FOUNDRY SANDS

BY

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LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGIST,
LANSING, MICHIGAN, May 6, 1908.

To the Honorable, the Board of Geological Survey of the State of Michigan:
Hon. Fred M. Warner, President.
Hon. D. M. Ferry, Jr.
Hon. L. L. Wright, Secretary.

Gentlemen—I herewith transmit to you for publication in your report for 1907 a paper primarily by Prof. H. Ries, of Cornell University, on the foundry or molding sands of the state. The field work and much of the laboratory work was done by him, but some aspirator tests made for him by J. A. Rosen at the Michigan Agricultural College, carefully conducted and admirably worked up, proved to be of such practical importance that Dr. Ries was very glad to add Mr. Rosen as co-author. It seems that porosity and permeability taken together give a factor which will grade a molding sand.

Very respectfully,
ALFRED C. LANE.

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REPORT ON FOUNDRY SANDS.

By Heinrich Ries and J. A. Rosen.

Introduction.

The following report on foundry sands is based on field work done during July, 1906, and laboratory work carried on in the following winter. The field work was done by the senior author, and the samples collected by him were subjected to a mechanical analysis, and determination of their specific gravity and percentage porosity. In this work Mr. H. Leighton of Cornell University gave valuable aid.

It was deemed desirable, however, to test the permeability of the sands, and this work was later performed by Mr. J. A. Rosen of the Michigan Agricultural College, whose results indicate, as explained on a later page, that the average fineness as worked out in connection with the permeability test is perhaps on the whole more valuable than that calculated from the sieve test. This does not mean, however, that the mechanical analysis is valueless, or should be neglected.

Before going into the field an attempt was made to obtain as complete a list as possible of the Michigan molding sand producing localities, for the purpose of visiting them.

This list was compiled from replies to inquiries sent out to the foundries within the State. Information was requested as to the source of the sand used, the character of material cast in it, and for an expression of opinion regarding the relative value of Michigan or other sand for casting any particular kind of goods.

The replies received are by agreement treated confidentially, but it is no violation of confidence to base some generalizations on them.

A careful analysis of the replies received shows that by far the larger number of foundries in Michigan, including the larger ones, use sand obtained from other states, and that sand is being dug at but a few localities in Michigan. When a local supply is obtained it is usually of pockety character, and only sufficient to supply the needs of a small foundry.

Comparison of the sands obtained locally with those shipped in from other states show that the local sands are usually of coarser grain, but as will be shown later, some of those dug in Michigan compare not unfavorably with some of those shipped into the state.

A comparatively small number of localities in the states of Ohio, Indiana, Illinois and Kentucky are now supplying hundreds of foundries in the central and eastern states, with the finer grades of sand, and the consumption from these is enormous. Large as the deposits are, the material is not absolutely uniform, and much careful sorting and sometimes even blending has to be done.

If the fears expressed by many foundrymen are well founded, the time may not be so far distant when the supply of the high grade sands will become exhausted, and what will follow then, if predictions are correct, will be the production of artificial materials, made by the admixture of sand and clay in proper proportions. One of the difficulties of this will be the intimate and uniform mingling of clay and sand.

There occurs to the writer another process of treatment, which is somewhat the reverse of the one just mentioned. This is the conversion of some loams into a fine-grained molding material by the removal of a part of the clay by washing.

One may perhaps ask whether there is any need of waiting for the exhaustion of these present high-grade sands, purchased at such expense by many foundries. If the production of artificial sands by an admixing or a washing process is possible, it would seem that many local points of production of such a material could be developed, resulting in the placing of a much cheaper article on the market. It is interesting to note that not a few foundrymen look forward to the necessity of using artificial sands at no very distant date.

Another point that may be raised is, whether the unfavorable opinions held by some foundry men are always justified. Does a sand fail always because it is deficient in certain qualities, or may this apparent worthlessness be due to the fact that the molder does not understand how to use it? The experiments of Mr. Rosen on the optimum water content seem to have an important bearing on this point. Failure of the foundryman to recognize that the maximum permeability is not developed in all cases with the same amount of water added to the sand, might lead to failure in the use of a good sand.

The original plan contemplated an examination of all the Michigan localities reported, but before the field work was well under way it was found that at many of these but a small pocket of sand had been found, so attention was restricted to the more promising ones. Samples were not only taken from the pits visited, but some were collected of sands shipped in from other states, so that these might be compared with Michigan ones.

Under the term foundry sand there is included:

1. Sands for making the mold proper, into which the metal is cast, and
2. Core sand, utilized for making the cores, which occupy the hollow spaces of the cast piece.

It can be said in general, that while the molding sands proper are on the average of finer texture and more loamy than the core sands, still the two grades overlap, and both grades show considerable range of texture.

Thus in the selection of molding sands, the finer grained ones are used for small castings, with smooth surfaces, while heavy castings take coarser sands. If a coarse sand were used for making light work the product would have a rough skin, while the use of a fine sand for heavy work tends to make scabs, or cause blowing because the sand is so fine that it will not allow the gases to escape. There is, moreover, the danger of a fine sand forming a fused coating or scale on large castings which is difficult to remove. The finer core sands are not dissimilar to some of the medium or coarse-grained molding sands. In general, however, the core sands have much less clayey matter; they are lacking in a natural bond.

But in the selection of molding sands, it is necessary to consider not only the size of the casting, but also the kind of metal to be cast in it.

For steel casting a highly siliceous sand appears to be commonly employed; one with a silica content of 97% or over. A small amount of clay is added to this for bonding purposes.

For iron castings a loamy sand is chosen, whose texture varies with the size of the casting.

Brass and aluminum are cast in molds of fine grained loamy sands, the grades used being often similar to those chosen for stove plate. Bronze is cast in an imported sand of very fine grain and good bonding power.

One aim of the present report has been to make if possible an intelligent comparison of the Michigan sands with those shipped in from other states. Such comparisons can be based on either the chemical or physical properties of the molding sand, but in most cases the latter are the more valuable.

Unfortunately no standard method of examination or testing has been adopted by the foundrymen, much as this is to be desired, and examinations of molding sand are confined largely to practical tests which are often time-consuming and costly.

With reference to the relative merits of a physical or chemical examination there is some difference of opinion among foundrymen.

A few buy their sand on the basis of composition, others may specify sand of a given texture, or both texture and composition may be considered; but the majority of foundrymen depend on the judgment of their foremen, who in many cases use purely empirical methods for determining the value of the material.

As the writer has remarked elsewhere,[1] satisfactory laboratory tests have been devised for the examination of other raw materials, and why can this not be done for molding sands.

Requisite qualities of molding sands.

In order to better discuss this it may be well to consider first what conditions foundry sands[2] are exposed to. Their properties may be enumerated as follows:

1. *Cohesiveness.*—The slightly moistened sand must possess sufficient cohesiveness to make the grains cohere when pressed together to form the parts of the mold. Core sands are usually deficient in this respect, and artificial bonds are supplied them.
2. *Refractoriness.*—A sufficient degree of refractoriness is necessary to prevent extensive fusion in the sand when exposed to the heat of the molten metal.
3. *Texture.*—The sands must possess the proper grain for the kind of castings that are to be made in them.
4. *Porosity and permeability.*—Sufficient porosity to permit the escape of the gases given off by the cooling metal is essential.
5. *Durability,* or sufficient length of life to permit as much of the sand as possible being used over again is important from the standpoint of economy.

These points may now be taken up in order.

Cohesiveness or bonding power.—A sand used for molding should when slightly moist possess sufficient cohesiveness to make the grains stick together following the removal of the pattern, and also to resist the pressure of the molten metal in the mold, or its corrosive action when poured into the mold. The cohesiveness of a sand depends probably in part on the amount of clayey matter which it contains, the character of the clay bond, and the texture. A finely-textured sand would, therefore, other things being equal, be likely to have a higher cohesiveness than a coarse-textured one.

[1]Wis. Geol. and Nat. Hist. Surv., Bull. XV.
[2]Under this head are included both mold and core sands.

At the same time, uniformity of distribution of the clayey matter is important. Sands containing little or no clay and of coarse texture, will cohere so little when moist that it will be necessary to add some artificial binder to them, as is done with many core sands.

The degree of cohesiveness of any given sand will naturally be somewhat affected by the degree of moisture which it contains, the particles of a moist sand cohering much better than those of a nearly dry one. An excess of moisture is, however, undesirable, as it causes the sand grains to pack too closely, an effect which is more noticeable in the finer-grained ones.

The cohesiveness may be tested by the tensile strength test, but the results do not in all cases appear to be satisfactory.

Experiments made by Parmelee[1] showed:

1. That the tensile strength increased with heavier tamping of the briquettes in molding, and

2. That there appeared to be no direct relation between average fineness and tensile strength. The following figures from the New Jersey work show this.

Table showing tensile strength of molding sands.

Kind.	Per cent water required.	Tensile strength, lbs. per sq. in.		Average* fineness.
		Light. tamping.	Heavy tamping.	
No. 0 Albany	16.6	6.9	11.00	99.5
No. 1 Albany	11.4	2.95	5.50	98.1
No. 2 Albany	10.5	4.39	....	84.8
Barlow's unused	14.6	4.31	8.65	95.0
Barlow's used	11.1	.75	1.75	....
Sandy loam, Wilburtha, N. J.	21.6	9.93	....	92.1
Sandy loam, Washington Crossing, N. J	12.8	4.58	11.50	88.6
Steel molding sand, Florence, N. J	5.2	1.59	....	79.5
Lumberton, N. J.	11.2	36.37	61.50	81.4
Lumberton, N. J.	15.1	15.37	20.25	67.2
Lumberton, N. J.	9.9	22.10	50.30	73.4
Core sand, Burlington, N. J	11.4	52.56	....	42.2
Core sand, Burlington, N. J	6.7	4.62	8.30	46.1
Molding loam, Hainesport, N. J	10.4	9.70	17.25	72.8
Molding loam, Paxon & Co.	11.2	32.04	40.50	78.6
Coarse loam, Hainesport, N. J	10.8	12.57	20.68	65
"Fine, mild" loam, Hainesport, N. J	10.1	10.35	19.50	76.6
"Strong" loam, Hainesport, N. J	7.9	23.72	42.13	74.4
Molding sand, Masonville, N. J.	9.4	10.20	25.00	61.4
Heavy molding sand, Barton's Landing	10.9	44.57	59.25	69.6

*The average fineness was obtained by taking the average of the percentage retained on each sieve.

It will be noticed from this that the bonding power or tensile strength did not seem to stand in any direct relation to the degree of fineness, some of the coarser sea sands showing a higher tensile strength. The strength when dry is usually very low.

The chemical analysis throws but little light on the cohesive properties. A sand with an appreciable alumina content may frequently be quite plastic and cohesive, but others with an equal amount of alumina may be the opposite. Take for example the two following analyses. No. I is that of a well-known molding sand of fine grain, and much used throughout the eastern and central states, while No. II is a sandy brick clay, of sufficient cohesiveness and plasticity to be used for brick making.

[1]N. J. Geol. Surv., Ann Rept. 1904.

	I	II
SiO_2	79.36	90.00
Al_2O_3	9.36	4.5
Fe_2O_3	3.18	1.44
CaO	.44	.10
MgO	.27	.10
K_2O	2.19	tr
Na_2O	1.54	tr
TiO_2	.34	.70
H_2O	2.02	3.04
Moisture	.74	....
	99.44	99.88

Judging from the analyses some might conclude that No. I was more plastic and cohesive because of its lower silica and higher alumina content, whereas the reverse is true.

Refractoriness.—Foundry sands should be sufficiently refractory to prevent the pores closing up by fusion when the material is exposed to the heat of the molten metal. Were this to occur there would be no openings for the gases to escape and serious trouble would result. We might divide sands used for molding into two classes, viz., those used for steel casting and those used for casting iron and other metals. The former are exposed to a much higher heat, and consequently a very silicious material, running above 97% of silica is employed. They usually require the admixture of some clay for bonding purposes. The latter are not exposed to as high a heat, and need not be as refractory. They are, therefore, less pure, carrying between 70 and 80% SiO, and do not usually require a bonding material.

In every sand we can roughly divide the grains into two groups, i. e., the siliceous or refractory ones, and the clayey or non-refractory ones. If the sand contains only the former it will be very refractory (sand for steel castings), while if any clayey matter is present it will tend to flux with the silica grains (if heated high enough), this fluxing action being the more intense the finer grained the siliceous particles. Uniformity of mixture will likewise promote fusion changes. The predominance of fluxes in the finest particles is well brought out in the following partial analyses.[1]

Size mesh	60	80	100	100+Clay	
Silica (SiO_2)	95.92	94.35	94.66	91.06	61.54
Alumina (Al_2O_3)	1.29	1.47	1.47	4.57	23.16
Ferric oxide (Fe_2O_3)	.56	.56	.40	.80	1.60
Lime (CaO)	.10	.04	.34	.72	1.37
Magnesia (MgO) and alkalies by diff.	2.13	3.58	3.13	2.85	4.43
Loss on ignition	Undetermined.				7.90

In judging the refractoriness, appeal may again be made by some to the chemical analysis, but the writer questions whether it is safe to base too much confidence on this. A pure silica sand would be refractory, and one containing an appreciable quantity of alumina, iron oxide, lime, magnesia, and alkalies would be less so, the last four especially tending to depress

[1]Wis. Geol. and Nat. Hist. Surv., XV, p. 225, 1906.

the fusion point. The latter however does not stand in direct relation to the quantity of fluxes present.

Some foundrymen advance the view that lime increases the refractoriness of a sand. If the lime is uniformly distributed through the sand it does not. It has been found however that sprinkling a layer of lime on the interior of some parts of the mold seems to prevent its corrosion by the iron, or its fluxing of the sand by the molten metal. But in this case we have to deal with the behavior of the metal towards the lime alone (which by itself is refractory) and acts as a fire wall between the hot metal and the sand.

Texture.—This property is of primary importance. As has already been pointed out it may affect the cohesiveness of the sand. In addition to this, however, it stands in close relation to the permeability of the sand, and determines also to a large degree the grade of metal work that can be cast in it.

The texture of a sand is commonly determined by noting the percentage of each sample that is retained on sieves of different mesh. Most foundrymen in making such a determination rarely use anything finer than a 100 mesh sieve. The writer feels, however, that this is not sufficient, for the reason that there is considerable diversity of size among the smaller grains than 100 mesh. We might thus have grains ranging from fine sand down to clay, all of them under 1-100th of an inch. Fine sand or coarse silt, would tend to act somewhat like sand, and while it would decrease the size of the pores, need not necessarily lower the total amount of pore space. Clay, on the other hand, not only decreases the porosity, but tends to close the spaces between larger grains and renders the sand less permeable and more plastic.

It is therefore important to make some further separation of sizes under 1-100 in. This was done by drawing a dividing line at 1-250 in.

The method adopted for this report was as follows:

Fifty grams of the sand were put in an eight ounce bottle and the latter half filled with water. This mixture was then placed in a shaker for half an hour,[1] in order to disintegrate it after which it was washed through a set of 20, 40, 60, 80, and 100 mesh sieves. The sand retained on each was dried and weighed. That which passed through the 100 mesh was caught in a jar. When all the water and suspended matter had been run through the sieves the contents of the jar were stirred up and allowed to stand 45 seconds. That which settled in this time consists almost entirely of fine sand and silt grains, ranging from 1-150 to 1-250 in. in size and is classed as 1-250 in the table. The water with suspended clay was then decanted off. Since some clay is drawn down with the silty particles the process was repeated in order to get out the remaining clay.

The water over the silt and fine sand is removed in part by decantation and the residue evaporated to dryness. That with the clay is also evaporated to dryness.

It might be urged against the shaking method that there is danger of breaking up loosely cemented compound grains, but if there are any which are broken down by the half hour's shaking it is probable that they would also be crushed while the moist sand is being tamped into the flask for casting. Those that are too hard to be crushed are likely to escape disintegration in the shaker. Compound grains cemented either by iron or lime were in several cases found on the 20, 40, and 60 mesh sieves.

[1]The author formerly kept the sand in the shaker for four hours, but has found that half an hour is sufficient to disintegrate most sands.

There are of course other methods employed for making a mechanical analysis to determine the texture.

Thus one commonly used and described by Mr. W. G. Scott consists in placing ten grams of sand on the 100 mesh sieve along with ten 7-16 in. steel ball bearing balls, and shaking with a circular motion for one minute. The sand passing through is weighed and credited to the 100 mesh sieve. The sand remaining on the meshes of the sieve, together with the balls, is emptied onto the 80 mesh sieve, the operation being repeated and so on up to the 20 mesh. The object of the steel balls is of course to break up any lumps or grains.

A similar method is advocated in the pamphlet on molding sand published by the International Correspondence School of Scranton.

Vinsonneau[1] has suggested the following method of mechanical analysis for the comparison of sands, which he terms the *decantation method.*

Two vessels are employed (Fig. 1), one, *a*, with a volume of *v*, and a larger one *A*.

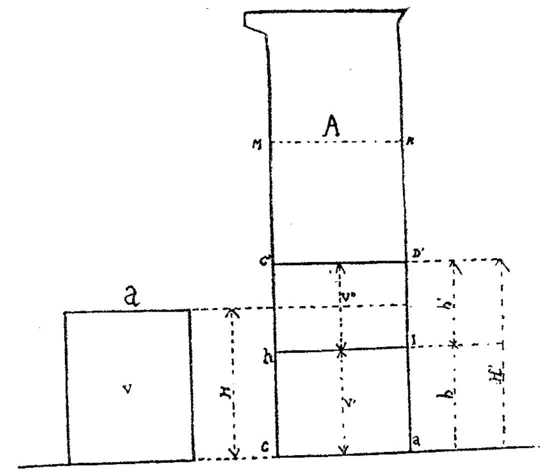


Fig. 1. Diagram showing Vinsonneau's method of mechanical analysis.

The vessel *a* is filled with sand, without tamping it in, and its contents then transferred to *A*, which is filled with water up to *mn*. The sand is then stirred up in the water and allowed to settle. In settling the heavier grains settle more rapidly, and accumulate in the lower portion of the vessel *A*, while the finer or lighter ones are on top. As a result of this the sand sample becomes divided into two portions. The one *c a h l* or v' and the other *h l c d* or v." Now $v' v'' = v$ plus a certain increase in volume, which is characteristic of each sand. The part *v'* is the refractory part, and *v''* or *h l c d* is the more aluminous or plastic portion.

Vinsonneau claims that in sands of the same strength the expression of $\frac{v'}{v''}$ is constant, and the strength is expressed by the ratio $\frac{H}{H'}$ representing the heights of the coarse and fine portions in the beaker.

[1]Notes sur les Sable a mouler er sur leur emploi en fonderie. Bull. de. la Soc. D'Encouragement pour L'Industrie Nationale. Vol. 3, No. 2, p. 112, 1906.

It appears to us that this method might work if the sand sample contained but two sizes of grains, but where a number of different sizes is present, it seems doubtful if we can get a sharp line of division between c a h l and h l c d, and therefore obtain exact measurements.

Vinsonneau goes a step farther and claims that the heights obtained in two sands by the settling method are nearly proportional to their alumina contents.

The mechanical analysis expresses the textural qualities of the sand. Those of very fine texture will show a high percentage of the finer sized grains, while those of coarse texture will exhibit a correspondingly large quantity of coarse ones. That there is considerable variation in texture can be seen at once by reference to the mechanical analyses on p. 52.

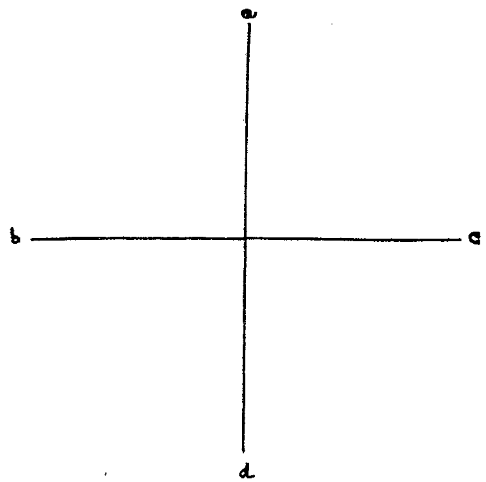


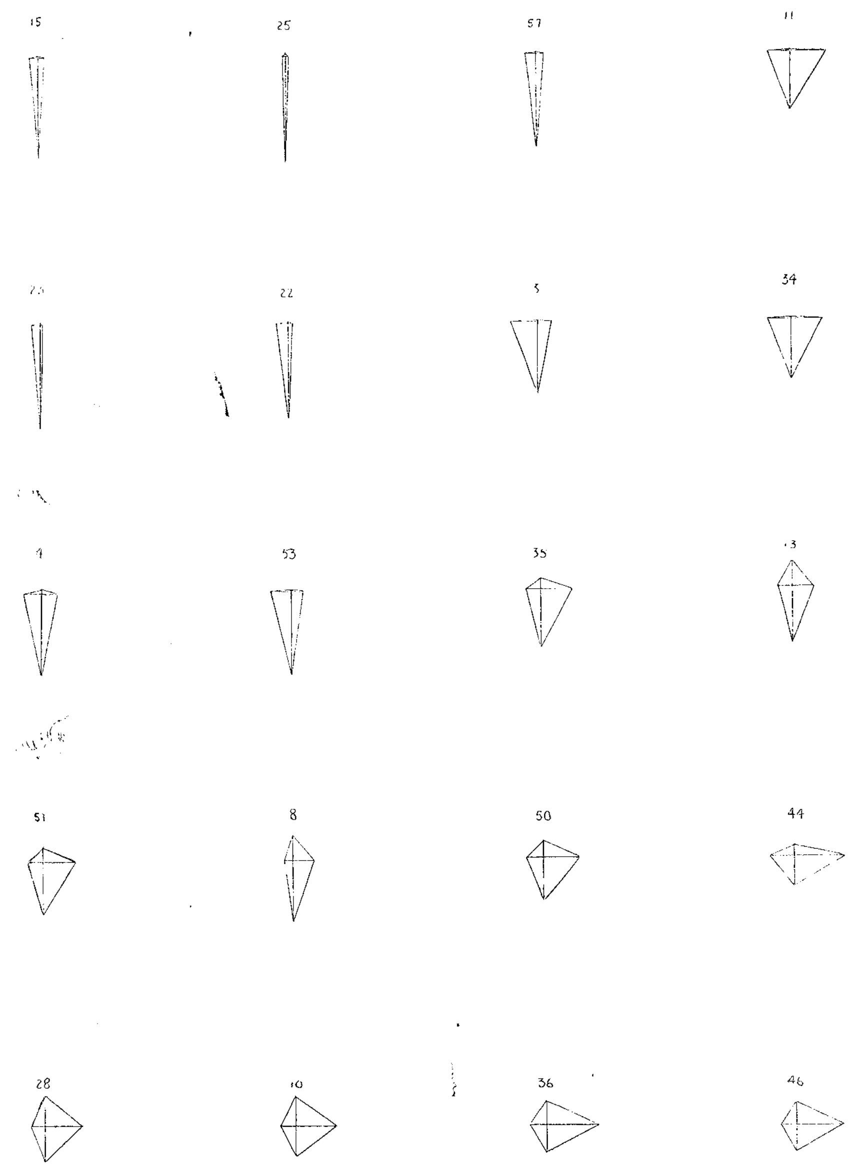
Fig. 2. Diagram showing graphic method of showing mechanical composition.

The writer has suggested elsewhere the possibility of expressing the texture graphically[1] to permit more rapid comparison of different sands. Fig. 2 represents the method used. On the four lines *a*, *b*, *c*, *d*, there are laid off equal distances corresponding to 100 per cent. On *a* the percentage of clay is laid off, on *b* the amount retained on 100 mesh, on *c* the percentage obtained by settling, and ranging from 1-100 to 1-250 in size, while on *d* the combined percentages of grains retained on the 20, 40, 60, and 80 meshes. These last four are combined as they represent the coarse particles of the sand. Having laid off the proportionate distances on the four lines, the points are connected by straight lines, and the resulting figure shows at a glance the texture of the sand.

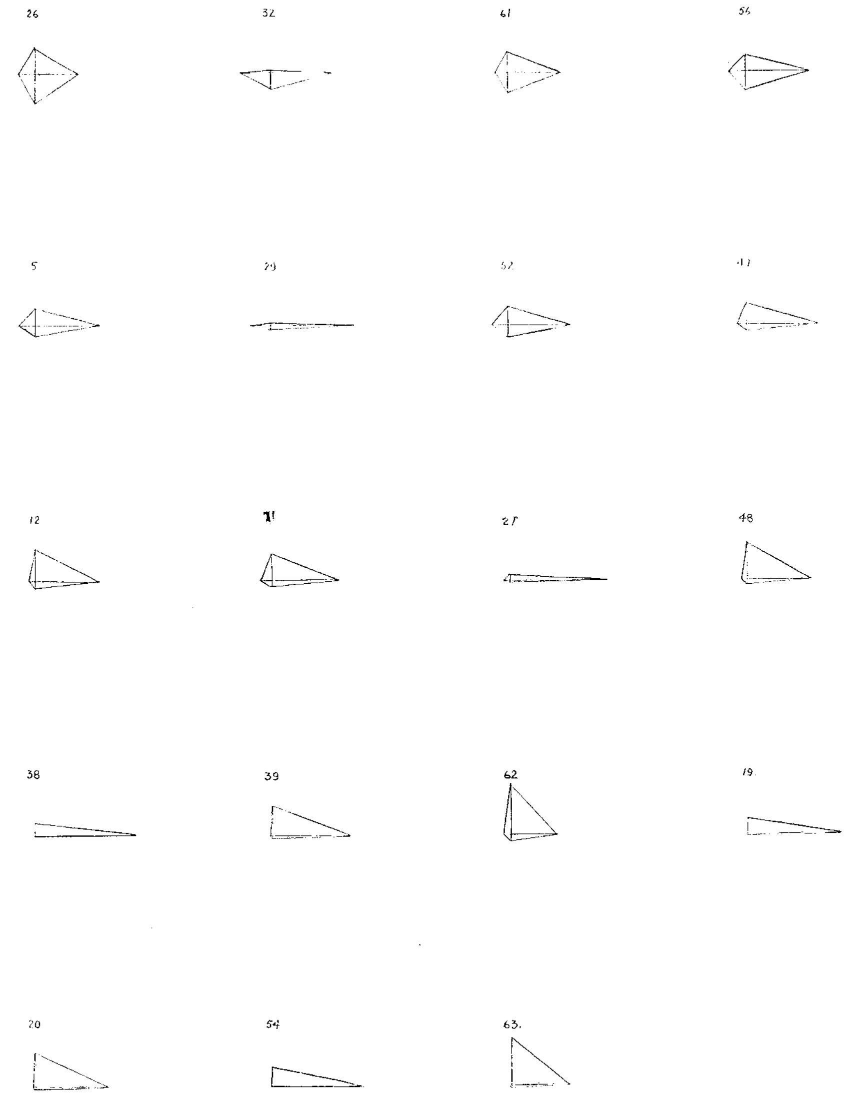
Plates I and II represent the texture of all the sands examined for this report. In the very fine ones it will be noticed that most of the figure lies above the horizontal line *bc*, while in the very coarse ones it lies below the horizontal.

It is sometimes regarded as desirable to express the average fineness by means of a single number, instead of stating the entire mechanical analysis. Several methods based on the sieve test have been suggested, but all are open to the objection that the results obtained by the different methods are

[1]Wis. Geol. and Nat. Hist. Survey, Bull. XV, p. 207, 1906.



GRAPHIC REPRESENTATION OF MECHANICAL COMPOSITION OF MOULDING SANDS. THE NUMBER ABOVE EACH IS THE LABORATORY NUMBER.



CONTINUATION OF SERIES SHOWN IN PLATE I.

not comparable, and only those sands can be compared which have been screened by the same method.

One method used by many foundrymen, and described in the Textbook on Molding issued by the International Correspondence Schools of Scranton is as follows: A set of sieves, including 20, 40, 60, 80, and 100 mesh is used. Exactly 100 grams of sand is sifted one minute on the 100 mesh sieve; the part that goes through is weighed, and the balance sifted in the 80 mesh sieve, and the process repeated on all the other sizes of sieves. Any loss is credited to the 60 mesh sieve, and any that does not go through the 20 mesh sieve is credited to a 1 mesh sieve. The weights of sand going through each sieve are then multiplied by the mesh and the total divided by 100 which gives the degree of fineness.

The following example will more clearly illustrate the method and calculations:

Weight of sand passing through.			Number of mesh of sieve.		
55.22	grams	by	100	mesh	5,522.00
20.89	"	"	80	"	1,671.20
11.64	"	"	60	"	698.40
10.57	"	"	40	"	422.80
1.20	"	"	20	"	24.00
.06	"	"	1	"	.06
.42	"	"	60	"	25.20
100.00					8,353.36

Thus, 8,363.66 divided by 100 gives 83.64 per cent as the percentage of fineness.

By this method the sand is graded into five grades according to its fineness.

No.	Grade.	Degree of Fineness.
1	Superfine	Above 100 per cent.
2	Fine	90 to 100 per cent
3	Medium	75 to 90 per cent.
4	Coarse or heavy	55 to 75 per cent.
5	Extra coarse	30 to 55 per cent.

This method is very simple, but does not differentiate sufficiently the finer grades. Moreover, the average fineness calculated according to it could never exceed 100 per cent. The average fineness of the sands tested for this report was also determined by this method and is given in the table on p. 52.

Parmelee* has suggested taking the sum of the percentages passing each sieve, and dividing this by the number of sieves used. This gives us a figure which may be called the *per cent of fineness*, and serves as an approximate means of comparing sands with each other, provided "they have each been screened with the same set of sieves."

He points out, however, that the per cent of fineness of the same sand will vary with the number of screens used. Thus in one case the average fineness figured out 72.2 per cent when 20, 40, 60, 80, and 100 mesh sieves

*N. J. Geol. Surv., Ann. Rept, 1904, p. 209, 1905.

were employed, but when a 200 mesh was added to the set it changed the result to 61 per cent.

A method previously used by the writer is as follows: The average being defined as the sum of all the quantities considered divided by the number of separate items, we assume that if in a sand we have

N_1 grains of size S_1
N_2 grains of size S_2
N_3 grains of size S_3

$$\text{Then average size of } S = \frac{N_1S_1 + N_2S_2 + N_3S_3 + \ldots\ldots}{N_1 + N_2 + N_3 + \ldots\ldots\ldots\ldots}$$

If the total number of grains is N, then

$$N_1 + N_2 + N_3 \ldots\ldots\ldots\ldots\ldots\ldots = N$$

$$\text{And } S = \frac{N_1S_1 + N_2S_2 + N_3S_3 + \ldots\ldots}{N}$$

$$\text{or } \frac{N_1S_1}{N} + \frac{N_2S_2}{N} + \frac{N_3S_3}{N} + \ldots\ldots\ldots\ldots$$

But $\frac{N_1}{N}$ = the fractional part of the whole quantity which has the size S.

So if the total number is taken as 100 (or proportional to 100)

$\frac{N_1}{N}$ = Per cent size of S_1

and $\frac{N_2}{N}$ = Per cent size of S_2

For application of this to the mechanical analysis of a sand it is necessary to assume an average size for each mesh, and this of necessity makes the method approximate rather than exact. In the case of the grains retained on the 20 mesh it was assumed that they average 1-15 in., as few of them were somewhat larger. This size would be expressed decimally by .066. Those which were retained on the 40 mesh might range from 1-20 to 1-40 in., and their average was taken as approximately

$$\frac{\frac{1}{20} + \frac{1}{40}}{2} = .037$$

and so on. The average size grain of the 1-250 in. was taken as

$$\frac{\frac{1}{150} + \frac{1}{250}}{2} = .005$$

The finest silt and clay was assumed as averaging .002. As an example: The mechanical analysis of one sand was

Mesh	
20	6.84
40	6.61
60	40.09
80	8.98
100	23.82
250	12.56
Clay	1.06
	99.96

$$\begin{aligned}
.0684 \times .066 &= .00451\\
.0661 \times .037 &= .00244\\
.4009 \times .019 &= .00762\\
.0898 \times .013 &= .00117\\
.2382 \times .011 &= .00262\\
.1256 \times .007 &= .00088\\
.0106 \times .002 &= .00002\\
\hline
&\ .01926 \text{ average grain size}
\end{aligned}$$

$$\frac{1}{.01926} = 51$$

In other words if all the grains in a given volume of the sand whose mechanical analysis is given above were reduced to a uniform size, they would pass through a 51 mesh.

In the accompanying table there are given the mechanical analyses of the sands made for this report, together with the average fineness, per cent porosity, and specific gravity. It will be seen that the majority of sands have a gravity so close to 2.6 that for all purposes this figure could be used in any calculations.

Lab. No.	On 20	On 40	On 60	On 80	On 100	On 250	Clay.	Average fineness.	Av. fineness Scranton method.	Sp. Gr.	Per cent porosity.
3	6.84	6.61	40.09	8.98	23.82	12.56	1.06	52	55	2.68	34.2
4	3.96	7.10	46.97	11.74	15.32	11.35	3.65	55	54	2.65	35.8
5	.06	.38	5.41	3.45	14.92	58.49	17.25	152	92	2.63	39.6
7	.28	.56	1.93	1.80	9.34	60.78	25.27	180	95	2.6	42.6
8	.96	12.42	34.41	4.31	7.50	18.29	22.06	69	65	2.61	35
10	3.29	3.05	15.49	4.24	12.64	35.19	26.11	95	81	2.64	43
11	11.13	12.08	21.93	4.33	19.16	30.01	1.35	49	60	2.68	30.6
12	.30	.77	4.52	1.63	5.35	57.95	29.44	178	94	2.59	39.5
13	4.69	13.34	23.96	5.01	11.95	18.22	22.79	63	66	2.66	42.3
15	25.69	24.67	30.57	5.47	7.16	4.64	1.76	25	33	2.70	28.4
19	.02	.20	.42	.09	.38	84.52	14.31	212	99	2.72	42
20	.09	.45	1.51	.31	.74	66.79	30.08	219	98	2.67	.....
22	.13	13.92	61.07	6.67	10.91	4.28	2.00	52	46	.....	33.5
23	.60	11.79	70.11	6.88	7.32	1.90	1.35	50	44	2.62	35.2
25	19.13	39.45	29.68	2.68	2.99	2.47	3.36	29	30	2.72	33.8
26	.13	.59	20.10	5.81	15.89	33.35	24.09	110	82	2.62	37.5
27	.33	.18	.55	.24	5.47	87.92	5.36	181	98	2.65	43.9
28	2.51	6.16	16.49	4.74	11.30	32.37	26.39	90	78	2.62	39.6
29	.00	.08	1.79	1.03	19.42	74.93	2.71	155	94	2.66	35.2
32	.00	.52	8.08	5.66	28.27	55.00	2.45	113	87	2.59	38.6
34	9.46	7.38	24.99	8.49	19.48	26.67	2.92	54	62	2.52	30.6
35	6.26	10.61	24.87	7.78	13.43	27.37	9.65	59	65	2.59	32.2
36	1.68	3.08	14.00	4.66	11.59	44.47	20.50	106	83	2.6	39.1
39	.27	.54	1.21	.32	1.21	69.46	26.97	209	98	.....	38.7
38	.08	.20	.17	.00	.14	87.56	11.82	205	99.6	2.7	45.9
44	3.40	3.07	12.99	6.22	20.85	42.77	10.75	88	80	2.71	40.7
46	1.36	3.44	14.78	4.24	12.82	40.74	21.64	107	82	2.48	43
47	.07	.24	3.47	1.78	8.42	66.21	19.78	176	95	2.61	43.8
48	.29	.85	2.20	.65	3.52	58.37	34.08	201	97	2.62	41.2
50	1.88	5.80	24.03	5.26	14.23	32.00	14.88	82	73	2.62	37.4
51	5.82	6.74	27.39	5.75	12.55	27.54	12.74	65	67	2.63	36.3
52	.11	.39	6.38	3.79	14.69	57.83	16.78	156	91	2.63	37.5
53	1.14	9.42	50.76	9.73	17.30	10.44	1.17	57	42	2.63	36.8
54	.09	.08	.29	.12	.57	79.02	18.41	220	99	2.73	38.3
56	.03	1.08	13.21	2.08	9.53	57.70	15.06	135	88	2.6	37.4
57	15.00	27.95	34.04	4.70	10.67	6.29	1.32	34	30	2.54	28
60	.29	.09	.23	.10	.56	95.59	1.64	241	.....	.....	38.9
61	.54	2.11	11.38	3.94	11.67	49.57	20.57	127	87	.....	37.4
62	.11	.32	2.93	2.59	5.96	41.87	45.23	211	95	2.61	40
Lane	.08	.71	1.65	.37	1.25	52.10	47.81	233	98	2.61	45.6

3. Fine core sand, Holton & Weatherwax Co., Jackson, Michigan.
4. Core sand, same locality as 3.
5. Under sand, Cory's pit, near Dimondale. Said to be of no value.
7. Molding sand from Reeve's pit, Lansing.
8. Eureka No. 4, from Zanesville, O., district. Used for general work.
10. Sand from town of Wells, near Escanaba.
11. Core sand and sand-lime brick sand, artificial mixture, Rochester.
12. Vrooman's pit, near Riverside.
13. Core sand, Niles.
15. Sand for car wheels, Rochester.
19. Fine-grained molding sand, Coldwater St., Battle Creek.
20. No. 2 Conneaut, Ohio. Used for stove plate.
22. Green sand for steel castings, from Ottawa, Ill.
23. Lake sand for cores, Lake St. Clair.
25. Core sand, near Jackson. Used also for sand-lime bricks.
26. Sand for general work, Garden City Sand Co., Vineland.
27. Leoni, 5 mi. N. E. of Jackson.
28. Heavier sand, Battle Creek.

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29. Fine sand, Rochester. Unused.
32. Light core sand, sand-lime brick pit, Saginaw.
34. Crushed quartz rock, Chalfonce, O. For steel casting.
35. Molding sand, F. Sadtler farm, Linden.
36. Reeves pit, near Lansing.
39. No. 5, Newport, Ky.
38. No. 3, Akron, O.
44. Christopher property, Lansing.
46. Town of Wells, near Escanaba.
47. Molding sand, Vornberg's property, Lansing.
48. Sand near cemetery, Port Huron. For general work.
50. Same locality as 10, but from east side of river.
51. Same locality as 10, but from east side of river.
52. Same as 5.
53. Core sand, McCamman property, Lansing.
54. From cut of L. S. & I. R. R., near Marquette.
56. Sand for general work, Kerlikowski's pit, Vineland.
57. Core sand, McCamman property, Lansing.
61. Sand for general work, Black Hills, Grand Rapids.
62. Ohio sand, for school furniture castings and as a substitute for 61.

While the full discussion of these sands is given on pages 66-78, the textural features may be mentioned here. Of the 39 sands whose mechanical analyses are given, 30 are from Michigan, and the others from outside localities. Six of these are listed as core sands, and their average fineness ranges from 29 to 113 on the author's scale, or from 30 to 87 on the Scranton scale. It will be seen from this that the core sands for some work are materially coarser than the molding sands for other work. A comparison of the average fineness figured by the two methods shows that the order of fineness remains about the same, but a serious objection to the Scranton method is that it does not differentiate sufficiently between the finer grades.

The method outlined above is, it seems to the authors, more satisfactory than the Scranton method, because it possesses greater accuracy, but it is open to the objection that the figures assumed for the average sizes have to be arbitrary, and in order to greatly reduce this error a very large number of sieves would have to be used. Moreover, the formula $1/L\ (1/n_1 + 1/n_2)$ is of necessity more or less hypothetical.

Again it is difficult to assume a satisfactory average size for clay by the sieve method. In many sands the particles which pass through the 250 mesh sieve are no smaller than the assumed average, while in other cases they are several times smaller.

Finally the error may be greatly increased if the percentage retained on any one sieve is very large.

DETERMINATION OF FINENESS BY ASPIRATOR METHOD.*

The method of determining the average fineness of a sand by means of an aspirator was devised by Prof. King in 1894, in order to determine what he called the effective size of soil grain. In addition to serving as a means of measuring the texture, it also determined the permeability of the material.

It had already been asserted that the rate of flow through sand was de-

*This portion is the work of Mr. Rosen.

pendent upon the size of grain. Poiseuille had demonstrated, or it was thought he had, that the flow of liquids and gases through capillary tubes was proportional to the pressure.

It was found further, that the weight of a given soil that could be packed in a given space was practically constant, and that therefore for a given soil the pore space was constant, and that fairly constant results were to be had in aspirating air through a given soil.

At this time Prof. King conceived the idea that the size of grain of a given soil might be determined in this way. The opinion of Prof. Slichter, Professor of Applied Mathematics at the University of Wisconsin, was asked as to the practicability of the plan, and so thoroughly did he believe in its possibility that he immediately set about developing a formula for making the necessary computation. He was so successful in this that measurements of soil grains have been made with an approach to accuracy that was at first hardly hoped for; and it is hoped that greater accuracy may still be secured as the method is further studied.

The apparatus used is the one figured in the Second Annual Report, Michigan Academy of Science, and is essentially the same as the one first used by Prof. King. It differs only in compactness of form. It consists of a soil tube (a), an aspirator of which (b) is the tank, and (c) the bell. The bell is lifted by the weight (d) by means of a cord (e) passing over the pulley (f). The tube (g) passes from the soil tube into the aspirator, and by way of this air is drawn by the aspirator through the soil in the tube (a). The dial (h) performs the function of air meter, and is calibrated for one litre in this case. The manometer or pressure gage (j) indicates the difference of pressure between the ends of the soil column in the tube, or conventionally speaking it indicates the pressure under which the air is drawn through the soil. It is connected with the air chamber (n) above (a). The height, cross section, inside volume, and weight of the tube (a) are carefully determined.

Before taking up the mode of operating the apparatus, let us consider briefly the points in Prof. Slichter's theory leading to his formula.

He considers a hypothetical soil having approximately spherical grains of nearly uniform size. The least pore space possible in such a soil occurs when the grains are so arranged that the element of volume is a polyhedron with face angles of 60° to 120°. In this case each grain of soil is in contact with other grains at 12 points, and the pore space equals twenty-five and ninety-five hundredths per cent. When the grains touch each other at eight points, the element of volume is a cube, and the pore space equals forty-seven and sixty-four hundredths per cent. Between these limits of arrangement we have a similar range of pore space and the face angle of the element of volume will be a function of the pore space and thus may be determined from it if the angle be known. The angle in actual practice can not be known, but conversely the pore space may readily be determined and the angle determined from it.

The length of pore in the soil is greater than the length, or height, of the soil column through which the air is aspirated and depends upon the angle as well as the height of the soil column. The cross section of the pore has for one of its functions the angle as well as the size of grain, and conversely the size of the grain will depend upon the cross section of the pore. The rate at which air may be aspirated through a soil will depend upon the size and length and number of its pores, upon the pressure under which it is forced through the pores, and upon the viscosity of the air which in turn depends

upon the temperature of the air. The length of pore will depend, as before stated, upon the height of the soil column. The number of pore will depend upon the cross section of the soil column, whence we have derived the formula:

$$d^2 = K \frac{H}{spt} (8.9431 - 10)$$

Where d is the diameter of the soil grain,
K a factor dependent upon the per cent of pore space,
h height of soil column,
s cross section of soil column,
p pressure in c. m. of water,
t the time in seconds required to aspirate 5 liters of air at 20° centigrade, and (8.9431 — 10) is the logarithm of a constant.

Such a soil, however, as Prof. Slichter hypothecates is never found and probably seldom approached in nature. It is probably approached more nearly in form than in uniformity of size. But whatever the irregularities in a given soil, it is found, as has been partly stated before, that its minimum pore space and its power to allow the passage of a fluid through its pores are practically constant, and, as Prof. Slichter says: "It would probably be admitted that no matter how complex a soil may be there exists a certain ideal soil of uniform spherical grains that will transmit, under given conditions, the same amount of" fluid (he says water) "that would be transmitted by the complex soil. The size of the grain of this ideal soil of the same transmission capacity as the complex soil we shall call the effective size of grain of the complex soil." This is the term applied to the size of grain as determined by the new method.

THE MODE OF OPERATION.

To perform an analysis the soil is prepared by drying and pulverizing in a mortar, using a rubber pestle. It is then sifted through a 1 mm. mesh sieve to remove gravel.

It is then introduced into the tube (a), the end of which is provided with a tight fitting cap, and the tube held firmly upon some solid surface, and lightly tapped with a light mallet or stick. As the soil settles more soil is added, and this is continued until no further settling occurs. The surplus soil is stricken off, and that which remains is smoothed down with some plane surface. In Prof. King's laboratory a piece of ground glass is used for the purpose. The tube and contents are now weighed. Knowing the volume and weight of the tube, and the specific gravity of the soil, it is an easy matter to determine the pore space in the soil, and with the pore space determined, K (in the formula) is found by reference to a table.

On the other end of the tube (a) is now screwed a gauze cap, the tube is inverted, the solid cap removed, and the tube is screwed into place. The weight d is next suspended and this acting upon the bell causes the aspiration of the air through the soil. The manometer indicates the pressure under which the air is drawn through the soil. Usually the initial and final pressures are recorded, and the average of the two taken as p in the formula. The pressure should not much exceed three centimeters of water.

The initial and final time are noted and the time required to aspirate one or more liters of air through the soil is determined by subtracting the initial from the final time, and is expressed in seconds. If only one liter is aspirated then the time must be multiplied by five. Substituting those values in the formula, d is readily determined."

In the table below are given the average size of grain determined by all three methods, in which the different results obtained by the three are strikingly brought out.

By the aspirator method the average size of the grain passing through No. 20 sieve was determined only.

In computing the size with the material "on 20" included, Mr. Ries' table of separations was used for taxing the per cent "on 20." It will be noted that in most cases it makes little or no difference.

To compute the size in terms of sieves the following formula was applied:

$$1 + \frac{\text{size in mm.}}{25.4} = \text{size in terms of sieves.}$$

MECHANICAL ANALYSES OF SOME MOLDING SANDS.

No.	Weight of sand.	Spec. Grav.	% of pore space.	°Logar. of K.	Pressure in c. m.	Time in sec.	°Average size in m. m.	Average size of grain in terms of sieves.		Size of grain in terms of sieves.		% of "Clay."	% of material "on No. 250" sieve.
								"On 20" exclusive.	"On 20" inclusive.	Ries' method.	Scranton method.		
3.....	171.9	2.68	36.2	1.4512	1.85	1900	0.2630	97	91	52	55	1.06	12.56
4.....	171.2	2.65	35.6	1.4755	2.00	2400	0.2040	125	120	55	54	3.65	11.35
5.....	152.9	2.63	42.1	1.2340	2.00	15000	0.0681	407	407	152	92	17.25	58.49
8.....	160.5	2.61	38.8	1.3521	2.00	60000	0.0352	714	714	69	65	22.06	18.29
10.....	141.9	2.64	46.8	1.0795	2.12	16500	0.0480	526	509	95	81	26.11	35.19
11.....	184.2	2.68	31.7	1.6414	2.00	5450	0.1640	156	140	49	60	1.35	30.01
12.....	154.2	2.59	40.9	1.2760	2.00	60000	0.0324	770	770	178	94	29.44	57.95
13.....	147.2	2.66	45.0	1.1370	1.80	4200	0.1100	232	222	63	66	22.79	18.22
15.....	184.4	2.70	32.1	1.6234	2.20	1250	0.1060	238	182	25	33	1.76	4.64
20.....	155.1	2.67	42.2	1.2305	2.00	165000	0.0185	1429	1429	219	98	30.08	66.79
22.....	177.8	2.60	31.9	1.6323	2.20	1220	0.3405	74	74	52	46	2.00	4.28
23.....	175.8	2.62	33.3	1.5716	2.20	1200	0.1040	244	243	50	44	1.35	1.90
25.....	176.3	2.72	36.2	1.4512	2.20	775	0.3900	65	56	29	30	3.36	2.47
27.....	149.2	2.65	43.0	1.2024	2.00	9600	0.0745	345	344	181	98	5.36	87.92
28.....	152.2	2.65	42.9	1.2064	2.00	11100	0.0696	370	361	90	78	26.39	32.37
29.....	169.2	2.66	35.7	1.4714	1.85	15000	0.0885	286	286	155	94	2.71	74.93
32.....	163.6	2.59	36.8	1.4272	2.00	7200	0.1115	230	230	113	87	2.45	55.00
38.....	144.7	2.70	46.7	1.0828	2.00	33000	0.0350	714	714	205	99	11.82	87.56
34.....	174.2	2.52	31.3	1.6596	2.00	7200	0.1410	191	174	54	62	2.92	26.67
44.....	150.4	2.71	44.8	1.1334	2.00	6600	0.0840	303	292	88	80	10.75	42.77
46.....	139.1	2.48	46.2	1.0992	2.00	13200	0.0585	435	428	107	82	21.64	40.74
47.....	142.8	2.61	45.6	1.1183	2.00	5300	0.0912	274	274	176	95	19.78	66.21
50.....	158.1	2.62	40.0	1.1945	2.20	16320	0.0573	435	427	82	73	14.88	32.00
51.....	158.3	2.63	40.1	1.3043	2.10	12000	0.0749	345	326	65	67	12.74	27.54
52.....	161.8	2.63	38.9	1.3482	2.00	28800	0.0509	500	500	156	91	16.78	57.83
53.....	173.8	2.63	34.3	1.5286	2.20	2000	0.2365	107	106	57	42	1.17	10.44
56.....	160.3	2.60	38.7	1.3556	2.20	12100	0.0792	319	319	135	88	15.06	57.70
57.....	183.7	2.54	28.1	1.8146	2.20	1225	0.3750	66	59	34	30	1.32	6.29
62.....	159.2	2.61	39.3	1.3335	2.50	76800	0.0274	909	908	211	95	45.23	41.87

Permeability and porosity.—The permeability of a sand may be defined as the property which it possesses of allowing liquids or gases to filter through it. The porosity can be defined as the volume of pore space between the grains. These two properties are therefore different and should not be confused.

Two sands might have exactly the same percentage of pore space, but vary in their permeability, and other things being equal, the one with the larger pores should be more permeable.

Again a sand might have a large total pore space, but owing to the smallness of the pores its permeability might be low.

The permeability of a sand will be influenced by several things, such as tightness of packing or tamping, size of grains, water content and fluxing impurities in the sand. The first two factors operate throughout the period of use in the mold, the third only while the sand is moist, and the fourth only after it has been exposed to the heat of the molten metal.

Clay if present in quantity tends to clog up the pores, and if the percentage of the coarser sizes remains the same, a decrease in silt grains, and increase in clay grains will reduce the porosity and permeability.

The two following sands are an example of this.

Lab. No.	38	39
On 20	.08	.27
40	.20	.54
60	.17	1.21
80	.00	.32
100	.14	1.21
250	87.56	69.46
Clay	11.82	26.97
Aver. fineness (Ries)	205	209
Per cent porosity	45.9	38.7

Both are in use at a foundry in Saginaw. The foundry superintendent states that No. 38 is the more porous, and permeable of the two, and allows the gases to escape more readily. This higher porosity is shown above, and is due evidently to the lower clay content. If the length of life of the sand is related to the clay content, then No. 38 should have a longer life than 39.

Another factor that should be considered in connection with the size of grain is the state of aggregation of the finer grains whether they be silt or clay. If these are separate they will pack much closer and tighter than if cemented or bunched together in the form of compound grains. Moreover such compound grains will because of their porous character raise the porosity of the mass.

From what has been said above several deductions of practical value can be made.

Tamping because it forces the grains into closer contact will decrease the pore space, but even so theoretic conditions can rarely be reached. Other things equal, sands of fair-sized grains pack closer than those of equi-sized grains.

The decrease in permeability under increased tamping may explain why some good sands behave badly when packed too tightly in the mold, refusing to allow the gases to escape and causing blow holes.

It would seem that the degree of tamping is perhaps too little considered in the use of sands. For example, one sand may yield excellent results with a given amount of tamping, but another one to yield good results may require less tamping. In trying this new sand this point may be overlooked, and the material be turned down as worthless because it was not properly handled.

Porosity alone cannot be used as a gauge of permeability, although it is probable that coarse texture combined with high porosity indicates good permeability.

The only sure way of determining the permeability is to actually measure it with the aspirator described on p. 53, and the results of a number of these determinations made by J. A. Rosen are given in the table on p. 56.

DETERMINATION OF THE OPTIMUM WATER CONTENT.

The permeability of a sand will also be influenced by the amount of water used in packing it. Foundrymen usually add a minimum quantity of water to the sand, in fact, just enough to make it cohere sufficiently, it being claimed by some that an excess fills the pores of the sand and thereby decreases its permeability.

At first glance it would seem that the addition of water to a sand would decrease its permeability to gases. In fact just the opposite is true up to a certain point.

Table D shows the rate of flow of air through two sands containing known percentages of moisture. In each case lots of 500 gr. of the air-dry sand were weighed out, the proper quantity of water added, thoroughly mixed and the moist sand sieved through a No. 8 sieve. The cylinder of the aspirator was filled by adding the moist sand in small portions and ramming it with a properly shaped piece of iron as nearly alike in each case as possible. The data obtained would seem to indicate that there is for each sand an optimum water content when the permeability is highest. After this optimum is passed the permeability again decreases. The explanation of the fact is that when the sand is dry the particles pack close together, and smaller ones fitting between the largest and reducing the porosity to the possible minimum. When water is added the particles readjust themselves, swell up, adhere to each other, forming a *spongy* mass with numerous passages, and the sand can not be packed so close as before. When an excess of water is added the sponges of grains fall apart, pack close, and the pore spaces fill with water. This behavior of the sands can be easily observed under a microscope with a stereoscopic arrangement.

Of course it would not do to fill the cylinder with dry sand to its full capacity and then add water. In this case the water would simply fill the pore spaces, there being no possibility for the grains to readjust themselves.

IMPORTANCE OF THE "OPTIMUM WATER CONTENT."

The practical importance of the determination of the optimum water content lies in the following facts:

1. It gives an idea how a given sand should be treated in regard to the addition of water when used for work.

2. It serves as a criterion of adhesiveness of the sand. From the above consideration it is evident that a low optimum goes with high adhesiveness. A very low optimum would indicate a high degree of genuine clay and inversely.

Since the chemical analysis of a sand can not supply the information concerning its adhesiveness a test like the above becomes of highest importance. Of course further investigations along this line are necessary.

TABLE D.

Table showing the (influence) relation of the per cent of moisture to the rate of air flow.

Sample No. 10.

Per cent of moisture.	Time required to draw one lit. of air. Seconds.
Air dry	3300
5%	2880
7%	1080
9%	640
11%	240
13%	305
15%	560
25%	4200

Sample No. 13.

Per cent of moisture.	Time required to draw one lit. of air. Seconds.
Air dry	840
5%	560
8%	240
10%	280
12%	320
15%	375
20%	3000

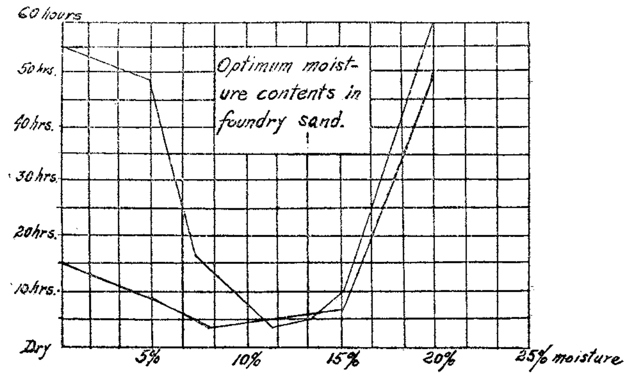


Fig. 3. Diagram showing the relation of the per cent of moisture to the rate of air flow.

Effect of fluxes.—The effect of fluxing impurities may show itself during the casting. If the clayey particles filling the interstices of the sand are sufficiently impure to fuse when heated by the molten metal, the coalescence of these in fusing would tend to close up the pores. For this reason partly a sand running high in fluxing impurities is undesirable.

The "factor of quality" of molding sands.—Granted the adhesiveness and refractoriness of a molding sand, its quality (for different purposes) would depend upon the fineness and its permeability, which can be measured by the rate of flow of air through a column of the sand. Considering the quality of the sand as a formation of its average fineness and permeability of rate of flow of air, we may express its "factor of quality" as the product of these two determinations. Thus let a, b, c, and d be the corresponding average fineness of four sands, and u, x, z, y, the times in equal units it takes to draw a given volume of air through an equal column of each of these sands. The ratio of the fineness of the sand then equals a:b:c:d; the rate of the flow of air being inversely proportional to the time it takes to draw an equal volume will be proportional to 1/u : 1/x : 1/z : 1/y, and the "factors of quality" of the sands will be in the ratio of a/u : b/x : c/z : d/y.

Table C shows the factors of quality of 14 samples of molding sands examined and distributed in the groups indicated by Mr. Jacob Siegrist of the Hildreth Manufacturing Company, a specialist foundry foreman. Within the groups the sands were placed by Mr. Siegrist in the same order as they are arranged in the table, except samples 52, 44, 47. Sample 47 was placed by him as No. 1 in the corresponding group, and 44 as No. 2. Sample 52 should be more properly classed as a brass core sand. The other sands tested were not considered good enough to be rated. The data would seem to indicate:

1. *That the quality factors as above determined of different groups differ from each other by the number of zeros preceding the first significant decimal.*
2. *That the groups blend into each other.*
3. *That the quality factor is a reliable indication of the relative desirability of sand within a given group.*

TABLE C.

Factors of quality of some molding sands. (Average fineness x ratio of air flow rate.)

No. of Sample.	Aver. fineness in mm.	Time in sec's.	Ratio of air flow rate.	Factor of quality.	Remarks.
	Fine sands for brass and very light iron work.				
20	0.0185	165000	1/1650	0.0000112	Grading agrees with that of practical molder, Mr. Siegrist.
62	0.0274	76800	1/768	0.0000356	
12	0.0324	60000	1/600	0.0000540	
8	0.0352	60000	1/600	0.0000587	
	Sands for general "medium" work.				
52	0.0509	28800	1/288	0.000180	This transition sand was included by Mr. Siegrist in the 1st group.
10	0.0480	16500	1/165	0.000210	
50	0.0573	16300	1/163	0.000350	
46	0.0585	13200	1/132	0.000440	
5	0.0681	15000	1/150	0.000450	
28	0.0696	11100	1/111	0.000630	
	Sands for heavier work.				
44	0.0840	6600	1/66	0.00127	These two were inverted in order by Mr. Siegrist.
47	0.0912	5300	1/53	0.00172	
13	0.1100	4200	1/42	0.00262	
4	0.2040	2400	1/24	0.00850	

There are a few comments which the senior author wishes to make regarding the foregoing table.

Samples Nos. 52 and 5 came from the same deposit, the lower stratum of Mr. Croy's pit near Dimondale. Through an oversight a mechanical

analysis by sieves was made of each, the duplicates showing a remarkably close agreement (see table p. 52), and yet by the aspirator method the average fineness of one is given as 407 and the other as 500. Moreover the permeability of one is nearly twice as great as the other. It is also interesting to note that according to Mr. Croy's statement several foundries tried this lower stratum and pronounced it to be no good. The comment made on it on a later page is that it resembles some brass core sands used in the state.

Life of a sand.—Practically all molding sands after being exposed to the full heat of the molten metal lose some of their desirable qualities, and become "dead" as the foundryman calls it. A dead sand has had its cohesion and texture destroyed, but may have changed but little in its ultimate composition. In casting it is the layer of sand next to the metal which is most affected, and the thickness of this will depend on the size of the casting and temperature of the metal. On removing the flask from the casting it is impracticable to separate all of this burned sand from the unburned, and moreover there is no sharp line of division between the two, so that much of it gets mixed up with the unaltered material. Since it is deficient in bonding power, a small quantity of fresh sand has to be added to counteract it.

The deadness of the sand is no doubt due to several causes. In the first place the heat brings about a dehydration of the clayey particles of the sand, and thus destroys its plastic and bonding qualities. Secondly the heat may be sufficient to cause some or many of the grains to agglomerate by fusion, thus altering the texture. Thirdly, the iron may be reduced largely or in part to the ferric condition, but this change need not necessarily affect the physical properties of the material. From the first of these causes it would appear that a clayey sand (loam) would become dead sooner than a more siliceous one.

The length of a sand's life is a matter of some importance. Some sands can be used over several times without the admixture of fresh sand, while others are easily "burned."

In this connection the following analyses are of interest. No. I is an unused molding sand from Richmond, Va. It is much used for general work in the foundries at that locality and known as the Redford sand. No. II is some of the "dead" sand, from the layer next to the metal.

Per cent retained on mesh.	I Mechanical	II analysis.
20	1.51	5.34
40	1.26	14.73
60	1.27	10.41
80	.56	1.28
100	6.27	14.61
250	71.69	59.37
C.ay	16.52	3.52

Chemical analysis.

Silica (SiO_2)	83.49	82.32
Alumina (Al_2O_3)	7.25	7.80
Ferric oxide (Fe_2O_3)	4.71	3.98
Ferrous oxide (FeO)	......	2.38
Lime (CaO)	.36	.54
Magnesia (MgO)	.35	.41
Potash (K_2O)	1.30	1.64
Soda (Na_2O)	.41	.80
Titanium oxide (TiO_2)	.30	.22
Water (H_2O)	1.66	.19
Total	99.85	100.28

Comparison of these two sets of analyses indicate that there is a decided increase in coarseness of texture; due to fusing together of the particles. There was in fact a greater agglomeration even than is represented by the mechanical analysis, because some of the coarse grains have been screened out.

The chemical analysis shows little difference between the fresh and the used sand, except in its water percentage and in the iron contents, which have been in part reduced to ferrous oxide, and moreover the sand has apparently absorbed some iron from the metal during casting.

Chemical composition and its bearings.—There appears to be a difference of opinion among foundrymen who have considered the question, as to the value of a chemical analysis. Certain foundries buy their sand largely on chemical analysis, while others claim that it is absolutely worthless.

There are two types of chemical analyses, the ultimate and rational. The former resolves the sand into its component oxides, and takes no cognizance of the mineral compounds present. The latter separates the sand into its mineral compounds. The two should be considered separately.

Ultimate analy is.—Before discussing the bearings of the ultimate analysis it may be well to quote a number taken from different sources. These are given in the following table:

CHEMICAL ANALYSES OF MOLDING SANDS.

No.	SiO_2	Al_2O_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Ignition.	Miscellaneous.
1	81.58	6.46	4.94	.14	.22	1.19	.59	1.63	Moisture...1.46; TiO_2 .....1.90
2.	82.08	7.12	4.63	.36	.35	1.28	.41	1.66	Moisture...1.52; TiO_2 30
3	66.12	16.54	4.46	.40	.22	2.67	.35	4.90	Moisture...4.15; TiO_2 ..... .14
4	79.36	9.36	3.18	.44	.27	2.19	1.54	2.02	Moisture... .74; TiO_2...... .34
5	79.38	9.38	3.98	1.40	.54	1.80	1.04	2.50	Moisture... .80; TiO_2...... .44
6	70.40	3.80	14.94	.12	.15	1.95	.41	4.08	Moisture...3.77; TiO_2...... .70
7	84.40	7.56	2.52	.06	.21	1.29	.65	1.49	Moisture...1.76; TiO_2...... .44
8	85.04	5.90	3.18	.06	.14	1.65	.83	1.57	Moisture...1.11; TiO_2...... .78
9	70.24	16.62	3.94	.08	.09	1.41	.74	4.16	Moisture...2.42; TiO_2...... .46
10	71.60	11.49	7.81	.65	.95	1.42	1.27	4.00	
11	81.45	7.30	4.10	.90	.68	1.40	1.38	2.50	
12	85.08	5.10	4.00	1.20	.25	1.28	.34	2.65	
13	86.80	3.05	5.32	.15	.65	.83	.04	3.25	
14	84.28	4.50	6.10	trace ..	.72	.91	.39	3.10	
15	87.00	6.70	3.20	....	....	.25	.65	2.20	
16	81.26	5.69	4.29	4.34	.36	.87	.38	2.81	
17	88.52	5.63	.88	1.20	.83	By diff. .29		2.65	
18	79.41	12.47	.80	.99	.81	1.56		3.96	
19	90.68	5.95	.48	.69	.44	.71		1.05	
20	57.63	10.03	.88	11.16	5.63	.01		*14.66	
21	44.24	11.89	1.44	13.71	5.90	4.33		*18.49	
22	80.35	11.57	1.04	1.33	.66	2.60		2.45	
23	87.47	6.59	.80	1.18	1.10	2.26		.60	
24	79.61	11.21	2.48	.74	1.07	2.24		2.65	
25	81.50	9.88	3.14	1.04	.65	Undetermined		3.00	
26	84.86	7.03	2.18	.62	.98	Undetermined		2.20	
27	82.90	8.21	2.90	.62	.00	Undetermined		2.85	
28	79.8	10.00	4.44	.70	.88	Undetermined		2.89	
29	82.21	9.48	4.25	**.68	.32	.05	.09	2.64	Organic matter.28
30	86.85	8.27	2.32	**.29 / .50	.81	.03	.10	1.08	Organic matter.15
31	88.40	6.30	2.00	.78	.50	....	....	1.73	MnO...... .23; Org....... .04
32	78.86	7.89	5.45	**1.46 / .50	1.18	.09	.13	3.80	Org......... .64
33	81.57	11.52	2.74	1.49	.18	....	....	2.50	

*Includes CO_2.
**Carbonate.

1–2. Fine sand for light castings, Redford pits, Richmond, Va.
3. Coarse, gravelly sand for cores, Harbaugh's pit, Richmond, Va.
4. Albany sand for stove plate work, sampled from a foundry in Richmond, Va.
5. Same quality as 4, from Newport, Ky.
6. Sand for general casting work, Blandford pits, Petersburg, Va.
7. Sand for general work, Armstrong pits, Petersburg, Va.
8. Sand for general work, Griffin's pit, Fredericksburg, Va.
9. Sand for general work, Bottersea farm, Petersburg, Va.
Nos. 1–9 from Report on Mineral Resources of Virginia, by T. L. Watson.
10. "Philadelphia" brass sand.
11. Albany sand for brass work.

12. French statuary brass sand.
13. Mild Lumberton, N. J., brass sand.
14. Strong Lumberton, N. J., brass sand.
15. Millville, N. J., gravel.
16. Charlesville French brass sand.
    Nos. 10–16, J. L. Jones, The Foundry, Feb. 1907.
17. Core sand, Miltmore quarry, Janesville, Wis.
18. Upper bed, Rockton, Ill.
19. Nos. 2 sand, White and Traugott, Berlin, Wis.
20. Lower bed, Rockton, Ill.
21. Brass sand, Pendleton's pit, Neenah, Wis.
22. Loamy sand, Menominee Hydraulic Pressed-Brick Co., Menominee, Wis.
23. Lake sand for cores, Superior, Wis.
24. Fine sand, Albany, N. Y.
    Nos. 17–24, Wis. Geol. and Nat. Hist. Surv., Bull. XV, p. 224, 1906.
25. Fine sand.
26. Sand for medium weight castings.
27. Coarse sand for heavy castings.
28. Sand for heavy machinery in dry sand molds.
    Nos. 25–28, W. Ferguson, Iron Age, Vol. LX, p. 16, 1897.
29. Sand for light iron work, Scott.
30. Sand for medium iron work, Scott.
31. Sand for heavy iron work, Scott.
32. Sand for light brass work, Scott.
    From printed specifications of Case Company.
33. Sand for stove castings, Conneaut, O.

An examination of the above table shows us that while the analyses range from 44.24 to 90.68 in silica, about half of them show a silica contents between 75 and 85 per cent, while 21 of the 33 show over 80 per cent of silica. They can therefore with but two marked exceptions be classed as highly siliceous. None of these so far as known are used for steel castings, and moreover such sands would be more siliceous, running over 96 or 97 per cent silica. Omitting the calcareous ones there is usually a decrease in alumina with an increase in silica. Iron oxide may also show considerable variation, but the other four common ingredients, viz., lime, magnesia, potash, and soda are usually present in small amounts, the first two rarely exceeding 1 per cent individually, and the last two 2 per cent. While we must admit the existence therefore of some variation, the question arises whether it shows any relation to texture.

Mechanical analyses of all the above are not available, but there are a sufficient number to show that two sands of quite dissimilar texture may agree closely in chemical constitution. This is well brought out by the four examples given below.

	I	II	III	IV
SiO_2	79.36	79.38	84.40	85.04
Al_2O_3	9.36	9.38	7.50	5.90
Fe_2O_3	3.18	3.98	2.52	3.18
CaO	.44	1.40	.06	.06
MgO	.27	.54	.21	.14
K_2O	2.19	1.80	1.29	1.65
Na_2O	1.54	1.04	.65	.83
TiO_2	.34	.44	.44	.78
H_2O	2.02	2.50	1.49	1.57
Moisture	.74	.80	1.76	1.11
On 20	.26	.06	.09	.19
40	.51	.12	.41	.19
60	2.53	.32	2.21	.39
80	.99	.16	2.67	.19
100	4.19	.83	17.37	.98
150	79.85	73.38	58.20	81.92
Clay	11.24	24.73	19.02	15.97

I. Albany sand used for stove plate work, sample taken from foundry at Richmond, Va.
II. Stove plate sand, from Newport, Ky.
III. Sand for general work, Armstrong's pit, Petersburg, Va.
IV. Sand for general work, Griffin's pit, Fredericksburg, Va.

Nos. I and II agree closely in chemical composition, but differ markedly in their texture, the sizes showing the greatest difference being underscored. The difference in mechanical composition of III and IV is still more striking, although they are closely alike in chemical composition.

Other examples showing the lack of relation between textural and ultimate chemical composition could be found, but it is believed that the foregoing will suffice.

There is no relation between the percentage of alumina and the degree of plasticity. Analysis No. 3 in the foregoing table is that of a coarse grained, gravelly sand, while No. 9 is a fairly plastic loam.

Finally we may inquire whether there is any relation between the chemical analysis and use. Samples No. 10 and 13 (Table p. 63) are both brass sands, but are quite dissimilar in their silica and alumina contents. No. 20 is also said to be a brass sand, but bears no resemblance chemically to 10 or 13.

No. 4 and 28 are not dissimilar, and yet the former is a stove plate sand, and the latter a sand for heavy machinery.

Of course there are cases where two sands used for the same class of work are of similar composition, as Nos. 25 and 29, but they are exceptions.

Within very wide limits the chemical analysis may give us some clew to the degree of refractoriness. Thus Nos. 20 and 21 with their high percentage of fluxing impurities would not stand as much heat as a steel casting sand with 98 per cent silica, but among all the others it would be difficult if not impossible to make any predictions regarding their fire resisting qualities from the chemical analysis because texture plays such an important role, a coarse-grained sand of given composition being more refractory than a fine-grained one.

To sum up then regarding the chemical analysis it would appear to the writer that it gives us no information regarding the cohesiveness, degree of plasticity, texture or use, and we may therefore ask of what value it is. So far as I can see it is of little direct aid, except possibly in the selection of sand for steel casting. If a sand is very calcareous a drop of muriatic acid will show it without the need of making a complete chemical analysis.

Field[1] has stated that the ultimate analysis of a good molding sand[2] should give results within the following limits:

Total silica	75–85 per cent.
Alumina	7–10 per cent.
Lime below	2 per cent.
Alkalies below	5 per cent.
Iron oxide below	6 per cent.

These limits hardly fit all the sands in the table on p. 63, all of which, so far as could be ascertained are giving good satisfaction.

Rational analysis.—The rational analysis could in the writer's opinion be made of far more service than the ultimate one. As commonly made it determines the percentages of quartz, clay, and feldspar present, and might afford us clews regarding the bonding power, and refractoriness of the sand. Very few rational analyses of molding sand have been published, but the following two[3] may serve for purposes of illustration:

The ultimate analyses are also given.

	I	II
	Rational analysis.	
Quartz	67.85	64.66
Clay	17.50	24.50
Feldspar	10.12	7.28
Iron oxide	4.53	3.56
	Ultimate analysis.	
Silica	80.66	77.22
Alumina	9.30	9.26
Iron oxide	4.53	3.36

I. Sharp molding sand.
II. Strong molding sand.

Both of them carry considerable clay, and the strong one it will be noticed has nearly 25 per cent.

Mineral composition.—Although molding sands may contain a number of different minerals, those present in quantity are but few in number.

Quartz is invariably present in large amounts, forming angular or rounded grains, which vary in size from the fine silty grain up to particles the size of a pin head or even larger. The quartz grains may be white, but they are more generally colored by iron oxide, which frequently forms a film on their surface. Quartz may be regarded as the non-shrinkage and refractory element in the sand, and sands used for steel casting contain a high percentage of it.

The size of the quartz grains, moreover, determine the use of the sand

[1]Iron Trade Review, Mar. 15, 1906, p. 19.
[2]He probably excludes highly siliceous sands for steel castings.
[3]Field loc. cit.

to a large degree; since they influence its texture, and since the quartz grains are most influential in affecting the refractoriness and porosity, the percentage of them in the sand should be as high as is possible without displacing any bonding material, for the quartz alone has no bonding power, unless very fine, and even then its cohesiveness is exceedingly slight.

As explained on another page, the percentage of quartz present cannot be determined from the ordinary chemical analysis with any degree of accuracy.

A microscopic examination of almost any sand will show the predominnance of quartz among the sandy grains.

Clay, although not a mineral, correctly speaking, may be considered under this head. It is the most abundant substance next to quartz, and forms the bonding material in the sand. A certain amount of it is desirable, but an excess is exceedingly harmful, because it tends to fill up the pores between the sand grains, and cause the material to shrink and crack when heated. What we need then is sufficient only to properly bond the sand grains. It is in the clay that most of the fusible elements of the sand, such as lime, magnesia, alkalies, and even iron are found. Still the quantity of these will vary in different clays, and the best would be one of refractory character and therefore containing these in but small amounts.

Clays vary, moreover, in their tensile strength or bonding power, and the same amount of one clay might bond much better than an equal quantity of another. This is noticed in the difference in bonding power of two sands of like texture, and also when steel manufacturers use different clays for mixing with the same sand. The percentage of clay in the sand can be only approximately figured from the alumina contents in the ultimate analysis. A rational analysis would yield more accurate information.

Iron oxide.—This mineral is present in all molding sands, and gives them their reddish or brownish color. It may be present as a film coating the sand grains (the most common mode of occurrence), as a cement binding the grains together, as limonite grains or nodules, or as an ingredient of ferruginous silicates. The last two are rare. Most analyses show but a small percentage of it, and while it acts as a fluxing impurity, its action in many cases is not strong.

Lime is found in many molding sands, but usually in small amounts. It is probably present as an ingredient of feldspar grains, but in a few it occurs as lime carbonates, forming a cement which binds the grains together. It makes the sand more fusible, and when in the form of carbonate may also cause it to crack or crumble in the mold. The conditions under which it may act as a refractory agent are mentioned under refractoriness.

Miscellaneous minerals.—These are sometimes present in small quantities, and may include feldspar, mica, hornblende and a few others. The quantity is usually a negligible one, with the exception of mica, which is sometimes present in noticeable quantities.

NOTES ON MICHIGAN MOLDING SAND OCCURRENCES.

The deposits of molding sand worked in Michigan are all obtained from surface formations of recent geological age. They may occur, 1, as pockets in morainal drift; 2, as outwash deposits from the glacier; 3, as lake deposits as those at Vineland; or 4, as silts bordering the rivers, and representing either flood deposits of the present day or glacial material that has been reworked and sorted, etc. The method of formation, and therefore relation to deposits of other materials, is quite varied.

In no case has an extensive deposit of uniform character been observed, the deposits being usually either lenses or pockets, surrounded by coarser material (Pl. IV, Fig. 1), or thin beds (Pl. IV, Fig. 2) immediately underlying the surface.

In every case care is necessary in digging the material, as it may suddenly change in character without any warning. Several grades are often obtainable from a small area, and the person in charge of the digging should not only have an accurate knowledge of the character of the sand required, but keep a close watch on the excavating.

There are a large number of small foundries scattered over the state, which make castings of medium weight, and do not require a very high grade of sand, nor large quantities of it. While some of these obtain sands from other states, not a few use a local sand, which they are able to get from pockets scattered here and there over the country. Many of these were visited, but in every case the available supply was found to be too small to be worth listing.

In the following notes, therefore, it is the more important ones that are referred to.

Battle Creek, Calhoun Co.—There are a number of foundries located in this town which in the aggregate consume a large quantity of sand annually, and while much fine sand is shipped in from other states, nevertheless a considerable quantity is obtained from local pits, and used by the foundries at Battle Creek, notably by the Advance Threshing Machine Company.

These local sands, which do not so far as known form extensive deposits, are obtained in part from the glacial drift and in part from silty beds bordering the rivers. The latter are the more extensive. A pit may not last more than a few months, and then another one is sought and opened. Much of the sand used by the foundries is dug by Geo. Baltz, who also locates the pits. So when one pit is exhausted he hunts up another one.

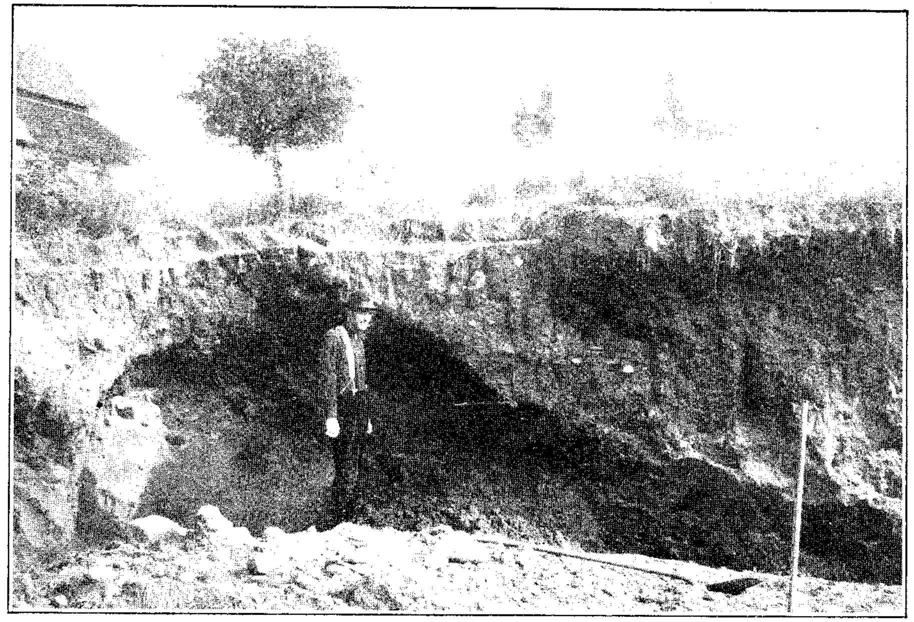
At the time of the writer's visit sand was being dug from a pit in the drift, located along Coldwater street, on the southern edge of the city, and just northwest of the mill pond.

The pit (Pl. IV, Fig. 1) shows an unassorted mass of dirt, very pebbly in its upper part, but containing pockets of molding sand, the one worked having a thickness of six to eight feet. Care has to be taken in digging the molding sand, as the deposit contains scattered streaks of coarse sand, which have to be thrown out.

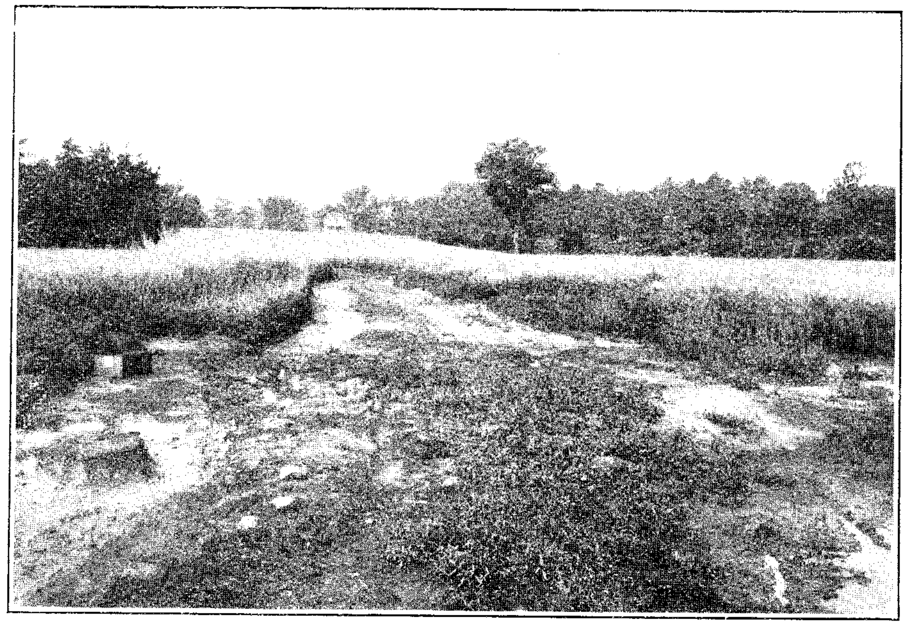
The following mechanical analysis represents the texture of this material (Lab. No. 19).

Mesh.	Per cent.
20	.02
40	.20
60	.42
80	.09
100	.38
250	84.52
Clay	14.31
Average fineness (Ries)	212
Porosity	42

The sand, which is regarded as an excellent grade of "light" molding sand for bench work, is nevertheless a little too heavy for brass work. It



1. POCKET OF MOULDING SAND IN MORAINE, BATTLE CREEK.



2. SILT SAND BORDERING KALAMAZOO RIVER, NEAR BATTLE CREEK.

is very similar to No. 38 (Table p. 52) a sand from Akron, Ohio. The pit from which it was taken is but one of a number which have been worked around the city.

A more important deposit, but of the river silt type, occurs at Niagara Park, on the S. side of Battle Creek, (Pl. IV, Fig. 2). The pit is located in a field at a point about 600 feet east of the buggy factory and about ¼ mi. S. E. of the electric light plant.

The sand underlies a low terrace bordering the river, and whose surface is 6 to 8 feet above it. Its thickness ranges from 6 inches to 2 feet, and the overburden consists of 6-12 inches of soil. Gravel underlies the sand. The area shown in the view has been worked for about two years.

It is quite evident that in order to get any appreciable quantity of material a considerable area must be dug over.

The mechanical analysis of this sand (Lab. No. 28) was as follows:

On 20	2.51
40	6.16
60	16.49
80	4.74
100	11.30
250	32.37
Clay	26.39
Average fineness	361
Per cent porosity	39.6

This material is used for floor work. A similar sand has also been obtained on the south side of the Kalamazoo river, about 2 miles from town and along what is known as the River road, leading to Augusta.

Dimondale, Ingham Co.—Sand has been dug for several years, by P. Croy to supply the foundries at Lansing. The pit is located along the Grand river, on Mr. Croy's farm, and the deposit, which underlies the lower edge of the slope bordering the river, is probably a river silt, but is not being added to at the present time. The section involves

Loamy soil	1-2 ft.
Molding sand	2 ft.
Coarser sand	

The molding sand, which has been worked for 10-12 years is nearly exhausted at this point. Mr. Croy states that the underlying sand is no good, or at least not satisfactory to the Lansing foundries, but it closely resembles some of the brass core sand used in Michigan.

Its mechanical analysis, made in duplicate, yielded the following figures:

	5	52
On 20	.06	.11
40	.38	.39
60	5.41	6.38
80	3.45	3.79
100	14.92	14.69
250	58.49	57.83
Clay	17.25	16.78
Average fineness	407	500
Per cent porosity	39.6	37.5

Although Mr. Croy has prospected his farm rather carefully, he states that he has not been able to find any other deposits of molding sand on it, even along the river.

Escanaba, Delta Co.—There is a rather extensive deposit of molding sand in the town of Wells near Escanaba. The material, according to Prof. C. A. Davis, who collected the samples, is situated on the lower terrace of the Escanaba river. He writes, "This terrace is a limestone one, 15–20 feet high, made up of thin-bedded limestone with a covering of from 1–5 feet of silt. The rock is quarried, and it is in the vicinity of these quarries that the molding sand is taken. The sand is here only about 1 foot deep, the bottom of the stratum being rather coarser and gravelly, and also containing a good many limestone fragments. The area now being worked is only a small one, and not a great amount of it has been carted away, but the area underlain by this silt is considerable, and across the river it is much thicker, and appears to be of the same quality as that now used."

"The river terrace is subject to overflow in the spring freshets, and at such times the old silts are washed away and damaged by the bringing in of coarser sands and gravels.

Four samples were tested as follows: No. 10 was taken from the west side of the opening on the west bank of the river, now being used for the local foundry of the Stephenson Company. The deposit here was about one foot deep, with the lower two or three inches gravelly. The latter was rejected.

No. 46 was collected on the east side of the same opening about 15 yards from the last. Here, after removing about 4 inches of soil, 6–7 inches of silt was taken out.

No. 51 came from the east side of the river, about 20 feet above the river level, where it formed a layer 1 to 3 feet thick on top of the limestone of the I. Stephenson Company's quarry. The sample came from about a foot below the surface.

No. 50 was also taken from the deposit on the east side of the river about 30 or 40 rods south of the quarry and opposite the head of a small island in the river. There the silt deposit is from 4 to 6 feet deep. It contains some scattered limestone fragments.

The first two are used for ordinary foundry work, but the last two were taken from unworked beds.

The mechanical analyses are given below:

	10	46	51	50
20	3.29	1.36	5.82	1.88
40	3.05	3.44	6.74	5.80
60	15.49	14.78	27.39	24.03
80	4.24	4.24	5.75	5.26
100	12.64	12.82	12.55	14.23
250	35.19	40.74	27.54	32.00
Clay	26.11	21.64	12.74	14.88
Average fineness	509	428	326	427
Per cent porosity	43	43	36.3	37.4

From these analyses it will be seen that the material from opposite sides of the river is not only dissimilar, but that the sands from adjoining pits on the same side of the river are not closely alike. None of the materials are in use, but certain of these samples are not unlike others which are being employed.

Thus No. 10 is not unlike No. 28 (Table p. 52) which represents the heavier grade of Battle Creek sand in use at the foundries there. No. 46 is rather similar to No. 36, one of the Lansing sands. The other two are probably classable as fine core sands, or sands for heavier grades of molding. The occurrence of these sands is important, because they are among the few reported from the Upper Peninsula.

French Landing, Wayne Co.—A sand suitable for molding occurs along the creek on Stofledt's and adjoining farms. The material is a river silt but little of it has been dug, and that was for use at a small foundry at Romulus.

Grand Rapids, Kent Co.—Of the many foundries here, only a few use local sand, the majority reporting that they employ Ohio material, similar to that of No. 62 in the table on p. 52. The local sand used comes mostly from a morainal(?) ridge known as the Black Hills, and located along the Grandville Avenue trolley line. A number of small pits have been dug here and there, but none could be called permanent excavations, and some dissatisfaction has been expressed with the sand because it is said to show a tendency to burn onto the castings. The mechanical analysis of this material (61) is as follows:

Lab. No.	61	36
On 20	.54	1.68
40	2.11	3.08
60	11.38	14.00
80	3.94	4.66
100	11.67	11.59
250	49.57	44.47
Clay	20.57	20.00
Per cent porosity	37.4	39.1

This most closely resembles that from the Reeves pit (36) near Lansing, but is slightly finer.

Jackson, Jackson Co.—Very little sand for molding is worked in the immediate vicinity of Jackson, and the deposits are, so far as known, small.

The best local sand now used here, is some which comes from the W. McGill farm at Leoni, 5 mi. N. E. of Jackson, where a bed 2 ft. thick is worked after first removing the soil. The deposit is not extensive, however. It makes an excellent material for general work, and has been used for castings weighing up to three tons. While it is not as long lived as might be wished, it is claimed to have the advantage of leaving the casting quite clean and not adhering to it, in fact less so than the St. James sand. The following is its mechanical analysis:

Lab. No.	27
On 20	.33
40	.18
60	.55
80	.24
100	5.47
250	87.92
Clay	5.36
Average fineness	344
Porosity	43.9

Its high porosity and good permeability make it a good sand. It would be well to test this as a substitute for No. 38, which is brought from Ohio (see table p. 52).

Two miles west of Jackson a sand bank has been opened by the Jackson Pressed Brick Company for the manufacture of sand-lime brick. While the bank (Pl. V, Fig. 1) shows no sand adapted to molds, it does contain much that could be used for cores, as shown by the following mechanical analysis of a sample of it:

Lab. No.	25
On 20	19.13
40	39.45
60	29.68
80	2.68
100	2.99
250	2.47
Clay	3.36
Average fineness	29
Per cent porosity	33.8

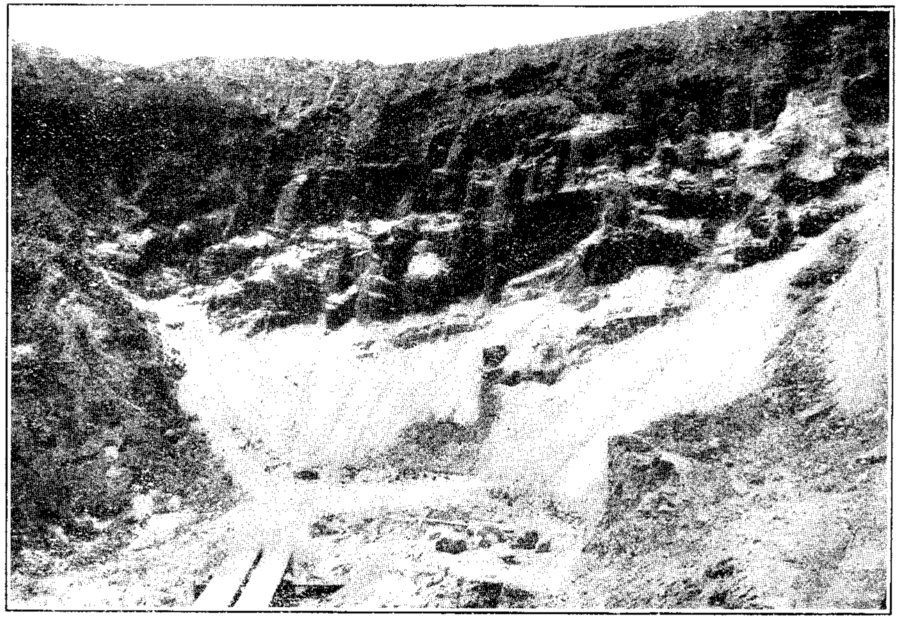
The Holton and Weatherwax Company get some sand from small pits in the drift around Jackson, and use it for general work. The drift also supplies core sands of different grades. Of the two given below, No. 4 is used for heavy work, and has of itself a fair bonding power, while No. 3 is a finer sand, and is employed for smaller cores. It is mixed with oil in the proportions of 1 oil to 35 sand by volume. The mechanical analysis shows its deficiency in clay bond.

Lab. No.	4	3
On 20	3.96	6.84
40	7.10	6.61
60	46.97	40.09
80	11.74	8.98
100	15.32	23.82
250	11.35	12.56
Clay	3.65	1.06
Average fineness	120	91
Per cent porosity	35.8	34.2

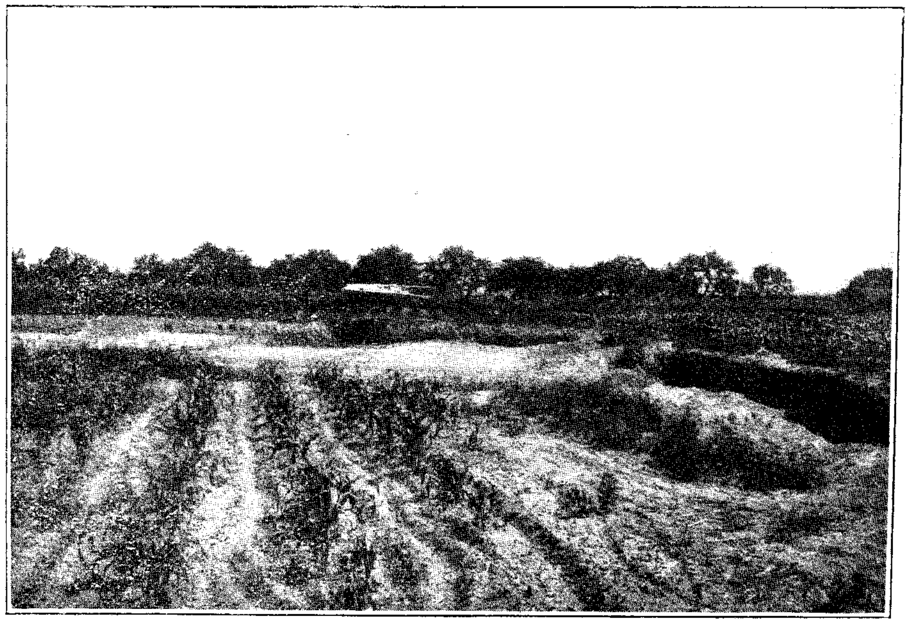
Lansing and vicinity, Ingham Co.—There are, perhaps, more local sources of supply of molding sand around Lansing, than are to be found around most towns, and some of it has been successfully used as a substitute for sands from other states.

For example the first of the following three mechanical analyses represents a sand from the Gillette property, 2 miles N. W. of Lansing, which is used as a substitute for a mixture of 2 and 3, formerly brought from Ohio.

	I	II	III
On 20	......	.04	.56
40	.01	.22	.93
60	.20	.88	9.59
80	.99	1.45	19.46
100	10.83	1.11	15.97
Through 100	87.90	96.30	53.49



1. SAND BANK AT SAND LIME BRICK WORKS NEAR JACKSON.



2. PITS OF GARDEN CITY SAND CO., VINELAND, NEAR ST. JOSEPH.

The section in the deposit which lies along the Grand River shows

Soil	1 ft.
Sand	2 ft.
Gravel	

The material, which underlies a narrow strip bordering the Grand river, is evidently a river silt deposited at some former period, and as one might expect, it varies somewhat in its texture from pit to pit.

Two different grades of washed over river silts are dug on the Reeves place 2½ miles west of Lansing. The first of these (Lab. No. 7) is used by the Hildreth Pump and Motor Works, and the second (Lab. No. 36) by the Lansing Wheelbarrow Works.

Lab. No.	7	36
On 20	.28	1.68
40	.56	3.08
60	1.93	14.00
80	1.80	4.66
100	9.34	11.59
250	60.78	44.47
Clay	25.27	20.00
Per cent porosity	42.6	39.1

A coarser grade adapted to core work occurs on the J. R. McCammans' place in the southeast part of Lansing. Two kinds are used by the Oldsmobile Company, and owing to their deficiency in bonding material (a characteristic feature of core sands), are mixed with from ⅛ to 1-20 flour. The mechanical analyses of these are as follows:

Lab. No.	53	57
On 20	1.14	15.00
40	9.42	27.95
60	50.76	34.04
80	9.73	4.70
100	17.30	10.67
250	10.44	6.29
Clay	1.17	1.32
Average fineness	106	59
Per cent porosity	36.8	28

The sand is stated by W. F. Cooper to be part of a kame-deposit.

Molding sand of the river silt type, similar in its mode of occurrence to that on the Reeves property, is found on the land of George Christopher, in the N. W. part of Lansing, and across the road from the School for the Blind. This had the following make up:

Lab. No.	44
On 20	3.40
40	3.07
60	12.99
80	6.22
100	20.85
250	42.77
Clay	10.75
Average fineness	292
Per cent porosity	40.7

A deposit not yet used is known to occur on the land of H. Vornberg, Lot 21, Lawrence subdivision, N. W. part of Lansing. On analysis it gave:

Lab. No.	47
On 20	.07
40	.24
60	3.47
80	1.78
100	8.42
250	66.21
Clay	19.78
Average fineness	274
Per cent porosity	43.8

Of the several other Lansing samples tested, this most closely resembles No. 7, from the Reeves property, but is a trifle coarser, having a little less clay.

Linden, Genesee Co.—More or less molding sand has been reported from this vicinity, but only a few small pits have been worked. These are all on the farm of Frank Sadtler, and the sand rarely runs over a foot in depth. It is rather coarse textured, and used for general work. The mechanical analysis is No. 35 in the table on p. 52. The product is all shipped to a foundry at Fenton, where it is used with satisfaction for medium and heavy weight castings.

Ludington, Mason Co.—The sands reported from this region are largely windblown materials, and that used by the local foundries is obtained from Ohio.

Marquette, Marquette Co.—Samples were collected by Professor C. A. Davis from a railroad cut of the L. S. & I. R. R., a few miles from Marquette. The bed is exposed in the cut for about 300 feet, and has a steep face 30-40 feet high. The deposit lies in the N. W. ¼ of the N. E. ¼, Sec. 12, T. 48 N, R. 26 W., and about 400 feet above Lake Superior. It is part of a sand plain or delta deposited in a temporary glacial lake.

The mechanical analyses are as follows:

	54	60	I	II
20	.09	.29	......	......
40	.08	.09	.10	.02
60	.29	.23	.18	.04
80	.12	.10	.06	.02
100	.57	.56	.12	.14
250	79.02	95.59	77.50	77.54
Clay	18.41	1.64	22.40	22.12
Porosity	38.3	38.9	42.66	40.11

These are two of the finest grained sands tested from Michigan, and No. 54 agrees quite closely with some of the finer grained American stove-plate sands which are given for comparison. No. I above is the B. Y. sand from Hamilton County, Ohio., and No. II, a No. 5 sand from Newport, Kentucky. Both these contain a little more clay and show a slightly higher porosity. No. 60 will probably be found somewhat deficient in clay.

Niles, Berrien Co.—There are no large foundries at this locality and consequently the demand for molding sand is limited, so that there has been no encouragement to search for large deposits. There seems, however, to be a considerable quantity of loamy sand underlying the soil on all sides of the town, but in no case has a large pit been dug, and as soon as one is abandoned it washes in readily, obliterating the section. One such pit occurs just south of the Niles Milling Company on the Howard Rose property, near Dowagiac Creek; another is 3 miles south of Niles near the electric light plant. At the time of the writer's visit the Garden City Fan Company was digging sand for floor work, from a surface deposit underlying the soil, and adjoining the factory, while core sand is dug not 150 feet distant. The molding sand appears to occur as pockets resting in the coarser core sand. Excellent sand is also said to occur on the adjoining LaPeer property. The following mechanical analysis represents the local molding sand used at the Garden City Fan Company's works.

Lab. No.	13
On 20	4.69
40	13.34
60	23.96
80	5.01
100	11.95
250	18.22
Clay	22.79
Average fineness	222
Per cent porosity	42.3

A sand which is used in some quantity at one of the larger foundries is a coarse sand known as Eureka No. 4, from Zanesville, Ohio, district. In some respects it resembles the Niles sand rather closely, especially in the proportions of its finer material. There is some disagreement, however, in the larger sizes. No. 8 represents the Ohio sand and No. 13 the Niles material.

Lab. No.	8	13
On 20	.96	4.69
40	12.42	13.34
60	34.41	23.96
80	4.31	5.01
100	7.50	11.95
250	18.29	18.22
Clay	22.06	22.79
Average fineness	714	222
Per cent porosity	35	42.3

Port Huron, St. Clair Co.—All the foundries at Port Huron, with one exception, claim that while core sand can be found in the vicinity of Port Huron, molding sand has to be shipped from other localities, situated mostly in other states.

The only local sand reported is one dug from small scattered pits near the cemetery, and this is probably of lacustrine origin, similar to that worked at St. Joe. The material runs barely over a foot in thickness, however. It is interesting in being one of the finest textured sands examined from the state, and its presence should stimulate further search in the laminated sand and clay formation which borders the lakes. At present it is used for general work. The following is its mechanical analysis. (48).

Lab. No.	48	12	A
On 20	.29	.30	.04
40	.85	.77	.42
60	2.20	4.52	3.90
80	.65	1.63	1.92
100	3.52	5.35	6.12
250	58.37	57.95	56.72
Clay	34.08	29.44	31.02
Average fineness	......	770	......
Per cent porosity	41.2	39.5	40.43

Of the different Michigan sands tested it most closely resembles that from Vrooman's pit at Riverside, near St. Joseph, and of which analysis (12) is also given for purposes of comparison. It is also similar in texture to the Waterford, Ill., No. 3, which is said to be used for malleable iron castings and agricultural implements (No. A of above table).

Rochester, Oakland Co.—An extensive kame deposit of sand occurs along the Michigan Central R. R. about ½ mile S. E. of Rochester. Indeed this ridge extends along the railroad for some miles, but the material composing it is not always fine sands, and in fact any one pit may yield both sand and gravel.

The pit referred to above is worked by G. Heal, and the section involved is

1.	Red loam	1½–2 ft.
2.	Cross-bedded sand and gravel with pebbles up to 1½ in.	4 ft.
3.	Sand	5 ft.

The beds may be used singly or mixed as indicated below. Beds 1 and 2 are mixed together and shipped to Detroit for use as cores in the car foundry. The third or bottom layer is also shipped to Detroit and used for cores.

A mixture of 1-10 No. 1 and 9-10 layer 2 is used for sand-lime brick manufacture.

The base of the pit is about 20 feet above the railroad track, and at the track level there is a 12 foot bed of fine sand exposed. This is covered by 2 feet sandy loam, and 1½ feet gravel. This is known as 100 fine and is shipped to several foundries in Detroit.

Underlying the bottom sand in the upper pit is 8 feet of blue sandy clay.

Another sand bed outcrops in the hill along the mill pond opposite Rochester station.

The following mechanical analyses were made of the sand in Heal's pit in Rochester.

No. 11 sand lime mixture referred to above.

No. 15, mixture of layer 1 and 2 for car foundry cores.

No. 29, No. 100 fine sand from along track.

	11	15	29
On 20	11.13	25.69	0.00
40	12.08	24.67	.08
60	21.93	30.57	1.79
80	4.33	5.47	1.03
100	19.16	7.16	19.42
250	30.01	4.64	74.93
Clay	1.35	1.76	2.71
Average fineness	140	56	286
Per cent porosity	30.6	28.4	35.2

Saginaw, Saginaw Co.—Although there are a number of foundries at Saginaw and Bay City, all of them report their inability to find a suitable sand for molding in the vicinity of these cities, and as far as could be ascertained none occurs. Light core sand does, however, occur in sufficient quantity in the valley at Saginaw, and much of that used is, it is said, obtained from the pit of the Sand Lime Brick Works near town. This, as will be seen from the following mechanical analysis, is a core sand of finer grain.

Lab. No.	32
On 20	.00
40	.52
60	8.08
80	5.66
100	28.27
250	55.00
Clay	2.45
Average fineness	230
Per cent porosity	38.6

The Bay City foundries report that some core sand is also dredged from the river.

St. Joseph, Berrien Co.—The region around St. Joseph is underlain by three important types of deposits. 1. Laminated sandy clays; 2. Loamy sands; 3. Dune sands.

Nos. 1 and 2 underlie the high terrace bordering the lake. Of these the clays form the thickest deposit, and extend from the lake level up to within a few feet of the terrace surface, and are overlain by the loamy sands. The dune sands are irregularly distributed, and are very prominent along the lake front.

Of these three materials the loamy sands are the only ones utilized for foundry purposes. These form a layer from one to three feet thick, immediately under the soil (Pl. V, Fig. 2). The deposit is not absolutely uniform, however, and more or less care has to be exercised in digging it, so that the layers or lenses of coarse sand can be thrown out. The main pits are at Vineland, south of St. Joseph, but the sand, which is shipped in large quantities, is known as St. James, Riverside, and even other names. The main producer is the Garden City Sand Company, which operates pits on the Tottske Brothers farm. Just north, on the adjoining property of Kerlikowski, is another extensive pit. In Vrooman's pits, which are nearer Riverside, the sand is somewhat more clayey.

The sand from this district is much used throughout Michigan and adjoining states, and in the main seems to give satisfaction for general work.

The following are a series of mechanical analyses of the product from this district.

Lab. No.	26	56	A	B	12
On 20	.13	.03	....	....	.30
40	.59	1.08	1.98	.54	.77
60	20.10	13.21	21.76	11.68	4.52
80	5.81	2.08	6.56	2.78	1.63
100	15.89	9.53	14.06	16.58	5.35
250	33.35	57.70	30.16	43.42	57.95
Clay	24.09	15.06	24.96	24.52	29.44
Average fineness	.....	319	.....	.....	770
Per cent porosity	37.5	37.4	40.60	46.45	39.5

No. 26. Sample taken in Garden City Sand Company's pits, near Vineland.
No. 56. Sample taken from car loaded at Kerlikowski's pits.
A. Sample of St. James sand from foundry at Grand Rapids, Wis. Wis. Geol. and Nat. Hist. Survey, Bull. XV, p. 206.
B. Sample supplied by Garden City Sand Company Ibid.
12. Vrooman's Riverside sand, sample taken from foundry at Saginaw.

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