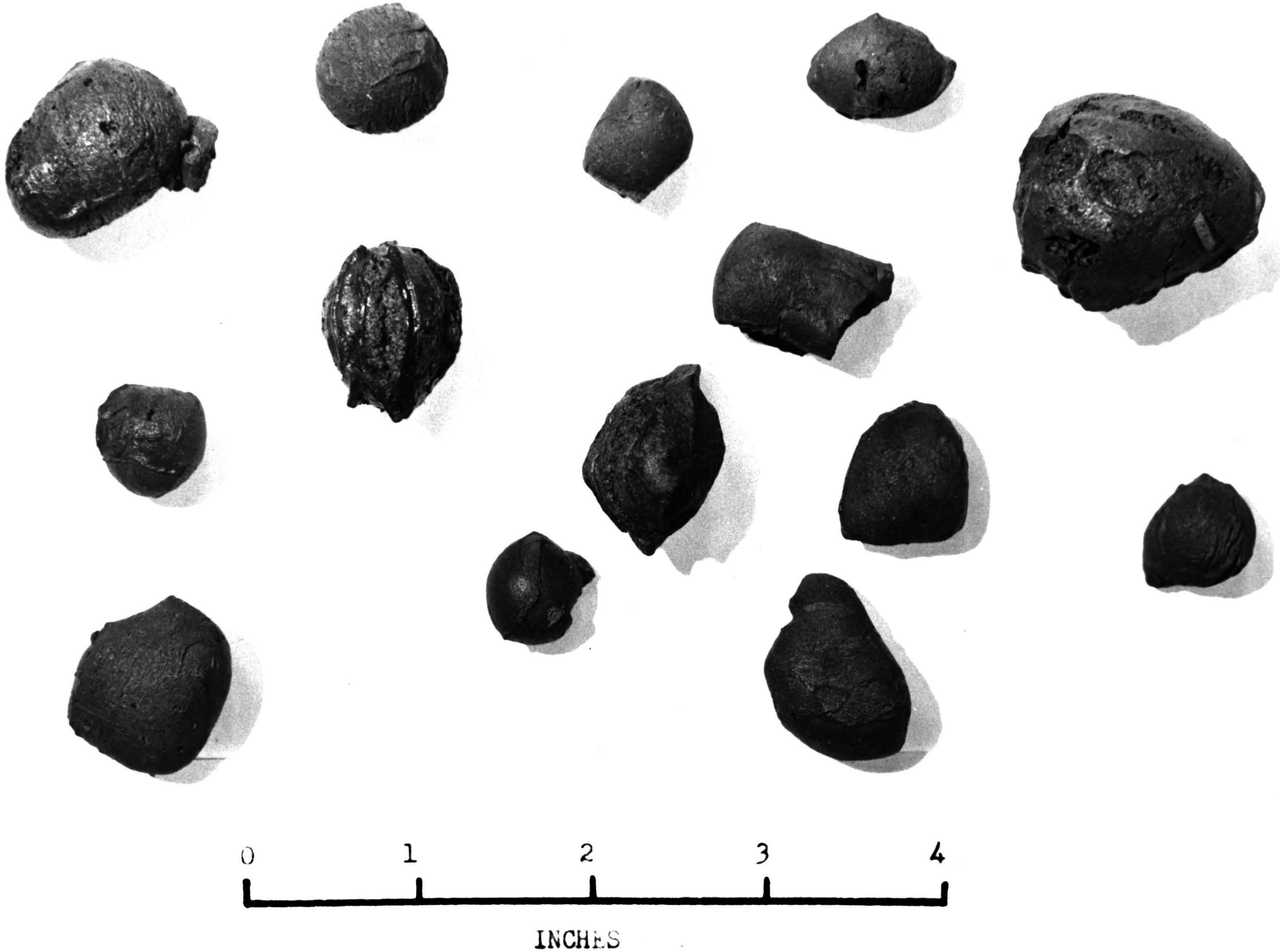
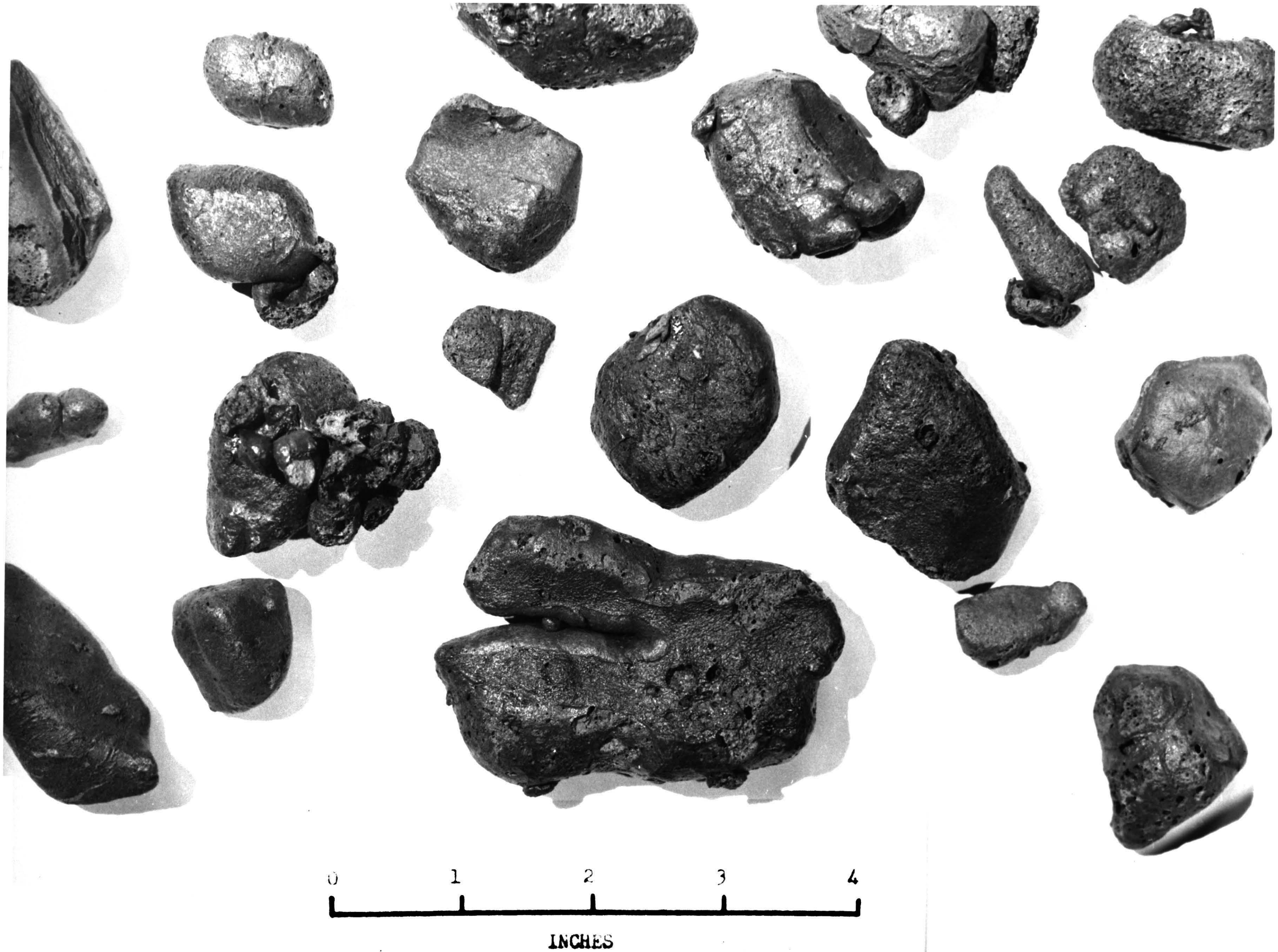
1,400
TEMPERATURE °C



ROTARY TEST KILN

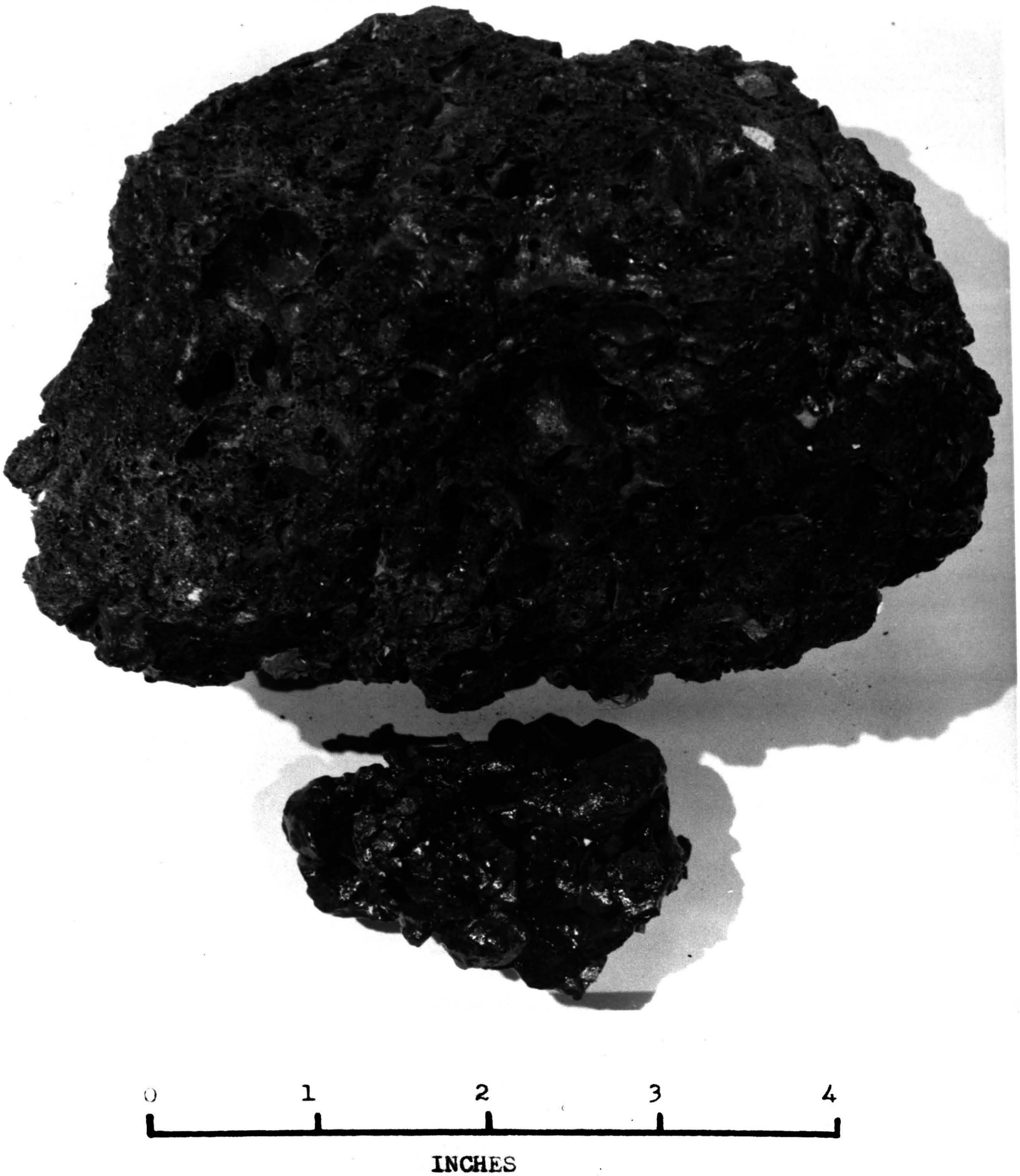


PHOTOGRAPH OF BLOATED SAMPLE NO. 2



PHOTOGRAPH OF BLOATED SAMPLE NO. 7

PHOTOGRAPH OF BLOATED SAMPLE NO. 23



PHOTOGRAPH OF BLOATED SAMPLE NO. 38

OPERATION OF THE ROTARY KILN

A batch rotary kiln was designed by Mr. Peter Kurtz, and built during the summer of 1953 by Mr. Kurtz assisted by Mr. W. T. Harper. The attached photo gives some idea of the size and shape of the kiln. The kiln was made to operate on a batch principle but still give results which could be compared to a standard rotary kiln of much larger size. Mr. Kurtz and Mr. Harper had only time to complete the construction of the kiln and to fire once to set the mortar holding the inside refractory material.

As a result of this first firing three modifications of a very minor nature were evidently needed to assure good and continuous operation of the kiln. These were: 1. Modification of the exhaust port to keep the flame from impinging upon the metal of the lid or door, 2. The inside of the exhaust stack was lined with a piece of transite to keep flames from the exhaust port from striking the metal of the stack. 3. A sighting hole was cut in the back of the exhaust stack to allow a direct view into the exhaust end of the kiln enabling temperature readings to be taken with an optical pyrometer during the firing of the kiln.

As the inside of the kiln was lined with insulating fire brick, which are friable and would wear rapidly from the impact of the sliding shale charge, a coat of mortar was added to the inside of the kiln. This served to protect the insulating fire brick from abrasion, and from attack by the glass of the molten shale charge. An attempt was made to coat over the layer of mortar with a layer of granular silicon carbide set in sodium silicate. The grains of silicon carbide were used to prevent the wetting of the mortar by the glassy phase of the aggregate. This idea did not prove successful as the bonding strength of the glassy phase and the silicon carbide was greater than the strength of the bond between the sodium silicate and the silicon carbide. The result was the carbide grains adhered to the surface of the molten shale. This might not have been true for some of the other materials tested later, but the sample used in the first firing was 20-B which proved to be the sample most prone to overbloating.

After several firings the following methods proved the best for the operation of the kiln. Here is the check list used in starting the kiln.

1. Introduce clay into the kiln.
2. Close and secure the door, tighten all door bolts.
3. Loosen turnbuckle to disengage door from the supporting arm.
4. Drop exhaust hood into position. (Open Draft)
5. Light pilot light.
6. Start furnace drive motor, this rotates the kiln.

7. Start exhaust fan.

8. Close burner air draft.

9. Start burner motor.

10. Open gas valve on burner to admit an excess of gas.

11. This will give a large bushy yellow flame.

12. After about ten or fifteen minutes of operation slowly open air port on burner till the flame begins to flutter, close the valve slightly. Repeat this operation every ten minutes or so until the kiln temperature exceeds 900°C.

13. After 900°C. check burner frequently. The gas quantity should be just sufficient to cause a slight amount of yellow flame to sweep out the exhaust port into the exhaust hood.

14. As the kiln continues to operate, check the rollers for clearance with the concrete supports.

15. To shut off furnace turn off main gas valve, and pilot light, then shut off burner blower and close burner air port.

16. Exhaust fan should be kept running for about fifteen minutes after the burner is shut off. This will allow the kiln to drop in temperature sufficiently to keep the charge from attaching itself to the kiln wall if it has over bloated and formed into a log.

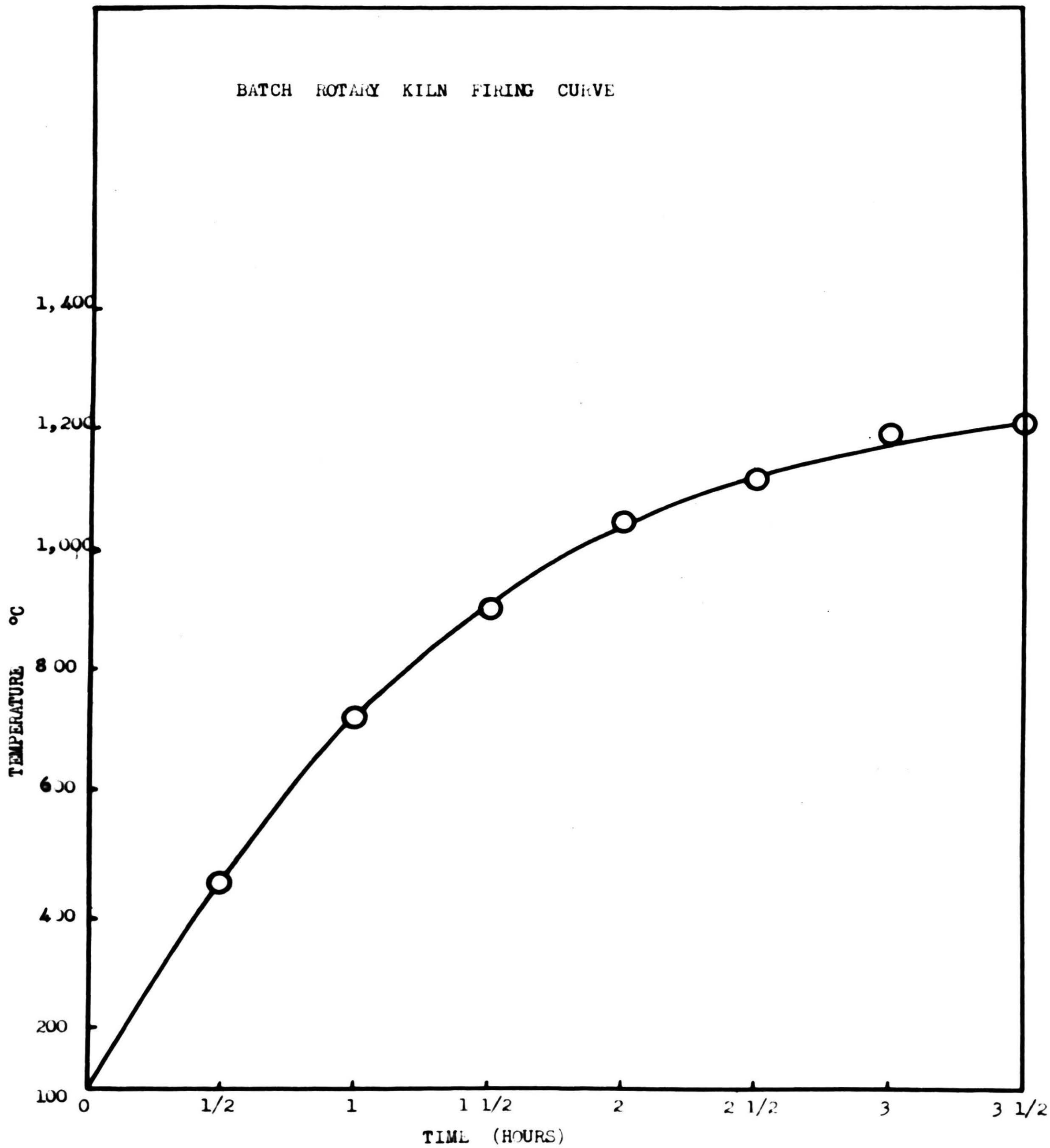
17. While waiting for the kiln temperature to drop, turn each grease cup one-half turn, and oil blower and drive motor.

After cooling the furnace door is unbolted and the charge removed. The appearance of the charge at this point will vary quite widely. Sometimes it forms into large logs or ropes of material, and at other times it adheres very strongly to the kiln wall and must be rodded off. The factor of sticking to the kiln wall could be of great importance to a commercial plant; therefore, this point was added to the comments on results of the bloating.

The first question to arise in connection with production of aggregate was, what size should the feed to the kiln be? Three charges of the same material were made and fed into the kiln. The sizes and results are as follows: 1. Three quarters to one and one-half inch diameter material did not bloat evenly and required a longer time for bloating. This fact was due to the poor heat transfer into the inside of the particle, as the outside of the particle reached bloating temperature, bloating resulted, and this very effectively insulated the inside from further heat penetration. 2. A charge of size three quarters of an inch down to dust resulted in uniform bloating, but the charge had a greater tendency to roll into a ''log'' and to stick to the kiln wall. This was believed to be due to the small particle being rapidly melted and acting as a glue between the others. 3. The third charge was of the size three quarters down to one-eighth of an inch diameter. This charge proved to be the optimum one, with good bloating and a minimum sticking tendency.

After determining the proper size of the raw material, the testing was then one of pilot plant operation. A rough calculation revealed that we would need to run about four twenty-five pound batches of raw material to get the proper amount of aggregate needed for four test cylinders and a small surplus.

In the pilot plant stage of the project great care was taken to prevent over bloating, which proved to be the big problem with some samples, particularly sample 20-B. On over bloating sample 20-B would form logs, on the other hand sample 4 would adhere to the kiln wall on over bloating. The other samples formed loose masses which could be broken apart with the fingers, but the individual particles were very strong. Sample number 2 formed individual spheres, or rounded shapes of different sizes. This sample seemed ideally suited for the manufacture of light concrete using these particles graded into the proper size range. Thus after a few tests to determine the correct raw material feed for any particular size range an aggregate would be produced to fit any particular need. Also these spheres were noted to be very strong as the outside surface was covered with a film of burned material, which was without holes. Of the seven samples tested, five (2, 3, 4, 7, and 20-B) bloated and produced good aggregate, while sample 23, and 38 did not bloat, and no aggregate was produced from these two materials.


BATCH ROTARY KILN FIRING CURVE
TEMPERATURE °C
1,400
1,200
1,000
800
600
400
200
100
0
1/2
1
1 1/2
2
2 1/2
3
3 1/2
TIME (HOURS)

COMPRESSION STRENGTH TEST OF LIGHT WEIGHT AGGREGATES

The purpose of this test was to determine the relative strength of the five aggregates produced in the batch rotary kiln (samples 2, 3, 4, 7, and 20-B) and to compare strengths with a commercial product (Sample X). To show only aggregate strength such factors as grain size, moisture content, cement ratio, mixing, forming, and curing conditions were held constant or as nearly constant as possible. Standard methods were used and followed closely.

With respect to grain sizing, as most lightweight aggregate producers sell their product to lightweight block manufacturers, most aggregates are ground to the grade BX Haydite. The published sieve analysis for grade BX Haydite is as follows, 5 to 15% retained on No. 4 sieve, 30 to 45% retained on No. 8 sieve, 60 to 70% retained on No. 14 sieve, 77 to 84% retained on No. 28 sieve, 85 to 90% retained on No. 48 sieve, and 90 to 95% retained on 100 mesh sieve. (All sieves are U. S. Standard)

Approximately the median value of each size range of BX Haydite was used, the following was the sieve analysis of materials used in the making of the compression test cylinders. Nothing larger than 3/8'' diameter, 10% retained on 4 mesh, 27.5% retained on No. 8 sieve, 27.5% retained on 14 mesh, 15.5% on 30 mesh, 7% on 50 mesh, 5% on 100 mesh and 7.5% through 100 mesh.

The five aggregate samples were ground first in the jaw type crusher, then in the roll crusher and run through a sieve stack. The exact amount of each sieve size was weighed separate, then blended together, this gave every sample exactly the same particle size distribution. The commercial material was run through the sieve stack and weighed quantities of each size were blended together in the same manner as the aggregate produced in this study.

The total weight of the crushed and blended material was sixty pounds. This was carefully mixed to blend all particle sizes evenly, then five cardboard test cylinders were filled with aggregate and weighed to determine loose bulk density in accordance with ASTM test C 29-46. In commercial practice lightweight aggregates are blended with cement and water on a volume basis. As this seemed the most practical procedure it was followed in this work. The volume of aggregate was determined and cement and water were added on the basis of six sacks of cement, and 5.5 gallons of water per yard of aggregate. This was calculated to be 20.5 pounds of cement and 2.91 pounds of water. The trial mixture was run and there was not sufficient water because the aggregate absorbed a large amount. The amount of water was determined and proved to be 8.73 pounds of water per sample.

Each sample was mixed in one batch. The mixer was started, the aggregate was introduced followed by the amount of water. These materials were allowed to mix for two minutes, then the cement was added and the mixer was timed to run for eight minutes with all ingredients mixing together. After the mixing was complete, as timed, the contents of the mixer were dumped into a large flat sheet metal pan from which the concrete was taken by a shovel and introduced into the test cylinder forms.

In the making, curing, and testing of compression cylinders ASTM test C 39-46 was used. Again great care was taken to insure that all operations were duplicated for each cylinder in exactly identical methods.

TABLE I

COMPARISON OF COMPRESSION TEST RESULTS ON CONCRETE

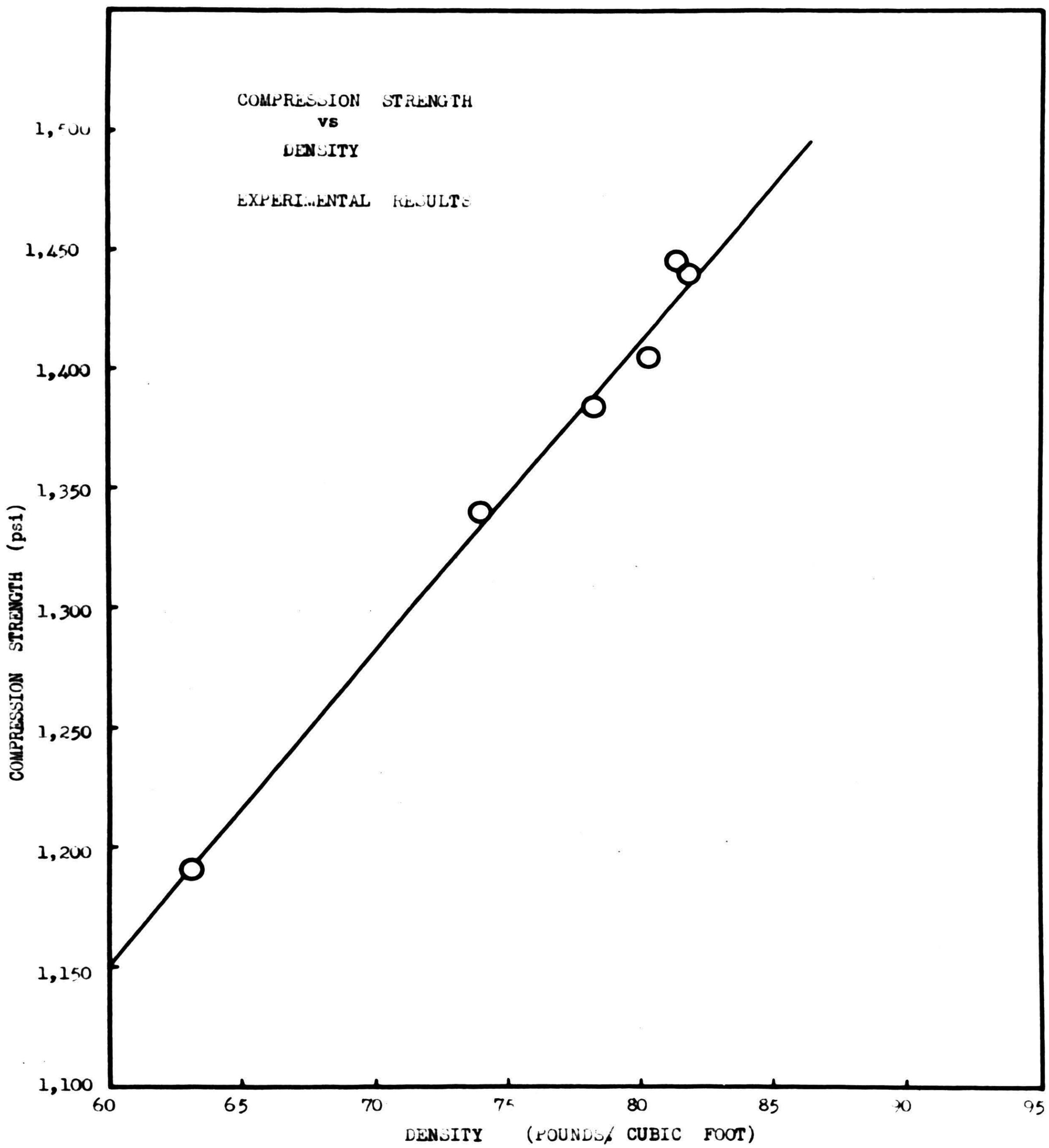
TEST CYLINDERS PREPARED WITH LIGHTWEIGHT AGGREGATE

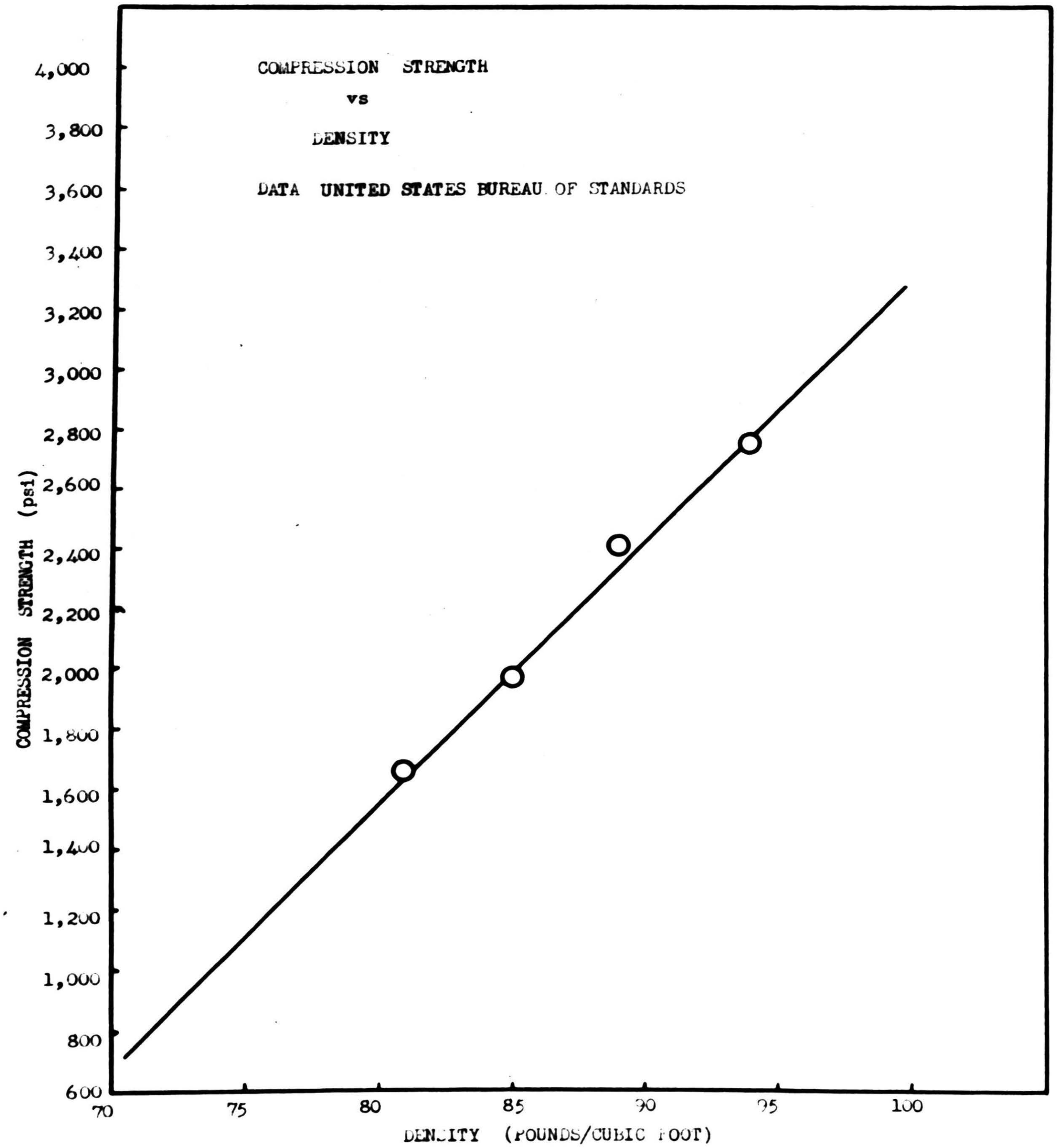
Sample No. & Test Cylinder No.	Bulk Density of Aggregate #/Cu. ft.		Density of Concrete #/Cu. Ft.	7 Day Compression Strength (psi.)
20-B	46.5			
1.			78	1,395
2.			78.5	1,350
3.			79.0	1,420
4.			77.5	1,375
		Mean	78.25	1,384
2	52.5			
1.			81.0	1,440
2.			79.7	1,390
3.			80.0	1,400
4.			80.4	1,395
		Mean	80.3	1,405
3	39.8			
1.			73.0	1,330
2.			74.2	1,365
3.			75.3	1,370
4.			73.5	1,290
		Mean	74.0	1,340
4	54.2			
1.			82.5	1,435
2.			81.3	1,420
3.			81.6	1,450
4.			82.1	1,455
		Mean	81.9	1,440

TABLE I

continued:

Sample No. & Test Cylinder No.	Bulk Density of Aggregate #/Cu. Ft.		Density of Concrete #/Cu. Ft.	7 Day Compression Strength (psi.)
7	30.7			
1.			63.3	1,195
2.			62.5	1,155
3.			64.6	1,210
4.			62.5	1,170
		Mean	63.2	1,190
X	53.2			
1.			81.0	1,445
2.			82.5	1,450
3.			80.5	1,470
4.			81.5	1,415
		Mean	81.4	1,445


COMPRESSION STRENGTH
vs
DENSITY
EXPERIMENTAL RESULTS
COMPRESSION STRENGTH (psi)
1,500
1,450
1,400
1,350
1,300
1,250
1,200
1,150
1,100
60
65
70
75
80
85
90
95
DENSITY (POUNDS/ CUBIC FOOT)


COMPRESSION STRENGTH
vs
DENSITY
DATA UNITED STATES BUREAU OF STANDARDS
COMPRESSION STRENGTH (psi)
4,000
3,800
3,600
3,400
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
70
75
80
85
90
95
100
DENSITY (POUNDS/CUBIC FOOT)

COMPRESSION STRENGTH TEST OF LIGHTWEIGHT AGGREGATES DATA AND RESULTS

The data were calculated and are presented herein, and plotted in graphical form (Figure 20). The results were quite surprising as the variation of strength was not a character of different samples, but appeared to be independent of the sample, and to be a function of the density of the material, furthur this function appeared to be linear. After a survey of the literature the only published data of the compression strength of lightweight aggregates was the work of Conley, Wilson, & Klinefelter[11] their work was performed using a different basis; the workability of the concrete produced was the criteria, thus the amount of cement used was variable. Several values of compression strength and density were found for cement ratios of between five and six sacks of cement per yard of aggregate. The values of strength were plotted (Figure 21), and again as in the results obtained in this work a straight line was obtained, but the values of strength were different, and the slope of the line was different by a factor of four.

There are three principle factors which could affect the strength of the lightweight concrete. The first we will consider

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(11) Conley, J. E., et. al, op. cit., pp 7.

is the strength of the glass. Winkelman and Schott[16] in work done on the change in compressive strength of glasses with change in composition of multicomponent systems show that the strength of glass decreases moderately with additions of Na_2O and K_2O, additions of CaO and Fe_2O_3 lower the strength only slightly, while Al_2O_3 causes slight increases in glass strength, MgO had no detectable effect. Riley[12] shows the area of bloating as being a small area on a three component diagram (Al_2O_3, SiO_2, fluxes) which does not extend over five per cent in relation to any of the three end points of the triaxel. Therefore, we can assume that the strength of the glass does not vary to any great extent. Another factor affecting glass strength is the annealing of glass after it is made. Annealing does not seem to be as variable as all the samples of aggregate were produced in the same kiln, with the exception of the control sample which was a commercial product. The rate of cooling was about the same for all the material produced, thus annealing should be the same in every case.

The second factor to be considered in the compression strength of the aggregate would be the voids. The number, shape, and size of the pores in the material would affect the strength and weight ratio. If a homogeneous material in different specimens were to have various numbers of small

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(16) Winkelman, A., Schott, O., Ann. Physik. Cham., 51, 697 (1894).

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(12) Riley, C. M. op. cit., pp 8

pores within it the strength would be a function of the volume of the material remaining plus some concentration of stress factor. In our selection of materials for this work from the preliminary tests we were careful to select only the best materials, and even those materials which did not show on visual examination to have the same pore structure were excluded. Thus the materials were of about the same pore structure.

The third variable in the test cylinders would be the cement used. In the work done by Conley, Wilson and Klinefelter,[11] they used a high early strength cement, which would account for the larger values of strength of the seven day tests. Also the grain size of their experiments was somewhat different, but not greatly so. It is felt that the slope of the line could be accounted for by these two differences plus the fact that the annealing conditions of their furnace could have been different.

It is suggested that more work be done to relate the density to the strength of the aggregate. If the results obtained were not as good as the present ones in showing this relationship the samples might be fired until completely molten and the crushing strength of this material tested.

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[11] Conley, J. E., et. al., op. cit., pp 7.

SUMMARY AND CONCLUSIONS

Fifty five different samples of Missouri shales, clays, and loesses were collected and tested for bloating properties. First a standard firing behavior test was run on all samples and secondly a quick firing test was made, and the results of both these tests were reported in a descriptive manner by Kurtz[14], but are included in this report in appendix A.

Seven samples (2, 3, 4, 7, 20-B, 23, and 38) of shales and clays which showed good bloating properties in the first tests were tested in a batch rotary kiln. The results of the rotary kiln tests showed that 2, 3, 4, 7, and 20-B bloated and produced aggregate of quality comparable to a sample of commercially produced material. Samples 23 and 38 did not bloat sufficiently to be used in the compression tests.

It is to be noted that the two materials which did not bloat were of higher CaO content than the other materials.[14] Also sample 20-B formed lumps or logs and had a very short firing range, and sample 4 showed a marked tendency to stick to the walls of the kiln. Also their CaO content is somewhat higher than the other good bloating materials.

Compression test results obtained for samples 2, 3, 4, 7, 20-B, and X (Commercial material) show a nearly linear

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[14] Kurtz, P., op. cit., pp 9.

relationship between the density and the compression strength. All five materials listed being good bloaters, and tested for strength, are of sufficiently good quality to be of commercial use. Attention is called again to the difficulties experienced with shale samples 4, and 20-B, which could cause difficulty in commercial production.

APPENDIX A

Sample # 1

Excellent bloating in the reducing atmosphere of the quick firing test, pore structure excellent, specific gravity less than one, best bloating temperature 1250° ± 20°C.

Very slight bloating at cone 9 in the oxidizing atmosphere of the firing behavior test. Sample melted at cone 11.

Sample # 2

Excellent bloating in the reducing atmosphere of the quick firing test, specific gravity less than one, pore structure excellent, best bloating temperature 1150° ± 50°C.

Slight bloating from cones 7 to 11 in the oxidizing atmosphere of the firing behavior.

Sample # 3A

Good bloating during the firing behavior at cones 7 and 9, oxidizing atmosphere, specific gravity less than one, pore structure good, bloating temperature 1250° ± 20°C.

Good bloating at same temperature during the quick fire.

Sample # 3B

Good bloating under the reducing conditions of the quick firing, specific gravity about one, pore structure fair, bloating temperature 1200° ± 50°C.

Slight bloating during the firing behavior at cones 7 and 9 under oxidizing conditions, melted at core 11.

Sample # 3C

Good bloating under the reducing conditions of the quick firing, pore structure very bad with large connected pores, bloated at 1250°C.

Very slight bloating during the firing behavior, melted at cone 11.

Sample # 3D

Very slight bloating during both firings. It didn't melt at cone 11 but was very well vitrified.

Sample # 4

Good bloating during the quick firing, reducing conditions, specific gravity less than one, good pore structure, bloating temperature 1300° ± 20°C.

Very slight bloating under the oxidizing conditions of the firing behavior, did not melt at cone 11 but was well vitrified.

Sample # 5

Good bloating during the quick firing, reducing conditions, specific gravity less than one, poor pore structure, bloating temperature 1250° ± 30°C.

Very slight bloating under the oxidizing conditions of the firing behavior, did not melt at cone 11 but was very well vitrified.

Sample # 6

Good bloating under reducing conditions of the quick firing, pore structure fair, specific gravity about 1, bloating temperature 1300° ± 30°C.

Slight bloating during the firing behavior, did not melt at cone 11.

Sample # 7

Excellent bloating during both firings, oxidizing or reducing conditions, specific gravity less than one, excellent pore structure, bloating temperatures 1200° ± 50°C.

S ample # 8A

Good bloating during the quick fire, reducing conditions, specific gravity about 1, good pore structure, bloating temperatures 1250° ± 50°C.

Fair bloating under the oxidizing conditions of the firing behavior, pore structure not well developed, specific gravity greater than one, melted at cone 11.

Sample # 8B

Poor bloating during both firings, oxidizing or reducing conditions, pore structure not well developed, specific gravity greater than one, did not melt down at cone 11 but very well vitrified.

Sample # 8C

No bloating in either firing. Sample was well vitrified at cone 11.

Sample # 9A

Slight bloating during the firing behavior, oxidizing conditions, pore structure not well developed, specific gravity greater than one, melted at cone 11.

No bloating when quick fired to 1260°C in a reducing atmosphere.

Sample # 9B

No bloating under reducing conditions of quick firing to 1300°C.

No bloating during firing behavior, did not melt at cone 11 but was well vitrified.

Sample # 9C

Poor bloating during the firing behavior at cones 9 and 11, pore structure not well developed, specific gravity greater than one.

No bloating under the reducing conditions of quick firing to 1270°C.

Sample # 10A

Poor bloating under the oxidizing conditions of the firing behavior at cones 9 and 11, pore structure not well developed, very well vitrified at cone 11.

No bloating under the reducing conditions of quick firing to 1260°C.

Sample # 10B

Fair bloating under the oxidizing conditions of the firing behavior at cones 9 and 11, pore structure good, specific gravity less than one, bloating temperature 1300° $\pm$ 20°C.

Fair bloating under the reducing conditions of quick firing to 1300°C.

Sample # 11

Poor bloating under the oxidizing conditions of the firing behavior at cone 11.

No bloating under reducing conditions of quick firing to 1270°C.

Sample # 12

Very poor bloating in the oxidizing atmosphere of the firing behavior at cones 9 and 11.

No bloating in the reducing atmosphere of quick firing to 1270°C.

Sample # 13

Very poor bloating in the oxidizing atmosphere of the firing behavior at cones 7, 9 and 11, very well vitrified at cone 11.

No bloating in the reducing atmosphere of quick firing to 1275°C.

Sample # 14

Very slight bloating in both firing tests at 1300°C, but very well vitrified at this temperature.

Sample # 15A

Very slight bloating in the oxidizing atmosphere of the firing behavior at cone 7. At cone 9 the bloating was good but the pore structure was bad (large, open and interconnected pores), sample melted down at cone 11.

Very slight bloating in the reducing atmosphere of quick firing to 1270°C.

Sample # 15B

Good bloating in the reducing atmosphere of quick firing to 1330°C., pore structure good, specific gravity less than one.

Slight bloating in the oxidizing atmosphere of the firing behavior at cones 5 and 7, sample melted at cone 9.

Sample # 16A

Poor bloating in the oxidizing atmosphere of the firing behavior at cone 11.

Poor bloating in the reducing atmosphere of quick firing to 1275°C., sample was well vitrified at this temperature.

Sample # 16B

Poor bloating in the oxidizing atmosphere of the firing behavior at cones 7, 9 and 11, practically melted down at cone 11.

No bloating when quick fired to 1275°C. in a reducing atmosphere.

Sample # 17

Slight bloating at cones 9 and 11 in the oxidizing atmosphere of the firing behavior. Sample was well vitrified at cone 11.

Very slight bloating when quick fired to 1275°C. in a reducing atmosphere.

Sample # 18

Very slight bloating at cones 7, 9 and 11 in the oxidizing atmosphere of the firing behavior. Sample was well vitrified at cone 11.

No bloating when quick fired to 1270°C. in a reducing atmosphere.

Sample # 19

No bloating in either firing test. Sample was well vitrified at cone 11 and also when quick fired to 1355°C.

Sample # 20A

No bloating in either firing test. Sample melted completely at cone 9.

Sample was quick fired to 1270°C. and melted completely without any bloating.

Sample # 20B

Excellent bloating in both firing tests, oxidizing or reducing atmosphere, excellent pore structure, specific gravity less than one, best bloating temperature 1250° ± 20°C.

Sample # 20C

Excellent bloating in both firing tests, oxidizing or reducing atmosphere, excellent pore structure, specific gravity less than one, best bloating temperature 1250°C. ± 20°C.

Sample # 21

No bloating in either firing test. Sample was well vitrified at cone 11 and when quick fired to 1250°C.

Sample # 22

No bloating in either firing test. Sample was well vitrified at cone 11 and also when quick fired to 1300°C.

Sample # 23

Excellent bloating in both firing tests, oxidizing or reducing atmosphere, excellent pore structure, specific gravity less than one, best bloating temperature 1200° ± 50°C., this sample showed the longest bloating range, the bloating was excellent from cone 1 through cone 9.

Sample # 24

Fair bloating when quick fired in a reducing atmosphere to 1200°C., pore structure fair, specific gravity less than one.

Slight bloating at cone 5 in the oxidizing atmosphere of the firing behavior. Sample melted down at cone 7.

Sample # 25

Slight bloating at cones 9 and 11 in the oxidizing atmosphere of the firing behavior. Sample well vitrified at cone 11.

Very slight bloating when quick fired to 1225°C. in a reducing atmosphere.

Sample # 26

Good bloating at cones 9 and 11 in the oxidizing atmosphere of the firing behavior test, good pore structure, specific gravity less than one.

Fair bloating when quick fired to 1270°C. in a reducing atmosphere, good pore structure, specific gravity greater than one.

Sample # 27

Excellent bloating in both firing tests, oxidizing or reducing conditions, excellent pore structure, specific gravity less than one, best bloating temperature 1225° ± 25°C.

Sample # 28

Poor bloating at cones 9 and 11 in the oxidizing atmosphere of the firing behavior test, pore structure fair, specific gravity greater than one. Sample very well vitrified at cone 11.

No bloating when quick fired to 1210°C. in a reducing atmosphere.

Sample # 29

Good bloating when quick fired to 1210°C. in a reducing atmosphere, fair pore structure, specific gravity less than one.

Slight bloating at cones 5 and 7 in the oxidizing atmosphere of the firing behavior test. Sample was pretty well down at cone 9 with large interconnected pores.

Sample # 30

Very slight bloating in both firing tests. Sample was very well vitrified at cone 11 and when quick fired to 1275°C.

Sample # 31

Very slight bloating at cone 11 in the oxidizing atmosphere of the firing behavior test, sample was well vitrified at cone 11.

No bloating when quick fired to 1245°C. in a reducing atmosphere.

Sample # 32

Slight bloating at cones 5 and 7 in the oxidizing atmosphere of the firing behavior test. Sample was almost completely melted down at cone 7.

Over bloated and melted down when quick fired to 1210°C. in a reducing atmosphere, the pores were large and interconnected.

Sample # 33

Fair bloating at cone 5 in the oxidizing atmosphere of the firing behavior test, fair pore structure, specific gravity about 1, sample melted down at cone 7.

Fair bloating at 1190°C. when quick fired in a reducing atmosphere, poor pore structure, specific gravity greater than one.

Sample # 34

Slight bloating at cones 7 and 9 in the oxidizing atmosphere of the firing behavior test, sample was well vitrified at cone 11.

No bloating when quick fired to 1250°C. in a reducing atmosphere.

Sample # 35

No bloating in either firing test. Sample was well vitrified at cone 11 and when quick fired to 1355°C.

Sample # 36

Good bloating at cones 7 and 9 in the oxidizing atmosphere of the firing behavior test, excellent pore structure, specific gravity less than one, sample melted down at cone 11.

Good bloating when quick fired to 1275°C. in a reducing atmosphere, poor pore structure because of over-firing.

Sample # 37

Good bloating at cone 7 in the oxidizing atmosphere of the firing behavior test, fair pore structure, specific gravity less than one, sample melted at cone 9.

Slight bloating at 1190°C. when quick fired in a reducing atmosphere, pore structure not well developed but uniform and well disseminated.

Sample # 38

Fair bloating at cone 7 in the oxidizing atmosphere of the firing behavior test, poor pore structure, specific gravity greater than one, almost melted down at cone 7 and completely melted at cone 9.

Over bloated and melted down when quick fired to 1245°C. in a reducing atmosphere.

Sample # 39

No bloating in either firing test. Fairly well vitrified at cone 11 and very well vitrified when quick fired to 1355°C.

Sample # 40

Very slight bloating in both firing tests. Sample well vitrified at cone 11 and when quick fired to 1250°C.

Sample # 41

No bloating in either firing test. Sample well vitrified at cone 11 and when quick fired to 1250°C.

Sample # 42

No bloating in either firing test. Sample fairly well vitrified at cone 11 and very well vitrified when quick fired to 1355°C.

APPENDIX B

Sample # 1

Section in clay pit at Carter-Waters Corporation, Haydite plant; NW 1/4 SE 1/4 NW 1/4 sec. 14, T. 54 N., R. 35 W., Platte County, six-tenths mile south of New Market on east side of U. S. Highway 71.

	Thickness Feet	Inches
Pennsylvanian System		
Missourian Series		
Peedee group		
Iatan formation		
2. Limestone, blue-gray - - - - - - - -		8
Weston formation		
(Spl. # 1) 1. Shale, medium gray, weathers to light gray, hard where fresh; contains scattered fragments of clam shells, forms steep slope - -	30	

Note: Description according to Greene and Howe.

Sample # 2

Section in clay pit at United Brick and Tile Company plant, SE 1/4 sec. 5, T. 44 N., R. 31 W., Cass County, about one mile southwest from Harrisonville.

	Thickness Feet	Thickness Inches
Pennsylvanian System		
Missourian Series		
Pleasanton group		
Exline limestone		
6. Limestone, and calcareous shale; limestone earthy, slabby; bed contains _Euphenrites_, _Trepospira_, _Crurithyris_, _Marginifera splendens_ -	0	4-10
Unnamed coal		
5. Coal, streak - - - - - - - - - - - - -		
Unnamed clay		
4. Clay (underclay) - - - - - - - - - - -	1-3	
Hepler sandstone		
3. Sandstone, impure and calcareous, and impure nodular limestone; limestone is marine and forms lodge; limestone locally conglomeratic, containing fragments of coal and silicified wood - - - - -	0-3	
2. Sandstone, shaly - - - - - - - - - -	5-6	

Desmoinesian Series

Marmaton group

Holderville formation

(Spl. # 2) 1. Shale, sandy and silty; sand occurs as varge-like stringers in upper part; entire unit used in manufacture of building brick - - - - 35±

Note: Description of section according to Howe, W. B.

Sample # 3A, 3B, 3C, 3D, 3E

Section in pit of Crowe Coal Company, center of North line NW 1/4 sec. 12, T. 42 N., R. 27 W., Henry County, about six miles northwest of Clinton.

		Thickness Feet	Inches
Pleistocene System			
	Loess		
(Spl. # 3E)	12. Clay, sandy in basal 4 feet; mottled brown and gray- - - - - -	14±	
Pennsylvanian System			
Desmoinesian Series			
Cherokee group			
Unnamed shale			
(Spl. # 3D)	11. Shale, drab or buff ''soapstone,'' contains clay-ironstone and secondary joint deposits of lime - - - - - - - - - - - - - - -	8±	
Unnamed beds			
	10. Limestone - - - - - - - - - - - -	0	0-10
	9. Coal - - - - - - - - - - - - - - - -	0	4-10
	8. Shale and underclay, limey at base; 2-1/2 - 3 feet true underclay- - - - - - - - - - - - -	4±	
(Spl. # 3C)	7. Shale, light gray ''soapstone,'' subconcoidal fracture; weathered		

		contains clay-ironstone concretions, also secondary gypsum --	3	
(Spl. # 3B)	6.	Shale, ''slate,'' dark, phosphatic and clay-ironstone concretions and streaks, possibly limey, marine fossils at base; pyrite masses in lower part - - - - -	3-4	
	5.	Coal, blocky, bright - - - - -	0	0-1 1/2
(Spl. # 3A)	4.	Shale, ''slate,'' black, slicken-sided in upper part, no concretions - - - - - - - - -	1-3	
	3.	Limestone, hard, gray (Tebo cap rock) - - - - - - - - - - - - -	1	2
	2.	Shale, ''slate,'' black, limey, somewhat fissile, with phosphatic concretions- - - - - - - - - - -	4	
	1.	Coal, (Tebo) - - - - - - - - - -	2	6

Note: Description according to Searight and Howe.

Sample # 4

Section in pit of Johnson Coal Company, NW 1/4 sec. 7, T. 40N., R. 26W., Henry County, about four miles west and north from Deepwater.

		Thickness Feet	Inches
Pleistocene System (?)			
	3. Clay - - - - - - - - - - - - - - -	6±	
Pennsylvanian System			
Desmoinesian Series			
Cherokee group			
Unnamed shale			
(Spl. # 4)	2. Shale, dark gray; thin clay-ironstone bands and nodules scattered throughout; upper 10 feet sandy - -	22±	
	1. Coal (Jordan) - - - - - - - - - - - -	0	30 (Av.)

Sample # 5

Section in pit of Mackie-Clemens Coal Company, on west line and 2500 feet north of south line of sec. 19, T. 33N., R. 33 W., Barton County, Missouri, about three miles north of Mulberry, Kansas.

			Thickness	
			Feet	Inches
Pleistocene System (?)				
	7.	Clay, yellow - - - - - - - - - - -	3-4 (Av.)	
Pennsylvanian System				
Desmoinesian Series				
Cherokee group				
Unnamed shale				
	6.	Shale, light gray to black waxy -	3±	
	5.	Coal (Pilot Coal) - - - - - - - - -	0	8
	4.	Clay, underclay, blocky, gray to gray-green - - - - - - - - - - -	3-4	
(Spl. # 5)	3.	Shale (?) very dense, greenish-gray - - - - - - - - - - - - - - - -	1-3	
	2.	Shale, medium gray, silty - - - -	11±	
	1.	Coal (Weir-Pittsburgh) - - - - -	2	6

Sample # 6

Section in bluff face on west side of Little North Fork Creek, SW corner sec. 12, T. 30 N., R. 33 W., Barton County, about thirteen miles west of Jasper. (Section taken in part from Searight).

			Thickness Feet	Thickness Inches
	7.	Soil cover containing fragmental sandstone, cobble to boulder size - - - - - - - - - - -	6±	
Pennsylvanian System				
Desmoinesian Series				
Cherokee group				
	6.	Coal (smut) - - - - - - - - - - -	0	3
	5.	Shale, black to dary gray, with siderite bands, poorly exposed -	16	
	4.	Limestone, dark, many fragmented fossils; hard, gray dense masses in upper part, to 2 feet in diameter with cone-in-cone - - - -	1	6
	3.	Coal (Rowe) hard, blocky - - - -	0	10
	2.	Clay, underclay, light gray, buff mottled, hard silty, some stigmaria - - - - - - - - - - - - - -	3	
(Spl. # 6)	1.	Shale, lower 4 feet black, hard, medium to dark gray above - - -	15	

Sample # 7

Section in bluff on east side of Mikes Creek, SW 1/4 SE 1/4 NE 1/4 sec. 12, T. 22 N., R. 30 W., McDonald County, about four miles northeast from Powell, top of grade north from Sugarcamp Hollow.

		Thickness Feet	Thickness Inches
Mississippian System			
Kinderhookian Series			
St. Joe group			
Compton formation			
	2. Limestone, gray, crinoidal, forms high vertical bluff - - -	20±	
Chattanooga formation			
(Spl. # 7)	1. Shale, light gray at top, grading downward through greenish gray to black; hard, blocky - - - - - - - - - - - - -	6	

Sample # 8A, 8B, 8C

Section in clay pit of Hydraulic Pressed Brick Company, center of NE 1/4 SE 1/4 sec. 10, T. 45 N., R. 5 E., St. Louis County, about one and three-quarter miles west of U. S. Highway 66, on south side of Ladue Road.

			Thickness Feet	Inches
Pleistocene System				
(Spl. # 8C)	5.	Loess, tan color - - - - - - - - - - -	20 (Est.)	
Pennsylvanian System				
Desmoinesian Series				
Cherokee group				
	4.	Sandstone, tan - - - - - - - - - - -	1	6 (Est.)
(Spl. # 8B)	3.	Clay, upper 1 foot, gray, lower 4 feet reddish-purple to maroon - -	5	
Squirrel sandstone				
	2.	Sandstone, tan - - - - - - - - - - -	3-5	
Lagonda shale				
(Spl. # 8A)	1.	Shale, maroon in upper part, gray in lowermost 2-3 feet- - - - - - -	30±	

Sample # 9A, 9B, 9C

Section in clay pit at Alton Brick Company plant, center NE 1/4 NE 1/4 sec. 26, T. 46 N., R. 5 E., St. Louis County, one-quarter mile northwest from U. S. Highway 66, on Dorsett Road.

		Thickness Feet	Inches
Pleistocene System			
(Spl. # 9C)	8. Loess, tan color - - - - - - - - - -	30 (Est.)	
Pennsylvanian System			
Desmoinesian Series			
Marmaton group			
	7. Limestone, gray - - - - - - - - - -	2 (Est.)	
	6. Coal, smut - - - - - - - - - - - - -	0	1
	5. Clay, gray, blocky, hard - - - - -	6	
	4. Limestone, greenish-gray, hard - -	1	
Cherokee group			
(Spl. 9B)	3. Clay, reddish-purple to maroon - -	4	
Squirrel sandstone			
	2. Sandstone, tan - - - - - - - - - - -	1	
Lagonda shale			
(Spl. # 9A)	1. Shale, maroon, somewhat silty; gray in lowermost 4 feet - - - - -	34	

Sample # 10A, 10B

Section in clay pit at Missouri Portland Cement Company plant, center west line SW 1/4 SE 1/4 sec. 10, T. 46 N., R. 7 E., St. Louis County, about three miles south of Chain of Rocks Bridge and on the west side of U. S. Highway 66 (City Route).

	Thickness Feet	Inches
Pleistocene System		
(Spl. # 10B) 5. Loess, tan - - - - - - - - - - - -	20-30	
(Sample 10B collected from 20')		
Pennsylvanian System		
Desmoinesian Series		
4. Sandstone (?) - - - - - - - - - -	2 (Est.)	
Cherokee formation		
3. Clay, upper 3-4 feet gray, lower maroon - - - - - - - - - - - - - - -	12-15	
Squirrel sandstone		
2. Sandstone, tan - - - - - - - - - -	2 (Est.)	
Lagonda shale		
(Spl. # 10A) 1. Shale, maroon, somewhat silty- -	54	

Sample # 11

Section in clay pit at Midland Brick and Tile Company plant, NW 1/4 SE 1/4 sec. 18, T. 57 N., R. 24 W., Livingston County, about one-quarter mile northwest of Utica, and five miles west of Chillicothe, Missouri.

		Thickness Feet	Thickness Inches
Pennsylvanian System			
Missourian Series			
Pleasanton group			
Knobtown sandstone			
	3. Sandstone, tan color, weathered -	15-20 (Est.)	
Unnamed shale			
(Spl. # 11)	2. Shale, gray, somewhat silty in upper part, topmost 6-10 feet highly sandy; two clay-iron stone bands in the bottom 2 feet of section, 2 feet apart, upper band 2 inches thick - - - -	60	
Exline limestone			
	1. Limestone, impure, wavy bedding; massive; forms floor of quarry; distinctive polygonal jointing; abundant horn corals, crinoid fragments, etc. - - - -	0	8-10

Sample # 12

Section in clay pit at Columbia Brick and Tile Company plant, center of E 1/2 NE 1/4 SW 1/4 sec. 8, T. 48 N., R. 12 W., Boone County, one mile east of Columbia city limits (U. S. Highway 63).

	Thickness Feet	Inches
Pennsylvanian System		
Desmoinesian Series		
Marmaton group		
Fort Scott formation		
9. Soil cover and green-gray clay - -	5±	
Houx limestone member		
8. Limestone, light gray, abundant crinoid stems - - - - - -	2±	
Unnamed clay		
7. Clay, light olive-green, at top grades down to black-waxy above smut - - - - - - - - - - - - - - - - -	1	9
6. Smut - - - - - - - - - - - - - - - - -		6
Unnamed clay		
5. Clay, light olive-green, grades down to green-brown- - - - - - - -	6	
Unnamed limestone		
4. Limestone, nodular - - - - - - - - -	1	9
Cherokee group		
Squirrel sandstone		

3. Shaly sandstone, light gray, fine grained, weathers with wide yellow brown streaks; finely micaceous, grades down into 20 inch bed highly sandy shales that weathers rusty-brown - - - - 9±

Lagonda shale

2. Shale, light gray, highly silty in upper 10 feet, lowermost 2-3 feet dark gray to gray-black - - - - - - - - - - - - - - - - 17±

1. Bevier coal (not measured)- - - - 1 (Est.)

Sample # 13

Section in bank on property of R. C. Renner, center NW 1/4 SW 1/4 sec. 4, T. 50 N. R. 33 W., Platte County, north side of Missouri Highway 45, at west apex of triangular intersection of U. S. Highways 69, 71, 169, and Missouri Highway 45, and two-tenth mile east of entrance to Fairfax bridge.

	Thickness Feet	Thickness Inches
Pennsylvanian System		
Missourian Series		
Kansas City group		
Cherryvale formation		
3. Undifferentiated alternating layers of limestone beds 1 foot thick and tan silty shale beds 3-7 feet thick (possibly slump material) - - - - - - - - - - - - -	12	
Westerville limestone member		
2. Limestone, light gray - - - - - - -	3-5	
Wea shale member		
(Spl. # 13) 1. Shale, blackish gray where fresh-	15	

Sample # 14

Section in stone quarry of Midwest PreCote Company, center of North line SE 1/4 sec. 25, T. 51 N., R. 34 W., Platte County, west side of gravel road about one and one-half miles north of intersection with Missouri Highway 45 at U. S. Air Force Bulk Storage Plant.

	Thickness Feet	Inches
Pennsylvanian System		
Missourian Series		
Stanton formation		
Eudora shale member		
4. Shale, poorly exposed mostly soil covered - - - - - - - - - -	5-10 (Est.)	
3. Captain Creek limestone, light gray member - - - - - -	3 (Est.)	
Vilas shale formation		
(Spl. # 14) 2. Shale, light gray, somewhat weathered - - - - - - - - - - -	3	
Plattsburg formation		
1. Spring Hill limestone member, light gray, jointed, with orange-brown residual material in joints and horizontal partings-	5	

Sample # 15A, 15B

Section in high bank on east side of Main Street cut, about 0.3 mile south of Union Depot, Kansas City; center of East line SE 1/4 SW 1/4 sec. 8, T. 49 N., R. 33 W., Jackson County.

	Thickness Feet	Inches
Pennsylvanian System		
Missourian Series		
Kansas City Group		
Zarah subgroup		
Wyandotte formation		
Argentine limestone member		
9. Limestone, gray - - - - - - - - -	6-8	
Quindaro shale member		
8. Shale, black - - - - - - - - - -	1±	
Frisbie limestone member		
7. Limestone, gray - - - - - - - - -	1±	
Lane Formation		
(Spl. # 15A) 6. Shale, blackish-gray, weathers light gray, contains scattered small clay-ironstone concretions; three light gray concretionary limestone layers 1 to 2 inches thick are found at 5, 13, and 17 feet from bottom of section - -	27±	
Iola formation		
Raytown limestone member		

5. Limestone, gray 6 - - - - - - - - 7

Muncie Creek shale member

4. Shale, black, thin, platy, hard - - - - - - - - - - - - - - - - 1±

Paola Limestone member

3. Limestone, gray - - - - - - - - - 1±

Chaunute formation

(Spl. # 15B) 2. Shale, blackish gray at top, grading downward to greenish gray at bottom; clay-ironstone concretions scattered throughout sections; three concretionary, light gray limestone layers in lowermost 5 feet; the bottom layer averages 3 inches in thickness and is about 2 feet above base of section; the middle layer averages 2-1/2 in thickness and is about 1-1/2 feet above bottom layer; the topmost layer averages 2 inches in thickness and is about 1-1/2 feet above middle layer - - - - - - - - - - - - - - 21±

Linn subgroup

Drum formation

Cement City limestone member

1. Limestone, gray (exposed) - - - 8±

Sample # 16A, 16B

Section in road cut, center of SE 1/4 SE 1/4 SE 1/4 sec. 22, T. 53 N., R. 33 W., east side of U. S. Highway 169 at southwest edge of Smithville, Clay County. Section is composite of two sample locations about 100 feet apart, one a crest of hill and other on north facing slope of same hill.

	Thickness Feet	Inches
Pennsylvanian System		
Missourian Series		
Lansing group		
Plattsburg formation		
5. Limestone, light-brownish-gray (exposed) - - - - - - - - -	3-4	
Kansas City group		
Zarah subgroup		
Bonner Springs shale formation		
(Spl. # 16B) 4. Shale, upper 20 feet somewhat weathered, dark brown color; color grades downward to dark gray in lower 30 feet; a few thin clay-ironstone layers in upper 20 feet - - - - - - - - -	53	
Wyandotte formation		
Farley limestone member		
3. Limestone, light-brownish-gray, fossiliferous - - - - - -		6 (Av.)

(Spl. # 16A)	2.	Shale, medium gray with occasional clay-ironstone nodules - - - - -	17
	1.	Limestone, light-brownish-gray (exposed)- - - - - - - - - - - -	3

Sample # 17

Section in bank at King Hill, center East line SW 1/4 NW 1/4 sec. 29, T. 57 N., R. 35 W., St. Joseph, Buchanan County, on east side U. S. Highway 59 in south part of city.

		Thickness Feet	Thickness Inches
Pleistocene System			
	3. Loess, tan - - - - - - - - - - - -	20 (Est.)	
Pennsylvanian System			
Virgilian Series			
Douglas group			
Lawrence formation			
Amazonia limestone member			
	2. Limestone, gray, crinoid stems observed in lower one foot - - -	7	
Unnamed shale member			
(Spl. # 17)	1. Shale, medium gray; weathers light gray, uppermost 2 feet medium brown and silty; occasional clay-ironstone concretions found throughout section -	21	

Note: McQueen and Greene (Missouri Geol. Survey and Water Resources Vol. XXV) assign an average thickness of 56 feet to bed No. 1 in northwestern Missouri.

Sample # 18

Section in bluff, center NE 1/4 NE 1/4 NE 1/4 sec. 1, T. 58 N., R. 36 W., about three-quarter mile south of Amazonia, Andrew County, on east side of County Road K.

		Thickness Feet	Inches
Pennsylvanian System			
Virgilian Series			
Douglas group			
Lawrence formation			
Amazonia limestone member			
	2. Limestone, gray, caps bluff - -	2	
Unnamed shale member			
(Spl. # 18)	1. Shale, medium gray, upper 10 feet silty, weathered to dark brown; color grades downward to dark gray. Occasional clay ironstone concretions found in section - - - - - - - - - - -	42	

Note: McQueen and Greene (Missouri Geol. Survey and Water Resources Vol. XXV) assign an average thickness of 56 feet to bed No. 1 in northwestern Missouri.

Sample # 19

Section at Lover's Leap, N 1/2 SE 1/2 sec. 28, T. 57 N., R. 4 W., east edge of Hannibal, Marion County.

	Thickness Feet	Inches
Mississippian System		
Osagean Series		
Burlington formation		
9. Gray to cream-colored coarsely crystalline limestone, beds 3-4 feet thick, containing beds and concretions of chert, some beds of brown sandy limestone, one 18 inch bed of brown sandstone near the top. Exposed as vertical cliffs and not accessible for detailed description - - - - - - - - - - - - - - - - -	80-90 (Est.)	
8. Highly crinoidal, coarsely crystalline, brown limestone; typical brown Burlington limestone - - - - - - - - - - - - - - - -	10-12	
7. Brown limestone in one bed - - - -	1	
6. Finely crystalline, highly crinoidal brown limestone - - - -	6-8	
Partial thickness of Burlington limestone - - - - - - -	111	

Kinderhookian Series

Chouteau group

Hannibal formation

(Spl. # 19)	5.	Greenish-brown to greenish-gray sandy shale, with beds of very argillaceous greenish-brown sandstone. One of these sandstone beds is about 5 feet above the base of the formation - - - - - - - - - - - - - -	70	
		Louisiana formation		
	4.	Brown argillaceous dolomite- -	1	8-12
	3.	Thin lenslike beds of brown dolomite and drab dolomitic limestone; dolomitic beds predominating and more continuous - - - - - - - - - - - - - - -	8-10	
	2.	Brown dolomite in thick beds, with some few thin beds - - -	15	
	1.	Alternating beds of dense gray to drab dolomitic limestone and brown argillaceous dolomite; beds 4-8 inches thick - - - - - - -	5	
		Partial thickness of Louisiana limestone - - - -	30-32	

Note: Description of J. S. Williams, U. S. Geol. Survey, Prof. Paper 203, p. 23.

Sample # 20A, 20B, 20C

Section along Ilasco Creek, N 1/2 SW 1/4 sec. 19, T. 56 N., R. 3 W., Ralls County, in bank, south side of creek, south of road, about 1-1/2 miles southwest from Saverton, Missouri.

			Thickness Feet	Inches
Mississippian System				
Kinderhookian Series				
Chouteau group				
Louisiana formation				
	5.	Limestone, partial section, exposed in bank; dense; buff colored, beds 6-8 inches thick separated by yellow sandy clay partings about 1 inch thick - -	9-18	
Saverton formation				
(Spl. # 20A)	4.	Silty blue-gray mudstone - - -	2	6
(Spl. # 20B)	3.	Blue-gray to brown silty shale, grades into mudstone above and into black fissile shale below—	11	
Grassy Creek formation				
	2.	Very thin bedded black fissile shale (platy), weathers brown- -	6	
(Spl. # 20C)	1.	Blackish-gray shale, fissile, to creek bottom - - - - - - - -	3	

Sample # 21

Section at Ardeola Hill, SE corner NW 1/4 NW 1/4 sec. 10, T. 27 N., R. 11 E., Ardeola, Stoddard County, Missouri, in bank on north side of road.

	Thickness Feet	Inches
Pleistocene System		
9. Loess, tan - - - - - - - - - - - -	6	
Tertiary System		
Pliocene (?) Series		
''Lafayette'' formation		
8. Gravel, rounded, brown to red brown with light to dark brown sand - - - - - - - - - - - -	4-5	
Paleocene Series		
Midway group		
Porters Creek formation		
7. Clay, dark gray-green on fresh exposure, weathers to light gray, with infrequent, thin layers of clay iron-stone - - -	45	
Clayton formation		
6. Clay, green, glauconitic, coarse sand in lower part - - -	5	
Cretaceous System		
Gulfian Series		
Owl Creek formation		

(Spl. # 21) 5. Clay, yellow-brown, very sandy - - 5

Clay, laminated, white and yellow sand with brown clay weathering to light gray-brown with yellow-brown stains, fossiliferous - - - - - - - - - - - - - - 6

Clay, brown, with muscovite along parting planes, interbedded sand, white to yellow-brown, varying from less than 0.1 inch to about 0.2 inch; fossiliferous - - - - - 11

McNairy (Ripley) formation

4. Sand, white to yellow-brown cross-bedded, slightly lignitic, local limonite bands - - - - - - - - - - - 11

3. Clay, brown, light to blackish gray, interbedded sand, limonite and muscovite along bedding planes - - - - - - - - - - - - - - - - 27

2. Lignite, sandy - - - - - - - - - - - 1

1. Sand, white with iron oxide stains only two feet exposed - - - 2

Note: Section taken mostly from Farrar (Missouri Geol. Survey and Water Resources, The Geology and Bleaching Clays of Southeastern Missouri, App. 1, Bienn, Rept. 58, 1935.)

Sample # 22

Section in road cut, center North line NE 1/4 NW 1/4 sec. 28, T. 27 N., R. 11 E., one-half mile northwest of Zeta, Stoddard County, Missouri, on southside of County Road Y, east face of hill overlooking lowlands.

		Thickness Feet	Inches
Pleistocene System			
	3. Loess, tan - - - - - - - - - - - - - -	5-20	
Tertiary System			
Pliocene Series			
''Lafayette'' formation			
	2. Gravel, yellow-brown, rounded, with light brown sand - - - - - - -	1-3	
Paleocene Series			
Midway group			
Porters Creek formation			
(Spl. # 22)	1. Clay, dark greenish-gray, weathers light gray, with infrequent clay ironstone nodules, some partings contain very thin silty, macaceous bands. Only upper 20 feet of section suitable for sampling - - - - - - - - -	20	

Sample # 23

Section in bluff NW 1/4 SW 1/4 SE 1/4 sec. 32, T. 30 N., R. 14 E., Cape Girardeau, Cape Girardeau County, Missouri, west side of Main Street, 100 yards north from intersection with Broadway.

		Thickness Feet	Inches
Pleistocene System			
	5. Loess, tan - - - - - - - - - - - - -	5±	
Ordovician System			
Upper Series			
Maquoketa-Thebes formations			
	4. Thebes sandstone, light brown, fine grained - - - - - - - - - - - -	5-6	
(Spl. # 23)	3. Maquoketa shale, reddish-brown weathers light gray, poorly exposed - - - - - - - - - - - - - -	8-12	
Fernvale formation			
	2. Limestone - - - - - - - - - - - - -	8	
Middle Series			
Kimmswick formation (undifferentiated)			
	1. Limestone, gray, fossiliferous - - - - - - - - - - -	15±	

Sample # 24

Section along West Fork, Cape La Croix Creek, SE 1/4 SW 1/4 SW 1/4 sec. 2, T. 31 N., R. 13 E., Cape Girardeau County, about one-half mile northwest of Randol School, and 5 miles directly east of Jackson, Missouri.

		Thickness Feet	Inches
Ordovician System			
Upper Series			
Maquoketa-Thebes formations (Orchard Creek Shale)			
(Spl. # 24)	1. Shale, fissile, yellow-green to brown at top grading downward to dark greenish-gray in lower half of section, weathers light gray to buff, clay-ironstone bands 3/8 inch to 3/4 inch thick about 9 inches to 12 inches apart found locally. Soil cover contains chert fragments and scattered boulders of lithographic limestone with chert concretions - - - - - - - - - - - -	18±	

Sample # 25

Section in clay pit of Kasten Brothers Brick Company, Jackson, Missouri, E 1/2 SE 1/4 NW 1/4 sec. 12, T. 13 N., R. 12 E., Cape Girardeau County, Brick Plant is just southwest of intersection, U. S. Highway 61 and Missouri Highway 25.

		Thickness	
		Feet	Inches
Pleistocene System			
(Spl. # 25)	1. Loess, tan clay - - - - - - - - - - -	35±	

Sample # 26

Section in bed and bank of East Fork, Cape La Croix Creek, at common intersecting corner for secs. 13, 14, 23, 24, T. 31 N., R. 13 E., Cape Girardeau County, about seven-tenth of a mile northeast from junction with the West Fork.

		Thickness Feet	Thickness Inches
Ordovician System			
Upper Series			
Maquoketa-Thebes formations			
	2. Thebes sandstone, light to dark brown, fine grained - - - - - - - - -	5±	
(Spl. # 26)	1. Maquoketa shale, light brown to blackish-brown, silty, fossiliferous, weathers light brown and light green - - - - - - - -	4±	

Sample # 27

Section in bank of Missouri Highway 25, about 75 feet inside city limits, north edge of St. Mary's, Ste. Genevieve County.

			Thickness Feet	Inches
Mississippian System				
Chesterian Series				
Renault formation				
	2.	Sandstone, light brownish-gray - - - - - - - - - - - - - - - - -	$3^{\pm}$	
(Spl. # 27)	1.	Shale, thinly fissile, slaty, purple, with alternating light gray-green bands, 3 to 4 inches thick (exposed) - - - - - - - - - -	$5^{\pm}$	

Sample # 28

Section in low-angle bank, cut into hillside at abandoned oil test well site, on Carl Hunter farm, center N 1/2 NE 1/4 NE 1/4 sec. 16, T. 64 N., R. 41 W., Atchison County, about 3 miles south of Rockport; east side of Missouri Highway 111, 0.3 mile south of junction of County road E. with Missouri Highway 111.

		Thickness Feet	Thickness Inches
Pennsylvanian System			
Virgilian Series			
Wabaunsee group			
Richardson subgroup			
French Creek formation			
	5. Shale, gray, undulating boundary with black soil cover - - - - - - - - - - - -	3±	
Jim Creek formation			
	4. Limestone, impure, brown fossiliferous, weathered - -	1±	6
Dry-Friedrich formation			
(Spl. # 28)	3. Shale, upper 5 feet rusty brown, sandy, not sampled; lower part light olive green grading downward to very dark gray in the lowermost 2 feet; plant imprints throughout, fine mica particles in parting planes - - - - - - - - - - -	19	6

Dover formation			
2.	Limestone, brown, impure, fossiliferous, weathered - -	0	6±
Langdon formation			
1.	Shale, gray-brown (exposed) --	1±	

Sample # 29

Section in ditch, north side of section line road, 3 miles south of Fairfax, center south line sec. 3, T. 63 N., R. 40 W., Atchison County; 1-1/2 miles west of U. S. Highway 275 and 59, on west facing slope of hill, 300 feet east of driveway to house north of road.

		Thickness Feet	Inches
Pennsylvanian System			
Virgilian Series			
Wabaunsee group			
Nemaha subgroup			
Elmont formation			
	3. Limestone, blue-gray to brownish-gray, fossiliferous - - - - -	2±	
Harveyville formation			
(Spl. # 29)	2. Shale, dark gray with undulating varve-like layers of light olive green color; finely micaceous, clay-ironstone concretions concentrated in band about 1 foot think in center of section - - - - - - - - -	13	6
Reading formation			
	1. Limestone, blue-gray, fossiliferous (exposed) - - - - - -	2±	

Sample # 30

Section in high bank, east side of road along foot of bluffs, center of south line SE 1/4 NW 1/4 sec. 12, T. 63 N., R. 41 W., Atchison County, 1-3/4 miles east-southeast from Nishnabotna, about 150 feet north of farmhouse, and about 0.3 mile north along road from quarry in hillside.

		Thickness Feet	Inches
Pennsylvanian System			
Virgilian Series			
Wabaunsee group			
Nemaha subgroup			
Willard formation			
(Spl. # 30)	1. Shale, hard, dense, blocky, gray olive-green to dark brown, weathers light greenish-tan to light gray, silty, finely micaceous, scattered clay-ironstone concretions and plant imprints. (exposed) - - - - - - - - - - - - - - -	10±	

Note: Hand levels run from quarry to shale outcrop indicate sample taken between 30 and 40 feet below base of Tarkio limestone.

Sample # 31

Section in road cut along east side of Missouri Highway 13, NE 1/4 NW 1/4 NW 1/4 sec. 10, T. 54 N., R. 28 W., Ray County; about 2.6 miles south of railroad viaduct at Polo Gravel road east, 0.15 mile south of section.

			Thickness Feet	Inches
Pleistocene System				
(Spl. # 31)	1.	Gumbotil, light gray with rusty brown spots and mottling in upper 7 feet; mostly light gray in lower 3 feet; gummy and silty throughout, weathers very light gray with polygonal-like system of cracks (exposed) - - - - - - - - - - - - - - -	10±	

Sample # 32

Section is composite of two sample locations; the first, at southwest corner of intersection of gravelled east-west section-line road with Missouri Highway 13, the second, in gulley feeding a north-flowing tributary of Long Creek. Road intersection is common corner for sections 3 and 4, T. 55 N., R. 28 W., and sections 33 and 34, T. 56 N., R. 28 W.; and gulley and its junction with tributary is at center SW 1/4 NW 1/4 sec. 3, T. 55 N., R. 28 W., four miles north of Polo, Caldwell County.

		Thickness Feet	Thickness Inches
	Pennsylvanian System		
	Missourian Series		
	Kansas City group		
	Linn subgroup		
	Cherryvale formation		
	Block member		
	5. Limestone, dark gray, fossiliferous, two beds; upper 9 inches thick, massive, jointed; lower 12 inches thick, slabby, layers 1/2 inch to 2 inches thick, fusulines common - - - - -	1	9
	Fontana member		
(Spl. # 32)	4. Shale, fissile blackish-gray, grades downward to dark gray - - - - - - - - - - - - - - - - -	17	

3.	Limestone, impure, brown color, slabby, layers separated by rusty-brown silty clay - - - - - - - - - - - - - - -	1	
2.	Clay, dark gray, coal-like in upper 1 foot, dark gray in lowermost part; irregular 4 inches of concretionary, nodular limestone in center of section - - - - - - - - - - - -	2	6

Bronson subgroup

Dennis formation

Winterset member

1.	Limestone, light buff-gray, brachiopods and crinoid stems common; outcrop shows partings up to 1 inch filled with brown silty clay, limestone layers, 2 to 8 inches thick (exposed - - - - - - - - - -	14	

Sample # 33

Section in west bank of north-flowing tributary to Long Creek, near center of SW 1/4 SW 1/4 SW 1/4 sec. 21, T. 55 N., R. 28 W., just north of Missouri Highway 116, about 0.9 mile west of Polo, Caldwell County.

	Thickness Feet	Thickness Inches
Pennsylvanian System		
Missourian Series		
Kansas City group		
Linn subgroup		
Iola formation		
Raytown member		
5. Limestone, gray; brown silty clay partings (exposed) - - - - -	3±	
Muncie Creek member		
4. Shale, black, thin, platy, hard - - - - - - - - - - - - - - - -	1	4
Paola member		
3. Limestone, gray - - - - - - - - -	0	5±
Chanute formation		
(Spl. # 33) 2. Shale; blackish-gray in upper 9 feet, light olive-green in lower 4 feet. Base of upper part contains a one foot thickness of dark gray, gritty limey, shale, overlain by a bed of		

coal 1/2 to 1 inch thick.
Lowermost 2 feet of entire section, immediately above underlying limestone, silty and blocky. Plant impressions found throughout section - - - - - - - 13±

Drum formation

Cement City member

1. Limestone, gray, fossiliferous (exposed) - - - - - - - - - - - 2±

Sample # 34

Section in north bank of road cut, center SW 1/4 NE 1/4 NW 1/4 sec. 31, T. 51 N., R. 9 W., Audrain County, about 3.4 miles west of cemetary at west edge of Mexico City limits; on east facing hill slope, 150 feet east of driveway to house of H. C. Hublitz north of road.

			Thickness Feet	Inches
Pleistocene System				
(Spl. # 34)	1.	Gumbotil, light gray with rusty-brown spots; weathers light gray. (soil cover about 7± feet) - - - - - - - - - - - - - - -	22±	

Sample # 35

Section in bank, east side of intermittent creek, W 1/2 NE 1/4 NE 1/4 SE 1/4 sec. 26, T. 29 N., R. 14 E., Scott County, about 200 feet north of County Road N. from a point about 350 feet east of A. J. Miller home. West edge of Commerce about 1 mile east.

	Thickness Feet	Inches
Cretaceous System		
Gulfian Series		
McNairy (Ripley formation)		
''Leaf member''		
(Spl. # 35) 3. Clay, brownish-maroon, weathers light chocolate brown, highly silty, finely micaceous, leaf impressions common; interbedded orange-brown sand lenses 2± inches thick, of varying lateral extent occur at infrequent intervals in vertical face of bank; total thickness of entire section variable owing to undulating contact with underlying beds, and the depth land surface has been eroded into the formation - - - -	22-27	

2. Sand, bright rusty-brown layers about 1/2 inch to 1-1/2 inches thick, cemented with limonite locally, separated by bands of white sand 2 to 3 inches thick. Thickness of entire bed varies greatly over short lateral extent - - - - - - - - - - - - - - - - 1-3

''Zodoc member''

1. Clay, 2 to 3 feet thick, blackish brown, finely micaceous, with interbedded white sand layers about 1 foot thick, streaked with 1/8 to 1/2 inch sandy-clay bands, brown to black (lignitic); exposed in creek bed about 100 feet upstream is a bed of lignite, apparently underlying the clay. This member shows evidence of much disturbance and exact thickness impossible to measure. Total thickness exposed varies between 3 to 5 feet - - - - - - - - 3-5

Sample # 36

Section in bank on south side of Grassy Creek, E 1/2 SW 1/4 NW 1/4 SE 1/4 sec. 19, T. 54 N., R. 2 W., Pike County, on property of Mr. Arch Hufford, about six miles west of Louisiana.

			Thickness Feet	Inches
Ordovician System				
Upper Series				
Maquoketa formation				
(Spl. # 36)	3.	Shale, dark brown, overlain by soil with Louisiana limestone float, contains graphtolite impressions and Linguella fragments - - - - - - - -	12	
	2.	Shale; hard, sandy, nodular, dark to medium gray - - - - - - - -	0	6-8
	1.	Shale, black to dark gray, with four hard sandy shale layers each about 4 inches thick, and approximately 2-1/2 feet apart in lowermost part of section just above creek bed (exposed) - - - -	26±	

Sample # 37

Section in ditch on north side of county-line road, south side SW 1/4 SW 1/4 SW 1/4 sec. 33, T. 55 N., R. 29 W., Caldwell County, on east facing hill slope leading down to Brushy Creek, about 4.2 miles east of U. S. Highway 69, and about 7 miles west and south of Polo.

		Thickness Feet	Inches
	Pennsylvanian System		
	Missourian Series		
	Kansas City group		
	Zarah subgroup		
	Wyandotte formation		
	Frisbie member		
	11. Limestone, medium gray, fossiliferous - - - - - - - - - - -	5±	
	Lane formation		
	10. Shale, light gray, silty finely micaceous - - - - - - - - -	8	
(Spl. # 37)	9. Shale, medium gray - - - - - - - -	2	6
	8. Coal, and smut - - - - - - - - - -	0	3
	7. Shale, medium gray - - - - - - - -	6±	
	Linn subgroup		
	Iola formation		
	Raytown member		
	6. Limestone, medium gray, fossiliferous - - - - - - - - - - -	5	6

Muncie Creek member		
5. Shale, black, platy, fissile, with upper 11 inches olive green and soft, probably weathered	2	4
Paola member		
4. Limestone, gray	0	4
Chanute formation		
3. Shale, gray	5	6
2. Shale, hard, silty, finely micaceous	0	7±
1. Shale, gray, weathered (exposed)	3±	

Sample # 38

Section in west bank of north flowing creek, tributary to Long Creek, center SW 1/4 SE 1/4 SW 1/4 Sec. 29, T. 55 N., R. 28 W., Caldwell County, 400 feet north of an east-west road from a point about 750 feet west of railroad crossing, and about 1.8 miles southwest of Polo.

		Thickness Feet	Inches
Pennsylvanian System			
Missourian Series			
Kansas City group			
Zarah subgroup			
Land formation			
	4. Shale, silty, blue-gray, with rusty-brown stains - - - - - - - - -	2	6
(Spl. # 38)	3. Coal, thin banded with smut - - -	0	6
	2. Shale, blackish-gray, fissile - -	10±	
Linn subgroup			
Iola formation			
Raytown member			
	1. Limestone, dark gray, in bed of creek - - - - - - - - - - - - - -		

Sample # 39

Section in road cut, U. S. Highway 54 on west facing slope of hill top, south side SE 1/4 SW 1/4 NE 1/4, and north side NE 1/4 NW 1/4 SE 1/4 sec. 30, T. 36 N., R. 28 W., Cedar County, about 1-3/4 miles west of junction of Missouri Highway 82 with U. S. Highway 54 at south edge of El Dorado Springs.

		Thickness	
		Feet	Inches
Pennsylvanian System			
Desmoinesian Series			
Cherokee group			
Dederick formation			
Unnamed sandstone			
	2. Sandstone, thin bedded almost platy; buff and brown bandings, finely micaceous, weathers light brown to gray - - - - - - - - - - -	11±	
Unnamed shale			
(S pl. # 39)	1. Shale, black, platy, fissile, weathers dark to light brown, (exposed) - - - - - - - - - - - - -	11±	

Sample # 40

Section in bank at east side of road-cut, Missouri Highway 39, on south facing hill slops, center of west side SW 1/4 SW 1/4 NW 1/4 sec. 7, T. 35 N., R. 26 W., Cedar County, about 2-3/4 miles northwest of Caplinger Mills.

		Thickness Feet	Thickness Inches
Pennsylvanian System			
Desmoinesian Series			
Cherokee group			
Dederick formation			
Unnamed sandstone			
	2. Sandstone, thin bedded, almost platy, buff, brown, and rusty brown banding, partings contain brown clay, finely micaceous - - - - - - - - -	4±	
Unnamed shale			
(Spl. # 40)	1. Shale, black, fissile, platy, color grades downward in lowermost 17 feet from black to dark gray and brown, also becoming less platy and fissile (exposed) - - - - - - - - - - - - - -	27	6

Sample # 41

Section in north bank of pit of A. P. Green Fire Brick Company E 1/2 SE 1/4 SW 1/4 sec. 31, T. 51 N., R. 8 W., Audrain County, about 1-1/2 miles southeast of main office building at brick plant.

		Thickness Feet	Inches
Pennsylvanian System			
Desmoinesian Series			
Cherokee group			
Cheltenham clay			
(Spl. # 41)	1. Clay, waxy, black to dark olive green; bloaky - - - - - - - - - - -	2	6

Note: This sample taken from an irregular band that appears at varying elevations from bottom of pit. It is most prominently exposed in the north bank.

Sample # 42

Section in pit of Plumb Mining Company NW 1/4 sec. 17, 34 N., R. 13 W., Cole County, about 3-1/2 miles southeast of Russelville, north bluffs of South Moreau Creek.

		Thickness Feet	Inches
Pennsylvanian	System		
(Spl. # 42)	1. Shale, dark to blackish brown, light weight; (sinkhole deposit) - - - - - - - - - - - - - -	(unknown)	

Note: Sample collected by Carl Plumb of Plumb Mining Company.

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VITA

Jerry D. Plunkett, was born February 13, 1928 at Latour, Missouri to Mr. and Mrs. Charles Amos Plunkett. Mr. Plunkett was employed as a depot agent in Latour by the St. Louis and San Francisco Railway Co.

After completing the first four grades of elementary school at Latour, at the age of nine he moved with his parents to Clinton, Missouri. At Clinton he completed elementary school, after which he attended Clinton High School graduating as an honor student in 1945.

In February 1946 he entered the United States Air Force as an enlisted man, and served thirty-four months, twenty-three of which were spent in the Far East. In service he graduated from the U.S.A.F. Photographic School at Lowry Field, Colorado. He served in this capacity during his period of service.

He was honorably discharged November 28, 1948.

He entered Missouri School of Mines as a ceramic engineering student in September 1949. While enrolled at M.S.M. he was a member of the American Ceramic Society, and the honorary societies of Keramos, Tau Beta Pi, and Sigma Gamma Epsilon. In his junior year he served as treasurer of A.C.S. student chapter, and Herald for the Keramos chapter. In his senior year he was president of Keramos and won the A.C.S. chapter speech contest, and entered the national contest at the A.C.S. convention in New York in May, 1953.

In January 1953 he completed his work for a B.S. in Ceramic Engineering, which was conferred at the June 1953 commencement.

During 1953 and 1954 he has been doing graduate work at M.S.M. as a partial requirement for a Masters Degree in Ceramic Engineering.