Brick which underwent normal changes in density, specific gravity and shrinkage, in spite of blackening due to imperfect oxidation.

ILLINOIS
STATE GEOLOGICAL SURVEY.

BULLETIN No. 9.

Paving Brick and Paving Brick Clays of Illinois.

BY

C. W. ROLFE, R. C. PURDY, A. N. TALBOT AND I. O. BAKER.

CONTENTS.

Contents—Continued.

Contents—Continued.

Contents—Continued.

Contents—Concluded.

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES.

LETTER OF TRANSMITTAL.

Governor C. S. Deneen, Chairman, and Members of the Geological Commission:

Gentlemen—I submit herewith for publication as Bulletin 9 of this Survey a report upon the Paving Brick and Paving Brick Clays of the State, prepared under the direction of Professor Rolfe and written by Messrs. Rolfe, Purdy, Talbot and Baker. This report has been prepared in coöperation, especially, with the Department of Ceramics of the University. The work was begun in 1906, but owing to various causes, particularly the desire to make it complete and conclusive, its completion has been delayed to this time. When the investigation began it was found necessary to take up first of all the study of the qualities in clays which permit their manufacture into satisfactory pavers, and the means of determining those qualities. The numerous excellent studies made by other states and by individuals, while clearing up many of the difficulties, had proved to a considerable extent inconclusive, and, as detailed in this report, there was no existing method of determining in advance of actual trial on a working scale, the adaptability of a clay to this purpose. Before we could test our clays it was clearly necessary to make a study of the methods of testing. In order to eliminate the possible effect of local peculiarities, it was determined to base this preliminary study upon the best known paving brick clays of neighboring states, as well as of Illinois. The active coöperation of Edward Orton then State Geologist of Ohio, State Geologist W. S. Blatchley of Indiana, Dr. E. M. Shepard of Missouri, and of State Geologist E. Haworth of Kansas, made this possible. It is regretted that, owing to various causes, it was impossible to secure samples from the Iowa plants at the time.

Profesor C. W. Rolfe, Consulting Geologist of the Survey, and Director of the courses in Ceramics of the University, has been in general charge of the work, and has prepared the chapters on the "Geology of Clays," the "Geological Distribution of Paving Brick Material in Illinois," and on "Clays Tested, Which are Suitable for Use in the Manufacture of Paving Brick." In the case of the latter, he is responsible for the form only, having compiled the subject matter from the field and laboratory notes of the various members of the Survey, in order to

secure a convenient and uniform presentation of results. The field collections were made by the following individuals, the samples collected by them being indicated by the accompanying initial:

Mr. J. F. Krehbiel, K 1-14.
Mr. H. B. Fox, F 1.
Mr. E. T. Hancock, H 16, 17, 18, 20, 21, 23.
Mr. F. H. Ridell, R 1-3.
Mr. E. M. Shepard, S 1-2.
Mr. Frank P. Brock, L, B, H 2.
Mr. Fred J. Cambern, G. I.

The special laboratory investigations of the clays themselves, together with the rattler tests of the brick, were carried out by or under the direction of Mr. Ross C. Purdy, then Instructor in Ceramics in the University of Illinois, and now associate Professor in Ceramics at Ohio State University. Mr. Purdy had the assistance of Messrs. J. F. Krehbiel and J. K. Moore, but the main burden of the work as well as the writing up of the report fell on him. To his ingenuity in experimentation and to his energy and enthusiasm are due the credit for the excellent results obtained.

The testing of the paving brick made from the various clays, aside from the rattler tests, were made in the Laboratory of Applied Mechanics of the University of Illinois, under the direction of Professor Arthur N. Talbot, Professor of Municipal and Sanitary Engineering, and in charge of Theoretical and Applied Mechanics. The absorption and transverse tests were made by Mr. C. H. Pierce, Instructor in Theoretical and Applied Mechanics, and H. L. Whittemore, Associate in Applied Mechanics. In addition to reporting on these tests, Professor Talbot has written on the Qualities of High Grade Paving Brick, and the tests used in determining them,—a paper which adds materially to the value of the report as a whole.

The rattler tests were made under the direction of Mr. Purdy in the laboratory of the Department of Civil Engineering of the University. Acknowledgments are due to Professor Ira O. Baker of that department for the use of these facilities and also for preparing the vary interesting discussion, the "Construction and Care of Brick Pavements," which appears in the report.

To the various authors and assistants employed in the work, as well as to the numerous manufacturers who have so heartily coöperated in the investigation, our hearty thanks are due.

It is believed that the results presented in this report will prove of large importance. The more important may be briefly summarized as follows:

(1.) As a result of Mr. Purdy's tests, a relation has been established between the specific gravity of the test pieces burned at different degrees of heat, and the qualities of the resulting product, so that a way is now open for testing at comparatively slight expense and with considerable security as to results, the various clays believed to be suitable for manufacture into pavers.

(2.) The origin of clays and their relation to the parent rocks and the processes by which the one comes from the other are discussed in detail.

(3.) It is shown that by suitable treatment it is possible to make satisfactory pavers from a larger number of clays than was previously believed to be possible.

(4.) It is certain that suitable material occurs widely distributed throughout the State, and probable that no considerable area is wholly destitute of satisfactory clays.

(5.) A large amount of analytical data on certain type clays has been accumulated, and on further study will probably lead to still further scientific and technical advances.

(6.) An accurate series of comparative tests of a large number of paving bricks is furnished and valuable suggestions are made for the improvement and refining of the methods of testing.

(7.) The methods of constructing and caring for brick pavements are presented in a simple statement suitable for general use, and methods of cheapening the cost of such pavements are pointed out.

It is believed that this report will prove stimulating to the paving brick industry, will point the way to improvements in methods of testing and manufacturing, and will lead to a large use by our cities and town of our very excellent home made paving material.

Respectfully,

H. FOSTER BAIN, *Director.*

PAVING BRICK AND PAVING BRICK CLAYS.

By C. W. Rolfe, R. C. Purdy, A. N. Talbot and I. O. Baker.

GEOLOGY OF CLAYS.

[By C. W. Rolfe.]

Introduction.

In order to understand the geology of clays it is necessary to think of the surface layers of the earth as an immense chemical laboratory in which exchanges are taking place on every hand, old compounds breaking down and being replaced by new ones continually. In this case it must be borne in mind that nature's laboratory differs from those with which we are familiar in that in hers the conditions are not constant but are continually changing, while in ours they are practically fixed and uniform.

Elementary Chemical Principles—§ 1. In considering whether a chemical union will probably take place when two substances are brought together, it is necessary to think not only of the materials mixed but of the conditions under which they are placed. For example, oxygen and hydrogen may be mixed in a tube in the proper proportions to form water, and if kept in the dark will continue indefinitely as a mechanical mixture of gases, but if exposed to sunlight or to the passage of an electric spark union at once takes place. Again air and illuminating gas may be mixed in the cold without union, but once the temperature is raised to the proper point the mass bursts into flame. Certain substances will combine in the cold which refuse to do so when the temperature is elevated. Some unite under heavy pressure and separate again when the pressure is reduced. Some unite in the presence of a third substance, which, however, does not enter into the compound, and separate again as soon as that substance is withdrawn. In the ordinary operations of the chemical laboratory, little account is taken of these things because there the conditions are either uniform or are so easily controlled that the operator gives little thought to them—he learns the necessary control by practice rather than by precept—but in nature's laboratory where conditions are constantly changing they come to be of supreme importance.

Silica and Silicic Acid.—§ 2. If a piece of ordinary granite be carefully examined, glassy grains will be seen distributed through its mass. These are particles of quartz or silica, a compound of the element silicon with oxygen. The chemist designates this material by the symbol SiO_2,

1

using the first two letters of the word silicon with the first of oxygen and adding a small figure 2 to indicate that the compound contains two atoms of oxygen for each one of silicon.

Under ordinary conditions quartz is considered one of the most inert substances with which we are acquainted. Water and the acids, other than hydrofluoric, seem to have little or no attraction for it, and very little affinity seems to exist between it and any of the other elements. If, however, finely-powdered quartz be mixed with pulverized compounds of the metals such as potash, soda, alumina, oxide of iron, etc., the mass saturated with water and the whole raised to high temperature under strong pressure, the quartz or silica will at once unite with water to form an acid called silicic acid and this will immediately unite with the compounds of the metals (bases) mentioned to form silicates.

So strong is the newly-formed acid that it is able to take the metallic elements or bases out of their combinations with other acids and convert them into silicates. Under conditions of high temperature and pressure we are accustomed to regard silicic acid as the strongest of all our acids and able to displace any of them. If a mass consisting of carbonate of soda, nitrate of potash, sulphate of alumina, sulphide of iron, oxide of magnesia, or other salts of the common bases, be mixed with finely-powdered silica, suspended in water, and raised to a high temperature in a sealed vessel, the silica will unite with water, forming silicic acid, and this will crowd out the other acids and unite with their bases, forming simple or compound silicates of potash, soda, alumina, magnesia and iron, the acids which were originally united with these bases being set free and dissolved in the water. This, it is believed, would be the case with the salts of any acid which might be placed in the mixture; silicic acid being stronger than the other acids under these conditions will crowd them out and unite with their bases.

If we again examine our piece of granite we shall see that besides the grains of glassy quartz there are several kinds of minerals which enter into its composition. Further examination will show us that these are all simple or compound silicates of the above-mentioned substances and so we believe that they were all formed when the mass was highly heated and subjected to great pressure. All granitoid, i. e. granite-like, rocks are believed to have been formed under these conditions.

§ 3. In the preceding paragraphs the term silicic acid has been used as though it referred to a single acid, and the word silicates as though the salts referred to were derived by the union of various bases with this acid. While this use is sanctioned by custom, chemists know that the term silicic acid refers not to one but to a series of acids, and that the salts of these acids differ as widely in their properties as do those of other similar series. It has been stated above that silicic acid is formed by the union of silica (SiO_2) with water (H_2O). $SiO_2 +$ $H_2O = H_2SiO_3$, or silicic acid. This union actually takes place as indicated and salts of the acid so formed are among the silicates most commonly met with; but we also know that one part of silica may and does unite with two parts of water to form another acid, $SiO_2 + 2H_2O =$ H_4SiO_4, with another well-known series of salts whose properties differ from those of the first-mentioned acid. In the same way a third acid,

$SiO_2 + 3H_2O = H_6SiO_5$, formed by the combination of one molecule of silica with three of water, and its union with bases, makes a series of known salts with properties quite different from those of either of the others. Theoretically, it would be possible to carry the series on indefinitely, each added molecule of water making a new acid whose salts would have properties differing from those belonging to other members of the series. We do not yet know what the limits of the series really are, but feel certain that they are much wider than those indicated in most text-books on chemistry.

Formation of Silicates.—§ 4. When these acids unite with bases it is the hydrogen atoms which are crowded out by the base, $H_2SiO_3 + K_2O = K_2SiO_3 + H_2O$. That is, if silicic acid (H_2SiO_3) is united with potash (K_2O) the K_2 will replace the H_2 and potassium silicate K_2SiO_3 with water (H_2O) will be formed. Consequently the larger the number of replacable hydrogen atoms the acid carries, the larger number of atoms of base will it unite with and the larger will be the proportion of base to silica.

Acids.   Bases.   Salts.   Water.

$$H_2SiO_3 + K_2O = K_2SiO_3 + H_2O \text{ or } K_2O.SiO_2 + H_2O$$
$$H_4SiO_4 + 2K_2O = K_4SiO_4 + 2H_2O \text{ or } 2K_2O.SiO_2 + 2H_2O$$
$$H_6SiO_5 + 3K_2O = K_6SiO_5 + 3H_2O \text{ or } 3K_2O.SiO_2 + 3H_2O$$

and so on.

It will be noticed that the proportion of base to silica increases regularly as the series advances.

Other series of acids are formed by the union of two or more molecules of silica to form a compound molecule which then combines with one or more molecules of water to form acids which, by their union with bases, form series of salts containing a greater proportion of silica than those noted above. Examples are:

$5H_2O + 2SiO_2 = H_{10}Si_2O_9$, the acid for kaolin.

$4H_2O + 3SiO_2 = H_8Si_3O_{10}$, the acid for sepiolite.

$45H_2O + 10SiO_2 = H_{90}Si_{10}O_{65}$, the acid for rumpfite, etc.

§ 5. The last three paragraphs explain how it is that in the natural silicates the ratio of bases to silica varies indefinitely in both directions. The silicates so formed are not stable. Changing conditions of heat, pressure, mechanical force, etc., as well as variations in the dissolved material carried by earthwater, cause certain bases to be replaced by others and even effect changes in the composition of silicic acid itself. In this way orthoclase feldspar ($KAlSi_3O_8$) is known to have been transformed into albite ($NaAlSi_3O_8$) through the replacement of potash by soda, and into anorthite ($CaAl_2Si_2O_8$) through the replacement of potash by lime with a change of acid from $2H_2O + 3SiO_2 = H_4Si_3O_8$ to $2H_2O + SiO_2 = H_4SiO_4$, as well as into a large number of minerals less closely related (§14). A glance at the table of analyses of any silicate given by Dana or Hintze will give evidence of such replacements, and will show the regular gradation from one mineral into another. For example, in the table of analyses of orthoclase we find the potash and soda content varying from 15.21% K-.65% Na to 2.62% K-10.52% Na with the greatest variety of intermediate forms showing the gradual passage from orthoclase to albite. It is for this reason that we often see the chemical

formula for a mineral written in this way (Mg Fe) SiO₄, which means that a variable quantity of magnesia and iron are combined with the silica. This mineral (MgFe) SiO₄, forms the intermediate member of a series of which MgSiO₄ and FeSiO₄ are the extremes, and the formula covers all the forms which are produced as the composition is gradually changed from that of a silicate of magnesia to that of a silicate of iron or the reverse. Changes like these are continually taking place in the crystalline rocks, some minerals being removed or transferred into others while entirely new minerals are being introduced.

CHEMICAL AND MINERAL COMPOSITION OF GRANITOID ROCKS.

§ 6. All granitoid rocks are made up of minerals like the above and nearly all of these minerals are silicates of one or more, often many, bases.

In Table I (§ 8) which is compiled from tables of analyses given in Kemp's Handbook of Rocks, I have indicated the composition of the various groups of rocks, giving in each case the upper and lower limits and the average, and in Table II (§ 9) I have listed the minerals which are most commonly found in these rocks and indicated the chemical composition of each. A careful study of these tables will show from what minerals each of the chemical substances listed in Table I is derived.

The analyses given are such as would result from the use of ordinary methods. More refined analytical methods would prove that these rocks contain all known chemical elements variously combined. Such analyses would prove to us that the crystalline rocks form the storehouse from which all inorganic materials have been withdrawn.

Table III (§ 10) gives F. W. Clarke's estimate of the proportion in which the more abundant elements occur in the earth's surface layers.

Principle Minerals which occur in the several Groups of Crystalline Rocks.

§ 7. Granite Group.
    Essential—quartz, orthoclase or albite.
    **Accessory—mica, amphibole, pyroxene.
Syenite Group.
    Essential—orthoclase or albite, mica or amphibole or pyroxene.
    Accessory—iron oxides, plagioclase, quartz, apatite.
Nepheline-Syenite Group.
    Essential—orthoclase, nepheline, amphibole or pyroxene or mica.
    Accessory—plagioclase, iron oxides, apatite, sodalite, leucite, cancrinite, zircon.
Diorite Group.
    Essential—oligoclase, hornblende, or augite or biotite.
    Accessory—labradorite, rhombic pyroxene, apatite, quartz.
Gabbro Group.
    Essential—labradorite or anorthite, pyroxene.
    Accessory—olivine, quartz, biotite, iron oxides, apatite, chlorite, serpentine.
Peridotite Group.
    Essential—absence of quartz, feldspar and the feldspathoids as prominent ingredients.

**The accessory minerals are usually, but not necessarily, present.

TABLE I.

§ 8.   *Chemical Composition of Crystalline Rocks.   (after Kemp).*

a⚌ averages of 12 to 30 analyses.

	Silica. SiO_2.	Alumina Al_2O_3.	Sesqui-oxide of iron. Fe_2O_3.	Pro-toxide of iron. FeO.	Lime. CaO.	Mag-nesia. MgO.	Potash. K_2O.	Soda. Na_2O.
Granite group.	78.95 to 63.63 a.70.00	18.32 to 10.22 a.14.92	6.1 to .15 a.1.96	5.76 to 0 a.1.11	4.89 to .29 a.1.99	2.39 to .12 a. .57	8.38 to .89 4.56	5.14 to .30 a.3.10
Syenite group.	66.03 to 46.11 a.58.73	20.76 to 10.05 a.18.09	6.77 to 1.31 a.3.21	8.20 to 0 a.2.91	7.82 to .96 a.3.05	'5.73 to .39 a.1.38	7.70 to 3.84 a.5.53	8.55 to 1.24 a.4.75
Nepheline Syenite group.	61.08 to 41.37 a.53.47	24.14 to 16.25 a.20.99	7.76 to .42 a.3.42	5.97 to 0 a.1.07	4.62 to .32 a.2.56	1.97 to .13 a. .53	7.17 to 4.63 a.5.80	11.17 to 6.29 a.8.47
Quartz Diorite group	70.36 to 62.43 a.66.55	17.88 to 14.57 a.16.22	3.05 to .88 a.1.86	3.97 to .34 a.1.90	4.79 to 1.73 a.3.23	4.57 to .64 a.2.22	4.12 to 1.60 a.2.52	4.91 to 3.10 a.3.94
Diorite group.	67.83 to 48.19 a.57.20	18.88 to 14.94 a.17.23	4.92 to 0 a.1.97	.7.32 to 1.09 a.4.55	8.98 to 3.54 a.5.98	7.36 to 1.32 a.2.32	5.56 to 1.11 a.2.32	6.77 to 3.67 a.4.09
Gabbro group.	59.55 to 46.28 a.52.55	28.01 to 12.96 a.22.05	6.60 to .41 a.2.34	10.20 to 0 a.4.66	13.16 to 6.02 a.9.95	9.78 to 2.95 a.4.24	3.01 to .09 a.1.06	5.83 to .95 a.3.34
Peridotite group.	55.14 to 29.81 a.43.11	11.76 to .25 a.5.40	15.01 to 1.41 a.4.65	9.94 to 3.90 a.5.46	15.47 to 4.06 a.9.40	32.41 to 15.34 a.24.42	2.48 to 0 a. .66	1.48 to 0 a. .40

Si=Silicon.   Al=Aluminum.   Ca=Calcium.   K=Potassium.
O=Oxygen.   Fe=Iron.   Mg=Magnesium.   Na=Sodium.

TABLE II.

Table of Minerals common in Crystalline Rocks, with the Chemical Composition of Each.

§ 9. Feldspar Group.
Orthoclase—$KAlSi_3O_8$.
Silica 64.7%; alumina 18.4%; potash 16.9%.
Albite—$NaAlSi_3O_8$.
Silica 68.7%; alumina 19.5%; soda 11.8%.
Anorthite—$CaAl_2 (SiO_4)_2$.
Silica 43.%; alumina 36.7%; lime 20.1%.
Other feldspars are regarded as admixtures of these in varying proportions.

MICA GROUP.

Muscovite—$H_2KAl_3(SiO_4)_3$.
Silica 45.2%; alumina 38.5%; potash 11.8%; water 4.5%.
Biotite—$(HK)_2(MgFe)_2Al_2(SiO_4)_3$.
Silica 39%; alumina 16.9%; iron 9%; magnesia 21.9%; potash 8.8%.
Other micas may for our purpose be regarded as admixtures of these or varieties containing small amounts of other substances.

HORNBLENDE GROUP.

Tremolite—$CaMg(SiO_3)_4$.
Silica—57.7%; magnesia 28.9%; lime 13.4%.
Hornblende—$(MgFe)_3Ca(SiO_3)_4$.
Silica 55.5%; iron 6.3%; magnesia 22.6%; lime 13.5%, or
Silica 40.1%; alumina 17.6%; iron 12.3%; magnesia 17.5%; lime 12.5%.
Other varieties of the hornblende group may be regarded as admixtures of these or varieties containing small amounts of other substances.

AUGITE GROUP.

Diopside—$CaMg(SiO_3)_2$.
Silica 55.6%; magnesia 18.5%; lime 25.9%.
Hedenbergite—$CaFe(SiO_3)_2$.
Silica 48.4%; iron 29.4%; lime 22.2%.
Augite—$CaMg(SiO_3)_2$.
Silica 52.5%; iron 3.1%; magnesia 19.8%; lime 24.6%, or
Silica 50.2%; alumina 3.8%; iron 8.4%; magnesia 16.4%; lime 20.3%.
Other varieties of this group may be considered as admixtures of these or varieties containing small amounts of other substances.

OLIVINE GROUP.

Olivine or peridotite—$(MgFe)_2SiO_4$.
Silica 41.2%; magnesia 50.2%; iron 8.5%.

FELDSPATHOIDS.

Nepheline—$K_2Na_6Al_8SiO_{34}$.
Silica 44%; alumina 33.2%; soda 15.1%; potash 7.7%.
Minerals similar to nephelite also occur in which a portion of the soda is united with carbonic and other acids.
Sodalite—$Na_3Al_3(SiO_4)_3+NaCl$.
Silica 36.4%; alumina 33%; soda 18.8%; salt 11.7%.
Minerals similar to sodalite also occur in which a portion of the soda is united with sulphur acids.
Leucite—$KAl(SiO_3)_2$.
Silica 55%; alumina 23.5%; potash 21.5%.
Quartz—
SiO_2=free silica 100%.
Magnetite—Fe_3O_4=Iron 72.4%; oxygen 27.6%.
Other oxides of iron.
Pyrite—FeS_2.=Iron 46.6%; sulphur 53.4.%
Other sulphides of iron which often also contain varying percentages of other metals.
Titanite—$CaTiSiO_5$= 30.6%; lime 28.6%; titanium oxide 40.8%.
Ilmenite—$FeTiO_3$.=Iron 36.8%; titanium oxide 31.6%; oxygen 31.6%.
Spinel—$MgAl_2O_4$.=Alumina 71.8%; magnesia 28.2%.
Zircon—$ZrSiO_4$.=Silica 32.8%; zirconia 67.2%.
Apatite—$3Ca_3P_2O_8+CaF_2$ or $CaCl_2$. Phosphorus pentoxide 42.3%; lime 55.5%; fluorine 3.8%, or Phosphorus pentoxide 41%; lime 53.8%; chlorine 6.8%.
Topaz—$(AlF)_2SiO_4$. Silica 32.6%; alumina 55.4%; fluorine 20.7%.
Garnet—
A series of minerals formed by the union of alumina, magnesia, lime, iron and oxides of other metals with silica.
Tourmaline—
A group of minerals containing potash, soda, magnesia, lime, alumina, iron and oxides of other metals united with boron and silica.

While this list covers practically all the minerals commonly found in crystalline rocks, many others occur in small quantities. The compositions assigned to the several minerals are ideal. The actual minerals vary in the proportions of the several ingredients. They also often contain small amounts of substances not named here because they are not typical.

TABLE III.

Table Showing Percentages of the More Common Elements in the Surface Layers of the Earth and the Symbols by Which They are Known.

§ 10.

1. Oxygen, O.	47.00%	12. Phosphorus, P.	.11%
2. Silicon, Si.	28.23%	13. Sulphur, S.	.11%
3. Aluminium, Al.	7.99%	14. Barium, Ba.	.089%
4. Iron, Fe.	4.46%	15. Manganese, Mn.	.084%
5. Calcium, Ca.	3.43%	16. Chlorine, Cl.	.07%
6. Sodium, Na.	2.53%	17. Strontium, Sr.	.034%
7. Magnesium, Mg.	2.46%	18. Chromium, Cr.	.034%
8. Potassium, K.	2.44%	19. Zirconium, Zr.	.026%
9. Titanium, Ti.	.43%	20. Nickel, Ni.	.023%
10. Hydrogen, H.	.17%	21. Fluorine, F.	.02%
11. Carbon, C.	.14%	22. Vanadium, V.	.02%
	23. Lithium, Li.	.01%	

ORIGINAL COMPOSITION OF THE EARTH'S CRUST.

§ 11. Geologists believe that there was a period in the history of the earth when its entire surface was composed of crystalline rocks like those described and that this was so because the whole earth was then highly heated and the atmosphere was many times denser than now. The conditions then were exactly those that make silicic acid more powerful than the other acids and consequently it was able to take possession of all the bases and so form crystalline (granitoid) rocks which are aggregations of silicates.

These conditions probably did not reach to any great depth, possibly some tens of thousands of feet, and below that the bases are probably either uncombined or exist in combination with each other. Let us then think of the earth at this early time as being covered with a mantle some tens of thousands of feet thick made up entirely of silicates and that this mantle then contained all the chemical elements with which we are familiar, except possibly the gases of the atmosphere, and to some extent these also, locked up in the form of silicates. As the earth gradually lost its heat, let us think of these silicates as passing from one form into another under the compulsion of changing conditions of heat, pressure, etc., and so come to look upon these outer layers of the earth not as something that is fixed, stable, immutable, the symbol of all that is untransformable and enduring, but as a busy workship in which the various chemical elements are always trying to adjust themselves to everchanging conditions and are never quite able to reach their goal.

After millions of years of this activity, the conditions at the surface of the earth came to be markedly different from those which have been

described. During all this time the earth had been absorbing the gases of the atmosphere and its pressure had been reduced to approximately what it now is. The absorption of gases made the atmosphere more transparent to dark heat† and so permitted the earth's surface to cool more rapidly, and this in turn allowed the water, most of which had up to this time been suspended in the atmosphere, to be precipitated and remain upon its surface.

The cooling of the earth's surface and the reduction of atmospheric pressure gradually destroyed the conditions which gave to silicic acid the power to keep possession of the bases in spite of the presence of other acids, consequently these acids feeling their newly acquired strength began to assert themselves, to crowd out the silicic acid, and to unite with its bases. Among these acids carbonic acid [$(H_2CO_3=CO_2H_2O$ (carbon dioxide $+$ water] easily takes first place, principally on account of its abundance in earth-water.

DECOMPOSITION OF GRANITOID ROCKS.

General Agents and Processes.—§ 12. All rocks and minerals are porous, that is, the particles of which they are composed cannot lie against each other in such a way as to occupy all the space, and hence openings or pores are left for the passage of air or water. This is as true of a crystal of quartz or a diamond as it is of the coarsest sandstone. If a crystal or fragment of any stone be dried for several hours at a temperature above 212 deg. F., carefully weighed by a delicate balance, then submerged in water and either placed in a receiver from which the air has been exhausted or boiled for several hours, then taken from the water, the surface carefully dried, and the specimen weighed again, the latter weight will be greater than the former by the weight of water which it has absorbed. This excess of weight used in connection with the specific gravity and the dry weight of the specimen, will give the pore space.

$$\frac{(\text{Wet weight—dry weight}) \text{ x specific gravity}}{\text{dry weight}} = \frac{\text{percentage}}{\text{of pore space.}}$$

Van Hise in his "Treatise on Metamorphism"[*] states that the pore space varies from a small fraction of 1% to 50% or more, and gives a very pretty experiment to prove the presence of pores in an apparently impervious material. In agate or chalcedony the pores are so small that the most powerful microscope fails to detect them, yet if thoroughly dried specimens be boiled in colored solutions the liquid will make its way into them and change their color.

The average pore space in building stones is variously estimated but as data are insufficient but little reliance can be placed upon any of them. Perhaps as fair an estimate as has been proposed for all rocks is 13% which would enable them to absorb about one gallon of water for each cubic foot. This may or may not be near the truth, but it serves to illustrate the fact that apparently solid rocks when saturated carry

†Heat radicated from a non-luminous body.
*Monograph 48, U. S. Geological Survey.

large volumes of water. It should also be remembered that this water is not confined to the inter-crystalline spaces, but permeates the inter-molecular spaces as well, even when they are so small that they cannot be seen by the aid of the microscope.

§ 13. Under the influence of gravity, changes in molecular attraction, temperature, and mechanical action, this water is continually kept in motion, but the velocity of movement varies widely. In coarse-grained rocks with large pore spaces, lying above the level of ground water, especially if cut by fissures or other openings produced by mechanical or chemical action, the flow would be relatively rapid, but in proportion as the rocks become finer-grained, the grains more angular, the structure more compact and the opportunities for drainage less, the rate of move-ment is reduced until it becomes so low as to be unmeasurable by the means at our disposal. Not only this, but the flow varies widely within the rock-mass itself, being relatively rapid in the inter-crystalline or inter-granular spaces and very slow in the pores between the molecules.

When the rock lies near the surface, well above the level of ground water, and is more or less cut up by joints, bedding planes and planes of cleavage or fracture, gravity becomes the dominant cause of motion and the water flows downward toward the base of the mountain or the immediate valley of some stream, but when it lies below the level of ground water, other forces often become strong enough to overcome grav-ity entirely and the water flows in the direction of the least resistance, whether that be upward, sidewise or downward. Under these condi-tions water often rises from great depths bringing increased temperature and a load of dissolved material which greatly increases its working power.

The water which circulates near the surface is almost entirely de-rived from rain. As water falls through the air it dissolves small quantities of carbonic and other acids and so reaches the surface in the form of a weak acid solution. The rain-water which falls upon the sur-face may be divided into three portions, of which the first, much the smallest, is immediately converted into vapor and rises; the second, the run-off, does not enter the ground but slides off into nearby streams, while the remainder sinks into the ground and fills the pores referred to above. This ground-water represents a varying percentage of the rainfall, depending on the physical condition of the surface layers. It may represent practically all the water that falls or only a very small fraction, but, except in the driest regions, it is always sufficient to keep the surface layers moist and the chemical forces active. As rain-water enters the rocks it carries its dissolved acids with it and so brings them into contact not only with each rock particle, but also with each molecule of which these particles are composed, and as this contact usually occurs under conditions which make carbonic acid stronger than silicic acid, a reaction takes place and the former replaces the latter. The table of rock-forming minerals given above shows that they are usually com-plex salts in which several bases are united with silicic acid. Some of these bases are more strongly held by the acid than others, and it hap-pens that those held with least force by silicic acid are most strongly attracted by carbonic acid. Potash and soda seem to be attacked first, then lime and magnesia, then iron, and lastly alumina.

§ 14. The statement commonly made is that carbonic acid enters the compound and first breaks up the union of the alkalies, potash and soda, with silicic acid, uniting with the bases and setting the silicic acid free; that it next attacks the lime and magnesia in the same way, and finally the iron, leaving the union between alumina and silica undisturbed.   We would then have, in place of orthoclase, carbonates of potash, soda and iron, and hydrous silicate of alumina with free silica. This seems not to be strictly true. The real reaction seems to be that carbonic acid breaks the complex silicate into its elements and that these elements re-unite to form a large number of compounds better suited to the new conditions. This charge is often so complete that even the union between water and silica (which forms silicic acid) is broken, and they unite in different proportions forming an acid with different composition and properties. When drainage is defective and the groundwater becomes saturated with dissolved salts, it often happens that the decomposition of a single complex silicate gives rise to a large number of simpler salts, some of which are silicates and some salts of other acids.

Van Hise in his "Treatise on Metamorphism" (pp. 372-4.) gives a list of the more common minerals and the varieties which result from their decomposition. As examples, I have selected those which follow:

Orthoclase alters to allophane, biotite, cimolite, damourite, epidote, gibbsite, halloysite, kaolin, muscovite, newtonite, pyrophyllite, quartz.

Biotite alters to chlorite, diaspore, epidote, gibbsite, hematite, hydrobiotite, hypersthene, kaolin, limonite, magnetite, quartz, serpentine, sillimanite, spinel.

Hornblende alters to augite, biotite, calcite, chlorite, epidote, hematite, magnetite, quartz, serpentine, siderite.

Nephelite alters to albite (conjectural), analcite, diaspore, gibbsite, hydromuscovite (pinite), hydronephelite, kaolin, muscovite, natrolite, sodalite, thomsonite.

It must not be inferred that whenever one of these minerals decomposes all the above-named alteration products result, but simply that any group of them may be formed. It is probable that many changes not included in the above list take place.

Formation of Residual Clays.—§ 15. It has been stated above that when acid solutions enter a rock, the acids unite most readily with the alkalies, next with the alkaline earths, and then with the iron. If the water circulation is poor and the solutions come to be saturated, most of the bases will be redeposited, either as silicates or salts of other acids or both, but if the circulation is free, most of them will be carried away in solution to be deposited elsewhere. The acids of ground-water seem to have much less attraction for aluminum than for the other bases, and so the greater portion of this base is allowed to form new compounds with the free silicic acids, such as halloysite (Al_2O_3. $2SiO_2+Aq$), allophane (Al_2O_3. SiO_2+5H_2O, cimolite ($2Al_2O_3$. $9SiO+6H_2O$), collyrite ($2Al_2O_3$. SiO_2+9H_2O), kaolin (Al_2O_3. $2SiO_2+2H_2O$), schrötterite ($8Al_2O_3$. $3SiO_2+30H_2O$), montmorillonite (Al_2O_3. $4SiO_2+H_2O+Aq$), the zeolites, etc. Some of the alumina, however, is nearly always redeposited without combination with silica in the form of gibbsite (Al_2O_3. $3H_2O$), diaspore (Al_2O_3. H_2O) and other oxides or hydroxides.

If granite or a granitoid rock should completely decompose through the action of acids under conditions which afford perfect drainage, most of the potash, soda, lime, magnesia, iron, etc., would be converted into soluble salts and carried away, while the aluminum and magnesium salts would mostly be left in the form of hydrous silicates and oxides. Such a mass would be composed of the minerals enumerated in the preceding paragraph, would be earthy in texture, and would have the properties which we assign to clay; in fact it would be what we call a pure clay. No fixed composition could be assigned to such masses because they would contain varying proportions of these minerals and others like them. Deposits rich in allophane, collyrite, gibbsite, etc., would be high in alumina while those rich in cimolite, montmorillonite, etc., would be high in silica. As kaolin has nearly the average composition of this group of minerals it is customary to use its name for the whole mass, and this custom is all right if we remember that deposits so named are not composed of a single mineral substance having fixed properties, but of a group of minerals whose properties vary among themselves quite widely.

A glance at the table of analyses of kaolin (§ 17) will make this point clear. Nos. 4 and 10 in the table have nearly the theoretical composition of kaolin, while 11 and 12 of this table, 7 and 8 of the table of ball clays, and 8 and 9 of that of flint clays, show too high a percentage of alumina in comparison to the silica, indicating the presence of gibbsite or some other mineral high in alumina, and Nos. 1, 2 and 6 are much too high in silica. These last may be explained by assuming the presence of free silica, or of minerals higher in silica than kaolin. Probably the true explanation would include both these causes.

Origin of Impurities Occurring in Clays.—§ 16. These tables (§ 17, 18, 19,) show also that small percentages of alkali, iron and the alkaline earths are present in nearly all clays, even those of the highest grades. This is brought about in three ways. It may be due to a lack of drainage which permits a recomposition of recently-liberated bases in the way described above. A second explanation involves the fact that slight differences in the molecular structure of crystals, even those of the same mineral, enables the acids to break up some of them much more readily than others; consequently in any mass resulting from the decomposition of crystalline material, a considerable percentage of unaltered or but slightly changed fragments of crystals is mixed with the products of decomposition, and these fragments usually represent most of the minerals originally present. (Users of high-grade clays usually remove the coarsest of these fragments, and like minerals produced in other ways, by washing.) Or, third, they may have been introduced by circulating earth-water bringing these ingredients from other sources and leaving them in this deposit. All these are real and active causes for the contamination of clays.

From the foregoing we learn that rain-water falling on granitoid rocks sinks into them and permeates their whole structure; that through the action of the acids which it carries, and to some extent of the water itself, the silicates of which the granitoid rock is made are broken into their elements, and that these enter into new combinations, the bases

uniting in part with acids carried in earth-water, and in part recombining with silicic acid, or with silicic acid and water to form new silicates; that in those situations where the movement of earth-water is free the soluble compounds formed by these unions are carried away to be deposited elsewhere; that, in proportion as the movement of earth-water is obstructed, these soluble salts enter into new combinations and are redeposited as silicates, oxides and salts of other acids; that the more insoluble salts formed, such as the silicates, hydrosilicates and oxides of aluminum and magnesium, and to some extent of iron and other elements, are left behind as earthy masses containing fragments of undecomposed minerals, and the products of recrystallization mentioned above, mixed with the earthy matters; that as shown by Table I (§ 8) alumina is much more abundant in most crystalline rocks than any other base, and hence its salts enter more largely into these earthy deposits than do those of any other; that nearly pure deposits of such aluminous material cannot form unless the rocks from which they are derived are made up almost exclusively of minerals carrying as bases only alumina and such other substances as form soluble compounds during decomposition, and these last only when conditions are such as to permit free circulation of water during the decomposition; (earthy deposits of other materials would be formed under similar conditions); that these combinations of conditions rarely occur, and consequently high-grade aluminous deposits are not common; that most granitoid rocks contain considerable percentages of magnesia, lime, iron and many other substances not shown in the tables, whose salts, formed during rock decomposition, are more or less insoluble and so enter into the earthy residual mass, and also that conditions which interfere with free drainage are more common than those which favor it, and so the earthy masses generally contain the products of the recomposition and redeposition of soluble salts; that these residual masses of earthy aluminous material are called clays, and that clays produced by the decomposition of rocks in situ are called residual clays.

It is also evident that the composition of residual clays will vary with that of the rocks from which they are derived, and will include nearly pure deposits of salts of alumina as found in so-called kaolin, ball, flint and fire clays, on the one hand, and the very impure brick, tile, and adobe clays, on the other. The variation in composition of such grades of clay as are used commercially may be seen by reference to the following table of analyses taken from the official publications of the United States, and those of the various states. The analyses are selected with the purpose of showing variations in composition. All are of clays that are highly esteemed for their several uses.

§ 17. ANALYSES OF TYPICAL CLAYS.

KAOLIN.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1.	King-to-Chin, China.....	73.55	21.00	....	2.55	.55	....	2.62
2.	Berlin, Germany.........	72.96	24.78	....	.10	....	1.22	....
3.	Sevres, France...........	58.00	34.50	....	4 50	....	3.00	....
4.	Cornwall (best) England..	46.30	39.70	.30	.40	....	.50	12.80
5.	Meissen, Germany........	57.70	36.00	.80	.30	....	5.20	....
6.	Wilmington, Del..........	72.40	14.80	....	.35	....	.75	....
7.	Woodbridge, N. J........	44.10	39.36	1.40	....	....	14.90	....
8.	Lawrence Co., Ind........	39.00	36.06	....	1.63	....	.54	23.50
9.	Inyo Co., Cal.......	44.74	33.23	1.08	.77	.23	2.24	17.56
10.	Edwards Co., Texas	45.82	39.77	....	....	....	.39	....
11.	Elgin, Scotland	39.30	38.52	....	.75	.83	....	19.54
12.	Steinbruck, Styria.........	40.7	38.40	....	.60	1.50	....	18.00

BALL CLAYS.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1.	Edgar, Florida	46.11	39.55	.35	....	.13	....	13.78
2.	Burt's Creek, N. J........	44.40	38.34	.86	....	.	.44	14.60
3.	South Amboy, N. J.......	44.89	37.27	.97	.41	.19	1.44	14.47
4.	Mayfield, Ky.............	56340	30.00	....	.40	....	5.27	7.93
5.	Wareham, England......	55.00	29.71	2.14	.62	....	3.44	10.84
6.	Jefferson Co., Mo	48.51	35.18	.92	1.01	1.47	2.30	10.72
7.	Union, Mo................	44.14	39.86	.46	.77	.46	.71	13.84
8.	Hall, England....	39.60	45 00	....	.10	3 30	....	12.00

FLINT CLAYS.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1.	Mineral Point, O..........	52.52	31.84	.67	.50	.19	.59	11.68
2.	Salinville, O.............	59.92	27.56	1.03	....	. ....	.67	9 70
3.	Beaver Co., Pa	65.85	22.87	1.14	.53	.37	2.01	6.93
4.	Swallow Falls, Ind........	61.00	26.36	.83	.21	.10	....	11.60
5.	Tipton, Ky...............	46.75	38.17	....	.11	....	.56	14.03
6.	Gorman, Ky	68.01	24.09	1.01	3.01	....	....	3.03
7.	Learburg, Mo............	43.82	38.24	.23	....1.93	....	.73	14.94
8.	Dry Branch, Mo...........	42.60	41.88	.62	.28	.20	.54	14.00
9.	Drake, Mo...............	40.50	43.22	.31	1.10	....	.51	14.15

FIRE CLAYS.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1.	Stonebridge, Eng........	65.1	22.22	1.92	.90	....	....	9.86
2.	Glenb'g Star, Scot	65.41	30.55	1.70	.69	.64	.55	....
3.	Gairnkirk, Scot............	53.40	43.60	1.80	.60	....	....	....
4.	Leeds, Eng................	78.60	15.90	3.60	.84	.42	.29	....
5.	Limoges, France..........	52.55	26.50	.55	3.00	1.50	....	16.55
6.	Sevres, France	42.00	38.96	.85	1.04	.17	....	19.23
7.	Climax, Pa	42.82	40.20	2.59	....	.35	1.24	12.80
8.	Morrison, Colorado.......	71.80	15.00	....	3.80	....	....	8.30
9.	Hickman, Ky	84.92	10.56	1.10	.57	.11	.65	2.09
10.	St. Lauis, Mo.............	61.22	25.64	1.70	.70	.08	.73	10.00
11.	Greenup, Ky....	46.75	38.17	.29	.57	.12	.07	14.03
12.	Gruenstadt, Germany.....	47.33	35.05	2.30	.16	1.11	3.18	10.51

STONEWARE CLAYS.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1.	Coblentz, Germany.......	55.28	24.19	1.00	....	2.02	....	5.76
2.	Meillonaus, France	59.00	22.00	5.05	3.85	....	....	11.00
3.	Meillonaus, France.......	57.26	16.04	12.00	2.15	4.52	....	10.46
4.	Roseville, Ohio	69.35	19.08	1.26	.60	.63	2.16	6.59
5.	Putnam Co., Ind..........	66.18	21.15	5.30	.70	.14	.33	4.11
6.	Bacon Hill, Md	65.70	20.30	1.00	3.50	1.44	.62	7.60

BRICK CLAYS.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1.	Indianola, Ia. (loess)	63.31	16.57	4.06	1.11	1.10	3.16	10.65
2.	Spencer, Ia. (loess)	52.42	13.04	6.24	7.98	2.24	8.08	6.73
3.	Mason City, Ia. (shale)...	54.64	14.62	5.69	5.16	2.90	5.89	9.39
4.	Carterville, Ga. (Alluv)..	69.18	15.43	5.83	....	.71	1.98	6.85
5.	Madison, Wis	75.80	11.07	3.53	1.84	.08	2.11	3.70
6.	Sayerville, N. J	60.18	23.23	3.27	1.00	.67	3.38	8.54
7.	Garfield, N. J	73.71	11.09	4.30	2.31	1.71	3.29	3.93

TERRA COTTA CLAYS.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1. Baltimore, Md	68.30	21.27	1.43	.52	.90	.20	7.55
2. Alfred Center, N. J	53.90	23.25	10.90	1.01	.62	2.69	6.39
3. Billings, Mo	63.11	23.11	1.79	.42	.70	3.71	7.05
4. Woodbridge, N. J	44.20	38.66	.74	....		.46	13.55

GLACIAL CLAYS.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
1. Chippewa Falls, Wis	71.77	13.74	3.60	1.23	1.17	3.50	5.00
2. Glenwood, Wis	73.14	11.14	5.00	.97	.88	3.68	4.58
3. Marshfield, Wis	68.74	10.65	3.16	3.81	2.73	4.00	6.55
4. Menomonie. Wis	63.36	14.01	6.40	2.63	2.21	4.50	6.79
5. Merrillan, Wis	62.59	17.42	5.88	....	1.29	8.60	4.15
6. River Falls, Wis	70.02	14.77	5.00	1.02	1 03	3.33	4.50
7. Tomahawk, Wis	70.41	13.64	5.20	1.54	1.49	4.12	3.37
8. Whittlesey, Wis	70.54	13.60	4.48	.70	1.41	4.30	4.10

LOESS CLAYS.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
Kansas City, Mo	72.00	11 97	3.51	1.80	1.35	3.25	5.42
Boonville, Mo	71.11	11.62	3.90	2137	1.47	3.14	6.71
Jefferson City, Mo	74.39	12.03	4.06	1.50	1.53	3.01	3.17
Hannibal, Mo	73.80	13.19	3.43	.86	.68	2.94	5.26
St. Louis, Mo	73.92	11.65	4.74	1.43	.60	3.13	3.08

ADOBE CLAYS.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Carbonic acid.	Organic matter.	Water.
Santa Fe, N. M	66.69	14.16	4.38	2.49	1.28	1.88	.77	2.00	4.94
Ft. Wingate, N.M	26.67	.91	.64	36.40	.51	....	25.84	5.10	2.26
Humboldt, Nev	44.64	13.19	5.12	13.91	2.96	2.30	8.55	3.43	3.84
Salt Lake City, Utah	19.24	3.26	1.09	38.94	2.75	....	29.57	2196	1.67

SLIP CLAYS.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
Akron, O	60.40	10.42	5.36	9.89	4.28	.87	8.05
Albany, N. Y	58.54	15.41	3.19	6.30	3.40	4.45	8.08

FULLERS EARTH.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
Reigate, Germany	53.00	10.00	9.75	.50	1.25	....	24.00
England	44.00	11.00	10.00	5.00	2.00	5.00	21.00
Florida	62.83	10.35	2.45	2.43	3.12	.94	14.13
Georgia	67.42	10.08	2.49	3.14	4.09	....	11.89
South Dakota	58.72	16.90	4.00	4.06	2.56	2.11	10.40

PAVING BRICK CLAYS.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Alkalies.	Water.
Fort Smith, Ark	58.43	22.50	8.35	....	1.14	3.21	6.20
Cartersville, Ga	58.63	20.47	8.58	....	1.42	4.00	7.06
Robbins, Ky	51.56	15.56	7.68	7.27	.82	3.57	13.44
Columbus, O	58.38	20.89	5.78	.44	1.57	5.02	7.53
Massillon, O	64.10	21.79	2.51	.10	.58	2.65	6.05
Palestine, O	57.80	25.54	2.51	.25	.61	2.69	8.35
Clinton, Ind	43.14	40.87	3.44	2.01	.97	.02	9.48

Percentage of Clay Substances.—§ 18. In a preceding paragraph (§ 16) the statement was made that clay contains a great variety of silicates, hydrosilicates, oxides and hydroxides of alumina, and these minerals differ widely in chemical composition and physical properties. It was further stated that the chemical composition of kaolin comes nearer a fair average of all these minerals than any other. Assuming for our present purpose that it is a true average, we may use its formula

to estimate the amount of true clay matter in any clay. This formula tells us that 39.5% of pure clay is alumina, or in other words, that if we multiply the alumina as given in any complete analysis by 2.53, we will have the proportion of true clay substance which the commercial clay contains.

Let us take for example the fourth analysis under the table of kaolins (§ 17), which shows 39.7% of alumina; $39.7 \times 2.53 = 100.4\%$, or the material is practically pure kaolin. Again No. 5, under brick clays, shows 11.07% alumina; $11.07 \times 2.53 = 28\%$, or only 28% of the mass is true clay. If we consider the last analysis under ball clays, we have alumina 45%. $45 \times 2.53 = 113.85\%$, or the alumina present represents an amount of kaolin 13.85% greater than the whole mass. This proves that the clay is in part composed of some compound richer in alumina than kaolin, as gibbsite, pholerite, etc. Further study of the tables in this way will be found instructive.

If the percentage of alumina in any such analysis be multiplied by 1.176, the result will be the percentage of silica, which combined with this alumina would form kaolin. If this factor be used with the tables it will be found that in quite a number of instances the silica shown in the analysis is less than that required for kaolin, which again proves the presence of some compound richer in alumina than kaolin. In the great majority of instances, however, the amount of silica found is less than that given in the analysis. This may be explained either by assuming the presence of free silica, or that of a compound poorer in alumina than kaolin, as cimolite. Usually the first of these explanations is the true one, but the second is occasionally, we do not know how frequently, true also.

There seems little doubt that the presence of compounds richer or poorer in alumina than kaolin will, in large measure, account for differences in behavior of clays whose analyses show similar compositions. This cannot be demonstrated until we know more about the properties of these compounds.

Agents which Aid in the Decomposition of Rocks.—§ 19. In § 12, 13, 14, 15 we have shown how hard granitoid rocks may be decomposed, by earth-water and the acids which it contains, to form an earthy mass called clay. This process is greatly aided by disintegration produced by alternation of heat and cold, freezing of water, mechanical action and effect of organisms. When rocks are heated they expand; when cooled they contract. This movement loosens the grains and allows water to enter more easily. When water in pores or cracks freezes and expands, it tends to break up the rocks or at least to enlarge the openings. Mechanical force in bending, compressing, or stretching rocks produces strain surfaces, cleavage planes, joints and fractures, and occasionally pulverizes rocks, all of which aids the circulation of water, and so decomposition. Mechanical force, by bending, breaking, compressing or stretching the rocks, also raises their temperature in the areas in which it operates, and this heat is imparted to the water and makes it more active. Heated rocks often liberate caustic acids, as those of sulphur, boron, fluorine, etc., which unite with water and are transmitted by

fractures to distant rocks, where they effect marked changes. Many deposits of kaolin and poorer clays doubtless owe their origin principally to these gases.

Plant roots when small enter crevices in rocks, and as they increase in size act as wedges to widen the cracks. They also have the power to some extent to eat their way into rocks and, enlarging, force off spalls. When organic matter decays, gases are produced which are taken up by water and aid in decomposition.

Depth of Deposits of Residual Clays.—§ 20. The depth to which the decomposition of crystalline rocks into clays may be carried has never been determined. It depends on many local conditions. Numerous instances are on record where the resulting clays showed a thickness of from 50 to 200 ft. This could only occur, however, in regions where the drainage was excellent and where the surface was protected from erosion.

FORMATION OF SEDIMENTARY ROCKS AND CLAYS.

Erosin and Transportation.—§ 21. As stated above, rain which falls upon the surface is divided into three portions; one part evaporates; one sinks into the ground; and one slides off the surface into the nearest stream or drainage channel. Water, like any other body sliding down an inclined plane, develops energy, and this energy enables it to pick up and carry obstructions, not too heavy, which it finds in its path. The law which governs the carrying power of water is that its carrying power varies as the sixth power of the velocity, i. e., if a current moving at a given rate is able to carry particles weighing one ounce, another current moving with double that velocity will carry stones weighing 64 ounces. This law makes it clear that water flowing over loose material will pick up portions which lie on its bed and carry them away. Rain falling on the surface of crystalline rocks would attack the more easily decomposable and convert them into earthy material, thus disintegrating the rock and covering it with a loose layer made up of clay, hydroxide of iron and other non-aluminous earthy matters, and grains of undecomposed minerals such as quartz, the less readily decomposable silicates, and the more resistant crystals of feldspar and other aluminous minerals. A portion of the next shower that falls will run off the surface and will carry with it more or less of this disintegrated material; the amount depending on the velocity. If the ground slopes sufficiently and there is no obstruction to the run-off, the loose material will be carried away as fast as it is formed, but if the flow is in any way obstructed, the granular matter will accumulate and the surface will soon be covered with vegetation whose roots help to bind the particles. Where fallen leaves and stems protect the surface they interfere with the action of running water and so prevent removal. In mountain regions on steep forested slopes the residual clays have often accumulated to a depth of 30 to 100 ft. In such places the grains at the surface are continually moving down the slope but so long as the forest covering remains, this action is so slow that new material is manufactured at the bottom faster than that on the surface is removed. So soon, however, as the forest covering is removed, rapid erosion sets in and the accumulated material is speedily carried away.

When these surface-waters with their load of debris are gathered into a stream each hard grain becomes a tool with which the stream tears up its bed. Each undecomposed fragment as it is carried down the slope acquires energy with which it strikes effective blows upon those portions of the stream-bed or banks which resist its progress, and in this way it loosens fresh fragments which are soon added to the load carried by the stream. It should be remembered that the fragments so added are not decomposed, but may be called silt or rock flour.

Transported Clays.—§ 22. Whenever the slope of the stream-bed is lessened the water loses velocity and consequently carrying power. It is thus compelled to deposit the larger particles in its load, and these accumulate to form beds of gravel or sand according to the velocity which the stream still retains, but the finer portions are carried on until some further reduction of velocity compels the stream to drop them also. In this way running water gathers the residual clays and other products of decomposition from the often widely separated deposits in which they were formed, mixes their ingredients, carries them to points more or less distant, assorts them and deposits the coarser or heavier grains in beds of sand or gravel while with the finer portions it builds up beds of transported clay.

If in the places where these clays are deposited, the current remains practically constant for long periods, thick beds of clay nearly or quite uniform in composition and texture will result; but as every heavy rain which falls on any part of the area drained by the stream increases its volume and consequently its velocity, the places where it deposits its clay may change frequently, and consequently the deposits at a given point may form alternating layers of coarser or finer material, fine clay, coarse clay, sands or gravels, the thickness of the individual layers being governed by the amount of sediment the stream was carrying and the length of time during which the velocity remained constant. Heavy deposits of transported clays, except as noted below, usually represent old lake beds or ponds, into which the clays are brought by streams. The clay brought by one of these streams will usually be uniform in composition, with varying texture, but that brought by different streams may be different if their drainage basins do not lie on the same kinds of rock. Consequently the deposits in such lake beds are likely to be more or less in pockets.

Comparison of Residual and Transported Clays.—§ 23. We can now understand the differences between such residual and transported clays as have been described above. These residual clays originate through the decomposition of crystalline rocks. They can only be pure or of high grade when the rocks from which they are derived are made up entirely of minerals which contain only silicates of alumina and of other bases whose salts formed with the acids of ground-water are soluble, and then only when the movement of the water is free enough to carry away these soluble salts as fast as they are produced. These conditions are almost never met. The purest deposits usually contain crystals of quartz and of other minerals which are not readily attacked by the acids of ground-water, and these are removed before such clays are used by weath-

—2 G

ering the clay or by washing, usually both.   Granitoid rocks usually contain a considerable percentage of minerals which carry iron, magnesia, lime and other bases, metallic and non-metalic, in such quantity that they do not form soluble compounds when the rocks decompose, and are retained in the earthy residual mass.   When the movement of the water is in any way obstructed, even the soluble salts tend to reunite with silica and precipitate in the form of zeolites and similar minerals, or are deposited direct as carbonates or salts of other acids.   For these reasons most residual clays are too impure for use in the manufacture of highgrade ware.

When the residual material is carried away by running water it is usually assorted before redeposition.   If it were not for changing velocity of currents all the coarser decomposed material would be laid down as separate beds of sand and gravel, and all dissolved matter would be carried on to the sea or find place in some special mineral deposit, leaving the clay by itself in relatively pure masses.   This assortment of material actually does occur occasionally, and very pure deposits of clay are sometimes formed in this way.   It always occurs in a greater or less degree, but we must not infer from this that transported clays are always more nearly pure than those formed in situ.   They often are, but during their journeys they are exposed to many sources of contamination.   Rivers erode their beds and rains wash materials of various kinds, organic and inorganic, into the current, so that it often happens that the transported clays are much less pure than the beds from which they were derived.

Re-erosin, Transportation and Final Deposition of Clays.—§ 24.   All such deposits of transported clays as have been described are to be regarded as temporary only.   They will in turn be broken down and carried further.   Whenever the debris of granitoid rocks is picked up by running water it starts on a journey whose only end is the sea.   This is as true of that which is carried in solution as of that in suspension. Both may find temporary lodgment many times on the way ; the dissolved substances in the form of ores and other mineral deposits, the suspended substances in that of earthy masses, but all of these will later be taken up again and continue their journey.   Every particle which enters into the composition of the original rock will in time find its way to the sea. Arrived at the sea the suspended materials are deposited on its shallow margin in beds roughly parallel to the shore line.   Here again the debris is more or less perfectly assorted into beds of gravel, sand or clay, and outside the clays in the clear water, sea animals absorb the dissolved lime and make of it skeletons and shells, which upon the death of the animals are ground into lime-sand and eventually consolidated into limestones. Certain animals too prefer to live in muddy or sandy water.   These also have the power to absorb lime from water and with it to harden their tissues.   Upon their death their hard parts are ground and built into the clays and sands.

Variations in velocity of the inflowing stream, in tidal action, and in storm waves, as well as changes in level on the sea margin, bring with them changes in position of the belts in which the assorted materials are laid down, and so produce alternations of gravel, sands, clays and limestones.   As the beds thicken these layers follow each other without

regular sequence and so build up masses of sedimentary material, which sometimes reach a thickness of thousands or even tens of thousands of feet. In the central part of the Appalahcian region such sediments are thought to have accumulated to the depth of 60,000 feet.

Formation of Shales.—§ 25. In such masses enormous pressures are generated, and the water with which they are saturated is rich in dissolved materials and moves but slowly; consequently in part by precipitation of dissolved material which acts as a cement, in part by recrystallization of amorphous (colloidal) matter, and in part by pressure bringing contiguous surfaces so near that they are held by molecular attraction, the loose sediments are consolidated into conglomerates, sandstones, shales and limestones. The alternation of coarse and fine particles due to slight variations in the currents during deposition, together with this pressure, develops a shell-like, shaly structure in this mass of clay, roughly parallel to the bedding, and partly on account of the recrystallization of the fine particles of clay, partly because of the cementation of its grains by dissolved lime, iron or silica, or partly because of the simple cohesion of the plates and grains, the plasticity of the clay is lost, but it may be regained by sufficiently fine grinding which restores the material to its original condition.

In § 26 we have shown how changes at the seashore, while deposits were being laid down, cause a layer of clay to be over or underlaid by one of sandstone or limestone. Changes smaller than these or of shorter duration may incorporate grains of sand with the deposit of clay and so make it more or less siliceous. On the other hand, the tests (hard covering) of silica-secreting animals and plants may be deposited in considerable amounts with the clays, and silica, which is always present in sea water, may be deposited in the inter-granular spaces of the solidfying mass. In one or more of these ways the clays may become very siliceous: in fact there is a regular gradation between pure clay on the one hand and pure sand on the other.

In the same way lime-secreting animals may live upon the bottom, and their hard parts be ground and mixed with the mud. Lime is also often chemically precipitated between the grains of the hardening mass, and so we have a regular gradation between pure limestone on the one hand and pure clay on the other. Iron, too, may be incorporated in the same way, and so when these clays are compacted into shales we may have calcareous, siliceous or ferruginous shales when these adulterants are less in amount than the clay, or argillaceous limestones, argillaceous sandstones, etc., when they are in greater amount. Shales then may be composed of absolutely pure clay or of clay mixed with lime, iron, silica, or any other substances deposited by sea water from suspension or solution, and this mixture may occur in any proportions. This is so true that it is a rare thing to find either limestone, shale, or sandstone which does not contain appreciable amounts of the other ingredients.

CHANGES IN SEDIMENTARY ROCKS.

Emergence of Sedimentary Rocks.—§ 26. Owing to changes which are taking place in the earth's interior, the altitude of most points on

the surface has changed repeatedly, and similar changes are now taking place. The gulf coast of the United States, the coast of Norway, southern France, northern China, North Africa, and Chili are rising; while the Atlantic coast of the United States, northern France, the Netherlands, southern China, Egypt and eastern Australia are sinking. That these changes in level are not confined to the coast is shown by the beach lines of all large lakes. The old beach lines are not parallel to those now being formed. Careful studies made within recent years show that the northern end of Lake Michigan is now rising at a rate which, in the opinion of G. K. Gilbert, would, if continued, cause the lake to find its outlet through the sag and the Illinois river within a few centuries.

Such movements have not been confined to modern times, but have been going on in all geologic ages. That vast areas of our present continents have been covered by the sea is shown by the presence of limestones, sandstones and shales, all stratified and all containing the remains of salt-water animals. It can also be proved that large areas now covered by the sea have once been dry land.

If from most points along the shore line we make a series of soundings running directly away from the shore, we will find that the sea deepens very gradually for a considerable distance and then its bottom plunges suddenly down a steep incline. This sudden drop marks the true border of the continent, and may be traced off the shore of all continental masses. If so traced on a map this line would be found to divide the earth's surface into two nearly equal portions, the continental masses and the ocean basins. The earth's surface carries more water than the true ocean basins can hold, and consequently some of the water overflows the lower portions of the continents. As the surface of the continent changes in altitude this water flows from point to point, and so portions which were once dry land are now covered, and portions which were once under the waters of the ocean are now dry land.

It is probable that every point on the earth's surface has at some time formed part of this submerged continental border, and some have been submerged many times. This will help us to understand the presence of the rocks referred to above at points now far inland, and successive elevations and depressions will help to explain their alternations.

Metamorphism of Sedimentary Rocks.—§ 27. These same internal changes produce marked wrinkles or folds on the continental areas, which we call mountains. The process of folding develops so much heat and pressure that many of the limestones, sandstones and shales are transformed into marbles, quartzites and slates. In some places the heat and pressure are so great as to melt and mix the rocks, causing the union of silica with the bases and so changing them again into granitoid rocks. As these changes always occur at great depths, and as the movements once started are apt to recur at the same point for a very long time, the heated rocks do not soon regain their normal temperature and water circulating through them and passing from them to other rocks acquires greater transforming power. Such waters passing through cracks and fissures become powerful agencies in transforming the newly formed granitoid

rocks into masses of clay. As these changes are most likely to occur in the walls of fissures, the clay deposits so formed are found in veins and pockets enclosed in crystalline rocks. As these deposits result from the decomposition of granitoid rocks they differ in no material way from the residual clays described above.

Slates are merely hardened and to some extent recrystallized shales which, when ground sufficiently fine, recover the properties of clays.

Decomposition of Sedimentary Rocks and Formation of Deposits of Residual Clays.—§ 28. When sedimentary rocks, such as limestones, sandstones and shales, which were formed in the bed of the ocean, are elevated into dry land, they are immediately attacked by erosive forces which seek to break them down and transport their debris again into the sea. In the case of sandstones and shales, earth-water dissolves the cement which helps to hold the grains together, and, aided by alternations of heat and cold, frost and winds, reduces them to masses of loose material, which are picked up and carried away by running water to be assorted and redeposited as beds of gravel, sand and clay. In protected locations where washing goes on but slowly, beds of shale are often transformed into clay without removal. Earth-water passing through these beds may, when conditions are favorable, dissolve the soluble salts which they contain and remove them, thus purifying the deposit. Valuable deposits of residual clays may in this way be formed from relatively impure shales. It must be understood, however, that under other conditions this same earth-water may carry impurities into the shales and so make them or the clays derived from them of lower grade than before.

In the case of limestones, rain-water carrying carbonic acid in solution enters the rock. The acid attacks the carbonate of lime, converting it into the bicarbonate which is far more soluble, and is consequently dissolved and carried away by the water when conditions favoring drainage prevail. If the limestone is pure it will be entirely removed by this process, but if it contains sand or clay these will be left and accumulate into beds whose thickness sometimes aggregates hundreds of feet. Most limestones contain more or less of clay which was deposited with the lime-sand when it was accumulating on the ocean bed, and so the decomposition of a limestone usually leads to the formation of a bed of clay of greater or less thickness, depending on the clay content of the rock and protection from erosion during decomposition. If the clay deposited with the limestone was pure and conditions during the breaking down of the rock were unfavorable to the introduction of impurities from outside, or if conditions during decomposition were such as to cause the impurities to dissolve and leach away, these clays may be of exceptionally high grade. Some of our very best deposits have originated in this way and will be described later. While deposits of this character are occasionally formed, it is usually the case that clays which result from the decomposition of limestones contain so much lime as to unfit them for anything but the coarsest wares.

Clays which have been derived from the decomposition of sedimentary rocks are classed with residual clays but differ from them in that they were at one time transported clays which have been built into these rocks and again recovered from them through decomposition without having

undergone any material change in composition or structure. These resemble transported clays more than they do residual. When such clays are carried from their place of origin by running water they form deposits which do not differ in any way from those derived from crystalline rocks. In the case, however, where sedimentary rocks are metamorphosed into crystalline rocks, as explained in § 27, and then broken down, the clays undergo great chemical and physical changes during the process, and when recovered are in every day like those derived from original granitoid rocks.

THE SPECIAL ACTION OF ICE.

Ice as an Eroding and Transporting Agent.—§ 29. In the preceding discussion we have for the sake of simplicity omitted the part which ice in the shape of glaciers has played in the formation of clays. At the present time, especially in temperate regions, this agent cuts so small a figure that it might almost be left out of consideration entirely, but there have been times when this was not true, and during one of these periods a large portion of our own country was covered with thick deposits of clay through its action.

During the geological period immediately preceding the one in which we live, immense fields of ice accumulated over Labrador and over the Keewatin country which lies just south and west of Hudson's Bay. These ice fields increased in thickness until it is believed they reached 10,000 feet or more. This great thickness induced large pressures which caused the lower layers to behave as if they were plastic and move out from under the mass, increasing the area of the fields until they united and covered all that portion of the United States which lies roughly north of the 37th parallel and east of the 100th meridian.

For a very long period preceding the action of the glacier this area had been exposed to the action of ground-water and had accumulated vast beds of clay and other residual material produced by the decomposition of the underlying rocks. As the ice sheet moved away from the centers in which it accumulated and passed over these areas covered with earthy accumulations, it gradually picked up the loose material over which it was passing and as the motion of the ice particles was one of flowage in consequence of which they moved upward and downward as well as on onward, the debris came to be distributed throughout the entire mass.

Chamberlin's articles on the glaciers of Greenland, published some years ago in the Journal of Geology, contain excellent illustrations showing the distribution of rock waste through the entire thickness of the ice sheet, and give a clear conception of the vast amount of such material which was carried by these glaciers.

In an earlier section (§ 28) it is shown that rock decomposition proceeds unequally, and that in consequence fragments of the original rock, less readily decomposed than the rest, are imbedded in the earthy mass. These fragments vary from minute pebbles to boulders the size of a 6-room house, so that the debris carried by the glacier contains not only clay and other results of decomposition but quantities of rock, sand,

gravel, and boulders as well. In addition to this each rock fragment
which is dragged along by the lower layer of the glacier becomes a
graver's tool which cuts away the bed over which the ice moves, wearing
away both itself and the surface over which it is dragged. Hundreds
of these glacial tools with their smoothed and striated surfaces may
be found in any bank of glacial gravel, and occasionally large boulders
carry facets which show that they have been used for this purpose. Two
boulders lying near this university are excellent illustrations. One is
of granite and weighs 10 or 12 tons, and the other of limestone weighing
probably not less than 20 tons. Both carry several facets beautifully
striated. When, as in the digging of the Chicago Drainage Canal, the
glacial debris is cleared from large areas of underlying rock, these sur-
faces are found to be smoothed, striated and grooved by the glacial mill.

Through the agency of this grinding action great quantities of rock
flour or ground but undecomposed rock debris (silt) are added to the
load carried by the glacier, and the finer particles are distributed among
and deposited with the clay and other products of decomposition, pro-
foundly affecting their properties. It should be noted that each kind
of rock over which the glacier passes adds its quota to the grist of rock
flour which the ice is carrying. There is no other known agency which
brings together such heterogeneous masses of material as glaciers.

As the ice sheet moved forward into warmer and warmer latitudes
it was continually wasted by the heat of the sun, but in spite of this
melting its front would continue to advance so long as the rate of motion
exceeded the rate of melting, and as the amount of heat to which it
was subjected varied from day to day, month to month, and year to
year, the ice front would continually change its position, now advancing
now retreating, as the balance between rate of motion and of melting
varied.

Ice as an Agent of Deposition.—§ 30. Over most of the area covered
by the ice it was an agent of destruction and transportation, picking up
any loose material with which it came in contact, and tearing away the
surface over which it moved, but near its lower end the whole character
of its work was changed. Here rapid melting caused it to deposit
great quantities of unassorted material, and whether its front moved
backward or forward in consequence of varying rapidity in melting, it
was continually dropping its load of debris. Near its front the thick-
ness of the sheet became so reduced and the rate of melting so rapid that
it no longer picked up the loose material which it found in its path,
but overrode it and so as it moved backward and forward it added
layer upon layer to the mass accumulating on its bed. If the excursions
were short and repeated many times over the same area, the successive
layers would build up one of those ridges, which we call terminal mor-
aines, because they mark positions in which the glacier was nearly
stationary for a long period, but if the excursions were long, these layers
would build up those broad level plains which we call ground moraines
(prairies). It was in this way that nearly the entire surface of Illinois,
but especially its north-eastern portion, was covered with a thick coat of
glacial debris aggregating from 5 to 10 feet in its thinnest portions and
250 to 300 feet in its thickest. The broad level prairies of our state

are in general its ground moraines which the retreat of the ice and the obstruction of drainage by the terminal moraines converted into broad lakes in which vegetation grew and, decomposing, imparted its black color to the accumulating lake sediments, while the relatively narrow, hummocky highland ridges are its terminal moraines.

Characteristics of Glacial Clays.—§ 31. Most, but not all, of this thick coating of glacial debris is made up of unassorted material.   In it the clays are mixed in all proportions with undecomposed rock particles and with rock flour (silt) both derived from all kinds of rocks. This is our boulder clay, and is probably more variable in its composition and properties and more difficult to use than any other variety with which we have to deal. Occasionally we find a deposit of this material whose properties fit it admirably for the manufacture of a certain kind of ware and sufficiently uniform in composition and texture to furnish an abundant supply, but this usually is not true. The conditions under which they are deposited usually make the boulder clays exceedingly variable, occurring in pockets rather than in large deposits. Let us understand that the finding of heavy deposits of boulder clays suitable for use in the manufacture of any grade of ware, even the best, is not to be considered as impossible, but rather as unusual.

The melting of the ice not only caused the deposition of great quantities of debris but produced large amounts of water as well, and as this water moved away from the points where it originated, it picked up more or less of the boulder clay, and after carrying it for some distance assorted and redeposited it. It is to this assorting action that we owe the pockets of sand and gravel which we find in glacial deposits, and it is to the same force that we owe many of the hills and ridges of sand or gravel which rise above them. It is to this action, too, that we owe the deposits, often small, but sometimes very large, of exceedingly uniform clay, free from pebbles or from any considerable irregularities in structure, composition or properties. We believe that these masses were laid down in lakes or ponds fed by streams which, before entering the pond, had so far lost their velocity that they had dropped all the gravel or sand which they were carrying and so brought only the fine clay-like materials which settled in the quiet waters.

When the ice front retreated it left a generally level but more or less billowy surface behind it. This character is given to the surface partly by the unequal distribution of debris in the ice mass, and partly by the fact that large pieces of ice often break from the retreating cliff and are buried in debris before they melt. This cover causes the melting to go on very slowly and as it progresses the covering gradually settles and forms a depression which subsequently becomes a pond. Another factor which tended to produce these ponds or lakes was the formation of small ridges at points where the ice front became practically stationary for a short time during its retreat. These ridges ran across the natural depressions which ordinarily furnish surface drainage and imponded the water. These ponds were generally small and the amount of material deposited in each was small also, but occasionally large and deep depressions were formed and in these, extensive masses of peculiarly uniform clays were laid down, so while heterogeneity is the most prom-

inent characteristic of the glacial clays, considerable deposits having just the opposite character are not very unusual.

As the water flowed away from the neighborhood of the glacier it formed large streams which carried great quantities of glacial material in suspension. These it worked over, assorted, and laid down in deposits which differed in no way from those described in preceding sections which treat of transported clays. § 21, 22, 23, 24, 29.

Origin of Loess.—§ 32. Sometimes the water spread out in broad, thin sheets which, having little velocity, deposited a fine silty material over broad areas, carrying the finer clays still further away. Later when the water had disappeared and the surface had become dry this silty deposit, whether worked over by the winds or not, became loess. Such deposits may accumulate until they attain great thickness. As the loess question is a matter of controversy and the way in which 'it was formed is still unsettled, it may be well, without attempting an extended discussion, to say here that loess is a siliceous silty clay. Silt is a finely granular material, usually composed in large part of undecomposed rock particles, or in other words of rock flour, but often containing coarser clay granules as well. Loess, then, is largely made up of rock flour, fine quartz sand and coarse clay. Such a deposit could only be made by an agent which could assort its material, for we know of no way in which so large a mass of uniform in texture could be produced directly, hence deposits of loess must have been produced through the action of wind or water or of both. Wind and water, however, can only transport, assort and deposit the loess. They cannot make the silty grains, hence the richer the transported material is in silt the more probable will be the formation of loess deposits. Silt may be composed of particles of those minerals which resist decomposition most effectively and consequently more or less of it may be formed when rocks break down under the action of ground water and other agents of disintegration, or it may be produced by abrasion of wind, water or ice-borne fragments against exposed rock surfaces, or its grains may be formed by the agglutination of particles of clay. The following propositions may, I think, be accepted as established.

The granular material which we call loess can be found in most earthy deposits.

Such material is more abundant in the deposits of dry than in those of humid regions. Such materials are more abundant in the deposits of the later glaciers than in those of the earlier glaciers, rivers, or in masses produced by decomposition of rocks, but are found in these also.

If such materials, no matter how they originated, are properly assorted and the different grades laid down in separate masses, loess-like deposits will be formed.

Water and wind working separately or together are the only agents that can effect this assortment and decomposition.

Water would tend to form broad sheets of nearly uniform thickness while winds would deposit their load in heaps.

Conditions are more favorable to the assortment and deposition of loess in dry than in ordinarily humid regions, because there the surface oftener becomes thoroughly dry and consequently the winds are there

more effective and because the rains come in heavy local showers which pick up large quantities of the dry and loosened dust and carry it into streams which when they leave their narrow beds and spread out upon the plains assort and deposit it again.

The large quantities of water and sluggish currents that attended the melting of the great glaciers were peculiarly favorable to the formation of deposits of loess.

Such granular deposits would whenever they become dry be peculiarly liable to be worked over, transported and redeposited by winds.

The loess problem so far as it concerns the history of individual deposits will not be solved until we come to understand the geographic, physiographic and climatic conditions which prevailed during each sub-stage of the glacial and post-glacial periods.

CLASSIFICATION OF CLAYS.

It has seemed best to carry on the discussion of the general problems involved in the geology of clays as we have done in the preceding paragraphs and then discuss the characteristics of each of the groups of clays and the conditions under which they were formed separately.

§ 33. No really satisfactory classification of clays has yet been proposed, but the following grouping adapted from Orton and Wheeler seems better suited to our purpose than any classification we have seen.

High Grade Clays.	Whiteware Clays.	Kaolin. China Clay. Ball Clay.
	Refractory Clays.	Plastic Fire Clay. Flint Clay. Refractoro Shale.
	Pottery Clays.	
Low Grade Clays.	Vitrifying Clays-	Stoneware Clays and Shales. Paving-brick Clays and Shales Sewer Pipe Clays and Shales. Roofing Tile Clays and Shales.
	Brick Clays.	Terra Cotta Clays and Shales. Common Brick Clays and Shales. Drain Tile Clays and Shales.
	Gumbo Clays.	
	Loes and Adobe Clays.	
	Slip Clays.	
	Fullers Earth.	

Kaolin.—§ 34. As has already been said, kaolin results from the decomposition of complex silicates whose principal base is aluminum and whose other bases form, with carbonic acid, compounds which are soluble in earth-water. As used commercially the word does not stand for a definite mineral substance, but rather for series of silicates, hydro-sili-

cates, oxides and hydroxides of aluminum, or occasionally of magnesium.

Mineralogically kaolin or kaolinite is a well defined mineral with the composition $H_2Al_2Si_2O_9 = Al_2O_3 2SiO_2 . 2H_2O$ and as this approximates the average composition of the whole group the name is used commercially to designate the widely varying mixtures of its members. This will be better understood by study of the table of analyses in § 17.

The minerals most commonly entering into commercial kaolin are so far as known—Kaolinite, $Al_2O_3 . 2SiO_2 . 2H_2O$; Pholerite, $Al_2O_3 . SiO_2 . 4H_2O$; Halloysite, $Al_2O_3 . 2SiO_2 . 3H_2O$; Cimolite, $2Al_2O_3 . 9SiO_2 . 6H_2O$; Montmorillonite $Al_2O_3 . 4SiO_2 H_2O$; Pyrophyllite, $4Al_2O_3 . 15SiO_2 . 4H_2O$; Allophane, $Al_2O_3 . SiO_2$; Collyrite, $2Al_2O_3 . SiO_2 . 9H_2O$; Schrotterite, $8Al_2O_3 . 3SiO_2 . 30H_2O$; Gibbsite, $Al_2O_3 . 3H_2O$; Diaspore, $Al_2O_3 . H_2O$; Sepiolite, $2MgO . 3SiO_2 . 2H_2O$; the Zeolites, quartz and undecomposed fragments of the minerals contained in the original rock. Admixtures of these minerals when pure form a white mass, pulverulent or easily made so by weathering, and but little plastic until finely ground, but its lack of plasticity is probably due to cementation of its grains. Absolutely pure kaolin can only be formed by the decomposition of rocks whose minerals contain no bases which form compounds with carbonic or other earth acids that are relatively insoluble in water, but commercially pure kaolins may contain any light colored minerals which do not act as fluxes or tend to discolor the ware.

Granitoid rocks sufficiently pure to form such kaolin are occasionally found, but are rare, but when such rocks are fractured and open fissures formed, these wounds are frequently healed by the deposition of a sort of scar-tissue called vein rock, made up almost entirely of quartz, potash or soda feldspar, and light-colored mica. These veins are often sufficiently pure to form kaolin of excellent quality when decomposed. Examples of this vein rock may often be seen in the ridges projecting from the boulders which are sometimes so abundant on our prairies.

Occasionally when white argillaceous limestones decompose they leave a clayey mass sufficiently pure to be classed as a kaolin.

Our deposits of kaolin then are formed in three different ways. First, by the decomposition of highly feldspathic granitoid rocks; second, by the decomposition of vein rocks; third, by the decomposition of white argillaceous limestones.

Principally on account of their lack of plasticity kaolins are seldom used alone, but they form the basis of most white or light wares, being mixed for this purpose with plastic clays, flint, spar, and often small amounts of ground bones and other ingredients.

Ball Clays.—§ 35. Ball clays are simply plastic kaolins. They are said always to have been transported, but there seems no good reason why any deposit of kaolin should not become plastic if exposed to conditions which favor the movement of ground-water through its mass and especially if this movement is accompanied by considerable changes in temperature.

A study of the table of analyses of ball clays (§ 17) shows that they are often somewhat richer in alumina than the kaolins. This would only be true of those which have been transported, because in these only would the assorting power of water come into play, causing the coarser

and heavier grains of silica to be deposited as the current loses velocity before the finer and more buoyant grains of clay. They are comparable in this respect to washed kaolins. This table also seems to indicate that ball clays are richer in minerals whose alumina content is too high for kaolin than are kaolins, but this is more apparent than real because the presence of free silica in kaolin masks that of minerals high in alumina. Ball clays are principally used to make kaolin more plastic. When used alone they shrink badly.

Deposits of ball clays occur as outwash aprons at the base of highlands containing deposits of kaolin. When running water passes over places where beds of kaolin come to the surface the clay will be picked up and carried to the base of the slope. On the way the lumps will disintegrate and the flakes and granules of kaolin be separated and more or less broken up, and these processes will develop plasticity in the mass. On the way also the residual kaolin will be assorted and at the base of the slope the quartz and fragments of undecomposed minerals will be deposited before the clay particles, and these last will build up aprons of pure plastic clay derived from non-plastic kaolin mixed with a varying proportion of undecomposed material.

In a preceding section (§ 25), we have explained how clay may come to enter into the composition of limestone, and in another (§ 28), how this limestone when it decomposes leaves the clay behind as a residual product. If, as sometimes happens, the clay which was built into the limestone was nearly or quite pure kaolin and the limestone itself was pure carbonate of lime, the residual clay would be a fine quality of ball clay. If, as is often the case, the limestone decomposed unevenly and cavities or caverns were formed in the mass which increased in size until the roof was too heavy to support its own weight and consequently broke down forming more or less conical depressions on the surface, called sink-holes, these clays as they were formed would be washed into and collect in the sink-holes making considerable deposits of the purest ball clay.

When beds of kaolin or of flint clay (described in § 40) are exposed to the action of the weather for a sufficient length of time disintegration takes place and the non-plastic material becomes plastic, but in this case any undecomposed granules in the original mass will be retained in the ball clay.

It rarely happens that when deposits of clay containing impurities which can be made soluble by weathering are leached, the foreign matters are carried away and pure ball clays left behind.

As may be inferred, deposits of a good grade of ball clay are not very common because the very agents which produce them tend to bring into them impurities of many kinds and so render them less pure than the beds from which they were derived. It is but seldom, although it sometimes occurs, that earth-water or surface water is pure enough to cause it to work the other way and produce a purer instead of a less pure deposit.

Fire Clays.—§ 36. A fire clay is one which will withstand a high temperature without softening to such an extent as to become misshapen even when subjected to considerable pressure; which will endure

rapid changes of temperature without shattering; whose wares have sufficient density to impede the passage of gases or liquids which would attack it, and a chemical composition such that it will not readily unite with the gases which it is likely to meet in use.

It will be seen that each of these qualities is variable and that in consequence no fixed definition of a fire clay can be formulated. Let us consider them in order. First it must withstand high temperatures without material softening. Authors assign widely different meanings to the expression high temperatures as applied to fire clays, and no agreement has been reached as to what temperature a clay must be able to withstand in order to merit a place in this class. Each user regards any clay which will bear the highest degree of heat which he uses as a fire clay.

The ability of a clay to withstand a high temperature depends upon its chemical composition and upon its physical constitution.

The temperature at which a clay softens is governed by the presence or absence of impurities which soften or melt at a temperature lower than that which would produce a like effect in the clay itself. It is a curious fact that the softening or melting of one substance often brings about a similar change in contiguous materials which would remain unaffected except for the presence of the more easily melted material. These less resistant ingredients of a clay are called fluxes. The more common fluxes are in order the alkalies, potash and soda, the alkaline earths, lime and magnesia, protoxide of iron, and to a certain extent sesquioxide of iron and silica.

§ 37. It has been found that pure alumina will withstand a temperature higher than that required to fuse Seger's cone 36, and pure silica withstands cone 35, but if a small amount of finely pulverized silica be mixed with alumina it induces slight fusion at a temperature less than that required to fuse either pure alumina or pure silica. If we increase the proportion of silica this effect increases also, but so slowly as to be hardly perceptible until the mixture contains 25 per cent of silica. From this point the effect increases rapidly with the increase of silica, until the proportion of alumina 10 to silica 90 is reached. This mixture melts at cone 30. Further addition of silica causes the mixture to become more and more refractory. It is thus seen that silica although a very refractory substance in itself becomes a flux when finely divided and added to alumina. In the same way lime and magnesia, which are among the most refractory substances known when pure, become exceedingly active fluxes when mixed with silica or alumina or both. Iron when in the condition of the sesquioxide or iron rust does not act vigorously as a flux but the protoxide is very active. Potash and soda are the most active of the common fluxes. Another curious fact is that a given percentage of mixed fluxes will produce a more marked effect than the same amount of any one of them and that the effect will be greater the larger the number of different fluxes contained in the mixture. It will thus be seen that the fluxing effect of impurities in a clay depends not only on the amount of fluxes present or upon their amount and kind, but upon the number of different kinds as well.

The effect of fluxes on a clay depends also on the fineness of grain of the clay as a whole and of the fluxes in particular. A coarse-grained clay will stand more fluxes than a fine one, especially if the fluxes be coarse. It will be seen then that a fire clay is likely to be refractory in proportion as the percentage of alumina is high and that of the fluxes low. It is evident also that a single flux will have less proportionate effect than a mixture and that fineness of grain is a determining factor of considerable importance. A study of the table of analyses of fire clays (§ 17) will bring out these facts.

§ 38. The temperature of fusion also depends upon the character of the fire to which it is subjected. Clays which withstand a high temperature when exposed to a strongly oxidizing flame will give way at a much lower degree of heat if exposed to reducing conditions.

Second, a fire clay must sustain rapid changes of temperature without shattering. This property depends on its homogeneity and openness of structure. If some of the ingredients of a clay expand more with a given increase in temperature than others the tendency will be for those which expand most to push the others away and weaken the whole structure. For this reason the more homogeneous clays are more valuable in this respect. It should also be noted that the larger the grains of the impurities the more harmful will they be in this way.

Again, so far as this property is concerned, it is desirable that the clay when burned should have an open porous structure. Clay is a poor conductor of heat, and if its structure is dense it takes a long time for the center of a block to become as hot as the surface. The difference in temperature between the outside and inside of a block is sometimes considerable, and the difference in expansion has a strong tendency to shatter it. If, on the other hand, the block is porous, the heat finds its way through much more readily and the tendency to fracture is less. No generally accepted test has been proposed to demonstrate the properties of a clay in this respect although some prominent French engineers claim that no clay should rank as a fire clay whose products shatter when heated to redness and immediately plunged in cold water—a very severe test.

§ 39. Third, fire clays are often made into crucibles in which glass or metals are to be fused. They are also often so placed that they are exposed to the action of ashes and various furnace gases. In order to withstand these conditions they require a certain degree of density and must have a chemical composition such that they will not be readily attacked by the substances to which they are exposed. First, for the above uses the clay should contain an amount of flux just sufficient to cause it to contract and fill the pore spaces during burning so that the wares will not be readily penetrated by the liquids or gases to which they are to be exposed. It will be noticed that this density of structure is a quality which is not desirable in a clay which is to be subjected to violent changes of temperature. Second, if the liquids or gases to which the clays are exposed are strongly basic they will attack a clay rich in silica much more readily than one rich in alumina. On the other hand, if they are strongly acid the aluminous clays will be more easily attacked than the siliceous ones.

From the above it may be seen that the term fire clay does not stand for a single kind of clay, but for a group whose only common property is the ability to withstand relatively high temperatures, which means that they must be high-grade clays relatively free from all fluxing ingredients. Any clay that is sufficiently pure may be used as a fire clay, but the better grades of kaolin and ball clay are generally too valuable for such use. Again, as shales or slates are only clays whose physical structures have been somewhat changed by pressure or heat or both acting together, some of them should be and are sufficiently pure to be used for the manufacture of refractory wares.

As weathering and leaching tend to remove the most active of the fluxing materials in clay they must improve its refractory properties also, except in so far as they make its component particles finer. It is then a question of balance between these two effects whether its refractory properties will be improved by these processes or otherwise. There is a method of purification which is thought to be responsible for the formation of many fire clays. Many of those most widely used lie immediately below deposits of coal, and it is generally believed that they were laid down in swamps before the coal was formed; that they were soils which supported and nourished the coal plants; and that these plants abstracted from the soil considerable portions of the alkalies and alkaline earths as well as iron and other fluxing materials and built them into the coal, thus materially increasing the refractoriness of the clay. Probably more is made of this process in accounting for the refractoriness of clays than should be, but nevertheless it is true that any process which removes fluxes from clay makes it more refractory, and growing plants have this effect to a degree.

Flint Clay.—§ 40. There is a class of clays of almost stony hardness having a conchoidal fracture and a structure so like flint that they are commonly known as flint clays. This flinty condition is believed to be due to a process of cementation, the clays having at some time stood below the level of ground-water under conditions which favored the precipitation of such salts as the ground-water carried in solution. This precipitated material cemented the clay particles and in connection with the weight of the overlying rocks induced the flint-like structure. There is then no necessary relation between the flinty structure and their chemical composition or any physical property except plasticity. All flint clays are non-plastic. Some are rendered more or less plastic by the ordinary grinding and kneading to which clays are subjected, but some are not. Some authorities assert that no mechanical or physical process to which these clays can be subjected will render some of them plastic. It is probable however that wet grinding and kneading if sufficiently prolonged will develop plasticity in any of them. It seems to be commonly accepted that all flint clays are refractory, but this is not true, for any clay will become flinty if placed under proper conditions. It is true, however, that most of the deposits of flint clay which are used commercially are high-grade clays and are consequently quite refractory. The preparation of the poorer grades is too expensive to permit their use.

Some very curious deposits are found among the eroded limestones of southeastern Missouri. They appear to have formed in sink-holes like the ball clays of the same region, but owing probably to defective drainage the clay particles have been cemented and the flinty structure developed. Where these deposits have been exposed to the weather and to leaching they have developed plasticity and have become ball clays. Most of the high-grade flint clays could be used in the manufacture of whiteware if it were not for the excessive shrinkage and the cost of preparation. As it is, they are rarely used except in the manufacture of fire brick or other refractory wares. The table of analyses (§ 17) shows the composition of some of the better known flint clays. It should not be inferred, however, that all flint clays are as pure as those here given.

Pottery Clays.—§ 41. This term does not stand for any particular group of clays or for those possessing any particular properties except that they must be sufficiently plastic to be formed into the ordinary potter's wares and must be capable of being readily burned to a pleasing color. The term then covers any high or low-grade clay that has these characteristics.

Vitrifying Clays.—§ 42. A vitrifying clay is one whose ingredients melt at widely different temperatures and in which the substances melting at relatively low temperatures are sufficient in amount when fused to fill all the voids and form a tough, nearly or quite impervious mass. It is desirable that there be several of these substances which fuse at regularly increasing temperatures, for in that case the ingredient which fuses first at once attacks that whose melting point is next higher and reduces it to a pasty condition before its fusion temperature is really reached. As the heat is increased this pasty mass passes into a fused condition and immediately attacks that ingredient whose melting point is next higher, converting it into a paste. This process continues as the temperature rises until enough of the pasty material is produced to fill all the voids. If the now solid mass is cooled slowly enough this almost fused material will become semi-crystalline and will show on fracture a dull stony rather than a lustrous or glassy surface. This semi-crystalline condition of the partially fused material is one of the factors which makes the body tough when burned.

It will be seen from the above that a vitrifying clay must contain enough relatively refractory material to form a skeleton or framework which will support the ware and keep it from changing its form during the vitrifying process. The skeleton may be made up of grains of refractory clay; of relatively coarse fragments of quartz, which, however, must not be too large or the resulting burned body will be too porous; or even of coarsely ground particles of the same clay whose more finely pulverized portions become pasty and fill the vacant spaces between the grains, always provided that the range between the melting points of the more and less refractory or of the finer and coarser material shall be 300° or more. This range must be demanded until we have learned to build kilns which distribute heat more evenly than those now in use.

That portion of a vitrifying clay which is expected to form the paste to fill the voids should not contain too large a percentage of carbonates or other compounds which give off gases at high heats, because these

gases in their effort to escape tend to form "blebs" or vacant spaces in the mass and thus undo the very thing we are trying to accomplish. Again all the particles of carbonate of lime tend to give up their carbonic acid at the same temperature. This disassociation leaves the calcium in what is called the nascent state in which condition it attacks the other ingredients vigorously and tends to produce compounds which soften at relatively low heat, and so the presence of a large amount of nascent calcium at any one time has a tendency to cause the whole mass to soften suddenly and flow so quickly that it cannot be readily controlled. The silicates of lime and the various compounds of potash, soda and iron, although the last somewhat resembles lime in its action, soften more slowly and so give greater latitude in burning, and for this reason are considered more desirable.

The virtrifying clays then are to be looked on as in all cases a mixture of refractory and non-refractory ingredients with enough plasticity to enable them to be molded into desirable forms and which may be burned to a tough impervious mass without losing their shape. These properties may be found in high as well as in low-grade clays, but of course are much more rare in the former than in the latter. The manufacturer of china finds it necessary to make his mixtures artificially by incorporating ground feldspar, flint, Cornwall stone and other ingredients with his kaolin, and in Holland and Germany, and at a few places in this country as well, fluxes and even low-grade clays are mixed with fire clays for the manufacture of pavers. Vitrified ware may be manufactured from any clay if it is properly prepared, the necessary admixtures made and carefully fired, but whether any given clay can be so used commercially is a question for each manufacturer to decide for himself.

There seems no good reason for the commonly held opinion that shales are better suited to the manufacture of vitrified ware than other clays except that the manufacturers of such wares in this country have adapted their methods to the use of shales and that consequently these methods do not lend themselves kindly to the use of clays of other grades. Practically every grade of clay has been successfully used for the manufacture of these goods on a commercial scale.

Terra-Cotta Clays.—§ 43. To the ceramist the term terra-cotta signifies porous unglazed as distinguished from faience or porous glazed ware, but in common use the term is restricted to high-grade artificial or ornamental wares having the above characteristics.

Clays for these purposes must be even-grained and smooth-working, fairly plastic with good binding power, and capable of being burned to a uniform pleasing color. These qualities call for a clay of uniform composition and texture which may be produced by weathering of residual masses, but is more usually formed by decomposition from bodies of water which have a slight but uniform current. As natural deposits having all these characteristics are not abundant, the manufacturer usually reaches his ends by washing and mixing several clays of uniform texture which by their combination will give the other qualities desired.

Some of the most progressive manufacturers of these goods now use vitrifying clays and burn them until the wares are impervious, thus removing them from this group entirely.

Brick Clays.—§ 44. This group is hard to describe because the requirements for brick are passing through a transition. Formerly any plastic clay with reasonable binding power fired to a heat somewhat above the end of the water-smoking period would meet all requirements. Then came the demand for face brick with definite shape, smooth surface, and uniform, well-defined colors, which made requirements the same in kind and nearly as exacting as those placed upon the manufacturer of terra-cotta. Now the trade begins to ask that these same wares shall be vitrified and so rendered non-absorbent. This last requirement has probably come to stay, and in a short time only vitrifying clays will be used for the manufacture of brick. Then only clays which have sufficient plasticity to enable them to be molded into definite forms, sufficient binding power to give the necessary strength, such openness of structure as will permit them to dry without cracking, such coloring ingredients as will cause them to take on a uniform and pleasing tint when properly burned, and such chemical and physical characteristics as will give them a wide vitrifying range will be used for the manufacture of brick. Such clays will be found among the somewhat impure residual deposits and the better grades of alluvial and diluvial clays.

Drain Tile Clays.—§ 45. The requirements for a drain tile clay are sufficient plasticity to permit its being readily molded into pipes, sufficient binding power to give it such strength as will withstand handling without breakage, and such openness of structure as will enable it to dry quickly without cracking and give it after it is burned such porosity as will enable water to pass through it readily.

These requirements call for the lowest grades of clays and shales usually carrying considerable quantities of lime carbonate or sand or both, and often a considerable admixture of soil to give the ware sufficient porosity. Of course any clays of higher grades which possess the properties designated above could be used if it seemed desirable to do so.

Gumbo Clays.—§ 46. These are composed of exceedingly fine clay-like material which packs so closely that water passes through it but slowly. It was laid down in still water, the streams which brought it having deposited all sediment coarser than the finest sand and clay, because of loss of velocity, before reaching this point. It is very plastic and possesses great binding power, but dries slowly and cracks badly. Such clays when black are called gumbo, but when lighter in color, hard pan. The black color is due to the admixture of a considerable amount of organic matter.

These clays are much used in some parts of the country to manufacture road ballast. Windrows of cordwood are covered with a thick coating of clay and fired. The wood burns slowly and imparts sufficient heat to the clay to drive off the combined water. As the clay shrinks badly it breaks up under the influence of heat into angular fragments which are found to be excellent material for ballasting roads.

Loess and Adobe Clays.—§ 47. Loess and its methods of formation have already been sufficiently described. It is largely used in the manufacture of building brick and to some extent also for vitrified ware.

Adobe is a very similar material found in the western states as outwash plains formed by streams which, swollen by cloudbursts, pick up great quantities of detritus produced by the decomposition of underlying rocks, and as they spread out upon the plains and lose velocity, drop first the coarser particles, sands and gravels, which they are bearing, then the silty material mixed with coarser clay which is called adobe, and carry the finer clay to more distant points.

Adobe is much used by the inhabitants of Arizona and New Mexico in the manufacture of unburned bricks, often reinforced with chopped straw, with which they construct their houses. In that dry climate with but little rainfall such buildings are found to be very satisfactory.

Fullers Earth.—§ 48. Fullers earth was formerly much used for removing grease from woolen cloth. It is a silty clay having little plasticity, but carrying a large amount of combined water. Clay has a strong affinity for oils and fats, as may be seen by the following experiment: Add a teaspoonful of oil to a glass of water, then drop into the water a lump of clay and stir vigorously for some time. If the clay is now allowed to settle it will be noticed that the oil has partially or wholly disappeared, depending on the amount and character of the clay used. Each particle of the clay has been covered by a film of oil and has carried it to the bottom of the vessel. This experiment explains why fullers earth is now so largely used in purifying oils. It may also be used for taking grease spots from cloth.

Minor Uses for Clays.—§ 49. Clay is also largely used in the manufacture of portland cement, and to a less extent as mineral paint, filler for paper, in confectionery and as an adulterant in various foods, in the manufacture of various soaps, window-cleaning and polishing powders, in the manufacture of medical plasters used to subdue inflammation, as a retardant to the setting of the cements now much used in place of lime mortar, and in the manufacture of alum, but the quantities used in these industries are not sufficient to warrant a separate description in a paper of this kind.

GEOLOGICAL DISTRIBUTION OF PAVING BRICK MATERIAL IN ILLINOIS.

[By C. W. Rolfe.]

Introduction.

What is a Paving Brick?—Before discussing the distribution of paving brick materials it seems best to at least attempt to define what a paving brick is.

Pages enough to make a fair-sized library have been written in the effort to describe the properties which a paving brick should possess and to formulate a series of tests which would enable a man always to select the best among the samples submitted to him, but no satisfactory conclusion has yet been reached. The chapter by Professor Talbot which appears in this volume is an admirable presentation of our knowledge on this subject; but all that is really known may, I think, be condensed into the following definition: A paving brick is a rectangular block of burned clay which possesses in a prominent degree the properties of hardness and toughness. It must be hard in order that it may wear as slowly as possible under the severe abrasion to which it is subjected. It must be tough so that it will not be broken or crushed by the shocks which it receives.

While every paving brick must possess both the properties named some lack in toughness is not so serious a matter as a lack in hardness, if the pavement is properly laid, because in that case all surfaces but one are thoroughly supported and it would require an unusually severe shock to shatter it. In the streets of Champaign and Urbana are several miles of pavements made from brick so brittle that they required the most careful handling to place them in the pavement unbroken, yet they have withstood wear, unusually severe for a country town, for more than a decade without serious injury. These brick were made from ordinary surface glacial clay and burned hard. They were so brittle that most of them would have made a very poor showing in a rattler. If, then, the brick are very hard and are properly supported on the bottom, sides, and ends, we can overlook some deficiency in the way of toughness, although of course every effort possible should be made to secure as great a degree of toughness as possible.

What is a Paving Brick Clay?—In order to answer this question intelligently we must know what properties a clay must possess and what changes it must undergo in order to gain the desired degree of hardness and toughness. We do not yet know enough about the pyro-chemical behavior of clay to enable us to answer either of these questions with confidence.

36

We know, or think we know, that vitrification tends to harden the brick and that proper regulation of the rate of cooling tends to make it tough. We also think we know that a mixture of ingredients which fuse at different temperatures is better than a mass of uniform composition, and that if the mixture while possessing the necessary degree of plasticity has its grains so firmly cemented that they will go through the processes of preparation and reach the molding machines as a mixture of particles varying in size from coarse to very fine it will enable us to reach the desired result more cheaply than would otherwise be possible.

In consequence of this we naturally look for an impure shale as the most available material for the manufacture of pavers, first, because the impurities it contains will probably give us the desired range in fusibility, and second, because shale after all is nothing but clay whose particles have been cemented and which by careful crushing can be converted into a mass which while having the necessary plasticity, will at the same time contain grains varying widely in size and density. In consequence of this many people have come to believe that shales furnish the only available material from which pavers can be made, and that shales from the coal measures are much more likely to make good pavers than those from any other horizon.

This opinion seems not to be well founded, for there is no good reason why coal measure shales should differ in any way from those of any other age. It seems to be true that the period of the coal measures was one of unusual instability, and that the frequent changes in conditions brought corresponding changes in the character of the sediments which were deposited at a given point, so that the content of sand in the coal measure shales varies more widely than is usual, and this in connection with the frequent occurrence of beds of coal at the base of the shale may account for the popular prejudice.

It is true, however, that some of the very best pavers are manufactured from clays of other ages and recent investigations seem to indicate that most, if not all, clays when properly handled, can be made into pavers of excellent quality. The Holland and Oldenburg clinkers, excellent pavers, are made from glacial clays.

What is Vitrification?—It is well known that clay as it comes from the machine contains a greater or less, but always a considerable, proportion of mechanical water, and that if the clay has been properly prepared this will all pass off in the dryer or during the first water-smoking without inducing any chemical change whatever. We also know that it contains a considerable percentage of combined water or water of hydration which is driven off during the second water-smoking, and that this process leaves the clay anhydrous, nonplastic, and incapable of recovering these properties by any known process. It is also known that after the clay has lost its water, if the temperature of the kiln is sufficiently high, it will shrink slightly, become less porous, and change its structure entirely. Instead of the granular or but loosely coherent structure shown by the surface of fracture immediately after the conclusion of the water-smoking process, we now have a compact glassy or felsitic, all but impervious, substance which plainly indicates that the body has undergone

profound chemical changes that have transformed it from an earthy into a stony material. It is to the sum of these changes that we apply the term vitrification.

We do not yet fully understand their nature, but we think we know some things about them. We believe that the increasing temperature of the kiln induces chemical changes and solid solutions in the clay in virtue of which more easily fusible compounds and mixtures are formed; that when these compounds reach incipient or actual fusion they induce similar changes in other ingredients of the clay which would not undergo chemical transformation at that temperature if it were not for the presence of the first formed compounds. When these last compounds reach partial or complete fusion they react on yet more refractory ingredients of the clay, and so on.

When fusion occurs in these compounds they increase in volume and become slightly blebby, they also tend to settle together, and by a combination of these two processes the pores are filled, the structure becomes more impervious, and the material harder.

Distinction between vitrifaction and fusion.—If a mass made up of a single chemical compound, like pure kaolin or any one of the group of similar substances which are found in clay, be ground to uniform fineness, moulded, dried, and gradually heated, it will pass through all the changes enumerated above; but as all the particles are of like size and have the same composition each will be affected in the same way by heat, and, consequently, each will pass into incipient fusion at the same temperature so that the whole mass will soften at approximately the same time and become deformed. In such a mass the temperature of vitrifaction and that of fusion will usually be so close together that it will be difficult so to control the fires as to produce complete vitrifaction without deformation of the brick.

On the other hand, if, as is usually the case with clays, the mass is made up of several compounds each having a different fusion point and which are also capable of uniting at certain temperatures to form new compounds which have yet other fusing points, the temperature at which incipient fusion or vitrifaction begins and that at which the whole mass softens may be widely different, and will usually be more widely separated than is the case with a pure substance.

Again, if the original mass contained both coarse and fine particles the finer particles will be first attacked, then those which are coarser and so on until the largest are involved and in this way the range of vitrifaction will be widened.

Conditions which are essential in a paving brick clay.—From what has preceded we can see that a clay from which paving brick are to be manufactured must be a mixture of more and less fusible materials, the more refractory particles forming a skeleton which holds the mass in shape, while the more readily vitrifiable portions undergo chemical changes, form solid solutions, become vesicular, and draw together until the pore spaces are partially or wholly filled and the mass becomes relatively impervious.

The skeleton spoken of above may be composed of more refractory material than the remainder of the brick or may simply be made up of

coarser particles of the same material as the rest, but in the latter case the range of vitrifaction would usually not be very wide.

If a given clay does not fulfill the conditions named above the defect must be remedied by mixing it thoroughly with more or less refractory material or by coarser or finer grinding of a portion, as the case may demand.

If a clay does fulfill the conditions in a measure, but the range of vitrifaction is narrow, this may often be remedied by proper mixing or handling.

If all or a large proportion of the particles are so very fine that the clay settles into a compact, almost impervious mass so that it is difficult to dry and cracks badly, some coarser material must be introduced or some method of handling devised to open the structure of the mass and allow the water to pass out readily. When, as is not infrequently the case, this fine-grained, compact mass shows a decided tendency to split up into cubes instead of disintegrating under the treatment ordinarily given to clays, some special plan such as mixing into a thin paste with water and allowing it to settle, or more thorough grinding and mixing than is usually resorted to will have to form part of the preparation in order that the coarser material may be thoroughly incorporated, or, exposing the clay to frost during the winter must be resorted to in order to break up the strong tendency to joint. Experience has shown that this tendency can be overcome by any of the methods mentioned, but as they are all too expensive to be used in general practice, some other plan of handling these clays must be devised.*

No attempt has been made in the foregoing paragraphs to enumerate all the difficulties that may arise in the preparation of materials for the manufacture of paving brick, but perhaps we have gone far enough to indicate what was meant by the claim that pavers of excellent quality may be made from clays which are not now considered available, if proper admixtures are made and the materials are correctly handled. Whether it will pay to do these things on a commercial basis is a matter which local conditions alone can decide in each case.

I repeat at this point what I said earlier in this section. We know very little about details in the pyro-chemical behavior of clays. It is a matter which we hope to see taken up in the near future and when this is done I have no doubt that many of the things we now think we know will have to be modified, but although this is true, such an investigation should point the way to the solution of many of the problems which now disturb us.

In the foregoing pages I have tried to show that in the present state of our knowledge it is impossible to answer the question "what is a paving brick clay?" I have endeavored to show that no special kind of clay is required for the manufacture of pavers, but its fitness for such use is more a question of physical structure than of chemical composition ; at the same time it must be realized that certain mineral substances when present in larger quantities unfit a clay for this purpose. I have also tried to suggest the possibility (which we know in certain cases to be a fact) that, while suitable structure has been given to certain shales by

---

* This has now been done, and the method will be described in a later bulletin.

nature, we may devise ways by which this lack of structure may be compensated in clays that do not now possess it, using means so inexpensive as to make the operations commercially successful.

We are now in a position to hurriedly trace the geological history of our State with a view to ascertaining where deposits of those materials which are most likely to be useful to the manufacturer of vitrified brick may be found. We hope the time will come when we can speak definitely of the properties of these deposits, but until a survey of the clays of our State, such as is now in progress in Ohio, shall be made, we must content ourselves with indicating where suitable deposits are likely to be found.

Geology of Clays.

ORIGIN.

The origin of clays has been discussed at length in the section on the geology of clays. It is there shown that primarily all clays come from the decomposition of crystalline rocks; that often these clays remain as a mantle more or less thick covering the undecomposed portion of the rocks from which they were derived, but that more frequently they are lifted by running water and carried to some more or less distant point and there assorted and deposited. When these deposits are made at the border of the ocean the clays are built into the rocks which are always forming in such places. Often the clays are deposited without much admixture of other materials and are afterward consolidated into shales, but more often they are mixed in greater or less proportion with materials which are to form limestones or sandstones, and so become an integral part of those rocks. As soon as these limestones, sandstones, and shales have been elevated into dry land they are attacked by erosion and undergo decomposition. The altered portions of sandstones become layers of sand containing more or less clay. In the case of limestones much of the lime is dissolved and carried away bearing a layer of clay which covers the undecomposed rock, while the shales often break down into beds of more or less plastic clay. Here again, as in the case of the crystalline rocks, the greater portion of the clay is carried away to be re-deposited as beds of alluvial clay.

OUTLINE OF THE GEOLOGICAL HISTORY OF ILLINOIS.*

General Section.—The geologist, like the historian, divides the history of a country into periods which are separated from each other by some noteworthy change either in the structure of the rocks or the fossil forms which they contain. These divisions of the geologist differ from those of the historian in that each covers an almost inconceivably long period of time, and that in that there is no sort of relation between them as to the

---

*A brief description of the geology of the State, accompanied by a geological map, prepared by Stuart Weller, is found in Bulletin 6 of the State Geological Survey. This will be sent for 45 cents on application to the Director State Geological Survey, Urbana, Ill. The notes given here are intended merely to bring out the facts necessary to a good understanding of the distribution of the clay-bearing formations.

length of time which each covers, the divisions of time represented in the history of Illinois are as follows:

Cenozoic Era.
{ Quaternary or Glacial Period.

Tertiary { Represented only in that part of the State south of the Ozark ridge; no subdivisions have been distinguished.

Mesozoic Era.
{ Represented in the same area as the Tertiary and has not been separated from it.

Paleozoic Era.

Carboniferous
{ Coal Measures or Pennsylvanian

Lower Carboniferous or Mississippian
{ Chester
St. Louis
Keokuk
Burlington
Kinderhook

Devonian { Upper
Middle
Lower

Silurian–Niagara

Ordovician
{ Trenton { Cincinnatian
Galena–Trenton

Canadian { St. Peters
Lower Magnesian

Cambrian–Potsdam.

CAMBRIAN.

Potsdam.—At the beginning of Potsdam time the entire area of this State was covered by the waters of a shallow sea, which gradually deepened until the close of the period. During the period 1,000 feet or more of sandstones, limestones, and shales were deposited. The rocks of Potsdam age do not appear at the surface at any point in Illinois, but do outcrop in southern Wisconsin. They are believed to underlie the entire State, and form our deepest source of artesian water.

ORDOVICIAN.

Lower Magnesian.—At the close of the Potsdam the condition of the sea had become such that lime-secreting animals could grow in abundance, but the waters were not completely or continuously clear. During this time 100 to 500 feet of a strongly argillaceous limestone was deposited over the entire area of the State. Its presence has not been actually demonstrated in the extreme southern portion, but there is every reason to believe it is there. It appears at the surface only in LaSalle, Ogle and Calhoun counties. Near Utica, in LaSalle county, it is used in the manufacture of hydraulic cement.

St. Peters.—After a geologically brief but really long period following the deposition of the Lower Magnesian, during which northern Illinois

was dry land, the State was again covered by a shallow sea and about 150
feet of a charactertistic white sand was deposited. This material is
much used in the manufacture of glass and forms, above the Potsdam,
the principal source of artesian water in the northern portion of the
state. It appears at the surface in the lower ten miles of the valley of
Fox river, and along the Illinois from Ottawa almost to LaSalle ; also
in the valley of Rock river from north of Oregon almost to Dixon and
at Cap-a-Grés near the southern end of Calhoun county.

  Galena-Trenton.—Following the period of deposition of the St. Peters,
the sea became again suited to an abundant growth of organisms, al-
though the waters still contained considerable quantities of clayey sedi-
ment. During this period 300 to 400 feet or more of dolomite and
limestone were formed. This formation carries the lead and zinc de-
posits of the northwestern portion of the State and corresponds with the
oil-bearing limestone of eastern Ohio and Indiana. While usually com-
posed of limestone, the formation contains pockets of shale and clay.

  Cincinnatian or Maquoketa.—At the close of the Trenton period the
seas became very muddy, but with clearer patches here and there in
which lime secreting organisms could flourish. During this period 50 to
200 feet of shales and shaly limestones were formed. While in Illinois
the Cincinnatian consists, for the most part, of argillaceous limestones
and limy shales, where it outcrops in the northern part of the State, it
contains local deposits of very pure shale.

SILURIAN.

  Niagaran.—With the close of the Cincinnatian the seas became clear
again, and a heavy bed of limestone 200 to 300 feet thick was deposited
over the entire area. This limestone is usually strongly magnesian in
the northern and central portions, calcareous in the southern. It usually
furnishes building stone of excellent quality.

  It has usually been assumed that at the close of the Silurian the
whole of the northern part of the State to the latitude of LaSalle was
elevated above the seas forming the first permanent land within its
borders. Only scattered Devonian and other rocks have been found in
this portion of the State except on a narrow strip along its southern bor-
der. Erosion has taken place to such an extent as entirely to remove to
the Silurian from one-half of the area and the Cincinnatian from at least
one-third, leaving the Galena-Trenton as the surface rock over the greater
portion of the northwestern counties.

DEVONIAN.

  The Devonian rocks offer little that is of practical interest in this
connection. They outcrop at only three or four points in the State and
form the surface over a very small area. At their outcrops, as at the
points where they have been pierced by wells, they vary from 10 to 150
feet in thickness divided between limestone and dark shale. Known
facts seem to indicate that the Devonian underlies the greater portion of
the State south of the latitude of LaSalle, excepting the eastern portions
of Will, Kankakee, and Iroquois counties.

CARBONIFEROUS.

Mississippian or Lower Carboniferous.—At the close of the Devonian that portion of the State south of the latitude named received a heavy deposit of limestones, sandstones, and shales aggregating 150 to 200 feet in thickness, called the Lower Carboniferous or Mississippian series. Worthen divides this series into five groups as follows: Kinderhook, mostly shales and limestones, 100 to 150 feet; Burlington, massive lime-stone, usually excellent as a building stone, 50 to 200 feet; Keokuk, mas-sive limestone below, passing into shales in the upper portion, 150 feet; St. Louis, mostly heavy bedded argillaceous limestone, 100 to 200 feet thick, passing locally into shales on one hand and a fine quality of oölite on the other, and Chester, consisting of heavy beds of sandstones and limestones with some shales, in all 500 to 800 feet thick.

The Lower Carboniferous forms the bluffs of the Mississippi and a variable belt to the eastward from the southern portion of Mercer county to Alexander county and a considerable part of the Ozark ridge across the State. It is believed to underlie all the central and southern part of the State, and well records indicate that it increases in thickness and be-comes more shaly towards the eastern border. Present information seems to indicate that the Chester does not occur north of a line drawn through Litchfield and Danville.

Pennsylvanian or Coal Measures.—For a long time subsequent to the deposition of the Lower Carboniferous, that portion of the State between the latitudes of LaSalle and Carbondale oscillated between a slightly ele-vated condition, in which extensive marshes and lakes were interspersed between areas of higher drier land, and a condition in which the entire area was covered by the waters of a shallow sea in which beds of shale and sandstone 20 to 200 feet thick and occasional thin beds of limestone accumulated. These conditions alternated many times with the result that a formation now 50 to 1200 feet thick was built up in this portion of the State. In the marshes and lakes great beds of vegetable matter accumulated, which were afterward converted by the pressure of subse-quent deposits into bituminous coal, and beds of this material are now found intercalated in the sandstones and shales before mentioned.

CRETACEOUS AND TERTIARY.

After the uplift that marked the close of coal measure deposition no portion of the State north of the Ozarks is known ever to have beneath the waters of the ocean, but south of the ridge thick deposits of sand-stones, limestones, and shales were laid down. These deposits have not been studied with sufficient care to make their differentiation possible, so that we need do little more in this connection than point out their presence.

PLEISTOCENE.

Glacial Deposits.—After the close of the Tertiary the entire surface of the State north of the Ozarks except small portions at the northwestern corner, and in Calhoun county, was covered with a sheet of ice of great

thickness. This ice sheet came to us from the regions southwest and southeast of Hudson's Bay, and on its way picked up the soils and loosened fragments of rocks which had been accumulating over that region for hundreds of thousands of years. When the ice melted these materials were deposited over the surface of Illinois, making a layer which varies greatly in thickness but will probably average 50 to 100 feet. This is known as boulder or glacial clay. Three ice sheets separated by long intervals are supposed to have covered portions of Illinois. The first Illinois Glacier extended as far south as the latitude of Carbondale, and when it disappeared left a thick deposit of glacial clay. The second, or Iowan Glacier, extended but a short distance below the northern boundary. We do not yet know the exact limits of the territory which it covered. The third, or Wisconsin Glacier, covered an area in the northeastern portion of the State which averages about 90 miles east and west by about 200 north and south. Its boundaries are marked by a prominent ridge or moraine which passes near Charleston, Shelbyville, Decatur, Peoria, Princeton, Rochelle, Woodstock, and Harvard.

Each of these ice sheets left its deposit of boulder clay, and as we dig through the deposits the upper surface of each is marked by one or more of the following characteristics, yellow clay, black earth, pieces of wood, gas, or large water-bearing gravel beds.

AREAL DISTRIBUTION.

Keeping in mind the brief descriptions of the foregoing paragraphs, we may now divide the State into the following geological areas, Ordovician, Silurian, Devonian, Lower Carboniferous, Coal Measures, and Cretaceous or Tertiary.

Ordovician.—This area is roughly bounded by the parallel 41 30′ and the meridian 88 36′, covering the northeastern part of the State, together with a narrow strip running southward through western Will, Kankakee, Iroquois, and Ford counties. The Galena-Trenton now forms the surface over the greater part of this area, but when it first became dry land it was also covered by the Cincinnatian and Niagaran. These have been removed from most of the area by erosion, but remnants of them still remains as mounds and elevated table lands. The lowermost beds of the Galena-Trenton include highly argillaceous limestones, and whenever the formation has been long exposed to the action of the weather the lime has been dissolved and carried away in solution, leaving the disseminated clay as a mass of loose material. Where this is not exposed to the action of running water, it has accumulated in beds or pockets which sometimes cover a considerable area. Considerable deposits having this origin are known to exist in the area, but their availability for the manufacture of pavers has never been tested so far as the writer knows.

In all the mounds and table lands referred to above the Cincinnatian or Maquoketa comes to the surface, either forming the apex of the elevation or lying immediately beneath a capping of Niagaran. This Cincinnatian usually appears in this part of the State as a thin bedded limestone which carries a large percentage of clay, but locally it becomes a pure

shale, often high in lime, but occasionally almost lime free, in which
case it becomes a promising source of paving material (See H 18 and
H 21.)   The Cincinnatian also outcrops as shale near Wilmington, Will
county.   A considerable percentage of the Ordovician area is covered
with glacial deposits, some of which may be found to be suited to the
manufacture of pavers.   Small areas of rocks of this age may also be
found near Batchtown, Calhoun county; Valmeyer, Monroe county; and
Thebes, Alexander county.   In some of these the rocks are shaly and look
promising but have not been tested.

Silurian.—This formation covers the greater part of McHenry, Lake,
Cook, Dupage, Kane, Will, Kankakee, and Iroquois counties, and small
portions of Boone and DeKalb, all lying in the northeastern corner of the
State.   The surface rock is the massive Niagarean limestone which fur-
nishes no deposits of clay or shales in this State.   It is everywhere over-
laid by thick deposits of glacial drift which permit the underlying rock
to appear at the surface in small areas only.

The glacial clays of this area present the wide range in composition
and properties so characteristic of deposits of that age.   No studies of
these clays have been made so far as the writer knows, but he feels certain
that some of them would make pavers of excellent quality if properly
treated.

Small areas of this age are also found at the mouth of the Illinois and
east of Thebes in Alexander county, but they afford no clays or shales.

Devonian.—The outcrops of Devonian rocks in Illinois are of small
area and are confined to three localities, viz.: near Rock Island, on
either side of the Illinois river near its mouth, and near Jonesboro in
Union and Alexander counties.   In all these areas shales are to be found
which may prove valuable as paving brick material, but they have not
been tested.

Lower Carboniferous or Mississippian.—The rocks of this area form
a broad, but very irregular belt, along the Mississippi from New Boston,
Mercer county, to the southern line of Union county and thence east
across the state, forming the Ozark Ridge.

Most of the rocks of this age outcropping in the area described are
limestones or sandstones, but nearly all the layers pass locally into shales,
some of which, notably those of the Kinderhook and St. Louis, have been
proved to have the qualities desired in paving brick material, but in
only one locality, and that from the Kinderhook, so far as the writer
knows, have they actually been used for this purpose.

Coal Measure or Pennsylvanian.—This area covers all that part of the
State lying between the parallel 41 30′ and the Ozark Ridge except those
portions included in the Silurian and Lower Carboniferous.   Over all
this area shales and fire clays are abundant along the banks of the
streams.   Many of them are all that could be desired as material for the
manufacture of pavers, and they often present the added advantage of
being underlaid by a bed of coal which may be used for fuel, thus lessen-
ing the cost of production.   All the paving brick plants now operating in
the State use these shales and all but one of those in the western part of
Indiana.

This area is everywhere overlaid by a deposit of glacial drift which is often from 50 to 300 feet in thickness, and it is only when this has been removed by erosion that the Coal Measure shales come to the surface.

These glacial clays are now only used in the manufacture of drain tile and common building brick, but it is hoped that means will soon be devised which will make their use in the manufacture of vitrified ware of good quality commercially possible.

Cretaceous and Tertiary.—This area lies entirely south of the Ozark Ridge and includes the greater part of Alexander, Pulaski and Massac counties, and a small part of Pope. Many of the clay deposits of this area are of excellent quality and the tests to which some of them have been subjected indicate that they would make excellent pavers.

It is thus seen that there are no larger areas within the boundaries of the State that do not contain deposits of clay which are at least promising as sources of material for the manufacture of pavers. It is hoped that in the near future the survey will find itself in a position to demonstrate the availability of these deposits for this use.

QUALITIES OF HIGH GRADE PAVING BRICK AND TESTS USED IN DETERMINING THEM.

[By Arthur N. Talbot.]

Introduction.

The extensive use of brick for street paving purposes makes the formulation of the qualities requisite for a good paving brick a matter of importance to both producer and consumer. Although it may not be difficult to agree on these qualities in the abstract, it is not easy to express the requirements in definite and concrete form and in terms acceptable to both manufacturer and municipality. It is an accepted principle that the quality of an engineering material should not be left merely to the judgment of an individual, no matter how experienced the individual may be; recourse should be had to physical tests and these should be definite and discriminating. Such tests may not of themselves be conclusive, the results are in the nature of evidence which must be interpreted and judged in the light of other information. Perfect materials for a pavement may not be obtained and high quality usually means increased cost of production, but on the other hand the additional cost of a good article is usually made up many times over in the increased length of life and improved surface of the pavement as compared with a pavement in which an inferior brick is used. The problem of formulating requirements and making tests is further complicated by the difficulties encountered in selecting brick for test and comparison from the piles of brick along the street and in judging whether the variation from the average throughout these piles is sufficient of itself to be cause for rejection. Enough has been said to justify the view that the formulation of the qualities needed in a high grade paving brick and the use and interpretation of physical tests for determining the qualities of the brick for aiding in deciding whether brick come up to the required grade, are matters worthy of discussion by engineers and manufacturers. A general statement of matters connected with brick testing may be of advantage to many who are interested in the construction and use of brick pavement.

Most specifications for materials set forth qualities of materials to be furnished by the producer to the consumer. In the case of brick pavements the producer (i. e., the manufacturer) and the consumer (i. e., the municipality and the property owner, as represented by the municipal administrative officers) are to use certain requirements to define the material to be put into the pavement. Some of the purposes of these requirements and tests may be expressed as follows:

1. To make a basis or definition of what is wanted and what is to be furnished. This is the commonly accepted purpose of such requirements and tests.

2. To enable the city to secure material which will be as serviceable as other material which has passed the requirements and which has stood the test of traffic and time. This makes the tests in a sense a guaranty of quality.

3. To enable comparisons to be made between the products offered. It is quite possible that tests may show that a given brick is above the requirements, or that a slight difference in price is made up many times by the superior quality of the article.

4. To improve the general quality of the product put on the market. It has frequently happened that the formulation of requirements and the careful inspection of the articles offered have resulted in improved quality and this in many cases even without increasing the cost of production. The manufacturer has been stimulated thereby to study the process of production and to seek to improve methods of manufacture and quality of product. One need instance only structural steel and paints and oils to show improvements in quality following carefully made requirements and tests to show the beneficial influence of adequate inspection and tests.

5. To safeguard the interests of the public and of the taxpayer. The Illinois law requires, and rightfully, too, that the nature and quality of the improvement shall be explicitly stated, and evidently intends that the taxpayer may be able to determine (1) what the improvement is to be, and (2) whether it is being put in as described.

6. In the occasional cases where abuse of authority or improper or dishonest construction may require a check, to enable control to be exercised over incapable or dishonest contractors or city officials, and to restrain careless or inefficient employes, or men who may have a mistaken notion of what their employer's interests are.

7. To educate producer, consumer, and their agents in a knowledge of the qualities needed in paving brick,—from the manufacturer and the contractor and their employes to the mayor, the engineer, the inspector, and the property owner. It should be recognized that those who have charge of municipal work are a constantly changing class, and that the property owner may have little knowledge of pavement construction.

8. Not the least important of the reasons for having an explicit and definite statement of the qualities and requirements for a paving brick is to give the opportunity for all bids to be made on the same basis and for the bidder to fix his price according to the quality of the article wanted and thus to facilitate fair competition.

It is evident that a knowledge of the qualities of a high-grade paving brick and of the defects to be avoided in the selection of brick will be useful in making up the requirements defining the grade of brick to be used and that the method of making tests ought to be studied both in relation to the wear of the brick in the street and to the bearing of the results of the physical tests upon the wearing and other qualities of the brick. In this article a discussion of the qualities needed in a paving brick will be given first, and the bearing of the tests upon these qualities will then be taken up, though it will be seen that the relation between the method of testing and the quality to be determined is so intimate that their discussion must be carried on together to a considerable extent.

QUALITIES FOR A HIGH GRADE PAVING BRICK.

General.—Paving brick should possess the following qualities: 1. Toughness, hardness, and strength. 2. Uniformity of quality throughout a given lot of brick. 3. Homogeneity of structure and freedom from laminations. 4. Weather-resisting quality. 5. Regularity in form and size. These qualities are named somewhat in the order of their

importance, though it should be recognized that several of them are mutually inclusive.

1. *Toughness, Hardness, and Strength.*—Toughness is that property of a material which indicates its ability to withstand destruction by shock or impact or by a marked distortion of the form of the piece. It is the opposite of brittleness. Of course toughness differs in different materials, and it varies in a given material. Mild steel has the property of toughness to a marked degree and will withstand distortion and abuse. One test of the toughness of a specimen of mild steel is to bend the piece cold 180° flat on itself without sign of fracture. Cast iron is a more brittle material and ordinarily is not used to take shock except in large masses and at low stresses. Different grades of cast iron, however, possess different degrees of toughness, and a good quality of cast iron will bend considerably before rupturing. With such materials the physical property of toughness which will permit bending and distortion in relatively thin pieces will give ability to withstand blows and the sudden application of loads in thicker masses. In the case of paving brick, a lack of toughness causes the brick to chip and spall under the action of horses' hoofs and not to resist blows and abuse under the action of traffic. This element of toughness is one of the most important qualities in a good paver.

Hardness is that property of a material which indicates its ability to resist abrasion. The necessity for hardness is self-evident. The grinding action of loaded wheels sliding sidewise or even rolling forward wears away the surface of the brick and forms grit or dust. This abrasion is the principal source of wear in a well-constructed pavement made of a good quality of brick. Soft brick will wear rapidly under the action of traffic. Hardness is therefore a desirable property for paving brick to possess.

Strength is another important element. The loads of wheels are concentrated on a small area, possibly a ton on a fraction of a square inch. With an uneven bedding of a brick or other conditions like its being supported on a pebble or by an adjoining brick, considerable flexural action is developed, and even twisting action, and the brick acts as a beam. With uneven surfaces there may be considerable horizontal thrust. It has been argued that lack of strength in the brick does not seriously affect brick pavements and that pavements do not fail from this source, but the writer has seen brick of a mediocre quality spall under the trust of a loaded wheel again and again, and it is not uncommon to see brick broken in two by the passage of loaded wagons. Moreover, when a material is otherwise severely strained the effect of abrasion and impact is greater, and the brick which under heavy stresses remains well below its ultimate strength will be better able to withstand the abrasive action which takes place under such conditions. Besides, high compressive strength is generally conducive to hardness, and for granular materials a relatively high tensile strength such as accompanies high values in cross breaking is an indication of toughness and high resilience in the material.

The elements of toughness, hardness, and strength are difficult to differentiate, since one involves the other. On the other hand, a very

hard brick may be quite brittle, so much so as to be an inferior article. Some very tough bricks are not hard enough to resist abrasive action sufficiently. Where this is so, there may be some defect in the process or treatment during manufacture. Generally flexural strength goes with toughness and compressive strength with hardness. Not all these qualities may be expected to exist to the same degree in brick of different makes, and hence the different properties should be considered in discussing the merits of a variety of brick.

2. *Uniformity of Quality.*—In the enumeration of properties needed in a paving brick, uniformity of quality throughout a given lot has been placed second in the list, and it is believed by the writer that it is hardly secondary to the qualities of toughness, hardness, and strength. It is highly desirable that all the brick in a given lot shall be as nearly uniform in make-up as is practicable with the best materials and manufacture, and especially that brick which will be near each other shall be of uniform quality. If one brick is soft and the next one hard, an uneven surface will be produced more quickly than otherwise, the resulting soft spots receiving harder wear as the low spots appear. A pavement of soft but uniform bricks will wear away at a uniform rate, and its surface may remain less objectionable than one containing a fair proportion of harder brick. The products of some plants are particularly troublesome in this direction, while those of others are fairly uniform. This quality or lack of this quality renders inspection on the street very difficult, and has done as much as any thing to throw discredit on brick pavement. Brick manufacturers will render service to their industry by striving to secure greater uniformity and municipalities must, on their part, protect their interests by holding stricter requirements than in the past. The importance of uniformity has not generally been sufficiently recognized.

3. *Homogeneity of Structure and Freedom from Laminations.*— Homogeneity of structure gives uniformity of wear throughout the brick and adds to ability to resist wear and breakage. A brick of homogeneous texture is more likely to possess toughness and strength to the requisite degree than is one of variable texture. Laminations in a brick are particularly objectionable, since they markedly decrease toughness and strength, and permit chipping and spalling. It is important that tests for toughness, hardness, and strength be made in such a way as to bring out the effect of laminations and other defects which may not be apparent near the surface of the brick. The brick should be uniform throughout, evenly vitrified, and free from spots which result from imperfect crushing and mixing of materials and from any element which will tend to disrupt the brick by later changes in condition.

4. *Weather-resisting Quality.*—Strong, tough, hard brick of low porosity and even texture are not injured by weather changes. Soft, weak and porous brick are affected by frost and other weather conditions, and a laminated and coarse structure promotes disintegration.

Generally speaking, high grade paving brick are of sufficient strength to withstand weather influences, but the combination of weather effect and traffic is more noticeable. The writer has observed the spalling and grinding of soft brick under heavy loads during the time when they were wet and frozen on pavement where the wear was much slower under

better weather conditions. Occasionally a pavement is found where rapid deterioration takes place during the early spring. Part of the trouble of this sort is due to improper bedding and filling.

5. *Regularity in Form and Size.*—Well-formed brick of uniform size give a smooth and regular surface to the pavement, and thus add to its attractiveness. Besides, such brick will have uniform bearing and exert even pressure on the sand cushion below, and thus will remain in position during the life of the pavement. Desirable as this uniformity is, it does not pay to obtain it at the expense of the wearing qualities, and pavements with the smoothest surfaces do not always give the best results. Some irregularity in shape and form must be expected and permitted, especially with clays of a certain character. No general rule may be formulated, and the amount of irregularity may easily be settled upon in connection with any given lot of brick.

TESTS FOR QUALITY.

GENERAL STATEMENT.

The main advantage of physical tests of paving brick lies in giving definite evidence having a bearing upon the properties and qualities of the brick. To make this evidence useful, the relation of the method of making the tests and their results to the qualities thereby determined must be understood. In several of the tests numerical standards may be set for general use. However, in many cases and especially for some of the tests which may be made, it is best to consider that the results are advisory in nature and that hard and fast limits may not be set. In subsidiary tests the results may give evidence which confirms findings otherwise made or which throws light upon unsettled questions and aids in interpretation of data obtained by other tests.

In tests of materials it is not essential that the material shall be subjected to the same action in the process of testing as it will receive in the structure in which it is to be placed. The cold bend test of steel is one of the most useful and instructive of tests, but it differs radically from any condition of service in which the steel will be placed. The value of a test will depend upon the properties determined, and the criterion will be, does the test establish definitely certain properties of the material, or does it give definite evidence concerning specific qualities, and does not the method give results similar to those found in service. Thus the ordinary rattler test is quite unlike the action of traffic on a street, but if it determines the toughness and hardness of a brick sufficiently well it serves its purpose. Because high grade paving brick do not crush in service is not conclusive evidence that the results of crushing tests do not give important information concerning the qualities of a given lot of brick. Of course, a test which approximates the conditions of wear and stress in the street pavement has a distinct advantage in that it appeals to the lay mind and gives the municipal officer and the tax payer confidence in the findings which would not be possible in a test of seemingly less direct applicability. Whatever the test, its purpose and the bearing of the results on the qualities desired in the brick should be understood and accepted by all.

The tests which have been used, some of them very commonly, others only occasionally, are: 1. the rattler test (called also the impact and abrasion test); 2. the absorption test; 3. the crushing test; 4. the cross-breaking test; 5. the specific gravity test. The rattler test is commonly considered to determine toughness and hardness, or resistance to impact and abrasion. The absorption test gives information bearing upon the degree of hardness to which the brick has been burned. The cross-breaking test and the crushing test determine strength and incidentally give evidence of the hardness and toughness of the brick. The specific gravity test must be classed among those tests which are of value in giving general information. The manner of making these tests will now be described and some discussion given of the meaning of the results found by the various tests.

THE RATTLER TEST.

It may be of interest to recount some of the efforts which have led up to the present standing of the rattler test. During the earlier years' experience in the construction of brick pavement the judgment of those in charge of the work was the only guide used when passing upon the quality of paving brick. It was soon seen that some test to measure the ability of a brick to resist wear was needed, and the use of the foundry rattler or tumbler, employed in foundries for cleaning castings, was suggested. Brick were placed in these rattlers with a charge of foundry shot, which is generally composed of a miscellaneous lot of broken castings of various sizes and weights and of varying degrees of roughness and irregularity. The rattler, with its charge of brick and shot, was then rotated for some time, and the loss in weight of the brick was determined. It is easy to see that there was small chance of anything like uniformity in making this test. Each individual used the rattler which was available for the purpose, without reference to its size. The speed used in the test was whatever the foundry happened to be using. The total number of revolutions depended also upon the time the rattler was run, and this varied. The weight of the foundry shot used and the size and condition of the pieces were whatever happened to be in use in the foundry where the test was made, though this was sometimes varied by using what the individual making the tests considered to be better. Some engineers were somewhat more definite and specified that a given weight of miscellaneous foundry shot was to be used. In 1896, H. J. Burt* reported that specifications from fifteen cities showed the following ranges in the dimensions of the rattler and conditions of the test: Length of rattler, 24 to 54 inches; diameter, 15 to 40 inches; speed, revolutions per minute, 15 to 45; duration of test, 30 to 360 minutes; weight of iron in the charge, 50 to 800 pounds; Loss permissable in one hour, 3 to 10 per cent. These figures show something of the variation in practice at that time.

It is quite evident that this lack of uniformity was conducive to confusion. The engineer was not able to compare the brick which he accepted with the material which the engineer of a neighboring city rejected. The manufacturer could not tell definitely whether his product

---

*The Technograph, University of Illinois, No. 10, p. 93.

would fill the requirements in a city where he had not furnished brick. There was considerable difference of opinion on the effectiveness of the tests specified in certain cities in determining the toughness and hardness of brick. The amount and nature of the foundry shot used in some cases rendered the test merely an abrasion test. Perhaps the greatest confusion was due to the lack of explicitness in the specifications. As an illustration the following example is cited. In 1895 when the writer was engage by the city of Chicago to make tests of brick from thirty yards in several states to find what makes of brick came up to the requirement of the specifications that the loss in one hour test should not exceed 12 per cent, he asked for instructions on the size of rattler, speed, and amount and nature of the foundry shot to be used in the test, and was told that these matters had not been specified and that he was to use his own judgment concerning them. Of course, in such cases manufacturers were not able to determine what grade of brick was wanted, and municipalities were uncertain about the quality of the pavement which they were putting down.

A number of efforts were made to standardize the rattler test. One of the earliest attempts was made by Prof. Ira O. Baker, in 1890, by subjecting brick which had seen service in a pavement and pieces of natural stones cut to standard form and size to the action of a rattler in which were also placed small pieces of scrap iron. This method was unsatisfactory on account of the trouble and expense of preparing the test pieces of natural stone and the lack of uniformity in the stone, as well as because as used it did not properly combine the two actions of impact and abrasion. Later, the same investigator made a series of tests using 2-inch cubes of brick and stone with a charge of foundry "stars," but this method did not prove satisfactory.

In 1895 the National Brick Manufacturers Association appointed a commission to investigate the subject of paving brick tests and to recommend standard methods for their conduct. This commission was made up of representative men, and they had unusual facilities for their investigation. The work done marked a distinct advance in the testing of paving brick. The report of this commission* made in February, 1897, contains much valuable data on the subject of testing paving brick. The investigation of the rattler test was made by Prof. Edward Orton, Jr., of Ohio State University. His experiments were conducted upon Canton red granite repressed brick pavers, burned so as to have a high degree of uniformity. These brick were of as high quality as is generally available for paving purposes. A general summary of the results of Professor Orton's investigation of the rattler test may prove of interest in this discussion.

Tests were made with charges of foundry shot made up of small scraps which had been used in a foundry as an abrasive to clean rough castings. These pieces composing the foundry shot were small, averaging less than one-half pound and in no case being more than one and one-half pounds. The resulting loss was small and, of course, was due

almost wholly to abrasive action, the impact effect being very slight. Cast-iron bricks weighing approximately seven pounds each were next used in the rattler. Charges of these cast-iron shot equivalent to 10, 15, 20 and 25 per cent of the volume of the rattler were tried, five paving brick being tested each time. The bricks subjected to this test sustained comparatively little loss by abrasion, the principal loss being by breaking and chipping. The effect of the impact with these heavy shot was very severe. Without trying another size of shot or attempting to blend the abrasive and impact effect by means of a mixture of sizes, the use of iron was abandoned, though Professor Orton felt that its cheapness, its long life, and its uniformity at all parts of the country would make it particularly suited for a standard filling if its action as an abrasive were favorable.

Tests were then made using natural stone of the general size of paving brick. It was found that limestone, sandstone, and granite were as variable in their losses as are brick, that the results obtained with the paving brick when tested with blocks of stone were exceedingly erratic, and that the accompanying expense and trouble themselves rendered this method unacceptable.

Tests were made with paving brick alone in the rattler, no other abrasive or filling material being used. After an elaborate set of tests made with a few of determining the best speed, size of charge, etc., Professor Orton reported that with brick alone in a rattler of 28-in. diameter the volume of the charge of brick should be from 10 to 15% of the volume of the rattler, the test should be continued for at least 1500 revolutions, that the speed should be between 24 and 36 revolutions per minute, and that the length of the rattling chamber should not be less than 18 inches. These conditions were found to give the least variation in results, the most severe wear, and to be the most convenient.

The commission also had the advantage of the tests made by Mr. E. F. Harrington, of the testing department of the city of St. Louis, which were along the same lines and gave confirmatory evidence. Professor Orton's report submitted specifications for the conducting of a standard rattler test and these were adopted by the commission almost without modification. These specifications are now known as the old National Brick Manufacturers Association test and sometimes as Orton's test. The making of a standard for the size and speed of rattler and for the charge was a great step in advance, but the peculiar feature of the test, the use of brick alone in the rattler, did not prove to be a fortunate arrangement, as it was soon shown that this test failed to discriminate to a sufficient degree between good and poor paving brick. This feature has since been eliminated, and a definite charge of cast-iron shot is now used in the standard test. However, as its reproduction here may make it convenient for reference for some, the specifications adopted by the Paving Brick Commission of the National Brick Manufacturers Association are here given.

ORIGINAL SPECIFICATIONS FOR A STANDARD METHOD OF CONDUCTING THE RATTLER TEST FOR PAVING BRICK. (KNOWN AS THE OLD N. B. M. A. TEST OR ORTON'S TEST).

I. DIMENSIONS OF THE MACHINE.

The standard machine shall be 28 inches in diameter and 20 inches in length, measured inside the rattling chamber.

Other machines may be used varying in diameter between 26 and 30 inches, and in length from 18 to 24 inches, but if this is done a record of it must be attached to official report. Long rattlers may be cut up into sections of suitable length by the insertion of an iron diaphgram at the proper point.

II. CONSTRUCTION OF THE MACHINE.

The barrel shall be supported on trunnions at either end; in no case shall a shaft pass through the rattling chamber. The cross section of the barrel shall be a regular polygon, having fourteen sides. The heads and staves shall be composed of gray cast iron, not chilled or case hardened. There shall be a space of one-fourth of an inch between the staves for the escape of dust and small pieces of waste. Other machines may be used having from twelve to sixteen staves, with openings from one-eighth to three-eighths of an inch between staves, but if this is done a record of it must be attached to the official report of the test.

III. COMPOSITION OF THE CHARGE.

All tests must be executed on charges composed of one kind of material at a time. No test shall be considered official where two or more different bricks or materials have been used to compose a charge.

IV. QUANTITY OF THE CHARGE.

The quantity of the charge shall be estimated by its bulk and not its weight. The bulk of the standard charge shall be equal to 15 per cent of the cubic contents of the rattling chamber, and the number of whole brick whose united volume comes nearest to this amount shall constitute a charge.

V. REVOLUTIONS OF THE CHARGE.

The number of revolutions for a standard test shall be 1,800 and the speed of rotation shall be 30 per minute. The belt power shall be sufficient to rotate the rattler at the same speed, whether charged or empty. Other speeds of rotation between 24 and 36 revolutions per minute may be used, but if this is done a record of it must be attached to the official report.

VI. CONDITION OF THE CHARGE.

The bricks composing a charge shall be dry and clean, and as nearly as possible in the condition in which they are drawn from the kiln.

VII. THE CALCULATION OF THE RESULTS.

The loss shall be calculated in per cents of the weight of the dry brick composing the charge, and no result shall be considered as official unless it is the average of two distinct and complete tests, made on separate charges of brick.

The abandonment of cast-iron shot as a feature of the rattler test was not in accord with the experience of others, and many engineers felt that it was a mistake. The results of tests made independently of the Paving Brick Commission pointed to this conclusion. The use of high grade brick only in the N. B. M. A. investigation of this new form of test was itself an element of weakness and a very bad feature as it proved to be.

Among experiments which threw some light on the discussion which came up about the efficacy of the new test were those conducted at the

University of Illinois from 1895 to 1899 under the direction of the writer to determine the best composition of the rattling material. The investigation showed that shot composed of small pieces gave an effect which was almost wholly abrasive and that the heavier cast-iron shot produced a spalling and breaking effect which was altogether too severe. It was felt that the rattler test should include the effect of both abrasion and impact, and a series of tests were made to determine what mixture of two sizes of shot would give the best combined effect of impact and abrasion, such as would approximate to the wear of brick in service in the street. The tests were conducted principally with a rattler 24-in. in diameter and 36-in. long. The small shot were 1x1½x2½-in. with rounded edges and weighed about 1 pound each. The large shot were 2½x3⅛x5¼-in. with edges rounded to ½-in. radius, and weighed about 8 pounds each. From the results of the experiments it was concluded that for the 24x36-in. rattler, 150 pounds of 8-pound shot and 150 pounds of 1-pound shot gave results with a satisfactory proportion of abrasion and impact. When a rattler 18-in. long was used, one-half of this charge was selected. The speed was about twenty revolutions per minute. Twelve brick were used in the full rattler and six in the half. The test was conducted for 1800 revolutions. These tests were reported to the Illinois Society of Engineers and Surveyors, and were described in an article on standard methods of tests of paving brick printed in The Technograph,* and reprinted in a number of technical journals. The tests brought out the facts that a combination of large and small shot give a test which will provide both impact and abrasive effects to any degree and that such a test will distinguish soft from hard brick to a fair degree.

The investigations by the writer also called attention to the fact that the test then adopted by the National Brick Manufacturers Association, using brick alone in the rattler, was defective in that it failed to distinguish in any marked degree between hard brick and soft brick. Objections were also made in various quarters. In some tests reported at that time, brick called by the maker as entirely too soft for paving purposes gave a smaller loss than the selected paving brick of the same manufacturer. In another test, three makes of brick of the same general quality made practically the same showing by other methods of testing, while by the National Brick Manufacturers Association, one brick lost less than two-thirds of that lost by either of the other two. It was also stated that in some instances the test gave as good standing to an inferior brick as to a superior paving brick. Soft brick soon broke in the rattler, and thereafter the loss was lighter, so that the final results were likely to be lower than would be expected from the apparent quality of the brick. In general, the test was not very efficient in measuring the toughness of brick. It seems that in the investigations conducted by Professor Orton the use of only one quality of brick, and that a high grade paver, did not permit the real deficiencies of the test to be discovered. The discussion of this test created wide-spread interest. Finally, as a result of a paper presented at the meeting of the Na-

*The Technograph No. 12, University of Illinois.

tional Brick Manufacturers Association in 1899, the association asked Professor Orton to make a further investigation of the subject.

The report of this second investigation, made by Professor Orton, as well as of the reports of tests made with the rattler designed by Gomer Jones, were submitted in January, 1900, to a committee consisting of Messrs. D. V. Purington, J. L. Hegley, H. A. Wheeler, Gomer Jones, Edward Orton, Jr., J. B. Johnson, and A. N. Talbot, which committee had been authorized to discuss these reports for the National Brick Manufacturers Association.   In the Jones rattler a few brick were clamped edgewise in pockets around the inside surface of a cylindrical rattler and 1½-in. cubes of cast-iron were used for the impact and abrading material. The report of Professor Orton's tests showed that the device of Mr. Jones embodied several objectionable features and the committee concluded that while the machine might appeal to the public as in a sense representing conditions of wear in the street and while the reports show that the machine is distinctly more sensitive in indicating the softer grades of brick, the variable amount of surface exposed on the brick and the discordant results coming from variations in sizes, as well as other defects of the machine, rendered it less satisfactory as a general matter of testing than the rattler already in use. The series of tests with the standard rattler reported by Professor Orton enabled a comparison to be made between the National Brick Manufacturers Association method in which brick alone were placed in the rattler and the method recommended by the writer which involved the use of cast-iron shot of two sizes. The investigation included the effect of variation in quality of brick, the effect of a change in the amount of shot, the effect of a variation in the proportion of small and large shot, the effect of the speed of the rattler and the effect of size of the brick themselves. The committee in their report advised the National Brick Manufacturers Association to abandon the old N. B. M. A. test and to adopt in its place the test with cast-iron shot of two sizes, definite proportions of small and large shot and of the total charge being adopted. This report was presented to the association in February, 1900, and the association changed its standard method of test to conform with the specifications recommended by the committee. It also accepted the recommendation that further tests and investigations be made.

The idea of clamping the brick in position seemed a promising one and soon after this the writer constructed a rattler in which the brick were securely held around the circumference of a cylinder, their inner faces thereby forming the surface of the cylinder. This machine will be described under the head of "Talbot-Jones Rattler Test." During the first months of 1901, Professor Orton experimented with this machine and reported the results of the tests together with the results of tests made with the standard rattler to a committee consisting of J. B. Johnson, W. K. Hatt, A. Marston, and A. N. Talbot, in August, 1901. This committee reported and recommended a continuance of the standard adopted in 1900, on the grounds that it is somewhat cheaper and simpler than the ordinary rattler in general use, and that the findings by the new N. B. M. A. standard tests are in accord with the results of other tests and with the results of the use of the paving

brick in actual service. The committee on Technical Investigation of the National Brick Manufacturers Association accepted this report and by virtue of the authority vested in them by the association reaffirmed the method of tests adopted in February, 1900, as the standard rattler test of the National Brick Manufacturers Association.

National Brick Manufacturers Standard Rattler Test.—The specifications for the present National Brick Manufacturers Association standard rattler test thus finally adopted are here given in full. It will be seen that they include requirements for the dimensions of the rattler chamber and the number of its sides, for the composition of the charge in the number of the paving brick or blocks and the amount of the cast-iron shot and the sizes and form of the shot to be used, for the speed of the rattler, for the number of revolutions for a test, for the condition of the brick, and for the method of calculation of the results.

AMENDED SPECIFICATIONS FOR THE RATTLER TEST.
PRESENT N. B. M. A. TEST.

1. *Dimensions of the Machine.*—The standard machine shall be 28 inches in diameter and 20 inches in length, measured inside the rattling chamber.

Other machines may be used, varying in diameter between 26 and 30 inches, and in length from 18 to 24 inches, but if this is done, a record of it must be attached to the official report. Long rattlers must be cut up into sections of suitable length by the insertion of an iron diaphgram at the proper point.

2. *Construction of the Machine.*—The barrel may be driven by trunnions at one or both ends, or by rollers underneath, but in no case shall a shaft pass through the rattler chamber. The cross section of the barrel shall be a regular polygon, having fourteen sides. The heads shall be composed of gray cast-iron, not chilled nor case-hardened. The staves shall preferably be composed of steel plates, as cast-iron peans and ultimately breaks under the wearing action on the inside. There shall be a space of one-fourth of an inch between the staves for the escape of the dust and small pieces of waste.

Other machines may be used having from twelve to sixteen staves, with openings from one-eighth to three-eighths of an inch between staves but if this is done a record of it must be attached to the official report of the test.

3. *Composition of the Charge.*—All tests must be executed on charges containing but one make of paving material at a time. The charge shall be composed of the brick to be tested and iron abrasive material. The brick charge shall consist of that number of whole bricks or blocks whose combined volume most nearly amounts to 1,000 cubic inches, or 8 per cent of the content of the rattling chamber. (Nine, ten, or eleven are the number required for the ordinary sizes on the market). The abrasive charge shall consist of 300 pounds of shot made of ordinary machinery cast-iron. This shot shall be of two sizes, as described below, and the shot charge shall be composed of one-fourth (75 lb.) of the larger size and three-fourths (225 lb.) of the smaller size.

4. *Size of the Shot.*—The larger size shall weigh about seven and one-half pounds and be about two and one-half inches square and four and one-half inches long, with slightly rounded edges. The smaller size shall be one and one-half inch cubes, weighing about seven-eighths of a pound each, with square corners and edges. The individual shot shall be replaced by new ones when they have lost one-tenth of their original weight.

The Talbot-Jones Rattler.

5. *Revolutions of the Charge.*—The number of revolutions of the Standard test shall be 1,800, and the speed of rotation shall not fall below 28 nor exceed 30 per minute. The belt power shall be sufficient to rotate the rattler at the same speed whether charged or empty.

6. *Condition of the Charge.*—The bricks composing a charge shall be thoroughly dried before making the test.

7. *The Calculation of the Results.*—The loss shall be calculated in percentages of the weight of the dry brick composing the charge, and no result shall be considered as official unless it is the average of two distinct and complete tests, made on separate charges of brick.

Talbot-Jones Rattler Test.—In the machine constructed by the writer in 1900 (shown in Plate 2) and named "The Talbot-Jones Rattler" by the committee of expert engineers, the head which forms one end of the rattling cylinder overhangs the frame of the machine. The ends of the brick are placed so as to abut on this head and are securely clamped by bolts so that their inner faces form the concave surface of the rattler cylinder. Spacers of wood of triangular or trapezoidal form are placed between the brick to keep them a fixed distance apart and to aid in holding the brick in place. An end, or second head of wood or of wire screen, is bolted on to close the cylinder. A sheet of metal is fastened to the head of the machine around the outside of the circle of brick and holds the brick in place during the process of inserting them and assists in taking the jar in making the test. In the original form this band was in a fixed position and since brick vary in thickness it was necessary to vary the spacing in order to divide up the space between the bricks throughout the entire circle. In the tests made by Professor Orton with this machine the brick were spaced one inch or more apart. This wide spacing and the variation found in filling the circle with bricks of different thickness seemed undesirable. The machine has now been modified so that the circle is adjustable and the spacing may be made uniform throughout the entire circumference. The average internal diameter of this chamber is 28 inches and the machine may be adjusted from $27\frac{1}{2}$-in. to $28\frac{1}{2}$-in. This permits a full ring to be made with an even spacing and any thickness of brick. It is recommended that the space between brick be made $\frac{1}{4}$-in. Other details of the machine are that the end of the band lacks about $\frac{1}{4}$ inch of being in contact with the head of the machine, this space being left for the escape of dust and chips; the heads of the bolts lie in a T-shaped groove in the head of the machine so that they are readily adjustable; the central portion of the head is recessed about $\frac{3}{4}$ inches so that the iron shot may strike the brick for their full length; the cover of the cylinder for the same reason is held away from the outer ends of the brick.

It will be seen that in this rattler the brick themselves form the outer surface of the rattling chamber and are laid at right angles to the direction of action of the shot, and that one face of the brick receives the wear about as it does in the street. The shot gives the abrading and grinding and impact effect. In many ways the test resembles the wear of brick in the street; it naturally appeals to the mind as resembling and approximating the wear in the street.

This method of testing is a promising one in many directions. The machine is a special one, but its cost is hardly more than the standard

rattler. Its use requires but little more skill. The time taken in charging the machine and in making the test is greater, so that the cost of a test by the Talbot-Jones process would be somewhat more than with the N. B. M. A. standard. If, however, it should be found to define the wearing qualities of a brick more definitely and with greater accuracy than does the ordinary rattler, these features would not interfere with its adoption. While considerable experimental work has been done with this machine, it is felt that the investigation has not proceeded far enough to standardize it nor to show its qualifications sufficiently to recommend it for adoption as a standard for testing purposes. The writer has been unable to carry on the necessary investigations, but he hopes that full tests may be made to determine its usefulness. All the tests which have been made are favorable to its efficiency and adaptability for general testing purposes. The uniformity of conditions for the tests and the opportunity to determine relative wear of individual brick are among the attractive features.

ABSORPTION TEST.

There has been a change of view in reference to the value, applicability, and purpose of the absorption test. In the early experience with brick pavement, soft and porous brick were used and the fear was expressed that the brick would crumble and disintegrate under the effect of a re-

Fig. 1. Rate of absorption of paving brick.

peated freezing and thawing, and an absorption test with an arbitrary limit was included in the specifications. This test was used without full information of the properties of the brick and frequently without good judgment. The experience of years and tests made by repeatedly freezing and thawing bricks have established the fact that the action of freezing and thawing is not likely to disintegrate brick of a high grade which will pass the requirements of other tests. This statement should not be interpreted to mean that the action of frost and traffic together will not cause disintegration of brick which, when dry and cold, would resist the wear of the traffic fairly well. The improper use of the ab-

sorption test resulted in an indiscriminate condemnation of it and also in a lack of appreciation of its value and usefulness as an auxiliary test and as a means for studying properties of the brick. The absorption test is a valuable adjunct for use in interpreting the results of the rattler and cross breaking tests and in studying the peculiarities of the particular make of brick which will be put into a pavement.

A good paving brick will absorb water quite slowly, the rate of absorption varying from hour to hour. Fig. 1 shows the rate of absorption through the period of some days, as given by Mr. F. F. Harrington. If the outside of the brick is more dense than the interior the rate of absorption is still slower. A broken brick or a rattled brick will absorb water more readily than whole brick for this reason, and such brick should be selected for the test. In some tests the brick have been partially submerged for some time to allow the escape of air. The absorption of water is more rapid in the beginning, is quite slow after 24 hours, and still slower after 48 hours. The absolute value of the absorption power is not required, and for comparative purposes the result at the end of 24 hours, or better, at the end of 48 hours, will be sufficient. Brick which absorb but a small part of their final amount are usually so dense that the total absorption would be very small and the variation in value for such brick will not affect comparisons. Since brick in their usual condition contain some moisture, the sample should be dried for several hours at a temperature at or above the boiling point of water. The method given below requires 48 hours, but this protracted period seems unnecessary for ordinary purposes.

The absorption test should be conducted under the following conditions: The test will be made on five brick which have been exposed to the action of the rattler, or if these are not available, on five brick which have been broken into halves. The brick shall be dried at a temperature of 200° to 300° F. for 24 hours and then after weighing shall be immersed in water for 48 hours. Before reweighing the brick, surplus water shall be wiped from its surface. The absorption shall be expressed in per cents of the dry weight of the brick.

The idea that low absorption is a guaranty of excellency of the wearing qualities of paving brick was held by engineers for many years. As brick are burned in the kiln the amount of their porosity becomes less and less until a point is reached when another change occurs and further burning will not decrease the porosity. The absorption test may determine or distinguish underburned brick, but overburned brick may not give a test much different from brick which have received the best degree of burning. The best limits for absorption will vary with the clay and method of manufacture and will have to be determined for every make of brick. This determination may be made by comparison with the results of other tests and by experience with the brick. In other words, no general limits can be placed for the absorption test, but special limits may be specified for particular makes of bricks used in any city. For a given brick, then, it may be said that the absorption test is able to distinguish underburned brick, and that it will be helpful in determining the length of burning permissible with a given grade and make of brick.

CRUSHING TEST.

Tests for crushing strength are open to the objection that the results obtained are extremely variable, especially as the method of making the test is not uniform. When the faces of the test cubes are ground accurately to plane surfaces, the results with high-grade paving brick are very high, running up to 20,000 pounds per square inch. The use of prepared test cubes makes an expensive and slow method of testing. Whole brick or half brick are tested on edge, sometimes with the bearing faces ground and in other cases not. If not ground, the faces may be bedded in plaster of Paris and crushed after the plaster has fully set, or the faces may be bedded in card-board or heavy paper. The last named method of testing is more readily made and if at least five specimens are tested the average may be expected to give representative results. In the tests described in this paper, half bricks were tested, several thicknesses of heavy building paper being used as bedding plates. Soft brick will give results as low as 1,000 pounds per square inch, when tested by this method. Occasionally a brick will run as high as 18,000 pounds per square inch. It may be expected that overburned or poor paving brick will stand a load up to 3,000 pounds per square inch. Good pavers will range between 6,000 and 12,000 pounds per square inch.

Crushing strength is a desirable property in a paving brick. The argument that such heavy loads as are indicated by crushing values will not come upon the brick and that the brick will not be crushed in the street is a negative one. There is a relation between crushing strength and hardness. The stronger the brick the better it will resist wear in the pavement. This quality of strength is particularly desirable where pavement is subject to heavy traffic. In comparing two bricks giving about the same rattler results, the one with high crushing strength will stand heavy traffic much better than the weaker one. For light traffic high crushing strength is not essential. It is further true that the crushing test throws light on other physical properties of a brick and is a source of evidence in the study of quality. Generally speaking, however, this test is not of a character to be included in specifications, but it is of value in connection with the study of the properties of different bricks. It will be seen, also, that the cross breaking test gives information which may permit it to take the place of the crushing test.

CROSS-BREAKING TEST.

The cross-breaking test is for the purpose of determining the general strength of the brick; incidentally it gives evidence of the toughness and the hardness of the brick. It indicates the ability to resist crossbreaking, twisting, or spalling by concentrated loads and is an index of the crushing strength of the brick.

Two objections to this test have at times been raised: (1) that the quality indicated by the test is not needed in a paving brick, and (2) that the results of the cross-breaking test are variable and even erratic. It is believed, however, that the test is helpful in judging of the quality and strength and toughness required of a good brick. It may be suffi-

Brick being tested for cross-breaking strength.

cient to specify only a medium value for the modulus of rupture, and . yet a brick with a fairly high value will be of higher grade. The brick which does not have the quality of high resistance to cross-breaking is likely to spall or break in the street and not to withstand traffic, even though the rattler test may show a low loss. Brick which have the toughness and strength which go with a good modulus of rupture may show a somewhat higher loss by the rattler and yet give better results in the street than other brick whose rattler losses are lower. It must be expected that there will be a variation in the results shown in tests of individual brick, for quality varies considerably in ordinary paving brick. The rattler tests of individual brick vary widely. Much of the variation which has been reported in the results of cross-breaking tests is due to the method of making the test commonly employed. It is believed by the writer that the method here given reduces the variation due to the method to a reasonable amount and that the variation now found represents quite closely the lack of uniformity in the brick. With the. test made in the manner here described cross-breaking tests, if properly judged, become a valuable adjunct in the determination of the qualities of a paving brick.

Brick should be tested as a beam on edge with a span of 6 inches and with the load applied at the middle of the span. The modulus of rupture is determined by the usual formula:

$$S = \frac{3}{2} \frac{Wl}{bd^2} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where W is the load applied, l is the span, b is the breadth of the brick, and d the depth.

Plate 3 gives a view of a brick being tested, and Fig. 32 shows details.

Fig. 2. Arrangement for testing cross-breaking strength of brick.

Attention is called to the use of steel bearing plates and to the use of the wooden block. The narrow soft steel plate gives a bedding on the brick which is slightly adjusting and overcomes the tendency to cutting. The knife edges are slightly curved in the direction of their length, to allow for irregularities or warping in the brick. The lower knife edges rest upon a wooden block which is curved laterally somewhat to allow a rocking movement. The main purpose of the wooden block, however, is to allow adjustment by its compression so that the load will be more evenly distributed and so that the work of applying the load and making the test will extend over a longer time. This arrangement allows a more accurate determination of the amount of the load and greater freedom in making the test. The results of the tests which are discussed later on, show that this method gives results well within the range of uniformity of the brick. Requirements for the cross-breaking test should specify that the brick be tested on edge, that the span be .6 inches, that the knife edges be slightly curved in the direction of their length, say with a radius of 20 inches, and that the test be made upon a wooden block similar to the one shown.

SPECIFIC GRAVITY.

The test for specific gravity gives general information but is not of service for general use. The specific gravity of a brick depends upon the material, the method of making, and the amount of burning. For certain clays and processes the specific gravity of a brick depends upon the amount of burning, up to a certain point, which varies with different clays. A dense, heavy brick has a high specific gravity. The range of specific gravity for shale paving brick is from 2.2 to 2.4. In making tests of specific gravity, the amount of water absorbed by the brick must be allowed for. The brick is weighed in air and then in water and again in air. Then specific gravity may be determined by the formula, $\dfrac{W}{W'-W''}$. where W is the weight of the dry brick, W^1 is the weight of the saturated brick in air, and W'' is the weight of the saturated brick in water.

DISCUSSION OF TESTS AND COMPARISON OF QUALITIES.

A comparison of the various tests may be made by studying the results of the extensive series of tests of brick of a wide range of character and quality made at the University of Illinois for the Department of Ceramics and State Geological Survey. These tests are more fully reported elsewhere. The brick were obtained from twenty-seven manufacturers in the states of Illinois, Ohio, Indiana, Missouri, and Kansas. From one to five grades of each make of brick were obtained. Duplicate rattler tests were made for each grade, and five or more brick were tested in cross-breaking and in crushing for each grade. The bricks used in the tests were generally selected and graded at the yards by a representative of the Ceramics Department, who was skilled

in selecting and grading brick. When more than one grade was ob-
tained, the first selection made was the best grade for paving pur-
poses, according to the judgment of the representative, care being
taken not to select too hard burned a brick. A grade harder or some-
what overburned and one softer or even underburned were selected.
When there seemed to be an opportunity for error in judgment, inter-
mediate grades slightly harder or softer than the first were also picked
out. The N. B. M. A. Standard rattler test was used, and the other
tests were made by the methods already described. Rattled brick were
used in the absorption tests.

The general results of these tests are plotted in Fig. 3. The three
makes of brick on which transverse and crushing tests were not made
are not included in this diagram. The average for the tests on a par-
ticular grade are shown. The brick were placed on the diagram gen-
erally in the order of the rattler loss, the grade which gave the lowest
rattler loss being used to fix the order of any make of brick. The
crushing strength is plotted in connection with the modulus of rupture,
(cross-breaking test), to enable a ready comparison between these two
tests to be made, the scale for the crushing strength being one-third
of the actual value. The figures given with the modulus of rupture
show the average variation of the modulus of rupture for the
individual brick in any grade from the mean of the test on that grade as
given in per cent of the mean value of the modulus of rupture. In
studying this diagram attention should be given to the amount of
variation in the absorption test for each make of brick, to the range in
the amount of absorption producing little change in the desirable qual-
ities in some brick and to the rapid change in quality for small changes
in absorption for others, and to the relation between the rattler test
and the other tests.

Attention is called to the following particulars shown on the diagrams.

Brick No. 2.—A range of absorption from ½% to 3% gives an excellent
quality of brick, as shown by the rattler tests, the cross bending test, and
the crushing test. Even with 6% absorption this brick gives a good rattler
test and a high crushing strength. It is apparent that there may be con-
siderable variety of burning with this brick and yet secure a good article,
providing, of course, that the heat treatment is otherwise suitable.

Brick No. 5.—In this make a change in the absorption amount is accom-
panied by a considerable change in the quality of the brick as shown by the
rattler test and the other tests. Much care must then be used in selecting
the right degree of burning.

Brick No. 7.—This is a fire clay brick and its strength can not well be com-
pared with the other brick. It seems probable that the smoothness of this
material gives it a higher rating in the rattler test than the brick should
have.

Brick No. 10.—In this brick the grading for hardness as made secured a
brick with but a small range in the absorption test, three grades varying less
than 1% in the absorption test. All of these were of very good quality.

Brick No. 12.—Absorption up to 5% has little effect upon the quality of the
brick, the cross-breaking strength being good for the grade having 5 per cent
absorption. The overburned brick is of poorer quality. The range in absorp-
tion from one to five per cent allows considerable latitude in the selection of
the brick.

Brick No. 15.—In this brick the amount of burning seems to affect the
quality very much and it is difficult to say just what range of absorption is

—5 G

allowable. 3½% absorption accompanies a fairly good brick, but variations on either side of this are very detrimental to the quality. The crushing and cross breaking tests for this brick are low. All of these conditions are indications of an undesirable brick for use as they would be delivered on the street.

Brick No. 14.—This brick has low cross breaking and high absorption. The samples tested do not indicate a first class brick.

Brick No. 16.—This brick permits a wide range of burning without much change in its quality.

The results of the absorption test show that there is generally little or no difference in the amount of water absorbed in overburned brick and

Note:—*Modulus of Rupture shown*; ☐ *Crushing Strength shown* △

The values given for Crushing Strength are to be multiplied by 3

Fig. 3—Results of Tests of Paving Brick.

well burned brick. This agrees, of course, with our knowledge of the change which takes place at vitrification. The amount of variation in absorption between brick of different degrees of harness (of the same make) which show practically the same good wearing quality by all the other tests is of interest. A favorable or wide range of absorption for the same wearing qualities must be considered advantageous to the manufacturer and also to the consumer, both by reason of the wider latitude allowed in burning and also upon the ease of inspection on the street. Other brick like No. 10 give a considerable difference in appearance with only a slight change in the qualities of the absorption test and without any marked change in the wearing qualities of the brick. The absorption test appears to be of value in studying a given make of brick or in learning of its properties and giving information bearing upon the inspection of the brick delivered on the street. For any given make of brick the specific range of absorption which will give a good article may be determined and required.

The results show that generally the rattler test made a fair determination of the quality of the brick, if we may judge by the appearance of the brick, the results of other tests, and the reputation of the brick. In some cases the rattler test gave a rank better than would be given by the character and appearance of the brick and by the results of the other tests. A few of the makes showed rather high rattler loss and gave a fairly good modulus of rupture and cross-breaking strength and uniformity, and some of these brick are reported to have given excellent service under light traffic. Brick 17, 18, 19, and 20 are in this class. The range of difference between that of a single test and the mean of the duplicate rattler tests averaged from about .5 to 1% for the better grades of brick, although in one case the variation was as high as 1.8% from the mean. The variations are smaller than is usual in the rattler test, and attest the care in selecting the brick. The value of the crushing strength was generally between three and four times the modulus of rupture. There was a fairly close agreement between these two tests. A high value in one test was accompanied by increased values in the other test. Generally speaking, it may be said that a value of 2,500 pounds per square inch for the modulus of rupture and 7,500 pounds per square inch for the crushing strength may be expected in first class paving brick. Lower values like 2,000 and 6,000 pounds respectively, are not especially objectionable. In the cross-breaking test the variation in the values for individual bricks is of interest and in some respects this variation may be considered a measure of the uniformity of the brick. As already stated, the numbers given with the cross-breaking test in Fig. 33 show the average range of variation in the modulus of rupture for individual brick from the average modulus for the given grade expressed in per cent of the mean modulus of rupture. In other words, a range of 10 per cent means that if the difference between the modulus of rupture for each individual brick and the average modulus for that grade be expressed in per cents of this average modulus, the average of the results for the given grade of brick will be 10 per cent. It will be noted that

for the better grades of brick this range is within 12 per cent. Attention is called to the much greater variation in bricks No. 13, 15, 16 and 17. Since uniformity of quality in a lot of brick is of considerable importance a test of this kind may be used to rate different makes of brick on the score of uniformity.

It should be understood that the brick tested were much more nearly uniform in quality than would be obtained in taking brick at random from piles along the street, since the selection was made with a view to securing uniformity. The variation between duplicate rattler tests is therefore smaller than may be expected in tests of brick from the street, and the uniformity in the modulus is also greater. There was greater freedom from the accidental variations which frequently affect the rattler test. Although the rattler test was fairly discriminating in determining quality, the results must not be taken to indicate that the rattler test may be used to settle the exact order of various makes of brick with respect to wearing quality; it should rather be considered a means of determining whether a brick is up to a required standard. The objection sometimes made that the rattler test does not easily permit determination of variation in individual bricks was not considered in the investigation, since so careful a selection of brick was made. The information given in the cross-breaking and absorption tests is valuable, and the usefulness of these tests is shown, particularly in connection with the study of the qualities of different grades of the same make of brick.

The effect of size of the brick upon the loss found in the rattler was not included in these tests. It is established that the brick size will sustain a greater loss than the block size of the same grade and quality. This excess is due to the greater relative exposure of the corners which chip off more or less, and to the greater proportional wearing surface exposed in the brick size. The amount of this difference depends upon various conditions, but with good material the brick size may be expected to lose, say, 3 per cent more than the block size. Of course, only a part of this difference would show up in the wear of pavements constructed with brick of the two sizes. The effect of accidental differences, or of variations in the quality of the shot, or of the smoothness or other conditions of the rattler was not studied, and will not be discussed here.

A study of Table II shows that the best grade of brick received in the first 450 revolutions of the rattler test from 47 to 53 per cent of the total loss and that the poorer grades lost during this stage a smaller percentage of their total loss, as little as 30 per cent in some cases. Similarly at 900 revolutions, the better grades had received 67 to 77 per cent of their total loss, while the poorer grades had received a smaller proportion of their total loss. It seems that the better grades wear more slowly, comparatively, after the corners are rounded off; and the poorer grades continue to grind off or break up during the latter part of the test.

This extensive series of tests gives data on a wide range of brick and enables comparison to be made of a wide variety of conditions. It is valuable for making a study of the properties of paving brick, as well as for making a comparison of the various tests and requirements for paving brick. It will be seen from Fig. 3 that the best grades of brick in the first ten makes of brick, as shown by the samples tested, are of excellent quality and will make a durable and satisfactory pavement. The remaining makes are less valuable as paving material, and besides many of these may not be judged from their general characteristics since they vary widely with slight changes in general appearance. The rattler test is a fairly satisfactory test for a particular make of brick in picking out the best degree of burning, etc., but in determining the ranking of several makes of brick it should be supplemented with the transverse and crushing tests. The absorption test is of value in studying the characteristics of a given make of brick and in judging of the effect of changes in the amount of burning.

Reference may well be made to the information which a careful observer will obtain in such a series of tests by means of the ocular examination of the structure and appearance of the brick. It suggests the desirability of a study by inspection of the structure and behavior of the brick in connection with the tests made on the brick to be used.

Requirements for Paving Brick.

The rigidity of the requirements to be inserted in specifications or to be taken as standard in selecting paving brick for a street will depend upon the conditions under which the brick are to be used. The amount of traffic and the methods and details of construction used in the construction of the pavement, including such matters as the kind of filler used and the character of the foundation, will naturally have a bearing upon the requirements. A brick may be used on a street where there will be little traffic if it has sufficient weather-resisting qualities when it should be rejected for use with heavy traffic. A large amount of light traffic produces less wear than a much smaller amount of heavy traffic. In a pavement made with a high-grade cement filler the brick will be protected and the effect of spalling and impact may be much less than in a pavement with a sand filler. In a similar way the character of the foundation has to do with the grade of the brick to be chosen. For the purposes of this article it will be sufficient to divide traffic into four classes: (1) Very heavy traffic; (2) Heavy traffic; (3) Medium traffic; and (4) Light traffic. Very heavy traffic would be such as would occur in the business district of our large cities and in certain districts of smaller cities. Heavy traffic would include that found in the business districts of smaller cities. Medium traffic would be such as is found on the streets used as main thoroughfares in the smaller cities. Light traffic is such as is found in the remotest residence portions of the small cities, or streets not frequented. For very heavy traffic it is evident that only the very best brick should be used and that a heavy

foundation and a high-grade filler to protect the brick should be used. For the other classes of traffic the requirements may be less rigid except that a high degree of uniformity in the brick should be maintained.

The following limiting values for the requirements for brick for the several classes of traffic are suggested. They are given for the usual block size of brick. The maximum loss by the N. B. M. A. standard rattler test: (1) Very heavy traffic, 15 per cent; (2) Heavy traffic, 17 per cent; (3) Medium traffic, 21 per cent; (4) Light traffic, 24 per cent. For the brick size, 3 or 4 per cent may be added to the above limits, except that the brick size would not be used for very heavy traffic. No values are suggested for the Talbot-Jones rattler since the standardization of this machine is not yet complete. For the cross-breaking test the limits for the modulus of rupture may be made as follows: (1) Very heavy traffic, 3,000 pounds per square inch; (2) Heavy traffic, 2,500 pounds per square inch; (3) Medium traffic, 2,000 pounds per square inch; (4) Light traffic, 1,500 pounds per square inch. It should be noted that these values are subject to modifications, according to requirements of traffic and conditions of the brick, and are not to be taken as iron-clad limits. They are intended to apply to average samples of brick taken from piles along the street. The requirements for uniformity and the methods of determining this uniformity from a separate consideration. The limiting variation from the specified value for the modulus of rupture may be made a requirement. It is frequently possible to select from the piles of brick of varying degrees of quality and make tests of these. In case that one of these grades representing a certain percentage of the brick on a portion of the street, say, 5 or 10 per cent, falls below the requirements, they should be rejected. The matter of the selecting of these samples will be discussd under "Inspection."

Inspection of Paving Brick.

In taking up the subject of inspection of paving brick it must be admitted that inspection is generally an unsatisfactory topic to both contractor and municipality. Inspection is a difficult task requiring skilled judgment, expert knowledge, intelligent action, and ability of no mean order, as well as the qualities of tact, balance and horse sense. Men having these qualities and available for this purpose are rare. It is not so much that the politician desires to appoint a favored citizen or that the residents on a street feel that one of their number will best serve their interests. The municipal administrative officer will usually gladly waive these considerations if an inspector of the ideal type can be found. But the work for an inspector is spasmodic, and the season is short. and his importance in the constructive world is not yet so well established that he receives a high salary; we must expect ideal inspectors to be rare. However, the first requisite of paving brick inspection is a level-headed and wide-awake inspector, and it is to the interest of all concerned that this class of men be developed.

Inspection involves a study of the brick put on the street. An inspector whose work came under my observation selected types of brick which he found—what he thought to be soft or hard or brown or brittle or red or black or what not—and made a lot of rattler tests and absorption tests to determine the relative place of these various types and to aid his judgment in the inspection. This is a step in the right direction. It illustrates what was meant by saying that tests and requirements should be useful in educating inspector and citizen and contractor.

.The difficulties of inspection are increased by the way material is loaded on cars and piled on the streets. Good and poor are mixed together indiscriminately, even when the change of quality is apparent as the wagon is loaded. Lack of uniformity is the bane of paving brick. May not the manufacturer remedy this in part at least, and place the mediocre brick on streets which want cheap brick and selected brick on streets which are willing to pay for a serviceable article?

Evidently the inspection of paving brick and the selection of the test brick form an important matter, and upon this depends, to a large extent, the quality of the brick used in the pavement. As it is an utter impossibility to test any considerable part of the brick, great care must be taken to select representative samples and samples which will show the variation of the materials To make severe requirements for the results of tests is only a part of the problem; the inspection must be efficient and thorough and wise in order that the results may be fair to both producer and consumer.

It is obvious, then, that in addition to the making of standard tests the work of supervision of the pavement must include a fair and definite method of securing sample brick, a fair and general method for standards of rejection, and a way of throwing out imperfect brick during the time of laying the pavement and before the filler is applied. The work of inspection, then, may be divided into the following: (1) A general inspection; (2) Rough culling of imperfect and inferior brick in pile and barrow; (3) A culling of inferior brick as they are about to be laid and immediately after they are laid. In the general inspection different car loads or loads of the same quality should be considered together. Samples representing as near as may be the average of the brick of a given lot should be made by a man skilled in such work. If any considerable number of a poorer grade are to be found in any lot, representative samples of these should be selected and tests made upon the selected brick. If the results of the tests of the average samples are not up to the requirements the whole lot of brick should be rejected. If the results of the poorer grade are also not up to the requirements and this grade constitutes such a part of the whole lot that they are not likely to be culled carefully during laying, the lot should be rejected with the provision that they be culled and then reinspected. In case the poorer brick in a pile show great inferiority by their appearance it may be sufficient to permit workmen to cull the brick as they are loaded into barrows, but this arrangement is not usually very

satisfactory. The culling of brick as they are laid in the street should be permitted only for such brick as show by their size, color, shape, or surface defects that they are inferior brick and there should be few enough of this class to enable satisfactory results to be obtained. With some makes of brick color or other appearance furnishes evidence of defect or of inferior grade, but in other makes little can be told by these methods and the quality can be established only by physical tests.

Some time ago the writer made the suggestion that a desirable solution of the inspection problem would be to have the brick inspected at the yards much as steel is inspected at the mills. This could be done by bureaus of inspection which would employ expert inspectors, as is done in the case of steel inspection, and this service would be paid for by the thousand of bricks inspected, or yard of pavement to be put down, instead of at a dollar and a half a day. The Bureau of Inspection would be given the requirements specified for the brick in the ordinance and the contract, and would certify to the quality of the brick. This inspection would not entirely relieve inspection on the street and in the pavement, for chipped, broken, and otherwise defective brick would still show up, but it would insure a better grade of brick and would make rejection of a poor lot of brick less objectionable to the producer, and if properly carried out would, in my opinion, result in great gain for both the manufacturer and the municipality.

Altogether, inspection covers a multitude of details, involves everlasting vigilance, and entails patience and even temper, and the city which can get good inspection is indeed fortunate. A reputation for severe inspection is said to cause an undue increase in the bids for work, but this charge must not be accepted without consideration. Five cents a yard extra is only the cost of a year's life of a pavement on a residence street or six months on a business street, and who will not say that the difference in quality of brick may not make five or ten years, or even more, difference in the life of the pavement? Surely, adequate and judicious inspection pays for itself many times over.

In this article the writer has not attempted to go into some of the details of testing and inspection; he has discussed principles governing the selection of the brick. Many questions arise between the producer and the consumer, and these may not always be decided according to numerical values of tests. It seems probable that brick will continue to be the principal material for street pavement in inland cities of Illinois, and the quality of the pavements may be improved if manufacturers and municipalities agree on definite and trustworthy requirements and tests and there is adequate and judicious inspection. An improvement in quality and uniformity will be advantageous to producer and consumer.

TESTS OF PAVING BRICKS.

GENERAL STATEMENT.

The tests herein reported were made on paving brick from twenty-four paving brick factories in Illinois, Indiana, Ohio, Missouri and Kansas. The samples of each make and grade were selected by representatives of the State Geological Survey at the yards of the factory. An effort was made to secure representative samples. The collectors were familiar with paving brick and their properties and exercised care in the selection, and it is believed that the brick obtained are fairly representative of the product of the various factories at the time the selection was made. In many cases samples of two to five grades of brick, varying from the softer grade to very hard burned, were obtained. The letter at the beginning of the mark or designation of the various samples is the initial of the collector who selected the brick, and the letter at the end refers to the grade of burning of the brick, *a* being the softest burned lot. In some cases the *a* grade was considerably under-burned and in others it represented the best grade.

The brick were held before making the tests, and the samples which were collected early in the spring were left for some time in their original packages in the open air and were subjected to dampness from the spring rains. However, before the tests were made, the brick were stacked openly under a tent and left for some time through hot dry weather so that each brick had ample opportunity to become dried throughout. The bricks which arrived last came direct from the kilns to the tent during dry weather without having become damp and were tested first. In this way the earlier brick were given from three to five weeks in which to dry. As the tent was open at the ends so that good circulation of air prevailed, the bricks had the opportunity to be thoroughly dried. While no tests were made on the amount of moisture contained, it is thought that all the bricks were as dry as they could be under the average humidity conditions of summer weather and without being dried in an oven. It is certain that the amount of moisture in the brick was as low as is required by the provisions of the N. B. M. A. specifications for the rattler test.

The rattler test of the brick was made in the Road Laboratory of the Civil Engineering Department of the University of Illinois. The standard N. B. M. A. rattler of the Road Laboratory was used. The number of bricks and blocks agreed closely with the standard specifica-

tions, although the relative cubical content of the rattler and the charge was not calculated for each lot, but the charge was varied with the judgment of the operator. At least 9 and not more than 10 blocks were considered a charge, and at least 10 and not more than 12 of the brick size. The results of the rattler test are given in Table I. The brick were weighed at the end of 450, 900, 1,350 and 1,800 revolutions and the corresponding losses are given in the tables. Table II shows the proportions of the final or total loss at the end of each of these periods given in per cent of the final loss, and Table III shows the percentage of the total loss for each of the four stages.

The rattler tests were made under the direction of Mr. R. C. Purdy. Acknowledgment is made to Professor I. O. Baker of the Civil Engineering Department of the University of Illinois for the facilities afforded in making the rattler tests.

After the brick were rattled, five of each set, two from one chamber and three from the other chamber, were taken to the Laboratory of Applied Mechanics and the amount of absorption determined. The brick were not dried further, but the conditions were such that the amount of moisture present would have little effect upon the determinations reported.

From the remainder of the brick not rattled, as many as could be spared up to ten of each kind were taken to the Laboratory of Applied Mechanics of the University of Illinois, and the transverse or cross-breaking test made upon them. The method of making this test is fully explained in the paper by Professor Talbot on the Quality of a High Grade Paving Brick and the Tests used in Determining Them. Crushing tests were made on half-brick placed flat-wise as described in the paper just referred to. The results for the absorption, transverse, and crushing tests, as furnished by Professor Talbot, are given in the tables. The average values for absorption, cross-breaking, and crushing are given in Table IV, and the detailed results follow in Table V. Transverse and crushing tests were not made on the Purington, Edwardsville and Streator Paving Brick Co. brick.

The absorption and transverse tests were made by Mr. C. H. Pierce, Instructor in Theoretical and Applied Mechanics, and the crushing tests by Mr. H. L. Whittemore, Associate in Applied Mechanics, and this work was under the direct supervision of Professor A. N. Talbot.

The general selection of the brick at the yards and the arrangements therefor were made by the State Geological Survey. Mr. R. C. Purdy, of the Department of Ceramics of the University of Illinois, had general supervision of the arrangements for testing.

TABLE I.

N. B. M. A. RATTLER TEST.

MARK, NAME OF BRICK.	GRADE OF BRICK.	AVERAGE TOTAL % LOSS OF TWO CHARGES AT END OF				Size of Brick in cm.
		450 Rev.	900 Rev.	1350 Rev.	1800 Rev.	
K3b Albion, Ill	Soft	18.5	29.5	38.4	46.2	22.5x10.5x8
K3c Albion, Ill	Alley	11.3	17.5	21.2	24.6	21x9.5x8
K3d Albion, Ill	No. 1 paver	12.7	19.0	22.5	24.9	21x9.5x8
K3e Albion, Ill	Overburned	11.1	18.6	24.1	26.4	21x9.5x8
K1b Alton, Ill	Soft burned	17.4	28.6	40.0	46.1	22x10x7
K1c Alton, Ill	Alleys	13.3	21.5	28.2	33.9	21.5x9.5x7
K1d Alton, Ill	No. 1 paver	8.4	11.5	14.1	15.8	21.5x9.5x7
K1e Alton, Ill	Overburned	9.4	16.2	21.8	27.0	....
B-IIa Atchison, Kan	No. 1 paver	.....	.....	.....	28.0	20x9.5x6.7
B-IIb Atchison, Kan	.do	13.6	19.5	23.9	27.9	....
K15b Bar Clay Co., Streator, Ill	Soft	14.5	20.9	25.4	29.5	21x9.5x8.5
K15c Bar Clay Co., Streator, Ill	Alley	10.2	15.4	19.0	21.8	....
K15d Bar Clay Co., Streator, Ill	No. 1 paver	10.3	13.9	16.7	18.4	....
K15e Bar Clay Co., Streator, Ill	Overburned	9.1	14.5	18.7	22.0	21x10x8
K11b Brazil, Ind	Soft	28.9	45.1	56.8	67.1	24x11x8.5
K11c Brazil, Ind	Alley	13.6	20.1	25.3	29.8	23x10x8
K11d Brazil, Ind	No 1 paver	13.5	20.1	24.5	28.1	22.5x10x8
K11e Brazil, Ind	Overburned	14.5	23.5	30.8	36.7	23.5x10.5x8
I-IIb Caney, Kan		9.7	17.3	22.0	25.7	22.5x10.5x6.5
K13b Clinton, Ind	Soft	16.1	26.0	33.6	41.6	24.5x11x9
K13c Clinton, Ind	Alley	14.5	22.7	29.0	34.7	23.5x10.5x8.8
K13d Clinton, Ind	No. 1 paver	12.9	19.6	26.2	31.5	23.5x10.5x8.5
K13e Clinton, Ind	Overburned	14.4	21 6	27.5	31.6	23.5x10.5x8.5
G-IIa Coffeyville, Kan	Brick	.....	.....	.....	13.7	21x10x5.5
G-IIb Coffeyville, Kan		5.6	8.5	10.9	12.8	....
G-IIc Coffeyville, Kan	No. 1 block	.....	.....	.....	15.0	21x10x8
F-Ib Danville Brick Co	Soft	19.3	29.3	38.9	46.7	22.5x11x8.5
F-Ic Danville Brick Co	Alley	12.7	19.8	25.1	30.2	22x10x8
F-Id Danville Brick Co	No. 1 paver	9.1	13.9	17.6	20.8	21x10x8
F1e Danville Brick Co	Overburned	9.8	17.2	23.3	28.4	22x10x8.5
K5b Edwardsville, Ill	Soft	17.8	28.7	37.0	44.9	21.8x11.3x7.3
K5c Edwardsville, Ill	Alley	12.6	19.5	24.3	28.7	21.2x10.4x7.0
K5d Edwardsville, Ill	No. 1 paver	7.8	12.5	16.3	19.4	....
K5e Edwardsville, Ill	Overburned	8.2	12.2	15.2	18.1	20.6x10.4x7.0
S2b Kansas City, Mo., Diamond	No. 1 paver	14.8	20.9	24.9	27.9	20.5x9.5x6.5
L-IIb Lawrence, Kan	.do	10 4	15.2	18.8	22.9	....
L-IIc Lawrence, Kan	No. 2 paver	8.7	11.0	16.0	18.6	20x9.5x6.5
K9b Poston B, Crawfordsville, Ind.	Soft	14.3	23.6	31.9	39.5	23x10x9
K9c Poston B, Crawfordsville, Ind.	Alley	8.9	14.3	18.0	21.7	23x10x9
K9d Poston B, Crawfordsville, Ind.	No. 1 paver	6.4	9.7	12 4	14.8	22.5x10x9
K9e Poston B, Crawfordsville, Ind.	Overburned	6.1	9.3	11.8	13.7	22.5x9.5x9
J-II Pittsburg, Kan	No. 1 paver	8 4	12.3	15.1	17.1	20.5x9.75x6.5
K6b Purington block, Galesburg, Ill	Soft	7.8	13.4	18.2	22 8	21.5x10.2x8.9
K6c Purington block, Galesburg, Ill	Alley	7.5	11.7	15.4	18.3	21.5x10 2x8.9
K6d Purington block, Galesburg, Ill	No. 1 paver	5.8	9.1	11.6	13.3	20.9x10.2x8.9
K6e Purington block, Galesburg, Ill	Overburned	8.4	12.9	16.5	20.3	20.9x10.2x8.9
K6b2 Purington block, Galesburg, Ill		14.7	23.7	31.7	38.6	21.5x10.2x8.9
K6c2 Purington block, Galesburg, Ill		9.9	16.6	21.9	26.6	21.5x10.2x9.5
K4a Springfield, Ill	No. 1 paver	.....	.....	.....	19.8	....
K4b Springfield, Ill	Soft	19.7	30.6	38.2	45.2	22x10.5x7
K4c Springfield, Ill	Alley	9.2	14.5	17.0	19.9	21x9.5x6.7
K4d Springfield, Ill	No. 1 paver	9.9	14.2	16.9	19.1	21x10x6.5
K4e Springfield, Ill	Over-burned	14.8	18.9	......		21x10x6.5
K2a St. Louis, Mo., hydraulic	No. 1 paver	.....	.....	.....	17.5	21x10x7
K2b St. Louis, Mo., hydraulic		7 9	12.2	14.2	15.9	....
V8c Streator Paving Brick Co	Soft	14.7	20.1	25 2	29 0	20.9x10.2x5.7
V8d Streator Paving Brick Co	Alley	10.7	16.8	21.6	24.3	20.3x10.2x5.7
V8e Streator Paving Brick Co	No. 1 paver	10.6	15.5	18.4	21.9	20.3x10.2x5 7
K10b Terre Haute, Ind	Soft	23.1	32.8	40.8	46.5	22x10x8.5
K10c Terre Haute, Ind	Alley	19.9	28.2	32.9	35.7	21.5x10x8

TABLE I—*Concluded.*

MARK, NAME OF BRICK.	GRADE OF BRICK.	AVERAGE TOTAL % LOSS OF TWO CHARGES AT END OF				Size of Brick in cm.
		450 Rev.	900 Rev.	1350 Rev.	1800 Rev.	
K10d Terre Haute, Ind	No. 1 paver	22.6	29.8	35.3	39.4	21.5x10x8
K10e Terre Haute, Ind	Over-burned	19.0	26.7	32.0	36.1	22x10x8 5
H-IIa Topeka, Kan		......	......	......	33.0	21x9.5x6.5
H-IIb Topeka, Kan		14.1	20.5	26.0	29.6	....
K8b Wabash Clay Co., Veedersburg, Indiana	Soft	26.5	32.7	45.6	53.5	23.5x10x9
K8c Wabash Clay Co., Veedersburg, Indiana	Alley	11.3	17.6	24.2	28.1	23.5x10x9
K8d Wabash Clay Co., Veedersburg Indiana	No. 1 paver	10.2	15.0	18.5	20.2	22.5x9.75x8.5
K8e Wabash Clay Co., Veedersburg Indiana	Over-burned	12.5	18.7	......	......	23x10x9
K14b Western Brick Co., Danville, Ill	No. 1 paver	8.4	13.4	17.3	20.8	23x10x8.5
K14a Western Brick Co., Danville, Ill	..do	......	......	......	21.2	....

MARK, NAME OF BRICK.	GRADE OF BRICK.		600 Rev.	1200 Rev.	1800 Rev.	Size of Brick in cm.
R3a Imperial, Canton, O	No. 1 paver		......	......	14.2	22x10x9
R3b Imperial, Canton, O	..do		8.7	12.2	14.8	....
S1b Moberly, Mo			13.9	20.9	26.3	20x9x8.5
R1a Nelsonville, O	No. 1 paver		......	......	16.9	23.3x10x8.2
R1b Nelsonville, O	..do		9.0	13.9	18.2	....
R2a Portsmouth, O	..do		......	......	17.8	22.75x9.9x8
R2b Portsmouth, O	..do		9.8	14.8	18.6	....
R4a Royal, Canton, O	..do		......	......	15.3	21.8x10x9
R4b Royal, Canton, O	..do		10.3	10.7	16.7	....

TABLE II.

Proportional Rattler Loss.

	450 Rev.	900 Rev.	1350 Rev.	1800 Rev.
K3b....................................	40.1	63.9	63.0	100 00
K3c	46.0	70.9	86.3	100.00
K3d....................................	51.0	76.4	90.4	100.00
K3e....................................	41.9	70.3	87.5	100.00
K1b....	37.7	62.0	82.4	100.00
K1c....................................	39.2	63.3	83.2	100 00
K1d....................................	53.3	72.7	89.0	100.00
K1e............	34.9	59.8	80.7	100.00
B11b...................................	48.8	69.7	85.5	100.00
K15b................................ ...	49.2	70.9	8 5.3	100.00
K15c	47.0	71.8	87.2	100.00
K15d...................................	56.1	75.5	90.7	100.00
K15e...................................	41.2	66.0	84.9	100.00
K11b...................................	43.1	67 2	84.6	100.00
K11c...................................	45.7	67.5	84.8	103.00
K11d.............	48.0	71.4	87.0	100 00
K11e...................................	39.5	64.2	84.0	100.00
I11b.......................	37.1	67.4	85.6	100.00
K13b...................................	38.8	62.2	80.6	100.00
K13c	41.7	65.3	83.4	100.00
K13d...................................	40.8	62.1	83.2	100.00
K13e...................................	45.6	68.4	87.3	100.00
G11b...................................	44.0	66.6	85.3	100.00
F1b....................................	41.4	62.8	83.3	100.00
F1c....................................	42.1	65.7	83.2	100.00
F1d....................................	43.8	66.6	84.6	100 00
F1e....................................	34.4	60.7	82.2	100.00
S2b....................................	52.9	74.7	89.1	100.00
L11b...................................	45.4	66.5	82.0	100.00
L11c...................................	46.9	58.9	85.9	100.00
K9b....................................	36.0	59.7	80.8	100.00
K9c	42.0	67.4	85.0	100.00
K9d....................................	43.3	65.4	83.4	100.00
K9e....................................	44.3	67.7	85.5	100.00
J11b	49.2	71.5	83.1	100.00
K4a	....	....	....	....
K4b....................................	43.7	67.8	84.6	100.00
K4c	46.2	72.6	85.3	100.00
K4d....................................	51.8	74.2	88.3	100 00
K4e....................................	....	....	....	....
K2a	....	....	....	....
K2b....................................	50.0	76.8	89.8	100.00
K10b...................................	49.6	70.4	87.7	100.00
K10c	55.6	78.9	92.1	100.00
K10d...................................	57.3	75.7	89.6	100.00
K10e	52.7	74.1	88.9	100.00
H11b	47.7	69.3	87.8	100.00
K8b....................................	49.5	61.1	85.2	100.00
K8c	40.3	62.7	86.2	100.00
K8d....................................	50.3	74.1	91.2	100.00
K14b...................................	40.2	64.2	83.2	100.00
		600 Rev.	1200 Rev.	1800 Rev.
R3b	....	59.0	82.6	100.00
S1b....................................	....	53.1	79.4	100.00
R1b	....	49.5	76.6	100.00
R2b	....	52.4	79.4	100.00
R4b	....	61.6	82.2	100.00

TABLE III.

	0–450 Rev.	450-900 Rev.	900-1350 Rev.	1350-1800 Rev.
K3b	40.2	23.8	19.1	17.0
K3c	46.1	24.8	15.4	13.7
K3d	51.0	25.4	14.9	9.7
K3e	41.9	28.4	17.2	12.5
K1b	37.7	24.3	20.4	17.6
K1c	39.2	24.1	19.9	16.8
K1d	53.3	19.4	16.3	11.0
B11b	48.8	20.9	15.8	14.5
K15b	49.2	21.7	15.4	18.7
K15c	47.0	23.8	16.5	12.8
K15d	56.1	19.5	15.1	9.3
K15e	41.2	24.8	18.8	15.1
K11b	43.1	24.1	17.4	15.4
K11c	45.7	21.8	17.3	15.2
K11d	47.9	23.4	15.7	12.9
K11e	39.5	24.7	19.8	16.0
I11b	38.0	29.4	18.3	14.4
K13b	38.8	23.5	18.4	19.4
K13c	41.7	23.6	18.1	16.6
K13d	40.8	21.3	21.1	16.8
K13e	45.6	23.8	18.9	12.7
G11b	44.0	22.6	18.7	14.7
F1b	41.4	21.4	20.5	16.7
F1c	42.1	23.6	17.5	16.8
F1d	43.8	22.8	18.0	15.4
F1e	34.4	26.3	21.6	17.7
S2b	52.9	21.8	14.4	10.9
L11b	45.4	21.1	15.5	18.0
L11c	46.9	12.1	27.0	14.1
K9b	36.0	23.7	21.1	19.2
K9c	42.0	25.4	17.6	15.0
K9d	43.3	22.2	18.0	16.6
K9e	44.3	23.4	17.8	14.5
J11b	49.2	22.3	16.7	11.9
K4b	43.6	24.2	16.8	15.4
K4c	46.2	26.3	12.7	14.8
K4d	51.4	22.4	14.0	11.7
K2b	50.0	26.8	13.0	10.2
K10b	49.6	20.8	17.3	12.3
K10c	55.7	23.3	13.2	7.9
K10d	57.3	18.4	13.9	10.4
K10e	52.8	21.5	14.7	11.1
H11b	47.7	21.5	18.5	12.2
K8d	49.5	11.6	24.2	14.8
K8c	40.3	22.4	22.5	13.8
K8b	50.3	23.8	17.2	3.8
K14b	40.2	24.1	19.0	16.8

	0-600 Rev.	600-1200 Rev.	1200-1800 Rev.
R3b	59.1	23.5	17.4
S1b	54.1	26.3	20.6
R1b	49.5	27.1	23.4
R2b	52.4	27.0	20.6
R4b	61.6	20.7	17.8

TABLE IV·

ABSTRACT OF REPORT OF TESTS OF PAVING BRICK.

NAME OF BRICK.	Lab. No.	Per Cent Abs. Water.	Modulus of Rupture.	Crushing Strength
"Albion," Albion, Ill..	K3b	10.0	995	....
	K3c	3.5	2100	4500
	K3d	1.05	2350	4800
	K3e	0.7	2700	3200
"Alton," Alton, Ill..	K1b	11.2	....	....
	K1c	6.1	1630	4000
	K1d	0.9	2535	8400
	K1e	1.2	1420	....
Atchison, Kans..	B2	....	1800	....
"Barr Clay Co.," Streator, Ill	K15b	7.67	1776	7800
	K15c	1.0	2365	11200
	K15d	0.83	2600	11700
	K15e	0.8	2870	8500
"Caney Brick Co ," Caney, Kans.......................	I2	3.416	1970	....
"Caney Vitrified Brick Co.," Topeka, Kans	H2	1.27	2300	....
"Clinton," Clinton, Ind....................................	K13b	9.3	1240	2700
	K13c	6.9	1280	....
	K13d	1.7	1620	6000
	K13e	1.1	1500	5600
"The Coffeyville Brick and Tile Co"....................	....	....	....	....
"Coffeyville Brick"...	G2	0.8	2320	6500
"Coffeyville Block"...	G2	0.83	1900	....
"Danville," Danville, Ill...................................	F1b	13.2	....	....
	F1c	4.8	1700	5200
	F1d	2.8	980	3400
	F1e	1.7	1670	6100
"Diamond," Kansas City, Mo	S2b	0.72	2410	....
"Hydrulic," St. Louis, Mo................................	K2a	....	....	....
	K2b	0.6	2430	8300
"Indiana Block," Brazil, Ind.............................	K11b	13.1	685	....
	K11c	2.9	1510	....
	K11d	1.89	2260	....
	K11e	2.7	870	....
Lawrence, Kans..	L2b	8.6	1770	....
	L2c	0.94	1960	10000
"Metropolitan Block," Canton, Ohio....................	R4a	....	....	....
	R4b	1.05	3130	7600
"Metropolitan Block" (Imperial), Canton, O...........	R3a	....	....	....
	R3b	1.27	2800	7200
"Missouri," Moberly, Mo.................................	S1b	3.313	2130	....
"Nelsonville," Nelsonville, Ohio	R1a	....	....	....
	R1b	1.68	1790	3800
"Peebles Block," Portsmouth, Ohio.....................	R2a	....	....	....
	R2b	2.211	2505	....
Pittsburg, Kans	J2	2.313	2220	....
"Poston Block," Crawfordsville, Ind...................	K9b	10.2	705	3900
	K9c	6.3	1080	8400
	K9d	2.513	2050	9800
	K9e	0.8	2050	10300

TABLE IV—*Concluded.*

ABSTRACT OF REPORT OF TESTS OF PAVING BRICK.

NAME OF BRICK.	Lab. No.	Per Cent Abs. Water.	Modulus of Rupture	Crushi'g Strength
Springfield, Ill	K4a	....	....	....
	K4b	12.2	980	2100
	K4c	5.0	2360	5200
	K4d	1.16	2250	....
	K4e	0.6	1890	3600
"Terre Haute Block," Terre Haute, Ind................	K10b	9.1	1375	....
	K10c	2.0	1910	....
	K10d	1.05	2340	6000
	K10e	0.8	1880	2400
"Wabash Clay Co.," Culver Block, Veedersburg, Ind	K8b	9.9	585	2700
	K8c	3.9	1035	4400
	K8d	3.9	1440	7600
	K8e	1.6	810	4400
"Western Paver," Danville, Ill........................	K14a	....	....	....
	K14b	4.218	1617	5200

TABLE V.

K$_3$b—ALBION, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.25	4.25	6	6020	925	995	— 70	7.0
2	3.30	4.25	6	6560	990	....	— 5	0.5
3	3.28	4.28	6	5500	820	....	—175	17.6
4	3.22	4.15	6	6260	1020	....	+ 25	2.5
5	3.28	4.40	6	6770	1050	....	+ 55	5.5
6	3.25	4.25	6	6030	925	....	— 70	7.0
7	3.20	4.15	6	7180	1170	....	+175	17.6
8	3.22	4.08	6	8160	1370	....	+375	37.7
9	3.30	4.25	6	4550	690	....	—305	30.6
				57030	8960	....	....	126.0
			Av.....	6337	995	....	....	14.0

ABSORPTION.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
b$_1$1..............................	2.385	2.615	.23	9.7
2..............................	2.72	2.965	.245	9.0
3..............................	2.65	2.885	.235	8.9
b$_2$1..............................	2.04	2.285	.245	12.0
2..............................	2.23	2.46	.23	10.3
				49.9
			Average	10.0

K$_3$c—ALBION, ILL.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Var. from av.	Per cent var.	Remarks
1.....	3.15	3.85	6	10650	2050	2100	—50	2.4	
2.....	3.30	3.80	6	12830	2420		+320	15.2	
3.....	3.20	4.00	6	4700	830		—1270	60.5	Fracture
4.....	3.40	3.55	6	12470	2610		+510	24.3	glassy on
5.....	3.20	4.00	6	8360	1470		—630	30.0	one side.
6.....	3.15	3.85	6	14710	2810		+740	35.3	
7.....	3.18	3.80	6	8950	1760		—340	16 4	
8.....	3.15	3.80	6	14100	2800		+700	33.3	
9.....	3.30	3.78	6	11330	2160		+60	2.9	
				98100	18940			220.3	
			Average	10900	2100			24.5	

Table No. 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet,	Gain.	
$c_1$1............	3.165	3.23	.065	2.1
2............	3.02	3.145	.125	4.1
3............	2.9	3.055	.155	5.3
$c_2$1............	3.26	3.34	.08	2.5
2............	2.775	2.875	.10	3.6
				17.6
			Av......	3.5

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress lb. per sq. in.
2....................	$3\frac{3}{8}$ x $3\frac{1}{4}$	10.9	39400	3600
4....................	$3\frac{3}{8}$ x $3\frac{3}{8}$	11.3	42000	3700
5....................	$3\frac{3}{8}$ x 3	10.1	63700	6300
8....................	$3\frac{3}{8}$ x $2\frac{1}{2}$	8.4	37200	4430
9....................	$3\frac{3}{8}$ x $3\frac{1}{8}$	10.5	51200	4870
9....................	$3\frac{3}{8}$ x $4\frac{3}{4}$	16.0	66600	4160
				27060
			Av	4510

K₃d—ALBION, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1.....	3.20	3.72	6	12380	2520	2350	+170	7.2
2.....	3.20	3.78	6	14450	2840	....	+490	20.8
3.....	3.20	3.75	6	9300	1860	....	−490	20.8
4.....	3.15	3.80	6	9880	1960	....	−390	16.6
5	3.10	3.75	6	12350	2550	....	+200	8.5
				58360	11730			73.9
			Av	11672	2350	....	....	14.8

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
1...	2.88	2.93	.05	1.7
2...	2.96	2.975	.015	0.5
3	2.96	2.975	.015	0.5
4...	3.045	3.08	.035	1.2
5...	2.98	3.02	.04	1.3
				5.2
			Average	1.0

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lbs. per sq. in.
1....................	3¼ x 3½	11.4	61000	5350
3....................	3¼ x 3¼	10.6	68000	6420
4....................	3¼ x 3⅝	11.8	58200	4930
5....................	3½ x 3½	11.4	34400	3000
5....................	3¼ x 3⅜	11.0	35100	3200
3....................	3¼ x 4	13.0	78300	6020
				28920
			Average........	4820

K₃e—ALBION, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1.....	3.20	3.80	6	10300	2070	2700	—630	23.3
2.....	3.18	3.72	6	13960	2860	....	+160	5.9
3... .	3.18	3.76	6	14860	2970	....	+270	10.0
4.....	3.20	3.80	6	15650	3060	....	+360	13.3
5.....	3 20	3.70	6	12360	2540	....	—160	5.9
6.....	3.18	3.82	6	13930	2700	....	0	0
				81360	16200			58.4
			Av	13560	2700	....	....	9.7

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
1..............................	2 84	2.875	.035	1.2
2..............................	2.785	2.81	.025	0.9
3..............................	2.915	2.93	.015	0.5
4..............................	2.84	2.86	.02	0.7
5..............................	2.92	2.925	.005	0.2
				3.5

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lbs. per sq. in.
1..................	3¼ x 3	9.7	29700	2960
2..................	3¼ x 3¼	10.6	45400	4280
4..................	3½ x 2⅞	9.3	26700	2880
6..................	3¼ x 3¾	12.2	41400	3380
6..................	3¼ x 4⅛	13.4	35800	2670
				16170
			Average	3234

K₁b—ALTON, ILL.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1..................................	1.28	1.435	.155	12.1
2..................................	1.08	1.215	.135	12.5
3..............................	1.07	1.205	.135	12.6
b₂1..................................	1.79	1.98	.19	10.6
2..............	1.875	2.025	.15	8.0
				55.8
			Average	11.2

Table 5—Continued.

K₁c—ALTON, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sqr. in.	Av.Mod.	Variation from average.	Per cent variation.
1......	2.85	3.90	6	8030	1660	1630	+ 30	1.8
2......	2.70	3.78	6	8390	1960	....	+330	20.2
3......	2.82	3.85	6	5770	1240	....	—390	23.9
4......	2 85	3.60	6	8120	1980	....	+350	21.5
5......	2.88	3.75	6	6480	1440	....	—190	11.7
6......	2.74	3.68	6	6200	1500	....	—130	8.0
				42990	9780			97.1
			Average	7165	1630	....	....	16.2

ABSORPTION.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
c₁1....................................	2.53	2.63	.10	4.0
2..............	2.08	2.23	.15	7.2
c₂1..............	1.945	2 085	.14	7.2
2..........	1.945	2.035	.14	7.2
2	2.44	2.555	.115	4.7
				30.3
			Average	6.1

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1...................	2¾ x 4	11.0	47800	4350
1...................	2¾ x 4¼	11.7	41000	3500
3...................	2¾ x 4¼	11.7	52000	4440
5...................	2¾ x 4¼	11.7	33000	2820
5...................	2¾ x 4	11.0	55800	5070
				20180
			Average	4036

Table 5—Continued.

K_1d—ALTON, ILL

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av. Mod.	Variation from average.	Per cent variation.
1.....	2.75	3.68	6	8580	2080	2535	−455	18.0
2.....	2.78	3.70	6	11420	2700	....	+165	6.5
3.....	2.70	3.85	6	11100	2500	....	−32	1.4
4.....	2.78	3.70	6	13020	3100	....	+565	22.3
5.....	2.70	3.85	6	9860	2220	....	−315	12.4
6.....	2.70	3·80	6	11330	2610	....	+75	3.0
				65310	15210			63.6
			Average	10885	2535	....	....	10.6

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$d_1$1........·	2.795	2.82	.025	0.9
2...........	2.815	2.83	.015	0.5
3...........	2.64	2.675	.025	1.0
$d_2$1...........	2.925	2.955	.03	1.0
2.............	2.655	2.68	.025	0.9
				4.3
			Average	0.9

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1....................	3¾ x 3	11.2	87700	7850
2....................	3¾ x 2¾	10 3	112000	10800
4....................	3¾ x 2¾	10.0	99000	9600
6....................	3¾ x 2¾	10.3	58000	5600
6....................	3¾ x 3	11.2	92300	8250
				42100
			Average	8420

Table 5—Continued.

K₁e—ALTON, ILL.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq. in	Av.Mod.	Var. from av.	Per cent var.	Remarks.
1.....	2.90	4.48	6	7800	1200	1420	—220	15.5	Very
2.....	2.90	4.20	6	9910	1750	....	+350	24.6	irregular
3.....	3.02	4.15	6	9650	1680	....	+260	18.3	and
4	3.00	3.90	6	6290	1240	....	—130	12.7	badly out
5.....	3.25	3.80	6	6380	1220	....	—200	14.1	of shape.
				40060	7090			85.2	
			Average	8012	1420	....	....	17.0	

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
e₁1........., ...	2.49	2.515	.025	1.0
2	2.495	2.525	.03	1.2
3	2.435	2.455	.02	0.8
e₂1.................................	2.27	2.3	.03	1.3
2	2.38	2.415	.085	1.5
				5.8
			Average	1.2

B₂b—ATCHISON, KAN.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Average	Variation from average	Per cent variation.
1	2.46	3.90	6	8140	1960	1800	+160	8.9
2	2.46	3.93	6	6950	1660	....	—140	7 8
3	2.46	3.90	6	6750	1630	....	—170	9.5
4	2.46	3.90	6	7920	1910	....	+110	6.1
5	2.52	3.90	6	9000	2120	....	+320	17.8
6	2.46	3.82	6	6650	1670	....	—130	7.2
7	2.46	3.84	6	6110	1520	....	—280	15 6
8	2.50	3.94	6	5940	1380	....	--420	23.4
9	2.52	3.90	6	7920	1860	....	+ 60	3.3
10	2.46	3.84	6	8950	2220	....	+420	23.4
11	2 46	3.84	6	6300	1560	....	—240	13.3
12	2.52	3.84	6	8670	2100	....	+300	16.7
				89300	21590			153.0
			Av	7440	1800	....	....	12.7

Table 5—Continued.

F$_1$b—ATCHISON, KAN.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
B$_1$1	1.926	2.175	.249	12.9
2	1.882	2.155	.273	14.5
3	2.105	2.385	.28	13.3
B$_2$1	2.032	2.325	.293	14.2
2	2.42	2.695	.275	11.3
				66.2
			Average	13.2

K$_{15}$b—BARR CLAY CO., STREATOR, ILL.

TRANSVERSE TEST.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq.in.	Av.Mod.	Variation from average.	Per cent variation.
1....	3.36	4.02	6	10400	1724	1776	— 54	3.4
2....	3.36	3.96	6	10950	1870	....	+ 94	5.3
3....	3.36	4.06	6	11580	1881	....	+105	5.9
4....	3.36	4.02	6	11800	1956	....	+180	10.1
5....	3.34	4.06	6	11250	1847	....	+ 71	4.0
6....	3.34	4.08	6	10350	1675	....	—101	5.7
7....	3.38	3.98	6	11360	1911	....	+135	7.6
8....	3.38	4.08	6	9790	1558	....	—218	12.3
9....	3.34	3.91	6	11100	1959	....	+183	10.3
10....	3.42	4.14	6	8980	1379	....	—397	22.4
				107560	17760			87.0
			Average	10756.0	1776.0	....		8.70

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
B$_1$1	2.965	3.155	.19	6.4
2	2.915	3.145	.23	7.9
3	2.88	3.105	.225	7.8
B$_2$1	2.808	3.035	.227	8.1
2	3.025	3.275	.25	8.3
				38.5
			Average	7.7

Table 5—Continued.

CRUSHING.

Number.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lbs. per sq. inch. •
3.....................	3⅜ x 2½	8.4	60000	7150
4.........	3⅜ x 3	10.0	68600	6860
5................. ·	3⅜ x 2½	8.4	84000	10000
7.....................	3⅜ x 2½	8.4	66000	7850
8.....................	3⅜ x 2¾	9.3	67500	7250
				39110
				Average 7822

K₁₅d—BARR CLAY CO., STREATOR, ILL.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.36	3.84	6	12990	2360	2365	— 5	0.2
2	3.36	3.84	6	12780	2320		— 45	1.9
3	3.36	3.74	6	12330	2360		— 5	0.2
4	3.26	3.84	6	9800	1840		—525	22.2
5	3.26	3.82	6	11920	2200		—165	7.0
6	3 30	3.94	6	14240	2500		+135	5.7
7	3.30	3.84	6	13700	2530		+165	7.0
8	3.34	3.78	6	13640	2580		+215	9.1
9	3.30	3.84	6	13780	2540		+175	7.4
10	3.34	3.84	6	13270	2420		+ 55	2.3
				128450	23650			63.0
			Av	12845	2365	....	....	6.3

K₁₅c—ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
C₁1	3.175	3.20	.025	.8
2	3.29	3.318	.028	.9
3	3.47	3.51	.04	1.2
C₂1	3.282	3.318	.036	1.1
2	3.315	3.348	.033	1.0
				5.0
			Average	1.0

Table 5—Continued.

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
3	3⅜ x 2	6.7₂	56000	8360
3	3⅜ x 2¾	9.3	105200	11300
5	3⅜ x 1½	5.5	97100	17700
8	3⅜ x 1¼	4.2	37800	9000
8	3⅜ x 1¼	4.2	40600	9700
				56060
				Av....... 11212

K₁₅c—BARR CLAY CO., STREATOR, ILL.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.34	3.84	6	14610	2670₂	2600	+ 70	2.7
2	3.30	3.84	6	14620	2720		+120	4.6
3 .. .	3.30	3.78	6	11870	2260		—340	13.1
4	3.24	3.96	6	14880	2640		+ 40	1.5
5	3.26	3.84	6	14730	2760		+160	6.2
6	3.26	3.90	6	15600	2840		+240	9.2
7	3.24	3.90	6	12000	2200		—400	15.4
8	3.26	3.86	6	15040	2810		+210	8.1
9	3.30	3.84	6	14270	2650		+ 50	1.9
10	3.30	3.90	6	13690	2490		—110	4.2
				141310	26040			66.9
			Av	14130	2600	....	....	6.7

K₁₅d—ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
D₁1	3.115	3.14	.025	0.8
2	3.005	3.038	.033	1.1
3	3.09	3.105	.015	0.5
D₂1	3.165	3.195	.03	0.9
2	3.255	3.282	.027	0.8
				4.1
			Average	0.8

Table 5—Continued.

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
3	3¾ x 2⅜	8.0	90500	11300
6	3⅜ x 2½	8.4	100300	11900
7	3⅜ x 2½	8.4	109100	13000
9	3⅜ x 2⅝	8.8	118200	13500
10	3⅜ x 3	10.2	90800	8900
				58600
				Av......... 11720

K₁₅e—BARR CLAY CO., STREATOR, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.36	3.90	6	17330	3050	2870	+180	6.3
2	3.22	4.14	6	18360	3000	....	+130	4.5
3	3.48	3.98	6	15110	2520	....	—350	12.2
4	3.36	3.84	6	14040	2560	....	—310	10.8
5	3.36	3.84	6	15710	2860	....	— 10	0.3
6	3.38	3.90	6	16020	2630	....	—240	8.4
7	3 30	3.90	6	19360	3460	....	+590	20.6
8	3.42	3.78	6	15760	2960	....	+ 90	3.1
9	3.26	3.84	6	13580	2540	....	—330	11.5
10	3.36	3.96	6	18470	3160	....	+290	10.1
				163740	28740	....	....	87.8
			Av	16370	2870			8.8

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
e₁1	2.94	2.965	.025	0.8
2	3.17	3.195	.025	.8
3	3.245	3.275	.030	.9
e₂1	2.96	2.98	.02	.7
2	3.01	3.04	.03	1.0
				4.2
			Average	0.8

Table 5—Continued.

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
3	$3\frac{3}{8} \times 2\frac{3}{8}$	8.0	55000	6880
5	$3\frac{3}{8} \times 2\frac{1}{2}$	8.4	56900	6780
6	$3\frac{3}{8} \times 2\frac{1}{4}$	7.6	78000	10300
8	$3\frac{3}{8} \times 2\frac{3}{4}$	9.3	92300	9930
9	$3\frac{3}{8} \times 2$	6.7	57200	8550
				42440
			Average	8488

I₂b—CANEY, KAN.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	2.34	4.26	6	8900	1890	1970	— 80	4.1
2	2.28	4.22	6	4940	1090	....	— 880	44.6
3	2.16	4.21	6	11920	2830	....	+ 860	43.6
4	2.28	4.21	6	7040	1570	....	— 400	20.3
5	2.22	4.08	6	12250	3000	....	+1030	52.2
6	2.28	4.21	6	8380	1860	....	— 110	5.6
7	2.22	4.14	6	9230	2190	....	+ 220	11.2
8	2.22	4.14	6	9050	2150	....	+ 180	9.1
9	2.28	4.08	6	6170	1460	....	— 510	25.9
10	2.26	4.26	6	7350	1620	....	— 350	17.8
11	2.26	4.08	6	8550	2050	....	+ 80	4.1
12	2.21	4.08	6	7700	1880	....	— 90	4.6
				101480	23590	....	....	233.1
			Av	8460	1970	....	....	18.6

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1	2.39	2.498	.108	4.5
2	2.517	2.63	.113	4.5
3	2.676	2,748	.072	2.7
b₂1	2.42	2.495	.075	3.1
2	2.45	2.505	.055	2.2
				17.0
			Average	3.4

Table 5—Continued.

R₃b—CANTON METROPOLITAN (Imperial.)

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq. in.	Av. Mod.	Variation from average.	Per cent variation.
1	3.48	4.02	6	16130	2580	2800	−220	7.9
2	3.48	4.02	6	16740	2680	....	−120	4.3
3	3.60	4.02	6	14680	2270	....	−530	18.9
4	3.54	3.96	6	20690	3350	....	+550	19.6
5	3.60	3.90	6	18110	2980	....	+180	6.4
6	3.48	4.02	6	19770	3170	....	+370	13.2
7	3.48	3.96	6	15730	2590	....	−210	7.5
8	3.48	3.90	6	16680	2830	....	+ 30	1.1
9	3.48	3.96	6	16970	2800	....	0	0
10	3.48	4.02	6	19310	3150	....	+350	12.5
11	3.48	3.96	6	16640	2470	....	− 60	2.1
12	3.48	3.96	6	15100	2490	....	−310	11.1
				206850	33630	....	....	104.6
			Av	17238	2800	....	....	8.7

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1	3.295	3.355	.06	1.8
2	3.975	4.015	.04	1.0
3	4.075	4.105	.03	0.7
b₂1	3.995	4.025	.03	0.8
2	3.775	3.83	.055	1.5
				5.8
			Average	1.2

CRUSING.

NUMBER.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lb. per sq. in.
2	3½ x 4	14.	94550	6750
3	3½ x 4½	14.4	109700	7620
6	3½ x 4¾	15.3	99250	6500
7	3½ x 4¼	14.9	141700	9500
1	3¼ x 4⅜	15.3	83500	5460
				35830
			Average	7166

Table 5—Continued.

Ʀ₄b—CANTON, METROPOLITAN, (Block).

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Var. from av.	Per cent variation.
1	3.60	3.96	6	19480	3100	3130	— 30	1.0
2	3.54	3.96	6	18980	3080	....	— 50	1.6
3	3.60	3.96	6 ·	15480	2470	....	—660	21.1
4 ...	3.58	3.96	6	18230	2930	....	—200	6.4
5 ...	3.58	3.96	6	20400	3280	....	+150	4.8
6	3.58	3.96	6	19830	3180	....	+ 50	1.6
7	3.60	3.96	6	21220	3380	....	+250	8.0
8	3.54	3.90	6	18690	3130	....	0	0
9	3.58	3.96	6	20770	3320	....	+190	6.1
10	3.58	3.96	6	17350	2780	....	—350	11.2
11	3.54	3.90	6	22170	3710	....	+580	18.5
12	3.54	3.90	6	18870	3170	....	+ 40	1.3
				231470	37530	....		81.6 ·
			Average	19290	3130	....		6.8

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1	3.835	3.885	.05	1.3
2	3.705	3.745	.04	1.1
3	4.12	4.155	.035	0.9
b₂1	3.755	3.785	.03	0.8
2	3.74	3.77	.03	0.8
				4.9
			Av	1.00

CRUSHING.

NUMBER.	Size inches.	Area inches.	Load— pounds.	Stress— lb. persq. in.
10	3½x4½	15.7	126700	8070
4	3½x4	14.0	128000	9150
5	3½x4½	14.4	135800	9440
7	3½x2⅜	8.3	58300	7030
8	3½x3⅞	13.6	61000	4500
				38190
			Av.........7638	

Table 5—Continued.

K₁₃b—CLINTON, IND.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av. Sr.	Var. from av.	Per cent. var.
1	3.35	4.15	6	9000	1400	1240	+160	12.9
2	3.48	4.15	6	7410	1110	....	—130	10.5
3	3.48	4.22	6	11190	1630	....	+390	31.4
4	3.50	4.25	6	7090	1010	....	—230	18.5
5	3.38	4.42	6	8670	1180	....	— 60	4.8
6	3.32	4.10	6	7290	1180	....	— 60	4.8
7	3.40	4.38	6	6850	945	....	—295	23.8
8	3.52	4.30	6	8000	1110	....	—130	10.5
9	3.38	4.32	6	9620	1380	....	+140	11.3
10	3.48	4.20	6	10120	1490	....	+250	20.2
				85240	12430	....		148.7
			Av	8520	1240	....		14.9

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1	3.46	3.678	.218	6.3
2	3.495	3.745	.250	7.2
3	2.66	2.698	.338	12.7
b₂1	3.59	3.81	.22	6.1
2	2.35	2.678	.328	14.0
				46.3
			Av......	9.3

CRUSHING.

NUMBER.	Size inches.	Area inches.	Load— pounds.	Stress— lb. per sq. in.
1	3⅜x4⅝	15.6²	40100	2580
6	3⅜x3½	11.8	19400	1640
7	3⅜x4	13.5	19500	1440
9	3⅜x3⅝	12.2	36700	3000
10	3⅜x4½	15.2	75600	5000
				13660
			Av 2732	

Table 5— Continued.

$K_{13}c$—CLINTON, IND.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of rupture,— pounds per sq. in.	Av. Sr.	Var. from av.	Per cent var.
1.....	3.48	4.08	6	8310	1290	1280	+10	0.8
2.....	3.36	4.21	6	10550	1590		+310	24.2
3.....	3.42	4.02	6	6850	1120		—160	12.5
4.....	3.28	4.32	6	9960	1470		+190	14.8
5.....	3.36	4.10	6	7820	1250		—30	2.3
6.. ...	3.42	4.08	6	7720	1220		—60	4.7
7.....	3.40	4.02	6	7410	1220		—60	4.7
8.....	3.42	4.16	6	9020	1380		+100	7.8
9.....	3.38	4.10	6	6310	1000		—280	21.9
				73950	11544			93.7
			Average	8220	1280			9.4

ABSORPTION.

NUMBER.	KILOS.			Per cent
	Dry.	Wet.	Gain.	
$c_1$1....	3.308	3.495	.187	5.7
2....	3.288	3.512	.224	6.8
3....	3 215	3.42	.205	6.4
$c_2$1....	3.265	3.48	.215	6.6
2....	3.23	3.525	.295	9.1
				34.6
			Av.....	6.9

$K_{13}d$—CLINTON, IND.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of rupture,— pounds per sq. in.	Av. Sr.	Var. from av.	Per cent var.
1.....	3.20	4.10	6	10240	1710	1620	+90	5.5
2.....	3.40	3.95	6	8580	1460		—160	9.9
3.....	3.20	4.05	6	8640	1490		—130	8.0
4.....	3.28	4.00	6	11100	1900		+280	17.3
5.....	3.30	4.02	6	8930	1510		—110	6.8
6.....	3.20	4.10	6	11620	1940		+320	19.8
7.....	3.25	4.02	6	5380	925		—695	42.8
8.....	3.35	3.98	6	12040	2040		+420	25.9
9.....	3.38	4.10	6	10040	1590		—30	1.9
10.....	3.15	3.90	6	8580	1610		—10	0.6
				95150	16170			136.5
			Average	9515	1620			13.6

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$d_1$1....................................	3.51	3.545	.035	1.0
2....................................	3.575	3.625	.05	1.4
3....................................	3.46	3.545	.085	2.5
$d_2$1....................................	3.035	3.078	.043	1.4
2....................................	3.768	2.835	.067	2.4
				8.7
			Av.....	1.7

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pound.	Stress— lb. per sq. in.
5....................	$3\frac{3}{8}$x4	13.5	54700	4050
6....................	$3\frac{3}{8}$x2½	8.4	66000	7860
8....................	$3\frac{3}{8}$x4	13.5	82300	6100
8....................	$3\frac{3}{8}$x3¾	12.7	54000	4250
9....................	$3\frac{3}{8}$x4	13.5	105400	7800
				30060
			Av........	6012

K_{13}e—CLINTON, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.36	4.20	6	6230	950	1500	− 550	36.7
2	3.38	4.14	6	3430	530	....	970	64.6
3	3.36	3.96	6	10650	1820	....	+ 320	21.4
4	3.40	4.26	6	22940	3350	....	+1850	123.2
5	3.36	4.20	6	9450	1440	....	− 60	4.0
6	3.42	4.50	6	12210	1600	....	+ 100	6.7
7	3.36	4.08	6	4950	795	....	− 705	47.1
8	3.36	4.24	6	6660	995	....	− 505	33.7
9	3.36	4.08	6	13460	2160	....	+ 660	44.1
10	3.42	4.02	6	8200	1350	....	− 150	10.0
				100120	14990			391.5
			Av	10000	1500	....	....	39.2

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
e₁1	3.778	3.812	.034	0.9
2	3 363	3.40	.037	1.1
3	3.58	3.62	.04	1.1
e₂1	3.122	3.15	.028	0.9
2	2.91	2.95	.04	1.4
				5.4
			Average	1 1

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lbs. per sq. in.
2	3½ x 3¼	11.4	63700	5600
3	3½ x 2¾	9.6	45400	4740
5	3½ x 4¼	14.9	71000	4760
9	3½ x 4¼	14.9	102900	6900
10	3½ x 4	14.	80700	5760
				27760
			Average	5552

G₂—COFFEYVILLE BLOCK, KANSAS.

TRANSVERSE TEST.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.18	4.02	6	7040	1240	1905	−665	34.9
2	3.12	3.96	6	13580	2500	....	+595	31.3
3	3.14	4.02	6	12970	2320	....	+415	21.8
4	3.18	4.02	6	7550	1330	....	−575	30.2
5	3.18	4.02	6	12060	2120	....	+215	11.6
6	3.18	4.02	6	6950	1220	....	−685	36.0
7	3.18	4.02	6	11370	2000	....	+ 95	5.0
8	3.18	3.96	6	10990	1980	....	+ 75	4.0
9	3.24	4.02	6	11550	1990	....	+ 85	4.5
10	3.18	3.94	6	12880	2350	....	+445	23.4
				106940	19050			202.7
			Av	10694	1905	....	....	20.3

ABSORPTION.

(See Coffeyville "Brick.")

Table 5—Continued.

G₂—COFFEYVILLE BRICK, KANSAS.

TRANSVERSE TEST.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	2.16	3.84	6	8890	2511	2325	+186	8.0
2 ...	2.14	3.78	6	9040	2659	....	+334	14.4
3	2.28	3.84	6	7520	2014	....	−311	13.4
4	2.18	4.14	6	7960	1918	....	−407	17.5
5	2.22	3.89	6	10630	2844	....	+519	22.3
6	2.16	3.84	6	8490	2398	....	+ 73	3 1
7	2.22	3.84	6	8610	2370	....	+ 45	1.9
8	2.18	3.82	6	7670	2171	....	−154	6 6
9	2.32	3.84	6	8000	2105	....	−220	9.5
10	2.22	3.84	6	7780	2141	....	−184	7.9
11	2.22	3.88	6	8800	2371	....	+ 46	2.0
12	2.28	3.84	6	8940	2395	....	+ 70	3.0
				102330	27897			109.6
			Av	8528	2325	....	....	9.1

ABSORPTION.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
b₁1..........	2.45	2.465	.015	0.0
2................................	2.322	2.35	.028	1.6
3................................	2.49	2.51	.02	0.2
b₂1................................	2.46	2.475	.015	0.8
2................................	2.408	2.425	.025	1.6
				4.2
			Average	0.8

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lbs. per sq. in.
1	3¼ x 3⅜	11	73700	6700
2	3¼ x 4	13	65000	5000
2	3¼ x 4	13	94700	7300
9	3½ x 4	13	79000	6080
10	3½ x 3½	11.4	82500	7250
				32330
			Average	6466

Table 5—Continued.

F₁c—DANVILLE BRICK CO., DANVILLE, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq in.	Av.Mod.	Variations from Average.	Per cent Variation.
1.....	3.24	4.20	6	9890	1560	1700	−140	8.2
2.....	3.18	3.98	6	11540	2060	....	+360	21.2
3.....	3.24	4.20	6	8980	1420	....	−280	16.5
4.....	3.22	4.20	6	8460	1340	....	−360	21.2
5.....	3.18	4.02	6	11290	1980	....	+280	16.5
6.....	3.14	4.08	6	10970	1890	....	+190	11.2
7.....	3.15	4.10	6	11420	1950	....	+250	14.7
8.....	3.13	3.96	6	8090	1480	....	−220	12.9
9.....	3.24	4.14	6	9100	1480	....	−220	12.9
10....	3.24	4.08	6	11370	1890	....	+190	11.2
				101110	17050	....	....	146.5
			Average	10110	1700	....	....	14.6

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
c₁1	2.94	3.115	.175	6.0
2	3.015	3.15	.135	4.5
3	3.23	3.322	.092	2.9
c₂1	2.085	2.23	.145	7.0
2	3.155	3.275	.12	3.8
				24.2
			Average	4.8

CRUSHING.

NUMBER.	Size— square inches.	Area— inches.	Load— pounds.	Stress— lb. per sq. in.
1...................	3¼ x 3	9.7	39900	4100
4...................	3¼ x 2¼	7.3	48800	6700
6...................	3¼ x 2¾	8.9	37700	4240
6...................	3¼ x 2⅝	8.5	42300	5000
10...................	3¼ x 3	9.7	58900	6100
				26140
				Average 5228

Table 5—Continued.

F₁d—DANVILLE BRICK CO., DANVILLE, ILL.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load pounds.	Modulus of Rupture—pounds per sq. in.	Av. Mod.	Variation from average.	Per cent variarion.
1....	3.34	4.24	6	4970	745	980	—235	24.0
2....	3.48	4.26	6	7180	1020	....	+40	4.1
3....	3.46	4.52	6	3000	420	....	—560	57.2
4....	3.34	4.10	6	7690	1240	....	—260	26.6
5....	3.36	4.20	6	8560	1310	....	+330	33.7
6....	3.34	4.14	6	6910	1090	....	+110	11.2
7....	....	....	....	....	....	....	....	....
8....	3.30	4.32	6	4700	690	....	—290	29.6
9....	3.30	4.26	6	5400	815	....	—165	16.8
10....	3.36	4.08	6	9090	1460	....	+480	49.0
				57500	8790	....	....	242.2
			Av.....	6370	980			26.9

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
d₁1..................................	2.955	3.03	.078	2.6
2..................................	3.16	3.268	.108	3.4
3..................................	3.18	3.285	.105	3 3
d₂1..................................	3.09	3.185	.095	3.1
3..................................	3.292	3.352	.06	1.8
				14.2
			Average	2.8

CRUSHING.

NUMBER.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lb. per sq. in.
6..................	3⅜ x 4½	15.2	60600	4000
6..................	3⅜ x 4¼	14.3	43400	3040
9..................	3⅜ x 4¼	14.3	55400	3880
9..................	3⅜ x 4⅜	14.7	37400	2550
10..................	3½ x 3⅝	12.2	40100	3280
				16750
				Average 3350

Table 5—Continued.

F₁e—DANVILLE BRICK CO., DANVILLE, ILL.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq.in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.36	4.08	6	14380	2300	1670	+630	37.7
2	3.36	3.96	6	12650	2160	....	+490	29.4
3	3.24	3.72	6	8160	1640	....	-- 30	1.8
4	3.30	3.84	6	9500	1760	....	+ 90	5.4
5	3.24	3.96	6	6330	1120	....	—550	32.9
6	3.42	4.20	6	13190	1980	....	+310	18.6
7	3.36	4.08	6	11440	1840	....	+170	10.2
8	3.42	3.96	6	7890	1330	....	—340	20.4
9	3.42	4.32	6	12260	1740	....	+ 70	4.2
10	3.48	4.44	6	6130	805	....	—865	51.8
				101930	16675			212.4
			Average	10190	1670	....	....	21.2

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
e₁1	2.92	2.96	.04	1.4
2	3.105	3.135	.03	1.0
3	2.75	2.79	.04	1.5
e₂1	2.92	3.005	.085	2.9
2	2.81	2.85	.04	1.5
				8.3
			Average	1.7

CRUSHING.

Number.	Size—square inches.	Area—square inches.	Load—pounds.	Stress—lb. per sq. in.
1	3¼ x 2½	8.1	41300	5100
6	3¼ x 2	6.5	34200	5260
6	3¼ x 2	6.5	50900	7830
7	3¼ x 2	6.5	43200	6650
9	3¼ x 2	6.5	36000	5550
				30390
				Average 6078

Table 5—Continued.

K_5b—EDWARDSVILLE.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b 1				8.67
2				10.71
3				10.36
$b_2$1				8.79
2				9.60
				48.13
				Average ..9.62
K_5c				
c 1				7.37
2				5.90
c 1				3.52
2				3.84
3				2.79
				23.42
				Average ..4.68
K_5d				
$d_2$1				2.42
2				2.86
d 1				2.71
2				2.59
3				2.54
				13.12
				Average ..2.62
K_5e				
$e_2$1				1.93
2				1.34
e 1				1.49
2				0.77
3				1.37
				6.90
				Average ..1.38

Table 5—Continued.

K₂b—HYDRAULIC, ST. LOUIS, MO.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Var. from av.	Per cent var.	Remarks
1....	2.88	3.90	6	11970	2460	2430	+ 30	1.2	
2....	2.82	3.84	6	11810	2570	....	+ 140	5.8	
3....	2.80	3.94	6	15750	3250	....	+ 820	33.7	
4....	2.88	3.88	6	16780	3480	....	+1050	43.2	
5....	2.86	3.96	6	13090	2640	....	+ 210	8.6	
6....	2.76	3.84	6	10340	2290	....	− 140	5.8	
7....	2.78	4.04	6	17380	3430	....	+1000	41.1	
8....	2.96	3.80	6	14150	2980	....	+ 550	22.6	
9....	2.80	4.05	6	5610	1100	....	−1330	54.6	
10....	2.85	3.95	6	6060	1230	....	+1200	49.3	
11....	2.78	4.05	6	14370	2830	....	+ 400	16.5	
12....	2.88	4.10	6	4640	860	....	−1570	64.6	Fracture glazed.
				141950	29120			347.0	
			Average	11830	2430	....	....	28.9	

ABSORPTION.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
b₁1....	3.005	3.025	.02	0.7
2....	3.23	3.24	.01	0.3
3....	3.235	3.275	.04	1.2
b₂1....	3.12	3.13	.01	0.3
1....	3.32	3.33	.01	0.3
				2.8
			Average	0.6

CRUSHING.

Number.	Size— square inches.	Area— inches.	Load— pounds.	Stress— lb. per sq. in.
11	2⅞ x 3¾	10.8	76200	7560
11	2⅞ x 3¾	10.8	69800	6940
7	2⅞ x 3¼	9.3	107500	11500
2	2⅞ x 3½	10.0	77900	7790
10	2⅞ x 3¼	9.3	80500	8650
9	2⅞ x 3½	10.0	75400	7540
				49980
			Average	8330

Table 5—Continued.

K₁₁b—INDIANA BLOCK, BRAZIL, IND.

TRANSVERSE.

No.	Breadth, inches.	Depth— Inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq. in	Av.Mod.	Var. from av.	Per cent var.	Remarks.
1....	3.30	4.35	6	4940	715	685	+30	4,4	
2....	3.35	4.40	6	6670	930		+245	35.8	
3....	3.35	4.30	6	4280	620		—65	9.5	
4....	3.35	4.40	6	3780	525		+160	23.4	
5....	3.35	4.34	6	5000	715		+30	4.4	
6....	3.40	4.30	6	3010	435		—250	36.5	
7....	3.35	4.38	6	6030	845		+160	23.4	
8....	3 30	4 35	6	5180	745		+60	8.8	
9....	3.32	4.42	6	7770	1080		+395	57.6	
10....	3.30	4.32	6	1740	255		—430	62.8	Break
				48430	6865			266.6	
			Average	4840	685			26.7	

ABSORPTION

NUMBER	KILOS.			Per cent.
	Dry.	Wet	Gain.	
b₁1..............................	1.5	1.745	.245	16.3
2..............................	1.395	1.602	.207	14.8
3..............................	2 528	2.83	.302	11.9
b₂1..............................	2.005	2.235	.23	11.5
2.	2.398	2.665	.267	11.1
			Av.........	65.6
				13.1

K₁₁c—INDIANA BLOCK, BRAZIL, IND.

TRANSVERSE

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Var. from av.	Per cent var.
1....	3.18	3.94	6	10850	1980	1510	+470	31.2
2....	3.18	3.84	6	7650	1470		—40	2.6
3....	3.16	3 98	6	8340	1510		0	0
4....	3.10	3.96	6	7000	1300		—210	13.9
5....	3.12	3.96	6	6950	1280		—230	15.2
6....	3.24	4.18	6	8320	1320		—190	12.6
7....	3.12	3.96	6	8330	1540		+30	2.0
8....	3.12	4.02	6	7600	1360		—150	9.9
9....	3.18	3.86	6	9280	1760		+250	16.6
10....	3.18	3.90	6	8660	1610		+100	6.6
				82980	15130			110.6
			Average	8300	1510			11.1

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$c_1 1$	2.938	3.062	.124	4.2
2	3.18	3.23	.05	1.6
3	3.003	3.095	.092	3.1
$c_2 1$	2.993	3.10	.097	3.2
2	3.11	3.185	.075	2.4
				14.5
			Av.........	2.9

K11d—INDIANA BLOCK, BRAZIL, IND.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1....	3.18	3.90	6	10490	1960	2260	—300	13.3
2....	3.14	3.90	6	10500	1980	....	—280	12.4
3....	3.14	3.90	6	10680	2020	....	—240	10.6
4....	3.14	4.05	6	13980	2450	....	+190	8.4
5....	3.15	3.94	6	12140	2250	....	— 10	0.4
6....	3.22	3.85	6	12850	2430	....	+170	7.5
7....	3.10	3.94	6	11960	2240	....	— 20	0.9
8....	3.15	4.00	6	13950	2500	....	+240	10.6
9....	3.10	3.95	6	13670	2540	....	+280	12.4
10....	3.20	3.98	6	12450	2220	....	— 40	1.8
				122670	22590			78.3
			Av	12270	2260		Av	7.8

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$d_1 1$	2.955	3.008	.053	1.8
2	2.96	3.015	.055	1.9
3	2.95	3.002	.052	1.8
$d_2 1$	3.025	3.075	.050	1.7
2	3.045	3.10	.055	1.8
				9.0
			Average	1.8

Table 5—Continued.

K11e—INDIANA BLOCK, BRAZIL, IND.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture-pounds per sq.in.	Av. Mod.	Variation from average	Per cent variation	Remarks.
1....	3.18	4.38	6	6480	955	870	+ 85	9.8	Overbur'd
2....	3.18	4.20	6	9260	1480	....	+610	70.1	.do ....
3....	3.30	4.56	6	4810	635	....	—235	27.0	.do ....
4....	3.42	4.80	6	6220	710	....	—160	18.4	.do ....
5....	3.18	4.38	6	8520	1260	....	+390	44.8	.do ....
6....	3.24	4.38	6	4310	625	....	—245	28.2	.do ....
7....	3.18	4.56	6	4040	550	....	—320	36.8	.do ....
8....	3.24	4.68	6	4830	615	....	—255	29.3	.do ....
9....	3.24	4.68	6	6950	880	....	+ 10	1.1	.do ....
10....	3.18	4 56	6	7350	1000	....	+130	14.9	.do ....
				62770	8710			280.4	
			Av	6280	870	....	....	28.0	

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
e₁1..............................	2.31	2.39	.08	3.5
2..............................	2.33	2.405	.075	3.2
3..............................	2.595	2.66	.065	2.5
e₂1..............................	2.625	2.678	.053	2.0
2..............................	2.675	2.74	.065	2.4
				13.6
			Average	2.7

S₂b—KANSAS CITY DIAMOND.

TRANSVERSE.

No.	Breadth, inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Var. from av.	Per cent. var.	Remarks.
1....	2.56	3.78	6	10480	2580	2410	+170	7.0	
2....	2.46	3.70	6	9590	2560		+150	6.2	
3....	2.50	3.66	6	9180	2470		+ 60	0.2	
4....	2.58	3.72	6	11400	2560		+150	6.2	
5....	2.46	3.82	6	5010	1260		—1150	47.6	Over-burned.
6....	2.54	3.66	6	7920	2090		—320	13.6	
7....	2.46	3.64	6	11620	3060		+650	27.0	
8....	2.58	3.78	6	7040	1720		—690	28.6	
9....	2.56	3.72	6	9000	2540		+130	5.4	
10....	2.52	3.66	6	10050	2680		+270	11.2	
11....	2.46	3.72	6	10620	2820		+410	17.0	
12....	2.52	3.60	6	9420	2610		+200	8.3	
				111330	28950			178.3	
			Average	9280	2410			14.9	

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.	Time.
	Dry.	Wet.	Gain.		
b$\bar{1}$1	2.180	2.200	0.020	0.9	48 hours.
2	2.315	2 330	.015	.6	..do ....
3	1.805	1.815	.010	.6	..do ....
b$_2$1	2.085	2.095	.010	.5	..do ....
2	2.185	2.205	.020	1.0	..do ....
				3.6	....
			Av	0.7	....

L$_2$b—LAWRENCE, KANSAS.

TRANVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Average Mod.	Variation from average.	Per cent variation.
1	2.53	3.61	6	9500	2600	1770	+830	46.8
2	2.55	3.62	6	6500	1750		— 20	1.1
3	2.55	3.68	6	5670	1470		—300	16.9
4	2.50	3.52	6	7200	2100		+330	18.6
5	2.53	3.65	6	6600	1770		0	0.0
6	2.52	3.60	6	6520	1800		+ 30	1.7
7	2.53	3.65	6	4870	1300		—330	18.6
8	2.50	3.68	6	5600	1490		—280	15.8
9	2.55	3.60	6	7250	1970		+200	11.3
10	2.55	3.65	6	5550	1480		—290	16.4
				652^{6}0	17730			147.2
			Av	6530	1770	....	....	14.7

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b$_1$1	2.06	2.112	.052	2.5
2	2.175	2.202	.027	1.2
3	2.10	2.142	.042	2.0
b$_2$1	1.90	1.932	.032	1.7
2	2.215	2.242	.027	1.2
				8.6
			Av	1.7

Table 5—Continued.

L₂c—LAWRENCE, KAN.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Var. from av.	Per cent var.
1....	2.40	3.60	6	9410	2730	1960	+770	39.3
2....	2.42	3.55	6	7380	2180		+220	11.2
3....	2.50	3.66	6	7120	1920		—40	2.0
4....	25.2	3.74	6	7240	1860		—100	5.1
5....	2.48	3.52	6	4820	1410		—550	28.0
6....	2.48	3.64	6	6100	1670		—290	14.8
7....	2.55	3.70	6	7020	1810		—150	7.6
8....	2.48	3.70	6	7610	2020		—60	3.0
9....	2.47	3.62	6	7090	1980		+20	1.0
10....	2.50	3.72	6	7630	2000		+40	2.0
				71220	19580			114.0
			Average	7120	1960			11.4

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
c₁1.	2.385	2.408	.023	1.0
2	2.382	2.40	.018	0.8
3	2.34	2.36	.02	0.9
c₂1.	2.45	2.47	.02	0.8
2	2.37	2.392	.022	0.9
				4.4
			Av	0.9

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds	Stress— lb. per sq. in.
7..................	2½ x 2½	6.2	52000	8400
8................	2½ x 2½	6.2	58700	9500
9................	2½ x 2½	6.2	45800	7400
10................	2½ x 2¾	6.9	90000	13000
11..................	2½ x 2¼	5.6	67700	12000
				50300
			Av........	10060

Table 5—Continued.

S₁b—MOBERLY, MISSOURI.

Transverse.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Var. from av.	Per cent var.
1....	3.24	3.62	6	9930	2100	2130	−30	1.4
2....	3.24	3.66	6	10900	2270		+140	6.6
3....	3.26	3.66	6	11570	2310		+180	8.4
4....	3.24	3.40	6	7840	1890		−240	11.3
5....	3.24	3.60	6	10910	2340		+210	9.9
6....	3.18	3.66	6	10070	2130		0	0
7....	3.18	3.62	6	10220	2210		+80	3.8
8....	3.30	3.72	6	9470	1860		−270	12.7
9....	3.30	3.66	6	10720	2180		+50	2.3
10....	3.18	3.66	6	11270	2380		−250	11.7
11....	3.30	3 62	6	9480	1970		−160	7.5
12....	3.22	3.66	6	9120	1910		−220	10.3
				121500	25550			85.9
			Average	10125	21300			7.2

Absorption.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
b₁1..........................	2.59	2.655	.065	2.5
2..........................	2.805	2.875	.075	2.7
3..........................	2.39	2.475	.085	3.6
b₂1..........................	2.66	2.775	.115	4 3
2..........................	2.625	2 71	.085	3.2
				16.2
			Av	3.2

R₁b—NELSONVILLE, OHIO.

Transverse,

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Var. from av.	Per cent var.
1....	3.24	4.02	6	9050	1560	1790	−230	12.8
2....	3.30	3.96	6	9350	1630		−160	8.9
3....	3.24	3.96	6	10910	1900		+110	6.1
4....	3.30	4.02	6	11050	1870		+80	4.5
5....	3.24	4.02	6	11750	2030		+240	13.4
6....	3.24	4.02	6	9610	1680		−110	6.1
7....	3.30	4.08	6	10900	1780		−10	0.6
8....	3.24	3.96	6	11820	2100		+310	17.3
9....	3.24	4.08	6	10390	1800		+10	0.6
10....	3.30	3.96	6	9580	1670		−120	6.7
11....	3.24	4.02	6	10860	1870		+80	4.5
12....	3.24	4.08	6	9600	1600		−190	10.6
				124870	21490			92.1
			Average	10406	1790			7.7

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1.....	3.465	3 53	.065	1.9
2..........	3.53	3.58	.05	1.4
3....	3.54	3.60	.06	1.7
b₂1	3.66	3.71	.05	1.3
2..........	3.43	3.485	.055	1.6
				7.9
			Av	1 6

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1.....	3¼ x 4⅝	15	70500	4700
11.....	3¼ x 4	13	64425	4950
10.....	3¼ x 4¼	13.8	39525	2860
4.....	3¼ x 4⅜	14.2	52450	3680
7.....	3¼ x 4⅝	15	39550	2640
				18830
			Av 3766	

R₂b—PEEBLE'S BLOCK, PORTSMOUTH, O.

TRANSVERSE TEST.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.22	3.90	6	10750	1980	2505	—525	21.0
2	3.18	3.90	6	14420	2690	....	+185	7.4
3	3.18	3.96	6	12590	2270	....	—235	9.4
4	3.22	3.94	6	12420	2250	....	—255	10.2
5	3.18	3.94	6	11980	2180	....	—325	13.0
6	3.12	3.90	6	12300	2340	....	—165	6.6
7	3.18	3.90	6	12140	2260	....	—245	9.8
8	3.14	3.86	6	15060	2900	....	+395	15.8
9	3.18	3.94	6	15290	2780	....	—275	11.0
10	3 12	3.96	6	16490	3040	....	+535	21.4
11	3.18	3.90	6	15850	2950	....	+445	17.8
12	3.22	3.96	6	13470	2410	....	— 95	3.8
				162760	30059			147.2
			Av	13563	2505	....	....	12.3

Table 5—Continued.

R$_2$b—ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b$_1$1..............................	3.375	3.45	.075	2.2
2..............................	3.525	3.6	.075	2.1
3..............................	3.395	3.47	.075	2.2
b$_2$1..............................	3.5	3.575	.075	2.1
2..............................	3.46	3.535	.075	2.2
				10.8
			Average	2.2

J$_2$b—PITTSBURG, KAN.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1....	2.60	3.70	6	9870	2500	2220	+280	12.6
2....	2.60	3.78	6	7830	1900	....	−320	14.4
3....	2.50	3.80	6	7860	1960	....	−260	11.7
4....	2.44	3.82	6	11600	2940	....	+720	32.5
5....	2.62	3.70	6	8420	2130	....	− 90	4.1
6....	2.55	3.80	6	10390	2530	....	+310	14.0
7....	2.58	3.85	6	10110	2380	....	+160	7.2
8....	2.60	3.94	6	8940	2000	....	−220	10.0
9....	2.45	3.86	6	9960	2460	....	+240	10.8
10....	2.58	3.85	6	7950	1870	....	−350	15 8
11....	2.45	3.80	6	8210	2100	....	−120	5.4
12....	2.52	3.92	6	8120	1890	....	−330	14.8
				109360	26660	....	....	153.3
			Av....	9130	2220	....	....	12.8

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b$_1$1	2.318	2.405	.087	3.8
2	2.33	2.37	.04	1.7
3	2.473	2.52	.047	1.9
b$_2$1	2.30	2.335	.035	1.5
2	2.49	2.55	.06	2.4
				11.3
			Average..	2.3

Table 5—Continued.

CRUSHING.

Number.	Size—inches.	Area—inches.	Load—pounds.	Stress—lbs. per sq. in.
6	2½ x 2½	6.2²	52000	8400
6	2½ x 2¾	6.9	78000	11300
9	2½ x 2⅝	6.6	96900	14600
9	2½ x 3	7.5	74500	9940
12	2½ x 3	7.5	57700	7700
				51940
			Average........	10388

K₉b—POSTON BLOCK, CRAWFORDSVILLE, IND.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.68	4.10	6	4000	585	705	—120	17.0
2	3.53	3.95	6	6340	1040	....	+335	47.5
3	3.75	4.00	6	5030	755	....	+ 50	7.1
4	3.62	4.15	6	4390	635	....	— 70	9.9
5	3.65	4.02	6	3760	575	....	—130	18.4
6	3.60	4.05	6	4920	755	....	+ 50	7.1
7	3.65	4.10	6	4120	605	....	—100	14.2
8	3.50	4.02	6	4550	725	....	+ 20	2.8
9	3.65	3.88	6	4870	795	....	+ 90	12.8
10	3.62	4.05	6	3960	600	....	—105	14.9
				45910	7070	....	....	151.7
			Average	4594	705	....	....	15.2

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1....................................	2.305	2.564	.259	11.2
2....................................	2.66	2 92	.26	9.8
3....................................	3.132	3.38	.248	7.9
b₂1....................................	2.415	2.68	.265	11.0
2....................................	2.37	2.636	.266	11.2
				51.1
			Average	10.2

Table 5—Continued.

CRUSHING.

NUMBER.	Size inches.	Area inches.	Load— pounds.	Stress— lb. per sq. in.
1	$3\frac{5}{8}$x4	14.5^2	56700	3900
4	$3\frac{5}{8}$x$4\frac{1}{4}$	15.4	60500	3940
5	$3\frac{5}{8}$x$4\frac{1}{2}$	16.3	69700	4280
6	$3\frac{5}{8}$x4	14.5	50000	3950
7	$3\frac{5}{8}$x4	14.5	52400	3600
				19670
				Average ..3934

K_9c—POSTON BLOCK, CRAWFORDSVILLE, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1.....	3.65	3.85	6	7300	1220	1080	+140	13.0
2.....	3.55	3.80	6	4790	840	....	—240	22.2
3.....	3.65	3.85	6	4960	830	....	—250	23.2
4.....	3.62	3.90	6	5230	860	....	—220	20.4
5.....	3.55	3.90	6	8230	1380	....	+300	27.8
6.....	3.50	3.90	6	5470	930	....	—150	13.9
7.....	3.55	3.95	6	10380	1690	....	+610	56.6
8.....	3.55	3.98	6	5690	910	....	—170	15.7
9.....	3.60	3.95	6	6490	1040	....	— 40	3.7
				58540	9700			196.5
			Av......	6505	1080	....	....	21.8

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$c_1$1....	3.555	3.79	.235	6.7
2..................	3.22	3.444	.222	6.9
3..................	3.71	3.87	.16	4.3
$c_2$1..................	3.34	3.542	.202	6.0
2..................	3.23	3.478	.248	7.7
				31.6
			Average	6.3

Table 5—Continued.

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress lb. per sq. in.
4	3¼ x 3	97.7	86400	8900
5	3⅝ x 3¼	11.8	114200	9700
8	3⅝ x 3	10.9	74300	6800
9	3⅝ x 3	10.9	100400	9200
9	3⅝ x 3	10.9	78800	7230
				41830
				Average ..8366

K₉d—POSTON BLOCK, CRAWFORDSVILLE, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Var. from av.	Per cent. var.
1	3.60	3.82	6	9700	1660	2050	—390	19.0
2	3.50	3.85	6	10560	1830	....	—220	10.7
3	3.48	3.88	6	15020	2580	....	+530	25.8
4	3.48	3.95	6	12460	2070	....	+ 20	1.0
5	3.50	3.92	6	10010	1680	....	—370	18.0
6	3.60	3.70	6	11640	2140	....	+ 90	4.4
7	3.50	3.90	6	13510	2280	....	+230	11.2
8	3.50	4.00	6	14420	2320	....	+270	13.2
9	3.55	3.90	6	12450	2070	....	+ 20	1.0
10	3.62	3.90	6	11450	1880	....	—170	8.3
				121220	20510	....		112.6
			Average	12120	2050	....		11.3

ABSORPTION.

NUMBER.	KILOS.			Per cent
	Dry.	Wet.	Gain.	
d₁1..........................	3.38	3.482	.102	3.0
2..........................	3.51	3.622	.112	3.2
3..........................	3 70	3.79	.09	2.4
d₂1..........................	3.675	3.76	.085	2.3
2..........................	3.82	3.872	.052	1.4
				12.3
			Average ...	2.5

Table 5—Continued.

CRUSHING.

Number.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lbs. per sq. inch.
1.....................	3½ x 3½	12.2	97800	8020
2.....................	3½ x 2¾	9.6	97800	10200
5.....................	3½ x 2½	8.7	79200	9100
9.....................	3½ x 2¾	9.6	95000	9900
10.....................	3½ x 2½	8.7	101200	11600
				48820
				Average 9764

K9e—POSTON BLOCK, CRAWFORDSVILLE, IND.

TRANSVERSE.

No.	Breadth, inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture, pounds per.sq.in	Av.Mod.	Var. from av.	Per cent var.	Remarks.
1.....	3.50	3.66	6	13100	2520	2050	+470	22.9	
2.....	3.67	3.55	6	11100	2170	....	+120	5.8	Badly
3.....	3.60	3.30	6	10970	2520	....	+470	22.9	ov'rburn'd
4.....	3.55	3.68	6	5420	1020	....	—1030	50.2	and
5.....	3.55	3.80	6	11790	2070	....	+20	1.0	very
6.....	3.55	3.60	6	10120	1980	....	—70	3.4	irregular
				62500	12280			106.2	
			Average	10420	2050	....	....	17.7	

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
e₁1........., ...	3.255	3.285	.03	0.9
2	3.41	3.433	.023	.7
3	3.485	3.505	.02	.6
e₂1.....................................	3.465	3.50	.035	1.0
2	3.665	3.69	.025	.7
				3.9
			Average	0.8

CRUSHING.

NUMBER.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lb. per sq. in.
1.....................	3½ x 2¾	9.6	108400	11300
2....	3½ x 2½	8.7	89500	10300
3.....................	3½ x 3	10.5	134000	12800
4.....................	3½ x 2¼	7.8	80500	10300
4.....................	3½ x 2¾	9.6	66000	6900
				15600
			Average	10320

Table 5—Continued.

K₆b—PURINGTON BLOCK.

ABSORPTION.

NUMBER.	Dry.	Wet.	Gain.	Per cent.
1				6.53
2				5.37
3				5.48
4				5.82
5				8.07
				31.27
			Average	6.25

K₆c.

c1				3.75
2				3.76
c1				4.92
2				4.92
3				4.38
				19.97
			Average	3.99

K₆d.

d1				0.27
2				0.84
d1				0.28
2				0.57
3				0.00
				1.96
			Average	0 39

K₆e.

e1				1.25
2				0.43
3				0.95
4				0.98
5				0.85
				4.46
			Average	0.89

K₆b₂.

II1				6.48
2				7.55
II1				5.88
2				4.90
3				7.76
				32.57
			Average	6.51

Table 5—Continued.

Purington Block—Concluded.

K_6c_2.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
$cII_2$1..........................	....	....	....	4.33
2..........................				7.17
cII 1.....	....	....	....	4.74
2...........	....	....	....	3.68
3...........	....	....	....	8.29
				28.21
			Average	5.64

K_4b—SPRINGFIELD, ILL.

TRANSVERSE.

No.	Breadth, inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Variation from average.	Per cent variation.
1	2.73	4.20	6	4150	780	980	−200	20.4
2	2.75	4.22	6	5120	945	....	− 35	3.6
3	2.75	4.10	6	3340	650	....	−330	33.7
4	2.70	4.15	6	3860	750	....	−230	23.5
5	2.72	4.20	6	5010	950	....	− 30	3.1
6	2.72	4.15	6	6150	1180	....	+200	20.4
7	2.70	4.15	6	6170	1195	....	+215	21.9
8	2.70	4.10	6	5380	10,0	....	+ 90	9.2
9	2.72	4.10	6	5160	1020	....	+ 40	4.1
10	2.70	4.18	6	6620	1260	....	+280	28.6
				50990	9800	....	....	168.5
			Average	5100	980	....	....	16.8

ABSORPTION.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
1	1.415	1.595	.180	12.7
2	1.625	1.825	.2	12.3
3	1.93	2.155	.225	11.7
4	1.93	2.165	.235	12.2
5	1.86	2.085	.225	12.1
				61.0
			Average	12.2

Table 5—Continued.

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
2	2¾ x 3¼	8.9	10200	1150
5	2¾ x 3¾	10.3	15700	1520
6	2¾ x 3¼	8.9	19100	2150
6	2¾ x 3	8.2	23200	2840
9	2¾ x 4	11.0	28800	2620
				10280
				Average ..2056

K₄c—SPRINGFIELD, ILL.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1......	2.58	3.95	6	11220	2520	2360	+160	6.8
2......	2.65	3.80	6	10350	2440	....	+ 80	3.4
3......	2.60	3.85	6	12630	2960	....	+600	25.4
4......	2.55	3.90	6	8260	1920	....	—440	18.7
5......	2.62	4.00	6	10510	2260	....	—100	4.2
6......	2.62	3.95	6	9400	2080	....	—320	13.6
				62370	14180			72.1
			Average	10395	2360	....	....	8.0

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
1	2.52	2.67	.15	5.95
2	2.51	2.61	.10	4.00
3	2.54	2.67	.13	5.12
4	2.425	2.56	.135	5.57
5	2.54	2.645	.105	4.14
				24.78
			Average	5.00

Table 5—Continued.

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1	2⅝ x 4	10.5	55400	5280
5	2⅝ x 3¾	9.8	52000	5300
5	2⅝ x 3½	9.2	56700	6170
6	5⅝ x 3¾	9.8	40200	4100
6	2⅝ x 3½	8.5	41700	4900
				25750
			Average	5150

K₄d—SPRINGFIELD, ILL

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	2.68	2.65	6	9120	2300	2250	+ 50	2.2
2	2.62	3.85	6	10770	2490	....	+240	10.7
3	2.58	3.88	6	11290	2610	....	+360	16.0
4	2.60	3.80	6	8350	2000	....	—250	11.1
5	2.62	3.82	6	10690	2520	....	+270	12.0
6	2.62	3.78	6	7470	1800	....	—450	20.0
7	2.62	3.90	6	10290	2330	....	+ 80	3.6
8	2.65	3.70	6	7850	1950	....	—300	13.3
9	2.65	3.70	6	11360	2820	....	+570	25.3
10	2.68	3.70	6	8170	2010	....	—240	10.7
11	2.55	3.90	6	8350	1940	....	—310	13.8
12	2.65	3.80	6	9410	2220	....	— 30	1.3
				113120	26990			140.0
			Average	9430	2250	....	....	11.7

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
D₁1	2.69	2.72	.03	1.1
2	2.76	2.794	.034	1.2
D₂1	2.645	2.675	.03	1.1
2	2.79	2.82	.03	1.1
3	2.565	2.593	.028	1.1
				5.6
			Average	1.1

Table 5—Continued.

K₄e—SPRINGFIELD, ILL.

TRANSVERSE TEST.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq.in.	Av.Mod.	Variation from average.	Per cent variation.
1....	2.60	3.98	6	16150	3530	1890	+1640	86.7
2....	2.63	4.03	6	3000	635	....	—1255	66.4
3....	2.65	4.10	6	9140	2000	....	+ 110	5.8
4....	2.70	4.08	6	8800	1760	....	— 130	6.9
5....	2.70	4.05	6	12260	2490	....	+ 600	31.8
6....	2.63	4.10	6	4430	905	....	— 985	52.2
				53780	11320			249.8
			Average	8960	1890	....		41.6

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
1	1.69	1.702	.012	0.6
2	1.625	1.642	.017	.7
3	1.64	1.655	.015	.6
4	2.37	2.392	.022	.5
5	2.635	2.665	.030	.5
				2.9
			Average	0.6

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1....................	2⅝ x 3⅜	8.8	33200	3780
3....................	2⅝ x 4	10.5	31800	3020
3....................	2⅝ x 4	10.5	31600	3000
4....................	2⅝ x 2¾	7.2	34600	4800
6....................	2⅝ x 3	7.9	26300	3340
				17940
		Average		3588

Table 5—Continued.

V8c—STREATOR PAVING BRICK COMPANY.

ABSORPTION.

NUMBER.	Kilos.			Per cent.
	Dry.	Wet.	Gain.	
$c_2 1$...	....	....	....	0.89
2..	....	....	....	3.96
c 1...	....	....	....	5.05
2..	....	....	....	4.24
3..	....	....	....	3.41
				17.55
			Average	3.51

V8d.

d 1...	....	....	....	0.47
2..	....	....	....	0.50
$d_2 1$...	....	....	....	0.46
2..	....	....	....	0.48
3..	....	....	....	0.46
				2.37
			Average	.49

V8e.

$e_2 1$...	....	....	....	0.00
2..	....	....	....	0.50
e 1...	....	....	....	0.47
2..	....	....	....	0.49
3..	....	....	....	0.50
				1.96
			Average	.39

$K_{10}b$—TERRE HAUTE BLOCK, TERRE HAUTE, IND.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of rupture,—pounds per sq. in.	Av.Mod.	Var. from av.	Per cent var.
1......	3.40	4.00	6	8510	1410	1375	+ 35	2.5
2......	3.20	4.10	6	7960	1330	....	− 45	3.3
3......	3.35	4.05	6	8560	1410	....	+ 35	2.5
4......	3.25	3.95	6	9170	1630	....	+255	18.6
5......	3.25	3.98	6	8030	1410	....	+ 35	2.5
6......	3.22	3.90	6	4480	825	....	−550	40.0
7......	3.35	3.95	6	8520	1470	....	+ 95	6.9
8......	3.42	4.10	6	12060	1890	....	+515	37.5
9......	3.25	3.90	6	5560	1010	....	−365	21.6
				72850	12385			135.4
			Average	8090	1375	....	....	15.0

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$b_1$1	2.69	2.948	.258	9.6
2	2.758	3.04	.282	10.2
3	2.39	2.565	.175	7.3
$b_2$1	2.42	2.64	.22	9.1
2	2.625	2.872	.247	9.4
				45.6
			Average.....	9.1

$K_{10}c$—TERRE HAUTE BLOCK, TERRA HAUTE, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of rupture,— pounds per sq. in.	Av.Mod.	Var. from av.	Per cent var.
1.....	3.15	3.71	6	11100	2300	1910	+ 390	20.4
2.....	3.30	3.72	6	4330	855	....	—1055	55.2
3.....	3.30	3.65	6	11730	2410	....	+ 500	26.2
4.....	3.25	3.80	6	4750	910	....	—1000	52.4
5.....	3.22	3.88	6	10560	1960	....	+ 50	2.6
6.....	3.30	3.75	6	12160	2360	....	+ 450	23.5
7.....	3.20.	3.80	6	8540	1660	....	— 250	13.1
8.....	3.20	3.80	6	10360	1950	....	+ 40	2.1
9.....	3.22	3.94	6	14480	2600	....	+ 690	36.1
10.....	3.35	3.85	6	11660	2110	....	+ 200	10.5
				99670	19110	....	....	242.1
			Average	9667	1910	....	....	24.2

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$c_1$1..................................	2.865	2.97	.105	3.7
2..................................	3.33	3.37	.04	1.2
3..................................	2.615	2.658	.043	1.6
$c_2$1..................................	2.91	2.968	.058	2.0
2..................................	3.065	3.105	.04	1.3
				9.8
			Average	2.0

Table 5—Continued.

$K_{10}d$—TERRE HAUTE BLOCK, TERRE HAUTE, IND.

TRANSVERSE.

No.	Breadth, inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Var. from av.	Per cent var.
1..............	3.20	3.75	6	14300	2870	2340	+530	22.6
2..........	3.25	3.75	6	11680	2300	....	— 40	1.7
3..............	3.15	3.75	6	13300	2710	....	+370	15.8
4..............	3.20	3.90	6	9680	1800	....	—540	23.1
5..............	3.20	3.80	6	11280	2210	....	—130	5.5
6..............	3.23	3.88	6	12290	2290	....	— 50	2.1
7..............	3.20	3.85	6	11730	2230	....	—110	4.7
				84260	16410	....		75.5
			Average	12040	2340	....		10.8

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$d_1$1	2.843	2.868	.025	0.9
2	2.61	2.625	.015	0.6
3	2.69	2.718	.028	1.0
$d_2$1	2.68	2.718	.038	1.4
2	2.51	2.538	.028	1.1
				5.0
			Average	1.0

CRUSHING.

Number.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lbs. per sq. in.
2..................	3¼ x 3¼	10.6	76700	7250
4..................	3¼ x 4	13.	76800	5900
4..................	3¼ x 3	9.7	34700	3580
5..................	3¼ x 3½	11.4	71500	6250
6..................	3¼ x 3⅛	10.1	70000	6940
				29920
			Average	5984

Table 5—Continued.

K10e   TERRE HAUTE BLOCK, TERRE HAUTE, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span - inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av. Mod.	Variation from average.	Per cent variation.
1	3.25	4.00	6	18010	3130	1880	+1250	66.5
2	3.33	3.88	6	12260	2200	....	+320	17.0
3	3.45	4.15	6	7250	1100	,..........	—780	41.5
4	3.40	4.10	6	13200	2080	....	+200	10.6
5	3.25	3.85	6	8020	1500	....	—380	20.2
6	3.32	4.22	6	10020	1530	....	—350	18.6
7	3.30	4.00	6	10100	1720	....	—160	8.5
8	3.30	4.00	6	7930	1350	....	—530	28.2
9	3.35	3.85	6	12670	2290	....	+410	21.8
				99460	16900	....	....	232.9
			Average	11050	1880			25.9

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$c_1$1	2.74	2.765	.025	0.9
2	3.03	3.048	.018	.6
3 ....:...............	2.80	2.82	.02	.7
$c_2$1	2.74	2.762	.022	.8
2	2.578	2.605	.027	1.0
				4.0
			Average	0.8

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
7	$3\frac{1}{4}$ x $3\frac{3}{4}$	11.	24300	2200
8	$3\frac{1}{4}$ x $3\frac{3}{4}$	12.2	43000	3520
9	$3\frac{1}{4}$ x $4\frac{1}{8}$	13.4	21000	1570
9	$3\frac{1}{4}$ x $3\frac{1}{2}$	11.4	21400	1880
10	$3\frac{1}{4}$ x $4\frac{3}{8}$	14.2	41500	2920
				12090
			Average	2418

Table 5—Continued.

H₂b   TOPEKA, KAN.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
2	2.58	3.90	6	8840	2030	2300	— 270	11.7
3	2.34	3.84	6	10540	2750	....	+ 450	19.6
4	2.46	3.90	6	12610	3040	....	+ 740	32.2
5	2.52	3.88	6	10360	2520	....	+ 220	9.6
6	2.46	3.84	6	8280	2020	....	— 280	12.2
7	2.46	4.02	6	11250	2550	....	+ 250	10.9
8	2.28	4.02	6	10160	2480	....	+ 180	7.8
9	2.44	3.90	6	8950	2180	....	— 120	5.2
10	2.46	3.96	6	9740	2270	....	— 30	1.3
11	2.52	3.84	6	9090	2220	....	— 80	3.5
12	2.46	3.96	6	9500	2220	....	— 80	3.5
13	2.44	3.90	6	5520	1340	....	— 960	41.8
				114840	27620	....	....	159.3
			Average	9570	2300	....	....	13.3

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1	2.235	2.315	.02	0.9
2	2.19	2.225	.035	1.6
3	2.098	2.118	.02	1.0
b₂1	2.092	2.115	.023	1.0
2	2.182	2.215	.033	1.5
				6.0
			Average	1.2

K₈b—WABASH CLAY CO., WEEDERSBURG, IND.

TRANSVERSE.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq.in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.62	3.90	6	1730	285	585	—300	51.3
2	3.60	3.95	6	4170	670	....	+ 85	14.5
3	3.50	4.05	6	4380	690	....	+105	17.9
4	3.50	4.05	6	4860	765	....	+180	30.8
5	3.60	3.90	6	4530	745	....	+160	27.3
6	3.55	4.00	6	2740	435	....	—150	25.6
7	3.60	3.95	6	3260	520	....	+ 65	11.1
8	3.50	4.09	6	3630	585	....	0	.0
				29300	4695			178.5
			Average	3660	585		....	22.3

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
b₁1	3.128	3.43	.302	9.7
2	3.055	3.338	.283	9.3
3	3.135	3.47	.335	10.7
b₂1	2.712	2.98	.268	9.9
2	3.192	3.485	.293	9.7
				49.3
			Average	9.9

CRUSHING.

Number.	Size— square inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1	3½ x 3⅝	12.7	56900	4500
3	3½ x 3 ⅝	12.7	34300	2700
4	3½ x 4	14.	26500	1890
4	3½ x 3½	10.9	27000	2480
8	3½ x 4¼	14.9	31800	2140
				13710
				Average 2742

K₈c—WABASH CLAY CO., VEEDERSBURG, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modluus of Rupture— pounds per sq. in.	Av.Mod.	Variations from Average.	Per cent Variation.
1.....	3.50	3.90	6	5530	940	1035	— 95	9.2
2.....	3.50	3.95	6	6730	1110	....	+ 75	7.2
3.....	3.50	3.90	6	5120	870	....	—165	16.0
4.....	3.52	3.88	6	7620	1300	....	+265	25.6
5.....	3.50	3.90	6	4470	755	....	—280	27.1
6.....	3.50	3.98	6	6040	980	....	— 55	5.3
7.....	3.55	3.92	6	7810	1290	....	+255	24.7
				43320	7245	....	....	115.1
			Average	6190	1035	....	....	16.4

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$c_1$1	3.135	3.38	.245	7.8
2	3.130	3.34	.21	6.7
3	3 098	3.375	.277	8.9
$c_2$1	3.085	3.345	.26	8.4
2	3.202	3.444	.242	7.6
				39.4
			Average	7.9

CRUSHING.

Number.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lbs. per sq. in.
1....................	3½ x 4⅜	15.3	83200	5440
2....................	3½ x 4	14.0	61400	4380
2....................	3½ x 5	17.5	65900	3760
3....................	3½ x 4½	15.7	47500	3020
4....................	3½ x 4½	15.7	107400	6800
5....................	3½ x 2⅝	9.2	37200	4040
6....................	3½ x 4⅝	16.2	72040	4450
7....................	3½ x 4⅜	15.3	46500	3040
7....................	3½ x 4¼	14.8	64400	4320
				39250
			Average........	4361

K8d—WABASH CLAY CO., VEEDERSBURG, IND.

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture— pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.48	3.80	6	10350	1860	1440	+420	29.2
2	3.38	3.90	6	5760	1010	....	—430	29.8
3	3.35	3.90	6	10960	1940	....	+500	34.7
4	3.45	3.80	6	10990	1990	....	+550	38.2
5	3.40	3.85	6	7750	1390	....	— 50	3.5
6	3.35	3.88	6	7190	1290	....	—150	10.4
7	3.40	3.80	6	3110	570	....	—870	60.3
8	3.40	3.80	6	9060	1660	....	+220	15.3
9	3.40	3.83	6	7050	1280	....	—160	11.1
				72220	12990			232.5
			Average	8020	1440	....	....	25.8

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry	Wet.	Gain.	
d_1...............	3 285	3.40	.115	3.5
2...................................	3.22	3.355	.135	4.2
3...................................	3.312	3.445	.133	4.0
$d_1$1.................................	3.362	3.488	.126	3.8
2...................................	3.362	3.40	.138	4.2
				19.7

CRUSHING.

Number.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lb. per sq. in.
1......................	3½ x 3¼	11.4	57800	5060
2......................	3½ x 3⅝	12.7	35900	2820
5......................	3½ x 3	10.7	26100	2480
7......................	3½ x 3¼	11.4	61500	5400
8......................	3½ x 3¼	11.4	71000	6230
				21990
				Average ... 4398

K_se—WABASH CLAY CO., VEEDERSBURG, IND.

TRANSVERSE TEST.

No.	Breadth—inches.	Depth—inches.	Span—inches.	Load—pounds.	Modulus of Rupture—pounds per sq. in.	Av.Mod.	Variation from average.	Per cent variation.
1	3.50	3.84	6	4350	760	810	— 50	6.2
2	3.50	4.00	6	6590	1060	....	+250	30.8
3	3.50	3.95	6	4050	670	....	—140	17.3
4	3.50	4.00	6	4900	790	....	— 20	2.5
5	3.50	3.90	6	2200	370	....	—440	54.3
6	3.55	3.80	6	2700	475	....	—335	41.3
7	3.50	3.80	6	1880	335	....	—475	58.6
8	3.50	3.90	6	1900	320	....	—490	60.5
9	3.52	4.00	6	11000	1760	....	+950	117.4
10	3.52	4.00	6	9750	1560	....	+750	92.5
				49320	8090			481.4
			Average	4930	810	....	....	48.1

Table 5—Continued.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
....	2.11	2.13	.02	1.0
2..................................	2.725	2.77	.045	1.6
3..................................	3.76	3.815	.055	1.5
4..................................	2.495	2.54	.045	1.8
5..................................	3.6	3.67	.07	1.9
				7.8
			Average	1.6

CRUSHING.

NUMBER.	Size— inches.	Area— square inches.	Load— pounds.	Stress— lb. per sq. in.
1...................	3½ x 3½	12.2	89300	7300
2...................	3½ x 3	10.5	70600	6730
5...................	3½ x 3½	10.9	100000	9160
7...................	3½ x 3½	12.2	115000	9450
10..................	3½ x 3¾	13.1	70100	5350
				37990
			Average 7598	

K₁₄b—WESTERN PAVER, DANVILLE, ILL,

TRANSVERSE.

No.	Breadth— inches.	Depth— inches.	Span— inches.	Load— pounds.	Modulus of Rupture, pounds per sq.in.	Av.Mod.	Var. from av.	Per cent var.	Remarks
1....	3.48	4.08	6	9180	1424	1617	−193	11.9	
2....	3.54	4.06	6	9820	1515	....	−102	6.3	
3....	3.48	4.02	6	11220	1795	....	+178	11.0	
4....	3.58	3.96	6	9610	1541	....	− 76	4.7	
5....	3.46	4.08	6	9260	1447	....	−170	-10.5	
6....	3.60	4.02	6	10510	1625	....	+ 8	0.5	
7....	3.48	4.02	6	10330	1653	....	+ 36	2.2	
8....	3.48	3.96	6	10310	1700	....	+ 83	5.1	
9....	3.46	4.02	6	10120	1629	....	+ 12	0.7	
10....	3.60	3.90	6	8300	1364	....	−253	15.6	Irregular
11....	3.42	4.02	6	12860	2094	....	+477	29.5	shape
12....	3.58	4.02	6	10370	1613	....	− 4	0.2	caused
				121890	19400			98.2	eccentric load.
			Average	10160	1167	....	....	8.2	

Table 5—Concluded.

ABSORPTION.

NUMBER.	KILOS.			Per cent.
	Dry.	Wet.	Gain.	
$b_1 1$	3.512	3.676	.164	4.7
2	3.810	3.975	.165	4.3
3	3.725	3.875	.150	4.0
$b_2 1$	3.505	3.675	.170	3.9
2	3.700	3.855	.155	4.2
				21.1
			Average	4.2

CRUSHING.

Number.	Size—inches.	Area—square inches.	Load—pounds.	Stress—lb. per sq. in.
5	$3\frac{1}{2}$ x 4	14.	50000	3580
7	$3\frac{1}{2}$ x 4	14.	94500	6750
9	$3\frac{1}{2}$ x $3\frac{3}{4}$	13.1	86800	6640
10	$3\frac{1}{2}$ x $3\frac{1}{2}$	12.2	51200	4200
11	$3\frac{1}{2}$ x $3\frac{1}{2}$	12.2	60400	4950
				26120
			Average	5224

QUALITIES OF CLAYS SUITABLE FOR MAKING PAVING BRICK.

[By Ross C. Purdy.]

Introduction.

Nature of the Problems Involved—In Holland brick has been used for street paving for more than a century, and in the United States for over thirty years. During this period, ceramics, or the study of clay working, has been developed as a science to such an extent as to become, especially in the last decade, a prominent factor in the technical advance that has been made in the various clay industries. The application of pure science, notably physics and chemistry, has solved a great many practical problems that clay workers have met in their endeavor to keep pace with the ever increasing requirements for better quality and greater adaptations of ware.

Ceramics, or the application of pure science to clay working, has been developed chiefly along two lines: first, the applications of mechanics to the evolution of methods of winning raw materials, and manufacturing of wares; second, the application of physical and chemical principles to the selection and mixing of clays and minerals.

Along these two lines ceramics has attained its greatest development in the pottery, floor and wall tile, and kindred industries where white burning-clays and pure minerals are blended in the manufacture of wares. The compounding of the white ware mixtures and the processes for their manufacture can now be said to have emerged from the strictly empirical stage and to· have reached a degree of perfection that correctly merits the designation of "applied science."

In the brick, tile and kindred industries which use more complex clays—clays that naturally contain sufficient fluxes to produce the requisite degree of hardness in the burned ware—ceramics has developed principally along the first line, the application of mechanical principles to the processes of manufacture. In this, ceramics has kept abreast of the demands. Along the second line, the application of pure science to the determination and control of the properties of body mixtures, but very little progress has been made. In this, science has been baffled by the complexity of the mineral mixture which nature has compounded and man calls clay.

Complexity of properties is the natural result of complexity of mineral composition. If this complexity of mineral composition resulted simply in variation of chemical constituent, the problem would be comparatively simple, but the physical properties of each of the several minerals are nearly, if not equally, as potent factors in complicating the problems, as the chemical.

The science of ceramics is making rapid progress in the solution of these problems; but today the question of what physical and chemical properties raw clay must possess that it might be suitable for use in the manufacture of paving brick is still unanswerable. Chemical analysis alone is not a safe criterion by which to decide this and similar questions, for, as can be shown in nearly, if not all, geological survey reports on clays, the analyses of clays that are known to be suitable for paving brick have their counterparts in analyses of building brick clays. Indeed in range of variation in chemical constituents, these two types of clays overlap one another to a very large extent. There are possibly one or two characteristics in the chemical composition of paving brick clays that are not common to those used for building brick, and yet no fixed rule has been, or so far as the writer can perceive, can be, laid down at present, by which to identify paving brick clay by chemical analysis.

Physical tests on green or unburned clay, so far as is now known, would not lead one any nearer the possibility of fairly judging a paving brick clay than would chemical analysis. Possibly an exception should be made of determinations of fineness of grain. Plasticity, tensile strength, bonding power, slaking properties, etc., are found to vary widely in different paving brick clays, so that no dependence can be placed upon any of them, taken alone. The determination of fineness of grain, however, does give a negative test that seems to be of some value.

Fine grained clays, as will be seen later, have not proved to be good paving brick clays. It cannot be said, however, that all coarse grained clays are good paving brick clays. Indeed, although evidence is lacking, there is no obvious reason for believing that any hard and fast rule can at present be laid down in regard to either fine or coarse grained clays.

When the history of a few paving brick plants in various parts of this country reveals the fact that experienced paving brick manufacturers have so misjudged a deposit of clay as to erect an extensive plant upon a particular site and soon find that they must abandon the idea of attempting to make any other than a building brick, it must be inferred that even a burning test as ordinarily conducted by ceramic engineers, surveys and brick machine manufacturers likewise often gives evidence that is untrustworthy. By what means then can the suitability of a clay for paving brick purposes be ascertained?

It was with hopes of obtaining evidence upon this problem that the Survey undertook a study of the properties of the clays and burned bricks of several of the leading paving brick manufacturies in the middle west, together with several samples of clays from various parts of this state, that are not now being used for paving brick manufacture.

For many years scientists have been devising methods with which to determine the cause and effect of the various properties of clay, but they have not made much progress. For instance, the reason why a kaolin and a ball clay, having similar chemical composition and size and apparently character of grain, should differ so widely in plasticity,

is still an open question. The refractoriness of a clay is still incalculable from analytical data, although exhaustive researches have been made to determine the pyro-chemical effect of inorganic acids and bases, singly, collectively, and in mixtures, with standard clays and compounds. While from these pyro-chemical studies it has been shown that the fluxing power of the bases is roughly proportional to their molecular weight, and that the several acids operate in a definite manner, so that synthetical mixtures can be made with assurance that each component will operate in a given manner, and that the resultant effect of the mixtures will in general be as presupposed, similar natural mixtures, known as clays, exhibit properties that are in the large majority of cases entirely contradictory to those of synthetical mixtures, due no doubt to differences in the physical properties of the minerals as well as to variation in mineral content.

Many theories have been advanced concerning the geological history of clays, and general statements can be made as to the probable conditions that cause the breaking down of the parent rock, the character of the residual debris, the agencies sorting and transporting this debris, and the conditions under which it can be deposited in different grades of fineness and purity. Geologists can state with considerable accuracy, the effect of vegetable growth and of ground water, the cause for the precipitation of salts from solutions, the cementing value of various compounds under different conditions, etc. They can establish the fact that there is a cycle of rock decomposition, residual deposition, and rock formation going on constantly *en masse,* as well as in the small grains of which clay and soils are composed. Yet, after all, neither geologists nor chemists are able to determine the exact stage of breaking down or building up, nor the exact combination of several ingredients existing in a clay at the time of examination. It certainly seems patent that until we can determine the exact mineralogical condition and chemical aggregation of a given clay it will be impossible to use the analytical data obtained by ordinary physical and chemical tests as ground for predictions concerning its probable pyro-chemical behavior.

In the process of any chemical analysis known to the writer, the character and exact identity of the clay as a whole, as well as its constituent parts, are destroyed by the disintegration or unlocking of the natural combinations, making an exact or complete determination of the chemical conditions originally present, a mere supposition. In fact all we know or can learn from a study of the origin and mode of formation of clays, and of the alterations in their composition constantly going on under varying conditions, as well as by attempts to unlock the combinations or separate the ingredients by chemical methods is, that we are arresting the changes of transition in the clay from one state to another, but are not able to ascertain the forms or conditions existing at that time. From these considerations it should be plain that two samples of clays having similar origin and chemical constitution, may differ radically in their mineralogical make-up. The kind, size and composition of the several minerals affect so materially the pyro-chemical properties of the clay as a whole, that until mineralogists can find means of determin-

ing the kind, quantity and relative size of the several mineral ingredients, ceramists cannot predict, even with a fair degree of accuracy, the behavior of a clay in burning.

Several of the so called physical properties of raw clay may, however, be measured and their effect on the behavior of the clay described. In this, physical conditions of the clay, such as hardness, fineness of grain, plasticity, etc., are by custom regarded as properties.

The properties of clays may be classified under three general heads: Physical, chemical, and pyro-chemical.

PHYSICAL PROPERTIES.

Introduction.

Ceramists have tested clays by all the means that have been suggested to them. Many of the tests have proven fruitless, and not a few now in use are of doubtful value.

The following physical tests on raw clays were made by the State Survey:

1. Specific gravity of the clay, or mineral aggregate. 2. Porosity of a dry, unburned brick made from "stiff mud." 3. Drying behavior. 4. Shrinkage. 5. Tensile strength. 6 Fineness of grain. 7. Water of plasticity. 8. Plasticity.

Specific Gravity.

REAL AND APPARENT SPECIFIC GRAVITY.

The determination of the specific gravity of a clay, if made at all, should be so conducted that the result would be a composite of the specific gravities of the several minerals that make up the clay mass. If the specific gravity of a lump be taken as a whole, unless the mass be so thoroughly saturated that each grain becomes surrounded by the saturating medium, it would vary with all kinds of irregularities incident to the processes of formation or manufacture. The first method would give what is known as true specific gravity, while the second would give only an apparent value.

The writer can see no value in finding the *apparent* specific gravity, for, as a means of detection of any *working property,* it is absolutely valueless. The true specific gravity *may* have direct value as indicating some working property of the clay, but if it has, the fact has not been demonstrated. The data for the true specific gravity can, however, be used, as will be demonstrated later, in the analysis of some of the changes that take place in drying and burning, and serves as a check on the accuracy of some of the other data.

METHODS OF DETERMINATION.

The true specific gravity of the clays included in this report was obtained by three methods: By Seger volumeter, using unburned bricks; by pycnometer; by chemical balance, using unburned bricks.

Determination by Seger's Volumeter.—Seger's volumeter was used in the determination of the volume shrinkage, porosity and specific gravity on the several clays, as noted in Table I.

TABLE I—Results of Physical Tests on Green Bricks.

	Kiln Letter	Sample number		Porosity %var	Porosity Avg	Porosity Min	Porosity Max	Sp. Gr. %var	Sp. Gr. Avg	Sp. Gr. Min	Sp. Gr. Max	Lin. Shr. %var	Lin. Shr. Avg	Lin. Shr. Min	Lin. Shr. Max	Vol. Shr. %var	Vol. Shr. Avg	Vol. Shr. Min	Vol. Shr. Max	Hygr. %var	Hygr. Avg	Hygr. Min	Hygr. Max	Plast. %var	Plast. Avg	Plast. Min	Plast. Max

Note: The original is a single large table in landscape orientation. Its structure is given below, grouped by measurement category; each category has the sub-rows Per cent variation, Average, Minimum, Maximum. Columns correspond to samples. Best-effort readings follow.

Sample	Kiln Letter	Porosity %var	Porosity Avg	Porosity Min	Porosity Max	Sp. Gr. %var	Sp. Gr. Avg	Sp. Gr. Min	Sp. Gr. Max	Lin. Shr. %var	Lin. Shr. Avg	Lin. Shr. Min	Lin. Shr. Max	Vol. Shr. %var	Vol. Shr. Avg	Vol. Shr. Min	Vol. Shr. Max	Hygr. %var	Hygr. Avg	Hygr. Min	Hygr. Max	Plast. %var	Plast. Avg	Plast. Min	Plast. Max
K1	S	11.04	26.06	24.8	27.7	3.9	2.54	2.51	2.61	133.3	1.50	0.8	2.8	33.8	6.2	5.5	7.6	13.9	2.01	1.88	2.16	4.9	14.9	14.6	15.3
K2	E	9.4	25.56	23.7	26.12	3.1	2.57	2.54	2.62	70.	3.47	2.1	4.6	2.4	12.20	12.00	12.30	9.9	1.62	1.55	1.70	4.11	16.77	15.23	17.0
K3	H	7.8	25.8	24.8	26.8	3.8	2.57	2.52	2.62	68.6	2.06	2.00	3.0	16.7	10.45	9.55	11.3	4.1	2.43	2.64	2.54	2.9	16.82	16.5	17.0
K4	D	9.3	27.81	26.6	29.2	4.6	2.58	2.51	2.66	73.6	3.28	0.8	4.8	16.7	5.17	4.32	5.67	13.0	0.923	0.87	0.99	5.4	13.06	12.8	13.5
K5	N	6.9	28.86	28.2	29.63	1.9	2.63	2.6	2.69	129.9	1.55	0.8	4.8	10.3	10.06	9.32	10.7	19.5	1.23	1.08	1.32	2.8	17.03	16.8	17.4
K6	R	4.1	27.9	27.2	29.1	1.5	2.59	2.54	2.65	43.9	4.1	2.4	4.4	6.7	9.62	9.66	10.35	25.9	1.93	1.65	2.15	8.6	17.57	16.8	17.9
K7	Q	1.7	25.2	24.1	25.9	7.7	2.64	2.51	2.67	51.2	4.9	1.0	4.4	10.3	9.27	6.72	10.0	4.7	1.70	1.66	1.74	6.0	14.4	14.2	14.6
K8	K	1.1	25.1	24.7	25.8	3.0	2.56	2.59	2.67	75.0	2.1	0.6	3.1	5.8	3.54	2.76	3.97	20.4	0.79	0.75	0.81	8.67	14.4	14.1	14.9
K9	G	7.1	25.44	25.3	26.6	0.9	2.56	2.51	2.68	37.8	0.9	0.5	8.2	21.5	18.29	18.24	18.34	13.4	2.31	2.19	2.50	3.74	19.6	18.7	20.4
K10	L	1.1	22.21	18.5	23.18	3.1	2.30	2.47	2.59	73.8	5.82	0.0	4.4	34.1	13.5	12.65	13.4	11.5	1.75	2.14	2.38	9.7	15.23	12.80	15.46
K11	F	3.8	18.26	16.3	20.5	1.6	2.65	2.62	2.68	24.4	3.25	0.6	4.4	0.5	13.5	12.65	10.62	8.1	5.09	4.93	5.52	9.7	15.3	15.0	14.00
K12	M	3.5	28.3	27.2	28.5	6.4	2.6	2.31	2.64	48.4	3.6	0.8	4.6	6.9	6.13	5.82	6.53	7.1	2.16	2.14	2.33	6.7	16.3	15.6	16.7
K13	I	27.0	24.5	23.2	29.1	3.3	2.41	2.21	2.67	93.3	3.5	1.2	4.6	11.5	6.13	5.82	6.53	8.1	0.795	0.693	0.86	4.7	16.9	16.4	17.2
K14	C	23.0	24.5	23.2	24.4	2.3	2.56	2.50	2.64	60.0	2.7	0.36	4.0	19.0	11.97	11.44	13.71	6.5	4.76	4.52	4.83	11.1	16.2	16.2	17.9
K15	C²	4.6	28.5	27.8	29.2	1.9	2.6	2.61	2.56	42.8	4.2	3.3	4.8	10.6	13.1	12.5	14.0	10.7	2.42	2.30	2.56	10.7	16.6	16.1	17.1
S1	L	4.5	24.0	24.7	24.3	3.8	2.53	2.54	2.61	53.3	4.3	3.1	4.5	5.7	9.1	8.00	10.31	32.3	1.95	2.30	2.42	10.2	13.2	13.1	14.0
S2	O	4.3	17.8	16.72	27.9	6.5	3.62	2.53	2.56	124	1.94	3.0	6.8	25.3	5.98	5.76	6.16	10.4	1.94	1.39	1.55	0.3	13.3	13.1	13.6
R1	S	39.0	26.4	25.5	24.2	3.5	2.47	2.51	2.61	65.4	4.5	4.1	5.1	6.7	1.15	11.0	11.9	20.5	2.02	1.67	2.33	1.3	13.3	12.5	13.6
R2	T	6.0	23.6	23.2	24.3	2.5	2.50	2.55	2.59	43.7	4.6	4.2	5.0	7.8	7.32	6.98	7.9	9.0	2.67	2.05	2.35	3.8	14.6	14.5	14.7
R3	U	12.0	23.6	23.6	27.1	1.9	2.46	2.40	2.56	15.2	3.7	3.0	5.1	12.5	14.3	13.7	14.8	24.5	1.14	1.08	1.89	2.1	11.8	11.5	12.0
R4	V	1.7	24.0	23.6	24.0	2.3	2.56	2.51	2.49	78.3	7.0	4.1	6.4	2.9	13.8	13.6	14.0	12.3	3.07	2.82	3.25	4.5	16.5	15.9	16.8
F1	D²	2.3	24.0	23.0	22.6	1.1	2.5	2.50	2.49	34.2	5.7	4.9	6.6	2.1	14.4	14.1	14.7	1.5	1.94	2.97	2.87	5.2	16.4	16.1	16.3
B-II		3.4	26.9	26.0	20.3	2.1	2.46	2.45	2.49	56.1	6.2	4.2	7.4	4.6	9.7	7.17	10.20	9.5	2.02	1.60	3.14	4.2	16.6	16.0	16.3
G-II		2.0	20.8	18.9	25.7	2.9	2.56	2.41	2.56	26.5	7.0	5.4	7.4	19.6	21.4	20.7	21.7	16.0	1.74	1.89	1.89	6.8	16.3	15.1	18.3
H-II		2.9	18.9	18.1	27.3	1.8	2.56	2.52	2.59	21.6	6.2	5.6	8.0	4.6	16.5	16.2	16.7	30.0	2.46	2.04	2.74	3.3	18.3	18.0	18.3
H16	P	1.8	24.2	22.9	28.9	2.2	2.5	2.46	2.56	43.2	7.4	5.6	8.0	3.0	18.0	16.8	20.0	20.9	2.58	2.32	4.22	2.7	18.0	17.8	18.8
H17	F11	9.8	27.8	26.5	20.0	3.2	2.56	2.46	2.56	45.0	4.0	3.6	8.4	10.5	11.4	10.07	11.9	14.7	1.63	1.50	1.74	6.2	12.8	12.5	13.3

The accuracy of the tests in the volumeter is shown in Table I by the percentage of variation volume shrinkage, specific gravity and porosity. These variations are very small considering the conditions under which the determinations were made.

The specific gravity of any substance is the ratio of the weight of that substance to the weight of an equal volume of some substance taken as a standard. In the metric system distilled water at 4°C. is taken as the standard. At this temperature a cubic centimeter of distilled water weighs one gram. Therefore, when using this system, volume and weight of water may be interchanged, i. e., 1 c.c.=1 gram.

With this understanding the formula by which the specific gravity of a clay can be obtained could be expressed as;

$$\frac{W}{V} = Sp. \ gr.$$

where W=dry weight in grams and V=volume in cubic centimeters. If the porosity of the brick has been determined the formula for the specific gravity could be written:

$$\frac{W}{V \ (100-P)} = Sp. \ gr.$$

Where W=dry weight as before, V=volume of the brick in cubic centimeters and P=percentage porosity.

It will be noted by comparing the specific gravities in Tables I and II, that those obtained by the volumeter are lower than those obtained by the pycnometer. This can be accounted for perhaps by the operator's inability completely to saturate a brick, that is, to fill all the pore spaces with oil without resorting to the use of a suction or vacuum pump to remove all the air from the pores so that oil could enter. If the air is not entirely exhausted it will pass through the oil very slowly, requiring a period extending over several weeks in which to esape. In ordinary laboratory practice sufficient time can not be given to permit the complete escape of the included air. In the porosity and specific gravity tests here reported, no attempt was made to fill the pores completely. The bricks were simply soaked in coal-oil for 48 hours, with one face exposed at the level of the surface of the oil. This incompleteness of saturation under these conditions is shown by the difference in the specific gravity as determined by the volumeter and pycnometer.

Determination by Pycnometer.—A pycnometer, or specific gravity bottle, as it is often called, is a small flask of known capacity, usually 25 to 100 c.c. When filled up to a given mark with air-free water at normal room temperature, its weight is noted. The flask is then partly emptied, a known weight of clay added, and the whole carefully boiled to exclude all the entrapped air, then cooled, filled up to the mark and weighed. By the formula, weight of dry sample (a) plus weight of bottle filled with cold air-free water (b) minus weight of bottle filled with sample and water (c), or a+b—c, will give the weight of water having the same volume as the sample or true total volume of the clay particles. Knowing the dry weight and true volume of the grains, their composite specific gravity is readily calculated by the formula (dry weight ÷ volume).

This may be illustrated by the following calculation:

Weight of bottle filled with water = 143.22.
Dry weight of sample = 3.41.
Weight of bottle + sample + water required to fill to mark = 145.35.
143.22 + 3.41 — 145.35 = 1.28 total volume of the particles.
3.41 ÷ 1.28 = 2.68 specific gravity of the sample.

In the following table will be found specific gravity of the clays by the pycnometer method.

TABLE II.

		I	II	Average
K	1 Alton, Ill..	2.666	2.664	2.665
K	2 St. Louis, Mo..	2.602	2 527	2.564
K	3 Albion, Ill...	2.688	2.684	2.686
K	4 Springfield, Ill......................................	2.667	2.668	2.667
K	5 Edwardsville, Ill....................................	2.676	2.626	2.651
K	6 Galesburg, Ill.......................................	2.661	2.664	2.663
K	7 Streator, Ill...	2.643	2.63	2.636
K	8 Veedersburg, Ind....................................	2.693	2.685	2.689
K	9 Crawfordsville, Ind	2.701	2.703	2.702
K	10 Terre Haute, Ind....................................	2.683	2.689	2.686
K	11 Brazil, shale..	....	....	....
K	12 Brazil, fire clay....................................	2.667	2.671	2.669
K	13 Clinton, Ind..	2.682	2.708	2.695
K	14 Western Brick Co...................................	2.633	2.646	2.639
K	15 Barr Clay Co., Streator, Ill........................	2.719	2.713	2.716
R	1 Nelsonville, O.......................................	2.633	2.632	2.633
R	2 Portsmouth, O.......................................	2.719	2.712	2.715
R	3 Canton Imperial.....................................	2.655	2.656	2.655
R	4 Canton Royal	2.720	2.722	2.721
S	1 Moberly, Mo...	2.643	2.646	2.643
S	2 Kansas City, Mo.....................................	2.717	2.716	2.717
F	1 Danville Brick Co....................................	2.708	2.710	2.709
H	24 Carbon Cliff, fire clay..............................	2.660	2.654	2.657
H	17 LaSalle, Ill..	2.608	2.591	2.599
H	16 Peoria, Ill...	2.700	2.690	2.695
H	18 Sterling, Ill...	2.653	2.690	2.671
H	23 Carbon Cliff, shale.................................	2.628	2.624	2.626
H	21 Galena, Ill..	2.718	2.715	2.717
H	20 Savanna, Ill..	2.718	2.715	2.717
H-II Topeka, Kan.......................................		2.683	2.685	2.684
L-II Lawrence, Kan.....................................		2.702	2.707	2.705
I-II Casey, Kan...		2.668	2.676	2.672
J-II Pittsburg, Kan.....................................		2.699	2.697	2.698
B-II Atchison, Kan.....................................		2.666	2.668	2.667
G-II Coffeyville, Kan...................................		2.704	2.707	2.706

Determination with Chemical Balance.—The dry, saturated and immersed weights of briquettes were determined by using a chemical balance. For this it was found that briquettes of the size ½″x½″x2½″ could be used. Obviously the larger the briquette the more nearly true will be the determined specific gravity. Sizes larger than that given, however, cannot be used to advantage on the ordinary chemical balance. This method was used for but a small number of samples.

The briquettes were dried to constant weight in an air bath at 120°C. cooled in a dessicator and their dry weight obtained as rapidly as possible. After weighing, the briquettes were immersed in clarified coal-oil with one face above the level of the oil. After standing thus for 20 to 24 hours, they were placed under a bell jar and the air kept exhausted for fifteen minutes, it having been found in previous work that this treatment was sufficient to attain nearly complete saturation. The briquette was then suspended by a silk thread from the beam of a chemical bal-

ance and its saturated weight noted. A breaker partially filled with oil was then so placed that the briquette could swing clear and be completely immersed. In this manner the immersed weight of the briquette was obtained.

By the formula then of dry weight (D) divided by (dry weight (D) minus suspended weight (S)) or D ÷ (D—S), the specific gravity of the material in the briquette was readily obtained.

The comparative accuracy attained in the determination of the specific gravity of clay by these three methods may be seen in the table following.

TABLE III.

	Volumeter— Average.	Pycnometer— Average.	CHEMICAL BALANCE.		Average of three determinations.
			Max.	Min.	
K 1.........................	2.54	2.66	2.614	2.616	2.615
K 14.........................	2.60	2.64	2.69	2.57	2.65
K 4.........................	2.58	2.67	2.63	2.58	2.61

It is evident from this table that the essential fault in the first and third method of determining specific gravities lies in the fact that the brick was not completely saturated, and therefore, gave low specific gravities. The closeness in agreement, however, suggests that by the use of extra precaution in the saturation of the bricks the specific gravities of the clays could be made quite accurately by either of these two methods.

PorOSITY.

DEFINITION.

The percentage of porosity expresses the relation between the volume of pore space and the combined volume of the particles of which the clay is composed. It is the ratio, in terms of volumes, of void spaces to solid particles. If determined on an unburned brick it would measure the degree of consolidation of the mass.

METHOD OF DETERMINATION.

The porosity of an unburned clay mass may be determined directly by two methods: first, by use of the Seger volumeter; second, by the use of a chemical balance, and indirectly, or by calculation on basis of the pycnometer specific gravity determination.

To obtain percentage of porosity by either of the direct methods, the briquette or lump must be dried to constant weight, and the dry weight obtained, then saturated in kerosene and the saturated weight obtained. The difference between the saturated and dry weights is obviously the weight of petroleum that is required to fill the pores. This weight divided by 0.8, the density of the oil, gives the equivalence of oil in

terms of water. Thus far, therefore, the actual amount of pore space in the brick in terms of water by weight is known. If the metric system has been used throughout, this amount of water by weight is equivalent to its amount by volume, since one cubic centimeter of water at room temperature weighs practically one gram.

Complete saturation of a lump of unburned clay even with kerosene, for which clay seems to have a peculiar physical attraction, cannot be obtained without resorting to the use of a vacuum pump. Standing in oil for 48 hours is not sufficient to cause complete saturation, as has been shown on preceeding pages by the specific gravity so obtained, as well as by the discrepancy between the directly measured and the calculated porosity as given in table IV, page 144.

In obtaining the dry and saturated weights, the two direct methods are alike. The data for actual volume of the pores thus obtained are, however, of no value in themselves, and cannot become of value until calculated to parts of 100 unit volumes of the whole brick. For this, it is more practical to determine the volume of the whole mass, i. e., pores plus solid particles. It is in the determination of the volume of the mass that the two direct methods above mentioned are differentiated.

First method, Volumeter.—After complete saturation, the brick is placed in the volumeter and its volume determined in cubic centimeters. By the formula $100 \left(\dfrac{W-S}{V} \right)$ where W=weight of oil taken up by the brick, S=the specific gravity of the oil, and V=the volume of the brick, there is expressed the part of 100 unit volumes of the brick as a whole which consists of open pore. In other words, it is the percentage porosity.

By referring to Table I it will be noted that the percentage of variation in the porosity determination was relatively small. Since the data given in Table I represents determinations made on 60 bricks of each clay 47.5 as the maximum, 0.6 per cent as the minimum, and 11.5·as the average percentage variation, is considered as being excellent.

These percentages of variation in results are not surprising in view of the fact that an error of 1cc. in determination of volume, or an error of 1 gram in obtaining either the dry or saturated weight, makes a difference of 0.3 in the porosity.

It is obvious, therefore, that when the dry weight of the bricks are obtained they must be absolutely dry, i. e., oven dried at 120°C. so as to expel all of the hygroscopic water. This was not done in obtaining the data given in Table I.

Second method, Chemical Balance.—When the porosity of the brick is determined on a chemical balance the volume of the briquette is found by the apparent loss of weight of the briquette when suspended in the oil. The briquette appears to lose weight when thus suspended, and this loss of weight is equivalent to the weight of a quantity of oil

equal to that of the briquette. This method was used by Dr. E. R. Buckley in the test on the Wisconsin clays, and the porosity calculated by him using the formula:

$$100 \left\{ \frac{(W—D) \text{ Sp. gr.}}{(W—D) \text{ Sp. gr.} + D} \right. = \text{ per cent of porosity.}$$

In this formula W=saturated weight; D=dry weight; and Sp. gr. the composite specific gravity of the clay particles, as calculated from dry, saturated, and suspended weights of the briquette.

This formula, however, can be simplified by substituting for the value of D in the denominator its value in terms of the Sp. gr. and suspended weight (S) as given in the formula for specific gravity where D=D (Sp. gr.)—S (Sp. gr.).

The Buckley formula then simplifies to the expression $100 \left\{ \dfrac{W—D}{W—S} \right\} =$

porosity. This formula holds true no matter what liquid is used in the saturation of the brick, so long as the same liquid is employed in obtaining the suspended weight.

The method is accurate but very slow and tedious, unless it is carried out with small pieces on the jolly balance.

If a jolly balance is used in this determination, the weight of the briquette or piece must not exceed that which would stretch the spring beyond its elastic limit. If any other than a light weight spring is used the difference between the several readings will not be sufficient to permit of very accurate determination. This method was used in the determination of the rate of vitrification, which will be described under the general heading of "Pyro-Chemical Tests," so will not be discussed in detail at this time.

Third Method, Calculation.—It has been noted that the specific gravity of the powdered clay by the pycnometer method is uniformly higher than that calculated from data obtained on the green bricks. It has also been noted that this difference between the specific gravities is due to the incomplete saturation of the brick. Since the formula for specific gravity is: Dry weight (W) divided by the combined volume of the particles (V) or $\dfrac{W}{V}=$Sp. Gr., the true volume of the particles in the brick can be obtained by the formula: Dry weight divided by the pycnometer specific gravity, or $\dfrac{D}{\text{Sp. Gr.}}=$Vol. Then the volume of the whole brick (V^b) minus the volume of the clay particles (V^c) would give the volume of the pore spaces (V^p), or $V^b—V^c=V^p$. To obtain the fractional amount of pore space in a brick, the volume of the pores (V^p)

must be divided by the volume of the brick, or $\dfrac{V^p}{V^b}$. But since $\dfrac{V^b - V^c}{V^b} =$

$\dfrac{V^p}{V^b}$ we have $100 \left\{ 1 - \dfrac{V^c}{V^b} \right\} =$ per cent pore space where $V^c = \dfrac{W}{\text{Sp. Gr.}}$

The economy and accuracy in determining porosity by this method lies in the fact that it is not necessary to saturate the brick and obtain the saturated weight. It is obvious, therefore, that the bricks would either have to be partially saturated or covered with a thin coating of paraffin and their volume determined in a volumeter. Without a volumeter this method cannot be used.

If the specific gravity has been determined by the pycnometer method and a volumeter is not accessible, the porosity is best calculated by the Buckley formula. In this, however, complete saturation of the brick must be assured, and the true specific gravity of the clay particles used.

Neither the Buckley method nor the indirect method here proposed is usable on any other than a green or unburned lump of clay. For the porosity of a burned lump or briquette, the formula $100 \left\{ \dfrac{W - D}{W - S} \right\}$ is the only one that will give accurate results, as will be shown under the discussion of Pyro-Chemical and Physical Properties of Clays.

In the following table are given porosity data obtained, first, by the usual volumeter method without taking into account the hygroscopic water; second, by the indirect method described above, without taking into account the hygroscopic water, and third, by the indirect method on a basis of absolute dryness of the bricks. The percentage of increase of porosity obtained in the second and third instance, over that obtained in the first is also shown.

TABLE IV—*Showing the percentage of errors in the Seger Volumeter method of determining porosity as customarily executed.*

Calculated results are by the indirect method.

Sample and Brick Number.	Dry weight in grains—		Volume in cubic centimeter.	Porosity by volumeter on air dried briquettes.	Porosity by calculation on air dried briquettes.	Percentage increase in porosity by calculations over that by volumeter.	Porosity by calculations on oven dried briquettes.	Percentage increase by calculation on overdried briquettes over that by volumeter on air dried briquettes.
	Air dried.	Oven dried.						
K 3—34	571.5	556.4	300.2	23.0	29.12	26.61	31.0	34.78
K 3—37	572.5	558.0	297.8	24.0	28.43	18.45	30.24	26.00
K 3—39	601.3	587.7	311.5	23.8	28.13	18.19	29.76	25.04
K 5—13	644.9	639.3	329.5	25.6	26.17	2.22	26.81	4.73
K 5—15	647.1	640.7	330.6	25.4	26.17	3.03	26.89	5.87
K 5—17	658.4	652.7	337.4	25.5	26.39	3.49	27.03	6.00
K 7— 1	607.4	596.6	327.7	27.3	29.69	8.76	30.94	13.34
K 7— 3	586.5	574.0	312.1	26.3	28.71	9.16	30.23	14.94
K 7— 5	600.4	587.5	323.4	26.9	29.57	9.93	30.08	11.82
K 8—19	663.7	652.4	336.6	24.3	26.67	9.75	27.92	14.89
K 8—24	631.2	620.7	320.7	24.1	26.81	11.24	28.03	16.31
K 8—31	621.5	611.7	316.3	24.1	26.93	11.75	28.08	16.51
K10— 1	545.5	533.2	284.6	25.0	28.64	14.56	30.25	21.49
K10— 2	539.9	523.5	281.6	24.7	28.62	15.87	30.79	24.66
K10— 4	532.2	520.0	278.8	25.7	28.94	12.60	30.56	18.91
K13—4‡	622.4	607 9	323.6	26.6	28.63	7.63	32.10	20.67
K13—46	600.7	587.8	310.3	26.6	28.17	5.90	29.71	11.69
K13—53	619.5	605.9	322.0	28.4	28.61	6.27	30.18	7.40
H18— 1	639.2	625.3	315.6	21.8	24.17	10.87	25.82	18.44
H18— 3	637.0	624.0	314.3	22.1	24.12	9.14	25.67	16.16
H18— 5	642.9	629.6	317.1	21.7	24.09	11.01	25.67	18.30
H20— 1	583.0	567.4	300.1	23.0	28.49	23.87	30.40	32.18
H20— 3	588.2	576.3	303.2	23.0	28.59	24.30	30.03	30.56
H20— 4	579.4	563.5	296.6	23.0	28.09	22.13	30.06	30.70
H24— 1	601.0	591.4	291.4	17.5	22.38	27.88	23.62	34.97
H24— 3	650.5	640.0	314.4	17.6	22.13	25.74	23.38	32.84
H24— 5	600.5	591.5	292.9	18.3	22.84	24.81	23.99	31.09
R 3— 1	687.1	672.9	344.3	23.2	24.83	7.03	26.39	13.75
R 3— 3	667.0	653.9	336.3	23.0	25.30	10.00	26.76	16.35
R 3— 5	690.9	678.7	348.5	23.1	25.33	9.65	26.65	15.37
R 4—26	705.6	689.2	348.7	20 3	25.64	26.31	27.36	34.78
R 4—29	678.1	663.0	337.0	21.2	26.05	22.88	27.70	30.66
R 4—36	716.1	697.8	352.0	20.3	25.24	24.34	27.15	33.74
S 1— 1	575.5	545.7	309.5	21.2	29.70	40.09	33.34	52.55
S 1— 3	573.0	541.5	307.2	20.0	29 48	47.40	33.36	66.80
S 1— 5	565.5	540.0	303.8	21.5	29.62	37.77	33.80	57.20
L-II—11	599.0	584.2	322.6	26.0	31.35	20.57	33.03	27.04
L-II—13	612.2	591.4	326.7	23.9	30.72	28.53	33.10	38.40
L-II—15	602.3	584.4	322.8	25.6	31.44	22.81	33.47	30.74
G-II—55	708.7	702.6	349.7	22.5	24.67	9.64	25.32	12.53
G-II—57	705.3	696.8	347.8	22.7	25.03	10.26	25.93	14.23
G-II—58	712.3	704.0	349.6	22.7	24.68	8.27	25.55	12.56

The data in table IV shows the inaccuracy of the usual method of determining the porosity in dried clay wares. It has been stated[1] that three to six hours is sufficient to saturate with oil unburned briquettes that measure 3x1½x½ inches. Forty-eight hours was therefore considered ample time in which to saturate a brick that cubically was about eight times as large. From the fairly close agreement in the specific gravities as determined by the pycnometer and the volumeter, it was thought that the briquettes had been fairly well saturated. Such, however, was evidently not the case.

[1] Iowa Geological Survey, Vol. 14, p. 18.

RELATION OF RATE OF ABSORPTION TO POROSITY.

Aside from exposing the irregularities in our method of analysis, this data gives evidence of the lack of relation of total porosity and rate of absorption in the green or unburned bricks. Since all the bricks were subjected to the same oil immersion treatment, it must follow that clays differ in the rate at which they can be saturated, and that this rate is not wholly a function of porosity.

The writer is not aware of tests ever having been made to investigate this property, which we may call "absorption ratio," but its significance in connection with the drying behavior of clays is obvious.

Johnson[1] has said, "Obviously, too, the quantity of liquid in a given volume of soil affects not only the rapidity, but also the duration of evaporation. The following table, by Schubler, illustrates the peculiarities of different soils in these respects. The first column gives the percentages of water absorbed by the completely dry soil. In these experiments the soils were thoroughly wet with water, the excess allowed to drip off, and the increase of weight determined. In the second column are given the percentages of water that evaporated during the space of four hours from the saturated soil spread over a given surface."

TABLE V.

	Per cent.	Per cent.
Quartz sand	25	88.4
Gypsum	27	71.7
Fine sand	29	75.9
Slaty marl	34	68.0
Clay soil (60 % clay)	40	52.0
Loam	51	45.7
Plough land	52	32.0
Heavy clay (80 % clay)	61	34.9
Pure gray clay	70	31.9
Fine carbonate of lime	85	28.0
Garden mould	89	24.3
Humus	181	25.5
Fine carbonate of magnesia	256	10.8

"It is obvious that these two columns express nearly the same thing in different ways. The amount of water retained increases from quartz sand to magnesia. *The rapidity of drying* in the air diminishes in the same direction."

Johnson affirms[2] that "these differences—(in the imbibing power of clays)—are dependent mainly on the mechanical texture or porosity of the material." That Johnson's statement, when applied to unburned bricks, is incorrect, is shown by the data in table IV. That there are other factors affecting the difference in rate of absorption and evaporation in different clays is quite evident.

Value of the Porosity Determination on Raw Clay Lump.—It has been contended at various times in ceramic literature that a porosity determination on a raw lump of clay would give evidence, concerning such properties, as slaking, weathering, amount of water required to de-

[1] Loc. Cit., p. 18.
[2] How Crops Feed, p. 175.

—10 G

velop plasticity, etc., and thus indirectly the shrinkage. Such claims have never been based on data, nor are they substantiated by the data secured by this Survey. As will be shown in later paragraphs, neither data nor sound reason would warrant such statements.

Value of the Porosity Determination on Green Brick.—Before the value of knowing the porosity of a green brick can be discussed it is necessary to show the correlation of that property with those which it affects. If porosity, fineness of grain, and drying behavior are in any degree related functions, curves plotted from data should show such relations. Such a relation is shown in Fig. 4 where there seems to be an inverse ratio between fineness of grain in surface or loose grained clays, and the porosity of the green or unburned brick. The data from which this

FIG. 4. Curve showing relation between porosity and fineness of grain. (From data of Beyer and Williams, Iowa Geol. Surv., Vol. 14, p. 123.)

curve was plotted was obtained from the work of Beyer and Williams[1]. The surface factor was calculated from their data by the method given on page 113. The porosity data and calculated surface factor are as follows:

TABLE IV.

	Porosity.	Surface factor.
Dale Brick Co..	18.14	136.40
Gethmann Bros..	22.43	114.38
L. C. Besley (bottom).......................................	24.03	119.98
L. C. Besley (middle).......................................	25.30	100.48
L. C. Besley (top)	29.77	74.77

This reciprocal relation between fineness of grain and porosity could be taken as evidence in proof of the close relation of fineness of grain and porosity of the green brick to drying, shrinkage and other properties that are peculiar to wares manufactured from fine but loose-grained clays or mixtures. The writer hesitates, however, to affirm the truth of

[1] Iowa Geol. Surv., Vol. XIV, p. 123.

such a relation from evidence obtained on a few samples of a single type of clay. Observation of the working behavior of boulder clays in building brick manufacture does not lead one to believe in such an exact relation.

In the manufacture of bricks by the ordinary dry process—where there is present only from 6 to 12 per cent of mechanical water, and the grains of the clay are not surrounded by slippery media that permit the particles to slide easily and freely upon one another—the clay cannot be formed into as compact a mass as when there is sufficient water present to permit of manufacture by the stiff mud process. If dry pressed bricks be formed in a hammer machine, or press, where the brick is subjected to repeated blows by a heavy hammer, the clay particles, even though nearly dry, would be forced over one another until the mass assumes a much closer or denser structure than is possible by the ordinary dry press process. The difference in structure, and its consequent effect on the burning properties of dry press bricks manufactured by these two methods in the St. Louis district is more evident than the difference between the structure of the dry and stiff mud or stiff mud and soft mud bricks.

When the grains are made to lie closer together, either by strong force, or by a lighter force supplemented by a floating medium, better opportunity is offered for the grains to fuse with one another. This is shown nicely by the fact that hammered brick can be burned in the colder parts of a kiln to a degree of hardness that is equal to and often exceeds the hardness of a brick made from the same clay by the dry press method and burned in the hotter portions of the kiln.

In the illustrations just cited, the difference in the burning properties of bricks made from the same clay by different processes, has been used as a means of noting that porosity of green brick is not wholly a function of size of grain. It is clear that it is also very largely a function of process of manufacture.

While there may be some relation between the size of grain of loose or soft clays and the porosity of the brick manufactured from them, it

FIG. 5. Diagram showing the relation between porosity of green shale brick and the absolute fineness of grain. (From data given in Table I.)

is still doubtful if a similar relation can be observed in the hard rock-like fossil clays, such as shales, where the mineral particles are so cemented as to very stubbornly resist separation by the crushing force of dry pan mullers as well as the disintegrating influence of the water used in pugging.

In Fig. 5 are shown curves plotted from data obtained with shales in the same manner as the data for surface clays in Fig. 4. The porosity is taken from Table I, and the surface factor from Table VIII.

The clay from which these shale brick were made had been crushed to pass through a dry pan and then screened. In the laboratory they were known as dry pan samples. These "dry pan samples" were then in the same state of mechanical subdivision as the clay used by the manufacturer.

In making the bricks from which the data in Table I were obtained, considerable time was expended in pugging or wedging the clays by hand, first in a large bulk, and later in quantities just sufficient for one brick. The operator batted a quantity of clay that would make approximately 60 bricks $4\frac{1}{2}''x2\frac{1}{2}''x2\frac{1}{2}''$ on a plaster top table until it was as compact as he could make it. Then by use of a trowel in some instances and a wire in others, he cut off from the large mass a quantity sufficient to fill the die of the press. This smaller piece was again thoroughly wedged by hand until all air blebs had been worked out and the whole took on the shape of a compact loaf. This loaf was then placed in the die, using care to see that it cleared the sides so as to prevent a shearing off of any portion of the loaf on the edge of the die when the plunger descended. The loaves were pressed into bricks on a slow screw tile press, so that the clay did not receive much compression, but yet sufficient to cause it to flow in shreds up around one side or another of the plunger. From this flowage of the clay past the plunger, together with the unusual amount of wedging by hand, it was considered that the clay had been subjected to a treatment that was approximately comparable to the pugging it would have received in the factory, so that the data as given in Table I show approximately the physical structure except for lamination that would be developed on a regular manufacturing basis.

It is commonly known by paving brick manufacturers that some shales require inordinate pugging before they develop sufficient plasticity to permit the production of a perfect bar in the die of the brick machine. In fact it is not uncommon to see a battery of two pug-mills through which the clay must pass before it enters the brick machine proper. In the brick machine the clay receives further pugging before it issues as a bar from the die. It is also not uncommon to hear the manufacturers claim that they cannot pug clay sufficiently unless they use hot water. Not all manufacturers have to resort to this extra care in the pugging process, for some shales develop plasticity with sufficient readiness to allow them to emerge from the first pug-mill in a workable condition. This same difference in the working property of the various shales was perhaps more noticeable in the laboratory than in the factories.

This difference in the working properties of shales is considered to be due to the fact that the grains of clay are cemented by substances that differ in their solubility in water. It is now well known that soils and

clays contain soluble salts that are adsorbed by, or, to use a more homely expression, smeared over the particles, and are not easily extracted by water. It has been learned by experiment that clays can take on or adsorb soluble salts from solutions and so retain these salts in their sub-microscopic pores that they cannot again under ordinary conditions be dissolved from the clay.

The amount of water used in the pugging of shales is not sufficient to dissolve or loosen all of the cementing salts in a clay even by continued pugging, so that at best, only a portion of the clay particles are separated from one another, but the manufacturers must continue the pugging until a sufficiently large number of grains are separated to form a slippery medium, by virtue of which the unslaked or undisintegrated bundles of particles can slip past one another freely enough to permit a flowage of the mass under pressure. The difficulty encountered by manufacturers in breaking down the cementing bond in shales is increased many-fold when an attempt is made to disintegrate a clay into its ultimate grains, as is done in mechanical analysis. The data for texture or size of grain used in plotting the curves in Figs. 4 and 5 were obtained by mechanical analysis and are supposed to represent the subdivision of the clays into their ultimate particles. While it is comparatively easy to obtain separation of the particles in loose-grained clays in the laboratory and in the factory, it is obvious that it is not possible to obtain a similar separation of the particles of the hard rock-like clays in the factory, and very difficult to obtain much more than an approximation of ultimate subdivision in the laboratory. It is owing to this indefinite degree of solution of the natural bond in pugging that we have, in the case of shale bricks, a discordant relation between the porosity of the brick and the fineness of grain, shown in Figs. 2 and 5, as contrasted with the semingly concordant relation in the case of the loess bricks, as shown in Fig. 4.

Although a porosity determination on a green brick may not be of value as direct evidence of the so-called "working properties" of a clay, it can be shown that it is of indirect value, in that the data can be used as the basis of many interesting and valuable calculations. For practical demonstration of the commercial possibilities, or exposition of the working properties of a clay, the writer has failed to find wherein porosity data on unburned bricks separately considered are of use.

FINENESS OF GRAIN.

DEFINITION.

By fineness of grain or texture of a clay is meant the size of its mineral particles. Experimental evidence indicates that variation in grain controls many of the physical and pyro-chemical properties exhibited by clays. Plasticity, shrinkage in drying and burning, tensile strength, drying properties, rate of oxidation, rate of vitrification, toughness of burned ware, and finally, to some extent pyrometric value of the clay, are all influenced by fineness of grain.

The grains of many clays are so cemented that they resist separation in the ordinary pug-mill or blunger. When two or more particles are thus cemented they operate as a unit in their influence upon plasticity, tensile strength, drying behavior, etc. This accounts, in part, for many of the apparent exceptions to the general rules deduced from experimental evidence, for, in the usual methods applied for determining fineness of grain, special effort is made to separate the particles completely. This raises the question whether separation of the particles should be carried to such extremes when attempting to trace direct relations between fineness of grain and the physical properties developed in the process of manufacture of clay into wares. On this point, however, we have no direct evidence, except perhaps as shown in Figs. 4 and 5, so the question will have to remain unanswered for the time being.

It is known, however, that it would be well-nigh impossible to determine how far a mechanical separation of the particles should be carried in the laboratory to make the test comparable to the separation effected in the pug-mill, wet pan, or blunger. For this reason it would seem as though the most useful data concerning texture or fineness of grain cannot be obtained by the present method of analysis.

MEANS OF EXPRESSING FINENESS OF GRAIN.

If all the particles of clay were considered as being spheres or cubes their superficial areas would be inversely proportioned to their diameters. The following calculations show this to be true in regard to the sphere:

Volume of a sphere is equal to $Pi \dfrac{D^3}{6}$; then if D and d are the diameters of two spheres their volumes would be proportional as $\dfrac{Pi\ D^3}{6} : \dfrac{Pi\ d^3}{6}$.

The number of spheres required to equal in volume a standard unit volume would be $1 \div \dfrac{Pi\ D^3}{6}$ or $\dfrac{6}{Pi\ D^3}$ in the one case, and $\dfrac{6}{Pi\ d^3}$ in the other. Since the surface of a sphere of each size is equal respectively to $Pi\ D^2$ and $Pi\ d^2$ the total surface area of a collection of spheres, having a total volume equal to unity, would be in each case $\dfrac{6}{Pi\ D^3} \times D^2$ and $\dfrac{6}{Pi\ d^3} \times d^2$ or $\dfrac{6}{Pi\ D}$ and $\dfrac{6}{Pi\ d}$ respectively. The combined areas of each group of spheres occupying the same volume but having different diameters are, therefore, inversely proportional to their diameters. This proportional relation of the surface of the particles in the several groups is taken as the surface factor of the respective groups, and the sum of these as the surface factor of the clay.

Cushman[1] has shown the error involved in thus taking the mean of the extreme diameters in a given group. According to data given by Cush-

---

[1] Air Elutriations of Fine Powders, Jour. Am. Chem. Soc., Vol. XXIX, No. 4, p. 589, April 1907.

man, a mechanical analysis of the separate groups would show a predominance (77 to 87 per cent in Cushman data) of the finer particles of that group. That the mean diameter obtained as described above, is not a true mean of the diameters of the particles in a group, is obvious. The error thus involved cannot, however, be obviated without a much more extensive subdivision of the groups than is possible under ordinary conditions. It needs no mathematical demonstration to make clear that, theoretically, the more extensive the analysis, the more accurate would the results be. It needs but a short experience with the mechanical analysis by any of the hydraulic methods, to learn that, practically, the more extensive the analysis is made, the larger will be the operating errors. In making a mechanical analysis one must choose between the Scylla and Charybdis of these errors and, naturally, will decide in favor of that one which involves the making of the fewest determinations.

In this report the mean of the extreme diameters of each group, irrespective of the distribution by number according to their volume, of the particles within the respective groups is taken as representing the diameter of the group. The mean diameter of each group and total surface factors for the clays here reported are shown in Table V.

VALUE OF DETERMINATION OF FINENESS OF GRAIN.

As before stated, fineness of grain is the probable cause of several of the other properties exhibited by clays. Since fineness of grain is the cause, and the other properties, in a large sense, the effects, the true significance of this determination can be best discussed by dealing separately with the properties induced by size of grain.

Numerical Results.—In Table VII is given the per centage by weight of calcined materials in each of the several groups according to sizes of particles.

TABLE VII.

Sample Number.	Hygroscopic water.	Combined water.	Percentage Amount by Weight of Particles, Grouped According to Diameters.					Total.
			1 M. M.	1-.1M.M.	.1-.01.	.01-.001.	.001-0.0	
K 1.............	0.47	5.73	6.92	6.19	54.24	22.92	7.87	104.36
K 2.............	1.03	3.77	0.96	1.14	63.75	18.04	13.33	102.04
K 3.............	0.97	6.90	1.42	1.47	54.38	23.03	12.00	100.18
K 4.............	1.68	5.43	1.30	1.66	46 47	27.76	19.34	104.68
K 5.............	1.10	5.60	5.91	1.04	58.01	21.04	9.69	102.41
K 6.............	0.70	4.76	1.14	1.74	63.17	23.49	7.62	102.65
K 7	0.67	5.46	1.14	3.42	58.82	24.45	9.75	103.73
K 8.............	1.20	7.40	8.76	6.55	45.95	22.48	8.26	100.61
K 9.............	0.83	3.32	11.03	1.49	63.80	13.79	6.53	100.83
K 10.............	1.74	5.52	0.85	2.09	22.96	40.72	23.93	97.84
K 11.............	1.78	8.32	3.02	2.69	40.44	33.76	11.13	101.15
K 12.............	1.48	8.66	3.64	2.21	38.03	35.83	12.13	102.00
K 13.............	0.92	6.13	1.60	0.79	44.70	38.80	11.37	104.33
K 14.............	0.66	5.08	13.66	5.76	41.24	24.34	8.14	98.91
R 1.............	1.33	7.69	1.76	5.90	36.59	36.23	12.97	102.49
R 3.............	1.10	5.29	10.92	5.84	50.67	20.52	9.93	104.30
R 4.............	0.82	6.11	9.47	2.54	47.69	26.78	8.98	102.43
G-II.............	1.35	4.28	12.67	2.38	50.78	20.19	12.80	104.48
I-II.............	2.01	4.35	4.14	3.62	44.37	25.24	17.53	101.30
H 18.............	1.69	14.95	12.14	12.14	24.57	20.88	17.60	103.99
H 20.............	1.98	11.97	1.00	1.86	39.73	29.73	16.69	102.79
H 21.............	1.63	12.26	0.19	0.50	22.50	39.21	26.39	102.71
H 23.............	2.48	7.71	1.60	2.56	28.11	38.20	21.89	102.57

In Table VIII will be found the same data with the hygroscopic water eliminated and the chemical water distributed over the various groups proportionally to the amount belonging to each, as determined by their loss on ignition.

TABLE VIII.

Sample Number.	1 mm mean diam. 1.25.	1 m m mean diam. 0.5.	0.1-.01 mean diam. 0.05.	.01-.001 mean diam. 0.005.	.001-0 mean diam. 0.0005.	Total.	Surface factor
K 1	7.27	6.53	56.07	24.86	9.76	104.51	256.
K 2	1.07	1.23	66.24	19.63	13.90	102.09	331.
K 3	1.50	2.41	57.15	25.14	13.96	100.18	341.
K 4	1.40	1.74	48.87	29.41	22.24	103.68	514.
K 5	6.38	1.46	60.57	22.93	11.43	102.80	287.
K 6	1.24	1.83	65.83	25.98	7.77	102.66	221.
K 7	1.35	3.75	60.87	25.89	11.81	103.69	300.
K 8	9.66	6.90	48.46	25.40	10.05	100.50	262.
K 9	11.39	1.55	65.50	14.72	7.63	100.80	195.
K 10	1.06	2.42	24.62	44.29	25.52	97.91	604.
K 11	5.36	3.76	43.74	35.45	12.94	101.26	339.
K 12	4.49	2.88	40.51	38.82	15.32	102.04	403.
K 13	1.82	1.35	46.74	41.73	13.15	104.80	356.
K 14	14.23	6.31	42.75	26.03	9.67	98.99	254.
R 1	2.16	6.51	38.70	39.32	15.53	102.25	397.
R 3	11.69	6.30	52.90	21.60	11.79	104.29	291.
R 4	10.15	2.84	49.32	29.13	10.85	102.31	275.
I- II	4.64	3.81	45.50	25.94	21.40	101.31	489.
H 18	13.05	17.71	27.57	26.58	19.22	104.16	444.
H 20	1.92	2.75	42.01	32.47	23.97	103.13	553.
H 21	0.34	0.80	24.34	42.77	34.62	102.89	783.
H 23	1.80	2.86	29.95	40.82	27.30	102.74	634.
G 2	13.17	2.47	52.57	20.57	15.72	104.52	366.

In Table IX is given the calculated loss on ignition of each group as nearly as it could be determined from the results of analysis. While this loss on ignition has been called "Combined Water," it must be borne in mind that the loss of many substances other than combined water has been included. Carbon, carbonic acid, sulphur, etc., are driven off on ignition and reduce the weight of the sample. The relations referred to are well expressed by the well-known Kennedy curves. (See Fig. 6.)

TABLE IX: *Distribution of combined water over the several groups of particles.*

Sample Number.	1 M. M.	1-.1 M. M.	.1-.01	.0—.001	.001-0	Total.
K 1......................	0.32	0.31	1.62	1.64	1.86	5.77
K 2......................	0.09	0.08	1.85	1.37	0.43	3.84
K 3.	0.06	0.92	2.28	1.88	1.86	7.03
K 4......................	0.07	0.05	1.66	1.25	2.69	5.74
K 5......................	0.31	0.41	1.98	1.67	1.64	6.03
K 6......................	0.09	0.08	2.22	2.33	0.09	4.82
K 7......................	0.22	0.31	1.69	1.29	2.00	5.52
K 8......................	0.82	0.30	2.01	2.69	1.71	7.55
K 9......	0.27	0.03	1.18	0.82	1.02	3.34
K 10...	0.19	0.28	1.24	2.83	1.15	5.71
K 11......................	2.27	1.03	2.58	1.08	1.61	8.58
K 12......................	0.80	0.63	1.95	2.49	3.02	8.91
K 13......................	0.20	0.55	1.68	2.61	1.68	6.74
K 14......................	0.48	0.33	1.26	1.54	1.48	5.11
R 3......................	0.66	0.39	1.72	0.87	1.75	5.40
R 4......................	0.60	0.27	1.45	2.13	1.80	6.27
R 1......................	0.39	0.55	1.74	2.73	2.43	7.87
I -1......................	0.40	0.17	0.24	0.19	3.51	4.53
G -2......................	0.33	0.06	1.13	0.11	2.75	4.39
H-18......................	0.79	5.45	2.76	5.49	1.44	15.95
H-20.....................	0.89	0.85	1.52	2.17	6.95	12.41
H-23......................	0.16	0.23	1.13	1.67	4.89	8.11

FIG. 6. Kennedy curves showing the reactive rate of loss on heating, calcareous and non-calcereous clays. (After Bleininger, Geol. Surv. Ohio, 4th Ser., Bull. 4, p. 19.)

NOTE—Based on behavior of briquettes containing pure kaolin only and kaolin 20 per cent, calcium carbonate 30 per cent. The course of the curves coincide up to 600 degrees when the bulk of the water is driven from the kaolin. At this point the carbonic acid begins to come off from the kaolin-lime briquettes showing a marked divergence in the curves from there on. The theoretical curve marks the course kaolin-lime curve would have taken had the lime been replaced with sand or other non-volatile matter

The distribution of "combined water" over the several groups, as given in Table I, was necessarily calculated by proportion, for the total loss on ignition of the finer groups in some cases amounted to two or three times that which occurred on ignition of the whole sample. Satisfactory explanation of this increase or gain in volatile matter during the process of analysis cannot be given. It is supposed, however, that it is due in part to some organic growth developed in the water, or, possibly, oil from the compressed air that was used in the siphoning off of the supernatant liquid. That this last suggestion will not account for all of this increase, if any, in the volatile matter accumulated in process of analysis, was proved by the fact that when precautions were taken to clear the air of all possible traces of solid material, there was still nearly the same increase. There is therefore considerable doubt as to the value of re-distribution of the loss on ignition by means of proportions, yet the data obtained in this way are considerably more accurate than they would otherwise be.

The irregularities in the data are pointed out solely to call attention to a weak point in this most important determination. Mechanical analysis of clays, as has been stated before, bids fair to become a very essential test in determining the full value of a clay, and attention should be given to the elimination of this increase in volatile matter during the process of analysis. Soil physicists are experiencing the same difficulty, and yet they have learned to give considerable, in fact, a large amount of credit to the mechanical analysis of soils as a means of determining its properties for their purposes .

Shrinkage in Drying.

Methods of Measurement.

The amount that a clay will shrink in drying is expressed in per cents of the unit length or volume. In the first instance the shrinkage would be designated as linear shrinkage, and in the second, as volume or cubical shrinkage.

In Table I, page ??, will be found the percentages of both linear and volume shrinkage for several shale clays as determined by direct measurement. It will be noted that the variation in linear shrinkage in 60 bricks of each clay is far in excess of reasonable limits. When the linear shrinkage varies from 32 to 133 per cent from the average, the data must be wholly unreliable. In presenting this data it is felt that the failure to produce more consistent results lies in part in the shortness of the shrinkage distance, and in part in carelessness of the operator.   In marking the freshly made bricks a stencil devised by J. F. Krehbiel was used, so that initially the shrinkage lines were marked upon the brick with accuracy. In measuring the decrease in length of the shrinkage line after the bricks were dried, a vernier shrinkage scale was used that read accurately to the third place. The large variations in the results were therefore a surprise to the operator.

The volume shrinkage varied within fairly reasonable limits, but even here the variations are quite large considering the size of the bricks used. It is felt that if in one case the variation could be only 0.5 per cent there ought not to be any excuse for a variation of 33.8 per cent in another or an average on all samples of 11 per cent.

Inasmuch as the volume shrinkage data proved to be the more accurate of the two they were used as a basis on which to calculate* the linear shrinkages as shown in the following table:

TABLE X. *Comparison of the measured with calculated linear shrinkage.*

SAMPLE No.	Average volume shrinkage in per cents.	Calculated linear shrinkage in per cents.	Average measured linear shrinkage in per cents.	Percentage variation on volume shrinkage.	Percentage variation in measured linear shrinkage.
K 1......................	6.2	2.1	1.5	33.8	133.3
K 2......................	12.2	4.3	3.5	2.4	70.0
K 3......................	10.5	3.6	2.1	16.7	68.0
K 4......................	10.1	3.5	3.3	5.8	73.6
K 5......................	5.2	1.8	1.6	6.7	129.0
K 6......................	10.1	3.5	4.1	10.3	43.9
K 7......................	9.6	3.3	3.9	12.2	51.2
K 8......................	7.5	2.6	2.1	21.5	95.2
K 9......................	3.5	1.2	0.9	34.1	75.0
K 10......................	18.3	6.5	5.8	0.5	37.8
K 11......................	13.5	4.7	3.3	16.3	73.8
K 12......................	12.7	4.4	3.6	5.9	44.4
K 13......................	10.5	3.6	3.3	7.5	48.4
K 14......................	6.1	2.1	1.5	11.5	93.3
S 1......................	12.9	4.5	2.7	19.0	60.0
S 2......................	13.1	4.6	4.2	10.6	42.8
R 1......................	13.9	4.9	4.5	5.7	53.3
R 2......................	9.1	3.1	3.3	25.3	36.3
R 4......................	6.1	2.1	3.2	6.7	56.2
B II......................	11.5	4.0	5.0	7.8	32.0
C II......................	7.3	2.5	1.9	12.5	124.0
H II......................	14.3	5.0	5.5	7.6	65.4
I II......................	13.8	4.8	4.2	2.9	33.3
J II......................	14.4	5.1	4.6	4.1	34.7
L II......................	9.7	3.4	3.7	6.8	54.0
H 16......................	7.8	2.7	2.8	19.6	78.5
H 17......................	21.4	7.7	7.0	4.6	34.2
H 20......................	16.5	5.8	6.8	3.0	26.5
H 21......................	18.0	6.4	7.2	1.7	41.6
H 23......................	20.4	7.3	7.4	5.8	43.2
H 24......................	11.4	4.0	4.0	10.5	45.0

* If a unit cube shrinks so that each edge is decreased by linear length "a" then the new length of the edges become (1-a). If the decrease in volume of this same cube be represented by "x" then the new volume will be (1-x). Since the edges of the cube are now (1-a) its volume can also be represented

by (1-a)^3 hence (1-a)^3 is equal to (1-x), or a$=1-\sqrt[3]{1-x}$. It was by this formula that the transformation from volume to linear shrinkages were made.

The linear shrinkage which probably is the more correct for that sample is underscored. In cases where there is not an underscored linear shrinkage, there is no possible way to judge which one is the most correct. In case the calculated practically agrees with the measured linear shrinkage, both are underscored.

If the volume and linear shrinkages had been correctly measured, there would have been no discrepancy between the calculated and determined linear data. If any importance at all is to be attached to shrinkage data it is evident that extreme care should be exercised in their determination. When possible, the measured linear should be checked by calculation from the volume shrinkage and *vice versa*.

RELATION OF VOLUME SHRINKAGE TO POROSITY.

It will be noted from a glance at Fig. 7 that there does not seem to be any relation whatever between volume shrinkage and pore space in the dried bricks.

Fig. 8 also represents the same sort of irregular relation between the volume shrinkage and pore space in the dried brick made from the Iowa loess clays.[1]

RELATION OF VOLUME SHRINKAGE TO WATER OF PLASTICITY.

The chart, (Fig. 9), showing the relation between the percentage of water of plasticity and the volume shrinkage from the green to the dried condition, proves that while there is some indication of a reciprocal relation between these two factors, this relation cannot be affirmed.

FIG. 7. Diagram showing relations between volume shrinkage and porosity of dried brick. (From data in Table I.)

---

[1] Ia. Geol. Surv., Vol. XIV, 1904, p. 109 and 113.

RELATION OF VOLUME SHRINKAGE TO WATER IN EXCESS OF THAT REQUIRED
TO FILL THE PORES.

It would seem that if the volume had been determined at regular intervals as the bricks lost their mechanical water by evaporation, the per centage up to the time that the brick reached its maximum shrinkage,

FIG. 8. Diagram showing relation between volume shrinkage and porosity of loess clays from Iowa. (After Beyer and Williams.)

would stand in closer relation to the volume shrinkage than does the total mechanical water and volume shrinkage. It is not known what value such a test would have, but it would probably be considerably more than is the determination of total mechanical water alone.

In Table XI is shown the percentage by weight of water that would be required to fill the pores of bricks made from Iowa clays and that which is in excess of the "pore water." These clays were ground until they would pass through a 40-mesh sieve,[1] then wetted with water and thoroughly wedged. Grinding the clay until it would pass a 40-mesh sieve would reduce the size of the larger grains, and to some extent break down bunches of grains by force that would not have been affected by the water used in wedging. The data is of interest on this account in connection with the problem of shrinkage.

[1] Ia. Geol. Surv. Vol. XIV, 1904, p. 76.

TABLE XI.

CLAY.	Per cent Water.	Porosity.	Sp. Gr.	Vol. of clay per 100.	Per cent by wt. of water in pores.	Per cent by wt. of clay.	Excess water for plasticity.
Flint Brick Co., top stratum......................	22.5	17.31	2.41	82.69	7.99	92.01	14.51
Flint Brick Co., middle...	25.0	23.00	2.51	77.00	10.64	89.36	14.36
Flint Brick Co., bottom...	25.0	30.04	2.40	69.96	15.83	84.87	9.87
Flint Brick Co., green brick...................	25.0	23.20	2.52	76.80	10.71	86.29	14.29
Iowa Brick Co., top stratum.................	17.5	17.43	2.53	82.57	7.52	92.48	9.98
Iowa Brick Co., second from top................	25.0	25.73	2.46	74.27	12.92	87.08	12.07
Iowa Brick Co., third from top................	27.5	29.57	2.40	70.43	15.32	84.68	12.18
Iowa Brick Co., fourth from top................	25.0	17.96	2.45	82.04	8.20	91.80	17.80
Iowa Brick Co., fifth from top................	25.0	26.04	2.37	73.96	12.93	87.07	12.08
Iowa Brick Co., bottom stratum................	27.5	28.69	2.36	71.31	14.76	85.24	12.74
Cap. C. Brick & P. Co., top stratum	30.0	30.80	2.69	69.20	14.43	85.57	15.57
Cap. C. Brick & P. Co., second from top.........	22.5	25.25	2.48	74.75	11.44	88.56	11.06
Cap. C. Brick & P. Co., third from top...........	22.5	17.00	2.53	83.00	7.49	92.51	15.01
Cap. C. Brick & P. Co., fourth from top	22.5	25.13	2.45	74.87	12.04	87.96	10.46
Jester Clay Bank..........	20.0	20.35	2.49	79.65	9.30	90.70	10.70
Harris Brick Yard..	22.5	24.33	2.56	75.67	11.15	89.85	11.35
Dale Brick Co., top loess..	22.5	18.14	2.44	81.86	8.32	91.68	14.18
Dale Brick Co., bottom shale	22.5	28.98	2.48	71.02	14.13	85.87	8.37
Corey P. B. Co., red burning clay...	25.0	30.10	2.54	69.90	14.49	85.51	10.51
Corey P. B. Co., buff burning clay............	25.0	28.10	2.54	71.90	12.86	87.14	12.14
Colesburg	27.5	28.36	2.62	71.64	13.12	86.88	14.38
Storm Lake B. & T. Co ...	25.0	19.27	2.42	80.72	8.97	91.03	16.03
Besley Brick Yard, top loess..................	22.5	29.77	2.34	70.23	15.34	84.66	7.16
Besley Brick Yard, middle loess..................	22.5	25.30	2.32	74.70	12.73	87.27	9.77
Besley Brick Yard, bottom loess................	22.5	24.03	2.40	75.97	11.64	88.36	10.86
Getham Bros., inland loess...................	25.0	22.43	2.41	77.57	10.71	89.29	14.29
Cap. City B. & P. Co., bottom stratum	22.	24.59	2.40	75.41	11.96	88.04	10.54
Cap. City B. & P. Co., green stratum	22.5	21.83	2.51	88.17	8.97	91.03	13.53
Granite B. Co., top stratum.................	22.5	23.06	2.25	76.94	11.75	88.25	10.75
Granite B. Co., lower stratum...............	22.5	22.41	2.42	77.59	10.51	89.49	11.99
Clermont B. & T. Co.....	20.0	22.66	2.58	77.34	10.10	89.90	9.90
Am. B. & T. Co	30.0	26.71	2.51	73.29	12.67	87.33	17.33

In making Table XI Byers' and Williams figures for porosity,* specific gravity† and water of plasticity‡ .were taken, and the data calculated as follows:

If porosity, or volume of pore space, is 29.77 per cent in a unit volume there would be 0.2977 parts by volume of pore space, and 1.0000—0.2977 or 0.7023 volumes of clay. On the assumption that the pore space is filled with water and the specific gravity of the clay is 2.34, there would be

---

* Ia. Geol. Surv., Vol. XIV, 1904. †Ibid 116 ‡Ibid 83.

0.2977×1.00=0.2977 parts by weight of water, and
0.7023×2.34=1.6434 parts by weight of clay, or ex-
pressed as per cents—15.3 and 84.6 per cent respectively of water and
clay. This 15.3 per cent of water then is the amount of water by weight
that would be required to fill the pore spaces in a brick that would weigh
100 at the time when all the particles have become fixed or arranged in
the exact position that they will maintain during the remainder of the
drying period. This, it is assumed, would give the weight of water that
remains in the pores of the bricks at the time the clay has reached its

FIG. 9. Diagram showing relation between amount of water required to develope plasticity
and volume shrinkage. (Data from Table I.)

maximum air shrinkage. This amount of water subtracted from the
amount required to develop plasticity would give, if the foregoing as-
sumption is correct, the amount, the amount of water required to lubri-
cate the particles sufficiently to cause a state of mobility which we have
learned to designate as plasticity.

Fig. 10 shows that there is some reciprocal relation between the amount
of water in excess of that required to fill the pores of a dried brick, (as
given in Table XI) and the volume shrinkage.

In Table XII are shown the calculations on the Illinois clays, designed
to bring out the same facts given in Table XI. In this table, however,
the amount of hygroscopic water is given in each case so that it can be
reckoned in as part of the mechanical water, if so desired. It must be
borne in mind, however, that the amount of water calculated as being
in excess of that required for filling the pores does not in any way include
the hygroscopic water. The hygroscopic water is not added in with the

Fig. 10. Diagram showing relation of volume shrinkage to water in excess of that required to fill the pores in Iowa clays.

TABLE XII.

Sample Number.	Plasticity water.	Porosity.	Sp. Gr. by pyc- nometer.	Per cent by weight of water required to fill the pores.	Excess water re- quired for plasticity.	Hygro- scopic water.	Vol. shrinkage.
K- 1	14.9·	26.0	2.67	11.6	3.3	2.01	6.2
K- 2	16.77	25.7	2.56	11.9	4.8	1.62	12.2
K- 3	16.82	25.6	2.69	11.4	5.4	2.43	10.45
K- 4	16.27	27.8	2.67	12.6	3.6	....	10.12
K- 5	13.06	25.4	2.65	11.3	1.8	0.923	5.17
K- 6	17.03	28.9	2.66	13.2	3.8	1.23	10.6
K- 7	17.57	27.9	2.64	12.7	4.9	1.93	9.62
K- 8	14.4	25.2	2.69	11.1	3.3	1.70	7.51
K- 9	13.4	26.1	2.70	11.5	1.9	0.79	3.54
K-10	19.6	25.4	2.69	11.2	8 4	2.31	18.29
K-12	13.35	18.3	2.67	7.7	5.7	5.09	12.74
K-13	16.3	28.3	2.70	12 7	3.6	2.16	10.54
K-14	13.6	24.5	2.64	10.9	2.5	0 79	6.13
S- 1	17.2	23.0	2.64	10.1	7.1	4.76	11.97
S- 2	16.6	26.4	2 72	11.6	5 0	2.42	13.1
R- 1	13 4	17.8	2.73	7.9	5.5	1 95	13.9
R- 2	13.0	24.0	2.72	10.4	2.6	1.53	9.1
R- 4	13.2	21 8·	2.72	9.3	3.9	2.28	5.98
B-II	17.7	26 9	2.67	12.1	5.6	1.67	11.5
G-II	11.8	22.4	2.70	9.6	2.2	1.14	7.32
H-II.........	16.5	20.7	2.68	8.8	7.7	3.07	14.3
I-II	14 4	18.9	2.67	8.0	6.4	2.85	13.8
J-II	16 5	24.2	2.70	10.5	6.0	2 70	14.4
L- II.........	16.4	24.5	2.70	10.7	5.7	3.05	9.7
H-16.........	16.2	27.8	2.70	12.4	3.8	1.74	7.8
H-17.........	16.6	19.0	2.60	8.2	8.4	3.7	21.4
H-20.........	18.3	23.9	2.72	10.3	8.0	2.58	16.5
H-21.........	18.0	21.6	2.72	9.2	7.8	3.98	18.0
H-23.........	21.4	24.9	2.63	11.1	10 3	2.05	20.4
H-24.........	12.8	14.5	2,66	5.9	6.9	1.63	11.4

water of plasticity, because there is some doubt as to just where and how the clay retains that water on drying. It is supposed to be held either in or between the grains, and does not greatly exceed the amount (on account of the natural humidity of the air) that the powdered clay would retain as moisture.

The porosity data used are those given in Table I.

In the above table there is the same indication of a reciprocal relation between the "excess water" and volume shrinkage as noted in the case of the Iowa clays and shown in Fig. 11. We have here then the promise of a means of obtaining analytically a line on the drying behavior of a clay other than volume shrinkage taken alone.

FIG. 11—Diagram showing relation of volume shrinkage to water in excess of that required to fill the pores in Illinois clays.

—11 G

RELATION OF VOLUME SHRINKAGE TO FINENESS OF GRAIN.

The volume shrinkage of a clay is a reliable index of its drying be-
havior only within certain limits. Take for instance K—14 and H—17,
which lie close to the extremes of minimum and maximum volume
shrinkage; both require considerable care in drying. Roughly we can

FIG. 12. Diagram showing relation of volume shrinkage to fineness of grain.

say that clays which exhibit an average shrinkage will dry safely, and
that if the ware exhibits either a high or low volume shrinkage it can
be assumed to be likely to occasion trouble in drying. But knowing this
general fact, how can the drying behavior of a particular clay be esti-
mated?

It has been suggested that clays which have a fair range in size of
grain, i. e., not too large a proportion of either the largest or smallest
grains, can be dried with greatest safety. This we proved to be true for

the clays plotted near the middle of a diagonally drawn dotted line in Fig. 12 were the easiest to dry and those at the extreme ends the most difficult.

It was demonstrated, however, that while there may possibly be a reciprocal relation between porosity and fineness of grain in the naturally soft and loose-grained clays, there is no trace of such a reciprocal relation in the harder clays, like shales, because the cement which holds the grains is not broken by the methods of preparation usually employed. It has also been shown that there is no reciprocal or proportional relation between the porosity of the dried ware and the volume of shrinkage. This same lack of proportional relations was found between water of plasticity and volume shrinkage, as well as water of plasticity and porosity. The only factors that seem to exhibit any proportional relation with volume shrinkage are "excess water" and fineness of grain. These factors alone are not, however, sufficient evidence on which to base an answer to our query.

TENSILE STRENGTH.

METHODS OF TESTING.

One of the vital factors affecting the drying behavior of clays is their cohesion. Many ways have been devised to measure this cohesion, but the tensile strength test seems to be the most popular. Determinations of tensile strength as usually made and reported, have so large a percentage of variation that they are practically worthless. This has been justly attributed to the personal factors entering into the preparation of the test pieces. It is indeed surprising how variable the results can be even when the operator uses all the care possible in wedging the clay and pressing the briquette. The personal factors have been largely eliminated in the tests here reported by following a method for making briquettes devised by H. B. Fox, of the University of Illinois.

Fox Method.—The Fox method is, in the main, as follows: The clay is mixed with just sufficient water to make a thick paste. It is allowed to stand in this condition for some time, generally twelve or more hours, and is then poured onto a slightly moistened plaster slab and allowed to harden until it has assumed about the consistency of "stiff mud." It is then cut into briquettes by a cutter similar to a biscuit cutter. The clay is forced out of this cutter into the briquette mold by a plunger under a given load; in our case about 50 pounds. While the load is still on, the cutter is removed and the briquette struck off with a wire. By this means the briquette is formed and pressed under uniform conditions without the introduction of personal factors, with the possible exception of the making up of the slip.

The briquettes are then room-dried. In this, care is exercised, for the fine-grained clays and the exceptionally weak clays can be dried so fast as to cause them to "dry check." It is not always possible to see these "dry checks," but there is no doubt that a considerable proportion

Fig. 13.   Krehbiel device for grooving briquettes.

The briquettes are then grooved to a slight depth by the use of a file operated in a miter,[2] making a uniform cross section in all cases. The object of this grooving is not to obtain a uniform cross section primarily, but to insure the breaking of the briquette at the narrowest section. Being uniform, the cross section can be considered as a constant factor, thus making easier the calculation of the results. This grooving was not trusted to give us a constant cross section, however, but each briquette was measured with a vernier shrinkage scale that reads to three places.

The results of grooving the briquettes may be noted in the table given below. There it will be seen that the strength per square centimeter cross section is not materially different. In fact the only difference in strength between the grooved and the ungrooved can be said to be within the limits of errors that are unavoidable in this test. The usual contrast between the variation in results in the grooved and in the ungrooved briquettes which ordinarily exists cannot be seen in the result given below. The results are exceptionally good in all cases, irregular results due to breaking elsewhere than at the neck not being reported.

After the briquettes are grooved they are made bone dry in a hot air-bath and cooled in a dessicator so as to eliminate all moisture, and then broken in a Fairbanks Tensil Strength Machine.

Wedging Versus Slip Process.—Clay workers, especially the old potters who make large jars by "throwing" on a wheel, recognize a difference in the working properties of clay when prepared by the slip process and when prepared by the "chaser," wet pan, or the old-time stamping process. In fact the difference in the clay when prepared in slip, or in one of the "plastic" methods, is so marked, that where ware is to be thrown they install special machinery on which to prepare the clay, and in one of the most up-to-date terra-cotta factories in the west, they keep four men tramping the wet clay with their bare feet, in preference to using the cheaper slip method. In the manufacture of glass pots, tramping with bare feet is the method most generally used in preparing the clay. For this reason the fairness to all clays in casting the slab from which the briquettes were cut was questioned, and the following tests were made to throw light on this point.

All the clays for both the "slip" and "wedge" process were made to pass through a 10-mesh sieve.

The clay for slip process was cast as in the Fox method.

The clay for the wedge process was thoroughly wedged by hand while at its state of maximum plasticity, and then worked into a sheet 1½" thick on the plaster slab by pounding it with a flat board. Briquettes were cut and forced into the mold under constant pressure as in the case of the slip clay.

The results are shown in Table XIII:

_____

[2] See Fig. 13.

TABLE XIII.

SAMPLE.	SLIP PROCESS AVERAGE STRENGTH IN LBS. PER SQ. CM.		PER CENT VARIATIONS USING AVERAGE STRENGTH AS BASIS.		WEDGE PROCESS. AVERAGE STRENGTH IN LBS. PER SQ. CM.		PER CENT VARIATIONS USING AVERAGE STRENGTH AS BASIS.	
	Grooved.	Not grooved.	Grooved.	Not grooved.	Grooved.	Not grooved.	Grooved.	Not grooved.
K—14 Western Brick Co., Danville, Ill	16.20	17.60	9.9	4.5	28.9	18.00	6.9	12.2
K—10 Terre Haute, Ind........	29.80	33.30	10.3	11.9	36.8	31.6	17.1	25.3
K—3 Albion, Ill................	17.65	20.40	10.3	8.8	23.9	23.9	16.7	18.4
K—11 Brazil shale, Ind........	17.85	21.90	13.3	13.0	24.0	24.3	37.5	30.0
K—9 Crawfordsville, Ind......	8.25	9.25	8.5	8.05	9.3	9.9	3.35	11.1
K—8 Veedersburg, Ind........	16.85	18.60	5.37	4.0	21.7	22.1	14.3	21.2
Average....................	17.60	20.17	9.61	8.37	24.1	21.60	15.97	16.3

The following conclusions were reached as a result of these tests:

First—In every case except that of the Terre Haute not grooved, the wedging process gave higher results.

Second—The variation is considerably lower in the slip than in the wedge process.

Third—The increased strength due to wedging was not sufficient to warrant the accompanying increase in percentage of variation.

Fourth—Grooving the briquettes did not materially better the results in the slip process and actually made the results worse in the wedge process. It must be remembered in this connection, however, that the results of briquettes that did not break at the necks were rejected. All grooved briquettes broke at the neck.

Fifth—Grooving increased the variation in coarse non-plastic clays, such as K—14 and K—9, but did not seem to effect the finer grained clays.

Effect of fine Grinding—In view of the fact that grooving aids materially in reducing the variation in all, except the less plastic, coarse grained clays, it was thought that perhaps the comparison would be more just if all were finely ground.

The dry-pan samples of the two plastic clays, K—10 and K—11, and the two coarse and less plastic clays, K—14 and K—9, were ground of the variations are due to them.
wet and also dry until they passed through sieves of 10, 20, 40 and 80 mesh, as follows:

A quantity of clay sufficient to make six briquettes was taken from the stock by quartering, making ample allowance for waste. This sample was first crushed to pass a 10-mesh sieve. It was then sieved

through the desired mesh and the residue placed in a small Bonnot mill with 100 Iceland pebbles. Both the wet and the dry samples were taken from the mill every five minutes, and the particles fine enough to pass through the desired mesh were sieved out. The residue left on the sieve was then placed in the mill and ground for another five minutes. This grinding was continued until all the clay passed through the desired mesh. In this manner there was prepared, by both wet and dry grinding, stocks that would just pass the 10, 20, 40 and 80 mesh sieves.

The clays that were ground were kept at casting consistency, i. e., quite thick slush, so that when completely ground they were cast into slabs as quickly as convenient. The clays prepared by the dry method were allowed to stand in water until they assumed the thick slip state and then cast on plaster of Paris slabs after standing from 10 to 24 hours.

Briquettes were cut and pressed by the Fox method. In table XIV will be found the results of this experiment.

The work was done by a man not accustomed to it who could not at first be made to realize the importance of taking the greatest pains to in-sure constant conditions and accurate results. This may account for the higher variations.

From these results the following conclusions may be drawn:

First—The variations with the grooved briquettes are on the whole lower than those with the ungrooved.

Second—The average strength of the grooved is practically equal to that of the ungrooved.

Second—The average strength of the grooved is practically equal to that of the ungrooved.

Third—Finer grinding either wet or dry does not materially better the constancy of the results. The fact is, in this experiment, the varia-tions in the finer ground samples were higher in many cases than in the coarsely ground samples.

Fourth—The average strength of the clay was not materially altered by finer grinding.

Fifth—The results by wet grinding differed but little, if any, from those by dry grinding.

TABLE XIV.

Sample	Mesh	Dry Grinding Grinding duration in minimum	Dry Strength Grooved Max.	Dry Strength Grooved Min.	Dry Strength Ungrooved Max.	Dry Strength Ungrooved Min.	Dry Per cent variation grooved	Dry Per cent variation ungrooved	Wet Grinding Grinding duration in minimum	Wet Strength Grooved Max.	Wet Strength Grooved Min.	Wet Strength Ungrooved Max.	Wet Strength Ungrooved Min.	Wet Per cent variation grooved	Wet Per cent variation ungrooved
K10 Terre Haute	10		33.4	31.7	39.08	33.22	5.41	14.99		32.6	25.7	34.1	26.5	21.16	22.28
	20	25	40.5	27.3	32.57	23.99	32.59	26.34	10	28.0	24.3	34.5	28.3	13.21	17.97
	40	25	35.4	31.4	39.10	36.2	11.32	7.42	15	34.1	24.6	33.6	33.5	27.82	2.94
	80	50	44.0	34.1	36.9	27.4	22.5	25.74	20	33.4	22.5	33.6	24.4	32.63	27.33
K11 Brazil	10		20.2	17.3	27.29	19.15	14.35	21.16		19.2	17.3	20.75	19.89	9.89	4.14
	20	25	21.4	19.7	25.72	23.58	7.94	12.09	15	17.8	15.5	23.88	17.84	12.92	25.29
	40	40	23.1	14.6	30.40	23.63	36.79	22.27	20	23.2	17.5	25.65	19.85	25.00	22.22
	80	50	26.9	26.6	30.81	26.01	11.15	15.60	20	22.7	22.5	25.36	21.31	8.81	15.92
K9 Crawfordsville	10		7.5	7.4	8.6	7.3	1.33	15.11		7.0	6.2	7.5	6.0	11.42	20.00
	20	15	8.1	7.7	8.7	7.9	4.93	9.19	10			8.3	7.0		15.83
	40	20	8.2	6.8	9.2	8.3	17.07	9.78	10	7.7	6.7	9.0	8.1	12.5	10.00
	80	30	8.5	7.0	7.9	6.9	17.7	12.66	20	8.7	7.8	9.1	8.6	13.25	17.62
K14 Western Brick Co., Danville	10		17.5	15.4	17.9	16.6	12.00	7.26		14.6	14.5	16.2	14.3	0.684	11.11
	20	20	15.6	14.7	17.6	14.6	5.76	17.05	10	15.9	14.9	16.2	14.0	6.29	13.5
	40	25	17.3	14.8	20.0	16.4	14.42	18.00	10	16.4	13.3	12.3	11.0	18.9	10.56
	80	30	16.1	14.1	20.0	11.7	12.42	41.50	20	15.6	11.2	12.9	11.5	21.79	10.8

RESULTS OF TESTS.

In the light of the foregoing tests it was decided to dry-grind the clays in a jaw crusher to pass a 20-mesh sieve. In this the whole sample, including the fine and coarse particles, was passed through the jaw crusher. Six briquettes were made by the slip method, as designed by Fox, and grooved to insure breakage at the neck. In this manner the following data was obtained:

TABLE XV.

TENSILE STRENGTH OF CLAYS.

Sample.	Strength in kilograms per sq. cm.		Percent of Variation.	
	Maximum.	Minimum.	As tested.	By elimination of irregularities.
K— 1 Alton, Ill	7.356	7.168	7.58	....
K— 2 Hydraulic, St. Louis, Mo	12.292	8.437	31.52	....
K— 3 Albion, Ill	9.934	8.074	18.72	6.84
K— 4 Springfield, Ill	10.806	8.664	18.8	11.1
K— 5 Edwardsville, Ill	5.715	5.216	8.73	....
K— 6 Galesburg, Ill	8.164	7.516	7.202	....
K— 7 Streator Paving Brick Co	6.985	5.896	15.62	....
K— 8 Veedersburg, Ind	5.359	4.717	11.9	....
K— 9 Crawfordsville, Ind	4.373	3.773	13.7	....
K—10 Terre Haute, Ind	13.245	11.762	5.508	....
K—11 Brazil, Ind	9.525	8.664	9.03	....
K—12 Brazil Fire Clay	12.971	12.201	6.78	....
K—13 Clinton, Ind	8.346	6.713	19.5	....
K—14 Western Brick Co., Danville, Ill	6.713	5.359	20.1	14.9
K—15 Barr Clay Co., Streator, Ill	6.124	5.629	8.08	....
H—16 Carter, Peoria	6.033	5.307	12.03	....
H—18 Sterling, Ill	7.212	8.942	12.5	....
H—20 Savanna, Ill	8.210	5.806	29.2	....
H—21 Galena, Ill	9.163	7.666	16.3	....
H—23 Carbon Cliff, shale	23.406	15.558	37.8	....
H—24 Carbon Cliff ' fire clay	8.664	7.503	13.4	....
R— 1 Nelsonville, Ohio	11.114	8.936	19.6	6.93
R— 2 Portsmouth, Ohio	9.662	7.393	23.4	....
R— 3 Canton Ohio, Imperial plant	5.216	4.717	9.56	....
R— 4 Canton Ohio, Royal plant	5.359	4.717	7.97	....
S— 1 Moberly, Mo	10.251	7.892	23.00	....
S— 2 Kansas City, Mo	10.513	9.252	11.9	....
B—II Atchison, Kan	9 753	8 664	11.1	....
G—II Coffeyville, Kan	9.254	8.014	13.4	....
H—II Topeka, Kan	14.469	13.880	4.4	....
I —II Caney, Kan	13.742	12.383	7.04	....
J —II Pittsburg, Kan	10.069	9.662	8.09	....
L—II Lawrence, Kan	8.925	8.028	10.0	....
F— 1 Danville Brick Co	12.111	10.523	13.1	....

CAUSE FOR VARIATION OF MORE THAN 15 PER CENT.

K-2. There were two briquettes that broke with high strength and two with low strength.

K-3. There was one briquette that broke with low strength. By throwing out that briquette the variation would be reduced to 6.84.

K-4. There was one briquette that broke with high strength. By throwing out that briquette the variation was reduced to 11.1.

K-7. There were two briquettes that broke with low strength.

K-13. There were two briquettes that broke with low strength.

K-14. There was one briquette that broke with low strength. Elimination of this briquette would make the variation 14.9.

H-20. There was one briquette that broke with high and another with low strength.

H123. There was one briquette that broke with high and another with low strength.

R-1. There was one briquette that broke with low strength. Elimination of this briquette would make the percentage only 6.93.

R-2. Three of these briquettes broke with high and three with low strength.

S-1. There was one briquette that broke with high and one with low strength.

The results here reported are exceptionally good. The variation in the strength of dry clay, as made by other methods, usually runs from 25 to 50 per cent in nearly every reported instance. In fact, it is seldom, if ever, that a report on tensile strength will show a lower variation than 25 per cent. The placing of 15 per cent as the maximum variation to be allowed would be very severe standard ordinarily, but the general character of the work as here reported justifies the limit.

RELATION OF TENSILE STRENGTH TO FINENESS OF GRAIN.

Curves were plotted from data given by Ries[1], and also by Beyer and Williams[2], showing the relation between fineness of grain, as delineated by the surface factor, and tensile strength. There did not appear to be any consistent relation between these two factors, shown by the curves.

FIG. 14. Diagram showing relation between tensile strength and fineness of grain.

Notwithstanding the apparent contradiction in the case of the New Jersey and Iowa clays, it is believed that fineness of grain in a given clay does bear a relation to the tensile strength. Orton[1] has shown the influence of different sized grains upon a very close grained and tough

[1] New Jersey Geological Survey, Vol. 6, p. 89.
[2] Iowa Geological Survey, Vol. XIV, p. 84.
[1] Trans. Amer. Cer. Soc., Vol. III, p. 117.

ball clay. This clay is so fine by itself that it is extremely difficult to dry without air checking, but with increasing adulteration of sand up to 30 per cent by weight, the tensile strength increased up to a maximum in the sample where the sand was of extreme fineness, and here again the tensile strength decreased rapidly. This drop in the curve is credited to the inability of the extremely fine mixture to part with its mechanical water without checking, thus causing flaws in the briquette and very materially weakening it. In this experiment we have at both extremes very fine grained materials; one a pure ball clay and the other the same ball clay adulterated by fifty per cent by weight of a very fine sand, both having a low tensile strength. The intermediate members of this series show increasing strength with decrease of size of grain. So far at least as this one case is concerned, increase in size of grain increases tensile strength. Fineness of grain and tensile strength are, therefore, functions of one another.

We know that a fine-grained shale is, in a majority of cases, improved by adulteration with sandstone, even in the fact of the fact that the sandstone is very coarse. At Streator, Ill., there are two strata of shale in one bank, the one, being very gritty, is easily manufactured into a good paver; the other, a close grained plastic shale, gives trouble in every stage of manufacture, and makes a poor paver. Yet these two shales are said to be of very similar chemical composition. The writer believes that the cause of this difference does not lie in their chemical composition. shrinkage, or ability to slake easily, but in their drying behavior. Judging from the results of Prof. Orton's experiment on the tough ball clay, it is believed that if many of the plastic, fine grained clays were by addition of coarse material opened sufficiently to permit ready egress of the mechanical water, they would be excellent paving brick material[1], while without such a treatment they would be worthless for anything other than building brick, simply because the bond of the clay would be weakened in drying by the expanding steam inside of the brick which could not readily escape.

In Fig. 14 data are plotted showing the relation between fineness of grain and tensile strength. This is indicated by the dotted line. It will be noted that there is a ´general relation between fineness of grain and tensile strength. This is indicated by the dotted line.

There is a remarkable coincidence in the relative positions of the several clays in Fig. 14 and Fig. 11. The same relative positions of the several clays is to be seen also in Fig. 12 which shows the relation between volume shrinkage and surface factor. This same relative position of the clays, one with another, was developed also when the relation between the sum of the excess and hygroscopic water and the surface factor, and also the relation between the sum of the excess and hygroscopic water and the tensile strength, were plotted. In the last two instances, however, the order in which the clays occurred was the reverse of that in Fig. 14 and 11.

[1] It is not desired that the reader should infer that this is suggested as a panacea for all clays or that all clays can be "doctored" so as even theroetically to make them fit for paving brick manufacture.

RELATION OF TENSILE STRENGTH TO VOLUME SHRINKAGE.

We have seen that there is a greater shrinkage of the mass when dried from stiff mud to bone dryness, as the grains of the clay decrease in size. If these fine particles are composed largely of clay substance they will possess a degree of cohesion that will cause the dried mass to become quite hard, the hardness increasing directly with increase of cohesion possessed by the individual particles. With increase of exposed surface,

FIG. 15. Diagram showing relation between volume shrinkage and tensile strength.

ought to be an increase in tensile strength, for the closer the particles are to one another the greater will be the bond between them. Decrease in size of grain, increase in volume shrinkage and increase in tensile strength should, therefore, follow one another in this order as

causes and effects. Such a relation is shown in Fig. 15 where the volume shrinkage and tensile strength are plotted coördinately.

The drying behavier of a given clay then can be said to be a function of four factors acting simultaneously, viz: Volume shrinkage, excess water, fineness of grain and tensile strength. The greater the volume shrinkage and the larger amount of excess water present, the more danger will there be in drying. The greater the fineness of grain and the larger the tensile strength, the safer ought the clay to dry, all other things being equal. If a drying modulus were to be formulated it would have in the numerator the surface factor (S), representing the fineness of grain, and tensile strength (T); in the denominator there would be the percentage of volume shrinkage (1) and excess water (E), that is,

$$\frac{S\ T}{V\ E}$$ This simple relation is not, however, expressive of the true relative value of the involved factors. It is believed that the formula.

$$\frac{S^3\ T}{V^3\ E}$$ approximates the truth more closely.

$$\overline{100}$$

PLASTICITY.

THEORIES OF PLASTICITY.

There is probably no property of unburned clay which has been more widely discussed than plasticity. To plasticity the clay owes its responsiveness to every touch of the potter's hand and its adaptability to the preservation of every line of the artist's tool; it is this quality that permits of its being drawn out into sheets and cylinders of the most astonishing thinness.

Of the many theories advanced as to the cause of plasticity the following are the most tenable:

Molecular Attraction Theory—To properly appreciate this conception of the cause for plasticity, suppose clay to be blunged into the form of a slip, as is the practice of the potter before casting a vase. In this slip or fluid condition each grain is surrounded or enveloped by a film of water. If the volume of water is large compared with the total volume of clay particles, the mass will behave in every respect like a fluid; indeed, as will the turbid water of the Mississippi. Suppose that, by evaporation, or adsorption by a plaster mold, the volume of the water be decreased. The clay particles will be brought closer and closer to one another, causing the mass to pass from a fluid state through various stages of consistency until it assumes a stiff plastic condition; a process to be observed in mud roads after every rain. When in this stiff condition the particles still have an envelope of water or, in other

words, they are still suspended in water just as truly as they were when the mass was more of a fluid. But, owing to their proximity, it is assumed by those advancing this theory of plasticity, that they are held in position by the molecular attraction which each particle of clay substance exerts on the other.

Molecular attraction is a known force, and there has been no adequate proof advanced upon which positive claims can be made against such a force operating between clay particles when brought into close proximity. The popular conception of a bar of iron is that it is a rigid homogeneous mass, but, as is shown in magnetization experiments, it is made up of individual particles which can be turned about or set up endwise, thus acting independently of one another except in the matter of the molecular attraction that each exerts upon its neighbor, binding or holding the whole together. Aside from composition the degree of molecular attraction determines the hardness of the iron. Iron, then, is a solid fluid, that is, it will flow. The force of gravity is not sufficient to overcome this molecular attraction and cause flowage, but when a force that exceeds that of the molecular attraction is applied, flowage follows in the direction of the greater force. It is in this respect that iron is a fluid.

If similar flowage is attempted when the grains in a clay mass are practically dry, or, in other words, not surrounded by water, except perhaps that held by absorption, pressure sufficient to overcome the force binding or holding the particles together will disrupt the ware. That is, instead of flowage of the particles in this comparatively dry state, rupture is a possibility. Further, maximum plasticity or ability to flow is not attained until the maximum number of particles is enveloped with the least amount of the suspending medium. This same phenomenon is to be noted with almost all fine insoluble powders. Wheeler[1] has shown, for instance, that the non-plastic slates, Iceland spar, propyllite, gypsum and halloysite can be made to develope a much smaller but still a fair degree of apparent plasticity with water as a floating medium. When dried, the force required to disrupt these masses, while small, is yet comparatively great. The difference, however, between the behavior of clay and these finely pulverized minerals is that the latter can be molded by pressure alone into a shape that will have a comparatively higher tensile strength than if they were caused to acquire that shape by flowage due only to assumed plasticity. But we know that maximum density and consequent strength can be best developed in plastic clay by the combined influence of pressure and plasticity. Now is it molecular attraction in the case of clay, as in that of iron which can be bent, stretched, rolled, etc., in the cold without rupture, or is it merely that clay grains may be pressed so close together that flowage is permitted so long as water is present in excess, but is resisted by fractional force when dry?

[1] Mo. Geol. Surv., Vol. XI. p. 106.
[2] Carhart, H.S., Univ. Physics, Pt. I.

Text books on physics give as an "expression"[2] for the force of molecular attraction between two molecules, M and M', MM'f (r). "All that is known about this funtion of r is that it is very large for insensible distances, that it diminishes very rapidly as r increases and that it vanishes while r is still very small. The maximum value of r at which molecular action ceases is estimated by Quincke to the 0.00005 mm. If the particles then were 0.00005 mm. or 0.00002 inches apart, they would be at the extreme distance through which molecular attraction can possibly operate. Grout[1] says, however, "Now a simple calculation, based on the mechanical analysis of the clays, will show that the amount of water needed to place a film 0.00005 mm. thick around each grain is often nearly equal to the amount added in tempering, so that in ordinary plastic clay, it is necessary to consider practically all the water as being under this influence."

Grout[2] bases his reasoning on the following calculations: He found that his "mechanical analyses frequently show a large percentage of grains below 0.001 mm. in diameter, also from 0.001 to 0.005 mm. The average diameter of grains below 0.001 mm. is 0.0005 mm. If these are considered spherical and of specific gravity 2.5, it would require 25.5 per cent by weight of water to place around each grain a film 0.00005 mm. thick."

On making these same calculations the following was obtained:

$$\text{Vol. of sphere} = \frac{PiD^3}{6}$$

Given diameter of sphere 0.00005

$$\text{Log } \frac{Pi}{6} = \overline{1.71899}$$

$$\text{Log } 0.0005^3 = \overline{10.09691}$$

$11.81590 = \text{Log } 6545 \times 10^{-14}$ volume of clay sphere.

Diameter of sphere plus water film $= .0005 + .0001$ or $.0006$

$$\text{Log } \frac{Pi}{6} = \overline{1.71899}$$

$$\text{Log } .0006^3 = \frac{\overline{10.33445}}{10.05344} = \text{Log } 1131 \times 10^{-13}$$ volume in cu. mm. of sphere of clay plus water.

Reducing these figures for the sake of convenience to

$0.6545 = $ volume of clay sphere,

$1.131 \;\; = $ volume of clay plus water sphere.

$0.6545 \div 1.131 = 0.5775$, part of unit volume of clay plus water sphere occupied by the clay.

$1.00 \;\; - .5776 = 0.4224$, part occupied by water film.

[1] Jour. Am. Chem. Soc., Vol. XXVII, No. 9, Sept. 1905.
[2] Loc. cit., p. 1046.

Given specific gravity of clay $= 2.5$
Since in the metric system Vol. X Sp. Gr.=Weight

$$0.5775 \quad X \quad 2.5 = 1.4540 \quad \text{parts by weight of clay}$$
$$0.4224 \quad X \quad 1.0 = .4224 \quad \text{parts by weight of water}$$

$$\overline{ 1.8764} \quad \text{total weight.}$$

$0.42246 \div 1.8764 = 0.2251$, parts by weight of water in a unit volume of clay plus water film, or 22.5 per cent.

This calculation, so far as the validity of Grout's argument is concerned, checks his results.

Grout further calculated that if this same volume of clay were considered as a square plate one-fifth as thick as wide, instead of a sphere, over 54 per cent of water would be held to the clay particles by this molecular attraction. Supposing it to be fair, inasmuch as the·kaolinite crystal is "plate-like," to consider that in a clay half of the grains are approximately spherical and the remainder plate-like. Grout figures that a clay having all its particles the size here assumed would take by virtue of the molecular attraction of the clay particles, 40 per cent of water.

In a personal interview the writer suggested to him that he was taking the maximum limit of the distance through which this molecular attraction can be said to operate. His defense was that when the spheres were devoid of a water film they touched one another, but as they gathered to themselves this water film, they need not necessarily be separated .00005 mm., for the film crowded from the points of closest proximity could be considered as filling up the space that would otherwise have to be considered as void.

It must be admitted by the supporters of Grout's molecular attraction theory for plasticity, that he used but a portion of a very fine-grained clay on which to calculate his demonstrating example. If he had taken into consideration the data for the sample of clay as published by him instead of only those for the finer portions, quite different results would have been obtained as is shown in Table XVI.

The calculations by which the data in the following table were obtained are,

(a) Volume of clay sphere $\dfrac{PiD^3}{6}$ where D is the mean diameter of the range in each group of the mechanical analysis.

(b) Volume and weight of water film $\dfrac{Pi\ (D - 0.0001)^3}{6} - \dfrac{PiD^3}{6}$

(c) Weight of dry clay particles as given in the mechanical analysis.

(d) Total or collective volume of spheres in each group: Weight given ÷ Sp. Gr. of the clay.

(e) Number of spheres in each group per unit volume: Total volume of each group ÷ volume of clay sphere or $\dfrac{d}{a}$

(*f*) Weight of water film surrounding the sphere in each group of the sample: Weight of water film times the number of spheres or e X b.

(*g*) Sum of water required to give each particle in the sample a water film of prescribed thickness.

TABLE XVI.

SAMPLE.	Sp. Gr.	Total dry weight of clay particles by analysis.	Total weight of water films by calculation	Analyst.	Reference to data used and explanatory notes.
S. C. Besley, top clay (1)	2.34	0.9844	0.0165	W iams.	pp. 116 and 123, Ia. Geol. Surv., Vol. XIV.
S. C. Besley, middle clay	2.32	0.9834	0.0219	..do........	Williams' first group was termed "above O.1 M M."
S. C. Besley, bottom clay	2.40	0.9819	0.0263	..do........	In this group the mean diameter of the particles was assumed to be O. 175 M. M.
Dale Brick Co............	2.44	0.9857	0.0320	..do........	....
Gethmann Bros..........	2.41	0.9739	0.00254	..do........	....
Clarksburg fire clay (2)...	2.52	0.9880	0.0393	Grout.....	pp. 65 and 251 W.Va. Geol. Surv., Vol. III.
Bridgeport stoneware clay (2)	2.35	0.9870	0.1750	..do........	pp. 65 and 162 W.Va. Geol. Surv., Vol. III. Attracted water = 15 + per cent.
Charleston river clay (3).	2.66	0.987	0.1009	..do........	pp. 65 and 200 W.Va. Geol. Surv., Vol. III.
Parkersburg pottery clay	2.58	0.984	0.1043	..do........	pp. 65 and 160 W.Va. Geol. Surv., Vol. III.
K-1 Alton, Ill. (4).......	2.66	1.045	0.0356	Krehbiel and Moore	....
K-2 St. Louis Mo.......	2.56	1.021	0.0491	....	....
K-3 Albion, Ill..........	2.686	1.002	0.0475	....	....
K-4 Springfield, Ill.....	2.67	1.037	0.0703	....	....
K-5 Edwardsville, Ill...	2.65	1.028	0.0390	....	....
K-6 Galesburg, Ill......	2.66	1.027	0.0320	....	....
K-7 Streator. B. B. Co..	2.636	1.037	0.045	Krehbiel and Moore	....
K-8 Veedersburg, Ind.	2.689	1.005	0.036		....
K-9 Crawfordsville, Ind.	2.702	1.008	0.029	Calculated by Merry..	....
K-10 Terre Haute, Ind...	2.69	0.979	0.0804	....	....
K-11 Brazil shale.........	2.659	1.013	0.0467	....	....
K-12 Brazil fire clay.....	2.669	1.021	0.0533	....	No. 2. fire clay.
K-13 Clinton, Ind........	2.71	1.048	0.0479	....	....
K-14 Western P. B. C., Danville...........	2.72	0.9899	0.0348	....	....
R-1 Nelsonville, O.....	2.73	1.023	0.0519	....	No. 2 fire Clay.
R-3 Canton, O. (Imperial)	2.66	1.043	0.041	....	....
R-4 Canton, O. (Royal).	2.72	1.023	0.03902	....	....

Table XVI—Concluded.

SAMPLE.	Sp. Gr.	Total dry weight of clay particles by analysis.	Total weight of water films by calculation	Analyst.	Reference to data used and explanatory notes.
I-11 Caney, Kan........	2.67	1.013	0.0670	....	....
G-11 Coffeyville, Kan...	2.71	1.045	0.0463	....	....
H-18 Sterling, Ill.........	2.67	1.042	0.0593	....	....
H-20 Savanna, Ill...:....	2.72	1.031	0.0739	....	....
H-21 Galena, Ill........	2.72	1.029	0.10301	....	....
H-23 Carbon Cliff, Ill. (shale)	2.63	1.027	0.0867	....	....

(1) The Iowa clays are loess.
(2) Stoneware or No. 2 fire clays.
(3) Alluvial clay.
(4) The Illinois clays are shales in every instance except K-12 and R-1.

In Table XVI there is but one instance that of the West Virginia stoneware clay, in which the amount of water molecularly attracted even approached that required to develop plasticity. In many instances it does not greatly exceed the hygroscopic water that the clay would retain when dried in open rack dryers. In fact the maximum amount of water which Grout admits could be so molecularly attracted, agrees quite closely with the water which in Table XI is shown to be in excess of that required to fill the pores. While Grout's statement of the facts in this case has been proved incorrect, further investigation may find a relation between the molecularly attracted water and "excess water." As yet, however, such a relation cannot be established.

That a clay particle does possess a molecular attraction peculiar to itself is not denied. That this molecular attraction alone is sufficient to cause a plasticity that is peculiar and belongs to no other substance must be discredited until evidence is brought forward that will bear an analysis such as is given in Table XIV.

It would be most difficult for supporters of the molecular attraction theory to prove that the kaolin grains in primary clays do not possess every physical property that is attributed to the grains of the clay substance in the secondary clays, save that of plasticity. Chemically alike, and differing physically only in this one respect, yet to the one, according to this theory, must be accredited no, or very little, molecular attraction for water, and to the other a strong molecular attraction.

Grout[1] may be quoted as follows:

"The attraction of two grains may vary with the nature of the grains. The greater the attraction the farther they can be separated without losing coherence. — — — —. Another way in which the films become viscous is the result of molecular attraction, which binds a film over the surface of the grain and renders it viscous. The friction between this film and the solid grain of clay is said to be infinite, compared with water outside of the film. But when forced to move, the resistance would depend on the strength of the attraction of clay and liquid. — — — —. The change in viscosity or

[1] Jour. Am. Chem. Soc.. Vol. XXVII, No. 9, Sept. 1905, p. 1016.

in thicknes of the film, seems to be beyond the region of experiment. The quantity is too small to admit the determination of slight changes, but such are constantly assumed in physical problems. W. J. A. Bliss speaks of clay particles and the surrounding adherent liquid as follows: 'The thickness of this shell depends on the intensity of the attraction between the solid and the liquid.' J. E. Mills says: 'Molecular attraction depends primarily on the chemical constitution of the molecule. — — — —.' Certain rare organic colloids increase the plasticity by rendering the water viscous. — — — —. The tendency for tensile strength to vary with plasticity is also easily explained in this way. Molecular attraction between two kaolin grains may be high. If the attraction for water is high, some water will be drawn between the grains and rendered viscous by the attraction; this makes plasticity high. But when the water dries out from such a mass, the kaolin grains still attract each other, and the chances are for greater strength than when wet, because the water has acted as a lubricant, allowing a readjustment of grains to fill the space left as the water moved out. The result is a high degree of consolidation."

Mr. Grout's arguments may be summed up as follows:

1. Attraction varies with the nature of grain, i. e., their chemical constitution, or in other words, molecular structure.

2. Films become viscous as a result of molecular attraction, the more strongly attracted film being the more viscous.

3. Organic colloids increase plasticity by rendering the water film viscous.

4. The tendency for tensile strength to vary with plasticity is explained by molecular attraction between grains.

5. Change in viscosity or in thickness of film is beyond the region of experiment.

Granting that these arguments may be valid and may be substantiated by facts, it will be shown later that they may be considered as establishing the existence of an effect rather than the existence of a cause.

Size of Grain Theory of Plasticity—It has been shown earlier in this discussion that the size of the grains as determined in the mechanical analysis does not agree with the normal fineness of grain in the clay as it issues from the pug-mill; there are bundles of grains that successfully withstand the disintegrating effect of water in the pugging process, but which are to a large extent disintegrated in the process of mechanical analysis. It is obvious therefore that conclusions based wholly on the results obtained in the mechanical analysis cannot be considered as necessarily agreeing with the facts observed in the actual behavior of the clay under factory conditions. In many clays, however, these bundles are broken down to such an extent that the analytical results indicate quite accurately their actual working properties.

Because in the mechanical analysis the coarser grains have been reported as sand and the finer particles as silt and clay, not a few have been led to conclude that clay particles, or at least particles in which clay substances constitute a large proportion, cannot be present in a clay as large grains after thorough disintegration in water. Grout has shown, however, that this conception is entirely erroneous.[1] In Table XVII is given the amount of clay substance that he obtained first from the analytical analysis, second, calculated from ultimate analysis, and third, obtained from mechanical analysis.

---

[1] W. Va. Geol. Surv., Vol. III, 1905, p. 26.

TABLE XVII.

Showing the discrepancy in the reported "clay substance" in clay, by the three methods for its determination now in vogue.

Specimen Number.	Rational Analysis	Calculated Kaolin	Mechanical Analysis.
4..	67.23	52.30	11.8
17...............	36.80	26.39	36.85
41.................................... .:.	72.26	41.65	63.70
62..	70.48	41.14	59.70
76............................	42.41	31.50	33.35

Mr. Grout has also given[1] results of the chemical analysis of a complete mixture of the several grades of fineness obtained from 16 samples of clay as follows:

TABLE XVIII.

Constituents.	.00 to .001	.001 to .005	.005 to .02	.02 to 0.15	0.15 up.
SiO_2.......................................	44.08	54.54	70.30	81.16	73.63
Al_2O_3....................................	28.16	23.00	16.04	9.76	13.01
Fe_2O_3...................................	7.94	5 91	3.21	2.13	4.71
FeO.......................................	0.99	0.99	0.63	0.40	.0.18
MgO.......................................	1.36	1.02	0 80	0.39	0.48
CaO.......................................	0.76	0.82	0.72	0.31	0.47
Na_2O.....................................	0.00	0.29	0.45	0.56	0.00
K_2O......................................	3,05	3 31	2.14	1.78	0.93
H_2O......................................	2.80	1.10	0.56	0.35	0.87
Ignition..................................	10.86	7.79	4.33	2.59	4.40
TiO_2......................................	0.84	1.12	1.08	0.78	0.60

In this he has proved conclusively that the "clay substance" is present in every grade of fineness. His own conclusions from these analyses are, however, rather startling. He says: "The silica percentage is higher in the coarser portions, where it probably is present in the form of sand or quartz. Alumina is higher in the finer material, but total fluxes are also higher, so that the finest particles are not the purest kaolin."

In order better to show the validity of his conclusions his data has been calculated into molecular equivalents as given in the following table:

---

[1] W. Va. Genl. Surv., Vol. III, p. 61.

TABLE XIX.

Grades of Fineness.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2
0.00 to 0.001............	2.66	1.00	0.18	0.05	0.12	0.05	....	0.12	0.04
0.001 to 0.005...........	4.03	1.00	0.16	0.06	0.11	0.06	0.02	0.16	0.06
0.005 to 0.02.............	7.45	1.00	0.13	0.06	0.13	0.08	0.05	0.14	0.09
0.02 to 0.15.............	14.14	1.00	0.14	0 59	1.02	0.58	0.94	0 19	1.02
0.15 up.................	9.62	1.00	0.02	0.002	0.01	0.007	....	0.008	0.006

A review of Grout's mechanical analysis of the West Virginia clays discloses the fact that he made 26 determinations:

  6 plastic fire clays, pp. 160, 162, 163, 233 and 251,
  1 flint fire clay, p. 218,
  7 shales, pp. 249, 251, 242 and 262,
 10 river clays, pp. 263, 265, 270, 272, 274, and 276.
  1 glacial clay, p. 265,
  1 residual surface clay, p. 200.

It is assumed, therefore, that the samples, the analyses of which are given in Table XVI, are composites of the several grades of grains from the above clays. Being in most cases very impure clays, it is considered that although a study of the possible mineral make-up of each grade is at the best largely based on hypothetical assumptions, such a study would aid in our attempt to understand the constitutional make-up of our clays.

On the assumption that all the alkali is present as a RO in orthoclase feldspar, the molecular ratio and ratio by weight of kaolin, feldspar and quartz present in each grade would be as follows:

TABLE XX.

Showing possible mineral constitution of the several grades of grains in impure clays.

Grade.	Molecular Ratio.			Weight Ratio.		Quartz.
	Kaolin.	Feldspar.	Quartz.	Kaolin.	Feldspar.	
0.00 -0.001................	0.88	0.12	.18	10	2.9	0.08
0.001-0.005................	.82	0.18	1.25	10	4.7	3.5
0.005-0.02.................	.81	0.19	4.69	10	5.1	13.5
0.02 -0.15.................	....	1.00	8.14	....	10.0	8.
0.15 up....................	0 992	0.008	3.62	10	0.18	8.5

This data checks the fact developed in Table XV, i. e., that clay substance is to be found in all of the grades of fineness, in the coarsest as well as the finest. It also shows that more than 50 per cent of the

coarsest group, or as it is customarily called, "coarse sand," may be kaolin, or is at least kaolinitic in composition.

As a further analysis of the probable mineral make-up of clays, Grout's data will be discussed by groups. In this only the most common and abundant minerals known to occur in clays are considered.

Coarsest grade (0.15 mm.) : This grade of grain, even if all the alkali is considered as being present as a constituent part of feldspar grains, would be assumed to be composed almost entirely of non-disintegrated kaolin and quartz grains. Only in one case, however, does Mr. Grout[1] speak of the physical character of the grains of this grade. In this particular case the clay examined is a shale. "The 12.9 per cent (referring to coarse sand grade) on 3 mm. screen was mostly flat scales of shale, about 5 mm. in size, of red and greenish color." The total absence of similar description of this grade in the other 25 samples justifies the conclusion that the grains of this grade were flat or scale like only in this one sample. If this conclusion is true, then it is fair to assume that either the kaolin scales are present in undissolvable bundles, or these grains are not composed of kaolin but some other aluminum compound like gibbsite, etc.

On the other hand, it is hardly possible that grains of feldspar of this size could remain unaltered in these old river clays that have been elutriated, mixed and moved by fresh waters possibly for ages. There is justification for the assumption, therefore, that these coarse grains are bundles of kaolinitic grains cemented together so tightly by some salt that they resist disintegration by water. If the alkalies had been present as constituent parts of feldspar grains of this size, the feldspar crystals could have been easily recognized under the microscope as cubical grains and not flat scales.

H. B. Fox, in the Ceramic laboratories of the University of Illinois, separated the grains of a shale and a glacial clay into the several grades of fineness, and found that all the grades possessed a plasticity that varied directly with the fineness of grain, and that the coarse grains which could not be disintegrated by 20 hours of constant shaking in water, when broken down in a mortar, developed plasticity that increased as the size of the grains decreased, until when the coarse grains had been reduced to an impalpable powder they developed a plasticity nearly equal to that exhibited in the finest grains that had been separated from the original sample, showing, it is believed, that the coarser grains were comprised of materials similar in every respect to those in the fine grains, but cemented in such a way that they withstood successfully the disintegration treatment.

(0.02 to 0.15) grade: It is highly improbable that this grade contained no kaolin or clay substance, but such would have to be the case if all the alkali was present as a constituent part of the orthoclase feldspar grains. The alkalies cannot be present in this case as easily soluble

---

1 W. Va. Genl. Surv., Vol. III, p. 249.

salts, for the alkaline salts would have been dissolved, carried in solution, and would affect only the finest grades. If the feldspar was oligoclase and not orthoclase, then the 0.5 equivalents of the alumina could be considered as a constituent of kaolin grains.

Although there is no statement made as to the presence of mica in the clays from which these grades of grains were obtained, Mr. Grimsley[1] states that it is a very common constitutent of the West Virginia clays. Stull[2] gives as the chemical formula of common muscovite mica the following:

$$
\left.\begin{array}{l}
0.1243\ CaO \dots \dots \dots \dots \dots \\
0.1103\ MgO \dots \dots \dots \dots \dots \\
0.3280\ K_2O \dots \dots \dots \dots \dots \\
0.0929\ Na_2O \dots \dots \dots \dots \dots
\end{array}\right\}
\left.\begin{array}{l}
1.000\ Al_2O_3 \dots \dots \dots \dots \dots \\
0.1857\ Fe_2O_3 \dots \dots \dots \dots \dots
\end{array}\right\}
\left.\begin{array}{l}
6.399\ SiO_2 - 0.974\ H_2O \\
Comb.\ Wt.\ 582.167
\end{array}\right.
$$

On the assumption that the alkali in this grade is derived wholly from muscovite mica of the composition given by Stull, the mineral constitutents of this grade of grain might be proportioned as shown by the following calculations:

	SiO₂	Al₂O₃	Fe₂O₃	FeO	MgO	CaO	Na₂O	K₂O	TiO₂
	14.14	1.00	0.14	0.59	1.02	0.58	0.94	0.19	1.02
.57 Eqv. Mica..........	3.65	0.57	0.11	....	0.06	0.07	0.05	0.19	....
	10.49	0.43	0.03	0.59	0.96	0.51	0.89	....	1.02
.43 Eqv. Kaolin........	.86	0.43	....	....	....	....	....	....	....
	.63						0.89		

$$
\begin{array}{llll}
0.57\ Eqv.\ Mica & x & 582.167 = 331.835 & \text{or by proportion } 30.0 \\
0.43\ Eqv.\ Kaolin & x & 258 = 110.940 & \text{or by proportion } 10.0 \\
0.63\ Eqv.\ Silica & x & 60 = 37.800 & \text{or by proportion } 3.4
\end{array}
$$

In this case, the formula most favorable to the supposition that all the K₂O is present in the form of mica has been taken. If the theoretical formula K₂O, 3 Al₂O₃, 6 Si O₂, 2 H₂O had been taken, there would have been either considerable K₂O to account for in some other way, or return to the original hypothesis that this group contained no kaolin. Either supposition leaves considerable alkali unaccounted for, which as has been pointed out, could not possibly be present in an early soluble form.

The supposition therefore that this grade is composed in part of kaolinitic grains cemented together by some alkaline salts, finds support in any plausible assumption that may be made.

(0.005—0.02 and (0.001—0.005) groups: If the kaolin grains in these groups were in their natural condition, i. e., flat plate-like crystals, they should, theoretically, be visible through the microscope. This evidently was not the case. Beyer and Williams[1] say: "While it is next to impossibleto make out much concerning the crystalline character of the minerals, it is also difficult, because of their minute size in most secondary clays, to say anything regarding their shape."—In other

---

1 W. Va. Geol. Surv., Vol. III, p. 12.
2 A. C. S. Trans. Vol. IV, p. 258.
1 Ia. Geol. Surv., Vol. XIV, p. 94.

words, the shape of the grains is irregular and non-conformable one with another. If in these grades there is as much kaolin as is shown in Table XVIII, its grains must be, to a very great extent, in bundles. If feldspar or mica is present in such amount and size of grain, as the calculated data suggest, their grains ought to be detectable with the aid of the microscope. Such, however, is not the case. The supposition, therefore, that all the akalies of these two grades are there as constituent parts of feldspar and mica is certainly untenable.

(0.000-0.0001) grade: The molecular composition of this group is certainly very instructive. That in such heterogeneous mixtures as shales and river clays the finest particles are found to be composed in the main of kaolinitic grains is certainly astonishing. If the bases present, as shown in Table XIX, page 181, are considered as being present as soluble salts that were either originally present in the clays or in part introduced during the process of analysis, (a most plausible assumption) then there would remain but one conclusion, that is, that the finest insoluble grains are almost entirely kaolinitic in composition.

Taking data given by Grout, it was calculated that if all the soluble salts originally in the clays were in the finest group, they would amount to 2.7 per cent of the weight of that group. The 2.7 per cent, together with the soluble salt introduced during the process of analysis from glassware, water, atmospheric dust, etc., would account for nearly all of the alkali in the finest grade. It is not mere assumption therefore, that the finest particles in clay, contrary to Grout's statement, are the purest kaolin grains.

In the course of the research on paving brick clays by the survey there was much speculation as to the number of these submicroscopic kaolin grains in the various shales. This was readily ascertained as follows: By dividing the percentage amount of the group (0.001 to 0) by 100, and considering that as being a part of 1 milligram of the sample, (for the size of the particles is in millimeters) then dividing this amount by the specific gravity of the clays, a figure is obtained that represents the sum or total volume in cubic millimeters of the particles comprising the group. Considering 0.0005 as the mean diameter of the particles,

by the formula $\dfrac{6}{PiD^3}$ the volume of each particle is found to be 654×10^{-13} cubic millimeters. Then for each day, by dividing the total volume of the particles, by the volume of one particle, the number of grains per milligram of the sample will be obtained. By multiplying the number of grains in one milligram by 1,000 there would be obtained the number of grains in 1 gram; or by multiplying by 352,740 there would be obtained the number of grains of this size in 1 oz. of the whole sample. In this way Table XXI was calculated.

1 This mean diameter is twice as large as that given by Whitney for the finest group; U. S. Dept. of Agr. Weather Bureau, Bull., No. 4, p. 35.

TABLE XXI.

Number of grains of group (0.001 to 0) in—

Sample No.	1 gram of the clay.	1 oz. of the clay.
K 1	560 trillions.	197,534 trillions.
K 2	829.0 trillions.	292,421 trillions.
K 3....	794.0 trillions.	280,075 trillion4.
H 23	1,588.7 trillions.	560,398 trillions.
H 21.	1,910.0 trillions.	684,315 trillions.
K 6	440.0 trillions.	166,205 trillions.

These figures, although beyond the limits of perception of the human mind, are not larger than the figures representing the countless germs that bacteriologists claim can exist in a single drop of a fluid. Startling as this data appears to be, it cannot be other than true if the analytical results of the mechanical separation are correct.

If these minute particles were not kaolin grains, would they add to the real plasticity of the clay? Potter's flint (dry ground) is finer grained than most clays, and particularly more so than the shales, yet it does not exhibit the faintest sign of plasticity. Orton[1] found that glass particles which were so fine that they remained in suspension for hours without settling, when collected exhibited no plasticity. Wheeler[2] found that while quartz crystals ground to 200 mesh, seemed to be appreciably plastic, on drying the coherence was so slight that it required the gentlest handling to prevent the molded sample from falling to pieces. Fine quartz dust and impalpable geyserite or finely precipitated opal, dried to a very tender mass. The same was true of tripoli. Wheeler[3] found that some plasticity could be developed in powdered slate, prophylite, talc, gypsum, halloysite, etc., but that the plasticity developed was only apparent plasticity, except perhaps in the case of slate. The powdered gypsum when molded and dried formed a relatively hard mass, but this hardness would be expected on account of the solubility of gypsum in water. The plasticity of the slate, which is a dehydrated shale has caused considerable surprise, and has strengthened the fineness of grain theory of plasticity. That powdered slate should develop plasticity need not be so great a source of wonder, for in the course of the Survey work a shale, after having been held at heat ranging from 500° to 800° C. for 17 hours, slaked down in water to a red plastic mass in the same manner as the unburned shale at the bank. True, the plasticity of this partially burned shale was not equal to the plasticity shown by the clay before dehydration, but its plasticity was considerably more than that of some of the harder shales before being burned. Fineness of grain in itself then does not seem to be the cause of plasticity. It may said, however, to be a required condition in the operation of the real cause.

1 Brick, Vol. XIV, No. 4, p. 216.
2 Mo. Geol. Surv., Vol. XI, p. 102.
3 Loc. cit., p. 106.

In seeming contradiction to this statement regarding the fineness of grain as a sense for plasticity, is the fact that finer grinding of given clay increases its plasticity; but quoting Wheeler[1]: "While it is true that fine clays are usually very plastic and coarse clays much less so, there are very many exceptions." And again, Grout[2] says that while the majority of clays improve on fine grinding, some are unchanged.

Wheeler[3] reports the physical structure of a few clays as follows:

Moberly shale (400 diam.):
    Mainly clusters of thick plates with minor portions split off; moderately plastic; suggests fine grinding to develop plasticity.
Aldrich shale (325 diam.):
    One-third dolomite crystals; bulk in coarse thick crystals or plates; rest in fine state of division; moderately plastic.
Unweathered Leasburg flint fire clay (950 diam.):
    Almost all fine particles; no plates or scales; devoid of plasticity.
Weathered Leasburg flint fire clay (950 diam.):
    Numerous coarse plates present and occasionally, apparently a few thin plates. Came from same bank the same day a few feet from the unweathered sample.
Hartwell loess clay (400 diam.):
    Large angular fragments which were undoubtedly sand, and apparently some clusters of plate crystals, with only a minor portion of small plates; very plastic.
    There is sufficient evidence in the above citations to show that any theory so far discussed other than that of molecular attraction, is insufficient to account for the presence or absence of plasticity.

Plate Structure Theory of Plasticity—Grout[1] has recorded the fact that in the case of the Thornton Brick Company's plastic clay the amount by weight of the particles below 0.005 mm. in diameter rose from 7.7 per cent to 17.8 per cent by weight in one wetting and drying. Fox, in our laboratories, found that the plates, although not disintegrated by twenty-four hours of shaking in water, would break down by mechanical crushing or by disintegration in acids and caustic alkali, and that when so broken down the mass became considerably more plastic. Wheeler[1] not only advises fine grinding in the case of the Moberly shales, but relates a most remarkable instance of a clay in which the grains on weathering formed themselves into clusters resembling plates. It seems highly probable, therefore, that these plates or coarse grains are bunches or bundles of minute grains cemented together by salts that are to a greater or less extent soluble in water, and that, depending upon the solubility of the cementing salt in a particular case, or the peculiar compactness of the grains in another, it requires a greater or less amount of time to cause a breaking down of these bundles. It can be readily conceived that the adsorptive power of the particles when combined with their axes in a certain general direction, for instance, has greater power in holding certain of these cementing salts than the solvent action exerted by the water can overcome. The solvent power of water, in other words, is not sufficient to overcome the adsorptive power of the kaolinitic grains.

1 Loc. cit., p. 109.
2 W. Va. Geol. Surv., Vol. III, p. 46.
3 Loc. cit., pp. 104 to 109.
4 W. Va. Geol. Surv., Vol. III, p. 46.
5 Loc. cit., p. 105.

These coarse grains add to the plasticity of the clay as a whole in a ratio to the surface exposed. Every exposed kaolin particle is as effective in enhancing plasticity as the very small independent particles. The extent to which the larger grains would affect plasticity would, therefore, be in proportion to the exposed surface of the particles of which the bundle or cluster is composed.

Further, it is fair to challenge the plate theorist to demonstrate that these small grains when cemented together in a bundle or cluster have not a tendency to line up one with another so that their longest axes will lie in the same relative plane, just as they are in the natural kaolin crystals, i. e., in plate forms. The plate theorist must admit that when these bundles are thus formed they are well-nigh indistinguishable from mica crystals, and that the very large majority of so-called plates or scales of kaolin in a clay are most likely to be mica. It is certainly strange that on one page of a report there will be a statement to the effect that "the clays of this state are quite micacious," and another page will report the scales that appear on the stage of the microscope as "kaolin scales or plates."

If the idea that has been put forward in the foregoing is correct, then we must agree with Dr. Ladd[1] when he says: "The question of fineness of grain and shape of the particle becomes, then, largely but modifying factors, affecting degree, and being, within large limits at least, modifiers, rather than determinants of plasticity."

It is quite evident that the peculiar physical make-up of a kaolin grain, so far as the eye by the aid of the microscope can discern, is not fundamentally responsible for their individuality, as expressed in their power to develop plasticity. If the structure of the grains which enables a mass of them to develop plasticity is not detectable by the microscope, direct observation and measurement are obviously inadequate in finding the true cause.

Pectoidal Theory of Plasticity—Turning to indirect or circumstantial evidence, there are many facts observed by a good many careful scientists that seem to point to one thing that is more characteristic of kaolin grains than of any other of the inorganic substances or minerals of which a clay is composed, i. e., adsorptive power. Some investigators have even gone so far as to attribute the plasticity of kaolin grains to an adsorptive power or actual taking into the grains themselves of foreign salts from solution. They advance the theory that these minute grains have a micellian structure. To such substance they apply the name "Pectoid," and to the theory the name, "Pectoid theory." To many, the absorptive and adsorptive properties of a clay are one and the same thing, and so far as can be judged, the most radical believe in either the adsorptive or the pectoidal theory, and oscillate from one to the other in a manner that induces skepticism. The fact remains, however, that both use the same arguments, the only difference being in the conception. It is safe to warrant, that when the pectoid theorist real-

---

1 Geol. Surv., of Ga., Bull. 6-A, p. 32.

izes than in one gram of clay, the disintegration of which has been effected only by shaking in distilled water, there can exist from 400 to 1500 trillion free and independent sub-microscopic particles, to say nothing about the larger particles, they will find interstices between these grains sufficient to satisfy even the most exaggerated conception of a micellian structure.

Dr. Cushman[1] in a brief review of the observations that point toward a colloidal substance as being the prime cause of plasticity, has given the following citations: "Daubree found that wet ground feldspar assumed a plastic condition, whereas dry ground feldspar did not." Ostwald, the eminent German physical chemist, Arons, Bischol, Seger, Rokland, and Van der Bellen, accepted and advanced in substance the colloid theory. T. Way[2] stated that while particles of sand and chalk absorbed water, owing to surface attraction and capillarity, clays and soils with a clay base behaved in a quite extraordinary manner. The more clayey the soil the more water it seemed capable of absorbing. But this was not all; besides water this clay substance exhibited a greater facility for absorbing the bases contained in certain salts which were dissolved in the water."

E. Bourry[2] says that if clay is mixed with a solution of calcium carbonate, the clay will retain some of the carbonate. "Kaolins do not retain more than 2 per cent of carbonate of lime in solution, while plastic clays can absorb from 10 to 20 per cent of it."

It is common knowledge among chemists that clay can extract soluble salts from solution and retain them very persistently against all attacks by dissolving mediums. Mr. Ackison[3] found that catechu and extract of sumac leaves, spruce bark, tea leaves, oak bark or straw would be absorbed by clays from solutions.

Further, Ries[4] advanced the theory that the action of hydro-carbons in solution was to deflocculate the particles. This he claims was proved by the fact that in the untreated clays the grains were bunched together while in the treated clays the particles were separated.

In the foregoing citations there is evidence sufficient to formulate a conception of what changes have taken place in a clay from the time it was first formed *in situ* by decomposition of the parent rock and left practically devoid of plasticity, until it was deposited elsewhere as a plastic clay. Organic matter would have deflocculated the particles, and the soluble salts, which are very naturally attracted to the kaolin grains, would soften when wetted, but the water could not extract them owing to the greater force exerted by the kaolin particles. Deflocculation by organic matter, recementation by salts of various kinds, may have formed a cycle of events that in the end would cause a condition of affairs that makes possible the property described as plasticity.

Molecular attraction for foreign substances which is peculiar to kaolin particles, and not to a very large degree to other common constituents of clay, may and does have its influence on plasticity affected by fine-

1 Vol. VI, A. C. S., p. 66.
2 Royal Ag. Soc., Jour. XI, 1850, cited by Cushman.
3 Emile Bourry, Treatise on Ceramic Industries, p. 54.
4 Amer. Cer. Soc. Trans., Vol. VI, p. 33.
5 A. C. S. Trans., Vol. VI, p. 43.

ness of grain.   Plate structure, a natural form in which kaolin grains arrange themselves, is a possibility under the right conditions, but there is also a possibility that organic matter and adsorbed salts may operate in the destruction and formation of the plate grains.   A clay that is of secondary origin, like our common clays, could not have passed through the many geological changes with which they are credited without being more or less deflocculated and saturated with these foreign substances. Micellian structure is not a necessary condition.   Minuteness of grain and consequently large surface or adsorbing area is sufficient.

Adsorption theory of plasticity—Existing data, accumulated for years by scientists, all point to the fact—which is almost beyond the theoretical state, lying wholly within the realm of experimentation— that the plasticity, tensile strength and general working properties of the clay can be traced back to the adsorptive property of kaolin.   Further, all the facts that have been cited in support of any and all of the theories are identifiable as conditions that allow of the fullest exhibition of the plasticity that seems to follow as a direct consequence of the adsorption of soluble organic and inorganic substances by the kaolin grains.

DEVELOPMENT OF PLASTICITY IN THE PRESENCE OF WATER.

Whatever may be the fundamental cause of this phenomenon we call plasticity, it is certain that it is manifested only when water is present. It has been shown that mere molecular attraction between the clay grains and the water molecules is not sufficient to account for plasticity. There must, therefore, be factors other than molecular attraction which becomes operative in developing this property, which, when water is not present, may be said to be latent.   Since it is the presence of water that makes the development or expression of plasticity possible, it is important that we consider some of the fundamental and well-known hydrostatic forces.

There are at least four forces operating on the water in a wet, un- burned brick: First, gravity, or the weight of the water itself; second, surface tension, which is due to attraction (cohesive) between the molecules of water themselves; third, molecular attraction (adhesive) between the water molecules and the mineral particles in the clay; and fourth, surface pressure, which is the opposite of surface tension.

Gravity—Surface tension, or the contracting power of any exposed water surface, may act with gravity or against gravity, depending upon circumstances.   Molecular attraction between the mineral and water molecules always acts in opposition to gravity.   Since, as can be shown, the conditions of capillarity in a mass of clay compressed into the form of a brick is such as to make surface tension the very much greater force, and operating in opposition to that of gravity, gravity will not be considered as one of the component forces in our problem.   If we were dealing with "slips" or even soft mud fixtures, the force of gravity would have to be considered.

Molecular Attraction—Milton Whitney[1] says: "The *potential* of a single water particle is the work which would be required to pull it

---

[1] U. S. Dept. of Agr. Weather Bureau, Bull. 4, p. 19.

away from the surrounding water particles and remove it beyond their sphere of attraction. It is the total attraction between a single particle and all other particles which surround it." It is called by some "molecular attraction."

Surface Tension—Because it has particles adjoining it only on one side, i. e., molecular attraction is affecting it only from one side, the potentiality of a water particle on the surface is, according to Whitney's definition, only one-half that of a particle in the center of a drop. That things tend to move from points of low to points of high potential is a well-known law of physics. The particles on the surface, will, therefore, strive to get to the interior of the drop. The results will be surface tension.

Looking at this proposition from the mechanical point of view, the force of molecular attraction operating on the surface particles, is effective along lines that extend from the center of each particle, to the center of the surrounding particles. Since the particle on the surface of a drop of water is under the influence of other particles only from one side, the several lines of force would extend radically from its center to the center of adjacent particles, having as a resultant a line of force extending from the center of the surface particle to the center of the mass.

Surface Pressure—Suppose that instead of a drop we have the same mass of water surrounding a solid particle as a film, say, 0.0005 m m. thick. We should have in this system two combating forces, first, molecular attraction of water molecules for each other, causing a pull on all water particles toward the center of the film, creating a tension on the outside surface as well as on the surface contiguous to the solid particles; second, attraction between the molecules of the solid particles and those of the liquid, tending to create a tension only on the outer surface of the glm.

Consider the water between four solid particles as shown in the following figure as having a potentiality less than that of the solid particles.

All water particles will press outward the solid particles along the resultant lines of force as shown in Fig. 16. In this case instead of tension we would have a pressure. This pressure is known as surface pressure.

If, on the other hand, the water had a potentiality that was greater than that of the solid particles, the resultant forces of attraction would be toward the cen-

FIG. 16. Diagram showing operation of forces causing surface pressure.

ter of the liquid mass as shown in Fig. 17.   This would result in surface tension.

FIG. 17. Diagram showing operation of forces causing surface tension.

The practical conclusion from the above discussion of greatest interest in connection with plasticity, is that when the surrounding fluid has the greater potentiality, flocculation, or drawing together of the solid particles will result. When the *solid particles* have the greatest potentiality, deflocculation or separation of the solid particles will result.   Citations by the score could be presented showing that clays can be flocculated, or deflocculated, depending upon the material carried in solution by the water used in tempering.   It is of interest, therefore, to consider the various solutions and their effect on clays.

Solutions causing deflocculation—Johnson in "How crops feed" cites a great many instances where solutions of organic compounds have caused deflocculation of soils. Ackison[1] has shown that tannin will deflocculate clay so thoroughly that when a thin slip of clay suspended in a solution of tannin is poured onto a filter paper the water passing through will be very turbid.   Ammonia is used in the water when a clay is being disintegrated preparatory to mechanical analysis.   Petroleum is greedily absorbed by clay because of its low surface tension or potentiality, being held between the minute grains of clay by virtue of the higher potentiality of the clay grains.   Whitney[1] has shown that cotton seed, meal, tankage, etc., have similar effects.

It will be important to note that the surface tension of solutions which cause deflocculation of grains of pure clay substance is without exception lower than the surface tension of water. It will also be important to note that physical differences in conditions such as degree of concentration of the solution, temperature, etc., that tend to decrease surface tension affect deflocculation.   For example, it is a common experience of chemists that boiling for the purpose of extracting soluble salts often so thoroughly deflocculates the clay that even filtering through a Gooch crucible will not clearify the filtrate.

In the following tables the surface tension of water and of various solutions is given.

1 A. C. S., Vol. VI, p. 44.
2 Bull. 4, Weather Bureau, Dept. of Agr., p. 17.

TABLE XXII—(1.)

Temperature C°	The surface tension of water and alcohol in contact with air.	
	Surface tension in dynes per centimeter.	
	Water.	Ethyl alcohol.
0°	75.6	23.5
3	74.9	23.1
10	74.2	22.6
15	73.5	22.2
20	72.8	21.7
25	72.1	21.3
30	71.4	20.8
35	70.7	20.4
40	70.0	20.0
45	69.3	19.5
50	68.6	19 1
55	67.8	18.6
60	67.1	18.2
65	66.4	17.8
70	65.7	17.3
75	65.0	16.9
80	64.3	
85	63.6	
90	62.9	
95	62.2	
100	61.5	

TABLE XXIII (2).

Miscellaneous Liquids in Contact with Air.

Liquid.	Temp. C°	Surface tension in dynes per centimeter.	Authority.
Acetone	14.0	25.6	Average of various.
Acetic acid	17.0	30.2	..do ....
Amyl. alcohol	15.0	24.8	..do ....
Benzine	15.0	28.8	..do ....
Butyric acid	15.0	28.7	..do ....
Carbon disulphide	20.0	30.5	Quincke ....
Chloroform	20.0	28.3	Average of various.
Ether	20.0	18.4	..do ....
Glycerine	17.0	63.14	Hall ....
Hexane	0.0	21.2	Schiff ....
Hexane	68.0	14.2	..do ....
Mercury	20.0	470.0	Average of various.
Methyl alcohol	15.0	24.7	..do ....
Olive oil	20.0	34.7	..do ....
Petroleum	20.0	25.9	Magie...............
Propyl alcohol	5.8	25.9	Schiff ....
Propyl alcohol	97.1	18.0	..do ....
Tolnol	15.0	29.1	..do ....
Tolnol	109.8	18.9	..do ....
Turpentine	21.0	28.5	Average of various.

1 Smithsonian physical tables.   Third revised edition, p. 128.
2 Smithsonian tables, Ibid.

TABLE XXIV (1).

Salts in Solution.	Density.	Temp. C^0	Surface tension in dynes per Cm.
BaCl$_2$	1.2820	15–16	81.8
..do..	1.0497	15–16	77.5
CaCl$_2$	1.3511	19	95.0
..do..	1.2773	19	90.2
HCl...	1.1190	20	73.6
..do..	1.0887	20	74.5
..do..	1.0242	20	75.3
KCl...	1.1699	15–16	82.8
..do..	1.1011	15–16	80.1
..do..	1.0463	15–16	78.2
MgCl$_2$	1.2338	15–16	90.1
..do..	1.1694	15–16	85.2
..do..	1.0362	15–16	78.0
NaCl...	1.1932	20	85.8
..do..	1.1074	20	80.5
..do..	1.0360	20	77.6
NH$_4$Cl	1.0758	16	84.3
..do..	1.0535	16	81.7
..do..	1.0281	16	78.8
SrCl$_2$	1.3114	15–16	85.6
..do..	1.1204	15–16	79.4
..do..	1.0567	15–16	77.8
K$_2$CO$_3$....................................	1.3575	15–16	90.9
..do..	1.1576	15–16	81.8
..do..	1.0400	15–16	77.5
Na$_2$CO$_3$...................................	1.1329	14–15	79.3
..do..	1.0605	14–15	77.8
..do..	1.0283	14–15	77.2
K No$_3$......................................	1.1263	14	78.9
..do..	1.0466	14	77.6
CuSO$_4$	1.1775	15–16	78.6
..do..	1.0276	15–16	77.0
H$_2$SO$_4$	1.8278	15	63.0
..do..	1.4453	15	79.7
..do..	1.2636	15	79.7
K$_2$SO$_4$	1.0744	15–16	78.0
..do..	1.0360	15–16	77.4
MgSO$_4$:	1.2744	15–16	83.2
..do..	1.0680	15–16	77.8
Mn$_2$SO$_4$...................................	1.1119	15–16	79.1
..do..	1.0329	15–16	77 3
ZnSO$_4$	1.3981	15–16	83.3
..do..	1.2830	15–16	80.7
..do..	1.1039	15–16	77.8

Smithsonian Tables Ibid.

Points to be noted in table—Notes: 1. Solution of organic compounds have a much lower surface tension than water. 2. Surface tension decreases as the temperature increases. 3. As the density of the solution increases surface tension increases.

From the above the following conclusions regarding deflocculation appears:

1. It has been shown that solutions of organic compounds cause deflocculation. It is needless to go into further discussion of this point, for the facts that have been stated are well understood by practical potters and agricultural chemists.

2. Increased temperature assists in producing deflocculation. Potters who use hot water in their blungers and brick manufacturers who use hot water in their pug-mills have learned that clays slake and develop plasticity more easily with hot than with cold water. These cases find their parallel in the laboratory when clay slip is boiled in the process of soluble salt determination. *Deflocculation is increased by the use of hot water.*

3. Increased density of a deflocculating solution does not increase its efficiency. "Ammonia (1) has a very marked action in breaking up soils containing particles less than 0.005 mm. in diameter. . . . One drop of

1 Bull. No. 24, Bureau of Soils, U. S. Dept. of Agr., p. 22-24.

ammonia (added to 5 grams or sample in 50 cc. of water) does not seem to be sufficient to break up the flocculations completely, *but no great change is produced by the addition of more than 5 drops to 50 cc. of water.*"

The preceding facts given by our foremost agronomists, when considered in the light of the fact that increased concentration of a solution increases its surface tension, are proof of the deduction that when the potential of the solid particles is greater than that of the surrounding fluid, deflocculation ensues. In the case of the ammonia solution, increased concentration by the addition of more than 5 drops of ammonia would so increase the surface tension and consequently the potentiality of the solution as the equalize the potentials of the soil particles and the solution.

Solutions causing flocculation—Having discussed the deflocculating solutions in detail, it will not be necessary to dwell at length on the flocculating solutions, for the effect on clay of each class of solution is the converse of the other. It is important to note that solutions which have surface tensions higher than that of water tend to cause flocculation.

The nature of solids affects flocculation in several ways. First, if the clay or soil under examination contains a large quantity of calcium or magnesium carbonate[1], it has been found that solutions having a surface tension as low as that of ammonia will cause flocculation. Data are not available concerning clay mixtures high in other minerals, but as is about to be shown, clays that have comparatively low content of clay substance probably have as an average for the several mineral grains a low potential in comparison with the potential of water. Clays high in products of decomposition of organic matter may be flocculated by ammonia. In fact the "potential" of the impure clays may be so low as to permit ammonia solutions to flocculate their grains. Pure clays, i. e., kaolins, require for their flocculation solutions having a "potential" that is higher than that of pure water.

Second, near[1] the surface of any soil there is a concentration of solutions. This is adsorption. If[2] the solid is exceedingly porous, this tendency to concentration near the surface is heightened. It is well known that salts, which are concentrated near the surface of solids are precipitated or at least are left clinging to the solids when the water is withdrawn. Soils[3], even sand, possess the property of attracting and fully absorbing salts which cannot be wholly washed out by new quantities of water. Solutions of many of the salts are materially weakened when brought in contact with solids, because of the adsorption of the salts, but if the surface of the solid be relatively small no weakening of the solution may be perceptible.

Summary—The well-known facts concerning a plastic clay when wetted with water are, first, that its finer portions are composed of a countless number of minute grains, the composition of which has been shown to agree closely with that of pure clay substance; second, that even the coarser grains are composed largely of kaolinite and other minerals

1 U. S. Dept. of Agr., Bureau of Soils, Bull. 24, p. 24.
2 U. S. Dept. Agr., Rept. No. 64, p. 142.
3 Comp. Johnson, How Crops Feed. p. 173.
4 Comp. Johnson, How Crops Feed, p. 334.

cemented into clusters or bundles; third, that clays having a high content of minerals other than kaolin, are flocculated by solutions having a surface tension lower than that of water, while the clays which are practically pure kaolinite in composition require for their flocculation solutions that have a surface tension higher than water; fourth, that clay particles extract salts from solutions and hold them near and on their surface at a high degree of concentration; fifth, that clay substance exhibits this property of adsorbing salts to a much higher degree than any of the common anhydrous minerals, a fact that makes the extreme fineness of the "clay substance in clays" of considerable significance.

The known facts concerning solutions are: first, that all solutions have a surface tension which is increased with increased concentration; second, that those solutions which have a surface tension higher than that of pure water, tend to cause flocculation of kaolin grains.

On putting together the known facts concerning clay and water, it is evident that *the film of water surrounding the grains of clay, (when the mass is in a plastic condition) has a very high potential, owing to the high degree of concentration of the salts that are held to the kaolin grains by adsorption.*

SUPPOSED HISTORY OF THE DEVELOPMENT OF PLASTICITY OF CLAYS IN NATURE.

Daubree[1], Cushman[2] and Mellor[3] have disintegrated feldspar in water either by grinding or by boiling. In all cases, the liquid in which the feldspar was ground contained alkali in solution. Mellor found that not only did the solution give alkaline reactions, but the *"outlines (of the solid particles) could be more readily stained with saffranine or with malachite green than before the action."*

Since the larger part of the clay substance is derived from the disintegration of feldspar, it can be considered that there was formed at the time of "kaolinization" insoluble hydrous silicate of alumina, soluble potash salt and soluble silicic acid. If feldspar has been disintegrated by atmospheric agencies, water and carbonic acid, and the residual mass is so situated as not to allow the soluble salts to be washed away, they will be retained in part by adsorption and in part by recombination, forming zeolitic masses. Data are not available to warrant the statement that plastic kaolins formed *in situ* owe their plasticity to these adsorbed salts, or that they even contain adsorbed salts. We do know, however, that nearly all kaolins contain alkalies that can *not* be shown to be present as constituents of such minerals as feldspar or mica. Further we know that "the less[4] free alkali a clay contains the more will it adsorb." We know also that clays which have been formed from feldspar under the disintegrating influence of fluorine are not plastic, and contain fluorspar[5] and other fluorine compounds.

1 Am. Rep. Smithsonian Inst., 1862, 228.
2 U. S. Dept. Agr., Bull. No. 92.
3 Eng. Cer. Soc., Vol. pt. 1, p. 72.
4 C. F. Binns, A. C. S., Vol. VIII, p. 206.
5 Jackson and Richardson, Eng. Cer. Soc., Vol. II, p. 59.   (1903-4.)

Cushman[1] reports that the residue left after disintegrating the feldspar and washing out the portions which have been rendered soluble, is composed of very minute particles. If this insoluble portion, kaolin, had been formed by nature, in whose laboratory reactions, precipitations, etc., extend over an almost infinitely longer time than is given to similar physical-chemical phenomena in the laboratory, there is no doubt but that these minute particles of kaolin would arrange themselves in the thin plate-like clusters that are characteristic of this substance, just as did the Leasburg clay cited by Wheeler. Conditions will control the size of the plate-like crystals so developed. In many kaolins these plate forms are discernable, ranging from those of sub-microscopic dimensions up to those that can be readily measured in the microscope. In a clay examined by the writer not only were there crystals of measureable size, but they appeared to be compounded, i. e., made up of several crystals, which could not be separated to an appreciable extent by vigorous shaking in distilled water. Under natural conditions, therefore, where the disintegrating water readily runs or seeps away, carrying the soluble portions and leaving the insoluble "residual clay" *in situ,* we can expect to find a deposit that is more or less crystalline, depending upon the attending conditions.

These deposits, we know, are practically non-plastic. We know further from Ackison's experiments and the testimony of many agricultural chemists, that these grains can be deflocculated by organic solutions. Since surface waters generally contain organic substances in solution, and since proximity of vegetable growth can give rise to a deposit of decaying vegetable matter on kaolin beds, it is easy to see how such a deflocculation can take place *in situ,* and especially so if the clay be moved by running water and deposited in the lower lands. By virtue of this deflocculation the clay has a smoother feel, i. e., texture, and thereby assumes a pseudo-plasticity. This fact has given rise to the fineness of grain theory of plasticity.

These deflocculated particles of kaolin have, as has been shown, a high adsorptive power. Whatever salts may be in solution in the passing waters, or may be carried upward from lower strata by rising waters, will be adsorbed by the kaolin particles. Now, depending upon the degree of deflocculation, amount of adsorption, and the kind of salt so adsorbed, plasticity will be developed.

When non-plastic kaolins are wetted with water, they are compressed into shapes only with difficulty, and when dried they either fall to pieces, as would so much fine sand, or have so weak a bond that they are easily crumbled. The finer the particles, as with the case of sand, the more readily can they be shaped into pieces that will retain their form, but no matter how finely sub-divided the grains may be, the mass is still very friable. In this fine condition the kaolin no doubt possesses every chemical and physical property possessed by the plastic kaolin (ball clay) save that of plasticity. It has water chemically combined, molecular attraction, and adsorbing properties. *It becomes plastic only when it*

---

[1] U. S. Dept. Agr., Bull. No. 92.

has adsorbed salts, the solution of which exhibits a high surface tension, or as Whitney would express it, which have a relatively high potentiality. Clays having adsorbed salts and consequently, plasticity are no longer friable when molded but, on the contrary, they are exceedingly hard.

It is because of this adsorption property which in kaoline grains seems to be manifested to a higher degree than in any other mineral substance, with perhaps the exception of zeolites, that many find reason to believe that plasticity is due to a pectoidal structure of the kaolin grains. Since, however, they cannot show that those substances which are *known* to have a pectoidal or colloidal structure can be made to show or develop plasticity, and since colloids cannot be extracted from plastic clays, rendering them non-plastic, nor added to non-plastic kaolins rendering them plastic, we must conclude that this theory is hardly tenable.

To what this great adsorptive power of clays is due has not as yet been determined. We, however, must accept the existence of this property as a proved fact. We must also concede that when water is added to a clay, that portion which envelops the very minute solid particles having a relatively large surface area in proportion to their volume, and holding salts by absorption, will be highly concentrated, that the potential of this film will be very much more than those portions of the water farthest away from the solid particles; and finally, as shown by the flocculation of the clay particles, the potential of this saturated film of water is higher than the potential of the kaolin particles.

The writer bases his assumptions as to the cause of plasticity on known facts: Adsorption of salts by the kaolin grains and the consequent high potential of the water film which surrounds the grains when a clay mass is in a plastic condition. On these assumptions, the cause of the latent plasticity when clay is dry and the developed plasticity when it is wet, are obvious.

Fineness of grain, molecular attraction, adsorptive property, are conditions that permit of the adsorption of salts. In other words, they are necessary conditions.

METHODS OF MEASURING PLASTICITY.

General—There have been many methods devised for measuring placticity. The methods suggested by Zschokke[2] and Grout[3] seem to be the most rational of any, for in them the resistance to deformation and amount of flow before rupture, two characteristic properties of plastic bodies, are measured. These methods are based on the same principle as the well-known but crude method of testing plasticity by squeezing a ball of plastic clay between the tips of the forefinger and thumb, and making a mental note of the amount of pressure required to affect a given degree of deformation. .

The test developed by this Survey involves the tensile strength of the plastic mass rather than its resistance to compression, as in the

1 For description of these methods see "Clays; Occurrence, Properties and Uses" by H. Ries. Wiley and Sons, 1906.
2 Thon-Industrie——Zeitung, No. 120, p. 1658. (1905.)
3 W. Va. Geol. Surv., III. p. 40.

Zschokke and Grout methods. It is believed that a tensile test gives a more accurate rating of the tenacity with which the several grains cling to one another, for in this, friction between the non-plastic grains and interference to flowage by the larger ones crowding into one another is entirely eliminated.

Shape of the test piece—The special features of the shape and size of the briquette employed in this test are, first, narrow neck, (¾″), wide ends (—″) and straight sides to fit the jaws, as explained later. The smallest portion is cubical in shape, being ¾″ x ¾″ x ¾″.

The clips—In previous experiments it was learned that the Standard Fairbanks clips, using the standard shape and size of briquette, would permit the stretching of the briquettes until they would slip out of the jaws. Special clips were therefore made to fit the briquette. These clips were designed after Orton[1], differing from his only in dimensions. angle of nip between the jaws, and manner of adjustment.

Manufacture of briquettes—Clay was mixed to a thick slip, cast and cut into briquettes by the Fox method, as described under tensile strength. When the cast slab had, in the opinion of the operator, assumed its maximum plasticity, the briquettes were cut and forced into steel molds under a constant pressure of fifty pounds. This weight was applied slowly but the briquette was not allowed to remain under pressure after it had received its full load.

Adjustment and calibration of the machines—Before the Fairbanks machine could be used, the balance beam had to be poised to allow for the difference between the standard and our special clips.

For measuring the stretch which the briquettes suffered, the small adjusting wheel was calibrated so that the peripheral distance through which the wheel was turned would represent the distance the under clip had been lowered. The amount of stretch which the briquettes suffered at any time during the test was measured by the fractional number of turns of the adjusting wheel required to lower the under jaw sufficiently to keep the beam in a predetermined position.

Method of procedure—The plastic briquette was carefully placed in the clips and the jaws adjusted to it, care being taken to see that the jaws on either side were at the same angle. The lower clips, suspended by counterpoise, were kept in a vertical line by hand guidance. Very small shot was allowed to run into the pail slowly until a rupture occured at the neck of the briquette. As soon as a rupture occurred, the beam dropped with a suddenness that shut off the flow of shot. At the moment of rupture the amount of initial stretch was noted by the fractional number of revolutions through which the adjusting wheel had been turned. Before removing the "load" the adjusting wheel was slowly turned until the briquettes was completely torn apart. The second peripheral distance through which the wheel had been turned was noted as "final stretch."

The weight of the shot required to cause rupture was obtained on a balance that is accurate to one centigram. While the weight thus obtained is not the force that was required to cause rupture, it does bear a

1 Amer. Cer. Soc., Vol. VI, p.

constant ratio to that force. The shot was not weighed on the Fairbanks machine because it was not sufficiently sensitive.

Plasticity modulus—It is obvious that since all three factors, initial stretch, final stretch, and load required to cause rupture, must be considered as being affected by the degree of plasticity of the clay, a modulus must be devised that includes all three factors. The one used in our tests was constructed as follows:

The central portion of the briquette is a perfect cube $\frac{3}{4}''$x$\frac{3}{4}''$x$\frac{3}{4}''$. On the assumption that the volume of this portion of the briquette remains constant throughout the test[1], and that its cross section decreases proportionally as the length increases, the decrease in cross section in centimeters due to the initial stretch would be $\left(1.9^2 x \dfrac{}{1.9+a} \right)$ or $\dfrac{1.9^3}{1.9+a}$ [2]

where a is the initial stretch. The decrease in cross section after the final stretch (here it is figured as though there has been no rupture) would be equal to $\left(\dfrac{1.9^3}{1.9+a} (—) \dfrac{1.9^3}{1.9+a+b} \right)$ or, by reduction,

$$\dfrac{1.9^3 b}{1.9^2 + 3.8a + 1.9b + a^2 + ab}$$ where b is the final stretch.

Now a measure of the tension that is holding the grains together would be directly proportional to the load and inversely proportional to the decrease in cross section of the briquette due to stretching. The modulus must, therefore, represent a value that is directly as the load and inversely as the product of the decreases in cross section due to the initial and final stretch. Performing this calculation and collecting terms the following plasticity modulus is obtained:

$$\dfrac{1 \ (6.859 + 10.83 \ a + 3.61 \ b + 5.7 \ a^2 + 3.8 \ ab + a^3 + a^2 b)}{24.76b} = M$$

in which L = load in centigrams, a the initial stand, b the final stretch.

While the modulus is very formidable looking it was found that the test could be made and the plasticity factor calculated quite readily. In fact the entire test required less time than did the Grout test as carried out in our laboratories.

With the heavy and far from delicate Fairbanks machine and the clumsy clips, plasticity factors were obtained that varied for any one clay not more than 50 per cent and in some cases only 13 per cent on six briquettes. This percentage of variation was considered too high to attach any value to the obtained data, and they are, therefore, not reported. It is believed that with a more delicate apparatus this method of measuring plasticity would give very close results and that the data obtained would be a true measure of plasticity.

---

[1] This is no doubt an incorrect assumption. In iron they figure that the length increases four times as much as the cross section decreases, in other words that in the stretch the volume of the test piece actually increases.

[2] The decrease in cross section of the briquette is calculated instead of taking the observed increase in length because it and the bond or strength of the mass are directly proportional while the length is not.

CHEMICAL PROPERTIES.

VALUE OF CHEMICAL ANALYSES.

Because, in private correspondence and on every public and semi-public occasion that has afforded opportunity, the writer has taken a stand against the large absolute value and importance of chemical analysis of clays that is contrary to views popularly held by practical clay workers and encouraged by many of the State Survey reports, the discussion of the chemical properties of clays is introduced by liberal quotations from the most eminent of ceramic chemists. Dr. Hermann Seger.

"The[1] demands which the cement and the ceramic industries make on the qualities of clay are as different as the purposes which these industries pursue.

"In the manufacture of Portland cement we have in mind the obtaining of a product of a definite chemical composition, and, since the character of clay as such must completely vanish in this, the mutual relation of the individual constituents is to be considered above all things, and the physical condition in which these are found be considered only as far as it opposes greater or less difficulties to the destruction of the clayey character.

"The clay industries, on the other hand, pursue a quite different purpose in the treatment of their raw material. The limits within which the chemical constitution of clay may vary are very wide, and, since the clayey character of the material is to be preserved, its physical qualities and those of its essential and accessory constituents are to be placed in the foreground. While for such a purpose, the chemical composition of clay, as a whole, appears more indifferent and accidental, inasmuch as it depends on the mutual relation of clay, rock flour, sand, accidental admixtures and their chemical constitution, the *physical* properties of the same, the grain and its form, capillarity, plasticity, fusibility, etc., are of greater importance, and the chemical constitution of each of these constituents is to be considered only as far as it permits us to infer the physical properties of the whole. *It is surely a serious mistake to treat material so heterogeneous chemically and mechanically, as the clays and earths used in the ceramic industries, like substances chemically and physically homogeneous, as for example glass, and to base conclusions with regard to their properties on their chemical composition.*

"The chemical changes which the materials of the ceramic industries suffer in the course of manufacture, step into the background, with the exception of the loss of chemically bound water, which has as a consequence the loss of plasticity, and must not be produced in the same degree as in the manufacture of cement and glass, or the material will lose its earthy character. In fact, it seems advisable to drop the investigation of the chemical composition of clay as a whole, and put in its place a deeper study of the composition of the essential and accidental constituents, in order to to infer the properties of the whole from the properties of the compounds thus obtained. For example, we need not ask how much pure clay and silicic acid we have in clay, but what part of the clay and silicic acid belongs to the sandy constituents, what part to the silty, or the clayey constituent, and what physical properties must we, according to these data, ascribe to the sand, rock dust, clay, etc., individually.

"It cannot be denied that in the examinations of clays scrupulously accurate analyses of the material have heretofore been made, but that little has been learned concerning structure, condition of plasticity, power of absorbing water, shrinkage on drying and burning, form and size of grains of sand, and rock dust, concerning the pecularities of the concretions, and concerning efflorescences and incrustations. In the consideration of the properties of clay for the purposes of the clay industries we must put ourselves more upon a physical than a chemical standpoint.

---

[1] Dr. Hermann Segar, the Collected Writings of, Trans. by A. C. S. p. 8-11.

"If[1] chemical analysis has discovered a fixed relation between alumina, silicic acid and flux, we know that these constituents belong essentially to a single well-characterized combination, so that we can take the degree of refractoriness from the laws established by Bischofand Ritchers with a greater or less assurance, according as this substance is present in a greater or less degree of purity. However, if we should proceed in a similar way in the investigation of brick clays, we would get a theoretical result so very different from the practical result,[2] *that it would have no value whatever in regard to* the knowledge of the material. The chemical analysis gives us only an average of the composition of the components forming the clay, differing very widely in their chemical composition and their physical properties. Since the clay, after burning, preserves its earthy character, and the various constituents act only superficially on each other, *the chemical analysis gives us absolutely no clue for the deduction of definite properties of the whole.*

"*Two brick clays may have exactly the same composition and still differ in every respect*, because the complete analysis, for example, gives us no idea whatever as to how much silicic acid, alumina and flux belong to the clay substance, to the rock dust, and to the sand individually; for instance, in the one case all or the greater part of the flux may belong to the clay substance, in another case to the constituents which make clays lean, and accordingly the properties of the compound be subject to the greatest variation with the same percentage composition. In the one case it may be the clay, in another the rock dust or sand, which, with the same percentage composition of the whole, is the most fusible constituent, as admixed iron oxide or carbonate of lime, which according to the manner of distribution are inclined to have the strongest effect sometimes on the clay, sometimes on the rock dust and sand, *and thereby produce a number of variations which find not the slightest explanation by a simple chemical analysis.*

"If we conclude from this that chemical analysis can claim only a limited value for the discovery of the properties of brick clay, such a judgment would be highly one-sided and inaccurate. . . . For our purpose it is especially the physical properties of clay that are of greatest importance in judging the same, and the chemical properties only as far as they supplement the former. Here, therefore, to express it in a few words, it will be the task of the chemical analyst to determine the composition of the constituents that are physically alike, that of the clay, rock dust, sand, and accessory constituents, separately and singly, and to make possible a comparison of these with each other. In this way we are able to get a good idea of the properties of the components,[1] *whereas an analysis of the whole mass would be of little use.* We are thus convinced of the necessity of physical analysis of clay simultaneously with, or rather before the chemical, as far as the investigation is made for the purposes of pottery ware, and especially for the manufacture of bricks. Even though scientific men have repeatedly referred to the importance of the mechanical and physical investigations, this direction of the investigation has not been pursued with such vigor that the results obtained from it show any real use for the brick industry."

In the foregoing statements Dr. Seger has very forcibly set forth the same doctrines that the writer has come to thoroughly believe as a result of observations in the factory and laboratory. In subsequent writings Dr. Seger set forth the value of what is known as the "Rational analysis" in which "clay substance," feldspar and free silica are differentiated. He cited many cases in which, with the aid of the Rational analysis, he was able to obtain more clearly an idea of the constitution

[1] Seger, loc. cit., p. 36.
[2] Italics not in the original.
[3] Italics not in the original.
[4] Italics not in the original.

and properties of clay than he could from any other method of analysis. In this, however, he was no doubt over zealous, for later studies by other chemists proved that not only does the "Rational analysis" fail to sharply differentiate between the "clay substance," feldspar and free silica, but that the analysis is of value only in the purest clays, viz.: China and ball clays. The writer has made 'rational" analysis of many types of clays, and, barring those used in the vitreous pottery wares, he is compelled to state that not once has he been able to obtain a clearer insight into the actual constitution of the clays than he could from the gross or ultimate analyses. Predictions concerning a clay based on a rational analysis in the great majority of cases, go very far wrong. After considerable pains and labor in the execution of the analysis the operator is compelled to make guesses that are much less scientific and accurate than he would if he had merely burned a piece of the same clay in a small muffle furnace, and noted the rate of change in color and density with increasing intensity of heat treatment, a test that ought not to require more than three hours time, and can be made by any one who has access to a kiln.

It was shown in a preliminary report on the fire clays of Illinois[1] that fire clays having the same ultimate chemical composition behave very differently in burning. Indeed the chemical composition and ultimate fusion period were very often found to coincide in clays which, on the one hand, would remain open and porous through sufficiently long and severe heat treatments to make them fit for use in fire brick, or, on the other, would be nearly vitrified under the heat treatment used in burning stoneware and sewer pipe. Such phenomena are discussed and illustrated in this report under the title of pyro-physical and chemical properties of clays.

In the manufacture of vitreous floor tile the writer learned by practical experience that particular effects either in color, vitreousness, ultimate fusibility, or any other physical property requisite in the production of floor tile, could not be duplicated on the basis of chemical composition.

This was also found true in the manufacture of porous white ware bodies, such as are used in jardinieres and art wares, and no doubt is entertained but that the same would be found to hold true to a large extent in the manufacture of vitreous china. In these cases, however, rational analysis, i. e., the determination of the proportional quantity of clay substance, feldspar, and free silica finds value in that these several minerals have decided effect on the expansion and contraction of the blended pottery body, and, consequently, upon the proper fitting on it of a glassy coating (the glaze.)

The only instance in which chemical analysis is of positive aid, aside from the explaining of some observed phenomenon, is in the execution and study of a systematically planned series of experiments. Seger's classical studies that resulted in the invention of the pyrometric cones would probably never have been carried out had he not followed closely

1 Purdy and De Wolf, Preliminary Report on the Fire Clays of Illinois, State Geol. Surv. of Ill. Year-book 1906, pp. 137.

the chemical analyses of the raw materials and planned his series on chemical formulae. Following him, there has been much of exceedingly great value resulting from researches in pottery mixtures that would have been impossible on any other than a strictly chemical basis. In the study of paving brick clays here reported the fact has been discovered that the best paving clays contain a relatively high content of magnesia. Such a discovery has been and would have been impossible from an analysis of an isolated sample. Further, this fact would not have been noted had no systematic researches on a chemical basis been made with pure clays, minerals, and magnesia compounds, showing that mixtures containing a comparatively high content of magnesia have a long fusion range, for, as will be seen later, the value of clays for paving brick manufacture, or even their fusion range, do not always correlate with high magnesia content.

The suggestion made by Dr. Seger in the paragraphs quoted in the introduction to this chapter, that a chemical analysis of the several subdivisions of the particles according to size would be of value, is possibly true. In fact it is obvious why such should be the case. The time and trouble involved in making a thorough mechanical analysis of a clay into several groups having different ranges in size of particles in quantities sufficient to make accurate and especially duplicated analyses of each group, places such a determination out of consideration as a commercial test on clays. But for a scientific purpose it is believed that the results obtained would justify the expense and trouble involved. Such a study was made by Grout on a composite sample of West Virginia clays. His results are cited and discussed on pages 179 to 180 of this report. So far as the writer is aware, Grout was the first to make such an analysis, and it is hoped that the deductions drawn from his results show justification for the making of similar studies on single clays.

Notwithstanding the fact that up to date it would be but a matter of chance that an interpretation of the results of a chemical analysis would agree with the observed working properties of a clay, it should not be concluded that our chemists may not in the near future devise a method of analysis that will meet the requirements of the case. In fact, so strongly do many believe that this will come to pass, that they see justification in making and reporting chemical analyses of clays by geological surveys, as has been their wont in the past. The writer firmly believes, however, that as a forerunner to such an event, many carefully executed and systematic physical and chemical researches on each type of clay must be made with parallel observations on synthetical mixtures of pure minerals. A few such observations will be made in subsequent paragraphs.

MINERALOGICAL COMPOSITION OF CLAYS.

Clay is a heterogeneous aggregation of minerals in which kaolin is present in sufficient quantities to give to the mass its characteristic physical properties. If kaolin is not present in sufficient quantities to

do this the mass should not be called clay. If limestone contains some
kaolin entrapped mechanically, the mass is a limestone, notwithstanding
the fact that it contains a considerable quantity of kaolin, for it looks
and behaves in every way like limestone. But if the lime should be
dissolved, as we know has often been the case, until the material is lar-
gely composed of kaolin, this residual mass is clay.

There is a commercial modification of this definition that involves
its economic use or value. For instance, if the mass should contain
iron in sufficient quantities to render it a commercial source of iron,
the mass is more properly called an iron ore, just as a limestone impreg-
nated with zinc or lead is termed a zinc or lead ore. Aside from cera-
mic consideration, a clay containing iron or any other substance of com-
mercial value in sufficient quantities to allow of its being considered a
source of that substance from a commercial standpoint would be con-
sidered an ore.

COMPLEXITY OF MINERALOGICAL COMPOSITION OF CLAY.

In the section, the "geology of clays," Professor Rolfe has set forth
in detail the most accepted theory of the origin of clays, the effective
agencies of rock decomposition, and the manner in which these agencies
operate. It has been shown clearly that the residual mass resulting
from rock decomposition may be comprised of a variety of silicates, the
kind and number of silicates formed being dependent upon the con-
ditions attending the rock decomposition. Professor Cook,[1] after giving
the analyses of several of the New Jersey kaolins that differ widely in
chemical composition, remarks:

"The examples above stated prove conclusively that clays are not
altogether uniform in composition, even after throwing out all the ac-
cidental or foreign constitutents. *Either the essential kaolinite is not
constant, or our clays consist of this mineral mixed in varying propor-
tions with other hydrous silicates of alumina. Inasmuch as the greater
number of the rich fire and ware clays of the State, and also others
which have been here examined, do correspond very closely to the com-
position and formula assigned to this mineral, the latter explanation is
more plausible.*"

After nearly thirty years of constant research Dr. Cook's problem
is no nearer solution, for Dr. Clark in Bull. 125 of the U. S. Geological
Survey, suggests that there are seven possible combinations of alumina,
silica and water of combination, which might form crystalized kaolin.

Professor Rolfe has shown that a pure kaolin can be formed only by
the decomposition of rocks that consist almost altogether of feldspathic
or other highly aluminous minerals, together with comparatively unde-
composed minerals like quartz and mica, that are in large part separa-
ble from the kaolinite grains by elutriation. If the parent rock con-
tains iron or other metallic oxide bearing minerals the residual kaolin
will be contaminated with these coloring oxides in such a manner as to
render its purification by elutriation impossible. If it is impossible to
determine the mineralogical constitution or makeup in the former case,

[1] Report on the Clay Deposits of New Jersey, Geol. Surv. of N. J. 1878, pp.
269-272.

where the residual deposit is largelyl pure kaolin, contaminated only
with substances that are separable in running water, it is obvious that in
the latter case, that of the impure deposit, the problem is far more com-
plicated.

The difficulty of determining the mineralogical composition of a clay
is increased many fold in the case of those that have been transported
from the place of origin and contaminated with a heterogeneous as-
sortment of inorganic materials encountered en route.   Shales may
vary so widely in their mineralogical constitution that in one case the
mass may be highly ferruginous, in another highly calcareous, and so
on, depending upon the amount and kind of contaminating substance.
Because the shale is highly calcareous it does not follow that it is a simple
mixture of calcium carbonate and kaolin, but rather that the predomin-
ant adulterant is calcium carbonate.   Silica, iron compounds, etc., may
be and usually are present in considerable quantities in the calcareous
shales.   The nearest that geologists or ceramists have come to deter-
mining what inorganic substances are present in a given shale, is sim-
ply to say that it is calcareous or silicious, etc.   It has not been found
possible to determine the mineralogical composition of any of the com-
plex secondary clays either by the microscope or by chemical analysis
Approximation to the mineralogical composition of the purer secondary
clays like the ball clays, is made possible by "rational analysis," in
which the differentiation of the minerals depends upon their relative
solubility in sulphuric acid, yet by this method it is incorrectly assumed
that only three mineral components are present, i. e., clay substance,
feldspar, and quartz, and the results are forced to tally with this as-
sumption.

It is obvious, therefore, that an attempt to distinguish the minerals
that occur commonly in clays would be useless in discussing the min-
eralogical composition of clays in general, and much more so in the case
of any particular clay.

Granted that it would be possible to make a fairly accurate mineral-
ogical analysis of a clay, it is doubtful if our present knowledge would
enable us to predict its working qualtities or even its fusibility with
accuracy.   When it is considered that a mixture of 40 per cent quartz
and 60 per cent feldspar has approximately the same pyrometric value
as feldspar taken alone, and that both have like effect on the green prop-
erties of clay, some idea of the complexity of the problem is apparent.
What is true of a mixture of feldspar and flint is true of a large number
of pairs of other minerals.   What is true of minerals when considered
in pairs, is true to a larger degree when taken in a multiple combin-
ation.   It does not require much imagination to see where one would be
led if it should be required to predict the fusion behavior or a hetero-
geneous mixture of a large number of minerals.

This sort of a study is of value and in fact is now looked upon as a
necessity in the compounding of artificial mixtures of clays and min-
erals for pottery purposes, but in these cases the operator is dealing

with substances the mineral character of which is to a large degree
known, and he is mixing these minerals in predetermined proportions.
He has in this case a synthetical mixture of known mineralogical con-
stitution adn of comparative simplicity (containing at the most not
more than four or five different minerals, and, therefore, his practical
experience ought to enable him to predict its physical and pyro-chem-
ical behavior.   In the case of nature's mixtures, however, man has at
present no way of determining their mineralogical constitution, and
must depend upon an actual test for obtaining a knowledge of the
working properties of the mixture.

To illustrate these difficulties reference might be made to the fire
clays, which are comparatively pure clay substance or at least rela-
tively simple mixtures of mineral ingredients.   It has been shown[1] that
in plotting the position that indicates the relative fusibility of the clays
on the basis of their alumina-silica ratio in reference to the position oc-
cupied by a synthetical mixture having a similar alumina-silica ratio,
no concordant relation existed between them.   Further the difference
between the No. 1 and the No. 2 fire clays of the usual clay workers'
classification having practically the same ultimate fusion point, but
differing from one another in the manner of vitrification is no doubt
explainable either on account of difference in mineralogical composi-
tion or character of grains.   What is true in the case of simple mineral
mixtures like the fire clays would be greatly exaggerated in the case of
the exceedingly complex mixtures, such as most of the shales and sur-
face clays.

ULTIMATE CHEMICAL COMPOSITION.

By ultimate chemical composition is meant the percentage by weight
of the several oxides of the elements that occur in clay irrespective of
their original state or combination.   Ordinary chemical analyses are re-
ported in terms of so much silican oxide, aluminium oxide, calcium
oxide, etc.   All are more or less familiar with such analyses, and not a
few brick manufacturers have had repeated analyses of their clays made
by chemists.   The reports they received are what is known as the
"Ultimate Chemical Analysis," in contradistinction to the rational
analysis, that gives the supposed approximate percentage of clay sub-
stance, feldspar and quartz in the clay, instead of the individual ox-
ides of which these substances are composed.

The persistent belief in the value of an ultimate chemical analysis
on the part of layman and scientist alike is a not wholly unwarranted
compliment to the science of chemistry.   It cannot be denied that there
is some slight foundation for this unflinching confidence in the value
of an ultimate chemical analysis, but it is equally true that even after
these many years of constant research by scientists the world over, very
little advance has been made in ability to interpret the facts that ought

---

1 Preliminary Report on Fire Clays, State Geol. Surv., Bull. 4, p. 138.

to be disclosed by such analyses. Because so many chemists, as well as laymen, do not seem to understand the difficulties that attend the interpretation of such an analysis, a brief review of a few of the recorded facts will be given.

In 1868, Richters[1] in his classic work entitled "Refractoriness of Clays," promulgated laws in regard to the fluxing effect of the various elements in simple mixtures at high heats that are now known as the Richters laws. In 1895, E. Cramer published in the "Thon-Industrie Zeitung" a review of Richter's work confirming his laws in every respect. The fluxing behavior of the various bases according to Richter's laws are shown in the following curves. Figs. 18 to 21.

FIG. 18. Diagram showing operations of fluxes in kaolin, using equal parts of each. (Example. kaolin=98%, K_2O—2%.)

1 From lecture notes by Prof. Edward Orton, Jr.

FIG. 19. Diagram showing operation of fluxes in kaolin using fractions of their atomic weights. (Example; $Al_2O_32SiO_2=222.8$ at. wt. K_2O 94.22 mol. wt. K_2O mixture$=222.8+\dfrac{94.22}{20}$, 1st vertical line.

FIG. 20. Diagram showing operation of fluxes on $Al_2O_3+2SiO_2+\frac{1}{2}SiO_2$ mixtures using equal weights of each.

F F. 21. Diagram showing the result of Richter's investigation of various oxides.

From Richters' and Cramer's investigations it is learned that the order of fusibility of the different oxides in simple clay mixtures is as shown in the first column of the following table. In the presence of free silica the order is changed somewhat, as is shown by contrasting the order given in the third column with that given in the first. Going to the other extreme of silicate mixture, that of glazes, the order of the fluxing effect of the various oxides is, according to Seger[1] as given in the fifth column.

Seger further says: "The law established by Richter and Bischof, concerning the fusibility of clays, 'that equivalent proportions of fluxes exert an equal influence on the fusibility,' and which appears to be ap-

1 Seger's collected works. Vol. 2, A. C. S. Translatun, p. 568.

TABLE XXV.

Showing fluxing behavior of the various oxides in—

Pure Kaolin.		Kaolin+½ mol. flint.		Glazes.	
Oxide.	Molecular weight.	Oxides.	Molecular weight.	Oxides.	Molecular weight.
Magnesia............................	40	Magnesia..	49	Lead	222
Calcium	56	Iron	72	Barium....	153
Iron	72	Calcium...	56	Potash	94
Soda	62	Soda.......	62	Soda.......	62
Potash...............................	94	Potash	94	Zinc.......	81
				Lime......	56
				Magesia...	40
				Alumina...	102

proximately correct for the very high temperatures employed in clay testing, and for the very small quantities of the fluxes coming into action in the clays, has no bearing on the glasses and glazes, far richer in fluxes and melting at far lower temperatures."

Ludwig[1] having made similar studies with more complex mixtures summarizes his results as follows:

"*First*—Richters' law is a special case of the general law of dilute solutions.

Second—This law is restricted by the following correlations:

a. It applies only to very dilute solutions, that is, clays with a small amount of fluxes and not to brick clays or glazes.

b. Is assumes intimate mixtures.

c. Iron shows a different effect, due to its two stages of oxidation, since one molecule of ferric oxide corresponds to two molecules of ferrous oxide. A given percentage of iron contains fewer molecules of ferric oxide than of ferrous oxide, since the former has a higher molecular weight. On changing to the ferrous oxide the number of molecules is doubled, and hence the fluxing action is doubled.

Third. The analysis of a fire clay is of great importance in estimating its refractoriness.

Fourth. The estimation of refractoriness by means of the percentage of alumina and fluxes leads to erroneous results."

From the above citation it must be concluded that the fluxing power of a given oxide is affected very materially by the kind and number of oxides present, as well as their chemical combination, degree of hydration, oxidation, etc. The facts gleaned from a study of the fluxing effect of a single oxide in a simple mixture do not necessarily hold true in the same degree in complex mixtures. It is well known in glaze manufacture, for instance, that a mixture of several fluxes provokes greater fusibility than a mixture of any two or them. What is true of glazes is likewise true of clays.

The difficulty of interpreting the results of chemical analyses is more largely due to a lack of experimental evidence on the fluxing behavior of known complex mixtures. Interpretation of the facts concerning

1 Thon-Industrie Zeitung, Vol. XXVIII, p. 773, 1904. Abstracted by Bleininger, A. C. S., p. 275. Trans. VII, p. 275, 1905.

a given mixture is impossible until there is more known about mixtures of the same component substances in different proportional combinations. For example, Seger[1] has shown that the fusibility of mixtures of pure Al_2O_3 and silica as determined by Bischof can be represented graphically as in Fig. 22.

FIG. 22. Seger's SiO_2—Al_2O_3 curve.

1 Seger's collected writings, Vol. I, p. 545, A. C. S. Trans.

Two important facts are shown in these curves.

First. That the kaolin-silica mixtures are more fusible than the aluminium and silicon oxide mixture of an equivalent chemical composition.

Second. That kaolin containing 58.2 per cent flint practically the same fusibility as one containing 83 per cent, while the kaolin-silica mixtures containing percentage of silica between these two limits are more fusible than either.

FIG. 23. Melting points of mixtures of magnesite and Zettlitz kaolin. (After Rieke.)

Dr. Rieke[2] has shown that magnesite will flux kaolin, as is shown in Fig. 23. From Dr. Rieke's results it would seem that a mixture of 85 per cent kaolin and 15 per cent magnesium carbonate has approximately the same fusion point as 43 per cent kaolin and 57 per cent magnesite.

Dr. Mellor[1] has shown a similar fusion phenomenon with mixtures of feldspar and quartz, as exhibited in Fig. 24.

Surprising as are the facts shown in these three curves, there has been but very little effort to determine similar relations between the several pairs of oxides and compounds, and practically none to demonstrate the fusion behavior of the several oxides and compounds in triple and quadruple combinations, and yet this is the very data that must be worked out before much can be accomplished in the interpretation of a chemical analysis. When ceramic technology reaches this

---

1 "Brick," p. 170, Oct. 1906.
2 Trans. Eng. Cer. Soc., p. 51, 1904-5.

FIG. 24. Mellor's fusion curve for flint–feldspar mixtures.

state of progress an explanation can perhaps be made regarding the fact that in some cases the admixture of the refractory kaolin will cause a lowering of the fusion point, while the admixture of a flux such as feldspar to the same mixture raises the fusion point.[2]

In the following Tables XXVI and XXVII will be found the percentages of the various oxides into which the clays considered in this report have been resolved. In Tables XXVIII and XXIX will be found the molecular composition of the clays as calculated from the analysis. In Table XXX will be found the results of a rational analysis of clays now used for paving brick manufacture in the State.

No attempt to interpret this data can be made at this time. After a discussion of the pyro-chemical properties of clays this data will be referred to with the endeavor to show all the possible relation there may be developed between the physical, chemical and pyro-chemical properties of clays.

1 See A. C. S. Trans., Vol. V, p. 158.

TABLE XXVI.

	SiO$_2$	Fe$_2$O$_3$	Al$_2$O$_3$	CaC	MgO	Na$_2$O	K$_2$O	Moisture.	Ignition.	FeO	TiO$_2$	S
K 1 ..	63.36	1.80	15.43	.93	1.58	.56	3.28	.48	6.99	4.02	1.00	27
K 3 ..	59.34	3.26	15.36	.76	1.82	.80	3.82	.29	7.89	3.84	1.31	.16
K 4 ..	60.31	5.04	17.74	.41	1.96	1.07	2.88	.81	6.71	1.96	.84	.14
K 5 ..	63.43	1.52	16.89	1.00	2.11	.20	2.03	.46	5.97	4.24	1.07	.11
K 6 ..	63.62	3.02	16.28	.63	1.44	1.50	2.60	.38	5.88	2.90	.96	.11
K 7 ..	59.86	1.42	17.43	1.05	2.32	.18	2.80	.20	6.35	5.10	1.61	.13
K 14 ..	64.09	2.65	14.16	1.69	1.64	.77	2.90	.51	6.47	3.16	.89	.24
K 15 ..	58.03	2.91	17.72	1.42	1.43	1.40	2.66	.97	6.47	5.77	1.02	.25
F 1...	58.52	4.99	15.67	1.05	1.45	1.48	2.94	2.02	7.72	3.37	.96	.32

TABLE XXVII.

	SiO$_2$	Al$_2$O$_3$	Loss on Ignition.	Fe$_2$O$_3$	CaO	MgO	Na$_2$OK$_2$O	Moisture.
K 2..........	63.35	16.27	4.75	7.56	1.01	1.33	3.80	.31
K 8..........	60.89	16.40	8.18	8.20	.55	1.61	4.15	.27
K 9..........	68.50	16.98	3.54	5.77	.99	1.71	2.97	.50
K 10..........	58.35	18.09	7.02	6.14	1.20	2.03	4.58	.81
K 11..........	55.18	19.22	10.45	8.19	.56	1.67	2.85	1.02
K 12..........	54.37	23.61	10.09	6.14	1.58	1 61	2.78	.60
K 13..........	57.09	19.07	7.97	7.92	.80	1.91	4.69	.43
S 1..........	55.02	20.35	9.40	6.26	.87	1.70	3 64	.83
S 2..........	56.29	20.32	4.39	7.90	.48	2.01	4.46	.79
R 1..........	58.42	25.05	8.08	3.04	.46	1.52	2.30	1.29
R 2..........	63.41	18.61	4.86	5.82	41	1.16	3.60	.68
R 3..........	58.57	20.40	5.95	7.40	.63	1.37	3.27	1.06
R 4..........	55.51	21.81	8.00	7.66	.56	1.63	3.56	.02
H 20.........	47.29	15.51	13.11	4.80	7.33	6.19	3.71	1.31
H 23.........	55.37	21.40	8.75	6.72	1.76	.65	2.41	3.39
H-II.........	56.25	18.79	7.01	8 02	2.39	1.33	4.61	1.49
H-16.........	60.93	17.93	5.73	8.12	1.33	.91	5.01	.55
H-17.........	56.56	12.64	6.02	13.56	2.22	2.75	4.82	3.70
H-18.........	39.91	16.43	21.20	4,80	7.57	5.08	3.71	.86
H-21.........	48.41	18.31	12.79	6.06	5.73	3.13	5.65	.79
G-II.........	63.42	16.24	5.14	6.62	1.64	1.87	4.83	.86
B-II.........	60.31	19.11	6.70	6.14	2.73	1.73	1.44	3.05
I-II.........	68.15	12.89	5.08	7.52	1.02	.59	2.93	1.57
J-II.........	62.70	16.95	6.76	8.98	1.17	1.47	3.03	.98
L-II.........	58.62	17.74	6.66	8.48	1.26	.98	3.92	2.55

TABLE XXVIII.

Sample No.	Location.	CaO	MgO	K$_2$O	Na$_2$O	FeO	Fe$_2$O$_3$	Al$_2$O$_3$	Si$_2$O	TiO$_2$
K 1.....	Alton, Ill...	0.110	0.261	0.231	0.059	0.369	0.074	1.00	6.98	0.083
K 3.....	Albion, Ill.............	0 090	0.302	0.270	0.086	0.354	0.135	1.00	6.57	0.108
K 4.....	Springfield, Ill..........	0.012	0.282	0 178	0.099	0.156	0.181	1.00	5.78	0.060
K 5.....	Edwardsville, Ill........	0.108	0.319	0.180	0.020	0.356	0.057	1.00	6.38	0.081
K 6.....	Galesburg, Ill............	0.070	0.225	0.173	0.152	0.252	0.118	1.00	6.64	0.075
K 7.....	Streator P. B. Co......	0.109	0.359	0.174	0.017	0.414	0.052	1.00	5.84	0.118
K 14.....	Western Brick Co.......	0.217	0.295	0.222	0.089	0.309	0.119	1.00	7.69	0.080
K 15.....	Barr, Streator Ill.........	0.146	0.206	0.163	0.130	0.461	0.105	1.00	5.57	0.073
F 1.....	Danville P. B. Co........	0.122	0.236	0.204	0.155	0.305	0.203	1.00	6.35	0.078

TABLE XXIX.

Sample No.	Location.	CaO	MgO	KNaO	Fe₂O₃	Al₂O₃	SiO₂
K 2......	St. Louis, Mo.........................	0.113	0.208	0.305	0.296	1.00	6.62
K 8......	Veedersburg, Ind......	0.056	0.250	0.331	0.319	1.00	6.31
K 9......	Crawfordsville, Ind	0.098	0.257	0.229	0.217	1.00	6.86
K 10	Terre Haute, Ind....................	0.121	0.286	0.331	0.216	1.00	5.48
K 11	Brazil, Ind...........................	0.053	0.222	0.194	0.272	1.00	4.88
K 13	Clinton, Ind	0.076	0.255	0.216	0.265	1.00	5.09
S1......	Moberly, Mo........................	0.078	0 213	0.234	0.196	1.00	4.60
S 2......	Kansas City, Mo....................	0.043	0.252	0.287	0.248	1.00	4.71
R 1......	Nelsonville, O.......................	0.033	0.156	0.120	0.077	1.00	3.96
R 2......	Portsmouth, O.......................	0.040	0.159	0.253	0.199	1.00	5.79
R 3......	Canton, O. (Imp.)	0.056	0.171	0.209	0.231	1.00	4.88
R 4......	Canton, O. (Metro).................	0.047	0.196	0.213	0.224	1.00	4.33
K 12	Brazil Fire Clay.....................	0.121	0.174	0.154	0.166	1.00	3.91
H-11.....	Topeka, Kan	0.232	0.181	0.321	0.272	1.00	5.09
H 16.....	Peoria, Ill...........................	0.135	0.129	0.365	0.289	1.00	5.78
H 17.....	La Salle, Ill.........................	0.320	0.556	0.499	0.684	1.00	7.96
H 18.....	Sterling, Ill.........................	0.839	0.788	0.295	0.186	1.00	4.13
G-II	Coffeyville, Kan................... ..	0.184	0.294	0.390	0.260	1.00	6.64
I-II.....	Caney, Kan..........................	0.144	0.117	0.297	0.372	1.00	8.99
J- II.....	Pittsburg, Kan	0.122	0.221	0.234	0.378	1.00	6.29
L-II.....	Lawrence, Kan	0.129	0.141	0.289	0.305	1.00	5.62
B-II.....	Atchison, Kan.......................	0.260	0.231	0.099	0.205	1.00	5.49
H 20.....	Savanna, Ill.........................	0.861	1.017	0.313	0.197	1.00	5.18
H 21.....	Galena, Ill...........................	0.570	0.436	0.404	0.211	1.00	4.50
H 23.....	Carbon Cliff Shale...................	0.149	0.074	0.147	0.200	1.00	4.39

TABLE XXX.

Rational Analysis.

Sample No.	Clay Substance.	Quartz.	Feldspar.	Phos.	Carbon.	Soluble Salts.
K 1............	35.90	46.60	17.50	.093	1.44	.13
K 3............	48.00	26.74	25.26	.078	1.50	.14
K 4............	43.32	43.66	13.02	.024	.72	.04
K 5............	38.92	46.54	14.54	.090	1.26	.08
K 6............	41.02	39.98	19.00	.067	.63	.38
K 7	33.14	49.36	17.50	.079	.71	Trace
K 14...........	25.28	48.54	16 18	.069	1.01	.04
K 15	53.36	22.82	23.82	.125	.90	.27
F 1............	51.12	29.38	19.50	.077	.92	.14

PRO-PHYSICAL AND CHEMICAL PROPERTIES OF PAV-ING BRICK CLAYS.

[By Ross C. Purdy.]

INTRODUCTION.

Relations—In the discussion of the physical properties of clays it was shown that there is a possibility of making some correlations between the several physical factors. It was also demonstrated that the physical properties affect the adaptation of clays to processes of manufacture. No relation was found to exist between the chemical composition and working properties, so no attempt was made to correlate the chemical and physical properties.

We are now to consider those properties of clays which are manifested in the process of burning, and it is here that we should be able to trace the combined effect of the physical and chemical properties. In burning, the physical and chemical properties of raw clays surely operate as causes having as effects the pyro-physical and pyro-chemical properties. If, knowing the physical and chemical composition of the raw clays and the pyro-physical and chemical effects produced in burning, we are not able to trace a logical and invariable sequence between the causes and effects, we will be forced to admit: either (a) That according to the data at hand, clays having similar physical and chemical properties in the raw state, may behave differently in burning, or, (b) That it is at present impossible to determine exactly the physical and chemical condition of raw clays; or, (c) It is impossible to trace the effect of individual physical and chemical properties where so large a number of changes occur simultaneously; or, (d) That, reasoning from analytically determined causes to observed effects is an absurdity if the evidence does not permit of a reverse reasoning, i. e., from effect to cause.

The first case, that of clays of similar character behaving differently in burning, is forcibly illustrated in the case of fire clays. Fire clays, having similar ultimate chemical composition and size of grain, may have radically different pyro-physical behavior. The one may burn to an open porous mass at cone 11, being fit for fire brick purposes; the

other may burn quite dense at cone 8, being fit for stoneware, sewer pipe, etc. This fact was noted in the preliminary report on fire clays,[1] and will be illustrated in this report under the topic "Changes That Take Place During Fusion."

The second case, the impossibility of determining exactly the physical and chemical condition of raw clays, is illustrated by the fact that in the more exact of the two analyses, the chemical, chemists do not claim to be able with ordinary care and attention to details, to determine all of the elements that may be in a clay, nor do they claim to be able to determine the combinations in which these elements exist.

The third case, or the impossibility of tracing the effect of several changes in physical and chemical conditions which take place simultaneously, is a well recognized fact. On a rectangular coördinate diagram, two changes; on a triangular coördinate diagram, three changes in properties can be traced with accuracy. No simple[2] method has yet been devised by which the effect of changes in four factors can be traced, and it is certainly beyond the capacity of the human mind to follow the effects of four or more changes, if they cannot be plotted diagrammatically. In the case of several clays, no two of which agree exactly in their several properties, and in all of which there are a great many properties peculiar to the individual clays, it is manifestly beyond our ability to satisfactorily follow even all the known details. Broad generalizations with numerous and well-known exceptions are the best that experimenters have been able to make from synthetical mixtures of fairly pure clays. It is obvious, therefore, that with a heterogeneous assortment of impure clays, conclusions concerning the relation between the causes (the physical and chemical properties of raw clay) and effects (the pyro-physical and chemical properties) cannot be other than broad generalizations.

The last case, that of the absurdity of claiming validity for deductions drawn by reasoning from cause to effect in cases where data do not permit of a reverse reasoning, i. e., from effect to cause, is very nicely illustrated in the work of Hoffman and Desmond[3] where an attempt was made to devise an indirect method of determining the refractoriness of clays. With a given furnace operating on a predetermined time-temperature schedule, they thought they were successful in determining the relative refractoriness of clays by toning up low grade clays with the addition of refractory material, and toning down high grade clays by the addition of known amounts fluxes, until the clays had the same refractoriness under the same heat treatment. This scheme worked

---

[1] State Geol. Surv. of Ill., Year Book 1906, p. 138.
[2] Solid figures are used by physical chemists in depicting the combined effect of more than three factors, but the drawing of such figures to scale according to given data presents difficulties which the writer, at least, has been unable to surmount. Judging from the fact that ceramists and other technical scientists have not as yet used solid figures it must be inferred that others have also found the involved difficulties insurmountable.
[3] Trans. Am. Inst. Min. Eng., Vol. XXIV, p. 32.

nicely until they assumed definite temperatures and attempted to prepare mixtures that would fuse at these temperatures. In the first instance they adopted a certain combination of "causes" and measured the "effects." In the second instance they adopted an "effect" and attempted to determine the combined "causes" that produced this effect. In this they failed so utterly that they abandoned this indirect method of estimating refractoriness. If their careful researches demonstrated no other fact than the futility of attempting to draw conclusions concerning the relation between cause and effects, when the data show this relation operating only in one direction, i. e., only from cause to effect or from effect to cause, their work was worth while and their report a valuable addition to ceramic knowledge.

Relative Importance of Raw and "Burning" Properties—It is plain that the physical properties of a raw clay influence its behavior mainly in the machines and dryers. True, the physical properties have their influence on the burning behavior of clays, and, as in case of size of grain, if the causes of the physical properties were determinable, their findings would be of value in predicting and explaining the properties developed in burning. Size of grain, as will be shown, is an important factor in the case of pure minerals, but when the grains do not have a homogeneous mineral composition, but are, in the main, clots of minute particles of several minerals, or particles of the same mineral substance cemented together, any data concerning the influence of fineness of grain on the properties developed in burning are apt to be very misleading. Grout's analysis of the grains of clays, given on pages —— shows that the grains are not individual particles but are aggregates, and Fox's results, cited on pages————— confirm the conclusions drawn from Grout's data. The writer has ground impure clays until they passed sieves of different meshes ranging from 10 to 200, molded the clays into cones and noted the effect of fine grinding on the refractoriness of the resulting masses. The difference between the ultimate fusion failure to stand erect under high heat treatment of the cones prepared from the same clay but differing in size of grain, was hardly observable. True there was a difference in that the finely-ground samples vitrified earlier and did not lag as much in bending over so that they could be said to be a trifle less refractory. In no case, however, was the difference in refractoriness between the 10 and 200 mesh sample of the same clay more than 20 to 40 degrees centigrade, as measured by LeChatelier electric resistance pyrometer.

Indirectly, fineness of grain affects the burned product in that internal fractures produced in drying and lamination in the machine dies caused by extreme fineness of grain weaken the finished product. These and similar considerations are not properly considered under the topic of Pyro-physical and Chemical Products.

The main consideration, in an analysis of the influence of the several properties of clays, is their influence on the character of the product manufactured from the clays in question. In the case of paving

brick the desired character of product is toughness or resistance to impact and abrasion. If coarse as well as fine grained clays, plastic as well as non-plastic clays, and tough clays or clays that show but little tensile strength, can be burned so as to make tough bricks, it is obvious that it will be impossible from such physical data to predict the character of ware which a given clay will make. Inability to trace the influence of so many factors may be largely responsible for this seeming lack of relation between the physical properties of the raw clay and the properties of the burned ware, but the fact remains that such is the case.

On the other hand it can be shown that there is a possible or seeming relation between pyro-physical and chemical properties and the properties of the burned ware. Such a relation has been shown to exist in the case of fire clays. In the case of paving brick clays there is not quite so distinct a relation between these factors, but still it is observable. The study of the pyro-physical and chemical changes produced in clays by heat is, therefore, of considerable more importance in the study of paving brick clays than the study of the physical properties of the raw clay.

DEHYDRATION.

Nature of process—Pure kaolin, the basic clay substance, contains in round numbers 14 per cent of water, chemically combined. At ordinary drying heats the amount of this chemically combined water in the kaolin is supposed to be unaltered. In fact, there is experimental evidence to support the belief that there is some water mechanically retained by the clay even at the highest heat ordinarily attained in any dryer, but this has no relation to the chemically combined water.

Since, however, in the ordinary clay or shale but a fractional part of the whole is kaolin, ranging from a possible 100 per cent in the purest varieties down to 25 per cent or less in the more impure clays, it is not surprising that the amount of chemically combined water varies greatly in the different clays. Even in the purest it varies to some extent, amounting in some cases to more than 14 per cent. In these not rare cases some other hydrous minerals are supposed to be present that carry a higher percentage of combined water. It is aside from our purpose to dwell upon the kind and nature of the hydrous minerals that may occur in clay except to note that, if they occur in the purest types of clays, and especially those which have not been moved from their place of formation, it is reasonable to suppose that in a heterogeneous mixture of minerals such as shales seem to be, these highly hydrous minerals may in some cases be present in considerable quantities. Since each hydrous mineral substance retains its chemically combined water with a tenacity peculiar to itself, it follows that the period of dehydration of clays will vary with each variation in quantity and kind of hydrous minerals present. Likewise the physical alteration in the mass at this period will vary with each variation in

kind and quantity of hydrous minerals present. Since, however, it is impossible to gather reliable data as to the mineralogical constitution of the impure clays, the quantities of these hydrous minerals present must be mere speculation. The varying effects produced during the period of dehydration, which probably originate in variable mineralogical composition, are the only known or determined facts in the case.

From the foregoing considerations it is not surprising that the temperature of dehydration has been considered as ranging from 550 to 650° centigrade (990 to 1170° Fahrenheit), and that there are clays which can withstand a heat treatment of 16 hours duration at a temperature which will average during this period at least 650° C. without entire loss of plasticity.

Six clays (K 5, H 16, K 8, K 13, K 14, K 15) after subjection to a heat treatment supposedly sufficient to affect complete dehydration, slaked down in water to a red plastic mass similar to that produced from hard shale on weathering. If it is true that on dehydration clay loses the properties that cause the mass to exhibit plasticity then these clays were not dehydrated. If clays that have been subjected to just sufficient heat treatment to cause their complete dehydration still retain considerable plasticity, then many will have to change their conception as to the cause of plasticity, for surely nearly, if not all, of the physical properties of the kaolin particles must be altered by dehydration. These six clays tested continued to lose weight after this period. This loss may possibly be accounted for by the loss of volatile matter other than chemically combined water. In the absence of analytical data, however, it was fair to assume that this additional loss was in part at least due to the further expulsion of the chemically combined water. If this assumption is correct, these cases would indicate that the usually allotted range in temperature for this period is altogether too limited. If a clay can withstand heat treatment for 16 hours at a temperature that ranges from 500° to 740° C., with an average equal to 650, without complete loss of its combined water, it is fair to conclude that the maximum temperature limit for the dehydration period is above 700° C.

Loss due to Constituents other than Combined Water—The actual loss in weight of a clay, aside from loss of the chemical water, up to this temperature may in part, according to Prof. Orton[1] be accounted for as follows:

Vegetable tissues, such as roots, leaves, etc., ignite and burn at about 300°C.

Bituminous matter, common to shales, ignites and burns between 300 and 400°C.

Graphitic carbon, does not ignite much before 500°C.

Sulphur distils from iron pyrites between 400 and 600°C.

Calcium carbonate decarbonizes between 600 and 1000°C.

Ferrous carbonate decarbonizes between 350 and 430°C.

1 Amer. C. Soc., Vol. V, p.

The loss of any or all these constituents would not materially affect the plasticity of clay, and in the main these reactions would be completed before or at the same time as dehydration. In caes of K 14 before referred to, they had all evidently been completed before the completion of dehydration, except perhaps the decarbonation of the small amount of contained calcium carbonate. The bricks were thoroughly oxidized and normal salmon-colored throughout. In this case the only possible conclusion seems to be that dehydration of clay requires more heat than heretofore supposed.

It has been demonstrated by Hopewood[1] that, aside from the loss of combined water, solid carbon, carbonic acid gas, sulphur, etc., quite a large variety of acids and bases[2] are expelled from the clay by volatilization at temperatures below the maximum required for complete dehydration. The evidence given to Hopewood's experiments, together with the vast accumulation of data by agricultural chemists, makes it appear as though the *ad*sorbed as well as the *ab*sorbed salts are seriously affected during this period. Direct evidence is not at hand that would throw light on this question, but the value of such evidence is considered by the writer to be of such importance that an extensive research dealing with this subject has been outlined. It is anticipated that the manner in which this period of burning (dehydration) is conducted will be found to play a very significant role in the character of the ware developed in "the finishing heats."

OXIDATION.

General Conditions.

Definition of terms—"Oxidation" and "Reduction" are chemical terms referring respectively to taking on and giving off of oxygen. When a piece of iron is rusting it is becoming oxidized, i. e., the metal (Fe) is being converted to an oxide of iron (Fe_2O_3) which is red in color. Iron rust can be reconverted to the unoxidized metallic state again by application of heat under reducing conditions, i. e., conditions that favor separation of the metallic iron and oxygen. When the quantity of oxygen in combination is reduced, then it is said that reduction has taken place. When the quantity of oxygen in combination has been increased then it is said that oxidation has taken place.

Evidence of reduced condition in raw clay—"Blue" clay and dark gray shale owe their characteristic blue color, in the main, to two classes of substances, (1) the ferrous compounds, principally ferrous carbonate and (2) carbon. Partially metamorphosed carbon adds to a clay mass its characteristic black, just as does lamp black when added to what would otherwise be a white mass. Lamp black, an amorphous form of carbon, is the product of decomposition of carbon compounds

1 Trans. Eng. Cer. Soc., 1904-5, p. 37.
2 R. K. Meade has shown analytical data in support of his claims that the alkalies in cement mixtures are expelled during the burning. "Portland Cement" p. 124.
J. W. Mellor also shows with data that the loss of alkalies from fire clays fired at 1400°C., amounts to 20 per cent of the total alkalies present in the unburned clay. Trans. Eng. Cer. Soc. Vol. VI, p. 130.

under the influence of heat, resulting from conditions that prevent its complete oxidation. The carbon in shales, at one time a part of the fibrous tissue of living plants, was buried in deposits of sea mud, and is found today in this same mud hardened into shale. Therefore, the dark iron compounds and the metamorphosed remains of carbon compounds combine to give the characteristic blue color to shales and many fire clays.

Evidence of oxidation in raw clay—Where the shale is covered with only a very thin "stripping," the color of the upper three or four feet of the bank will be red. In the lower portion of these red strata the color shades off gradually into the blue of the more solid strata below. In this red portion near the top of the bank the ferrous compounds have been oxidized to ferric compounds by the action of the oxygen from the atmosphere. Below the belt of weathering, the clay retains its blue color owing to the fact that either air cannot penetrate to those depths or that its oxygen is largely spent before it can reach the lower limit of the belt of weathering. It is observed that oxidation starts at the surface and proceeds downward. The depth to which evidence of oxidation can be seen depends upon the nature and amount of the oxidizable mineral present, the solidity of the rock mass, the prevailing atmospheric conditions and the length of time of exposure.

OXIDATION OF CLAY IN BURNING.

The very same processes that are effective in oxidizing the blue shale to "red outcrop" are operative in burning when the blue clay brick is converted into "salmon brick." In nature, at ordinary temperatures and under varying conditions, this oxidizing process is very slow, but in the kiln at temperatures ranging from 500 to 800° centigrade, with the high draft that is usually maintained at this early stage of the burning, conditions under which oxidizing processes operate are very much intensified and consequently comparatively rapid in their action. In the case of surface clay, and red clays generally, oxidation is so rapid that the lag in time incident to raising heat in a large kiln of relatively cold ware is sufficient to complete the oxidizing processes.

In the case of many of the shales, the time required to completely oxidize the clay is so much longer that either the burner must "hold the kiln at red heat" for a time, or, especially in the case of bricks which have been set wet, evidence of incomplete oxidation will be very evident when the bricks are drawn. The change in color from blue in the "green" ware, to red in the salmon is the result of oxidation. Red surface and black centers are results of incomplete oxidation. These changes in color are the same indicators of oxidation and lack of oxidation noted in the case of shale in the bank.

SUBSTANCES IN CLAY THAT ARE AFFECTED BY OXIDATION.

In general terms, the oxidizable substances in clays are carbon compounds, carbonates, nitrates, sulphites, etc. The most noteworthy oxidizable substances in clays are: Carbon and the carbon compounds, ferrous carbonate and ferrous sulphide.

Carbon and the Carbon Compounds—Carbon is present in practically all of the secondary clays in forms ranging from unaltered vegetable matter, humus and its compounds, to the highly metamorphic carbon-graphite in graphitic shales. The least altered carbon ignites and oxidizes most easily and the highly metamorphosed carbon most difficulty. To the decomposing carbon compounds and their by-products, the organic acids, are due many of the physical properties of clays. It has been shown in earlier pages that organic acids are the main agents that cause deflocculation, a condition that must exist before plasticity can be developed. It could be readily shown that humic acid ($C_{20}H_2O_9$) with its peculiar properties of absorbing and holding heat, moisture and soluble salts, is a very active agent in promoting chemical changes in the mineral ingredients of clay, thus altering the physical condition of the mass. Unaltered carbon compounds and their by-products are, therefore, not only easily oxidized in burning, but have been highly beneficial in that they have promoted the development of those physical properties which, if the carbon is not in excess, permit of easy manufacture into wares.

The more metamorphosed the carbon compounds the less active they are in promoting physical and chemical alterations in the clay mass and the more difficult are they to oxidize in the kiln. For these reasons fire clays and clay shales in which the carbons compounds have been completely converted to graphite are—within small areas—more constant in their properties, thus being more constant in their working and burning behavior, and at the same time, more difficult to burn.

Ferrous Carbonate—Ferrous carbonate occurs in clay in various physical conditons and sizes of grain. Large concretions—"nigger heads"—which are often composed mainly of ferrous carbonates, are to be seen in most shale banks. Ranging in size from 12 to 18 inches in diameter, down to minute, almost microscopic particles, these concretionary and globular forms of ferrous carbonate play a role in burning clay wares which, while most peculiar, is but little understood. The ferrous carbonates that exist as finely precipitated powder surrounding the other mineral grains must, in burning, pass through the same chemical alterations as the ferrous carbonate in lump form, but under such different conditions that distinction must be made between its behavior when in these two conditions of aggregation.

One of these large ferrous carbonate concretions pulverized, pressed into brick form and burned under the same heat treatment required to produce pavers from the shale in which the concretion was found, produced a brigh red brick which possessed a toughness that was equal to that of the brick made from shale. This experiment proved that the clay mass which is bound together by ferrous carbonate in a mass so hard as to wreck ordinary crushing machines like dry pans, and containing a comparatively large quantity of ferrous carbonate, can be burned as safely and into just as good brick as the softer shale containing but a small quantity of ferrous carbonate (3 per cent of total ferrous iron.)

In this brick made from the crushed concretion there was practically no carbon, while the shale contained three quarters of one per cent. While it is true that the carbon content of the shale is so small that no difficulty is experienced in thoroughly oxidizing the mass under the time temperature schedule required to raise heat uniformly in a large kiln, yet it is a significant fact that occasionally unoxidized brick *are* drawn from the kilns,. and that the mass containing a large amount of ferrous carbonate *was* perfectly oxidized under similar kiln treatment.

Singer[1] has shown that the acid radical (CO_2) is expelled from ferrous carbonate at temperature below 430 C. The basic radical (FeO) would thus be given ample time to become thoroughly oxidized to Fe_3O_4 or Fe_2O_3 before the temperature could be raised sufficiently to cause fusion between the ferrous iron and the silicates. Under normal kiln treatment complete oxidation of the iron would be effected, provided the clay mass contained but a small amount of carbon. In the almost total absence of carbon, our experiment with the concretionary mass proved that the iron could be quite readily oxidized. As the carbon content increased, the difficulty in oxidizing a given amount of ferrous iron would increase, for between carbon and oxygen there is a stronger affinity than between iron and oxygen. In case there is a high content of both carbon and ferrous carbonate, time would have to be allowed in burning to completely burn out the carbon before the heat is raised. If this should not be done the ferrous oxide would flux with the silicates causing an early fusion in the unoxidized portion of the brick.

In case the carbon is easily ignited and burns freely it has been found that the fires in the furnaces have to be drawn, all air supply shut off and the carbon allowed to smolder until completely burned out. If these precautions are not taken in such cases, the heat from the burning carbon will raise the temperature in the kiln to the point where the ferrous iron will be slagged with the silicates. In fact, the iron that was originally in an oxidized condition would be reduced, and the whole iron content thus be brought to its most active fluxing condition.

Where the carbon is less inflammable, a longer time would have to be allowed for its complete combustion, but such stringent precautions would not have to be taken as in the case where the clay contained more inflammable carbon.

The chemical explanation of these cases is that although the CO_2 radical is expelled from ferrous carbonate at an early stage in burning, the basic radical (FeO) cannot receive the oxygen required to convert it to its less active fluxing form, i. e., to Fe_2O_3 as long as there is carbon left in the clay mass. Carbon having a greater affinity for oxygen than the ferrous iron will withhold it from the iron. If a clay contains insufficient carbon of an easily inflammable variety, or, if the carbon, even though present in quantity, is difficultly inflammable, time must be allowed to permit the oxygen to penetrate the brick, for oxidation proceeds from the exterior towards the interior in a manner similar to the oxidation of shale in the bank from the outcrop downward.

---

1 Class exercise under Orton, Ohio State Univ.

High content of ferrous carbonate does not in itself mean that trouble will be experienced in oxidation, nor does a high content of thoroughly oxidized iron considered alone indicate immunity from oxidation troubles. The substance that controls the manner in which the oxidation period of burning clay wares must be conducted is carbon. Burning carbon not only will prevent oxidation of the ferrous iron, but will reduce the iron that may have originally been in a thoroughly oxidized condition. It depends, therefore, upon the amount and form of carbon present in a given case, as to whether in burning there must be allowed a short or long oxidizing period.

Ferrous Sulphide—This very frequently occurs in clays as bright yellow or white crystals. The first of these forms is often mistaken for gold because of its similarity in color. It is commonly known as "fool's gold." Mineralogically it is known as iron pyrites or marcasite, depending upon its crystalline form.

If clay containing pyrites is loosened and allowed to weather, the pyrites will be desulphurized. The iron will, in the dry, oxidize to the hematite (Fe_2O_3), or, if moisture is present, to limonite ($2 Fe_2O_3$-$3H_2O$). The sulphur will at the same time oxidize to sulphurous or sulphuric acid. By weathering, therefore, iron pyrites can be thoroughly oxidized and the sulphurous and sulphuric acid removed in solution by percolating waters. These reactions require time, especially under dry conditions. Brick manufacturers cannot, under the existing trade conditions, weather their clay. The face brick manufacturer, therefore, must allow as little time as possible to elapse from the time that his clay is mined until it is under fire in the kiln if he wishes to avoid that bane of the face brick manufacturer, scumming, which results from the formation of soluble salts by the sulphurous and sulphuric acid from iron pyrites.

To the front brick manufacturer, the presence of iron pyrites is not, aside from the question of scumming, a serious disadvantage, for the black-slagged specks resulting from ferrous iron from the pyrites fluxing with the silicates is not objectionable to architects. If, however, a clean buff brick is resired or if, for any reason, the smoother and more uniformly distributed black specking by the use of pyrolusite (MnO_2) is needed, then a clay practically free from iron pyrites must be used.

In face brick, soundness and color are the prime requisites. In paving brick, toughness alone is the prime requisite. If a clay contains sulphide of iron (pyrites) scattered throughout the mass, local slagged spots scattered all through the brick will be formed in burning. These slagged spots will be spongy or vesicular, i. e., full of cavities, just as is the black warty mass that appears on the face of a brick made from a pyritiferous clay. The local fused spots are detrimental to the toughness of the brick, not only because they are spongy but also because they are fused glassy ferrous silicates, which are generally very brittle and have no property in common with the tough, stony matrix which makes up the body of the brick.

As in weathering, the first step in the oxidation of iron pyrites is the separation of the iron and sulphur. In the kiln, however, sufficient length of time cannot be allowed to drive off more than one of the two atoms of sulphur. The first atom is expelled early in the oxidation period and passes off in the waste gases as sulphurous and sulphuric acid gases. The remaining atom of sulphur is not expelled readily, in fact either a very long time or much higher heat is required for its expulsion. In the customary heat treatment in kilns, this last atom of sulphur probably remains with the atom of iron until a temperature is reached that will cause fusion between the iron and silicates, forming the black slag mentioned in preceding paragraphs. It can be said, therefore, that under the usual kiln treatment, iron pyrites is oxidized as follows: (1) One atom of sulphur is oxidized and expelled during the oxidation period. (2) The other atom of sulphur is oxidized and expelled only by long heat treatment or higher temperatures. (3) The atom of iron, under the long heat treatment, will oxidize to the higher oxide forms before slagging begins, but under the usual heat treatment, in which sufficient time is not allowed for the oxidation and expulsion of the last atom of sulphur at a low temperature (about $500°C$), the iron is not freed from its sulphur radical and oxidized to FeO until a temperature has been attained that would cause this FeO to flux with silicates.

From these discussions of oxidation it is evident that a good paver cannot be made from a pyritiferous clay unless it either be thoroughly weathered, or an unusually long time be given to thoroughly oxidize the iron and sulphur before fusion is allowed to take place.

Other Substances—There are many substances other than carbon and iron that suffer oxidation, but inasmuch as their oxidation is not attended with serious difficulties and is, therefore, of little consequence to the paving brick manufacturer, they will not be discussed. The gases given off from clay wares under oxidizing and reducing conditions are just now being studied by ceramists. By these studies many phenomena in fusion, discoloration, etc., of pottery wares are being explained and the potter is receiving much benefit. It is not necessary, at this time, to discuss the results of these studies.

EFFECT OF PHYSICAL AND CHEMICAL PROPERTIES OF CLAYS.

The effect of carbon in its different forms has been discussed. The oxidation of ferrous compounds in the presence and absence of carbon has also been considered. Certain other points need be considered under this heading. Among these are: distribution of the carbon, fineness of grain of the clay, iron in combination as a stable or not easily altered silicate, the structure of the clay mass, the presence of moisture, and the temperature factor.

Varied distribution of carbon—If carbon is thoroughly disseminated through the mass, it will be so surrounded by the mineral matter as to cause slow oxidation in a manner similar to the slow burning of a fire banked with earth. If, on the other hand the carbon is concentrated

in particles the size of coal dust, oxidation can take place much more readily. Anthracite screenings added to a clay either for the purpose of effecting equal distribution of heat or making the ware more porus, seldom give trouble in oxidation. The quantity of carbon, therefore, is not so important a factor in determining the oxidizing behavior of clay as its character and distribution. On this account chemical analysis has failed to give much aid in detecting the difficultly oxidizable clays.

Fineness of grain—If the clay itself is fine grained, and especially if very plastic, it will prevent oxygen getting to the carbon and will delay the expulsion of the gases formed by the burning carbon. Further, in case of fine-grained clays, the carbon will not be completely oxidized, i. e., CO instead of CO_2 will be formed and in escaping from the center of the bricks will keep the iron in the outside portions in a reduced condition long after the carbon here has been burned out and time given to oxidize the iron to the ferric condition. Fineness of grain of a clay, therefore, plays an important role in the oxidation of clay wares.

Stable iron compounds—Iron combines with silicates in both the "ous" and "ic" condition, i. e., we have ferrous silicates and ferric silicates. The instances, however, of iron in the "ic" condition combining with silicates are comparatively rare. This was shown in a very forcible manner in a series of experiments in which the writer used several varieties of granite in porcelain floor tile bodies. The granites were obtained from different quarries in the form of "spalls" that are made when the rough granite is cut into shapes. These spalls were ground to powder that was as fine as feldspar and flint, as prepared by millers for pottery use. In the majority of cases the tiles were full of minute black specks with but a trace of the buff color that would be given if the iron had been in the "ic" condition. In one or two cases the iron specks were buff instead of black, showing that the iron was either in the "ic" form in the granite or had been oxidized in the burning. From the fact that all these "granite trials" were burned at the same time and hence under the same heat treatment, it was concluded that in these exceptional cases the iron was originally in the more highly oxidized form. This conclusion was substantiated in later experiments in which iron calcines were used.

When fusion in a clay or clay mixture has progressed sufficiently to cause the whole to be vitrified, iron, if originally present as an oxide, carbonate or hydrate, will generally combine as a lower oxide, forming ferrous silicate. The blueing of fire clays and the changing from red to chocolate in shales is evidence of this. For this reason iron oxide added to a porcelain body either as an oxide or as an ingredient of a shale will, on vitrification of the body, result in a blue tint. Iron precipitated into a mass of silica or alumina, and the mixture dried and calcined under oxidizing conditions, will when added to the porcelain body, produce a buff or pink, never a blue color. These experiments

proved conclusively that iron can combine with alumina and silica in the "ic" condition forming ferric compounds, and, further, that when so combined fusion of the body will not result in the reduction of the iron compound.

The practical lessons to be learned from these two experiments, the first with granite dust and the second with iron free as an oxide and combined as a silicate, are: (1) that when combined as a ferrous silicate the maintenance of strictly oxidizing conditions in a kiln will not result in oxidation of the iron; (2) that iron oxide uncombined is not only easily reduced but will form ferrous compounds when fused with silicates; (3) that when iron is combined as a ferric compound with alumina and silica, it will retain its ferric condition against the reducing influence of fusion and hence is very apt to retain its "ic" form even under reducing conditions. This latter statement is an assumption, for no direct evidence bearing on the point is at hand, but deduction from known data seem to leave no doubt as to the validity of the assumption.

In clays we have iron combined with silicates in a large variety of mineral forms and compounds. If these compounds are stable when heated, the iron will retain its form of combination against oxidizing and reducing influences. Iron when combined as a silicate, therefore, will not be affected during the oxidation period. In this connection, however, chemical analysis of a given clay will not show exactly how much of the iron is combined or in what form it is combined with the silicates.

Structure of clay ware—Orton and Griffin have shown that the more porous the brick the more readily can it be oxidized. Soft-mud bricks by actual porosity determinations were found to be the most porous, dry-press somewhat more dense, and the stiff-mud bricks the most dense. Our experiments have shown also, that clay issuing from the machine die in as dry or "stiff" a condition as is compatible with formation of a perfect bar, will produce a denser brick than when the bar is permitted to issue in a softer condition. While maximum density in unburned bricks means minimum toughness that can be produced with a particular clay, it means also maximum difficulty in oxidation. This, however, is a minor factor in the problem of oxidation of clay wares, for an easily oxidized clay will still be easily oxidized and a difficultly oxidized clay will be difficultly oxidized, no matter how dense the wares may be in either case.

The thickness of ware and consequently the manner of setting is a more important factor than density of the clay body. Hollow goods, where the walls are thin, would be completely oxidized under conditions that would not permit the complete oxidization of bricks manufactured from the same clay. Depth to which oxygen must penetrate is obviously the effective factor in these cases.

Temperature as a Factor in Oxidation—Quite obviously, the higher the temperature the more rapid will be the combustion of the carbon. In the case of clays free or practically free from iron, or where the iron is in a stable silicate combination, rapid combustion at high temperatures would have no attending evils and would materially shorten the oxidation period. When the iron is present in the "ous" condition, or where it can be easily reduced to the "ous" form, combustion of the carbon at temperatures above 1000° C. would result in partial slagging of the iron with the silicates forming a dark gray mass that cannot, without expenditure of excessive time, be reoxidized. Such action would cause premature fusion of the clay mass, especially near the bag walls of the kiln, and, as a consequence, careening of the whole "setting," or at least a falling over and fusing together of the bricks near the bags.

Oxidation at too high temperatures is frequently shown by a permanently discolored center or core, in which vitrification has progressed further than in the outside shell of the brick. Orton and Griffin found that 800° C was the safest temperature at which to oxidize the average clay. In some rare cases, like the clay found at Loraine, Ohio, which Orton and Griffin cited, even 800° C would be too high for safe oxidation.

Moisture as a Factor in Delaying Oxidation—In the majority of yards which were visited by the writer evidence could be found of incomplete oxidation of a few bricks in an otherwise thoroughly oxidized kiln of brick. Inquiry developed the fact that in most instances, in the rush to make a day's work, the setters would set the bricks as they came from the dryer, no matter how wet or dry they may have been. Invariably either the head setter or superintendent would recall that a carload or two of wet bricks were set in the particular place where the unoxidized bricks were found on "drawing the kiln." It is evident, therefore, that moisture in the bricks has an influence on oxidation of the clay.

Theoretical calculations, laboratory experiments and factory observations have proved that wet brick set in a kiln of dry bricks, are delayed in heating up by the fact that the heat, which in case of the dry bricks is sufficient to carry it well into the oxidizing period, is spent in evaporating the water from the wet bricks, thus delaying their "heating up" process. Bricks thus delayed will not be heated much more than is sufficient to cause the beginning of oxidation, when in the bulk of the bricks oxidation is completed and fusion begun. Under these conditions the bricks that were wet will pass through the oxidizing period (450 to 1000° C) too rapidly to permit their complete oxidation. Water, therefore, indirectly delays oxidation.

PHYSICAL AND CHEMICAL EFFECTS OF INCOMPLETE OXIDATION.

Usual effects—Reduction of iron and the consequent early fusion of the unoxidized portion of a brick results in the formation of a partially fused glass surrounded by a shell that has as a rule just begun to vitrify. Entrapped in this glass is some burned carbon which when

partially oxidized is converted into a gas. Aside from the CO_2 formed by the oxidation of the entrapped carbon, there are salts that are volatilized into vapors at this heat. These gases and vapors expand on heating, causing the black unoxidized core of the brick to swell up until, in extreme cases, the brick is twice its normal size and will float in water. Inasmuch as the oxidized shell is thickest on the edges and thinnest of the faces, the swelling core will bulge out the faces of the brick until it approximates the shape of a cylinder.

It is obvious at once that bricks which have swollen centers will not be fit for pavers. It follows also that the toughness of a brick is lessened in proportion to the extent that its center is reduced and rendered vesicular. It is imperative, therefore, that ample time be given at the oxidizing period (red heat) to insure complete combustion of the carbon and oxidation of the iron.

Exceptional Effects—In the case of H, 23, oxidation had not progressed very far at the end of 24 hours exposure at 650°, and the unoxidized portion of the briquettes vitrified on further heating to as hard hard and dense a mass as did the outer oxidized portions. No swelling or distortion of the brick due to the oxidation of the carbon and ferrous iron was noted. In fact, the shrinkage and rate of decrease in porosity was not abnormal in any respect. In Fig. 25 are shown the volume-shrinkage, porosity, and specific gravity curves for this clay.

In this figure, the specific gravity, porosity and volume of the bricks burned at different temperatures are calculated in terms of the percentage of increase or decrease over those of the unburned bricks. In other words, the raw factors are considered as a basis from which the "burned" factors are calculated as increase or decrease. Zero, therefore, represents the data obtained from the unburned bricks.

The percentage of increase of the burned ware over that of the unburned is shown above the datum line on the ordinate, and the percentage of decrease is shown below the datum line. On the abscissa is shown the actual percentage of porosity of the burned brick.

Points on the same ordinate represent a single brick. Data ·from all the bricks studied in this test have not been plotted, but only those in which the percentage of porosity differed sufficiently to fix points on the curves that would show a comparative increase or decrease in the several factors.

The fact that the actual percentage of porosity of the burned brick was taken in each case as a point on the abscissa, without regard to the porosity of the unburned brick, will account for the irregularity in the curves.

Notwithstanding the fact that the black unoxidized core remained, even when the whole exhibited a porosity of only 2 per cent, the brick continued to shrink normally with each increase of temperature, and the specific gravity of the brick decreased less than in the case of many

normally burned paving brick shales. This steady decrease in volume and comparatively slight increase in specific gravity gives evidence of a thermo-physical behavior that is opposite to that of the majority of clays containing carbon.

Fig. 25.   Physical alterations produced by burning compared with unburned condition of clay.

Fusion[1].

FUSION PERIOD OF CLAYS.

From the laws of physical chemistry, it could not be expected that the heterogeneous mineral mass called clay, consisting largely of amorphous materials, would have a definite fusion point. According to Walker[2], this would more properly be called a fusion period.

[1] A large part of this discussion of the fusion period appeared by permission in advance in a paper by Purdy and Moore in Trans. Am. Cer. Soc., Vol. IX.

[2] Introduction to Physical Chemistry, p. 64.

Our studies, a part of the data of which are shown in subsequent curves, bear out this statement. It will be seen that in the case of the purest clays, according to the specific gravity curves, fusion begins as early as cone 3. In the case of some of the most impure shales, high in lime, fusion begins at a period considerably earlier than cone 010. Fusion thus early begun progresses with more or less regularity until the whole mass enters into active thermo-chemical reaction[1] and deformation of the ware ensues. Incipient vitrification, vitrification, and like terms are only descriptive of the effects at different stages of fusion. It is the rate of fusion, therefore, that determines the pyrophysical effects produced in the burning of clay wares during this period.

FACTORS AFFECTING RATE OF FUSION.

Mineralogical Composition—Synthetical studies of the fusion of mixtures of pure minerals, have shown that the same chemical elements, brought together as constituent parts of different minerals, produce mixtures having unlike fusion periods. The rate of fusion and the regularity with which it progresses, as well as the point of complete yielding, are affected very largely by the manner in which the various elements are previously combined. Because of the difficulty of making a microscopic mineralogical analysis of a clay, we are not able to obtain information that would aid in an attempt to foretell or explain in full the fusing behavior of clays. Realization, therefore, of the fact that difference in the mineralogical make-up of clays of like ultimate chemical constitution, causes difference in their fusion behavior, is the only result of practical value that has so far come from the study of the fusion behavior of synthetical mixtures of minerals.

There is one very notable exception to the above, and that is in the case of calcium carbonate. The effect of calcium carbonate, depending upon size of grain and extent and homogeneity of diffusion throughout the clay mass, operates in a two-fold manner. If thoroughly blended with the clay in small particles a portion of it (on the average up to about 8 per cent of the total clay mass) operates as a very active flux. Its fluxing effect is most notable on account of the rapidity with which it combines with clay substance to form a molten mass. This reaction is in some instances so rapid as to make it very dangerous to approach the vitrification temperature. If the calcium carbonate is present in nodules, the thermo-chemical reaction just described can take place only at the points of contact of the decarbonized lime and clay,

---

1 The expression "thermo-chemical reaction" is used here because we are accustomed to thinking of fusion as resulting from chemical combination of the clay ingredients. The idea conveyed by a literal definition of the term is, however, very erroneous. The alterations in the clay mass during fusion are more largely that of mutual solution of the mineral compounds than of chemical reaction one with another.

the remainder of the carbonate being converted into quicklime. The different effects of lime in these two physical conditions one the rate and regularity of fusion of the clay mass is obvious.

In the very valuable researches recently published[1] by Dr. Reinhold Rieke, it is demonstrated that lime added in excess of a given amount does not act as a flux and cause sudden failure of ware with slight increase of heat treatment. In fact, it happens that this excess lime seems to counteract the effect produced by the smaller quantities. Experiments in the compounding of pottery bodies have shown that notwithstanding the fact that wares containing lime in excess of this amount do not fail by sudden fusion, i. e., with slight increase in intensity of heat treatment, they suffered a rapid decrease in porosity and specific gravity when the heat treatment had become sufficiently intense to cause the formation of the more fusible lime-silicate solution. It accords entirely with the facts to conceive of the fused portion as a mutual solution of minerals becoming saturated with lime. Up to the point of about one-third saturation the lime is very active as a flux and decreases in activity as the saturation approaches completion. It is easy to see, therefore, that any lime which may be present in quantities in excess of that which can go into solution will not have any fluxing action.

In most mineral mixtures (and this is true in clays) the first which fuses is not the most fusible individual mineral or substance which may be present. The first to fuse will be the most fusible *mixture* of the minerals present known technically as a eutectic mixture. This mixture may consist of two or more of the clay ingredients. Whatever the mixture may be—and this depends largely upon the size and character of the grains—it will fuse some time before the fusing point of the most fusible mineral has been reached. This is shown in the curves given in the section of this report which deals with the chemical properties of clays.

Now (repeating for emphasis) any lime in excess of that which is required to form this most easily fusible (eutectic) mixture which is possible with the kind and condition of minerals present in a given clay, will not be active as a flux. That portion of the lime necessary to form this eutectic mixture goes into solution with a rapidity which is inversely as the degree of saturation. The lime which goes into solution is least active as a flux when sufficient is present to completely saturate the fused portion, most active at about one-third saturation.

The rate of formation and the amount of fused material formed in a brick very obviously determine the rate at which the open pores will be eliminated. Since lime readily forms solutions with silicates, and particularly with clay substance, those clays which contain from 2 to 8 per cent of free lime will vitrify rapidly. Other clays having the same ultimate chemical composition as the rapidly vitrifying ones, but in which the lime is already combined as in a lime-bearing silicate, will *not* vitrify rapidly, other factors which influence fusion being equal. We

---

[1] Sprechsaal, Nos. 45 and 46, Nov. 1907.

must recognize, therefore, that when the other factors which effect fusion are the same, the amount of lime which will combine to form this most easily fusible mixture depends upon whether the lime is free or combined, as well as upon the kind and relative quantities of the other oxides present.

The per cent of calcium oxide which Rieke found would form the most fusible mixture of the formula $XCaO$ 1 Al_2O_3 $ySiO_2$ were as follows:

$$XCaO \ 1 \ Al_2O_3 \ 1 \ SiO_2 \ ; - 25.6 \ \text{per cent CaO}$$
$$XCaO \ 1 \ Al_2O_3 \ 2 \ SiO_2 \ ; - 33.4 \ \text{per cent CaO[1]}$$
$$XCaO \ 1 \ Al_2O_3 \ 3 \ SiO_2 \ ; - 33.1 \ \text{per cent CaO}$$
$$XCaO \ 1 \ Al_2O_3 \ 4 \ SiO_2 \ ; - 24.6 \ \text{per cent CaO}$$

In each of these mixtures the per cent of calcium oxide taken into solution up to the point where the rate of solution began to decrease as shown by his curves, were as follows:

$$XCaO \ 1 \ Al_2O_3 \ 1 \ SiO_2 \ ; - \ 7.9 \ \text{per cent CaO}$$
$$XCaO \ 1 \ Al_2O_3 \ 2 \ SiO_2 \ ; - 10.0 \ \text{per cent CaO[1]}$$
$$XCaO \ 1 \ Al_2O_3 \ 3 \ SiO_2 \ ; - \ 9.8 \ \text{per cent CaO}$$
$$XCaO \ 1 \ Al_2O_3 \ 4 \ SiO_2 \ ; - \ 7.5 \ \text{per cent CaO}$$

Size of Grain—The full significance of this factor can be appreciated only by considering extreme cases, as in the case of calcium carbonate, above cited, or as in a mixture of two minerals such as feldspar and flint. When feldspar and flint are mixed as fine powders in the proportion of 75 per cent feldspar and 25 per cent flint, the mass will be fused to a fluid at approximately 1100°C in a comparatively short time. If, however, these two minerals were placed side by side in the shape of rectangular pieces having the same proportional weight as in the first case, the only fluxing action that would take place at 1100°C would be at the points of contact. Even if the heat was held at 1100°C, complete fusion of the two pieces of mineral could only take place when the glass, formed at the point of contact, enveloped and slowly ate into the unfused portions, and thus produced an intimate mixture of the two minerals by diffusion or surface tension. It is common experience that if complete fusion of the two minerals at 1100°C is desired when brought together in the form of coarse particles, considerable time must be allowed, and that to effect complete fusion in a shorter time, the heat must be raised from 1100°C to 1230°C (approximately), or the fusing point of feldspar. At this temperature the feldspar melting would completely envelop or perhaps float the flint particles, and slowly attack and dissolve them, just as water will attack and dissolve a piece of loaf sugar.

The above illustration, while an exaggerated case, nevertheless is descriptive of the effect of fineness of grain on the fusion of any two minerals which the mutually soluble, and also descriptive of the fusion of a mixture containing particles of several minerals, as a clay.

---

[1] This mixture is lime with pure clay substance. Note how much more active the lime is in this mixture than in the others.

In the burning of clay wares, where time is an important and unavoidable factor, the effect of fineness of grain influencing the fusing of clays is particularly noteworthy. By the manufacturers of pyrometric cones it has been recognized as such a powerful factor that the utmost care is taken to maintain uniformity in size of grain in their materials, both before and after manufacture into powdered cone stock.

The statement has been made in preceding paragraphs that differences in mineralogical constitution cause differences in behavior of clays during fusion. That statement is correct for the heat treatment or time and temperature required to affect either the partial or complete fusion of the mass. It would *not* be correct, as will be shown, if the temperature alone was considered.

The mixture of minerals in a clay which has been ground in a dry pan is far from being homogeneous. Our discussion earlier in this chapter of the constitution of the grains should make it plain that even if they were as finely ground and as thoroughly disintegrated as is practiced in the potteries, the mixture would lack very much of being homogeneous. Now the molten silicates are so viscous that diffusion in them is exceedingly slow compared with diffusion of salts in water[1] and hence a very long time would be required to obtain the homogeneous mixture that is necessary before the mass will fuse at its true melting point.

Walker has been quoted to the effect that crystalline substances have a definite melting point while amorphous substances do not. The reason for this is based very largely upon this matter of absolutely perfect homogeneity of constitution. When a substance crystallizes, its components are as intimately and homogeneously blended as it is possible to conceive of, hence, when the mass fuses the components are in a position to dissolve in one another as soon as a temperature is attained at which the solution is affected. In amorphous compounds[2] we have not this intimate molecular mixture[3] and hence not a sharp melting point. In the case of clays and clay mixtures, where we are not able to cause a mixture of the components that is any other than a comparatively very poor approximation to intimacy and homogeneity, it must be expected that either an inordinarily long time will have to be taken, or a temperature higher than the true melting point of the mixture be maintained in order to effect the fusion. This is why in research laboratories they either remelt the mixture at least once before determining its true melting point, or, take it to complete liquid fusion and note the temperature at which the mass solidifies. This is also the reason why potters find that a mixture will melt more easily the second and third time. This is also one of the reasons why so much stress was laid by the writer upon the mineral constitution of the grains as Grout found them in the West Virginia clays.

---

[1] Diffusion of salt in water is so slow as to permit of easy measurement. Diffusion of sugar in a cup of hot coffee is so slow that it necessitates stirring in order to dissolve a teaspoon full of sugar within a reasonable time.
[2] Here reference is made only to inorganic compounds.
[3] This is not the sole reason.

Reference was made to the attempt by Hoffman and Desmond to test the refractoriness of clay by toning up or down as the case required. The only reason that they failed, aside from the fact that they were not taking note of the ultimate composition of the clays, was the unequal degree of homogeneity of mixture of the fusing components. Their method would have failed even had the clays and flux been ground and mixed as thoroughly as is possible by any physical means so far devised. If they had desired to be extravagant of time and fuel they could have caused their mixtures to fuse at the arbitrarily chosen temperatures, or even lower. They, however, were not seeking to determine the true melting point of their mixture but rather its refractoriness. If they had been seeking the true melting point they could have resorted to the customary method of noting the point at which the fused mass solidified.

Refractoriness of a clay is its ability to withstand heat treatment. The relation between refractoriness and true melting point of a clay is as difficult to trace as the relation between refractoriness and ultimate chemical composition—if, indeed, it is not more difficult. This is due principally to the character of the mineral aggregate contained in the clay.

In the case of shales, the same is true to a very much more marked degree. In the shales the rate and final attainment of fusion is affected so largely by the character of the mineral aggregates that we find clays which are serviceable for paving brick manufacture differing very greatly in physical properties. It is for this reason in large part that coarse-grained clays vitrify more closely and form stronger bricks. In fact, the writer does not know of a single factory in which paving brick is manufactured from fine-grained clays, although in the laboratory several fine-grained clays have given promising results. If there is a preponderance of stable, not easily fusible minerals present, there is no reason, so far as the pyro-chemical properties are concerned, why fine-grained clays cannot be used in the manufacture of paving brick.

Volatile Matter—Chemically combined water, carbonic acid gas, carbon, etc.. do not of themselves, on expulsion, cause thermo-physical and chemical reactions to take place between the stable bases, acids and silicate compounds left behind, but their expulsion does involve changes in physical and, in some senses, chemical conditions that provoke thermal reactions between the remaining substances. For example, in terra-cotta lumber, sawdust is added, so that when it burns out, the mass will be left extremely porous, i. e., not dense, as it would otherwise have been. The sawdust in this instance has been effective in opening the structure of the ware and preventing the particles of clay from coming within fluxing distance of one another as they otherwise would. What is true in the case of the sawdust in terra-cotta lumber is true of combustible organic matter in clays. It is obvious, however, that the influence of carbon in this connection depends to a very large degree on the size of the carbon particles.

The effect of the expulsion of CO_2 from such compounds as ferrous carbonate, calcium carbonate, etc., on the thermo-chemical behavior of clays, is another familiar phenomenon, the importance of which is not recognized in the attempt to interpret the results of an ultimate chemical analysis. If two equal portions of the same clay are taken, and to the one a quantity of red iron oxide (Fe_2O_3), while to the other an equivalent quantity of powdered ferrous carbonate ($FeCO_3$) is added, and the two mixtures burned under the same thermal conditions, it will be found that the mixture containing the ferrous carbonate will begin to fuse earlier, exhibit a more erratic rate of decrease in specific gravity as the intensity of the heat increases, and may or may not, depending upon conditions other than those here considered, cause an earlier ultimate fusion. The same is true to a greater or less extent in the relative fluxing effect of the oxides and carbonates of other bases. The same phenomena are also notable in the comparative fluxing effect of such hydrous and anhydrous silicate compounds as raw and calcined kaolin.

Meade[1] and Meller[2] have shown that mineral mixtures containing alkalies lose when burned as high as 20 per cent of the total alkalies present. Such a loss is bound to affect the fusibility of the mass very considerably. Now we know that the alkalies are less volatile when combined with some constitutents than with others. The amount of alkali volatilized, and hence the effect on the fusibility of the clay, is dependent, therefore, quite largely upon the manner of its combination.

Structure of Ware—Intimacy of contact of the clay grains with one another is probably affected more largely by the manner in which the mass is formed into ware than by any other factor within the power of man to control, save the grinding of the clay. In dry-pressed bricks the clay particles are not in such close contact with one another as they would be if the ware were formed by the stiff-mud method. In soft-mud bricks the excessive amount of water used prevents the clay particles from coming into as intimate contact with one another as in the stiff-mud manufacture. As a result of these differences in the degree of compactness of the grains, it is found that not only a more easily vitrified and fused mass is formed, but also that the resultant ware is very much stronger when made by stiff-mud methods. For the same reason this same difference is found between the pressed and jiggered pottery wares.

Material—Calcium carbonate, hydrates of silica, alumina, and iron, as well as zeolitic compounds, when first precipitated or formed, are in the majority of cases in extremely fine grains. The fluxing behavior of any substance is materially different when thoroughly disseminated in minute grains, especially in the colloidal form, than when present in coarser grains. Iron, for instance, has been found to enter into chemical combination with silica as a ferric silica when the iron is precipitated on flint and as a ferrous silicate, if at all, when the two are mixed as dry powders. The vast difference between the fluxing action

---

1 "Portland Cement," Easton, Pa., 1906.
2 Trans. Eng. Cer. Soc., Vol. VI, p. 130.

of ferrous and ferric oxides and compounds need not be discussed at this time. The important fact in this connection, is that it depends to a very large extent on the form and manner in which the iron is disseminated through the clay, as to whether it will combine as the lower or higher oxide. What is true of iron in this respect is true to a degree of other fluxes.

Summary of Factors Affecting Manner of Fusion of Clays—First— The manner in which the several constitutent elements are combined, one with another, very materially affects the fluxing behavior of a clay.

Second—The size of grain of the several mineral constitutents is an important factor in determining the fusing behavior of clays.

Third—The amount, form, and character of the volatile constitutents of clay does not directly affect the thermo-chemical reactions, but the difference in physical condition and structure of the clay, and the stability of the non-volatilized compounds, caused by the expulsion of these substances, does materially affect the manner in which fusion takes place.

Fourth—The importance of the role that absorbed salts play in the fusing behavior of clays is little appreciated. The evidence on the manner in which they operate is so indirect that definite statements or conclusions are impossible. That they are important factors, however, there is no doubt.

Fifth—Concerning precipitated materials, we have evidence from synthetical experiments that prove beyond doubt that they must be considered as most potent in affecting the fusion of clays.

From the above, it is evident that the writer has but little confidence in the efficiency of an ultimate analysis of a clay as a means of foretelling its burning properties. The combination, size and character of grain, solubility, volatility, and dissemination of the several salts, and, lastly, the manner in which the uncombined oxides are introduced into the clay are more effective factors than the total ultimate composition.

Relation of Chemical and Physical Constitution to Behavior in Fusion.

Chemical Composition.

Historical—Search in ceramic literature disclosed the fact that practically no data have yet been published that have a direct bearing on the relation of chemical and physical constitution, behavior of clays in fusion, and toughness of the burned ware. Ogden[1] did some preliminary work on the relation of composition to toughness in porcelains and found the remarkable fact that increase of clay content from 30 to 60 per cent caused a decrease in the toughness of porcelain. Inasmuch as he employed the "rattler test" in determining relative toughness of

---

1 Trans. Am. Cer. Soc., Vol. VII.

his bodies, his studies are directly applicable to the study of paving brick clays. While the development of toughness has not been shown to have a direct relation to the rate and manner of vitrification except in our own results, yet that such a relation exists can be assumed until other evidence proves the contrary. If this assumption is correct, Ogden's results would show that the evidence developed by metallurgists to the effect that addition of either aluminum oxide or silicon oxide not only raises in degrees centigrade the period at which fusion is completed, but also increases the viscosity of the molten mass, and the rate at which verification takes place, is not applicable to certain mixtures It must be admitted that before Ogden published his results, ceramists entertained the belief that the greater the content of Al_2O_3 and SiO_2 in clays, the greater would be the toughness. The findings in the case of fire clays here reported confirm Ogden's ideas.

In the following paragraphs will be given such evidence as seems to bear on this point.

Effect of Al_2O_3 in Ceramic Mixtures—It has been known for some time that the addition of Al_2O_3 to clays and clay mixtures increases their refractoriness. Fire clays, high in Al_2O_3, are, as a rule, the most refractory. Al_2O_3 not only raises the actual period at which fusion is completed but also causes the wares made from aluminous clays to soften and deform very slowly. The slower softening and deformation of ware made from aluminous clays has been attributed to increase of viscosity[1] of the mass caused by alumina.

The writer has shown[2] that the addition of Al_2O_3 as a constituent of clay to stoneware glazes until the proportion of alkali and alkaline earth to alumina was 2.5 to 1, not only rendered the glaze more fusible but also less viscous. Additions of Al_2O_3 above this proportional amount increased the refractoriness of the glaze, if not its viscosity. Addition of Al_2O_3 as a constituent of feldspar did not have as great effect on the fusibility of the glaze as did the same equivalent of Al_2O_3 from clay, notwithstanding the additional alkali that would be introduced by the feldspar.

From these stoneware glaze studies it was concluded that it was not so much a question of quantity of Al_2O_3, but of the manner in which it was added. If added as a constituent of clay it is already combined with silica and water. Whether it is this mutual solution of calcium carbonate and clay that caused greater ultimate fusibility in the stoneware glazes, when clay was increased to a definite amount, or whether it was a complex case of an eutectic mixture of several substances, is not yet determined. The fact remains that addition of clay did cause greater fusibility and less viscosity, notwithstanding the fact that with each addition of clay the Al_2O_3 was being increased.

Bleininger[3] has shown experimentally that calcium carbonate reacts with finely pulverized feldspar as readily as with washed kaolin. From his results it would seem as though fusion is initiated between calcium

---

1 Molasses is more viscous than water, i. e., it flows more sluggishly. Its molecules are less free to move. Slow-flowing fluids are said to be viscous.
2 Trans. Am. Cer. Soc., Vol. V.
3 Geol. Surv. of Ohio, Bull. No. 3, 4th series, p. 128.

carbonate and feldspar as early as between calcium carbonate and kaolin (pure clay). This being the case it would seem as though the addition of clay to stoneware glaze mixtures was merely the formation of a eutectic mixture of minerals.[1]

Evidence thus far developed in the case of simple mixtures is summarized in the following table:

TABLE XXXI.

Showing the proportions by weight, which cause maximum fusibility between the two mineral substances stated in each case.

		(1)	(2)
(1)	Magnesium carbonate (1) and kaolin (2)	2	3
	Calcium carbonate (1) and kaolin (2)	2	3
	Finely pulverized flint (1) and kaolin (2)	2	7
	Finely pulverized flint (1) and feldspar (2)	1	3

(1) With quick fire.

Any increase or decrease of Al_2O_3 outside of the limits given in the above table results in increase of refractoriness of the mixtures as shown in the several curves to which reference has been made. Similar points of greatest fusibility have been noted in the case of glazes, but data have not been obtained that permit showing the facts in tabular or curve form. Al_2O_3 then increases the fusibility of mineral mixtures when added in amounts not exceeding a given proportional limit, the limit being different for different mixtures.

Second, in slags, glazes and glasses addition of Al_2O_3 above a given amount increases their viscosity, but no limiting points have, as yet, been determined except in the case of slags. Since slags are comparatively simple in composition and usually relatively high in lime, we can learn very little by reviewing in detail the researches that have been made on the vicosity.

Third—Increase of Al_2O_3 in small amount in glasses increases their toughness. So far as data have been obtained increase of Al_2O_3 in porcelain bodies *does not* increase their toughness.

From these conclusions a query is at once presented concerning the relation between fusibility, viscosity and toughness. At present any discussion of this query would be based wholly on assumption, for there are no experimental data bearing on the point.

Effect of Silica in Ceramic Mixtures—Anhydrous silica is practically inert at ordinary temperatures, but at the temperature usually attained in brick kilns it becomes very active, forming compounds having very varied oxygen ratios, i. e., amount of oxygen in the basic to the oxygen in the acid oxides.

On heating, silica expands considerably, indicating peculiar molecular changes. LeChatelier[2] has shown that at 500°C. this molecular

1 The mixtures that gave the greatest fusibility, as shown in each of the figures 19, 20 and 21, are said to be eutectic mixtures.
2 See Bleininger, Ohio Geol. Surv., Bull. 3, p. 28.

change takes place to a very pronounced degree in all forms of silica, the least in amorphous and the most in highly calcined flint. Permanent expansion in highly silicious bricks and the "punkness" of bricks made from a mixture of clay and sand are evidence of the effect of this peculiar property of silica.

No matter how fine the free silica is, it does not seem to be as active in forming new silicate compounds under the influence of heat as is the silica that is previously combined, as for illustration, in clay or feldspar. In other words, silicate combination with free basic elements is affected more readily when the silica is added to the mixture as a constituent of a pre-existing silicate. This was shown very prettily in an experiment reported by Bleininger.[1] He prepared a mixture of 20 per cent finely ground flint and 80 per cent precipitated calcium carbonate and two other mixtures each containing respectively 20 per cent finely ground feldspar and 20 per cent of kaolin with 80 per cent calcium carbonate. These mixtures were maintained at a temperature of 1100 C. for 75 minutes. At this temperature calcium silicate compounds are formed which are soluble in hot hydrochloric acid and sodium carbonate solutions. The residue left after this acid and alkali treatment is the material which is unattacked or unlocked by the fluxing action of the lime. In the following table are Bleininger's results.

TABLE XXXII.

	Ground Flint.	Ground Feldspar.	Ground Kaolin.
Per cent residue......................................	28.83	3.75	3.07
Per cent taken into solution...........................	71.17	96.25	96.93

Bleininger's results strongly support the doctrine that has, for the sake of emphasis, been repeatedly stated in this report, to-wit: That very little can be told concerning the fusing behavior of silicate mixtures from an ultimate analysis, for if this were not the case, feldspar should have reacted far more vigorously with calcium carbonate than did clay. Since cement investigators have found that the hydrous amorphous silica reacts with lime in a manner similar to finely pulverized crystalline quartz, it can be readily seen that misleading data would be obtained even in the rational analysis, in which the hydrous amorphous silica is taken into solution by the sulphuric acid and thus considered as a part of the clay substance.

Addition of silica to pure clays like shales increases their refractoriness and, (reasoning from data on slags) possibly, their viscosity. There is no evidence showing that the addition of flint to a clay increases its toughness, but quite the contrary, empirical experiments by several practical brick manufacturers have proved that the additon of ordinary bank sand makes the bricks less tough or even very "punky." On the other hand an investigation by Worcester[2] proved that Bedford shale, which

1 Loc. cit., p. 128.
2 Trans. Am. Cer. Soc. Vol. II, pp. 295.

outcrops near Columbus, O., is materially benefitted by an addition of crushed Berea sandstone from the same locality. Instances are recorded of addition of certain sands in Europe having proved beneficial, but in neither Worcester's experiments nor in the European cases was there reported a determination of the effect of sand on the toughness of the burned mixtures.

In the manufacture of floor tile the writer found that a porcelain body consisting of 40 per cent clay, 45 per cent feldspar and 15 per cent flint was much tougher than a body containing 35 per cent clay and 65 per cent feldspar. It is impossible to say why the body containing flint should be tougher but certainly some credit must be given to the influence of the flint.

Reviewing the known facts about the effect of silica on either the fusion of clays or development of toughness in clay wares, it must be admitted that we have not at present much positive evidence.

Effect of Magnesium Oxide in Ceramic Mixtures—In figure 20 on page 209 is shown graphically in fluxing effect of magnesium oxide with kaolin. Metallurgists report that magnesium oxide is a much "harder" flux than calcium oxide and produces a much more viscous slag. Ceramic investigators have reported conflicting results in their attempts to use MgO as a flux, some claiming that it is more active than CaO and some that it is less active. Claims have been made by some that in glazes it gives greater fusibility and slower fusion, while others claim opposite results. From this accumulation of apparently conflicting data it has been shown that in short quick burns, as in experimental kilns, MgO is an active flux causing more rapid fusion, but in longer burns its fluxing action begins as early as in the shorter burns but progresses less rapidly and requires more intense heat treatment to effect complete fusion.

The lag in the fusion of mixtures containing magnesium oxide is attributed to either the viscosity of the resulting magnesium silicate, if it enters into combination with the glassy matrix that fills and seals the pores of vitrifying wares, or to the formation of non-fluid magnesium compounds.[1] Cement investigators claim that the alkaline earth silicates formed by heating mixtures of clay and calcium or magnesium carbonate at temperatures below that required to cause sintering of the mass into a hard cake or brick are simple silicates of calcium or magnesium oxide which are not necessarily fluid. At any rate, the effect of magnesium in ceramic mixtures differs from that of calcium in that the magnesium mixtures fuse very slowly over a long heat range, while the calcium mixtures, especially when present in amounts equal to or more than 10 per cent, remain porous up to the time that fusion begins, and then fluxing ensues very rapidly causing the ware to pass from porous into the overburned condition within a very short range of heat treatment.

---

[1] Eckel states in "Cements, Limes and Plasters," p. 154, that when magnesia is burned in a quick fire its density (specific gravity) is 3.0 to 3.07, while if burned in a slow, long-continued fire its specific gravity will range from 3.6 to 3.8.

The only known facts concerning the influence of magnesium oxide in ceramic mixtures are: (1) magnesium oxide increases viscosity; (2) magnesium oxide causes slower rate of fusion, at least when it is the predominating flux; (3) as has been stated earlier in this report, clays which make good paving bricks contain a larger amount of magnesium than calcium oxide; (4) the Italians are now making low-fired porcelain of which toughness is a special feature, and in which magnesium is the only Ro or fluxing base present.

Effect of Calcium Oxide in Ceramic Mixtures—Watts[1] has shown that the presence of a *small* amount of calcium oxide in porcelain mixtures results in increased toughness of the ware. His investigations are not, however, sufficiently exhaustive to warrant more definite statement.

It is known that lime causes a breaking down of the silicates with comparatively little heat treatment, and also that the new silicates formed are probably very simple in composition until higher temperatures are attained, in which event these simple silicates suddenly fuse, causing the whole to pass rapidly into a fluid mass.

Dr. Rieke[2] has shown that in mixtures of from 1 to 10 per cent of calcium carbonate with kaolin very close tight bodies are obtained which have quite a large range of vitrification and in the end fuse quite gradually. Mixtures containing more than 10 per cent of calcium carbonate remain quite open until final fusion begins, at which time the whole mass fuses very rapidly.

In comparison with Rieke's work it is of interest to study results obtained by Nauss,[3] who worked with a mixture similar to Rieke's high calcium body.

The two bodies were as follows:

<div align="center">Table XXXIII.</div>

	Nauss.	Rieke.
Calcium carbonate	70	70
Kaolin	11.05	30
Flint	18.66	....

In the following table are Nauss' results and in a separate column are placed the data obtained by Rieke. Rieke measured his heat by cones and hence the temperatures obtained in these two studies cannot be compared closely. Since, however, Rieke used a Seger trial kiln and very short firing periods, his cone readings can be approximated in terms of degrees centigrade within the accuracy of and discrepancy between the method by which each research was executed.

1 Trans. Am. Cer. Soc., Vol. V, pp. 175.
2 Sprechsaal No. 38, 1906.
3 Reported by Bleininger, Ohio Geol. Surv. Bull. No. 3, p. 175.

TABLE XXXIV.
Reaction of Calcium Oxide upon Kaolin and Quartz.

No.	Temp. °C	Loss on burning	Loss on completed ignition	Carbon dioxide remaining	Fusible silica—per cent	Remarks.	RIEKE'S RESULTS.	
							Porosity	Cone of heating
1	550	1.79	27.79	28.48	......	....	....	....
2	585	1.88	27.96	28.44	......	....	....	....
3	610	1.80	28.67	28.84	......	....	....	....
4	655	1.91	28.83	27.83	......	....	....	....
5	700	4.81	25.17	25.89	......	....	....	....
6	725	6.18	24.30	24.58	......	....	....	....
7	750	6.99	23.02	23.88	......	....	....	....
8	775	8.35	21.90	21.07	19.70	....	....	....
9	800	12.51	17.94	18.72	......	....	....	....
10	850	20.34	10.64	7.32	19.00	....	....	....
11	900	24.42	5.89	5.29	......	....	....	....
12	950	27.56	2.88	2.17	18.90	....	....	....
13	1000	30.00	0.60	0.40	18.83	....	....	....
14	1050	29.75	......	......	18.75	....	30.3	05
15	1100	29.65	......	......	18.75	....	....	....
16	1150	29.74	......	......	18.26	....	....	....
17	1150	30.10	......	......	16.19	Held at this temperature for 12 hours...	42.5	2
18	1200	30.10	......	......	16.10	....	....	....
19	1200	30.10	......	......	15.37	....	45.9	5
20	1250	30.10	......	......	13.13	Dusted, i. e., fell to pieces.............	....	....
21	1250	30.10	......	......	13.34	Dusted...................................	....	....
22	1300	30.10	......	......	11.97	Dusted...................................	42.0	8
23	1300	30.10	......	......	10.68	....	....	....
24	1325	30.10	......	......	......	Began to fuse, "melt"	10.2	10
25	......	......	......	......	......	....	Fused.	23-24

Professor Bleininger's conclusions from Nauss' work are:

"*First*—In regard to the decomposition of calcium carbonate, it is clearly shown that it begins to break up between 610° and 650°C., and before 700° is reached the evolution of carbon dioxide is going on quite rapidly. At 1000° the evolution is practically at an end."

"*Second*—On examining the amounts of insoluble[1] residue and comparing the percentage with the known amount of quartz in the mixture, 18.66 per cent, and making allowance for the small amount of quartz in the kaolin itself, it is seen that the kaolin is decomposed completely at 850°C., and almost completely at 800°C."

' *Third*—Free quartz seems to be attacked by the calcium oxide soon after the completion of the decomposition of kaolin, probably at about 950°C., which reaction continues at an increasing rate up to the highest temperature employed in these experiments. It is quite evident, also, that the length of time of burning influences the amount of quartz attacked somewhat, so that by longer burning, at least with temperature over 1100°, more quartz may be rendered soluble than in a short period of ignition."

Prof. Bleininger, continuing, says:

"A very interesting fact was brought out by the tendency to dust observed with the mixture at temperatures above 1200°C. While at 1200° the briquettes were hard, at 1250° they dusted very rapidly, and at 1300° almost instantaneously."

---

[1] Insoluble in hydrochloric acid and sodium carbonate solutions.

"On calculating the formula of this mixture from the composition we find it to be 1.77 CaO, 0.108 Al_2O_3, SiO_2, that is not quite a singulo calcium silicate, and hence must properly be classed within the group of natural cements. It is not difficult to understand that the dusting must be coincident with a significant molecular change from the condition of the loose, friable mixture to a hard body breaking down at once to a powder. *Might not this fact indicate that up to 1200° these calcareous mixtures are but pozzuolane-like, simple silicates, consisting of silica and base which on further application of heat become chemically more complex and non-or but slightly hydraulic?* This view is strengthened by the results of another investigation which have shown that on increasing the free silica, with but sufficient base to convert the quartz into the active state, the hydraulicity is practically as great as with a greater amount of base."[1]

Rieke's data is evidence that Bleininger's query can be answered in the affirmative, for it was at this same temperature, 1200° C., that his body ceased to increase in porosity and began to vitrify. From 1200° C. on, Rieke's body vitrified quite rapidly showing that "a significant molecular change" is taking place. From Nauss' results it must be conceded that the clay has suffered a very significant change. No doubt it has passed completely into solution with lime and silica. In fact Bleininger's results given in Table XXXVI page 248 proves this to be so.

Rieke's porosity data show also that prior to this critical temperature, 1200°, (rough approximate) the grains must be changing form and size, for the mass is getting more porous with each increase in heat treatment, yet, according to his shrinkage data (1.2 per cent at cone 05 and 3.7 per cent at cone 5) the mass as a whole is decreasing in volume. Similar simultaneous increase in porosity and decrease in volume was noted in several instances in our own researches, so this phenomenon is not alone peculiar to simple mixtures high in lime.

Important as are these observations, and especially that of complete solution, and possibly the formation of entirely new compounds before the mass begins to decrease in porosity, i. e., vitrify, the more important item to note at this time is, in the writer's opinion, the difference in the ultimate fusion behavior of the two bodies, the one containing free silica and the other supposedly none. It was shown by Bleininger's result[2] that quartz is not nearly as readily attacked by CaO as is kaolin or feldspar, and hence it could be inferred that the higher the content of quartz in a mixture, the later and slower would the mass fuse. In decided contradiction to such an inference we find that in Nauss' body, containing 18.7 per cent quartz, the original minerals have been completely broken down and the whole began to "melt" at the same temperature at which Rieke's body containing no quartz exhibits a porosity of 10 per cent, but complete fusion does not take place until a temperature of about 1600° C. has been reached. We are learning not to wonder at such apparent discrepancies in experimental work where simple mixtures of two minerals are compared in their fusing behavior with more complicated mixtures of minerals.

1 Italics not in the original.
2 See Table XXXVI p. 248.

Summarizing these observations the following facts appear: First, Watts has shown that a small quantity of lime toughens a porcelain mixture. Second, Rieke has shown that in a simple mixture of kaolin and 1 to 10 per cent calcium carbonate there is quite a large vitrification range and slow fusion, while in mixtures with kaolin containing more than 10 per cent of calcium carbonate the body does not vitrify until late and then rather suddenly fuses. These findings by Rieke and Watts agree with ours in support of the assumption that long vitrification range and slow fusion generally result in the production of tough ware. Third, the results of Bleininger, Nauss and Rieke studied together show very forcibly that chemical alterations and reactions may take place long before vitrification and fusion begin. Also, that each mixture has its own peculiar pyro-chemical and physical behavior, and, as the mixtures become complicated in composition, the deductions drawn from simple mixtures are found to hold true only in very small part.

Beyond these studies in simple mixtures by Bleininger, Nauss, and Rieke, and the observation in complicated porcelain mixtures, we have no data that have a bearing on the effect of smaller or larger quantities of lime on toughness of burned wares made from shales. Contrasting the work of Rieke and Nauss, the difficulties that are encountered when attempt is made to trace the effect of lime in such severely complicated mixtures as shales are clearly shown.

Effect of Other Oxides in Ceramic Mixtures—Practically nothing is known concerning the influence of oxides other than those considered above, except that in slags titanium causes increased viscosity; that potash silicates are more fluid than soda silicates, and yet, as a rule, less fusible; that phosphoric acid is expelled from ceramic mixtures only at high temperatures, and that, before expulsion it is combined with the bases forming phosphates that are analogous to the silicates. A detailed study of the influence of the several oxides, alone and together, on the fusion of silicate mixtures and the toughness of the burned mixtures, offers a very fruitful and interesting field for research.

INFLUENCE OF SIZE OF GRAIN ON THE FUSION OF CLAYS.

Direct evidence—According to Wegemann's microscopic studies given on later pages, coarse quartz does not enter into the fluxing reactions even at cone 5. With a heat treatment sufficient to fuse cone 5 feldspar is completely fused especially if mixed with free silica, and yet at this cone Wegemann reports that the quartz grains are apparently unaffected to any noticeable extent until cone 9 is fused down. He affirms that if any reaction has taken place between the free silica and feldspar, the silica must have been supplied from what he terms the ground mass, i. e., the mass that consists of particles too fine to be distinguished through the microscope. According then to Wegemann's studies, the melting feldspar in shales affects the coarse flint to but a slight extent.

Bleininger[1] experimentally determined the effect of size of flint and feldspar grains on the rate at which lime would decompose them at 1100° C., forming silicates that could be dissolved in hydrochloric acid

TABLE XXXV.

Effect of Size of Grain on Extent and Rate of Combination of Silicia and Lime.

Sizes.	Ground Flint.	150-120 mesh.	120-100 mesh.	100-80 mesh.	80-60 mesh.	60-40 mesh.	40-20 mesh.
Per cent residue....................	28.83	63.8	78.53	86.52	86.27	93.78	96.83
Per cent taken into solution........	71.17	36.2	21.47	13.48	13.73	6.27	3.17

TABLE XXXVI.

Effect of Size of Grain on Extent and Rate of Combination of Feldspar and Lime.

Sizes.	Ground Feldspar.	150-120 mesh.	120-100 mesh.	100-80 mesh.	80-60 mesh.	60-40 mesh.	40-20 mesh.
Per cent residue....................	3.75	15.45	31.00	64.29	79.63	95.72	....
Per cent taken into solution......	96.25	84.55	69.00	35.71	20.37	4.28	....

and sodium carbonate. The data he obtained are given in the following tables:

This data, together with Wegemann's microscopic observations, proves conclusively that a variation of this physical factor—fineness of grain—has an influence on the fusing behavior of clays that is as positive, if not as potent, as a variation in the quantity of the oxides of any of the elements.

GENERAL ANALYSIS OF RESULTS.

The foregoing detailed discussion of the various elements affecting the manner in which silicate mixtures fuse, has been given in addition to the more general statements on pages 217 and 232 so as to make more plain the deductions that are to be drawn from our own data. This detailed citation, it is hoped, has clearly demonstrated that our present knowledge of the influence of the several factors even in simple mixtures is very fragmentary and that in the more complex mixtures the evidence is, in the main, either conflicting or entirely lacking. In the following analysis of the chemical data obtained by this Survey, and attempts to show a relation between the chemical and physical constitution of the clays, their pyro-physical behavior, and toughness of the burned bricks, liberal assumptions must be made and only general conclusions, if any, drawn.

These assumptions are: First, Those elements which are supposed to increase the viscosity of the mass when fused lengthen the vitrifying range of the clay and increase the toughness of vitrified wares. Second, Those chemical or physical factors which tend to make the mass more fusible or to hasten the pyro-chemical reactions which result in vitrification are detrimental to development of toughness. Third, That

1 Loc. cit. p. 127.

lime is detrimental both to slow fusion and toughness, while magnesia is beneficial. Fourth, That the higher the acid content, or its equivalent, the oxygen ratio, the more viscous will be the fused ingredients and the tougher the burned ware. Fifth, The higher the proportion of Al_2O_3 to other basic oxides the slower will be the fusion, the more viscous the fused ingredients and the tougher the mass. Sixth, The finer the material of which clay is composed, the more rapidly will it fuse and the more brittle will be the burned mass.

In the following table will be found the ratio mentioned in the foregoing assumptions, as calculated from the chemical data given on pages 215 and 216. In the first column is the ratio of CaO to MgO. In this ratio, CaO is taken as unity. In the second column is given the total oxygen in the basic oxides where Al_2O_3 is unity.

In summing up the oxygen atoms, the iron oxides were considered as reported, i. e., where FeO is given, only one atom of oxygen to one atom of Fe, and where Fe_2O_3 is given, three atoms of oxygen to two atoms of Fe were taken. The difference between the value given in the second column and 3 (oxygen in Al_2O_3) gives the factors for the

TABLE XXXVII.

Sample No.	1 (A) Ratio of CaO to MgO.	2 Total oxygen in bases.	3 Oxygen in acid.	4 (B) Oxygen Ratio.	5 (D) Surface factor, Purdy's Method.	6 Modulus A.B.C./D. = M	7 Rattler loss N. B. M. A. Standard.	Remarks.
K— 1.....	2.39	4.25	13.96	3.27	257	7.3	15.82	....
K— 2.....	1.84	4.51	13.24	2.92	331	3.24	17.48	Good red when vitrified ....
K— 3.....	3.36	4.50	13.14	2.90	341	5.70	24.89	
K— 4.....	6.70	4.3	11.56	2.67	514	8.00	19.11	Not screened when used at factory.....
K— 5.....	2.95	4.1	12.76	3.1	287	8.65	19.36	.do ....
K— 6.....	3.21	4.2	13.28	3.17	221	11.5	13.25	
K— 7.....	3.10	4.2	11.68	2.8	300	7.2	13.89	
K— 8.....	4.47	4.59	12.62	2.75	262	8.85	20.23	
K— 9.....	2.62	4.23	13.72	3.22	195	10.6	14.84	Very hard coarse clay.................
K—10.....	2.36	4.39	10.96	2.5	604	2.1	39.36	
K—11.....	4.20	4.28	9.71	2.27	339	6.6	28.13	
K—12.....	1.44	3.95	7.82	1.98	403	2.22	.....	
K—13.....	3.35	4.34	10.18	2.35	356	4.95	31.50	
K—14.....	1.36	4.5	15.38	3.4	254	3.65	21.24	Very hard coarse clay ....
K—15.....	1.42	4.4	11.14	2.52	.....	......	18.44	
F— 1.....	1.94	4.63	12 70	2.75	.....	......	20.84	
S— 1.....	2.74	4.11	9.20	2.23	.....	......	26.25	
S— 2.....	5.89	4.33	9.42	2.17	.....	......	27.94	
R— 1.....	4.72	3.54	7.92	2.50	397	16.5	16.92	No. 2 Fire clay ....
R— 2.....	3.99	4.05	11.55	2.85	.....	......	17.80	
R— 3.....	3.05	4.13	9.76	2.36	291	6.55	14.80	
R— 4.....	4.17	4.13	8.66	2.10	275	8.45	15.33	
H—16.....	0.95	4.5	11.56	2.55	.....		.. ..	
H—17.....	1.74	6.43	15.92	2.47	.....		.....	
H—18.....	0.95	5.48	8.26	1.51	444	0.39	.....	
H—20.....	1.17	5.78	10.36	1.86	553	0.42	.....	
H—21.....	0.765	5.04	9.5	1.88	783	0.27	.....	
H—23.....	0.497	3.97	8.71	2.2	634	0.53	.....	
B—II.....	0.895	4.20	10.98	2.61	.....		28.03	
G—II.....	1.62	4.65	13.28	2.85	366	2.3	14.98	Good dark red when vitrified...........
H—II	0.78	4.55	10.18	2.27	.....		32.97	
I—II.....	0.82	4.67	17.98	3.85	489	1.16	25.65	Bright red when vitrified...............
J—II.....	1.77	4.71	12.58	2.65	.....		17.14	
L—II	1.09	4.47	11.24	2.51	.....		18.58	

proportion of oxygen in Al_2O_3 to oxygen in the other bases, i. e., (a—3) : 3::O in fluxes: O in Al_2O_3. In the third column is given the number of atoms of oxygen in total SiO_2. In the fourth column is given the ratio between oxygen in SiO_2 to oxygen in total bases. This ratio is known as the oxygen ratio and is customarily taken as the ratio of the acids to the bases. In the fifth column is given the surface factor representing fineness of grain by the writer's method. In the sixth column is a modulus calculated on the formula $\dfrac{A.\ B.\ C.}{D.} = M$ where "A" is the lime-magnesia ratio, "B" the total oxygen ratio, "C" the ratio of oxygen in the Ro bases to oxygen in Al_2O_3, and "D" the surface factor divided by 100. In the seventh column is given the rattler loss determined on commercially manufactured blocks made from each clay.

Deductions Drawn from Table XLI—Without going into details concerning the probable reason for the lack of correlation between the chemical and physical constitution and the toughness of the burned ware as shown in the above data, it is sufficient to state that it be granted that these data corroborate those of Ogden, proving that our notions about the relation of the chemical and physical constitution of clays to the toughness that is developed in burning are in the main, if not wholly, erroneous. Data on mineralogical composition as obtained by the Rational Analysis, gave results that were still less easily correlated with data on toughness of the burned ware than are those in the above table. Before such data can possibly be of value there must be considerably more learned concerning the fusing behavior and the physical properties of sintered masses of simple mixtures of minerals. There is not much of any hope of learning much concerning these relations from data obtained by any process of chemical analysis now used.

THERMO-CHEMICAL AND PHYSICAL CHANGES DURING FUSION.

It is indeed very difficult, if not impossible, to determine what the actual thermo-chemical reactions really are, which take place in the fusion of the clay particles, first between themselves, and, secondly, when the whole mass becomes a more or less homogeneous solution.[1] By the aid of the microscope, as will be seen later, more can be told concerning these changes in an unknown mixture of minerals than by any other means; inferences from artificial and known mixtures being of no avail. The effect of thermo-chemical reactions, however, can be detected by the changes in porosity and specific gravity. Because of our present inability to ascertain in full the reactions that take place, it seems best to refer to the chemical phases of fusion as "changes" instead of "reactions."

---

[1]Prof. G. Tamman, Sprechsaal No. 35, 1904, summarizing his studies on silicates says, "The volume of the glass is, at the lowest temperatures, larger than that of crystals." Mellor, Vol. V, p. 78, discusses the volume changes in silicates and cites A. Laurent (Ann. Chim. Phys. (2) 66,96,1837; A. Brongniart, Traite des Arts Ceramiques, 1, 283, 720, 1877) and G. Rose (Pogg, 111, 123, 1890; A. R. Day and E. S. Shephard, Am. Jour. Science, (4) 22, 262, 1906. Dr. E. Berdel (cited Vol. VII, p. 148 A. C. S. Trans.) described similar physical changes in the heating of ceramic materials and bodies.

The greater portion of the constituents of our clays being mineral substances, many of which do not entirely lose their identity in the burning of clay wares, it is most natural that these should exhibit in nature the same changes when treated separately that they do when heated together in clays. Roth[1] gives the following description of the physical changes in minerals on melting:

TABLE XXXVIII.

Mineral.	Specific Gravity of the Crystal.	Specific Gravity when melted to glass	[1]Per cent Reduction in Spec. Gravity.	Remarks.
Quartz	2.663	2.228	16.3	
Quartz	2.65	2.19	17.3	Average.
Olivine	3.3813	2.8571	15.6	
Mica	3.0719	2.2405	27.0	Glass compact.
Adular	2.561	2.3512	8.1	Glass full of fine bubbles.
Adular...............	2.5522	2.33551	8.5	Glass full of fine bubbles.
Sanidine	2.58	2.381	7.6	Glass full of fine bubbles, and dark-colored.
Orthoclase...........	2.574	2.328	9.6	Glass full of fine bubbles.
Orthoclase...........	2.5883	2.3073	10.9	Glass colorless.
Microcline...........	2.5393	2.3069	9.1	Glass colorless.
Albite	2.604	2.041	21.9	Full of fine bubbles; white glass.
Oligoclase ...:.....	2.66	2.258	15.1	Glass full of fine bubbles.
Oligoclase	2.6061	2.3621	9.1	White glass; bubbly.
Oligoclase	2.6141	2.1765	16.7	Glass full of bubbles.
Labradorite.........	2.7333	2.5673	6.1	Glass slightly bubbly, with black and white portions
Hornblende	3.2159	2.8256	12.2	Glass compact.
Augite...............	3.2667	2.8035	14.2	Glass compact.
Epidote..............	3.409	2.984	12.5	
Red brown garnet....	3.90	3.05	20.5	Green glass.
Lime-iron garnet....	3.838	3.340	25.6	
Granite	2.680	2.427	12.9	Green glass; transparent; strongly blebbed.
Granite	2.751	2.496	9.3	Black glass; opaque; strongly blebbed.
Hornblende granite..	2.643	2.478	6.2	Black glass; opaque; strongly blebbed.
Felsite porphyry.....	2.576	2.301	10.7	Transparent; very blebby; difficult of fusion.
Syenite	2.710	2.43	10.3	Glass homogeneous; dark colored.
Quartz diorite	2.667	2.403	9.8	Glass homogeneous; dark colored.
Diorite, quartz free..	2.779	2.608	6.3	Black glass; opaque; compact; somewhat difficult to fuse.
Gabbro	3.100	2 664	14.2	Black opaque glass; easily fusible.

1 Not in original table.

The alterations in the minerals and rocks above cited are those induced when they are changed by melting, from a crystalline to an amorphous condition. Such complete changes as this cannot be permitted to take place in the whole mass of clay ware during burning, and yet, as will be shown, the percentage of decrease in specific gravity of many of our clays from the unburned to the vitreous stage is greater than that given in the above data. This being true, it is evident that there are factors other than the alteration of minerals from the crystalline to the amorphous condition that affect decrease in the specific gravity of clays.

In the following table are given data which show the effect of heat on physical structure of briquettes made from various clays:

1 Allegemeine und Chemische Geologie, Vol. 11, p. 52.

TABLE XXXIX.

Types of Clay.	Sample No.		Normal Vitrification.			Maximum Heat Treatment.			Rattler Loss on Commercial Product.	Remarks on Conditions at Maximum Heat treatment.
			Cone No.	Per cent decrease in Specific Gravity.	Porosity.	Cone No.	Per cent decrease in Specific Gravity.	Porosity.		
No. 1 Fire Clay....	H	24				9	5.38	20.9		Light buff; black iron specks.
No. 1 Fire Clay....	V	11				9	5.6	20.2		Flashed; small black iron specks.
No. 1 Fire Clay....	F	5				11	4.7	16.6		Light buff; no iron specks.
No. 1 Fire Clay....	F	19				11	4.1	17.9		Dark buff; no iron specks.
No. 1 Fire Clay....	F	18				11	5.2	14.1		Flashed; small black iron specks.
No. 2 Fire Clay....	V	4				11	4.2	10.65		Bluestoned; no black iron specks; coarse grains.
No. 2 Fire Clay....	F	4				11	8.8	11.3		Flashed; no iron specks.
No. 2 Fire Clay....	F	21				9	7.66	11.7		Bluestoned; no iron specks.
No. 3 Fire Clay....	R	1	5	3.14	10.2	11	8.66	4.26	16.92	Bluestoned; no iron specks.
No. 3 Fire Clay....	V	5	7	8.5	9.19	11	8.6	3.46		Heavily flashed; no iron specks.
No. 3 Fire Clay...	F	20	5	14.5	10.9	11	17.3	3.36		Bluestoned; even color; no swelling apparent.
No. 3 Fire Clay....	F	7	5	7.3	5.01	11	11.9	5.7		Bluestoned; black iron specks very pronounced.
No. 3 Fire Clay....	K	12	3	4.16	9.35	9	16.2	3.47		Bluestoned; local patches of glass; no swelling.
No. 3 Fire Clay....	V	3	5	4.3	13.35	11	10.6	4.20		Bluestoned; large black iron specks.
Paving Brick Shales.	K	1	5	15.0	7.4	9	36.0	2.2	15.82	Dark red at cone 3; swollen and self-glazed at cone 9.
Paving Brick Shales.	K	2	3	6.7	4.6	5	19.7		17.48	Bright red at cone 1; chocolate at cone 3 and black at cone 5; no apparent swelling at cone 5.
Paving Brick Shales.	K	3	5	10.7	6.9	9	29.6	2.4	24.89	Chocolate in color at cone 5, black at cone 7 and 9; swelling began at 7.
Paving Brick Shales.	K	4	5	12.7	3.9	9	29.5	3.7	19.11	Dark red at cone 3; black at cones 5, 7 and 9; swollen quite badly at 9.
Paving Brick Shales.	K	6	3	8.1	7.4	9	30.0	3.0	13.25	Dark red at cone 3; spongy at 9 and black in color.
Paving Brick Shales.	K	8	5	17.7	13.3	9	19.6	5.4	20.25	Same as K6.
Paving Brick Shales.	K	11	3	7.7	11.9	7	23.0	5.2	28.13	Black but not swollen at cone 7.
Paving Brick Shale..	K	14	5	13.6	7.0	7	19.00	3.3	21.24	Red at cone 3; dark at cone 5 and black at cone 7; do swelling apparent.
Paving Brick Shale..	R	2	3	5.57	11.0	11	26.00	1.4	17.80	Bright red at cone 3; swollen and self-glazed at 11.

TABLE XXXIX—Concluded.

Types of Clay	Sample No.	Normal Vitrification			Maximum Heat Treatment			Rattler Loss on Commercial Product.	Remarks on Conditions at Maximum Heat treatment.
		Cone No.	Per cent decrease in Specific Gravity.	Porosity.	Cone No.	Per cent decrease in Specific Gravity.	Porosity.		
Paving Brick Shale..	B 11	3	8.1	14.4	9	33.00	4.1	28.05	Darkened at cone 3; self-glazed at 5; swollen at 9.
Paving Brick Shale.. Paving Brick Shale..	G 11 L 11	3 5	10.6 7.86	7.17 1.75	9	23.0	1.97	12.76 18.58	Bright red at cone 1; dark red at 3; self-glazed at 5; swollen at 9.
Paving Brick Shale..	J 11	5	9.72	5.32	7	14.3	1.62	17.14	Dark red at 3; self-glazed at 5; not swollen at 7.
Paving Brick Shale..	V 9	3	13.1	14.5	9	35.1	3.4		Dark red at 3; quite spongy at 9; black at 7.
Paving Brick Shale..	V 7	5	11.2	8.2	9	21.5	2.9		Dark red at 3; self-glazed at 7; local glass patches at 9, with but very little swelling.
Paving Brick Shale..	F 1	5	17.7	6.5	9	30.77	2.1	20.84	Dark red at 3; self-glazed but not swollen at 5.
Paving Brick Shale..	H 16	3	6.15	7.85	3	39.3	6.0		Chocolate at 3; self-glazed at 5, swollen at 7.
Building Brick Shale	H 17	1	9.09	7.50					Began to swell at cone 1.
Building Brick Shale	H 21	3	15.8	7.0					Cone 5, briquettes missing.
Building Brick Shale	S 1	3	7.2	13.6					Cone 5, briquettes missing.
Building Brick Shale	V 6	3	19.0	7.95	5	42.00	5.6	26.23	Swollen at cone 5.
Building Brick Shale	V 1	3	8.8	8.37					Cone 5, briquettes missing.
Building Brick Shale	V 10	5	10.8	2.25	11	33.0	1.6		Olive green at cone 5; began swelling at cone 7.
Building Brick Shale	F 8	04	14.8	6.66	1	22.8	2.87		Bright red at cone 06; chocolate in color and began to swell at 04; swollen irregularly at 1.
Building Brick Shale	F 9	02	6.0	10.04	1	49.7	6.6		Bright red at cone 02; dark red at 1; self-glazed and badly swollen.
Building Brick Shale	F 10	06	7.84	6.42	1	51.0	8.86		Bright red at cone 06; bright red at 04 but badly swollen; still red at cone 1,
Building Brick Shale	V 2	1	1.5	1.64	9	24.0	4.56		Did not bloat materially at cone 9.

It was a surprise to learn that bricks will decrease in volume without loss of weight, and at the same time decrease in specific gravity. Had the clay been carried to complete fusion, i. e., to a glass, the decrease in specific gravity would have been credited to the phenomenon as in the case of minerals, i. e., the changing of its constituents from crystalline to amorphous forms. But in the case of a clay briquette, a small portion of which enters into the fusion, decreasing in specific gravity before the minerals have been rendered amorphous, i. e., fused to a glass or even before vitrification has been completed, cannot be explained wholly on this basis. Mr. C. H. Wegemann, of the geological department, was, therefore, requested to make a microscopic study of briquettes of two different clays burned at different temperatures. His report follows:

NOTES ON THE MICROSCOPIC STRUCTURE OF CERTAIN PAVING BRICK CLAYS, AT VARIOUS STAGES OF FUSION.

[BY C. H. WEGEMANN.]

In the hope of explaining some of the phenomena of simultaneous decrease in volume, porosity and specific gravity without loss in weight and to obtain some idea of the manner in which fusion takes place in a vitrifying brick, microscopic sections were prepared from briquettes of two paving brick clays.

GENERAL STRUCTURE.

Thin sections of the briquettes burned at a low temperature exhibit under the microscope a very fine-grained fragmental ground mass, or matrix, in which are imbedded crystalline and other fragments which were present in the original clay. From these materials are developed, at high temperature, amorphous glasses and crystals.

The cavities between the particles of a brick may be divided into two classes:

(1) Pores, which are present in pieces fired at low temperatures, due to the incomplete consolidation of the clay. These are the original interstitial spaces of the unburnt clay.

(2) Blebs or bubbles, which are formed in the glass at higher temperature by the liberation and expansion of gases.

Pores of the first sort are of small size and irregular outline. As the temperature increases, and the material of the matrix gradually fuses into glass, these interstitial spaces tend to disappear.

Cavities of the second sort, which we may for convenience designate as blebs, are simply gas bubbles in glass. They are circular in outline and vary greatly in size. They are not present in the bricks burned at lower temperatures, but appear only after the formation of considerable glass.

DESCRIPTION OF SLIDES.

R3-14—This briquette was drawn at cone 3 or about 1190°C. The color is red. Under the microscope, the earthy matrix or ground mass is dark brown, the color being due to the presence of iron oxides.

The mineral fragments are quartz, feldspar and mica, named in the order of their abundance. They are angular in outline, the thin edges being sharply defined.

Glass has formed to some extent throughout the ground mass and in a few instances it has separated out into clear transparent masses, in several of which blebs appear. The blebs, however, are so few and so small that the cavities may be considered as made up almost entirely of pores of the first class. As estimated under the microscope, the porosity is 1.9 per cent.

R3-16—Drawn at cone 5, or approximately 1230°C; color dark brown. Under the microscope the ground mass appears somewhat denser and darker than in R 3-14. The quartz fragments are apparently unchanged. The feldspar fragments, however, have disappeared.[1] Mica is present, but in very small quantity.

Glass has been formed in considerable amount. It appears in clear transparent areas, often 0.1mm. in diameter. In some of the glass, needle-like crystals have begun to form, but where free from these the glass is colorless. This fact would seem to indicate that but little iron has entered into its composition.

As stated above, fine needle-like crystals are often present, imbedded in the glass. They do not appear to have any definite arrangement with respect to each other, but occur singly or in dense masses. When viewed singly they are colorless, but when seen in masses, they possess a greenish yellow tint, which they impart to the glass in which they are imbedded. What the crystals are was not determined.

The iron oxides present in the matrix have become segregated into dense masses, which, where they transmit light at all, show the red of hematite, but no definite crystals are to be seen. Pores of the first class have disappeared, and blebs in the glass have become numerous and large, their average diameter being 0.066 mm. The estimated pore space has increased to 4.2 per cent.

R 3-18—Drawn at cone 7, or 1270°C. The fragments of quartz appear unchanged. The earthy ground mass is rapidly fusing into glass, which has increased greatly in amount over that in the preceding slide. The fine needle-like crystals are also present in greater number.

Minute crystals of iron oxide are seen, apparently in the form of rhombohedrons, having slightly concave faces. They do not exceed 0.0014 mm. in diameter. The blebs have an average diameter of 0.1 mm. and the pore space has increased to 12.05.

R 3-20—Drawn at cone 9, or approximately 1310°C. Quartz fragments are present as before, but occasionally one is observed the edge of which has fused into a glass. The needle-like crystals are everywhere present in the glass, giving to it the yellowish-green tint before mentioned. The iron oxides appear much the same as in the last specimen. The blebs are but little changed.

R 3-22—Drawn at cone 11, or approximately 1350°C. The earthy matrix has given place entirely to glass. Quartz particles are still present, but thin; their edges have been rounded by fusion.

The fine needle-like crystals in the glass have increased greatly in length, being in some cases 0.03 mm. long. They exhibit for the first time a marked tendency to collect in radiating clusters. Often they appear to be attached to the corners of the crystals of iron oxide. These latter have increased in number and size, being 0.005 mm. in diameter. In some cases the individuals unite, forming long serrated columns.

Blebs have increased in size, their average diameter being 0.128 mm. The pore space as estimated from them is 19 per cent.

G 11-10—Drawn at cone 02, or approximately 1110°C. Color, brick red.

As in the R 3 series already described, the mineral fragments consist of quartz, feldspar and mica. Very little glass seems to have developed at this temperature, and no blebs are present. The pore space is made up entirely of pores of the first class, or those due to the imperfect consolidation of the bricks. The average diameter of these pores is 0.065 mm., and the pore space as calculated is 2.6 per cent.

_____
[1] Hintze gives the fusion points of the feldspar as ranging from 1140C., in sanidine to 1230 C., in labradorite. In the briquette under consideration it is evident that the feldspar has fused into glass. It is to be supposed that in this fusing, it would flux some of the quartz. If it did so, however, the quartz must have been furnished by the ground mass, for the coarser fragments are apparently not changed in outline nor diminished in amount.

G 11-12—Drawn at cone 1, or approximately 1150°C. Color red.

A little glass appears, but no blebs are seen. The average size of pores is lower than in the last slide, being 0.045, but the pore space as estimated runs a little higher, or 3.6 per cent.

It may be remarked that in the slides there is no marked increase in the pore space, as temperature increases, up to the point where blebs appear. From that point on, pore space increases rapidly.

G 11-14—Drawn at cone 3, or approximately 1190°C. Color, reddish brown.

Fine needle-like crystals have formed in the glass. A few blebs appear, but are not in sufficient number to affect the pore space materially. As estimated, is is 3.2 per cent, while the average size of the pores of both classes is 0.06 mm.

G 11-15—Drawn at cone 5, or approximately 1230°C. Color, dark brown.

Quartz fragments are still present, but the feldspar and mica have disappeared. Glass has formed in great quantity, being colorless, or when acicular crystals are present, greenish yellow. These crystals are present in great numbers and resemble those described in the former series. Microlites of iron oxide are also present, but have not yet grouped themselves in dendritic forms. Pores other than blebs have disappeared, but the blebs have increased greatly in size, the average diameter being 0.175 mm., while the pore space amounts to 12 per cent.

SUMMARY OF CHANGES OBSERVED AT DIFFERENT HEAT TREATMENTS.

Cone 12—Quartz and feldspar fragments are unchanged.
        But little glass is developed.
        No blebs have yet formed.
Cone 1—No marked change has taken place over cone 12.
Cone 3—A small amount of glass is developed from the ground mass.
        A few blebs appear.
        Needle-like crystals are developed in the glass.
Cone 5—Feldspar fragments are fused into glass.
        Quartz fragments are fused into glass.
        Blebs increase in number and size.
        Minute crystals of iron oxide develop.
Cone 7—Glass increases in amount.
        Blebs increase in number and size.
        Quartz fragments are unchanged.
Cone 9—Quartz fragments begin to fuse into glass along their edges.
Cone 11—Ground mass is completely fused into glass.
        Some rounded quartz fragments still remain.
        Blebs have increased remarkably in size and number.
        Microlites are more numerous.

It should be borne in mind that this is but a preliminary study. The number of slides examined is too limited to warrant broad generalizations.

SPECIFIC GRAVITY, VOLUME AND POROSITY CHANGES OF CLAYS STUDIED.

(BY R. C. PURDY.)

Owing to the absence of similar data on other clay samples and the incompleteness of the present researches, the writer has no definite conclusions to present concerning the surprising facts presented by Mr. Wegemann. This data does, however, establish the facts that neither a mineralogical analysis nor an ultimate or rational analysis of clay will indicate the nature of its pyro-chemical and physical behavior. Indeed, the above data would seem to throw doubt on the value of pyro-chemical and physical study of a synthetic mixture of minerals as a basis on which to interpret the thermal changes in an "unknown" clay mixture.

In the following figures 26 and 27 are shown the specific gravity, volume and changes in porosity in the two clays of which microscopic studies were made by Mr. Wegemann. It will be seen that all three

factors decrease simultaneously, showing that the increases in molecular volume and in bleb structure is not sufficient to counteract the shrinkage of the mass as a whole, and is not to be accounted for by the sealing up of the original pores.

FIG. 26. Curves showing physical changes in clay at various stages of burning, compared to its properties in the unburnt condition as a datum.

FIG. 27.   Curves showing physical changes in clay at various stages of burning.

DIFFERENTIATION BETWEEN CLAYS ON BASIS OF DIFFERENCE IN RATE AND MANNER OF DECREASE IN POROSITY AND SPECIFIC GRAVITY.

INTRODUCTION.

Importance of Slow Vitrification—It is the consensus of opinion among those who have given serious thought to the vitrifying properties of ceramic mixtures, whether natural, as ordinary clay, or artificial, as pottery bodies, that those mixtures which vitrify most slowly and at a uniform rate, all other things being usual, will produce the strongest and toughest ware. Chemical analysis and synthetical mixtures have failed to reveal the happy combination of minerals or chemical elements that will produce this slow, uniform rate of vitrification. A few general rules can be stated as to combinations of ingredients required to produce tough bodies, but none of them can be applied with absolute assurance that they will operate in a given case. With our present information empirical trials have to be resorted to find the proper combination in each case.

It is commercially impractical to alter the composition of clays used for paving brick manufacture except in so far as different strata permit of the use or rejection of materials that effect the character of the ware. This the paving brick manufacture has learned by experience, so that the composite "dry pan" sample, before described, is supposed to represent the best "mix" that is commericially possible in a given case. On the supposition that, according as its rate of vitrification is slower, one clay is more suited for vitrified paving brick than another, and that there is no means of obtaining information that bears on this problem other than determining this very pyro-physical property in paving brick clays, clays were molded into cones having the same shape and dimensions of Seger pyrometric cones manufactured by Prof. Edward Orton, Jr.

PRELIMINARY TRIALS.

Manufacture of Test Cones—The clays in this experiment were dry ground in a mortar to pass a 40 mesh screen, wetted with water from the University mains, wedged thoroughly and molded into cones with a spatula in a regular cone die as used by Orton. On the upper face of each cone was scratched its sample and serial number. After removal from the die the cones were placed in a cool place protected from drafts to dry.

Setting of Test Pieces After Drying—One cone each of four different clays was set in a row in the center of a fire clay slab. On either side of the row of test cones was placed a row of three standard Seger cones arranged in opposite order from one another. There were eight groups of such slabs for each set of four test cones, thus allowing eight heat treatments of different intensities on each clay.

The eight groups with the standard cones were as follows:

First group 010-09-08.
Second group 07-06-05.
Third group 04-03-02-01.
Fourth group 01-1-2.
Fifth group 2-3-4.
Sixth group 4-5-6.
Seventh group 6-7-8.
Eighth group 8-9-10.

Special saggars were prepared, being $3\frac{1}{2}$ inches deep and 8 by 8 inches in area, and having only three sides. These saggars were placed in four bungs in the side down-draft kiln designed by the writer for the ceramic department of the University of Illinois, and shown in Fig. 28. Four of these special saggars were placed in each bung, making 16 saggars in all.

Burning—Four separate burns were made, one of the first four groups, one of the last four groups, and a duplicate or check burn on each.

The kiln was fired with coke, in a manner that maintained oxidizing conditions throughout the entire burn. In all four burns the fire clay slabs were burned to a clean buff color showing no evidence of having been subjected at any time to reducing influences. Inasmuch as the buff color of a fire clay is very sensitive to reducing action, and if once reduced the buff tint is irrevocably bleached, confidence is felt that in these burns we were successful in maintaining oxidizing conditions.

When a temperature had been reached sufficient to cause cone 09 to bend, the wicket was opened and the top saggers from each of the four bungs were drawn and placed in the ash pit of the kiln where they cooled slowly. After placing a cover over the exposed cones left in the kiln, the wicket was resealed and the heat raised until cone 06 was bending, and so on until the center standard cones of the last set of four saggers were bending.

By this scheme of setting twenty-four clays could be tested in one series of four burns, there being in each draw two slabs of the same group in each of the four saggers. This scheme of burning was made possible by the fact that the openings in the flash wall leading into the firing chamber, and openings in the opposite side of the firing chamber leading into the draft flue caused, with the down draft, an equal lateral distribution of heat. In no instance was there a failure to have the center test cone bent, although in some cases in the same draw it was bent more than in others.

Testing of the Trial Pieces—The cones were detached from the slabs, marked with lead pencil, weighed one at a time on a jolly balance and then placed in clear hydrant water. After twenty-four hours of saturation, the wet and immersed weights of each cone were made and from the data so obtained, their porosity and apparently specific gravity calculated.

Difficulties Encountered—First, when the cones were detached from the slabs many broke into two or more pieces; second, a few of the cones were bloated at the base, due to a lack of oxidation; third, the cones were

SIDE DOWN-DRAFT TRIAL KILN
IN USE IN THE CERAMIC DEPARTMENT OF THE
UNIVERSITY OF ILLINOIS
SCALE 0 1 2 3 FT.

FIG. 28. Kiln used in burning experiments.

invariably vitrified more at the top than at the base, thus causing ir-
regularity of results in those that were broken; fourth, in those cones
which had softened sufficiently to cause them to bend over, the pore sys-
tem was not normal, owing to the strain set up on the upper side and
compression on the under side of the bent cone; fifth, we were not suc-

cessful in making a jolly balance spring that was heavy enough to pre-
vent the weight of a cone stretching it beyond its elastic limit, give suffi-
ciently delicate reading.

   Data Obtained—Although the test as a whole was unsatisfactory, it
is believed that the data obtained has a value. The porosity data were
ploted on a diagram as shown in Figure 29. In this the linear distance
between points on the abscissa, indicating difference in melting periods
of the standard cones, is equal to the linear distance assigned to repre-
sent a difference of two per cent in porosity. The solid line is drawn

FIG. 29. Decrease in porosity with burning in terms of cones.

through points representing the average data obtained on the two dup-
licate cones, and the points indicated but not on the heavy black line
represents in each case the data obtained from each of the two cones.
In case the data for one of the duplicate cones were missing, as in K 2
for instance, the heavy black line traces the points representing the de-
termined data.

The dotted line was drawn through all possible combinations of three points that were found to lie in line with each other. In some cases there was only one light line and in others more than one, as shown by the data given in Table XL. The lines drawn through three points lying in a straight line are taken as representing the slope of the curve describing the change in porosity with regularly increasing intensity of heat treatment. Where there is a possibility of more than one slope, as indicated by the light lines, each is recorded and their average calculated. The data in Table XXX is, therefore, the slope or tangent of the angle that the light lines drawn through three points makes with the abscissa.

To obtain this data a protector was so placed on the line that the angle could be read. The natural tangent of the angle was then obtained from a logarithmic table of natural functions. Since the tangent of the angle which a line makes with a given base line, is the slope or inclination of that line, this tangency can be taken as representing the rate at which the porosity decreases with increasing heat treatment.

In the following Table will be found the values; first, of each of the tangents of the angles made by the dotted line and abscissa; second, the average of the tangents; and third, the rattler loss as determined on bricks obtained from factories using the several clays.

TABLE XL.

| SAMPLE. | RATE OF VITRIFICATION. | | | | | |
	1	2	3	4	Average.	Rattler Loss.
K— 1	1.1708	....	....	....	1.1708	15.82
K— 2	1.9007	....	....	....	1.9007	17.48
K— 3	2.0323	....	....	....	2.0323	24.89
K— 4	1.9626	....	....	....	1.9626	19.77
K— 5	2.0732	....	....	....	2.0732	19.36
K— 6	2.0503	....	....	....	2.0503	13.25
K— 7	1.5900	1.9840	....	....	1.7870	13.89
K— 8	1.4733	1.7675	....	....	1.6204	20.03
K— 9	2.0965	1.1504	1.3151	....	1.5208	14.84
K—10	1.5301	....	....	....	1.5301	35.74
K—11	1.1041	1.1508	....	....	1.3079	28.13
K—12	1.0538	1.6107	....	....	1.3322	....
K—13	1.0265	0.9708	....	....	0.9986	31.50
K—14	1.0355	1.2685	1.8103	....	1.3714	21.24
S — 1	1.5697	1.9486	1.2167	....	1.5783	26.25
S — 2	1.3270	....	....	....	1.3270	27.94
R — 1	0.6208	0.7673	0.6128	....	0.6669	16.92
R — 2	0.9601	1.7321	0.8541	1.1237	1.1677	17.80
R — 3	1.0538	1.5061	....	....	1.2799	14.80
R — 4	.9657	2.1283	....	....	1.5470	15.33
H—16	1.9347	2.1445	1.1882	....	1.7558	....
H—18	1.2799	....	....	....	1.2799	....
H—20	2.5386	....	....	....	2.5386	....
H—21	2.4142	1.4641	....	....	1.9391	....
H— 1	1.1041	2.1609	....	....	1.6325	29.61
H—24	1.1106	0.7954	0.6208	....	1.2344	....
H—23	2.7475	....	....	....	2.7475	....
B — 1	2.5826	....	....	....	2.5826	28.03

Summary—Owing to the unavoidable inaccuracies of the work and the erroneous assumption that a porosity graph would trace a straight line, the data given in the above Table has but little value. Its principal value lies in the developed fact that as a rule the slower the clay fuses the tougher appears to be the mass.

FINAL TRIALS.

Failing to solve the problem at hand in the above test, another and more thorough investigation was at once started, using not only a large number, but also a larger variety of clays. The manner in which the test pieces for this latter study were prepared was as follows:

Wedging—Approximately one pound of dry clay was placed on a dampened plaster-covered table and sufficient water from the University mains added to develop the plasticity required to permit batting the clay into loaves. This was accomplished by adding water in small quantities, and thoroughly working it into the clay each time, until the mass had the desired plasticity. It was then thoroughly wedged by kneading and batting until, on cutting the mass open, it appeared to be compact, i. e. without air blebs.

Molding—The loaf was then subdivided into smaller portions, each just sufficient to fill a mold $\frac{3}{4}$ inch by $2\frac{1}{4}$ by $4\frac{1}{4}$ inches. The slabs were made to fill the mold by pressure applied in a screw press. They were then placed in a miter-box and cut into briquettes $\frac{3}{4}$ inches by $1\frac{1}{3}$ inch by $2\frac{1}{2}$ inches.

Marking—The laboratory sample number and a serial number was stamped on each briquette.

Drying—The briquettes were dried in an open room at summer heat. It had been found possible to dry even the most tender of clays in this manner, so it was assumed that all clays used in this test could, without detriment, be subjected to this treatment.

Firing—Twenty-four briquettes of each clay were prepared. The ones on which the serial numbers 1 and 2 had been stamped were placed in a saggar to be drawn at cone 010, those on which the serial numbers 3 and 4 were stamped were placed in a saggar to be drawn at cone 08 and so on—each successive pair of briquettes of each clay being placed in a saggar to be drawn at a predetermined heat treatment as follows:

Series No. on briquette.	Heat at which drawn.	Hours intervening between draws.
1, 2..	010	Oxidized at 800° for 2 hours. From 800°C to cone 010 6 hours.
3, 4..	08	2 hours
5, 6..	06	2 hours
7, 8..	04	2 hours
9, 10...	02	2 hours
11, 12..	1	2 hours
13, 14..	3	2 hours
15, 16..	5	2 hours
17, 18..	7	2 hours
19, 20..	9	2 hours
21, 22..	11	2 hours

The briquettes in the saggars to be fired from cones 3 to 11 were packed loosely in coarse white placing-sand, as to prevent their sticking one to another. Only those clays known to be fire clays, or at least sufficiently refractory to withstand severe heat treatment were placed in the saggars to be drawn at the higher cones.

The eleven saggars were placed in a coke-fired, side down-draft kiln in a manner convenient for drawing. The "spy" cones were centrally located in the kiln in a shield that protected them at all times from direct contact with the flame. When cone 010 was bent over sufficiently to touch the plaque, the wicket was opened enough to draw the cone 010 saggar, the wicket replaced, and the heat slowly raised as shown in the above table.

Cooling—The saggars in which the briquettes were placed were "tile setters" 2 inches deep and 8 inches by 8 inches in area. Before placing, another saggar was inverted over the one containing the briquettes, so that on drawing, the briquettes were at no time exposed to the relatively cold temperature of the room, except in one case of accident. The saggars were placed, uncovered, in the ash pit of the kiln, where they were exposed to the direct radiation from the hot grate bars above. In this manenr, the briquettes were cooled rapidly at first, thus preventing the fused portions in the briquettes from crystallizing very much, but from dull redness down to blackness the cooling extended over a considerable period.

The method of cooling pursued in this investigation was not ideal. The briquettes should have been cooled slowly for the first 200° C. which, as above stated, was not the case. Inasmuch as there is danger of checking the vitrified briquettes by cooling down to room temperature too rapidly, some attention should be given to the last as well as to the first stage of the cooling period, but more particularly to the first. It was not possible to cool the briquettes under these ideal conditions, for the services of the kiln were in demand for other purposes, and circumstances did not permit of delaying the burning until such time as the kiln would not be in use.

Preparation of Briquettes for Testing—When cooled, sand grains were found to be fused to many of the briquettes, requiring that they be ground off on an emery wheel. Care was taken not to unduly heat the bricks while grinding off the sand, and yet as little water as possible was used. The bricks that were thus ground were washed in distilled water to remove all traces of dirt and adhering particles. From the unground briquettes all adhering particles were removed by a dry stiff brush. Each briquette was carefully examined for flaws induced during manufacture or cooling, and also in order to remove all adhering portions, such as broken corners that might have been detached later in the test.

Up to this point, all briquettes were handled together, without regard to sample or series number, except as before indicated.

In all, 60 clays were prepared for testing, as above described, using 16 to 22 briquettes for each. The briquettes were not sorted, those of each clay being treated as a unit, so as to insure like conditions at all times for all briquettes of the same clay.

Drying of Briquettes—Briquettes belonging to two or three clays were placed in a drying oven and dried at 240° C. At the expiration of four hours at this temperature, they were cooled in dessicators preparatory to obtaining the dry weight of each briquette. The dry weight of each briquette was found to the third decimal place on a chemical balance.

Saturation of Briquettes—After the dry weights had been obtained, the briquettes were placed in aluminum pans, keeping them arranged in the pans in their regular serial order. Distilled water was added until only the upper surface of each test piece was above the level of the water. This exposure of one face of the briquette was to permit easy escape of the air from the interior of the brick, as it was being displaced by the distilled water. After standing thus in water for 18 to 24 hours, they were completely immersed.

After a total of 48 hours in water, the briquettes were placed in water under a bell jar, and the air exhausted. In nearly every case, when a partial vacuum had been created, the air escaped from the briquettes at such a rate and in such volumes as to cause the water to appear to be boiling. From a previous experiment, the data of which are given in the following table, it was thought that in the average case, fairly complete saturation could be attained with 15 minutes treatment in a partial vacuum.

TABLE XLI.

Showing efficiency of vacuum treatment in effecting saturation.

SAMPLE.	Porosity as determined after 48 hours' saturation without air exhaustion.	PERCENTAGE OF GAIN IN POROSITY AT CONCLUSION OF VACUUM TREATMENT EXTENDING OVER PERIOD OF			
		5 min.	10 min.	15 min.	20 min.
S — 2	3:22	48.1	51.8	57.9	65.0
G—11	3.3	38.7	42.1	48.4	50.6
K— 4b	3.93	27.3	....	35.6	37.5
K—15d	4.22	13.48	14.48	18.7	20.8
K—13c	4.27	44.60	46.60	46.6	46.6
K—15c	4.51	33.40	37.50	36.8	38.2
R — 4	5.12	58.2.	59.4	61.7	63.7
H—11	5.29	31.2	35.4	37.6	38.9
R — 2	6.1	27.5	32.2	35.6	36.0
K— 6d	6.46	29.9	31.6	35.3	39.3
K— 2	6.55	18.6	20.1	21.6	24.3
R — 1	6.7	10.2	11.0	11.0	11.0
B—11	6.91	28.0	30.4	31.4	32.0
J — 11	7.53	11.8	13.7	15.7	16.0
I — 1:	8.64	11.8	12.8	14.1	14.8
K— 8d	9 06	22.0	23.5	24.0	24.9
B — 1	9.39	13.11	20.3	23.4	....
K—15b	19.8	6.05	6.22	6.84	7.34

Each saturated briquette was in turn suspended by a silk thread from the beam of a chemical balance, and its saturated weight taken, allowing for the weight of the thread. Without removal from the balance, a glass of water was placed on a bridge spanning the scale pan in such a manner as to cause the briquette to swing absolutely free but completely immersed in the water. The suspended weight of the briquette was thus taken.

Calculations—The percentage of porosity of each briquette was calculated by the formula:

$$\text{Percentage of Porosity} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet Weight} - \text{Suspended Weight}} \times 100$$

Plotting of Results—In the previous study, that with clays molded into cones, the writer had arbitrarily established the following proportion: Linear length on ordinate, equal to 2 per cent porosity; linear length on abscissa equal to difference of heat treatment of one cone: that is, 2:1. This (as before explained, was maintained between the coördinate factors of the porosity-graphs, so that the rate of decrease in porosity could be expressed numerically in terms of the tangency or slope of the curves, and that the factors so obtained would be comparable one with another at all times.

The divisions on the abscissas of the specific gravity curves are the same as those of the porosity curves. The divisions on the ordinate are proportionally; 0.1 Sp. Gr. :2 cone heat ::1:2.

Data obtained—In the following table are the data obtained in the above study. Data for a few more clays were obtained, but owing to their incompleteness they are not recorded at this place:

TABLE XLII.

Sample Number.	POROSITY AND SPECIFIC GRAVITY OF BRIQUETTES BURNED AT CONES.											Decrease in Porosity.		Commercial Possibility as Judged by this test.
	010	08	06	04	02	1	3	5	7	9	11	Per cent.	Cone.	
K–1	36.9 / 2.69	36.1 / 2.67	33.1 / 2.68	29.5 / 2.65	24.7 / 2.635	28. / 2.53	20.60	7.4 / 2.29	5.6 / 2.15	2.2 / 1.72		85.0	7	Paving brick
K–2	31.4 / 2.62	32.9 / 2.65	29.05 / 2.64	16.2 / 2.54	15.7 / 2.55	17.6 / 2.56	4.54 / 2.48	3.08 / 2.09				90.0	5	.do
K–3	34.5 / 2.70	36.0 / 2.70	31.5 / 2.68	30.7 / 2.70	24.5 / 2.69	26.1 / 2.68	2.57	6.95	3.55 / 2.19	2.45 / 1.90		90.0	7	.do
K–4	36.1 / 2.67	36.4 / 2.66	33.4 / 2.69	28.4 / 2.70	21.9 / 2.64	20.85 / 2.66	14.3 / 2.47	2.41 / 2.95	2.90	3.7		92.0	7	.do
K–6	32.5 / 2.57	31.5 / 2.56	29.9 / 2.55	20.3 / 2.51	17.7 / 2.36	15.5	7.42 / 2.43	2.33 / 2.28	2.00 / 2.62	1.88 / 3.02		92.0	7	.do
K–8	34.0 / 2.70	34.00 / 2.53	33.9 / 2.73	31.6 / 2.73	26.8 / 2.62	25.2 / 2.62	22.7 / 2.57	2.31 / 13.4	12.4 / 2.00	1.79 / 5.4		84.0	9	.do
K–11	33.9 / 2.60	30.2 / 2.55	28.3 / 2.59	20.0 / 2.60	*18.5	17.0 / 2.49	11.9 / 2.40	6.2 / 2.21	4.85 / 1.95	1.92		86.0	7	.do
K–12	30.8 / 2.64	31.3 / 2.68	28.5 / 2.76	24.6 / 2.63	22.9 / 2.63	21.9 / 2.63	14.35 / 2.53	*9.5	4.47 / 2.35	3.97 / 2.21		87.0	9	.do
K–14	32.5 / 2.63	31.9 / 2.64	30.4 / 2.63	26.2 / 2.61	24.2 / 2.60	23.7 / 2.57	21.6 / 2.58	7.0 / 0.29	3.35 / 2.14			90.0	7	.do
K–15	32.2 / 2.56	30.7 / 2.54	27.35 / 2.53	18.65 / 2.45	20.30 / 2.56	17.35 / 2.50	6.45 / 2.43	1.94 / 2.19	2.91 / 2.00			93.8	5	.do
F–1	34.5 / 2.65	31.9 / 2.67	27.5 / 2.58	24.9 / 2.60	20.6 / 2.61	18.5 / 2.59	10.2 / 2.47	6.45 / 2.18				81.1	5	Building brick
S–1	34.2 / 2.41	33.6 / 2.48	31.7 / 2.50	21.6 / 2.44	23.9 / 2.48	17.9 / 2.41	9.97 / 2.31	2.18				71.00	3	Paving brick
R–1	26.55 / 2.54	20.8 / 2.55	25.4 / 2.56	23.4 / 2.56	21.4 / 2.57	20.7 / 2.55	17.4 / 2.52	10.2 / 2.41	7.6 / 2.36	4.4 / 2.34	4.3 / 2.32	83.90	11	.do
R–2	29.3 / 2.61	28.3 / 2.60	25.4 / 2.60	18.95 / 2.56	17.9 / 2.55	19.5 / 2.57	11.05 / 2.46	4.66 / 2.38	2.51 / 1.28	1.93 / 2.07	1.41 / 1.92	93.50	9	.do
H–16	34.0 / 2.60	33.5 / 2.58	29.7 / 2.58	20.6 / 2.51	18.1 / 2.53	18.3 / 2.49	6.85 / 2.43	*6.9	4.3 / 2.22	2.16 / 1.80		87.50	7	.do
H–17	23.7 / 2.64	23.8 / 2.61	15.6 / 2.62	11.3 / 2.51	9.5 / 2.45	7.5 / 2.40	6.0 / 1.6					68.2	1	Building brick
H–21	33.2 / 2.59	30.4 / 2.50	22.9 / 2.34	20.4 / 2.28	20.2 / 2.33	15.7 / 2.21	7.07 / 2.18	25.5	24.2 / 2.56	20.9		79.0	3	Paving brick
H–24	29.1 / 2.59	29.2 / 2.60	26.9 / 2.61	27.9 / 2.60	28.6 / 2.63	28.3 / 2.60	26.7 / 2.60	3.7 / 2.05	4.0 / 1.93	4.1 / 1.76		28.1	9	Fire brick
B–II	35.6 / 2.63	36.1 / 2.68	31.0 / 2.65	17.5 / 2.56	18.7 / 2.56	16.7 / 2.53	7.4 / 2.31	1.4 / 2.14				88.7	7	Doubtful brick
G–II	28.0 / 2.62	28.2 / 2.61	27.2 / 2.61	22.5 / 2.58	18.0 / 2.51	15.6 / 2.50	7.15 / 2.35	5.32 / 2.32	1.62 / 2.21			95.0	5	
J–II	38.1 / 2.56	32.6 / 2.58	28.3 / 2.55	21.5 / 2.53	20.3 / 2.52	19.8 / 2.51	16.7 / 2.47	2.32	2.21			94.8	7	.do

Lab. No.															Porosity	Cone	Description
L—11															94.0	9	Sewer brick
F—4															56.1	11	Paving brick at cone 8
F—5															38.9	11	Fire brick
F—7															92.5	11	Paving brick
F—8															87.0	1	Building brick
F—9															71.5	1	.do
F—10															76.5	06	.do
F—16															85.8	9	Paving brick
F—18															52.0	11	Fire brick
F—19															39.0	11	.do
F—20															88.0	11	Paving brick
F—21															59.5	9	Paving brick at cone 8
V—1															68.5	3	Data insufficient
V—2															93.0	9	Sewer brick
V—3															80.5	11	.do
V—4															59.3	11	Paving brick at cone 8+
V—5															88.3	11	Paving brick
V—6															77.0	5	.do
V—7															70.0	5	.do
V—9															94.8	5	.do
V—10															96.0	7	.do
V—11															35.5	11	Fire brick

Upper figure in each case is percentage of pore space. Lower figure, specific gravity.
*Porosity data marked with a star were calculated by interpolation.

On plotting the data obtained in this experiment they were found in most cases to be consistent, i. e., clay used for particular industries such as paving brick, fire brick, etc., exhibited porosity changes that were so concordant that the possible commercial use for each was predicted from the curves and in no case where the clays are now being employed did the predicted use differ from their present use as reported by those who collected the samples.

The curves in every instance were not straight, but curved so that their tangent or rate of declination could not be ascertained without the use of calculus. Inasmuch as the curves did not describe gradually sloping curves, but in most cases exhibited well defined lags in decrease of porosity, it was found that a simple tangent factor would not describe in full the fusion behavior of the clays. A complicated modulus was devised which was not only a function of the tangents of the sections of the curves between points of lag, but also the length of each section. Considering the fact, however, that this scheme of studying the fusion phenomenon is here first presented, thus not finding confirmation by other experimenters, and since the modulus does not show more clearly the rate fusion than does the curve, no attempt was made to apply the modulus on the different types of clays.

SUMMARY OF RESULTS OF TESTS.

In subsequent curves are given the limits of the areas traversed by the porosity and specific gravity curves of the different types[1] of clays.

In Fig. 30 are shown the limits of area traversed by porosity-graphs of the fire clays. The fire clays are grouped into three classes according to their rate of decrease in porosity.

Number One Fire Clays—The writers of Clay Reports have heretofore failed to recognize that of two clays having similar ultimate chemical compositions and similar ultimate fusion periods, one can be used in No. 1 fire brick, while the other would fail as a first-class fire brick material,[2] and the one failing as a fire brick material would be the only one that could with success be used in the stoneware industry. Several examples of the foregoing were noted in the examination of the Illinois fire clays. In fact, the case is not an uncommon one.

In fire brick, maintenance of an open structure through the entire heat range used in the various ceramic industries is essential. On the other hand, in stoneware, closeness of structure at comparatively low temperatures, or early vitrification followed by a long fusion range is absolutely required. It is evident, therefore, that a classification of refractory fire clays (so called because they withstand heat equivalent to cone 27 or more without failure) should take account of this dif-

---

1. "Types," as here used, does not refer to geological origin or age, but rather to the possible commercial use of the clays.

2 By fire brick material is meant what is known in trade as No. 1 fire brick The so-called No. 2 fire bricks are, as a rule, not worthy of the distinctive title "fire brick." Used in places exposed to fire does not necessarily make a brick a fire brick, for, if this were so, the comparatively fusible Chicago brick placed in the arches of their scove kilns would have to be called "fire brick."

FIG. 30.   Differentiation of fire clays on basis of porosity changes.

ference in their manner of fusion.   This essential difference in the be-havior of fire clays is recognized in a tentative scheme of classifica-tion presented by the present writer and Mr. Moore.[1]

It will be noted from Fig. 30 that these clays show comparatively little decrease in porosity from cone 010 to cone 11.   This decrease averages from 7 to 15 per cent of the initial porosity and in no case does it exceed 17 per cent.

The specific gravity,[2] as shown in Fig. 31 remains fairly constant from cone 010 to cone 3 and then, even in the purest clays, it begins to decrease slightly.   This decrease in specific gravity in the No. 1 fire clays, even when the porosity remains very high, is considered as evidence of the influence of the adsorbed or cementing salts .which, while constituting but a very small part by weight of the whole, are nevertheless potent factors in causing fusion.

1 Trans. Am. Soc., Vol. IX, pp. 239.
2 The specific gravity here referred to is the specific gravity of that portion of a saturated brick not occupied by water.   Inasmuch as this water impermeable mass very often, in fact, in the case of impure clays generally does contain in-closed or sealed pores known as blebs, the specific gravity so obtained cannot be the actual specific gravity of the material of which this water impermeable portion consists.   The true specific gravity of the material can be obtained by crushing the brick to fine powder, thus eliminating the sealed pores, and then determining the specific gravity of the powder in a specific gravity bottle as before described.   For this reason, the writer has classified specific gravities under three heads: First, false specific gravity, or the weight per unit volume of the whole brick ; Second, apparent specific gravity, or the weight per unit volume of the water-impermeable mass; Third, true specific gravity, or weight per unit volume of solid material in the water-impermeable mass.

FIG. 31.   Curves showing changes in specific gravity of fire clays with progressive intensity of heat treatment.

Number Two Fire Clays—It will be noted that while the decrease in specific gravity of this group of clays is about the same as that shown in the No. 1 fire clays, the porosity shows a much larger decrease. The earthy vitrification and slow fusion is quite pronounced in this group, permitting their use in the paving brick, sewer pipe, stoneware and terra-cotta industries, but not in the manufacture of No. 1 fire brick.

Number Three Fire Clays—In Figs. 27 and 28 are shown the limiting area of porosity and specific gravity curves of a class of clays which, in the judgment of the writer, ought to be put in a different category from the preceding group, or number two fire clays. Heretofore, both have been classed together indiscriminately in ceramic and geological

literature, as number two fire clays, but they are not the same. Clays of this class differ from the No. 1 and No. 2 fire clays, in that they seldom have a fusion point exceeding cone 16 or 17, fuse in a very irregular manner, and exhibit a much larger decrease in specific gravity owing probably to the presence of iron in nodular form as sulphides or carbonates.

Fire Clays in General—These conclusions may be summarized as follows: First, While all the types of fire clays here tested maintained the same range in porosity up to cone 010, there is a marked differentiation of each at cone 08. Second, From cone 08 to about cone 1 the No. 2 and No. 3 fire clays traverse a common area, but at cone 1 the No. 3 type begins to fuse more rapidly, until when cone 7 is reached, the No. 3 fire clays have fused sufficiently to be wholly differentiated from the No. 2. Third, Since the porosity curves in Fig. 27 are composite curves showing the limits of variation in the few clays tested, it is possible that broader limits will be determined when more and a larger variety of clays are tested, yet the data here presented are sufficient to demonstrate that where chemical analysis and fusion period determinations have failed, this method of differentiation has proved successful. Fourth, Differentiation of fire clays on the basis of specific changes will hardly be possible on account of the limited differences between the areas traversed by the specific gravity curves of each type of fire clay, yet as is shown in Fig. 28 the specific gravity curves parallel and diverge from one another at about the same temperatures as do the porosity curves in Fig. 27.

Chemical analysis and points of fusion of a few of the fire clays from which curves were drawn are as follows:

TABLE XLIII.

No. 1—Fire Clays.

Sample Number.	Moisture.	Volatile Matter.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Total.	Fusion point.
H—24	0.6	4.63	76.10	15.81	1.10	1.31	99.06	30
V—11	1.74	10.28	56.28	26.68	3.21	1.29	99.50	Not reached...
F—18	0.84	6.66	66.88	21.87	2.23	1.18	99.86	29
F—19....	1.19	6.31	68.12	20.08	1.76	1.16	98.62	31

TABLE XLIV.

No. 2—Fire Clays.

Sample Number.	Moisture.	Volatile Matter.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Total.	Fusion point.
V—4	2.37	8.84	54.80	29.44	1.70	0.82	97.97	Not reached...
K—12....	0.60	10.09	54.37	23.61	6.14	[1]5.97	100.78	..do.............

1 Total fluxes TiO_2 was not determined in K-12.

Chemical analyses were not made of all the clays of the No. 1 and No. 2 type and none of the No. 3. From the few that were made, however, it is evident that refractoriness and slow fusion are not always dependent upon the proportional content of alumina and silica, for the two No. 2 fire clays have on the average higher Al_2O_3 and lower SiO_2 content that the No. 1 fire clays. This is directly contrary to our past teachings and contrary to what might be expected from Segar's Al_2O_3-SiO_2 curve, as shown in figure 19, page 208.

Paving and Building Brick Clays—The standardization of tests for first-class paving brick clays has been and perhaps will be for some time the subject of consideration by ceramic investigators. The pyro-physical and chemical tests here reported can be said to give negative rather than positive information, in that they very effectively differentiate the clays they *cannot* from those that *may* be utilized in paving brick manufacture. Judging from the results so far obtained, they fail, however, to differentiate the paving brick clays one from another in regard to their comparative quality. For example, we have not been able to distinguish by these tests between the clays of 14 per cent and the 24 per cent type, measured in per cents of loss in the rattler test, nor between the clays that preserve their maximum strength through a wide heat range and those which attain and preserve their maximum strength only within a very narrow heat range.

The cause of failure of the pyro-chemical studies in this respect is, no doubt, to be found in the fact that inherent strength is not wholly a function of rate of vitrification or development of vesicular structure. As shown in earlier pages, physical tests on the raw clays failed to differentiate paving from building brick clays. The pyro-chemical studies here reported are the only ones that give any clue to cause of toughness or strength of the burned ware.

Pyro-chemical studies similar to those here outlined, together with a determination of the maximum strength and the range of temperature in which this maximum strength is developed, would enable the observer to properly classify and differentiate paving brick clays. This, however, amounts to a sub-classification of the paving clays on a basis different from that of the main sub-division.

The striking differences between the building and paving brick clays are apparent from figures 32 and 33. Earlier vitrification, irregularity in decrease of porosity and specific gravity, apparently larger quantity of vessicular glass formed within the mass, or at least a more notable bloating, due to volatilization of certain constitutents, probably the soluble and adsorbed salts, are the distinguishing features of the strictly building brick class.

Sufficient evidence is at hand to warrant the statement that any clay which vitrifies to a porosity of 2 or 3 per cent before cone 5 is reached, in the heat treatment prescribed in this method of burning test pieces,

will be too brittle for use as paving brick material, no matter how little vesicular structure is developed. The fact is, however, that it will be a rare case in which vesticular structure is not strongly developed if the clay shows an early[1] and rapid rate of vitrification.

In figures 32 and 33 are shown the upper and lower limits of areas that were traversed respectively by the porosity and specific gravity curves of clays that either are being or can be used for the purposes indicated in the figures.

FIG. 32. Curves showing changes in porosity of paving and building brick clays with progressive intensity of heat treatment.

_____

1 The use of the comparative terms "early" and "rapid" in reference to this type of clays, in contrast to their relative use in regard to fire clays, is best illustrated by reference to the curves.

FIG. 33.   Curve showing changes in specific gravity of paving and building
brick clays with progressive intensity of heat treatment.

The boundary limits shown in these figures are those obtained in these tests, and, therefore, may not show exactly the true limits of the several areas. They indicate, however, approximately the relative manner in which the clays used for the several industries behave in fusing.

All clays used for paving and sewer brick may be used for building brick, but what are here defined as strictly building brick clays cannot be used for paving or sewer brick. All paving brick clays can be used in the manufacture of sewer brick, but the sewer brick clays cannot be used for paving brick. The points of differentiation are; first, the paving brick clay fuses more slowly and decreases less in specific gravity;

second, the sewer (and side walk) brick clay fuse more rapidly but maintain their shape through a considerable range of heat treatment before failing; third, those clays which are fit only for building brick vitrify rapidly and fail as soon as, or before they are completely vitrified. The sewer brick clays can be brought with safety to complete vitrification without much danger of loss except perhaps from "kiln marking" while those clays which are fit only for building brick bloat and become spongy as well as soft almost as soon as vitrification takes place.

Since the tracing of the porosity curves through the upper or paving brick clay area does not necessarily signify that they are good for paving brick manufacture, the lower limit may appear to be superfluous. It remains a fact, however, that, according to the tests here reported, a clay must have its porosity curve confined within the limiting boundaries shown in order to develop the required toughness. So far as experience with the Illinois clays is concerned, the curves for porosity and specific gravity in figure 29 and 30 respectively, denote quite rigidly the allowable variation in rate of decrease in porosity and specific gravity.

GENERAL CONCLUSION.

In the preceding discussions of physical, chemical, and pyro-physical and chemical properties of clays all of the relations between these properties that were known or observed have been shown. A review of these discussions reveals the following as being the most important.

1. Measurement of some of the properties failed to give results that show the factors which affect them or which are involved with them. This was made plain in case of the "individual grains" as obtained by mechanical analysis. We have seen that the methods universally employed to effect the physical disintegration of clay are not sufficiently intensive to produce complete disintegration. It has also been demonstrated that the grains or particles so obtained do not usually consist of one mineral substance. As a consequence of this cementation of smaller particles of different substances into bundles or groups, any inference or conclusion based on fineness of grain cannot be very general in application.

2. Ultimate analysis or gross rational analysis of clay cannot reveal qualities that affect either the "working" or "burning" properties.

3. Either ultimate or rational analysis of the several groups of grains *may* reveal some important relation of constitution to manifested properties. This, however, remains to be demonstrated. It can be said however, that such determinations will not likely become "commercial" tests of clays. On the other hand, however, it seems certain that they will be valuable for research purposes.

4. Vitrification behavior, rate of fusion or toughness of bricks, do not seem to depend within any but very wide limits or in any traceable manner upon chemical or mineralogical constitution of clay.

5. No combinations of physical and chemical properties can be said to be essential to clays from which first-class paving brick may be manufactured.

6. The most satisfactory tests tried or developed during the course of these researches for distinguishing between clays on the basis of their commercial availability are rate of decrease in porosity and specific gravity. While even these tests, so far as can be judged by our results, do not make an absolute discrimination, the discussions and curves here given make plain the fact that such tests are the most serviceable of any so far developed. The other tests have special uses and are not to be entirely condemned.

7. Toughness of brick does not bear a consistent relation to degree or range of vitrification. Each clay has its own peculiar range and degree of vitrification at which its maximum toughness is developed. In some clays this range is very small and in some quite large. In some clays maximum toughness is attained when the brick still shows an absorption of 8 or 12 per cent and in others not until the absorption has been decreased to 2 or 4 per cent. No tests other than the "rattler test" on full size brick which have been burned with different intensity of heat treatment have brought out data which bear on this peculiarity of clays.

8. The pyro-physical studies which have been described suggest a series of determinations which should be more valuable in that they ought to reveal the cause for this want of correlation of toughness and vitrification behavior. The series of determinations referred to is that of the volume changes which take place with increasing intensity of heat treatment.[1]

The volume changes which are important are:

(a) exterior volume of brick.
(b) volume of skeleton of brick.
(c) volume of open pores.
(d) volume of sealed pores.

---

[1] See Trans. Am. Cer. Soc., Vol. X.

CLAYS STUDIED WHICH ARE SUITABLE FOR USE IN THE MANUFACTURE OF PAVING BRICK.

[Compiled by C. W. Rolfe.]

Introduction.

The clays especially studied for the purposes of this report are listed below. They are, with few exceptions, now being used in the manufacture of pavers of proved excellence.

While the writer believes that most counties in the State contain clays from which high grade pavers could be made, if the materials were properly handled, there are only eight localities where this is actually done. This is probably due to the facts, that there is no very large demand for pavers; that both Indiana and Iowa have large plants near the borders of this State; that commercial considerations which are in no way influenced by the qualities of the clays favor these plants; and also to a large extent because no systematic survey of our clays has been made and so their qualities are not known.

In order to give the reader a clearer idea of the qualities a paving-brick clay should possess, it was decided, because the Illinois factories are so few, to include a number of those which are making first class pavers in the neighboring states of Ohio, Indiana, Iowa, Missouri and Kansas. All the Illinois clays now used for pavers are from the coal measures, and many people have an idea that shales from this horizon furnish the only material suitable for the manufacture of such wares. The clays used in these other states are from various horizons, and, as will be seen by a comparison of the tables below, they possess qualities in every way equal to the coal measure shales used in Illinois.

Preliminary tests were made on a considerable number of samples covering a large part of the State. These tests were made on small samples taken usually from more or less weathered outcroppings. Such tests are always unsatisfactory because the samples are not large enough to permit studies which will give decisive results, and also because the changes which occur in weathering usually tend to destroy those qualities of a clay, which make it desirable for the manufacture of pavers. While the tests made indicated that a considerable percentage of the clays tested, some 30 or 40 in all, were suited to the manufacture of pavers, the limitations under which the work was conducted made it impossible to carry out complete studies on any large number of samples. H16—H23 are examples of such clays.

It is hoped that at a future time studies of a larger series of un-weathered clays, taken from all parts of the State and from as many geological horizons as possible, may be carried on with the result of demonstrating possibilities for the use of Illinois clays now recognized only by those who have studied the problem from the geological side. It is the belief of the author that there is no considerable section of the State that will not furnish clays well adapted to the manufacture of pavers if skillfully handled. This opinion is based on the results of tests made in our laboratories, but whose character was not such as to warrant publication of the results.

DESCRIPTION OF DEPOSITS.

Descriptions of the deposits from which the clays studied were taken will be found below. The samples were taken from the clay which had passed the dry pan and was ready for the pug-mill.

K 1—This clay is used by the Alton Paving Brick Co. in the manufacture of paving blocks and dry pressed building brick.

A section taken from the bank is as follows:

	Feet
Loess	2-20
Yellow sandy clay	8
Soft sandstone	4
Sandy blue shale	12
Coal	4
Fire clay	18

The shale alone makes a very tough brick but it is found desirable to mix with it more or less of the overlying materials. The loess is principally used in making dry pressed building brick. The sandstone and all strata belong to the coal measures.

K 2—This is a coal measure shale used by the Hydraulic Press Brick Co. of St. Louis, Mo., in the manufacture of pavers at their factory near Glen Carbon, Ill. The deposit is about 30 feet thick and consists of thick beds of shale separated by bands of sandy shale and sandstone.

K 3—Used by the Albion Vitrified Brick Co., at Albion, Ill., in the manufacture of paving blocks, which are used to some extent also in building. The works are situated a short distance from the town on the Southern Railroad.

A section of the bank shows:

	Feet
Yellow clay	6
Argillaceous sandstone	8
Soft blue shale with thin partings of sandstone	2
Hard blue shale	22
Softer blue shale	4

This clay required thorough pugging under heavy pressure to produce the best results. The sandstone and shales belong to the coal measures.

K 4—This highly plastic shale from the coal measures is used by the Springfield Paving Brick Co., in the manufacture of paving blocks exclusively. The works are located near Springfield, Ill.

A section of the bank shows:

	Feet
Yellow loess-like clay	6-8
Weathered shale	6
Blue compact shale	45

The shale includes a thin seam of coal. Rapid pugging under light pressure seem to produce the best results with this clay. It will be noticed that the material used, which includes all shown in the above section, is entirely free from sandstone or sandy layers.

K 5—This clay, which is used by the Banner Clay Co., of Edwardsville, Ill., for the manufacture of paving blocks, lies under a heavy overburden of loess and drift often aggregating 25 to 40 feet in thickness. The shale from which the brick are made belongs to the coal measure series and is exposed only in the bluffs of streams which run in deep valleys. The shale is all more or less sandy and is composed of alternating layers of harder and softer material.

A section at the bank shows:

Feet
Loess-like clay 12
Yellow clay 8
Tough blue clay 6
Sandy shale in alternating harder and softer layers 36

K 6—The Purington Paving Brick Co. of Galesburg, Ill., have probably the largest plant in the State devoted to the manufacture of paving blocks and paving and building brick. Their annual output is about 90,400,000 of which about 80,000,000 are pavers. In spite of its sandy character and moderate plasticity it yields readily to the methods of manufacture, and makes a compact body of excellent quality.

The section of the bank shows:

Feet
Glacial drift 18
Weathered shale (not used) 12
Blue shale with thin partings of soft sandstone 60

The shale belongs to the coal measure series, and lies between the horizons of "coals 3 and 4."

K 7—This clay, which lies immediately above "coal 7," is used by the Streator Paving Brick Co., at Streator, Ill., in the manufacture of brick and blocks which are used for paving and for the facing of buildings.

A section of the bank appears below:

Feet
Glacial deposits consisting of loess-like clay, yellow and blue clays 20
Blue shale with nodules and thin partings of sandstone 30
Coal 4-5
Fire clay ....

The glacial deposits are stripped and the shale and sandstone alone are used in the manufacture of brick.

K 15—Lies immediately above "coal 7." The bank is located near Streator, Ill., and is operated by the Barr Clay Co., in the manufacture of paving and building brick of good quality.

A section of the bank follows:

Feet
Glacial deposits, loess-like, and yellow and blue clay, gravel, sand, etc. 5-15
Sandstone 2- 3
Sandy blue shale in thin layers 5-10
Sandy blue shale, massive 10-20
Very fine grained, plastic blue shale 10-12
Coal 4- 5

The glacial deposits are rejected. All the other strata are mixed and used in making the brick.

K 14—The Western Brick Co., of Danville, Ill., uses this material for the manufacture of building and paving brick. They have one of the largest and most successful plants in the State.

A section of the bank follows:

Feet
1. Glacial deposits, variable thickness 2-33
2. Shale with sandstone partings 50
3. Coal, No. 7 6
4. Fire clay 2
5. Thin layers of coal and fire clay 3
6. Fire clay 5
7. Clay rich in lime 10
8. Clay with layers of limestone 6
9. Coal, No. 6 8
10. Fire clay 6

11.	Sandstone	10
12.	Sandy shale	25
13.	Shale	200

Building brick are manufactured from No. 2 as a whole. The lower half of No. 2 is used for pavers. Nos. 12 and 13 are reached by shaft.

F 1—The Danville Brick and Tile Co., manufacturers pavers from No. 12 of the section shown under K 14. This deposit outcrops near their plant.

H 16—Is a blue coal measure shale from the pit of Mr. Carter at East Peoria.

H 17—This clay was obtained from the bank of the LaSalle Pressed Brick Co., near LaSalle, Ill. It is not now used for the manufacture of pavers.

Feet
1. Stripping ...12
2. Sidewalk clay v 2 ...10
3. Green clay v 1 ... 7
4. Clay with much pyrites ... 5
5. Red burning clay H 17 ...14

The indications are that v 1 and 2 and H 17, if mixed, could be used in making pavers of good quality.

H 18—From a weathered outcrop probably 40 feet thick situated one mile east of the station of the C. & N. W. R. R. at Sterling, Ill. It belongs to the Cincinnati (Maquoketa) series of the Lower Silurian (Ordovician). The indications are that it would probably make good pavers.

H 20—Cincinnati shale from the farm of Dupiers & Son, near Savannah, Ill. It is a weathered sample and unless the unweathered portion should make a better showing, is worthless as material for pavers.

H 23—Is from the bank of the Argillo Works at Carbon Cliff, Ill. Would probably make good pavers.

H 21—This sample of Cincinnati shale came from the west end of the tunnel of the Great Western R. R. near Rodden, Ill. Aside from its fineness of grain the material seemed to be well adapted to the manufacture of pavers. As the sample was from a weathered outcrop it is possible, perhaps probable, that the unweathered material could be so treated as to overcome this difficulty.

K 8—This is a Carboniferous shale used by the Wabash Clay Co., of Vedersburg, Ind., in the manufacture of paving blocks. The material heretofore used is a mixture from two banks, one located one mile north and the other one and one half miles south of the plant. As the use of material from the north bank is soon to be discontinued, the material tested and the section given below are from the south bank alone.

Feet
1. Surface deposits ... 4
2. Rotten yellow sandstone ... 12
3. Shale varying from hard to soft, and in color from very light to black ... 24
4. Fine grained dark shale ... 10
5. Coal ...1-1½

K 9—This shale, used by the Poston Paving Brick Co., at Crawfordsville, Ind., for the manufacture of pavers, belongs to the Knobstone formation of the Lower Carboniferous or Mississippian series. The material has but little plasticity, but when burned makes blocks of excellent quality. The section is as follows:

Feet
1. Surface deposit, gravel and clay ...14
2. Shale, very constant in quality, except that the lower 12 feet are harder than the rest. (This shale contains more or less nodules which are separated before the clay is used) ...35

1. Soil and joint clay 5
2. Sandy shale 3

K 11—The Terre Haute Vitrified Brick Co., of Terre Haute, Ind., uses this shale in the manufacture of paving and building brick of excellent quality. This material comes from the Coal Measures immediately above "Coal 7."

The section of the bank follows:

Feet

3. Light gray shale with bands of limestone and ironstone nodules 12
4. Dark shale with hard oölitic nodules 14
5. Coal, No. 7 5
6. Fire clay ....

The margin of vitrification is narrow.

K 11—The Indiana Paving Brick and Block Co., of Brazil, Ind., uses this material in the manufacture of paving block.

The section at the plant is as follows:

Feet

1. Buff colored clay 8
2. Grey and yellow clay 4
3. Stoneware clay 9
4. Shale with cubic cleavage containing harder layers and kidney-shaped con-
   cretions 24
5. Coal 1½
6. Fire clay ....

K 12—This is a fire clay coming from below the coal in the section above.

K 13—The Clinton Paving Brick Co., of Clinton, Ind., uses this material in the manufacture of paving blocks. It lies just below the upper Clinton coal.

The section at the bank follows:

Feet

1. Fire clay 3
2. Sandstone 1
3. Dark blue or gray shale with nodules of pyrites, large above and smaller
   below 30
4. Shale with thin layers of limestone 6
5. Fine, fat, massive, black shale 22
6. Hard black shale 2
7. Coal 1½
8. Fire clay 2

R 1—This impure fire clay, obtained by mining just below their coal No. 5, is used by The Nelsonville Brick Co., Nelsonville, Ohio, in the manufacture of paving block and some building brick. Their annual output is about 25,000,000 blocks.

R 2—This is a shale from an outcrop of the Subcarboniferous near Portsmouth, Ohio, and is used by the Portsmouth Paving Brick Co., in the manufacture of their Hallwood Block.

R 3 and 4—These are shales obtained from near the base of the Coal Measures at Canton, Ohio, and used by the Metropolitan and Cleveland and Canton Paving Brick Companies in the manufacture of paving blocks, with an output of about 500,000 per day.

S 1—These Coal Measure shales are used by the Moberly Brick, Tile and Earthenware Co., in the manufacture of building brick and paving blocks, at Moberly, Mo.

Section of bank:

Feet

1. Soil 2
7. Loess 10
3. Dark, thin layered shaly sandstone 20
4. Fine grained bluish gray shale with sandy layers 30
5. Mixture 1-5 dark, 4-5 blue shale ....

S 2—These are Coal Measure shales used by the Kansas City Hydraulic Pressed Brick Co., at Diamond, Mo., eight miles from Kansas City. This clay is mined and consists of a layer 20 feet in thickness of which the upper 4 feet is quite sandy while the lower 16 feet is a fine grained, grayish blue shale. The two grades are used in the proportions indicated: i. e. 1 to 4.

L 2—This material is used by the Lawrence Vitrified Brick and Tile Co., of Lawrence, Kans., in the manufacture of both building brick and pavers.
Section of bank:

Feet
1. Red quartz sand 5
2. Shale, yellow above, blue below 20
3. Mixture 11-12 shale, 1-12 sand ·..

B 2—The Atchison Paving Brick Co., of Atchison, Kans., uses this material in the manufacture of building and paving brick.
Section of bank:

Feet
1. Limestone 4
2. Yellow shale 14
3. Soft sandstone 5
4. Sandy shale (50 per cent sand) 16
5. Blue shale 11

For pavers Nos. 4 and 5 are mixed in such proportions as to make ⅓ sand and ⅔ shale. They also try to combine Nos. 2, 3 and 5 so as to give the same mixture.

G 2—This shale is used by the Coffeyville Brick and Tile Co., Coffeyville, Kans., in the manufacture of paving blocks exclusively.
Section of bank:

Feet
1. Stripping, gravel, clay and limestone 10
2. Shale, very uniform ....:..............90

I 2—This material is used by the Caney Vitrified Brick Co., of Caney, Kans., in the manufacture of building brick and such pavers as may be needed for local consumption.. The surface of the shale where it is weathered is yellow in color but becomes blue with depth. The thickness of the deposit has never been ascertained. It is covered with a thin layer of soil which is stripped.

H 2—This shale is used by the Capital City Vitrified Brick and Paving Co., in the manufacture of pavers, near Topeka, Kans.
Section of bank:

1. Surface soil 3
2. Limestone 1
3. Yellow clay 1
4. Coal ....·. ½
5. Yellow clay 10
6. Blue shale 35
7. Mixture ¼ yellow clay, ¾ shale .;...

TABLE I—CHEMICAL ANALYSES.

Illinois Clays Now Used in the Manufacture of Paving Brick.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	Ignition	Moisture	TiO_2	S
K— 1................	63.36	15.43	1.80	4.02	1.58	.93	3.28	.56	6.99	.48	1.00	.27
K— 2................	63.35	16.27	7.56	......	1.33	1.01	3.	80.—	4.75	.31	......	......
K— 3................	59 34	15.36	3.26	3.84	1.82	.76	3.82	.80	7.89	.29	1.31	.16
K— 4................	60.31	17.74	5.04	1.96	1.96	.41	2.88	1.07	6.71	.81	.84	.14
K— 5....	63.43	16.89	1.52	4.24	2.11	1.00	2.03	.20	5.97	.46	1.07	.11
K— 6................	63.62	16.28	3.02	2.90	1.44	.63	2.60	1.50	5.88	.38	.96	.11
K— 7................	59.86	17.43	1.42	5.10	2.32	1.05	2.80	.18	6.35	.20	1.91	.13
K—14................	64.09	14.16	2.65	3.16	1.64	1.69	2.90	.77	6.47	.51	.89	.24
K—15................	58.03	17.72	2.91	5.77	1.43	1.42	2.66	1 40	6.47	.97	1.02	.25
F — 1......:........	58.52	15.67	4.99	3.37	1.45	1.05	2.94	1.48	7.72	2.02	.96	.32

Illinois Clays Not Now Used for Paving Brick.

	SiO₂	Al₂O₃	Fe₂O₃	FeO	MgO	CaO	K₂O and Na₂O	Ignition	Moisture
H—16	60.93	17.93	8.12	....	.91	1.33	5.01	5.73	.55
H—17	56.56	12.64	13.56	....	2.75	2.22	4.82	6.02	3.70
H—18	39.91	16.43	4.80	....	5.08	7.57	3.71	21.02	.86
H—20	47.29	15.51	4.80	....	6.19	7.33	3.71	13.11	1.31
H—21	48.41	18.31	6.06	....	3.13	5.73	5.65	12.79	.79
H—23	55.37	21.40	6.72	....	.65	1.76	2.42	8.75	3.39

Clays from Other States from Which High Grade Pavers Are Made.

		SiO₂	Al₂O₃	Fe₂O₃	FeO	MgO	CaO	K₂O and Na₂O	Ignition	Moisture
Indiana.										
K— 8		60.89	16.40	8.20	....	1.61	.55	4.15	8.18	.50
K— 9		68.50	16.98	5.77	....	1.71	.99	2.97	3.54	.27
K—10		58.35	18.09	6.14	....	2.03	1.20	4.58	7.02	.81
K—11		55.18	19.22	8.19	....	1.67	.56	2.85	10.45	1.02
K—12		54.37	23.61	6.14	....	1.61	1.58	2.78	10.09	.60
K—13		57.09	19.07	7.92	....	1.91	.80	4.69	7.97	.43
Ohio.										
R—1		58.42	25.05	3.04	....	1.52	.46	2.30	8.08	1.29
R—2		63.41	18.61	5.82	....	1.16	.41	3.60	4.86	.68
R—3		58.57	20.40	7.40	....	1.37	.63	3.27	5.95	1.06
R—4		55.51	21.81	7.66	....	1.63	.56	3.56	8.00	.02
Missouri.										
S—1		55.02	20.35	6.26	....	1.70	.87	3.64	9.40	.83
S—2.		56.29	20.32	7.90	....	2.01	.48	4.46	4.39	.79
Kansas.										
B—2		60.31	19.11	6.14	....	1.73	2.73	1.44	6.70	3.05
G—2		63.42	16.24	6.62	....	1.87	1.64	4.83	5.14	.86
H—2		56.25	18.79	8.02	....	1.33	2.39	4.60	7.01	1.49
I —2		68.15	12.89	7.52	....	.59	1.02	2.93	5.08	1.57
J —2		62.70	16.95	8.98	....	1.47	1.17	3.03	6.75	.98
L—2		58.62	17.74	8.48	....	.98	1.26	3.92	6.66	2.55

TABLE II—RATIONAL ANALYSES.

Number.	Clay Substance.	Quartz.	Feldspar.	Phosphorus.	Carbon.	Soluble Salts.
K— 1	38.90	46.60	17.50	.093	1.44	.13
K— 3	48.00	26.74	25.26	.078	1.50	.14
K— 4	43.32	43.66	13.02	.024	.72	.04
K— 5	38.92	46.54	14.54	.090	1.26	.08
K— 6	41.02	39.98	19.00	.067	.63	.38
K— 7	33.14	49.36	17.50	.079	.71	Tr.
K—14	25.28	48.54	16.18	.069	1.01	.04
K—15	53.36	22.82	23.82	.125	.96	.27
F— 1	51.12	29.38	19.50	.077	.92	.14

Illinois Clays Now Used in the Manufacture of Pavers.

TABLE III—PHYSICAL TESTS.

NUMBER.	Tensile strength of green clay—Kilos per sq. cm.	Specific gravity	Porosity	FINENESS OF GRAIN.					Volume shrinkage	Linear shrinkage	Water of plasticity	Hygroscopic water.
				1 mm.	1—.1 mm.	.1—.01 mm	.01—.001 mm	.001—0 mm				
K— 1	7.262	2.66	26.00	7.27	6.53	56.07	24.86	9.76	6.20	1.50	14.90	2.01
K— 2	10.364	2.56	25.68	1.07	1.23	66.24	19.63	13.90	12 20	3.47	16.77	1.62
K— 3	9.004	2.68	25.56	1.50	2.41	57.15	25.14	13.96	10.45	2.06	16.82	2.43
K— 4	9.735	2.67	27.81	1.40	1.74	48.87	29.41	22.24	10.12	3.26	16.27	......
K— 5	5.465	2.65	25.44	6 38	1.46	60.57	22.93	11.43	5.17	1.55	13.06	.92
K— 6	7.840	2.66	28.86	1.24	1.83	65.83	25.98	7.77	10.06	4.10	17.03	1.23
K— 7	6.435	2.64	27.90	1.35	3.75	60.87	25.89	11.81	9.62	3.90	17.57	1.93
K—14	6.036	2.72	24.50	14 23	6.31	42.75	26.03	9.67	6.13	1.50	13.60	.79
K—15	5.876	2.65	28.50	......	......	......	......	......	......	......	16.90	......
F—1	11.317	2.60	24.00	......	......	......	......	......	......	3.60	14.60	2.02

Illinois Clays Not Now Used for Pavers.

NUMBER.	Tensile strength of green clay—Kilos per sq. cm.	Specific gravity	Porosity	FINENESS OF GRAIN.					Volume shrinkage	Linear shrinkage	Water of plasticity	Hygroscopic water.
				1 mm.	1—.1 mm.	.1—.01 mm	.01—.001 mm	.001—0 mm				
H—16	5.670	2.57	27.80	......	......	......	......	......	7.8	2.80	16.20	1.74
H—17	......	2.50	19.00	......	......	......	......	......	21.4	7.00	16.60	3.70
H—18	8.117	2.67	20.30	13.05	17.71	27.57	26.58	19.22	......	5.70	15.40	2.46
H—20	7.008	2.72	23.90	1.92	2.75	42.01	32.47	23.97	16.5	6.80	18.30	5.85
H—21	8.401	2.73	21.60	.34	.80	24.34	42.77	34.62	18.0	7.20	18.00	3.98
H—23	19.482	2.63	24.90	1.80	2.86	29.95	40.82	27.30	20.4	7.40	21.40	2.05

Clays from Other States from Which High Grade Pavers Are Made.

NUMBER.	Tensile strength of green clay–Kilos per sq. cm	Specific gravity	Porosity	FINENESS OF GRAIN.					Volume shrinkage	Linear shrinkage	Water of plasticity	Hygroscopic water.
				1 mm	1–.1mm	.1–.01 mm	.01–.001 mm	.001–.0 mm				
Indiana.												
K— 8	5.038	2.69	25.20	9.66	6.90	48.46	25.40	10.05	7.51	2.10	14.40	1.70
K— 9	4.023	2.70	26.12	11.39	1.55	65.50	14.72	7.63	3.54	.90	13.40	.79
K—10	12.503	2.69	25.40	1.06	2.42	24.62	44.29	25.52	18.29	5.82	19.60	2.31
K—11	9.094	2.66	22.21	5.36	3.76	43.74	34.45	12.94	13.50	3.25	15.23	1.75
K—12	22.586	2.67	18.26	4.49	2.88	40.51	33.82	15.32	12.74	3.60	13.35	5.09
K—13	7.529	2.71	28.30	1.82	1.35	46.74	41.73	13.15	10.54	3.30	16.30	2.16
Ohio.												
R—1	10.025	2.73	17.80	2.16	6.51	38.70	39.32	15.53	13.9	4.50	13.40	1.95
R—2	8.527	2.64	24.00	......	......	......	......	......	9.2	3.30	13.00	1.53
R—2	4.996	2.66	23.60	11.69	6.30	52.90	21.60	11.79	......	3.00	13.30	1.94
R—4	5.032	2.72	21.80	10.15	2.84	49.32	29.13	10.85	5.98	3.20	13.20	2.28
Missouri.												
S—1	9.071	2.41	23.00	......	......	......	......	......	11.97	2.70	17.20	4.76
S—2	9.882	2.60	26.40	......	......	......	......	......	13.1	4.20	16.60	2.42
Kansas.												
B—2	9.208	2.53	26.90	......	......	......	......	......	11.5	5.00	17.70	1.67
G—2	8.634	2.71	22.40	13.17	2.47	52.57	20.57	15.72	7.31	1.94	11.80	1.14
H—2	14.174	2.47	20.70	......	......	......	......	......	14.3	5.50	16.50	3.07
I—2	13.062	2.67	18.90	4.64	3.81	45.50	25.64	21.40	13.8	4.20	14.40	2.85
J—2	9.865	2.50	24.20	......	......	......	......	......	14.4	4.60	16.50	2.70
L—2	8.526	2.46	24.50	......	......	......	......	......	9.7	3.70	16.40	3.05

Changes in Porosity When Fired at Different Cones.

	010	08	06	04	02	1	3	5	7	9
K— 1	36.9	36.1	33.1	29.5	24.7	28.0	20.0	7.40	5.60	2.20
K— 2	31.4	32.9	29.1	16.2	15.7	17.6	4.5	3.08	......	......
K— 3	34.5	36.0	31.5	30.7	24.5	26.1	14.3	6.95	3.55	2.45
K— 4	36.1	36.4	33.4	28.4	21.9	20.8	7.5	2.95	2.90	3.70
K— 6	32.5	31.5	29.9	20.3	17.7	15.5	7.4	2.28	2.62	3.02
K—14	32.5	31.9	30.4	26.2	24.2	23.7	21.6	7.00	3.35	......
K—15	32.2	30.8	27.4	18.7	20.3	17.3	6.4	1.94	2.91	......
F— 1	34.5	31.9	27.5	24.9	20.6	18.5	10.2	6.45	......	......
H—16	34.0	33.5	29.7	20.6	18.1	18.3	7 85	6.9	4.3	2.16
H—17	23.7	23.8	15.6	11.3	9.5	7.5	6.00	......	......	......
H—21	33.2	30.4	22.9	20.4	20.2	15.7	7.00	......	......	......
K— 8	34.0	34.0	33.9	31.6	26.8	25.2	22.7	13.4	12.4	5.4
K—11	33.9	30.2	28.3	20.0	18.5	17.0	11.9	6.2	4.8	......
K—12	30.8	31.3	28.5	24.6	22.9	21.9	14.3	9.5	4.5	3.8
R— 1	26.5	20.8	25.4	23.4	21.4	20.7	17.4	10.2	7 6	4.4
R— 2	29.3	28.3	25.4	18.9	17.9	15.5	11.0	4 6	2.5	1.9
S— 1	34.2	33.6	31.7	21.6	23.9	17.9	9 9	......	......	......
B— 2	35.6	36.1	31.0	17.5	18.7	16.7	7.4	3.7	4.0	......
G— 2	28.0	28.2	27.2	22.5	18.0	15.6	7.1	1.4	......	......
J— 2	38.1	32.6	28.3	21.5	20.3	19.8	16.7	5.3	1.6	......
L— 2	34.4	34.1	27.1	16.7	16.6	15.7	7.1	1.7	1.6	......

Changes in Specific Gravity When Fired at Different Cones.

	010	08	06	04	02	1	3	5	7	9
K— 1	2.69	2.67	2.68	2.65	2.63	2.53	2.60	2.29	2.15	1.72
K— 2	2.62	2.65	2.64	2.54	2.55	2.56	2.48	2.09	.....	.....
K— 3	2.70	2.70	2.68	2.70	2.69	2.68	2.57	2.41	2.19	1.90
K— 4	2.67	2.66	2.69	2.70	2.64	2.66	2.47	2.33	2.00	1.88
K— 6	2.57	2.56	2.55	2.51	2.36	.....	2.43	2.31	2.00	1.79
K—14	2.65	2.64	2.63	2.61	2.60	2 57	2.58	2.29	2.14	.....
K—15	2.56	2.54	2.53	2.45	2.56	2.50	2.43	2.19	2.00	.....
F— 1	2.65	2.67	2.58	2.64	2.61	2.59	2 47	2.18	.....	.....
H—16	2.60	2.58	2.58	2.51	2.53	2.49	2.43	.....	2.22	1.80
H—17	2.64	2.61	2.62	2.51	2.45	2.40	1.60	.....	.....	.....
H—21	2.59	2.50	2.34	2.28	2.33	2.21	·2.18	.....	.....	.....
K— 8	2.70	2.70	2.73	2.72	2.62	2.62	2.57	2.22	2.21	1.92
K—11	2.60	2 55	2.59	2.48	.....	2.49	2.40	2.21	1.95	.....
K—12	2.64	2.68	2.76	2.63	2.63	2.63	2.53	.....	2.35	2.21
R— 1	2.54	2.53	2.56	2.56	2.57	2.55	2.52	2.41	2.36	2.34
R— 2	2.61	2.60	2.60	2.56	2.55	2.57	2.46	2.38	2.28	2.07
S— 1	2.47	2.48	2.50	2.44	2.48	2.41	2.31	.....	.....	.....
B— 2	2.63	2.68	2.65	2.56	2.56	2.53	2.31	2.05	1.93	1.76
G— 2	2.62	2.60	2.61	2.58	2.51	2.50	2.35	2.14	.....	.....
J— 2	2.56	2.58	2.55	2.53	2.52	2.51	2.47	2.32	2.21	.....
L— 2	2.51	2.52	2.49	2.46	2.43	2.48	2.40	2.29	2.13	1.96

CONSTRUCTION AND CARE OF BRICK PAVEMENTS.*

[By Ira O. Baker.]

Introduction.

It is not the purpose of this article to give a detailed description of the various operations connected with the construction of a brick pavement, since those having the direction of such operations are already familiar with the work or can easily find the information desired, but it is proposed to consider some fundamental relations whose importance seems to have been overlooked by writers on the subject as well as by those having the construction of brick pavements in charge. In short, this article is intended more for the property holder, the manufacturer, and the layman than for the professional engineer. The subjects to be considered will be taken up approximately in the order in which they occur in the work of construction.

Historical—A brick pavement consists of brick set on edge on a suitable foundation—either concrete, gravel, a course of brick flatwise, or a layer of plank. Such pavements have been used in Holland for perhaps a century, and to a much less extent and for a shorter period in northern England. Brick pavements were first used in the United States in 1870 at Charlestown, West Virginia, a place having a population of 12,000. The experiment was tried with a short section—less than a block—and in 1873 a block on the principal business street was laid with a good quality of building brick, and is still in service after 29 years. A block of brick pavement, laid in 1875 on a leading business street of Bloomington, Illinois, a place of 20,484 population in 1890, though constructed of an inferior building brick made of superior clay, continued in service for 20 years.

At present brick is the only paving material employed in most of the smaller cities of the Mississippi Valley, and it is used extensively in many of the larger cities in that territory. In all parts of this country, the use of brick for residence streets and light traffic business streets is rapidly increasing. A recent canvass shows about as much brick pavement in progress as granite block, asphalt, and wood com-

* Printed by permission in the Clay Record, October 30, 1906.

bined.   There are in this country nearly two hundred plants, devoted
to the manufacture of paving brick, some having annual outputs of
60,000,000 to 100,000,000 bricks.

Width of pavement—In many cases a considerable part of the money
spent for a pavement is wasted by making the pavement wider than is
really necessary.   A narrow pavement not only costs less to construct,
but also costs less to clean and to sprinkle.   Of course, except for the
cost, the wider the pavement the better; but length is more desirable
than width.   An excessive width is a needless expense, and delays or
wholly prevents the getting of any pavement at all; and hence one
help towards securing pavements is to make them only wide enough to
accommodate the travel.

It is not unusual to find residence streets in small cities, without
street car tracks, with pavements 36 to 40 feet wide.   The only travel
over such streets consists of private carriages and the delivery wagons
that supply goods of various kinds to the residents.   All the pavement
that such streets really require is a width such that two vehicles may
pass at a reasonable speed and with ordinary care without interference.
A width of 18 feet affords sufficient room for a vehicle to pass when
another is standing on each side of the pavement—a rare occurrence;—
and therefore it appears that a pavement 18 feet wide, or at most 20
feet, is sufficient for the less frequented residence streets.   Therefore
any money spent to construct a wider pavement is really not necessary;
and the cost of sprinkling and sweeping is also needlessly increased.
Further, narrowing the pavement increases the lawn space, which not
only improves the appearance of the street, but also gives additional
space in which to place gas pipes, water pipes, etc., and thereby pre-
vents the tearing up of the pavement which is always a damage.   The
only objection to a very narrow pavement is the difficulty of turning
a team on it.   The seriousness of this objection depends upon the
construction of the vehicle.   Many delivery wagons, express wagons, etc.,
may be turned easily on an 18 foot pavement.   If occasionally a vehicle
is compelled to go to the corner to turn, or even to drive around the
block, the inconvenience is not very serious, and it is so infrequent as
not to justify any considerable expense to prevent it.   If the block
is long, or if the objection to some vehicles being compelled to drive
around the block is considered important, then it is much cheaper to
construct a turning place near the center of the block than to build an
additional strip of pavement the entire length of the street.

The cost of a pavement, per square yard, is practically independent
of its width, and therefore the reduction of the width of the pavement
on residence streets from 36 or 40 feet to 18 or 20 feet will save nearly
50 per cent of the cost, and if the cost can be reduced one-half, the
number of paved streets will be increased much more than propor-
tionally.

It is not wise to take time to discuss the width of pavements on resi-
dence streets containing car tracks, nor on business streets; but a little
investigation will show that in many cases the pavement is considerably

wider than has been found entirely satisfactory under similar condi-
tions. The views here express not mere theory, but are supported by
experience in a number of cities. In recent years there has been a
marked tendency, in the middle West at least, to reduce the width of
pavements on residence streets and on business streets in the smaller
cities. Attention is here called to the matter because far too often the
width of the pavement is made a fixed proportion of the total width
of the street regardless of the real needs of travel. This is only one of
the many ways in which some municipalities suffer from the lack of
more competent engineering service—the loss frequently being many
times the supposed saving.

CONSTRUCTION OF SUBGRADE.

It is necessary to say that the subgrade is the ultimate support of
any pavement, and that both the cost and the efficiency of a pavement
depends upon the supporting power of the soil upon which it rests.
There are only two ways of increasing or supplementing the supporting
power of the subgrade: (1) by underdrainage, or (2) by constructing a
pavement that will distribute the concentrated load of the wheel over a
considerable area of the subgrade. Usually the former is both the
cheaper and the more effective. Tile drainage is cheap to construct, is
certain in action, and costs nothing for maintenance. With all soils,
except clean dry sand, the cost of both the construction and the main-
tenance of the pavement can usually be materially decreased by proper
underdrainage. Unless the subsoil is very open and porous, it is
economical to lay a tile under each edge of the pavement, 2 or 3 feet
below the surface of the subgrade.

Not only should the subgrade be properly drained, but it should be
thoroughly rolled to compact the surface and also to reveal any soft
spots. Usually just before a pavement is to be constructed, the street
is dug up to lay sewers and water and gas pipes and to connect these
with the private property; and almost universally the trenches are re-
filled in such a manner that great care and skill are required to con-
struct a pavement which will not ultimately settle over the trenches,
much to the damage of the pavement and the disfigurement of the
street. It is always specified that the subgrade shall be thoroughly
rolled; but it needs only a casual inspection of the pavements of any
city to show that this is seldom in a manner to prevent settlement. The
cheapest and surest method of preventing such settlement is to properly
re-fill the trenches; but usually this is indifferently done, owing to the
ignorance or the carelessness of the proper municipal officer, and as
a consequence the remedy of this defect is left to the paving contractor.

The method to be employed in refilling trenches so that they will not
settle, depends upon the kind of soil and also upon the relative cost of
labor and water. The problem of the proper filling of trenches is too
intricate to permit a thorough discussion here; but briefly it may be said
that except in the case of comparatively clean sand and gravel, back-
filling can be thoroughly done only by tamping; and to make this
method successful it is necessary (1) that the material shall be moist

enough to be plastic, but neither too wet nor too dry, (2) that it shall be deposited in layers not more than 3 or 4 inches thick and (3) that each layer shall be thoroughly tamped. To secure thorough tamping the relative number of tampers and shovelers is sometimes specified; but this alone is ineffectual since there is a natural tendency for the tampers to work less energetically than the shovelers, and besides more labor is required to tamp the soil around a pipe than higher up. No kind of municipal work should be more rigorously inspected than the filling of a trench over which a pavement is to be laid. The nearly universal result of a neglect in this respect is that a pavement built at great expense is disfigured or damaged by settlement, the repair of which will cost many times as much as it would have cost to properly fill the trench originally.

The subgrade should be rolled both longitudinally and transversely with a steam roller weighing not less than five tons. If the street is rolled in only one direction, only one set of trenches will be compacted. The subgrade can not be rolled transversely with a horse roller; and besides the horses' feet tear up the subgrade nearly as much as the roller compacts it, particularly when the rolling is almost completed. The roller should pass over the surface several times to settle the filling into the trenches and also to compact the surface by the kneading action of many passes of the roller. Unfortunately the specification requiring the use of a steam roller adds somewhat to the cost of a pavement, since that implement is expensive in first cost and also in maintenance; and since ordinarily it can be used only a comparatively short time each year; but its use is believed to be worth its cost, particularly if the trenches were not properly back-filled.

FOUNDATION.

Choice of Materials—There are several forms of foundation suitable for brick pavements, viz.: Concrete, gravel, macadam, a course of brick laid flatwise, or a layer of plank. Concrete is by far the most common foundation; and apparently a plank foundation was never used except in a single city, and it has been abandoned there.

It seems to be the common belief that only a 6-inch layer of concrete is a suitable foundation for a brick pavement. The truth is that in some cases a 6-inch layer of concrete is unnecessarily thick, while in other cases a layer of gravel or of broken stone will make an equally good and more economical foundation. Less skill is required with a gravel or broken stone foundation than with a concrete foundation. Those who have made cuts into concrete pavement foundations report that in many cases the concrete is no better than a layer of broken stone without cement, due apparently to carelessness, or inefficiency, or dishonesty in the construction. The process of placing gravel or broken stone is simpler, and therefore there is less danger of inferior work; and the gravel or broken stone requires less hand labor, which is an advantage to contractors in these days of inconsiderate demands of laboring men. As to whether concrete, gravel, or broken stone be used

for the foundation in any particular case depends upon local prices and the local condition; and right here is where the city needs engineering advice of a high order, for a single word in the specification may add hundreds of dollars to the cost of the work without any return. It is more scientific and usually more profitable to give time to the consideration of the specifications beforehand than to the higgling with the contractor afterwards.

The various forms of foundations will be considered separately.

Concrete—Nowadays it seems to be the general belief that a 6-inch concret base is necessary for a brick pavement; at least, this foundation is used indiscriminately for business and residence streets, and is used indiscriminately also on the stiffest soil and on the softest. A 6-inch concrete foundation is ordinarily used under an asphalt pavement, which is a more or less flexible layer from 2 to $3\frac{1}{2}$ inches thick; while the same thickness of concrete is ordinarily used with a brick pavement having a cement filler, which is a very rigid layer from 5 to 7 inches thick. Is there any evidence that the foundations of asphalt pavements are generally too weak?

An engineering journal recently contained an account of a test of the supporting power of an asphalt pavement, made by hauling over it a truck weighing 22,300 pounds and giving a pressure of slightly over three tons on two wheels having tires four inches wide. The foundation consisted of a 4-inch layer of natural-cement concrete mixed in the proportion of one part cement, two parts sand, and five parts crushed stone. The asphalt wearing surface was two inches thick. The subgrade consisted of "soft wet clay which has been much disturbed by many trenches for sewers and for water and gas pipes." The pavement had been in use twelve years when tested, and had shown no signs of failure. "The above load was hauled over this pavement from end to end and produced no effect upon the pavement except to make a slight depression in the asphalt where the wheels stood for half an hour, the day being warm."

Does this prove that the concrete foundation of brick pavements are generally needlessly thick? Surely if four inches of concrete over soft clay and under a 2-inch asphalt wearing-coat can support such loads, six inches of concrete is needless under brick pavement with cement filler.

Let us consider this question from another point of view. There are three and only three reasons for constructing a pavement, viz.: (1) To secure a smooth surface for ease of cleaning and to decrease tractive resistance; (2) to secure an impervious roof to prevent rainwater from softening the subgrade; and (3) to interpose a layer that shall distribute the concentrated load of the wheel over so great an area of the subgrade that it can safely support the load without depression. For the moment, we are not concerned about the smoothness of the surface, and hence nothing will be said here about the first reason for constructing a pavement. The wearing surface of a brick pavement is practically impervious whether sand or cement filler be used, and consequently a concrete foundation is not necessary to secure a

water-tight roof to protect the subgrade. Therefore, the concrete foun-
dation of a brick pavement acts only to distribute the load of the wheel
over the subgrade. The concrete distributes the load by virtue of its
ability to act as a beam; and this property is due to the cement which
the concrete contains. If there were no cement in the concrete, the layer
of gravel or crushed stone would distribute the concentrated load of the
wheel over a considerable area. The pressure of the wheel is transmitted
downward in diverging lines; and if the point of contact of the wheel
is considered as the apex of a cone having its base on the subgrade, it
may be assumed that the load of the wheel distributed nearly uniformly
over the base of this cone. It is unwise to attempt here to go into the
mathematics of the subject further, but the efficiency of a layer of
broken stone in distributing a concentrated load is proved by the
fact, that, under favorable circumstances as to soil and drainage, 4
inches of broken stone has successfully carried considerable travel,
while 6 inch macadam roads are quite common in a number of states.
If 4 or 6 inches of macadam without any other pavement will carry
travel, the same thickness will certainly make a good foundation for a
brick pavement under ordinary conditions—particularly if a cement
filler is used, since the filler gives the course of brick a considerable
transverse strength, as will be discussed later. The writer recently
saw a piece of brick pavement with sand filler which is laid directly
upon the black loam of the Illinois corn belt, which for six or eight
years has carried the heaviest travel of a city of three or four thousand
inhabitants, and which is still in good condition. A tile drain was laid
at each side of the street, the subgrade was well rolled, and the paving
bricks (not blocks) were laid upon a layer of sand and small gravel
only one or two inches thick. Probably no small part of the success
of this pavement is due to the fact that a prominent intelligent and
successful local business man acted as inspector. The writer does not
advocate the general adoption of this form of construction; but cites
this case to show what can be done by intelligence and care, and to prove
that a layer of concrete is not always necessary. A needlessly expen-
sive form of construction is not only money wasted, but deters the con-
struction of other pvaements.

Not infrequently pavements having a concrete foundation are found
which have settled over trenches. Does not this prove that the ordinary
concrete foundation is not strong enough? No, it simply proves that
the foundation over the trench was not strong enough. There are two
remedies for this condition of affairs. Either consolidate the filing in
the trench better by rolling or tamping as described above, or make the
concrete thicker over the trench. The first is cheaper and more scien-
tific. In no case is it justifiable to thicken or strengthen the founda-
tion over the entire street simply because trenches occupying from 5
to 10 per cent of its surface may not have been properly back-filled.

Before considering substitutes for concrete foundations, let us exam-
ine the concrete a little further. Formerly it was the custom to use a
rich natural-cement concrete, because it was cheaper than a Portland-

cement concrete of equal strength. A few years ago nearly all the
Portland cement used in the country was imported, while now nearly
all of it is of domestic manufacture; and further, it is not only home-
made, but is both better and cheaper. Although natural cement is
marvelously cheap, a concrete of a given strength can be made cheaper
of Portland than of natural cement. Experiments made at the Uni-
versity of Illinois show that a concrete composed of one part cement,
eight parts of coarse sand or fine gravel, and eight parts of screened
or broken stone was considerably stronger in compression and also in
bending than a concrete composed of one part natural cement, three
parts of the same sand, and three parts of the same broken stone.
These proportions have been practically tested in the construction of
half a mile of pavement with the greatest satisfaction to all parties
concered. Prices vary greatly with the locality, but in most, if not all,
cases Portland-cement concrete is cheaper in proportion to strength
than that made with natural cement.

Before dropping the subject of concrete foundations, a few words
should be said in condemnation of the quite general practice of leaving
the upper face of the concrete needlessly rough and irregular, with loose
stones strewn over the surface. To secure a uniform surface for the
pavement, the cushion coat should be of uniform thickness, and hence
the top face of the concrete should be practically parallel with the sur-
face of the finished pavement. Also any loose stones on top of the
concrete causes the brick to be broken during the rolling and produces
inequalities in the surface of the finished pavement. Both of these
effects can be eliminated without appreciable expense by a little care.

Gravel—Where gravel is cheap, it is better to use a thicker layer of
gravel without cement than a 6 inch layer of gravel with cement, i. e.,
a 6 inch layer of concrete. To secure a good foundation, the gravel
must be properly used, which apparently is seldom or never done.
The usual method seems to be to dump the gravel upon the subgrade
directly from wagons, and then to level off between the piles with
shovels. By this process the lower part of the original piles is much
more compact than the space between the piles; and rolling does not
materially lessen the inequalities; since the roller, being a cylinder of
considerable length, rides upon the tops of the piles and does not com-
press the gravel between them. The result is that soon after the pave-
ment is completed, the natural settlement of the gravel foundation
causes the surface to be full of depressions.

The better and cheaper method is to level off the piles with a scrap-
ing road-grader, (the ordinary "road machine") and then thoroughly
harrow the gravel with a long-toothed harrow, after which the founda-
tion should be rolled. For the best results, the gravel should be spread
in layers not more than three or four inches thick. Brick pavements
upon gravel foundations laid by this method have shown no depressions
after many years, while those constructed with the utmost care by the
preceding method with the same gravel on the same soil have been

full of holes. This is another example showing that cheaper materials and proper methods intelligently give better results than expensive materials improperly used.

Broken-stone—Where broken stone is cheap, it is better economy to use more stone and omit the cement from the foundation, i. e., use broken stone alone instead of concrete. If the rock is soft or contains much fine material as it comes from the crusher, it should be screened to take out all dust and most of the pieces up to say $\frac{1}{4}$ inch in greatest dimensions. The broken stone may be hauled to the street in wagons, and dumped upon the subgrade. It may be spread by hand with forks or rakes, or it may be spread with a scraping road-grader, the latter method being the cheaper. In spreading the stone care should be taken that the several sizes are not separated too much, and that the piles on which the stone was dumped from the wagons are not left too high. The layer of stone should be rolled until the individual stones do not move as one walks over the surface, or until the surface stones are not easily kicked out with the foot. After the completion of the rolling, the surface of the broken stone should be impervious to the sand to be used in the cushion coat. With most stone this condition will be secured by the crushing of the top layer of the broken stone during the rolling; but if there are spots that are porous, throw on a few shovelfuls of fine stone and roll again. If the stone is hard, it may be necessary after the rolling is nearly completed to apply a thin coat of finer or softer stone. Of course the top of the foundation should finally be left smooth and of proper grade and crown.

The rolling required with either a gravel or broken-stone foundation can best be done with a steam roller, which is only an additional reason for specifying that the subgrade shall be rolled with a steam roller. Although it is a little out of place here, this is the most convenient place to say that a steam roller is also much better than a horse roller for rolling the brick. If the subgrade, and the gravel or broken-stone foundation, and the brick are all rolled with a steam roller, the cost of rolling any one of these is materially lessened, since the roller is thus used a greater part of the time.

Brick—The first brick pavements were laid on a foundation consisting of a layer of gravel and a course of brick laid flatwise. This form of foundation has been abandoned for two reasons: first, because some other form is usually cheaper; and second, because of the lack in the past of proper precautions in laying this form of foundation. There have been two defects in constructing this form of foundation. First, the gravel is neither spread nor consolidated uniformly. The proper method of spreading and rolling the gravel has been described above under the head Gravel. The second defect consists in laying broken bricks with their broadest side up, and hence the space below is not well filled while the cushion coat is being spread, and consequently after the pavement is completed the cushion coat works into these cavities and permits the surface of the pavement to sink. If all broken brick are laid on the broad side and care be taken thoroughly to fill the joints while laying the cushion coat, this form of foundation will

give satisfaction, even though the lower course of brick be quite in-
ferior. The writer is quite familiar with a piece of such pavement laid
on a very unfavorable subgrade, but with proper precautions in the two
respects mentioned above, which for ten or fifteen years has given entire
satisfaction and has as good a surface as adjoining pavements on a con-
crete base, even though the latter are on a more favorable subgrade and
carry less travel. This pavement illustrates a rule of construction
that can not be repeated too often, viz.: No good brick pavement can
be constructed without proper attention to all details.

CUSHION.

The cushion is a layer of sand 1 to 2 inches thick between the founda-
tion and the wearing course of brick, to secure a uniform bed or bearing
for the brick. Unless the bricks or blocks are unusually uniform, the
cushion layer should be 2 inches thick.

The thickness should be as uniform as possible so that the bricks will
settle evenly during the rolling; and therefore the top of the concrete
foundation should be carefully finished with a surface parallel to the
surface of the pavement. Not infrequently loose fragments of stone
are left on the surface of the concrete, a result which is very undesirable,
since they necessitate a thicker cushion and at best prevent the bricks
from coming to a uniform bearing. With good workmanship in laying
the concrete, there will be no loose pieces of stone on the surface; and
if they do happen to get there, they should be removed before laying
the cushion coat.

When the sand cushion is laid on a foundation of broken stone, care
must be taken to roll the stone so that the jar of the traffic will not
cause the sand to work into the broken stone, thus permitting the pave-
ment to settle and to become rough and uneven. If the broken stone is
rolled until the surface of the layer is firm and solid and does not shake
under the foot in walking over it, unless the stone is very hard and
tough there is not much danger of the sand's sifting into the stone.

The sand for the cushion should preferably be so fine as to be of a
soft, velvety nature, and should contain no pebbles of any considerable
size, or loam or vegetable matter. The size of pebbles permissible de-
pends upon the thickness of the sand bed. Pebbles will prevent the
brick from having a uniform bearing; the loam is likely to be washed
to the bottom of the layer and cause the brick to settle; while the vege-
table matter will decay or wash away, and leave the brick unsupported.

The spreading of the sand should be carefully done, so as to secure
a uniform thickness and to have its upper surface exactly parallel to
the top of the finished pavement. After the sand has been distributed
approximately to the proper thickness with a shovel, the surface should
be leveled by drawing over it a template conforming exactly to the
curvature of the cross-section of the proposed surface of the pavement.
The template should be drawn slowly over the sand bed several times,
any depressions that develop being filled by sprinkling sand into them
with a shovel. A considerable quantity of sand should be drawn along

in front of the template, as this aids materially in packing the bed. It is necessary to draw the template several times to pack the sand well, particularly if there are wet and dry spots, as the successive jarring of the sand grains causes them to settle more closely together. When the sand cushion is properly packed it will have a uniform, smooth, velvety appearance, and will not look rough, porous and grainy.

The surface of the cushion layer is often prepared with a short lute; but the template secures a more uniform surface and also gives a greater compression and more even bed. With hand luting the surface of the pavement is almost certain to be covered with saucer-like depressions after it has been rolled. Hand luting should be prohibited except where the use of the template is impossible, as around man-hole covers, at street intersections, etc.

THE BRICK.

Character—A paving brick is simply a brick which, owing to careful selection of the clay and to skill in the manufacture, is so hard and tough that it will resist the crushing and the abrading action of the traffic. The brick should be reasonably perfect in shape, should be free from marked warping or distortion, and should also be uniform in size, so as to fit closely together and make a smooth pavement. Any particular brick should be homogeneous in texture and should be free from lamination or seams, so as to wear uniformly; and all the brick used in a pavement should be of the same grade so that the pavement may wear evenly.

Testing—To determine the difference in quality of bricks of different manufacture, it is necessary to carefully test them. This is done by rolling the bricks or blocks with blocks of cast-iron in a revolving cast-iron cylinder or "rattler." The National Brick Manufacturer's Association, as a result of an extended series of experiments, has adopted a standard method of conducting this test which is so well known or so easily obtained as to make it unwise to give the details here.

Different bricks are rated according to the loss by wear in the "rattler;" but the per cent of loss will depend upon the care employed in culling the brick and in selecting the samples, as well as upon the character of the brick. To show the results that may be expected, the following data obtained by a city in Illinois in the ordinary course of business are given. The samples were selected after delivery upon·the the street, by a representative of the city. The tests were carefully made according to the "N. B. M. A. standard" as above. The material was in the form of books approximately 3″ x ″ 9″. The average loss of ten lots was 18.34 per cent with a range from 15.4 to 24.6 per cent; and omitting the largest result, the average was 17.64 per cent with a range from 15.4 to 21.2 per cent. Of the ten kinds of blocks, two had losses of less than 16 per cent, four less than 18, six less than 19, and eight less than 20 per cent.

The above data are for blocks approximately $3'' \times 4'' \times 9''$. Bricks approximately $2'' \times 4'' \times 8''$ will lose from 2 to 6 per cent more than the above blocks; but not enough data have been accumulated to determine with any accuracy the effect of size upon the loss in the rattler test.

A study of the details of the experiments referred to above indicates that an occasional manufacturer can furnish paving blocks giving a loss of 15 per cent or even less; but whether it is wise so to specify will depend upon the service required and upon the cost of different grades of paving blocks. A severe specification will require more careful culling of the product of the kiln and will also limit competition—both of which demands will increase the cost. The limit to be specified in any particular case will depend upon the special conditions; and should be the result of very careful study of the attendant conditions.

Setting the Brick—There is neither space nor need of discussing this subject here, further than to say that each brick should be pressed or rather struck against the side and also the end of the bricks already in position.

Inspection—After the bricks have been set in position the pavement should be carefully inspected, and all very soft or very hard bricks should be removed so that the pavement may wear uniformly. A brick having only a small piece chipped from the corner or edge may be turned over.

ROLLING THE PAVEMENT

After all rejected brick have been removed and the pavement has been swept, it is ready for rolling, which should be done with a steam roller weighing from 3 to 6 tons. A very heavy roller is undesirable, at least in the beginning of the rolling, since the first passage of it tilts the brick to one side so much that it is nearly impossible to straighten them up again. The roller should not weigh more than six tons, and four is better. Unless the top faces of the bricks are brought to a plane, the pavement will be rough and noisy, and will lack durability. The bricks should be firmly settled into the sand bed so that traffic may not depress some of the brick, which will make the pavement rough and also make it wear needlessly fast.

The pavement should first be rolled longitudinally, beginning at the crown and working toward the gutter, taking care that each return trip of the roller covers exactly the same area as the preceding trip so that the second passage of the roller may neutralize any careening of the brick due to the first passage. Pavements that have been rolled only once or always in one direction are very much rougher and more noisy than when properly rolled. If a spot is skipped on the return passage of the roller, it can be detected by a casual inspection of by the noise of a passing vehicle. The first passage of the roller should be made at a slow speed, not faster than a slow walk, to prevent undue canting of the brick. After the pavement has been rolled longitudinally, roll it back and forth transversely, or at least in both directions at an angle of

45 degrees from curb to curb. The purpose of the rolling is to settle the bricks uniformly into the cushion layer or sand bed. The rolling should not be done with a horse roller, since the horse's feet disturb the position of the loose brick, and also it is impossible to roll the street transversely.

FILLING THE JOINTS.

The joints between the bricks or blocks should be filled to keep the brick in the proper position, to lessen the chipping of the edges of the brick, and to prevent water from penetrating to the cushion coat and to the foundation. Three forms of filler are in common use, viz.: Sand, tar and hydraulic cement.

Sand Filler—Sand was the first filler employed for brick pavements, and in the Middle West is even yet almost exclusively used. The sand should be fine and dry, and should be worked into the joints by sweeping it over the pavement, which also should be dry. Although the sand is nominally always swept into the joints, it is usually simply spread upon the surface and left to be worked in by traffic, which is undesirable since the joints are eventually filled with manure and street dirt. The sand can be swept into the joints effectively and economically with a revolving machine sweeper. The cost of sweeping the pavement preparatory to filling the joints and the filling of the joints, including the cost of sand, is usually about two cents per square yard.

The advantages of a sand filler are: 1. It is cheaper than any other form of filler. 2. The pavement may be thrown open to traffic as soon as the bricks are laid. 3. The pavement may be taken up easily and without breakage of the brick. 4. It is practically watertight, particularly after being in service a short time.

The disadvantages of a sand filler are: 1. It does not protect the edges of the brick from chipping. 2. It may be washed out on steep slopes. 3. It is removed from the top of the joints by the street sweeper.

Tar Filler—Tar is occasionally used as a filler for the joints of a brick pavement pavement. The grade ordinarily used is that known to the trade as No. 5 or No. 6 coal-tar distillate. The bricks should be dry, and the tar should be applied at a temperature of 300° to 320° Fahr. by being poured into the joints with a vessel very much like a sprinkling pot without the nose. The success or failure of the tar filling depends on the efficiency and care of the person in charge of heating the tar. If the tar be too hard, it pulverizes in very cold weather; if it be too soft, it runs and becomes sticky in very hot weather. The cost of a tar filler depends upon the locality and upon the closeness of the joints. Usually tar costs from 6 to 8 cents a gallon; and one gallon is generally sufficient for one square yard of pavement. The total cost of the filler varies from 10 to 12 cents per square yard of pavement.

Tar is superior to sand in that it makes a perfectly watertight joint; and it is superior to hydraulic-cement grout in that it is not so rigid and therefore makes a more quiet pavement. Tar costs more than sand, and does not protect the edges of the brick as well as hydraulic-cement grout.

The objections to tar are: 1. In summer it is likely to melt and run out of the joints; and in winter it is brittle and likely to chip out of the joints. 2. The heating of it makes unpleasant odors on the street.

Cement filler—The most common joint filler, other than sand, is a thin mortar composed either of neat Portland cement or of 1 part cement and 1 part fine sand, the latter proportions being the more common. The pavement should be copiously sprinkled immediately before the grout is applied. The sand and the cement should be mixed in batches say of not more than 40 to 50 pounds of each at one time, in a tight mortar box. The box for this purpose should be $3\frac{1}{2}$ to 4 feet long, 27 to 30 inches wide, and 12 to 14 inches deep, and should have legs of different lengths, so that the mixture will readily flow to the lower edge of the box, which should be 8 to 10 inches above the pavement.

The sand and the cement should first be mixed dry; and when the dry mixture assumes an even and unbroken shade, water should be added in a sufficient quantity to form a grout of the consistency of thin cream. The grout should be removed from the box to the pavement with a scoop shovel, and not by overturning the box; since by the last process the sand, cement, and water are separated and are deposited on different portions of the pavement. While the box is being emptied the grout should be constantly stirred to prevent a separation of the sand from the cement; and after the grout has been applied to the pavement, it should be quickly swept into the joints with steel brooms. It is better that the joints should be only about half filled at the first application, since then there is a less depth of grout in the joints and consequently less liability of the separation of the sand, the cement, and the water.

To secure the best results, a mortar box should be provided for each 10 feet of width of the street, and the full width of the street should be filled at practically the same time. After the filling has been carried forward for 40 or 50 feet, the same space should be filled again in like manner, except that the mixture for the second filling should be slightly thicker than the first. The joints should be filled entirely to the top in the second application. After the joints have thus been filled, a half inch of fine sand should be spread over the entire surface of the pavement; and if the weather is very hot or dry, the sand should be sprinkled at intervals for two or three days, to insure that the cement does not lose by vaporation the water necessary for chemical combination in setting. Traffic should be kept off the pavement from 7 to 10 days, or at least until the cement has firmly set. If the cement filler is disturbed before it is fully set, it is practically no better than sand. If

the cement filler is put in as described above and allowed to set firmly before being used, it will wear no faster than the best paving bricks and will prevent spalling and chipping of the bricks at the edges and corners.

The amount of grout required will vary with the openness of the joints, with the depth of the grooves, and also with the quantity of sand of the cushion coat that works up into the lower part of the joints, while the bricks are being rolled. With a grout mixed 1 to 1, a barrel of cement will usually fill from 25 to 40 square yards. The cost of mixing the grout in small quantities and applying it as above varies from 1 to $1\frac{1}{4}$ cents per square yard; and with ordinary re-pressed blocks and reasonable care in securing close joints, the cost of a 1 to 1 Portland-cement grout applied as described above will usually vary from 10 to 12 cents per square yard.

The advantage of the cement filler is that it protects the edges of the bricks from chipping, and thus adds to the durability of the pavement. When the joints are filled with sand or tar, the edges of the bricks chip off, the upper faces wear round, the pavement becomes rough, and the impact of the wheels in jolting over the surface tends to destroy the brick; while with a good cement filler, the edges do not chip, the whole surface of the pavement is a smooth mosiac over which the wheels roll without jolt or par, and consequently the life of the pavement is materially increased.

An objection to the cement filler is that it does not take up the expansion of the pavement due to increase of temperature, and that consequently the pavement is likely to rise from the foundation and give out a rumbling noise as vehicles go over it. This rumbling can be prevented by placing a tar-joint from $\frac{1}{2}$ to 1 inch thick next to each curb. The compression of the tar allows the bricks to expand without lifting the pavement from its foundation. This tar-joint can be inserted by setting a 1 inch board next to the curb before laying the bricks, and then after the bricks are laid withdrawing it and filling the space with coal-tar distillate No. 5 or 6. The longitudinal expansion can be taken up either by filling three or four transverse joints with tar, each 25 or 30 feet, or by inserting a 1 inch tar-joint each 40 or 50 feet. These expansion joints will require a gallon of tar for each 5 or 6 square yards.

An alleged objection to the cement filler is that in making repairs it is difficult to remove the brick without breaking many, and it is difficult to clean brick so that they may be used again. This is really an advantage if it will in any degree prevent the tearing up of the pavement; and at best this objection ought not to have much weight against durable construction.

A third objection is that the street can not be used while the cement is setting. Often the cement is not allowed to set fully before throwing the street open to travel, and consequently the chief advantage of the rigid filler is lost.

MERITS OF BRICK PAVEMENTS.

Bricks as paving material have some attractive features.

1. They may be had in small units of practically uniform size. 2. They may be had in large or small quantities. 3. They may be laid rapidly without special expert labor. 4. When failing pipes or other causes necessitate the disturbance of the pavement, ordinary tools and intelligence can restore the original surface. 5. Brick pavements give a good foothold for horse. 6. They do no wear slippery. 7. They are adapted to all grades, being used upon grades of 10 to 15 per cent without serious accident or inconvenience. 8. They have low tractive resistance, particularly if the joints are filled with Portland cement grout. 9. They are not specially noisy when properly laid. 10. Brick pavements themselves yield little or no mud or dust. 11. They are easily cleaned. 12. If the joints are filled with sand, they are only slightly absorbent; and if filled with tar or cement, they are absolutely non-absorbent. 13. Brick pavements have a pleasing appearance. 14. They are very durable, particularly if the joints are filled with Portland cement. 15. They are easily repaired.

INDEX.

305

—20 G

Index—Continued.

Index—Continued.

Index—Continued.

Index—Continued.

Index—Continued.

P

Index—Continued.

Index—Concluded.

LIST OF PUBLICATIONS.

A portion of each edition of the Bulletins of the State Geological Survey is set aside for gratuitous distribution by the Survey and by the Secretary of State. To meet the wants of libraries and individuals not reached in this first distribution, 500 copies are in each case reserved for sale at cost, including postage. The reports may be obtained upon application to the State Geological Survey, Urbana, Illinois, and checks and money orders should be made payable to H. Foster Bain, Director, Urbana.

The list of publications is as follows:

Bulletin 1. The Geological Map of Illinois: by Stuart Weller. Including a folded, colored geological map of the State on the scale of 12 miles to the inch, with descriptive text of 26 pages. Gratuitous edition exhausted. Sale price *45 cents.*

Bulletin 2. The Petroleum Industry of Southeastern Illinois: by W. S. Blatchley. Preliminary report descriptive of condition up to May 10th, 1906. 109 pages. Gratuitous edition exhausted. Sale price *25 cents.*

Bulletin 3. Composition and Character of Illinois Coals: by S. W. Parr. With chapters on the *Distribution of the Coal Beds of the State,* by A. Bement, and *Tests of Illinois Coals under Steam Boilers,* by L. P. Breckenridge. A preliminary report of 86 pages. Gratuitous edition exhausted. Sale price *25 cents.*

Bulletin 4. Year Book of 1906, by H. Foster Bain, director, and others. Includes papers on the topographic survey, on Illinois fire clays, on limestones for fertilizers, on silica deposits, on coal, and on regions near East St. Louis, Springfield and in Southern Calhoun County. 260 pages. Gratuitous edition exhausted. Sale price *35 cents.*

Bulletin 5. Water Resources of the East St. Louis District: by Isaiah Bowman, assisted by Chester Albert Reeds. Including a discussion of the topographic, geologic and economic conditions controlling the supply of water for municipal and industrial purposes, with map and numerous well records and analyses. Postage *6 cents.*

Bulletin 6. The Geological Map of Illinois: by Stuart Weller. *Second edition.* Including a folded colored geological map of the State on the scale of 12 miles to the inch, with descriptive text of 32 pages. It includes corrections and additions to the former map and text and shows locations of mines where coal, lead, zinc and flourspar are produced. The great oil fields of southeastern Illinois are also outlined. Gratuitous edition exhausted. Sale price *45 cents.*

Bulletin 7. Physical Geography of the Evanston-Waukegan Region: by Wallace W. Atwood and James Walter Goldthwait. Forming the first of the educational bulletins of the survey and designed especially to meet the needs of teachers in the public schools. 102 pages. Gratitous edition exhausted. Sale price *25 cents.*

Bulletin 8. Year Book for 1907: by H. Foster Bain, director, and others. Including administrative report; papers on the general geology and mineral production of the State; a directory of the clay industries; reports on stream improvement, land reclamation and topographic mapping; on field and laboratory studies of coal, cement materials, oil, gas, lead, zinc and silica. 393 pages. Gratitous edition exhausted. Price *30 cents.*

Bulletin 9. Paving Brick and Paving Brick Clays of Illinois: by C. W. Rolfe, R. C. Purdy, A. N. Talbot and I. O. Baker. Including a discussion of the geology of clays, the qualities of high grade paving brick, the properties of paving brick clays, tests and methods of testing, and the construction and care of brick pavements. 315 pages. Postage *13 cents.*

Circular No. 1. The Mineral Production of Illinois in 1905. Pamphlet, 14 pages, postage *2 cents.*

Circular No. 2. The Mineral Production of Illinois in 1906. Pamphlet, 16 pages, postage *2 cents.*

Circular No. 3. Statistics of Illinois Oil Production. 1907. Folder, 2 pages postage *1 cent.*

Circular No. 4. The Mineral Production of Illinois in 1907. Pamphlet, 16 pages, postage *2 cents.*

ERRATA.

p. 141. Formula in third paragraph should read

$$100 \left[\frac{(W-D) + S}{V} \right] = \% \text{ porosity}$$ where W is the saturated weight of the briquette; D, the dry weight of the briquett; S, the density of the oil, V, the volume of the briquette.

p. 175. The expression which is assumed to present the relative value of the several factors controlling drying behavior of clays should read.

$$\frac{S^3 \, T}{\left(\frac{V}{100} \right)^3 E} = M \text{ (drying modulus)}$$ where S is the surface factor representing fineness of grain; T, the tensil strength; V, volume shrinkage in percents and E, the excess water.

p. 181. Second paragraph. Instead of table XVI it should read table XVIII.

p. 181. In table XX data in the last column are parts of the "Weight Ratio." The subheading "Weight Ratio" should have been extended so as to cover all of the last three columns.

p. 190. Second paragraph next to the last line, in place of the word "radically" it should read "raidialy."

p. 199. The development and final expression of the plasticity, modulus should be as follows:—
For the decrease in area of cross section due to the initial stretch we have

$$1.9^2 = \frac{1.9^3}{1.9-a} = \frac{1.9^3+1.9^2 a - 1.9^3}{1.9+a} = \frac{1.9^2 a}{1.9+a}$$ where "a" is the amount of initial stretch.

For the decrease in cross section due only to the final stretch we have

$$\frac{1.9^3}{1.9+a} - \frac{1.9^3}{1.9+a+b} \text{ or } \frac{1.9^3 b}{1.9^2+3.8a+1.9b+a^2+ab}$$

A measure of the tension which is holding the grains together is assumed to be directly as the load and inversly as the product of the decrease in cross section due to the initial and final stretch. On performing these indicated operations we have resulting

$$L \left[\frac{6.859+10,83a+3.61b+5.7a^2+3.8a\,b+a^3+a^2b}{24.76ab} \right] = M$$

p. 210. Fig. 21 should be described as "Diagram showing operations of fluxes on $Al_2O_3 + 2SiO_2 + \frac{1}{2}Sio_2$ using fractions of their molecular weights."

p. 219. The page citations left blank should read for the Grout reference p 181-186 inclusive and for the Fox reference p. 186.

LIBRARY CATALOGUE SLIPS.

[Mount each slip on a separate card, placing the subject at the top of the second slip. The name of the series should not be repeated on the Series card, but the additional numbers should be added, as received, to the first entry.]

Rolfe, C. W., and others.

<small>AUTHOR.</small> Paving Brick and Paving Brick Clays of Illinois.

Urbana, University of Illinois, 1908.

(33 fig., 3 pl., 316 pp.) State Geological Survey. Bulletin No. 9.

C. W. Rolfe and others.

<small>SUBJECT.</small> Paving Brick and Paving Brick Clays of Illinois.

Urbana, University of Illinois, 1908.

(33 fig., 3 pl., 316 pp.) State Geological Survey. Bulletin No. 9.

State Geological Survey.

<small>SERIES.</small> Bulletins.

No. 9. C. W. Rolfe and others.

Paving Brick and Paving Brick Clays of Illinois.