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THE GLASS SANDS OF OKLAHOMA
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CHAPTER I.

GENERAL CONSIDERATION OF GLASS AND GLASS SAND.

HISTORICAL.

Glassmaking is one of the oldest industries, there being good reason to believe that it dates far back in the development of civilization, probably antedating the brickmaking industry. The earliest evidence of the manufacture of glass has been found in Egypt where archaeologists have discovered sculptured designs representing glassblowers at work. The evidence is that these designs date as far back as 4000 B. C.

Although the Phoenicians are accredited with the discovery of the methods of glassmaking, the majority of authorities are of the opinion that this honor belongs to Egypt since the most ancient relics of the glass industry have been found in that country. Pliny, however, writes that the discovery was made by a group of Phoenician merchants returning by ship from Egypt to Syria with a cargo of natron (crude soda). Overtaken by a storm, they landed on a sandy beach at the mouth of the river Belus, which flows from Mount Carmel into the Mediterranean Sea near Tyre and Sidon. While cooking their food they supported their cooking utensils on blocks of natron. This material acted as a flux and the fire melted the sand. This story is probably a pure fable, as such results under these conditions are impossible. There is little doubt, however, that the discovery of the methods of making glass was purely accidental, but the discoverer, and the time and place of the discovery are absolutely unknown.

The advancement which has been made recently in the process of manufacture of decorated glass is not as real as it seems; for the Egyptians were acquainted with the art of pressing the glass while hot into metallic molds—a feat which was performed as successfully then as it is in modern times. Archaeologists have taken from Egyptian tombs glass coins on which have been impressed figures of deities and various sacred emblems, the glass being colored to imitate precious stones.

INTRODUCTION.

This report is based on field work carried on by the writer during 1911 and 1912 under the direction of the Oklahoma Geological Survey, and on subsequent chemical and physical analyses made in the laboratory of the survey. In the work in the Arbuckle Mountains the writer availed himself of Taff's¹ and of Reed's² investigations. In the Tablequah region free use has been made of Taff's investigation³. In the study of the Trinity sand the author has had access to the dissertation of Pierce Larkin in the Library of the State University of Oklahoma dealing with the Cretaceous area of the southeastern part of the state.

In the present report a general discussion of the glass sand industry will be given, this to be followed by a detailed account of the distribution and character of the glass sands of Oklahoma, which are adapted to and available for glass manufacture.

1. Taff, Jos. A., Preliminary report on the geology of the Arbuckle and Wichita mountains: Prof. Paper, U. S. Geol. Survey, No. 31, 1904.

2. Reeds, C. A., A report on the geology and mineral resources of the Arbuckle Mountains: Bulletin Oklahoma Geol. Survey, No. 3, 1910.

3. Taff, Jos. A., Tablequah folio (No. 122), Geol. Atlas U. S., U. S. Geol. Survey, 1905.

As nearly as can be learned, the glass industry lived and thrived until the overthrow of the Roman Government by the Barbarians from the north, when the glass industry suffered the fate of nearly all the other industries. During the dark ages one branch of the industry—the making of mosaics and stained glass—was perpetuated by the church. Not until the nineteenth century, however, did the art of glassmaking begin to emerge from the almost total eclipse it had experienced and to this century most of the improved methods which have placed it once again among the arts must be assigned.

DEFINITION OF GLASS.

According to Bizer, "Glass is a transparent solid formed by the fusion of siliceous and alkaline matter, which assumed while passing through said state of fusion at a temperature sufficiently high, a fluid condition, and, as the temperature falls, passing from the fluid through a ductile viscous state to a solid,—devoid of crystalline structure, impervious and impenetrable to both gases and liquid fluids—a hard, brittle mass which exhibits, when broken, a lustrous fracture."

This definition shows clearly how difficult it is to frame an exact definition of glass from a chemical standpoint, because no one of the several varieties has definite chemical composition; but still the fundamental constituents of all commercial glass are very similar.

COMPOSITION OF GLASS.

The chief raw constituent of glass is quartz sand which, when pure, is composed of silica (SiO_2). After fusion the glass consists of a mixture of two or more silicates united into a homogeneous, hard, brittle mass. The variety or character of the glass is determined by the proportion and molecular composition of these silicates. In the process of manufacture the silicates are formed by the union of the silica with potash, soda, lime, lead, and other bases. Other ingredients are sometimes added in small amounts for special purposes, such as deoxidizing and decolorizing agents, and for imparting special colors and properties to the silicates.

For the formation of a silicate it is necessary that at least one alkali base be present to combine with the acid

4. Bizer, Benjamin F., Elements of glass and glass making, 1899, p. 7.

radical silica. The quantities of the various constituents are made to vary according to results desired. These proportionate quantities are determined by experiment and so the formulae for the various varieties of glass are established. Although a close approximation of the relative amounts of silica and added bases in the several varieties of glass may thus be made, yet in several samples of the same variety the chemical composition may vary within comparatively wide latitude, so that it is quite impossible to classify the several varieties on the basis of their chemical composition.

CLASSIFICATION OF GLASS.

Commercial usage has established four general classes of glass, viz:

1. Plate glass, comprising rough plate, rolled plate, ribbed plate, and polished plate.
2. Window glass, including ordinary and colored, or painted, sheet glass.
3. Flint glass. This term has an extensive application and includes all common (or lime), flint, and crystal glass.
4. Bottle glass. This grade is coarse and inferior in quality. It is used extensively in the commonest grades of bottles and other hollow ware. It is usually of a greenish, amber, or black color.

The approximate composition of these grades of glass is shown below:

Analyses of plate glass.

	FRENCH		ENGLISH			Belgian. Charleroi. Benrath.	German. Jaekel.	Hanoverian. Emmerling.	Venetian. Berthier.
	St. Gobain. Peligot.	French. Dumas.	Chances. Benrath.	British Plate Glass Co. Mayer & Brazier.	London and Thames.				
Silica	73.00	75.90	70.71	77.36	78.68	73.31	72.31	73.79	68.60
Soda	11.50	17.50	13.25	13.06	11.36	13.00	11.42	13.94	8.10
Potash				3.01	1.34			0.60	6.90
Lime	15.50	3.80	13.38	5.31	6.09	13.34	14.96	8.61	11.00
Magnesia								0.12	2.10
Manganese								0.32	0.10
Sesqui-oxide of Iron....			1.92	0.91	trace	0.83		0.68	0.20
Alumina				trace	2.68		0.81	0.58	1.20

Analyses of window glass.

	French. (Dumas)	English. (Dumas)	Chance's. (Cooper)	Russian. (Benrath)
Alumina	7.60	69.09	71.40	71.27
Silica	68.00	11.10	15.00	20.10
Soda	10.10	12.50	12.40	8.14
Lime	14.30	7.40	0.60	

Analyses of lead glass.

Glass	Analyst.	Silica.	Soda.	Potash.	Lime.	Lead.	Iron.	Alumina.
English crystal	Faraday	51.93	.....	13.67	.....	33.28	.....	.....
" "	Berthier	59.20	.....	9.00	.....	28.20	0.40	.....
French crystal	Sauerwein	48.10	.....	12.50	0.60	33.00	0.50	.....
" "	Benrath	50.18	.....	11.62	.....	33.11	1.30	1.30
American crystal	Fletcher	53.98	6.71	7.60	.....	29.78	1.93	1.93
" "	"	54.12	5.58	7.98	.....	31.27	1.05	1.05

Analyses of lime glass.

Glass	Analyst	Silica.	Soda.	Potash.	Lime.	Magnesia.	Manganese.	Iron.	Alumina.	Baryta.
French	Pelouze	72.10	12.40	.....	15.50	.....	.....	.....	.....	.....
" tubes	Berthier	69.20	3.00	15.80	7.60	2.00	.....	0.50	1.20	.....
Bohemian	Rowney	73.13	3.07	11.49	10.43	0.26	0.46	0.13	0.30	.....
American	De Brunner	71.92	14.55	.....	5.14	2.04	.....	.....	6.22	.....
"	Henrivaux	70.40	9.13	8.66	10.00	.....	0.50	0.02	0.99	.....
"	Benrath	67.10	10.30	4.20	5.10	.....	.....	0.10	0.30	11.90

Analyses of bottle glass.

Kind of Glass.	Analysts	Silica.	Soda.	Potash.	Lime.	Manganese.	Sesqui-Oxide of iron.	Alumina.	Magnesia.
French..... } Sauvigny ... }	Berthier	60.00	3.10	3.10	22.30	1.20	4.00	8.00	.....
St. Etienne... }	Berthier	60.40	3.20	3.20	20.70	.....	3.80	10.40	.....
Epinac..... }	Berthier	59.60	.....	3.20	18.00	0.40	4.40	6.80	7.00
Sevres..... }	Dumas	53.55	.....	5.48	29.22	.....	5.74	6.01	.....
Clichy..... }	Dumas	45.60	.....	6.10	28.10	.....	6.20	14.00	.....
Bohemian... } Champagne. }	Maumeno	58.40	9.90	1.80	18.60	.....	8.90	2.10	.....
Champagne... }	Maumeno	62.21	5.69	1.91	22.93	.....	6.10	1.16	.....
German..... }	Benrath	69.82	18.28	1.50	7.82	.....	2.58	2.58	.....
German..... }	Benrath	62.78	19.14	11.24	6.11	.....	0.73	0.73	.....
Russian..... }	Benrath	65.77	11.75	11.75	16.58	.....	5.90	5.90	.....
Russian..... }	Benrath	68.38	19.03	19.03	10.19	.....	2.40	2.40	.....

The above tables of glass analyses were taken from Elements of Glass and Glass Making by Benjamin F. Bizer.

PROPERTIES OF GLASS.

Glass possesses peculiar chemical and physical characteristics, the combination of which isolate it from other substances. Among these are transparency, viscosity, elasticity, devitrification, specific gravity, expansion and contraction, tensile and crushing strength, non-conductivity, decay, and iridescence.

Transparency.—Colorless glass is pervious to light and has the property of transmitting all the rays of white light without appreciable absorption. The degree of transparency in glass depends, first, upon the proportion of the raw materials and the thoroughness with which they are mixed in the preparation of the batch. Unless the batch contains the proper proportion of raw materials to form a chemical compound in the fusion, a homogeneous transparent mass of glass cannot be formed. And, second, the transparency depends upon the completeness of the fusion of the batch in the melt. Insufficient heating prevents a proper fusion, and repeated heating tends to crystallize the glass and largely destroys its transparency by causing it to become tough, fibrous, hard and causing a multitude of grains, chords, and semi-opaque matter, disseminated throughout the glass.

Viscosity.—One of the most important properties of glass is its power, in the viscous state, to yield continually under stress. After the batch is melted and the major portion of the impurities has been driven off through evolution and expulsion of the generated gases, the glass is in a liquid condition. In this condition it cannot be worked but as the heat is diminished, or, as it is chilled by exposure to air, it becomes viscous. In this viscous state it is ductile and tenacious and capable of assuming any shape. It can be rolled like dough with an iron roller and can be formed into hollow shapes by the pressure of the human breath or by compressed air. So extensible is viscous glass that it can be drawn out into a filament sufficiently fine and elastic to be woven into a fabric. Therefore, it is during the viscous stage that glass is best adapted to the principal processes of manufacture. On further cooling the glass rapidly assumes a solid condition and soon becomes hard and brittle.

Elasticity.—The elasticity of glass is such that, when in a viscous condition, it may be spun into minute threads, which when cold, may be bent, twisted or woven into cloth. A ball of glass let fall upon an anvil will rebound two-thirds the distance of its fall. This elasticity is due to a play of the particles in the glass ball which return to their original position when the disturbing force is removed.

Devitrification. Devitrification is the conversion of amorphous, transparent glass into a crystalline, opaque material by very slow cooling. Ordinary glass is cooled suddenly and therefore lacks crystalline structure. But glass that is repeatedly heated and cooled in the process of manufacture devitrifies and has a tendency to become tough, difficult to fuse, and fibrous; and usually many solid grains of semi-opaque matter are disseminated through it. Devitrification may be prevented by a careful regulation of the length and number of times the glass is heated and the temperature to which it is heated.

Opacity and semi-opacity which always occur in devitrified glass may be produced by adding to the batch materials such as oxide of tin, oxide of arsenic, or phosphate of lime, which will remain in suspension in the glass. The change in the structure in the glass consists simply in the formation of so-called crystallites, or small crystals in the glassy bases. Those glasses with bases containing lime, alumina, and magnesia in excess devitrify easiest. Glass, such as window, that is subjected continually to the action of the

atmosphere and gases, devitrifies, i. e., becomes dull and opaque and loses its lustre and transparency.

Specific gravity. In the manufacture of glass little attention is paid to specific gravity except in the manufacture of object glasses, lenses, artificial gems, and similar articles. The value of these depend upon their power of refracting light and, since the light-refracting power of glass increases with the increase of molecular weight, the specific gravity of glass varies with its composition. This ranges from 2.5 in the lime glass to 5.0 in the heavy lead glass. The specific gravity of glass is also slightly influenced by the amount of contraction resulting from cooling. It is further influenced to a slight extent by the relative amount of the volatile matter driven off. The specific gravity increases with the expulsion of volatile matter.

Expansion and contraction. Glass is affected by changes in temperature and follows the rule of expanding when heated and contracting when cooled. The amounts of expansion and contraction for equal changes in temperature are not equal in all grades of glass, but are higher in glasses containing the alkalis, especially soda and potash. The decadent effects of expansion and contraction caused by daily changes in the temperature of the atmosphere will be discussed below. Great and sudden changes in temperature may cause sufficient expansion or contraction to break the glass. Hot water poured into a thick glass bottle or jar often breaks the vessel. This is because of the expansion produced on the inner surface while the outer surface is still cool. If the changes in temperature can be made to take place uniformly throughout the mass there is little danger of breaking, but as glass is a poor conductor of heat this condition is seldom realized except in very thin glass.

In the manufacture of glass care should be taken to produce as nearly as possible an absolutely uniform homogeneous body, in order to guard against the effects of contraction and expansion. This is accomplished by annealing. The process of annealing is discussed later.

Tensile and crushing strength. The term tensile strength as here used refers to the amount of force necessary to break a glass rod or bar of given cross-section by straight pull. Crushing strength refers to the weight necessary to crush a glass body of given dimensions usually a cube. The tensile strength of glass is greater than that of granite and ranges from 6,000 to 10,000 pounds per

square inch. The tensile and crushing strength of a glass depend much upon the manner in which it is annealed.

A glass well annealed has less structural lamination, or flakiness, and less undue internal tension than a glass improperly cooled; because the molecules are allowed time to effect a greater degree of compactness and the pores thus become regularly and uniformly closed or at least diminished in size throughout the entire body which, by this process, acquires regular and dependable strength. The effect of improper annealing is illustrated by putting a piece of hot glass in cold water. The sudden cooling causes rapid and unequal contraction in the molecules of the glass near the point of contact and fracture occurs.

Non-conductivity.—Glass is a poor conductor of heat, but one of its peculiar properties, generally speaking, is that it transmits the luminous heat rays and absorbs the non-luminous. This is evidenced by the fact that a person may stand by a window on which the sun is shining and feel the warmth of the sun, yet if he touches the window it will feel cold. On the other hand, the same piece of glass when placed between him and a fire will shield him from the heat, but in so doing becomes rapidly heated itself. If the claim of different glass experts, however, can be substantiated, a window glass which will not transmit heat rays may soon be in common usage. This grade of glass is supposed to absorb a large per cent of the heat striking it and thus keep a house cool in summer and tend to keep it warm in winter.

Decay.—Many think of glass as a hard substance, devoid of crystalline structure, impervious to both liquid and gaseous fluids, and capable of preserving its beauty, retaining its surface, and not even losing any of its substance by the most frequent usage. It is, however, subject to decay, and is attacked by almost all substances which come in contact with it. A characteristic indication of decay is a dullness of color with a gradual increase of opacity, decomposition finally setting in just as in rocks and minerals subject to weathering.

The chemical composition of glass determines, to a large extent, the rate of decay. Its resistance to decay increases with rate of approach to, and decreases with departure from a definite chemical compound, and its constituents dissolve in about the same ratio as they are contained in the glass. The larger the amount of alkali in any glass, the more easily the glass is attacked by the simultaneous action of the moisture and carbonic acid when exposed to atmos-

pheric moisture. The change in color is due to the combined action of the carbonic acid and atmospheric moisture which form an insoluble crystalline film of silica upon the surface of the glass as a result of the action upon the silicates. The carbonic acid and atmospheric moisture also form a soluble silicate with a base which decomposes and leaves the surface pitted. This offers greater surface for additional moisture and consequent forces to aid in its destruction. Hydrofluoric acid attacks glass readily by decomposing the silicates, and forming fluorides with silica and its metallic bases. Hydrochloric, nitric, sulphuric, and phosphoric acids, and even pure water by prolonged action exert a decomposing influence.

Iridescence.—As has been stated, glass in the process of decay becomes pitted and laminated, that is, composed of thin plates or scales. In glass of this kind a beautiful iridescence or rainbow-like play of interference colors of much brilliancy is frequently observed. This play of colors is due to the thin films of air between the minute scales of glass and to the irregular surface of the pits, both of which refract and decompose the rays of light. Iridescence is produced in glass by artificial means with a fair amount of success. The best methods adopted are those which alternate the refractory power of the external layers of the glass by subjecting them to vapor from volcanic ashes or to the combined action of heat, pressure, and weak acids. Many beautiful effects may be produced in this way.

RAW MATERIALS.

Sand.

As previously noted, the chief constituent of glass is silica in the form of ordinary sand. In the preparation of the batch, however, chemically prepared basal and auxiliary substances are added. Soda, potash, lime, and lead constitute the principal basal elements used, and nitre, salt-cake, arsenic, antimony, and manganese the principal auxiliary elements. The kind and amount of material added in each case is controlled by the hardness, luster, color, or other properties desired. The several ingredients will be discussed in the section treating of basal and auxiliary substances. Only a small per cent of the accessory ingredients comes from the alkalies and other substances which are added to the sand to form the batch. It follows, therefore, that the color, transparency, brilliancy, and hardness

of the glass are determined largely by the quality of the sand which is the only one of the components occurring in a natural state, the others being chemically prepared substances.

The factors which determine the value of a deposit of sand for glassmaking are : (1) chemical composition; (2) physical properties; (3) available supply; (4) conditions of quarrying, or mining; and, (5) location with respect to fuel supply, transportation facilities, and market. These will be discussed in order.

Chemical Composition.

Silica.—Sand is composed principally of silica (SiO_2), and the purest glass sands contain practically 100 per cent of this oxide, with only traces of impurities. From this maximum all gradations in composition may be found down to sands containing such large percentages of impurities that they cease to be sands. The best grades of glass sand obtained from the Illinois and Missouri fields are reported to contain from 99 to 99.9 per cent silica, while the poorest grades sometimes run as low as 90 per cent silica.

Impurities.—The most harmful impurities found in sand are iron, clay, magnesia, and organic compounds. Iron is a strong coloring agent imparting to the glass a green, yellow, or red color, which varies with the amount and the degree of oxidation of the iron. Aluminous substances (principally clay) lessen the transparency of the glass and for the higher grades their presence in excessive amounts must be avoided. The presence of magnesia raises the fusion point of the batch and thus more fuel must be used to melt the charge. Organic matter is a strong coloring agent and produces a dark amber color.

To neutralize the coloring effects of these impurities upon glass, decolorizing agents are sometimes used. The principal decolorizing agents are manganese, arsenic, antimony, potassium nitrate, nickel oxide, and cobalt oxide. These ingredients are used in small quantities, since in large quantities they become colorizers instead of decolorizers.

The percentage of impurities allowable in glass sand depends upon the grade and character of glass desired. For the finest flint ware, such as optical and cut glass, only the purest sand can be utilized, perfect transparency, great brilliancy, and uniform density of product being required.

For manufacture of this ware the sand should not carry more than .05 per cent of iron (ferric oxide, Fe_2O_3), or .1 per cent of alumina (Al_2O_3). For the manufacture of plate and window glass, however, which are commonly a pale green, and which do not require as pure a grade of sand, .2 per cent each of iron and alumina is not injurious; and, in some cases, as when decolorizing agents are used, the sand usually contains .3 to .4 per cent iron and .6 to .7 per cent alumina. Some grades of English plate and window glass contain as much as 1.92 per cent iron and 2.68 per cent alumina. The French mechanically pressed plate glass averages about .14 per cent iron and 1.27 per cent alumina, and the English, .49 per cent iron and .7 per cent alumina. Lead glass contains as high as 1.93 per cent each of iron and alumina, and lime glass, as high as 5 per cent iron and 6.22 per cent alumina. In the better grades of bottle glass the iron averages about .65 per cent and alumina about 2.2 per cent. Since sand forms only 50 to 80 per cent of the batch, the percentage of iron and alumina may be still higher than these figures.

Methods of Chemical Analysis.

The writer finds no great amount of information extant on methods of chemical analyses of glass sand. In the present investigations two methods were used, the results of each being checked against those of the other in every analysis. The first, or direct method is that ordinarily employed in silica analysis and will be discussed first; the second, or hydrofluoric method, will then be treated briefly, wherein will be shown the manner in which results were made to check against those obtained by the first method.

The Direct Method.

Preparation of sample.—In order to hasten the fusion and the total decomposition of the ingredients of the sand it was found necessary to grind it into a fine powder. As a means of securing an average sample in each case several hundred grams of the sand were taken and well mixed. From this about four grams were taken, placed in an agate mortar and ground to a fine powder.

Fusion with silica flux.—One gram of the finely pulverized sample was mixed thoroughly with five grams of a silicate flux which was composed of 53 parts by weight of sodium carbonate (Na_2CO_3), and 70 parts by weight of

potassium carbonate (K_2CO_3). The mixture was placed in a covered platinum crucible and by means of a Bunsen burner was heated until all was in a state of quiet fusion. At this point the crucible was placed over a blast lamp and heated to a white heat until no bubbles were seen to escape.

When the fusion was complete the crucible with the contained fused mass was immersed in cold water to about one-half the height of the crucible. The immersion caused the fused mass to cool suddenly and shrink away from the crucible thus loosening itself and making removal easy.

Determination of silica.—The fused mass was then transferred from the platinum crucible into a 400 c. c. casserole and about 100 c. c. of hot water were added. In order to remove all of the fused mass from the platinum crucible, about 10 c. c. of dilute hydrochloric acid (HCl) were added to the crucible and gently heated on the water bath for a few minutes. The dissolved contents were then washed into a small beaker with a jet of hot water and the operation repeated until all the fused mass was dissolved. The casserole was covered with a glass and the solution from the small beaker was carefully transferred to it, care being taken that nothing was lost by effervescence. The contents of the beaker were then transferred to the casserole, and to the contents of the latter about c. c. of concentrated hydrochloric acid were added. The casserole was then placed on a water bath and heated until all the fused mass was dissolved. Sometimes small amounts of the silica were left in the bottom of the crucible and flocculent particles were seen floating about in the solution. In such case the solution was filtered and silica subjected to a second fusion and the contents added to the casserole. The casserole was then placed on a water bath and the solution evaporated to dryness; 25 c. c. more of concentrated hydrochloric acid were added and the solution evaporated to dryness again. The solid substance was removed from the bath and ground thoroughly in a mortar and again transferred to a casserole. The casserole was again covered with a watch glass and this time placed in a drying oven heated to about $135^\circ C$. and let remain forty-five minutes. About 50 c. c. of dilute hydrochloric acid were added and the casserole placed on the water bath and heated until all the contents except the silica were dissolved. While being heated the solution was stirred with an ordinary glass rod. The solution was filtered through an ashless filter paper into a 200 c. c. graduated flask and thoroughly washed with hot water, the washings

being caught in a beaker. The wet paper and silica were placed in a weighed platinum crucible and heated over a Bunsen burner until the paper was charred. The temperature was then raised and the crucible kept red until the silica became white. The crucible was cooled in a desiccator and weighed. The weight of the silica multiplied by 100 gave the percentage of the silica.

The filtrate from the silica contained the alumina (Al_2O_3), lime (CaO), and magnesia (MgO). The contents of the beaker were evaporated to small bulk and washed into a 200 c. c. graduated flask. The solution was cooled and the beaker then filled with pure water to the mark. A stopper was inserted and the solution was well mixed by shaking. With a graduated pipette, 100 c. c. of the solution were removed into a 250 c. c. beaker and the pipette and first beaker were washed into their respective beakers.

Determination of iron (Fe_2O_3) and alumina (Al_2O_3).—To each beaker a drop of nitric acid (HNO_3) and about 5 grams of ammonium chloride (NH_4Cl) were added and the solution heated to boiling, after which the solution was removed and, when cool, sufficient ammonia was added to give a decided odor. The solution was boiled again for a few minutes and then set aside for the precipitates to settle. After settling the precipitates were filtered out through separate 11 cm. ashless filter papers and washed thoroughly with hot water until the last drops produced no turbidity with silver nitrate ($AgNO_3$).

To one of the filter papers just mentioned 25 c. c. of dilute (1 in 5) c. p. sulphuric acid (H_2SO_4) were added and the dissolved precipitate was received in a 100 c. c. Erlenmeyer flask. The filter paper was washed three or four times with hot water.

In order to reduce the iron from the ferric to the ferrous condition, a piece of platinum foil was placed in the solution in contact with a piece of c. p. stick zinc and allowed to remain one hour. The solution was then filtered into a beaker and the filter washed.

The solution and washings were placed under a burette and titrated with a weak standard potassium permanganate ($KMnO_4$) solution. One c. c. of the permanganate solution equaled .0014 grams of iron. The number of c. c. and tenths used, multiplied by .0014 gave the weight of the iron; this was multiplied by 2 because the previous solution was divided into two parts. The weight of iron multiplied by 100 gave the percentage of iron.

The other filter paper and contents were placed in a weighed platinum crucible and heated over the Bunsen burner until the paper was charred. The crucible was then heated to a white heat over a blast lamp for five minutes. It was then cooled in a dessicator and weighed. The increase in the weight of the platinum crucible gave the weight of the alumina and iron. The weight of iron as found in the manner above described was subtracted from the total weight and the result multiplied by 200 gave the per cent of alumina.

Determination of lime (CaO).—The filtrates in the two 200 c.c. beakers above mentioned together with the washings from the alumina and iron precipitates were transferred into a larger beaker and the 200 c.c. beakers washed into it. Five grams of ammonium chloride and sufficient concentrated ammonia (NH_4OH) to give a decided odor were added. The solution was heated to boiling and, while boiling, 25 c.c. of a hot solution of ammonium oxalate [$(\text{NH}_4)_2\text{C}_2\text{O}_4$] reagent strength were added. The boiling was continued until the slight precipitate granulated. The solution was set aside to allow the precipitate to settle, then filtered and placed in a weighed platinum crucible. Ignition was begun over the Bunsen burner, and finished over the blast lamp. The increase in the weight of the platinum crucible divided by 2 and multiplied by 100 gave the per cent of lime.

Determination of magnesia (MgO).—To the filtrate and washings from the calcium oxalate precipitate in the operation above described nitric acid was added and the solution concentrated by boiling to about 100 c.c. The solution being cooled, 5 c.c. of ammonia and 25 c.c. sodium ammonium phosphate ($\text{HNaNH}_4\text{PO}_4$) were added and the solution was set aside in a cool place for 24 hours. It was then filtered and washed twice with small portions of two per cent ammonia. The precipitate was placed in a weighed platinum crucible and treated in the same manner as the calcium oxide. The magnesium phosphate ($\text{Mg}_2\text{P}_2\text{O}_7$) thus found, multiplied by the factor .3624, and this result by 100, gave the percentage of magnesia.

Determination of organic matter.—Two methods were used in the determination of organic matter. In the analyses of the sands containing a small amount of limestone, the following method was used:

Five grams of the sand (not pulverized) were placed

in a weighed platinum crucible and ignited for a half hour over the Bunsen burner, and then five minutes over the blast lamp. The crucible and contents were cooled in a dessicator and weighed. The loss of weight gave the amount of organic matter, as all the samples analyzed had been exposed long enough to lose all but atmospheric moisture. In the analyses of the sands containing limestone in any considerable quantity the following method was used: About five grams of the sand were placed on a weighed filter paper and washed with dilute hydrochloric acid until all of the limestone was decomposed into calcium chloride (CaCl_2) and calcium oxide (CaO). These were washed through the filter paper by repeatedly pouring small amounts of warm water on the contents of the filter. The filter and contents were then dried in a drying oven for one hour at a temperature of 100°C . and cooled in a dessicator, after which they were weighed. The total weight less the weight of the filter paper gave the weight of the silica and other non-volatile substances plus the weight of the organic matter. The procedure from this point on was the same as the method above.

No quantitative analyses were made for titanium, sodium or potassium, because qualitative tests on the sands showed that they do not occur in sufficient quantities to be harmful.

Hydrofluoric Acid Method.

As above mentioned, in chemical analyses the writer employed the foregoing or direct method, and the hydrofluoric acid or indirect method, checking the results of each method against those of the other. The procedure in the latter method consisted briefly as follows:

Two grams of the finely pulverized sand were placed in a platinum dish and about 7 c. c. hydrofluoric acid (HF) were added drop by drop, the mixture being stirred at the same time with a platinum wire. A few drops of sulphuric acid were added and the mixture was evaporated to dryness on a sand bath, and then heated over the naked flame of a Bunsen burner until all fumes ceased coming off. It was found necessary to repeat this process about twice before all the sand was decomposed by the hydrofluoric acid. After the silica was expelled by the repeated evaporations in hydrofluoric acid and sulphuric acid, the mass was digested with hydrochloric acid until all went into solution. The silica was obtained by the difference. The other con-

stituents were determined in the filtrate by the same methods as in the previous method.

Physical Properties.

Shape of grains.—The prevailing opinion among glass sand experts has been that the sand grains should be sharp and angular, never rounded and smooth. The contention has been that the rounded and smooth grains do not leave as many interstices through which the heat can pass as do the sharp angular grains. For this reason it has been maintained that the round grains have a tendency to settle to the bottom of the batch in the melting pot and prevent an even flux, producing an unevenness and irregular quality in the glass. Some of our prominent glass men of today, however, are of the opinion that more attention has been given to the shape of the grain than is warranted, and they contend that it is not an important factor and that any good silica sand, if of a proper degree of fineness, will become liquified very readily. This conclusion has been reached because of the fact that several prominent glass plants in the Mississippi Valley are successfully making both the ordinary grades of glass and the fine flint wares from the sand composed entirely of rounded grains.

The Oklahoma sands are prevailingly subangular. Most of the grains show irregular fracture surfaces, angles and edges. In the case of those grains larger than the 60 mesh the angles and edges are more or less rounded; while of the grains smaller than 80 mesh there are almost none that are not sharply angular. The general rule is the smaller the grain the more angular it is.

Size of grains.—There are also varied opinions as to the most desirable size of the grains. There are those who contend that the size and shape of the grains have nothing to do with the quality of the glass, but that a small grain will melt more quickly and consequently require less fuel, as the flux can act only on the surface of the grain. But the prevailing sentiment is that to produce the best results the grain should not be larger than 30 mesh nor smaller than 120 mesh. If the sand is pure, however, the size of the grains may have a somewhat wider range and still good results be obtained, so long as the grains are comparatively uniform in size.

The finer sand is said by some to "burn out" in the batch and not produce as much glass per unit as does coarser sand. The grains larger than 30 mesh on the other

hand are more difficult to fuse. This lowers the amount of sand each furnace can melt per day and consequently increases cost of production. As already noted, in a mixture of coarse and fine sand the finer is liable to settle to the bottom of the batch, thus preventing an even mixture of the materials and producing in consequence a glass uneven in texture.

Physical Tests.

Determination of the size of grains.—In the present investigation in order to determine the size of grains, a series of sieves of 40, 60, 80, 100, and 200 mesh were arranged in regular order, the coarsest above and a pan beneath the series. One hundred grams of sand were placed in the 40 mesh and covered with a tight lid. The nest of sieves was then taken in the hand and given one hundred circular motions. The sand was removed from each sieve and weighed, the amount retained on each gave directly the per cent of sand that was unable to pass that particular mesh. Although in the coarser screens there is a larger percentage of mesh space in proportion to the total area than in the finer sieves, owing to the fact that in the coarser sieves the diameter of the wire is less proportionately to the size of the mesh than in the finer sieves, the ratio of volume of material to mesh spaces is approximately preserved. On the whole, therefore, it seems that the best results were obtained by shaking all the sieves together.

Available Supply.

There are numerous small deposits of good glass sand near fuel and accessible to transportation facilities that can never be developed in the United States, because the deposits do not contain a sufficient quantity of sand. Glass sand is not very valuable. In 1910 its average price in the United States was \$1.04 per ton. It is obvious that at this price, the sand must occur in sufficient quantities and under such conditions as to reduce operating expenses to a minimum. Under favorable geographic and geologic conditions thin ledges affording relatively small amounts of sand may be worked at a profit while the cost of working thicker ledges unfavorably situated would be prohibitive. Ordinarily a deposit of sand 20 feet thick should have an areal extent of 25 acres of good sand in sight to warrant the erection of a mill and construction of trackage.

Conditions of Quarrying or Mining.

Character of sand.—The ease with which sand may be removed from the ledge and prepared for mixing depends largely on the degree of its consolidation or induration. Other things being equal, a loose friable sand which may be worked with a steam shovel or by similar means is preferable to an indurated sand which must be blasted in order to remove it from the quarry, as well as ground to prepare it for mixing into the batch. Some sands were once firmly cemented or perfectly indurated but have become friable through the solvent work of waters slowly precolating through them.

Character of outcrop.—In a general way the sand occurring in a bluff is more easily worked and is usually obtained at less expense than that secured by removing the surface soil and working from above. Sharp contacts with rocks above and beneath are to be preferred because usually under this condition a less amount of the sand is likely to be contaminated with foreign material from the other rocks.

Drainage.—Glass sand is often more easily eroded than the rocks with which it is associated and as a result is often found outcropping in ravines and creek beds. Especially is this true of the sands in Oklahoma. In selecting a place to open a quarry care should be taken to avoid a location in which surface waters might interfere with quarrying.

Location.—Good transportation facilities and a ready market are indispensable to a glass sand industry. The locality that is handicapped by poor transportation facilities or an unsteady market cannot hope to be a successful competitor. Since fuel is so important a factor in the manufacture of glass it is also evident that a sand must be within reasonable distance of a center of fuel supply, the glass factories being necessarily located at some such center.

Basal Substances.

Soda, potash, lime, and lead constitute the major basal substances of all commercial glass. They are necessary as reducing and combining agents with the silica in the formation of the silicate glass. In addition to these, salt-cake, nitre, borax, saltpetre, and barium carbonate are quite often used and may be classed as minor basal substances.

The table already given in the section on the classifi-

cation of glass shows approximately the extent of variation of amount of these basal substances.

The several major basal substances will be briefly discussed in order:

Major Basal Substances.

Soda—(soda-ash, sodium carbonate, Na_2CO_3) constitutes the principal base for most of the commercial glass of the present day. The chief source of soda to supply the demand of the earliest glass houses was obtained from the natron lakes of Egypt. In later times the soda was obtained from the ashes of certain plants that grew in the sea or along the seashore. The natron secured by these two methods was very impure and produced a glass inferior in every way.

Realizing the need of a purer grade of soda, the French Government offered a reward of 12,000 francs to any one who would succeed in devising an artificial process of converting common salt (NaCl) into soda. Nicholas LeBlanc succeeded in accomplishing this in 1790 and this discovery opened up a new era in the glassmaking industry. The LeBlanc process was universally used until 1863, when Earnest Solvay devised the ammonia process. This latter process has replaced the LeBlanc process since it is simpler and more effective. Solvay's process consists in treating a pure solution of salt charged with ammonia with pure carbonic acid. The precipitates of sodium carbonate formed is purified by filtering, drying, and heating.

Soda is crystallized sodium carbonate deprived of its water of crystallization. Its value depends upon the sodium oxide (Na_2O) which forms practically 58 per cent of the mass. During fusion 31.67 per cent of the soda is lost through evaporation and volatilization. In addition to its acting as a reducing and combining agent with the silica, as has already been mentioned, the soda-ash adds a brilliant lustre to glass.

As already noted several compounds which may be called minor basal substances merit separate discussion. They are:

Potash (pearl-ash, potassium carbonate, K_2CO_3).—Potash produces fusion in the batch more readily than soda, and also produces less coloring; but since it diminishes the brilliancy of the glass and is somewhat more expensive than soda, it is not used to any great extent in the manufacture of glass.

Lime (calcium oxide, CaO , and calcium carbonate, CaCO_3).—Lime in the form of calcium oxide or calcium carbonate is a very important ingredient in glassmaking. It is an alkaline base, facilitates fusion, adds stability, and increases the insolubility of the glass. Care must be taken that the proper amount be added, since an excess retards fusion, hardens the glass, and renders it more liable to devitrification, and also produces a milky appearance in the glass. The amount of lime required varies considerably in the different glasses, the limits being as follows: window glass, 8 to 15 per cent; plate glass, 3.5 to 16 per cent; bottle glass, 6 to 30 per cent; lime flint, 5 to 16 per cent.

Litharge (PbO) and *red lead* (Pb_2O_3).—Litharge and red lead, once extensively used in glass manufacture, have been largely replaced by soda. They are used now only in the manufacture of artificial gems, optical glasses, and similar products possessing as they do the power to produce brilliancy and density. Red lead is preferred to litharge because of its being in a finer state of subdivision and because it liberates oxygen readily upon fusion. This ready liberation of oxygen facilitates the removal of the impurities.

Lead glass is very soft, highly refractive, and dense, and is less apt to break when exposed to sudden changes in temperature.

Minor Basal Substances.

Salt-cake (sodium sulphate, Na_2SO_4).—Salt-cake is made by decomposing sodium chloride (common salt) with sulphuric acid. The sulphate is known as Glauber's salt. It contains ten molecules of water of crystallization, or 55.9 per cent of its weight. Although this water of crystallization is driven off before the salt is used, yet 56.3 per cent of the remainder is lost during the melt.

Salt-cake is sometimes used instead of soda because it is cheaper and renders the glass less liable to devitrification and produces a harder glass which will take a better polish and be less liable to sweat. In recent years, however, salt-cake, for the reasons given below, has largely given way to soda. It requires 130 to 150 pounds of salt-cake to produce the same quantity of glass as 100 pounds of soda. The salt-cake usually contains more iron and other impurities than the soda and also produces fumes that are destructive to the pots, tanks, and walls of the furnace. Because of these impurities, the glass made from the salt-cake is

more deeply colored. The prevailing color is a bluish green which is chiefly due to the presence of iron. The most serious objection to the use of salt-cake in the batch is the fact that 10 to 20 per cent more fuel is required than if the carbonate were used. The additional amount of fuel is necessary because a higher temperature is required to force the silicic acid to decompose the salt-cake than is required to decompose the soda. To aid in this decomposition carbon is added to the batch, generally in the proportion of one equivalent of the carbon to two of the salt-cake. The carbon added abstracts one oxygen equivalent from the sulphuric acid leaving sulphurous acid which readily forms a silicate of sodium and hence aids in fusion. Care must be taken to get the carbon thoroughly disseminated throughout the batch, otherwise quantities of undecomposed sulphate may occur in the glass. In a few places vegetable and animal fats, oils, and similar substances are successfully substituted for carbon.

Nitre (Chili saltpetre, sodium nitrate, NaNO_3).—Sodium nitrate enters the batch in conjunction with the other alkaline bases and acts as an auxiliary base. It is used chiefly as an oxidizing and decolorizing agent, since its oxidizing properties aid in the expulsion of the carbonaceous matter, thereby facilitating the fusion and improving the quality and color of the glass.

Borax (sodium borate, $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$).—Borax is a powerful flux and facilitates the fusion of the batch, by its readily becoming a fluid at a comparatively low temperature. At the fusion point it becomes considerably agitated and this agitation has a tendency to purify the glass by dispersing and expelling many of the impurities in the batch.

Saltpetre (potassium nitrate, KNO_3).—Potassium nitrate is very seldom used in the manufacture of glass and then only as an oxidizing agent in the finer wares.

Barium carbonate (BaCO_3).—Barium carbonate is sometimes used as a substitute for lead, lime, potash, or soda; but, since it is more costly and less pure than the other bases, it is not generally used. Pure barium carbonate facilitates fusion, imparts lustre, adds hardness, and increases the density of glass.

Auxiliary substances.

The auxiliary substances used in the manufacture of

glass are cullet, manganese, arsenic, antimony, cobalt, zaffre, nickel, and bone-ash. These are added to act as deoxidizing and decolorizing agents to remove or neutralize the accidental color which is usually produced in the glass by the impurities contained in the raw materials. They are often added also to impart special colors to the glass, but this phase of the subject will be treated later under the heading of "Colored Glass."

Cullet.—Cullet is pulverized waste glass. When added to a batch it should be as near the nature of the glass desired as possible, otherwise the product will have a tendency to become stratified and lumpy. Cullet is more fusible than the raw materials in the batch and, therefore, when properly disseminated throughout, it facilitates fusion since it keeps the materials open and in a porous condition. This facilitates also the transmission of heat through the mass. When the transmission of heat is well regulated undue loss of the alkalines through volatilization is prevented and also a more uniform product is obtained. The cullet should not be used in excess of possibly one part of cullet to two parts of sand, since in larger quantities it reduces the strength, firmness, elasticity, and resistance of the glass and causes it to become very brittle.

Manganese.—The manganese used in glass manufacture is chiefly the dioxide (MnO_2). It is a strong oxidizing and decolorizing agent and is often termed "the great decolorizer of glass." The chief function is to neutralize the greenish color imparted to glass by the protoxide of iron (FeO). From every 100 parts of the dioxide $18\frac{1}{2}$ parts of oxygen are set free. This liberated oxygen combines with the protoxide of iron to form the peroxide (Fe_2O_3), which produces a reddish-yellow tint in the glass and neutralizes the green tint produced by the protoxide. This oxygen set free by the manganese also assists very materially in washing out the impurities from the constituents and thus aids in purifying the color of the glass. The use of manganese, however, is being largely abandoned in the manufacture of glass that is exposed to the continued action of sunlight, especially window glass, since the sunlight produces chemical changes which render inconstant the color in glass containing manganese.

Arsenic (As_2O_3).—The function of arsenic in the manufacture of glass is that of a purifier. It acts principally upon the carbonaceous matter present and is often called

"the great decarbonizer of glass." In addition to the removal of the impurities from the constituents and their expulsion, by means of carbon dioxide formed, the arsenic in small quantities also facilitates the fusion and decomposition of the other materials. Color imparted by arsenic is not affected to any noticeable extent by continued exposure to sunlight. Hence arsenic is used extensively as a decolorizer in window glass. Care must be taken, however, to avoid using an excessive amount of arsenic since it produces an objectionable milky color in the glass, which increases with age.

Antimony (Sb_2O_3).—Antimony is very seldom used in glass manufacture, and then only as a substitute for arsenic. In small quantities it performs the same function as arsenic, facilitating fusion and aiding in the elimination of impurities. In excessive quantities it produces objectionable effects and is even more deleterious in its effects than is arsenic.

Cobalt, zaffre, and nickel are sometimes used in the manufacture of lime and other flint glasses as decolorizing or neutralizing agents. *Bone-ash*, [calcium phosphate, usually $Ca_3(PO_4)_2$], is also sometimes added in small quantities to the batch, especially of opal glass, as a decolorizer, since it is especially active in neutralizing the impurities.

Before leaving this phase of the subject it will be in order to note that the basal and auxiliary substances are manufactured products and hence are not important factors, as are sand and fuel, in the location of a glass plant.

FUELS.

Experience has shown that the success of the glass industry in a given locality is determined largely by the fuel supply. The fuels are wood, coke, coal, oil, natural and producer gas. In the early days the fuel consisted in *wood* thoroughly dried or baked. In the last 50 years it has given way to other fuels. In recent years *coke* also has been superseded, therefore, both of these many eliminated from the discussion. Recently, in many localities in the east the industry suffered for lack of cheap fuel and in many places plants have suspended operations. On the contrary the industry in the Mississippi Valley has made a wonderful progress. In Kansas and Oklahoma the rapid progress is due to the large amount of cheap fuel furnished by the Mid-Continent natural gas fields, while in the other states it is

due to the large supply of bituminous coal which is used in the manufacture of producer gas. As an example of the value of cheap fuel to the glass industry it may be noted that there are about 25 glass plants in southeast Kansas and six in northeast Oklahoma, obtaining their sands from east Missouri and yet successfully competing with the plants located in the sand regions of Illinois, Missouri, and Indiana. This is because the plants in Kansas and Oklahoma have a large supply of natural gas which they obtain at four cents per thousand cubic feet, while the plants located in Missouri, Illinois, and Indiana are paying eight to twelve cents per thousand cubic feet for producer gas.

Coal probably takes precedence over all other fuels for glassmaking. This is true because it is found in almost inexhaustible quantities near most of the large glass sand deposits in the United States. Used directly it is not the best fuel since the smoke and by-products have always been a serious objection, especially where the materials to be melted are exposed to direct action of the flame. But in this country very little coal is used directly as a fuel in the manufacture of glass, but vast quantities are consumed for producer gas. When coal is utilized in this manner the chief objections are overcome. There seems to be an increasing preference for producer over natural gas, because the supply is constant.

Oil is not used to any great extent as a fuel in the glass industry as it produces no better results than other fuels and is much more expensive. To operate successfully with oil a more or less complicated system of burners for generating gases or producing combustion in some other manner is required. This entails too great an expense to make the use of oil profitable.

Natural gas, where found in sufficient quantity, is the ideal fuel. It produces a constant and intense heat and no harmful by-products are given off. In a great many of the eastern districts, however, the supply is fast diminishing and is so uncertain as to cause the manufacturer much annoyance and loss.

Producer gas. In most of these localities the manufacturers are substituting producer gas for natural gas. This is generated from bituminous coal by a process of destructive distillation and is beyond question the best form of fuel yet utilized in the glass industry, as the heat produced is intense and its use gives a direct saving in fuel of from 35 to 70 per cent.

The gas producers are usually arranged outside the glass works where all the manipulations of feeding, of stoking, and of removing the ashes are performed without interfering with the work inside. Care must be taken to place the gas producer at a lower level than the furnace in the glass plant as the gas has a natural tendency to pass upward to the furnace.

FURNACES, POTS, AND TANKS.

The outer walls and the pillars of furnaces are constructed of ordinary yellow or red brick, or of common building stones. The wall lining and all parts exposed to intense heat are constructed of high grade fire brick. Little mortar is used and that is made of a refractory clay and pure sand.

The clay best adapted for the manufacture of fire brick for glass furnaces should be as pure as possible and very refractory, breaking with a clear, smooth, bright fracture, and free from lime and calcium sulphate and should contain the least possible amount of iron. The most essential property in good fire clays, or in any of the objects made from them, is a high fusion point. To obtain this high fusion point the clay should be free from metallic oxides, such as lime and iron, which unite with the silica with comparative ease. In addition to being refractory the clay must also be sufficiently plastic to be readily moulded and at the same time should not shrink much.

Before the final decision can be given on the adaptability of a clay, an examination of its physical properties must be made, its plasticity, bonding power, amount of water required to make a plastic mass, specific gravity, tensile strength, shrinkage in drying and in burning, vitrification, viscosity, slaking, fineness of grain, feel and color, and the proper proportion of other ingredients required in mixing must be determined. A fire clay used in the manufacture of glass pots or high grade fire bricks should have a formula approximating closely to $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$.

The fire brick should be even and rather open in texture, fairly coarse in grain, and free from cracks or warping. Since there are no single fire clays which will produce brick that meet all these requirements it is customary to make the fire brick from a mixture of a plastic fire clay, a non-plastic or flint fire clay and ground fire brick or other form of burnt clay. The clays are seasoned, ground, thoroughly kneaded or pugged, and then mixed with the

ground fire brick or grog. Fire brick are usually molded in hand molds, repressed on hand represses, dried on steam-heated floors, and burned in down draft kilns at high temperatures.

In order to protect the surface of the fire brick from the disintegrating effects of the flue gases and other deteriorating substances, the surface of the brick is washed with a thin paste of some very refractory material such as kaolin. Very recently a thin paste of carborundum and clay, or carborundum and silicate of soda has been used for the same purpose. These materials melt and run over the surface and form a glaze, which prevents deposits of clay on the sides of the furnace, pot or tank by retarding corrosion.

Glass pots and tanks are made from a very high grade fire clay or mixture of clays. The clay is weathered, ground, tempered by pugging or treading, and then allowed to season for a considerable length of time in order to develop its maximum plasticity and working properties. The pots or tanks are usually built by the hand of skilled labor. Several are started at the same time and a few inches built on to each one each day until the whole set is finished. The size of the pots or tanks for different kinds of glass may vary considerably. The walls are usually about 4 inches thick. The drying of the large pieces must be done very slowly and requires several weeks. Before being used the pots are tempered by being heated gradually to the temperature required in their use in the furnace and then cooled slowly. When in use the pots are fired once each day until they fail by breaking or loss of material by fluxing. There is great variation in the life of pots, some break on their first firing while others may last for fifty or more firings. The average is probably about twenty casts per pot.

A great many of the clays for the construction of furnace pots and tanks are imported into this country from Germany, but there are large deposits of excellent clays for this purpose in many localities in our own land. The chief supply, however, is obtained from Missouri, Pennsylvania, and New Jersey. The Missouri plastic clays are purer than the German clays and have a fusing point ranging from 2400° to 2800° F. They are more refractory than the German clays but not as dense and do not resist the action of the fluxes so well. So far no suitable fire clay for glass furnaces, pots, and tanks have been found in this state.

Silica is used in furnace, pot, and tank building in the form of a slightly plastic siliceous sand or in the form of a

loose disintegrated sandstone which is crushed between rollers, mixed with about one per cent of lime and molded into bricks and heated in kilns at a very high temperature. These bricks, because of their heat-resisting power, are used for the roof, fire arches, flues, and other parts subjected to intense heat.

Alumina chiefly in the form of bauxite is used as a refractory material, but its applications are somewhat restricted. It has been found that under long continued heating the alumina changes into a substance as hard and refractory as natural emery.

Coke dust or graphite is largely used in an admixture with fire clay in the production of pots and tanks. The proportion of the coke dust or graphite added to the clay varies with the quality from 25 to 50 per cent. The articles made from this admixture are the most enduring of all.

Glass furnaces are constructed according to many different patterns with varying degrees of complexity in arrangement, yet modern glass furnaces may be divided into two general classes, namely: pot furnaces, and tank furnaces. The pot furnaces are usually constructed in the shape of a square or oblong for the manufacture of flint glass. Tank furnaces are arranged to give either continuous or intermittent results without the use of pots and may be of almost any shape, but are usually oblong. Tank furnaces are now more commonly used than pot furnaces and are gradually replacing them. This change is due to the increased production, economy in working, economy in time, durability of furnace, regularity of working, and superiority of the glass produced by the tank furnace over that of the pot furnace.

A few of the furnaces are built to consume coal or coke by its direct introduction into the furnace. But as already noted, coal or coke, on account of smoke and by-products, is not often used by direct firing for the better grades of glass and in the last few years almost all of the furnaces have been equipped for natural gas or producer gas.

The ordinary furnace heated by coal or coke is composed of three essential parts, namely: the fire place, in which the fuel is consumed; the melting chamber, in which the tanks or pots are placed; and the apparatus for producing rapid combustion by the supply of air to the fire. The fuel is placed on a grate which occupies the center

of the furnace. The combustion gases then pass into the melting chamber where the pots or tanks are placed.

Pot furnaces have no fixed size, neither is the number nor size of the pot themselves fixed. In the manufacture of plate glass the pots are filled with the mixed raw material and then placed in the furnaces by means of long tongs mounted on wheels, and are removed in the same manner after the firing. For blown ware, such as bottles and lamp chimneys, the pots or tanks are stationary in the furnace and the material is introduced through a small arched opening situated directly over each pot, except in the case of the covered pot in the furnace for making flint glass, in which case the mouth of the pot extends outside the furnace walls. After the mixture is properly fused, the molten glass may be withdrawn from the pots or tanks through openings in the furnace walls by means of long rods which are dipped into the molten mass.

The gas furnaces consist of two principal parts, namely: a combustion chamber and a producer. The combustion chamber is essentially the same in the gas furnace as in the coal or coke furnace. In the latter class of furnaces the hot gases from the combustion chamber are usually allowed to escape into the air through flues, but in the more modern plants much of the energy contained in these gases is utilized by means of the Sieman's system of regenerative heating. It is the most perfect method of utilizing the waste heat that has been tried. Its value lies in the fact that the spent gases are made to travel through chambers, known as regenerators, which contain a large number of thin fire bricks arranged with narrow interspaces so as to offer a very large heat-absorbing surface. These thin fire bricks absorb much of the heat from the spent gases and soon become red hot. Then the current is diverted to an adjacent chamber and the acquired heat in the fire bricks is removed by a current of cool gas and air passing toward the furnace, where it arrives sufficiently heated to insure the greatest possible heating effect. As soon as the chamber is cooled the action is reversed and the gas and air pass through the chamber which has just been heated, while the waste gases reheat the first chamber or chambers and prepare them for again performing their functions.

Some electric furnaces have been erected for melting and molding quartz. Their success would seem to suggest the possibility of electricity being employed in the future for the manufacture of glass.

Mechanical Processes.

The raw materials, fuel, furnace, pots, and tanks have been discussed and now we come to the manufacture of glass itself. There are three stages in the manufacture of glass, namely: first, the synthesis of the materials; second, molding; and third, annealing.

The Synthesis of the Materials.

By the synthesis of the materials is meant the entire process from the assembling of the raw materials, through the successive steps till the batch is completely melted. This synthesis is accomplished by mechanical and by chemical processes.

Mechanical Processes.

Compounding of the batch.—In the preparation of the batch only the experienced glass makers who possess a sufficient amount of technical and practical knowledge to make a careful and accurate calculation of the quantity of ingredients necessary for the grade of glass desired, should be employed. Although the batches vary greatly in the different grades of glass and although even in the same grades of glass different glassmakers use the materials in widely varying proportions, yet glass is a chemical compound and the same grade under similar conditions always requires the same amount of bases, fluxes, colorizers, or decolorizers and other accessories. The varying amount of materials used in the preparation of the batch by different glassmakers for the manufacture of a certain grade of glass, may be due to a difference in the arrangement, equipment, and serviceability of their furnaces or to a difference in fuel and to irregularity in raw materials; otherwise a slightly different grade of glass will always result. In other words, in order to insure a uniform result, it is necessary to make careful calculations and chemical tests of the raw materials. No guess work or uncleanness should be tolerated, and all ingredients should be carefully weighed, ground, and sifted.

Silica is the foundation and chief constituent of all commercial glass but most of its special qualities are dependent upon the bases, fluxes, and coloring or decolorizing agents. As an example, an increase in the quantity of bases, fluxes, etc., causes the glass to soften and to lose strength, resistance, tenacity, and lustre; while a decrease in the quantity of the ingredients increases the hardness,

strength, tenacity, and lustre, but also raises the fusion point.

It is important to remember that the quality of a glass improves or deteriorates as its composition deviates from that proportion required to form a definite chemical compound, and that the softness, hardness, durability, brilliancy, uniformity, homogeneity, and color of a glass are largely dependent upon the proportion of the raw materials in the batch.

Mixing.—A thorough and uniform mixing of the raw materials in the batch is necessary in order that a proper chemical association may take place when the batch is melted, and homogeneity and uniformity in the structure of the glass be insured. The mixing should be done by a machine as it gives more accurate, thorough, and uniform results than can be obtained otherwise. To insure this proper mixing of the raw materials, the bases, fluxes, etc., should be finely pulverized and sifted thoroughly.

Chemical Process—The Melt.

Fusion.—After the materials in the batch have been added in the right proportion and thoroughly mixed mechanically, they are then transferred to the pot or the tank which has been previously heated to a sufficiently high temperature so that melting begins immediately. When fusion is accomplished a chemical compound is formed. This process completes the association.

Upon melting, the raw materials in the batch disintegrate, and moisture, acids, and gases are expelled. In this way the aggregate bulk is decreased and room is left in the vessels for additional material which is introduced about twelve hours after the first filling. One refilling is usually sufficient, although in some cases it is best to add several successive smaller amounts.

It is important that before filling, the vessel be heated above the fusion point of the batch and this temperature maintained. In this manner a homogeneously fused mass is obtained, the fusion proceeding regularly from the bottom upward and from the sides toward the center. The first filling should be completely melted before any more raw material is added, otherwise the liquefaction of the remainder and the escape of the gases and impurities will be retarded by the addition of the second filling.

During the fusion of the raw materials, chemical dissociation is continually taking place, gases and acids being formed. These gases and acids perform a double function, first, generating an agitation of the particles in the semi-fluid mass and thus aiding in the production of a homogeneous and even-tempered product; and second, absorbing, expelling, or otherwise disposing of most of the impurities of the batch in the process of fusion. If at any time the temperature of the batch falls below the fusion point and the dissolution and agitation cease, "glass goll" is likely to be produced. This is simply masses of non-fused particles of the batch remaining disseminated in suspension throughout the melted material. The "glass goll" impairs clearness and transparency by producing white blotches and spots in the glass. Another serious result of insufficient and irregular heating is that the volatile ingredients of the batch escape at a temperature which is not sufficiently high to fuse the silica. Another deleterious effect is that the alkaline silicates fuse more easily than silica, resulting in a partially crystalline structure in the mass. This devitrification manifests itself in the form of stones, cords, and striae.

Refining.—Refining consists in removing, or otherwise freeing the fluid mass of, its many seeds, bubbles, and other impurities which are found in the batch just after it is melted. This purification is accomplished by increasing the temperature to about 3400° F. At this temperature the mass becomes very fluid and the infinitesimal seeds, bubbles, and other impurities either escape through volatilization or gather on the surface where they may be removed by skimming. As soon as the glass is purged of these impurities the temperature is decreased gradually and the mass reduced to a viscous state. While the mass is cooling it is usually stirred with a fireclay cylinder which is inserted through a small opening at the upper end of the containing vessel. The object of this operation is to render the glass as homogeneous as possible by freeing it of veins, cords, and striae. The cylinder is allowed to remain in the viscous mass only for a short time when it is exchanged for another since its surface quickly oxidizes resulting in scales which contaminate the glass. The stirring is continued until the glass has cooled to such degree of consistency that the cylinder can hardly be moved, when it is discontinued and the cylinder removed. From this point on no molecular movements occur and the glass remains a homogeneous mass.

Molding.

According to the methods used in manufacture, all glass products are divided into the following classes: optical glass, blown glass, and pressed glass.

Optical Glass.

Optical glass is the most expensive glass made and demands the greatest skill, precision, and care in its manufacture, since a good quality requires perfect transparency and freedom from colors, homogeneity, great hardness, absolute chemical stability, absence of internal strain, and high power of refraction and dispersion. To secure the qualities only raw materials of the purest grades may be used.

In the process of molding and annealing optical glass the desired amount is taken, and heated to a temperature just sufficient to soften the glass. It is then placed in a mold made of iron or fire clay and forced to assume the shape of the mold. The glass which is now in the approximate form desired is placed in a heated chamber and passed through the process of annealing. The minimum time allowed for annealing optical glass is six days, while for "fine annealing" several weeks are sometimes consumed.

Oftentimes at the end of the fine annealing process as much as 1,000 pounds are found in one single mass which is free from cracks and fractures and is entirely intact; but it is usually found broken up into a number of pieces of various sizes. The larger pieces are used for lenses and mirrors of considerable dimensions such as are required in telescopes of large aperture. The smaller pieces are utilized for the production of discs and slabs with which the general optical glass trade is usually supplied.

The discs or slabs at the end of the annealing process are slightly larger than the size required by the opticians and therefore must be ground down. Sometimes defections cannot be detected until grinding is complete or nearly so, hence rigid inspection is required before the finished discs and slabs are delivered to the trade.

Blown Glass.

Blown glass embraces, first, table ware and vases; second, tubes; third, sheet glass; and, fourth, bottles and similar articles.

Tableware and vases.—The tools used in the production of tableware and vases are simple and extremely primitive.

They consist of lathes; hollow, iron blowing rods; spring tools with steel or wooden blades to fashion the viscous glass; callipers and measuring sticks; molds of carbon, cast-iron, gun metal, wood, or plaster of Paris; and strong rods for holding the vessels during manipulation.

The method of making a tumbler illustrates all the ordinary processes used in the manufacture of tableware and vases. A sufficient amount of viscous glass to form the tumbler is gathered on the end of a blowing iron, and rolled on a polished slab or iron, called the "marvor," to solidify it. The solidified mass is then fashioned by being blown into a mold. In case a vessel with a foot (such as a goblet) is desired the mass is blown into a particular mold which gives the desired shape to the bowl and also forms a leg. A small lump of molten glass is added to the extremity of the leg and by being trundled and pressed between slabs or against an upright board the foot is fashioned. The bowl of the tumbler is then severed from the blowing iron and put in an annealing oven. When the tumbler is cold it is removed from the oven and the rough fractured surfaces are polished by grinding or smoothed in a gas flame. Sometimes the surplus glass is removed by some such method as applying heat to a line that has been scratched by a diamond.

Tubes.—Tubes are made by blowing a hollow mass of viscous glass. They are used chiefly in thermometers, test tubes, and similar laboratory and other articles. Viscous glass has the peculiar property of retaining its shape while being drawn out. As an example, if a triangular thermometer tube is desired the molten mass is pressed into a V-shaped mold. On being drawn out the V-shape is retained.

Sheet glass.—Numerous inventions have been made recently in an endeavor to procure a direct method by more or less mechanical means that can be substituted for the complicated and indirect process that is in vogue at present in the manufacture of sheet glass. None of these have proven entirely satisfactory, however, because of the difficulty of transferring the molten glass to the machines without the introduction of air bells which are always formed when molten glass is poured from one vessel into another. The complicated and indirect process described below is typical of the methods in use in the majority of the sheet glass works.

Sheet glass is generally fused in regenerative tank furnaces, some of which have a capacity for as much as 250 tons of molten glass. These furnaces are tilted and have a temperature gradient, the upper end being hotter and the lower cooler. There is a continuous movement of the liquid material from the hotter upper end to the lower cooler end where the glass is in a viscous condition. The glass is withdrawn from the lower end of the furnace through openings provided with movable covers, by means of a ladle or gatherer's pipe. This pipe is an instrument composed of an iron tube about 5 feet in length with an enlarged butt at one end, and a wooden covering used as a handle and mouthpiece at the other. The gatherer dips the butt of his previously heated pipe into the molten glass and withdraws it. The small ball of viscous glass that adheres to the butt cools while the mass is being rotated in the air so as to keep it as nearly spherical as possible. As soon as the mass has cooled sufficiently, the whole is again dipped into the molten glass and another layer adheres. It is again withdrawn and the process repeated until the proper amount of molten glass has been gathered to yield the sheet which is to be blown.

The gathering is then placed in a block or mold and rolled and blown until it acquires roughly the shape of a hemisphere, the diameter of which is approximately that of the cylinder which is formed in the next step.

The hemispherical mass is now taken over by the blower and introduced into some special furnace or "blowing hole". The blower, by swinging and blowing, extends the mass into the form of a long cylinder which is closed at the lower end. In small thin cylinders the closed end is spun out to the diameter of the whole by the centrifugal effect produced by rapidly spinning the pipe between the hands, while with large thick cylinders the opening is accomplished by an assistant attaching a small lump of viscous glass to the closed end, which softens the glass of the cylinder sufficiently to enable him to cut the end open with a pair of shears, and the opening is then accomplished as in the case of the small cylinders.

The pipe is next detached from the cylinder by applying cold and hot irons to the neck of the hot glass that connects the pipe-bath and cylinder. The cylinder is then prepared for the flattening furnace first by cutting the rough ends with a diamond applied internally, and second splitting it longitudinally by the same means. In the flattening fur-

nace the split cylinder is exposed to a sufficiently high temperature to soften the glass and is then placed upon a smooth flat slab and flattened by a rubbing instrument composed of a block of charred wood or some similar material. The sheet of glass finished, only the process of annealing remains. This is accomplished by the methods discussed under the head of Annealing.

Bottles.—More progress has been made in the last decade in the manufacture of bottles than in any other grade of glass, and the demand has increased to such an extent that the manufacture of bottles has become an industry of vast proportions.

In recent years bottle-making machines have been successfully operated and they are destined to replace the old method of manufacturing in which most of the manipulation in the process is done by manual labor, because the machines insure absolute regularity in form of the vessel and save both time and labor. Since both methods are used at present a brief description of each will be given.

Five persons are required by the old process of bottle manufacture. The gatherer gathers the glass from the tank furnace on the butt of a blowing iron, rolls it on a stone or iron plate and, after slightly expanding the glass by blowing, hands it over to the "blower", who places the glass in a mold, closes the mold with a lever, and by means of compressed air or the breath, forces the glass to take the form of the mold. The bottle is removed from the blowing iron by applying a moistened piece of iron to the neck of the bottle and tapping it. The bottle is then gripped with a clip and handed to the "bottle maker". The bottle maker attaches a piece of molten glass to the end of the fractured neck and with a specially arranged tool simultaneously shapes the inside and outside of the neck. The "taker in" then removes the bottle to an annealing furnace, where it is properly annealed by being placed on trucks which are moved slowly away from a constant source of heat in a heated furnace so adjusted as to cool slowly.

The different bottle making machines vary considerable in details, yet the general principles involved are the same. The machine patented by Michael Owens contains a revolving table carrying five or six molds which are opened and closed by cams operated by compressed air. The blowing iron with the molten glass attached to it, which has just been gathered from the furnace, is placed in a mold. It is soon

in contact with an air jet which admits compressed air and forces the glass to assume the form of the mold. The bottle is then removed from the machine, severed from the blowing iron, and the rough edges smoothed. The annealing is accomplished as above noted. In some other makes of bottle machines, the molten glass is placed in a funnel-shaped vessel, and a plunger is thrust upwards into the glass from beneath, forcing a part of the glass into a mold stationed above which forms the neck. The funnel is removed and the plunger, neck mold, and molten glass attached to the neck are inverted. A bottle mold then rises and envelopes the molten glass, immediately after which compressed air is admitted to an opening in the plunger and forces the molten glass to take the form of a bottle mold. After annealing the bottle is ready for the market.

Mechanically Pressed Glass.

With a few minor exceptions all products of this class are pressed by mechanical means, and comprise chiefly plate glass.

Plate glass.—When the molten glass has cooled to a viscous condition, the whole pot with its contents is transported by means of huge tongs or cranes operated by mechanical means, to a rolling table, and the viscous mass poured on the casting table which usually consists of a perfectly smooth cast-iron slab mounted on a low massive truck running on rails so that it can be readily moved to any desired position in the casting room. As soon as the viscous mass is poured on the table a large roller, sometimes weighing as much as five tons, is passed over the glass, pressing it into a sheet, the width of which is regulated by guides pushed along in front of the roller, while the thickness is regulated by raising or lowering the roller relatively to the surface of the table. Figured rolled plate is produced in this way also by using rollers which have the pattern imprinted upon them.

Since the surfaces of the glass produced by rolling are uneven and must be ground and polished, it is essential that care be exercised in the handling and annealing of the large sheets, otherwise irregular thickness would be formed and extra expense incurred in grinding away the extra mass. The annealing process is therefore carried out in specially arranged annealing kilns, composed of large fire brick chambers containing sufficient floor area to accommodate several large slabs. The chambers are low and the slabs are placed

on blocks of burnt fire clay which form the floor of the kiln. In order to prevent any displacement and to give sufficient room for expansion, the blocks are set slightly apart resting on a bed of sand. After the kiln has been sufficiently heated and the glass introduced, the opening through which the glass is introduced is built up with fire brick and fire clay and the whole is then allowed to cool. Air passages or special cooling channels are provided in the walls and floor of the kiln, and by a gradual opening of these to admit the air the cooling is greatly accelerated and the larger slabs may be satisfactorily annealed in three or four days. The slabs are then transferred from the annealing kiln to the cutting room where they are cut into the different desired sizes and shapes.

The glass is now ready to receive its final form. It is placed on a rotating table, and either two surfaces of glass, or, one surface of glass and one cast iron, are rubbed together with the interposition of sand, emery, carborundum, or some other powerful abrasive. The surface is soon ground down to a plane and the pits produced are removed by grinding successively with abrasives of gradually increasing fineness, leaving ultimately a smooth gray surface. This smooth surface is then brilliantly polished by adding some polishing material, such as rouge, and rubbing with an instrument covered with some soft material like leather or felt.

Annealing.

Annealing is the gradual cooling of heated glass sufficiently slowly to allow the constituent particles to settle into a condition of equilibrium. In spite of the fact that annealing is one of the principal processes in the manufacture of glass it is the least understood, and manufacturers seem content to use the primitive methods that have been handed down from generation to generation. There are two methods of annealing in vogue at present, one being to move the glass gradually away from a constant source of heat by means of a train of small iron trucks drawn along a tramway by an endless chain, and the other, to allow the heated kiln to die out gradually. The latter method is used especially in annealing large quantities of glass at a time.

Glass follows the general law of expanding when heated and contracting when cooled. If this cooling is brought about gradually the various stages of viscosity, ductility, and solidity are produced and the glass acquires regular and re-

liable strength, since the molecules are given time to rearrange and reset themselves from the center outward and so avoid molecular strain. On the other hand, if the glass is cooled rapidly the molecules on the cooled surface rush to adjust themselves and as a result the glass becomes intensely solidified, which prevents the molecules of the interior from uniting and reducing the internal porosity by adhesion to the solidified exterior. In this condition the glass is in a continual strain and is prevented from collapsing only by the intense rigidity of the exterior walls. At the least provocation, however, the surface will break and disintegration quickly ensues.

Colored Glass.

Historical.—Coloring glass is principal one of the arts of glass making and dates back almost as far as glass making itself. The principal colored vessels that are found in Egypt consist of small, columnar, stibian jars, flattened bottles, and tiny wide-mouthed vases and jugs, decorated with zigzag lines.

The earliest decorated glass consisted of patch work of little pieces of variously colored glass set together in a heavy fretwork of stone or imbedded in plaster. In the medieval period they were set together by strips of lead arranged something like the letter H. The character of the glass is explained by the fact that colored glass originally was not made on a large scale and in big sheets such as are produced nowadays, but rather in imitative jewels that were made to appear as much as possible like sapphire, ruby, emerald, and other precious stones.

The process of staining glass was at first primarily the art of the glazier, but the painter later on took almost complete charge of it and during the Renaissance developed it to such an extent that it was one of the most important and remunerative trades of that age. The greatest patron of glass painting was the church, and the art depended upon church building for its development.

The last stage in the development of glass painting was the employment of enamel to produce color. It was first used in the early part of the 16th century. Many colors were introduced but enamel has not proven successful and has fallen into disuse because the colors produced are not permanent.

Glass painting and the other medieval means of glass decoration have given way largely to more advanced and

systematic methods of coloring glass through coloring agents incorporated directly with the batch. White light is composed of an innumerable number of light waves of different lengths. The prism separates the component parts of white light into the seven prismatic colors, namely: violet, indigo, blue, green, yellow, orange, and red. Physicists have proven that color is caused by the vibrations of light waves, and that the different colors are due to waves of the different wave lengths. The rays of shortest wave length impart the sensation of violet; the next length, indigo; the next, blue; the next, green; and so on. The vision is not affected by those wave lengths that exceed that of the red. Again, if the various wave lengths reach the eye at the same time the result is the sensation of white light.

Light and color.—The seven prismatic colors are divided into three primary colors, blue, yellow, and red; and four secondary colors, violet, indigo, green, and orange. The primary colors are pure and cannot be produced by mixing other colors. Their color may vary in intensity but it cannot vary in hue. On the other hand the secondary colors may vary in hue indefinitely, by varying the amount of the primary colors from which they are formed. Again, two colors are said to be complementary to each other when by their mixture they produce white.

The color in glass is due to a chemical combination of the oxides of certain metals used as coloring agents with the silica, soda, lime, and other ingredients in the glass. The resultant product possesses the power to retard or extinguish certain of the components of white light and transmit the remainder. Some metals, such as iron, nickel, cobalt, manganese, and chromium form two or more series of compounds which produce different colors in a borax bead when subjected to the reducing and oxidizing flames of a blowpipe. As an example: Iron in the oxidizing flame gives a deep orange color, while in the reducing flame it gives a dull green color. Thus by varying the nature of the metal, quantity present, state of oxidation, conditions under which it is seen, and by blending different colors, hues, and intensity into new colors modified in tone and intensity, an indefinite number of colors may be produced.

Coloring agents.—The principal coloring agents used in glass are manganese, cobalt, iron, gold, silver, copper, nickel, uranium, chromium, minium, antimony, selenium, zinc, carbon, calcium phosphate, sodium, selenite, tin oxide, guano, and borax.

Manganese when used in quantities in excess of those required as a decolorizer produces a color varying from rose to violet, purple, brown, and black, according to the quantity of manganese. When exposed continually to the action of the sunlight and air glass colored with manganese loses its color, since the manganese partly deoxidizes and becomes manganese oxide which produces no color in glass.

Cobalt is one of the principal coloring agents since it is cheap and produces positive results that are exceedingly easy to control. In small quantities it produces a deep rich blue color.

Iron in the ferric condition (Fe_2O_3) imparts an orange red color to glass; while the protoxide of iron (FeO) imparts a green color. *Gold* in the aurous condition produces a red color in glass. In fusing gold in the batch particular care should be taken to mix in the right amount of reducing agents so that the gold may not be super-oxidized to auric oxide; and on the other hand so that it may not be deoxidized to the metallic condition. Auric oxide does not color glass; while metallic gold produces a blue color which reflects a dull brown. Again, gold must not be added to any batch that will produce salt water or "glass goll", since it cannot be thoroughly disseminated in the batch so long as this impurity is present.

Silver is applied with a brush to the surface of the glass in the form of silver chloride mixed with some medium such as powdered clay, and heated gently in a muffle. The silver penetrates the glass and gives a light yellow to orange color. It is rarely introduced into the batch, because thereby it is reduced to the metallic state, and in this condition produces no color.

Copper forms two oxides, namely: the peroxide (Cu_2O) and the suboxide (Cu_2O) or red oxide. The former produces a green color and the latter a red or ruby color in glass. Reducing agents are added to the batch in order that the coloring agent may not be superoxidized. Care must be taken to avoid the use of ingredients that will generate "glass goll". Another important matter is the careful regulation of the temperature of the furnace and the thorough dissemination of the copper throughout the batch.

Nickel oxide produces a constant bluish to a violet tinge in glass. *Uranium* imparts a yellowish-green color, but is too expensive to be used except for the best grades of glass. *Chromium* oxide imparts an emerald-yellow which shades into a grass green. *Lead oxide* or minium yields a pale yellow

low color to glass. *Antimony sulphide* produces a yellow color. *Selenium* imparts a rose tint to glass. The depth and intensity of the color depends upon the quantity of selenium used and the quality of the glass. *Zinc* oxide produces a yellow color. *Carbon* which is generally added to the batch in the form of powdered charcoal, anthracite, or coke, produces a shade varying from straw color to dark amber. *Calcium* phosphate, or bone-ash, imparts an opalescent color in glass. The depth of the color depends upon the amount of lime used, and the temperature at which it is re-heated. *Tin oxide* produces a white opacity in glass, but since it is expensive, it is seldom used as a coloring agent. *Guano* imparts a white opacity in glass and is used instead of tin oxide, inasmuch as it is cheaper than the latter. *Borax* is sometimes used to intensify the color of glass.

CHAPTER II.

GLASS SAND DEPOSITS IN OKLAHOMA.

GENERAL REMARKS.

So far as is known the available glass sand deposits of Oklahoma occur in three regions, namely: the Arbuckle Mountains, southeastern Oklahoma, and near Tahlequah in northeastern Oklahoma. Beds of almost white sand, however, are reported near Tulsa, Bartlesville, Claremore, Ramona, Cleveland, Catoosa, Muskogee, and Holdenville, but so far as has been determined no large quantities of easily accessible sand in these regions has been found to be of sufficient purity to be used for anything but the poorest grades of glass, since all analyses show a large amount of iron oxide and other impurities which exclude them from consideration except for bottle glass. The deposits of each of the three principal areas will be considered in turn.

ARBUCKLE MOUNTAIN REGION.

General Features.

The Arbuckle Mountains consist of a low plateau, or table land situated in the southern part of Oklahoma, in Murray, Carter, Pontotoc, and Johnston counties. The Arbuckle Mountains proper form a roughly triangular area covering approximately 860 square miles. The plateau ranges in elevation from 1350 feet above the sea level in the western part to 750 feet in the eastern. On the northwest, the plateau is covered with Carboniferous conglomerate and "Red Beds" and on the southeast dips beneath the Cretaceous rocks. Plate I is a general geologic map of the region.

Mr. Joseph A. Taff⁵ gives the following stratigraphic succession in the Arbuckle Mountains:

Age		Formation	Thickness in feet
Carboniferous	Mississippian	Caney shale	1600
		Sycamore limestone	0-200
	Devonian	Woodford chert	650
Silurian	Upper Silurian	Hunton formation	0-300
		Sylvan shale	50-300
	Ordovician	Viola limestone Simpson formation	500-750 1200-2000
Cambrian	Upper Cambrian	Arbuckle limestone	4000-6000
	Middle Cambrian	Reagan sandstone	0-500

The chief topographic features of the Arbuckle Mountains are due to the varying resistance of the different formations, and to structure. The Sycamore, Hunton, Viola, and Arbuckle limestones are hard rocks and resist erosion more effectually than the softer Caney shale, Woodford chert, Sylvan shale, and Simpson formation which are interposed between the harder rocks, alternating ridges and valleys resulting. Erosion has also been greatly influenced by a large number of anticlines and faulted synclines. Most of the folding and faulting took place in Mississippian time after the deposition of the Caney shale.

The glass sand in the Arbuckle Mountains occurs in the Simpson formation which outcrops as a belt around the Arbuckle table-land. This table-land is formed by the Arbuckle limestone in Murray and Johnston counties and at other places in the mountains where the folding or faulting and subsequent erosion have brought the formation to the surface. The Simpson is composed of 1,200 to 2,000 feet of sandstone and fossiliferous limestone with interbedded greenish

5. Geology of the Arbuckle and Wichita Mountains: Prof. Paper U. S. Geol. Survey No. 31, 1904; Tishomingo folio (No. 93), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

clay, shales, and marls. Taff⁶ gives the following general section of the Simpson, taken on the south side of the uplift west of the Washita River, which with a few exceptions noted later, is characteristic of the Simpson throughout the area:

Section of Simpson formation on south side of Arbuckle uplift, west of Washita River.

	Feet.
1. Thin limestone with green shales interstratified In the lower part the limestone is subcrystalline, resembling beds lower in the formation, while higher it becomes fine grained and argillaceous, resembling that of the succeeding Viola formation.	400
2. Sandstone	90
3. Limestones and shales interbedded. Some of the limestones are highly fossiliferous: <i>Orthis tricenaria</i> , <i>O. deflecta</i> , <i>Monticuliporoid</i> Bryozoa, highly ornamented cystid plates, and species of <i>Ctenodonta</i> .	400
4. Sandstone	100-200
5. Shaly limestone The lower 50 feet highly fossiliferous, containing Ostracoda with numerous Bryozoa and bases of crinoid columns, making a fauna sufficiently peculiar to be easily distinguished.	195
6. Sandstone	33
7. Thin-bedded limestone and shales interstratified Contains fossils in great abundance, chiefly Ostracoda of large and small species, and numerous gasteropods, pelecypods, brachiopods, and trilobites.	295
8. Greenish shales with few thin limestone layers Thin sandstone.	245
9. Granular crystalline limestone in thin beds. Contains an abundance of Ostracoda (<i>Leperditia</i> chiefly) and other fossils so rare as to appear wanting.	350
10. Thin limestone and shales interstratified with occasional thin sandstone	29
11. White to light-brown sandstone, occurring locally	0-100

6. Geology of the Arbuckle and Wichita Mountains: Prof. Paper U. S. Geol. Survey No. 31, 1904, p. 23.

On account of the large amount of shale and loosely cemented sandstone in the Simpson formation, it is much softer and more easily eroded than the Arbuckle and Viola limestones which outcrop on either side of it. Its outcrops, therefore, form belts of low land between the Arbuckle tableland and the rows of knobs of the Viola, with minor irregularities due to the varying hardness of the different members of the formation (fig. 1).

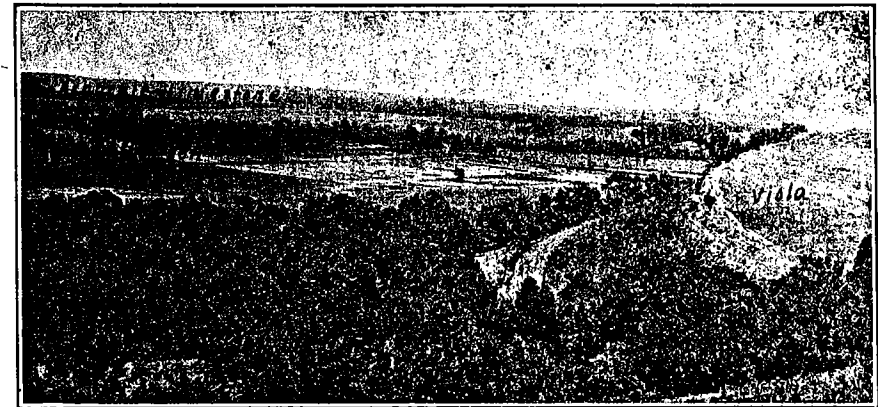


Fig. 1.

The Simpson is correlated with the Black River, Upper Stones River, and Chazy formations of Ordovician age. The beds of pure white sand in it are evidently beach or near shore deposits. Their purity, freedom from mud and other fine detritus, the comparatively uniform size of grains, and their sub-rounded character indicate long continued sorting action of the waters.

The workable glass sands in the Simpson occur within the limits of four well defined beds or series of beds, called in this report the basal, lower, middle, and upper beds. The basal beds contain sand only locally, but in some places the sand reaches a thickness of 200 feet, while the lower, middle and upper beds are fairly constant in thickness and character. The outcrops of these beds are usually marked with a heavier growth of timber than that found on the outcrops of the other members of the formation.

The Simpson formation is exposed in eight general areas in the Arbuckle Mountains, namely: the Southern Belt, which is a narrow strip along the south side of the mountains, the

Deleware Creek area, the Roff area, the Hickory area, the Mill Creek area, the Nebo area, the Buckhorn area, and the Davis area. In the following pages each area is discussed in some detail.

Southern Belt.

General Features.

The name Southern Belt is applied to the narrow strip of Simpson outcrop along the south side of the mountains, extending southeast from near Poolville to within three miles of Ravia, a distance of approximately 55 miles. The dip of the rocks in this belt varies from 18 to 80 degrees to the southwest, and the width of the outcrop varies from one-half to three-fourths of a mile.

The Sycamore limestone, Woodford chert, Hunton limestone, Sylvan shale, Viola limestone, and Simpson formation border the mountains on the southwest, all being steeply upturned. Because of their weaker resistances to erosion the Woodford chert, Sylvan shale, and Simpson formation form depressions which are usually wooded, alternating between the narrow limestone ridges. The Simpson formation is the thickest and most prominent, and outcrops in the wooded depressions between the row of rounded knobs of the Viola limestone on the south and a comparatively flat table-land of the Arbuckle limestone on the north. The Washita River and several smaller streams cut across all these formations almost at right angles, and form deep gulches or narrow canyons where they cross the more resistant formations. All the small streams, the more important of which are Henry House, Phillips, Cool, Oil, and Mill creeks, head in the more elevated parts of the Arbuckle plateau. Most of these streams contain water the year around. On account of the varying resisting powers of the beds of sandstone and shales in the Simpson, the formation is often etched by a number of small rivulets which parallel one another and empty into the larger streams that flow across the formation.

There is very little faulting in this area and the Simpson outcrop is continuous, except in the southwest corner of T. 2 S., R. 3 E., where it is faulted out. At the northwest end of the belt it passes beneath the Redbeds and in the southeast it disappears under the Cretaceous sediments.

At present none of this area is accessible to transportation facilities except that at Crusher, where the sand ledges outcropping along the bank of the Washita River are traversed by the Gulf, Colorado, and Santa Fe railroad. Condi-

tions are particularly favorable at this place since the sand, railroad, and water are in close proximity.

If at any time a railroad should be built along the level fertile plain at the base of the mountains on the south, unlimited supplies of pure white sand would be within easy reach, since the streams cutting their way across the formations have in most cases formed bottoms sufficiently wide to permit spurs to be built through to the sand ledges at little expense. The principal streams along which such spurs might be laid are Oil, Cool, Phillips, and Henry House creeks.

Occurrence and Character of Sands.

In order to obtain the thicknesses of the different beds in the belt several sections were made, the more important being on Phillips Creek, Cool Creek, at Crusher, on Oil, and on Mill creeks. These sections will be discussed severally.

Phillips Creek section.— The following partial section of the Simpson formation was made on Phillips Creek in sec. 25, T. 2 S., R. 1 E., the beds dipping west of south 52 degrees:

Partial section of Simpson formation on Phillips Creek (No. A1).

		Glass sand.	Total.
		Feet.	Feet.
Upper Beds.	25.	Hard, brown sandstone containing much iron, and a few small seams of white, soft sand....	23
	24.	Shale	2
	23.	Hard, brownish, impure sandstone	10
	22.	Covered	16
	21.	Hard, white sand, good for bottles and the cheaper grades of glass	18
	20.	Green shale	252

Middle Beds.	19. Impure sandstone		4
	18. White, friable glass sand, good for bottles	4	4
	17. Concealed, apparently sandstone		6
	16. Beds of hard sandstone, 2 inches to 1 foot in thickness, alternating with softer beds...		14
	15. Massive, soft white sandstone, good quality	8	8
	14. Sandstone beds of unequal hardness and irregular in size of grain, containing too much iron for glass sand		12
	13. Sandstone, limestone, and shale interstratified		16
	13a. Massive, white sandstone of good quality	26	26
	12. Coarse-grained, brownish-gray sandstone		10
	11. Soft sandstone, good for bottle glass	8	8
10. Massive, white sandstone, good for all glassware except the best grade	12	12	
9. Soft, irregular sandstone		11	
8. Fairly massive, soft, white sandstone, good for bottles ...	8	8	
7. Irregular beds of sandstone with considerable foreign material		28	
6. Green shale with 4 thin ledges of coarse-grained sandstone ..		87	
5. Hard, coarse-grained, siliceous limestone		8	
4. Limestone and shale		330	
Lower Beds.	3. Thin layers of white sandstone varying from 1/4 inch to 1 foot in thickness, interstratified with shale and limestone		12
	2. Solid mass of white friable glass sand, good quality	12	12
	1. Thin layers of white sandstone varying from 1/4 inch to 1 foot in thickness, interstratified with shale and limestone		150

The sandstone in the above section is not sharply exposed and no fresh samples were collected as they could be obtained only with some difficulty. The sandstone was sufficiently exposed, however, to enable a fairly accurate determination of the quality of the sandstone in the different beds to be made.

Thin beds of good glass sand also occur locally at the base of the Simpson from Phillips Creek westward, but it is not in sufficient quantities to be worked.

Cool Creek section (No. A2).— Along Cool Creek, in sec. 35, T. 2 S., R. 2 E., a good exposure of the Simpson formation is offered, a partial section of which is as follows:

Partial section of Simpson formation on Cool Creek.

	Glass sand.	Total	
	Feet.	Feet.	
Upper Beds.	9. Not sharply exposed, surface indicates a solid mass of soft white unstratified sand. No appreciable quantity of impurities except in the 10 feet near the base	91	91
	8. Limestone with interbedded beds of shale		461
Middle Beds.	7. Impure sandstone		5
	6. Massive, white glass sand	53	53
	5. Interstratified sandstone shale and limestone		25
Lower Beds	4. Shale and limestone		200
	3. Massive, white, friable glass sand	67	67
	2. Brown, siliceous limestone		10
	1. Sandstone grading rapidly downward into limestone		20

Certain units in the above section merit special and detailed consideration. Number 9 is practically one single bed of glass sand as nearly as can be determined. From this bed samples A1 to A6 inclusive were taken, analyses of which are shown in a succeeding paragraph under corresponding numbers. Sample A1 was taken 5 feet from the top; A2, 12 feet from the top; A3, 18 feet from the top; A4, 27 feet from the top; A5, 39 feet from the top; and A6, 60 feet from the top. These samples may be taken as indicative of the quality of the sand at the respective horizons. In the bed of the creek many little crevices are seen in the sand which would

seem to indicate the presence of thin layers of foreign matter. Higher up on the bank, however, where sand is not subjected so much to the action of running water the sand appears to be of one quality, showing that the crevices seen in the bed are due to unequal hardness of the sandstone caused by the varying amounts of lime which acts as a cementing material. The per cent of this lime as shown in the analyses is not large enough to make it unfit to be used as a glass sand.

Number 6 is also one solid mass of sandstone. From this bed samples A7 to A10 inclusive were taken. Analyses are given below. Sample A7 was taken 10 feet from the top; A8, 30 feet from the top; A9, 40 feet from the top; and A10, 50 feet from the top.

Analyses of samples of sand from section on Cool Creek.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter
A1	.07	.353	.138	.0137	99.305	
A2	.042	.661	.49	.0686	98.36	.012
A3	.042	.421	2.075	.0260	95.785	.011
A4	.028	.335	2.137	.0280	95.82	.013
A5	.042	.421	.44	.1730	98.586	.0098
A6	.063	.48	8.81	.0540	83.787	.0091
A7	.084	.349	.463	.0170	98.706	.0063
A8	.07	.213	.188	.0190	99.349	.021
A9	.084	.249	.028	.0260	99.585	.029
A10	.133	.75	1.425	.0260	96.525	.0018
A11	.042	.216	3.146	.0790	94.07	.0054
A12	.028	.215	6.945	.0110	87.337	.0014
A13	.084	.349	.463	.0170	98.706	.001
						.0027

Size of grains in samples of sand from section on Cool Creek.³

No.	Mesh.						
	40	60	80	100	200	Pan.	Total
A1	.79	5.69	38.1	32.32	23.02	.1	100.02
A2	.86	5.5	45.64	29.57	18.39	.07	100.03
A3	.8	3.66	31.92	36.27	27.16	.2	100.01
A4	.71	2.34	40.5	36.72	19.48	.29	100.04
A5	1.59	8.52	51.64	26.37	11.81	.06	99.99
A6	1.05	2.27	39.43	35.31	21.83	.13	100.02
A7	2.93	9.98	31.42	26.97	28.44	.27	100.01
A8	1.72	4.2	17.62	34.04	42.09	.37	100.04
A9	1.3	3.46	21.97	33.62	39.56	.1	100.01
A10	7.63a	24.73	33.99	20.17	13.38	.04	99.99
A11	6.92	14.43	40.35	23.52	12.52	2.22	99.96
A12	28.23a	32.62	21.24	10.37	6.21	1.31	99.98
A13	6.17a	14.39	31.73	26.49	18.9	2.34a	100.03

a. Most of this can be mashed up finer between the fingers.

3. The per cent in each column of this and similar tables shows the amount of sand left on the sieve after 100 circular motions of the sieve in the hand, with the given number of meshes per inch.

Number 3 is one uninterrupted bed of glass sand from which sample A11, 20 feet from the top; A12, 43 feet from the top, and A13, near the bottom may be taken as indicating the general quality of the sand. Analyses will be found in table. The beds of sand in the Cool Creek section dip 75° to the southwest.

Crusher section (No. A3).— One-half mile below Crusher on the Washita River is a good exposure of the Simpson. In the construction of the Gulf, Colorado, and Santa Fe railroad fresh exposures were made which greatly improved the natural section. The following succession was determined:

Partial section of Simpson formation at Crusher.

		Glass sand. Feet.	Total Feet.
	17. Siliceous limestone		7
Upper Beds.	16. Massively bedded white glass sand	36	36
	15. Siliceous limestone		5
	14. Alternating layers of shale and sandstone		45
	13. Siliceous limestone		3
	12. Brown impure sandstone containing much limestone		23
	11. Fairly good grade of massive white glass sand but it is probably too thin to be worked.....	11	11
	10. Coarse-grained sandstone with interbedded shale and limestone		56
	9. White sandstone	11	11
	8. Shales and limestone		387
	Lower Middle Beds.	7. Siliceous limestone .....		7
6. Massive white sandstone		42	42
5. Siliceous limestone			5
4. Shale and limestone			526
3. Massive white sandstone		86	86
2. Shale and limestone		202	
1. Hard siliceous limestone		27	

In the above section are several beds of valuable glass sand. The beds dip southwest at an angle of 75°. The character of the sand from No. 16 is indicated below in analyses of samples A14, taken from the top half of the bed, and A15 from the bottom half. Number 12 carries too

large percentage of lime to be considered a glass sand. The general quality of the sand from No. 11 is shown in analysis of sample A16. Number 9 has a small amount of high grade glass sand about the middle of the ledge, but the remainder is suitable only for the manufacture of bottles. Number 6 is not sharply exposed and no fresh samples were collected. The bed was sufficiently exposed, however, to enable one to determine fairly accurately its quality. The small amounts of sand gathered from different places in the ledge show that it is of as good a quality of glass sand as that found in the 53-foot ledge in the middle beds in the Cool Creek section which has already been discussed. Sample A17 shows the character of the sand in bed No. 3, 10 feet from the top, A18 represents the middle of the ledge while A19 was taken 10 feet from the bottom. The following table shows complete analyses:

Analyses of samples of sand from Crusher section.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
A14	.042	.161	.15	.03	99.469	.0013
A15	.042	.091	3.887	.031	92.941	.0032
A16	.07	.176	1.04	.054	97.844	.0097
A17	.028	.152	.37	.119	99.03	.008
A18	.14	.08	.2	.039	99.362	.005
A19	.056	.087	3.687	.042	93.236	.009

Size of grains of samples from Crusher section.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
A14	.67	2.45	31.12	36.00	27.69	.1	100.03
A15	6.743	15.45	32.98	25.13	19.22	.04	99.98
A16	.80	4.10	32.18	34.46	28.39	.08	100.01
A17	.75	3.94	41.27	29.52	24.67	.06	100.01
A18	2.2	41.65	36.52	13.44	6.2	.02	100.08
A19	.54	42.54	36.85	14.25	5.84	.03	100.05

a. Most of this can be mashed up finer between the fingers.

The sand in this section is easily accessible. It outcrops on the bank of the Washita River in the large solid walls of the cuts of the Gulf, Colorado, and Santa Fe railroad. The strata are almost on edge and the river has cut across them approximately at right angles to the strike. The lower beds are represented by a single bed of 85 feet of good glass sand as shown in the analyses of samples A17, A18, and A19 above. The outcrop of the bed is 30 feet above the railroad at the edge of the cut and from this height the surface rises gradually for a distance of 560 feet back from the railroad to the top of the divide. At the top of the divide the outcrop turns gently to the south. The sand is more easily eroded than the associated shales and limestones of the Simpson formation and consequently the sand ledges usually outcrop in small ravines. On the north of the divide there is a small ravine which runs on the bed of sand to within 235 feet of the railroad. At this point the depression passes to the shales which lie below the sand and goes under the railroad 100 feet east of the outcrop of the sand bed.

The middle series is comprised in a single bed which is 43 feet thick and the whole is composed of glass sand. One hundred and twenty-five feet back from the railroad a small V-shaped ravine strikes the top of the bed and passes over the base of it at the point where it runs into a small culvert under the railroad. Each side of the ravine has a slope of about 30°. On account of this steep slope the bed, as it passes from the ravine to the side of the hill, is exposed only at short intervals, since it is covered with surface detritus that has worked down from above. The middle beds pass over the divide in the same manner as the lower beds.

The upper beds are 63 feet thick and are comprised of a single bed of good quality of glass sand as the analyses show. At the railroad cut the surface of the bed is 33 feet above the railroad and from this point it rises gradually to the southeast for about 1000 yards where it passes over the divide. On the divide it is about 100 feet above the railroad. Between the divide and the railroad the bed outcrops half way down the west slope of the hill.

Oil Creek section (No. A4).—On Oil Creek in sec. 17. T. 3 S., R. 4 E., is a good exposure of the Simpson formation. The beds here dip 82° to the south. A section of that part of the formation which contains glass sand follows:

Partial section of the Simpson formation on Oil Creek.

		Glass sand. Feet.	Total Feet.
Upper Beds.	19. Sandstone, quality indeterminable	?	65
	18. Shale and limestone		150
Middle Beds.	17. Impure sandstone and limestone		40
	16. White sand	15	15
	15. Impure sandstone		15
	14. Massive, white sand	45	45
	13. Dirty, brown, shaly limestone.		9
	12. White, hard sandstone	10	10
	11. Siliceous limestone		22
	10. Massive, white sand	45	45
	9. Alternating sandstone and limestone		47
Lower Beds.	8. Shale and limestone		425
	7. Sandstone		25
	6. Covered, very likely soft sandstone	?	20-50
Basal Beds.	5. Shale and limestone		663
	4. White glass sand	42	42
	3. Impure sandstone		20
	2. Massive, white sand	34	34
	1. Coarse-grained, impure sandstone		5

In this section the basal sandstone 100 feet thick is found resting on the Arbuckle limestone. Seventy-six feet of this is a good grade of glass sand as shown by samples A20, A21, and A22. These basal beds are much more prominent than at Crusher, where they are composed of only a few feet of hard, siliceous limestone, while the middle beds are more than twice as thick. The upper and lower beds apparently contain approximately the same thickness of sand and as good a quality of sand as that found at Crusher, but they are not nearly so prominent and good samples could not easily be obtained from them. In the above section the quality of sand from No. 16 is shown in analysis A20 in the table below. Samples A21 and A22 indicate the quality of the sand from bed No. 14, the former being taken from the top 25 feet and the latter from the lower 20 feet. The character of the sand in bed No. 12 is shown in the analysis of sample A23. Sample A24 indicates the quality of the sand

in the upper 20 feet of bed No. 10, and A25, that of the lower 25 feet. Sample A26 shows bed No. 4 to be a very pure sand. Sample A27 was taken 5 feet from the top and A28, 2 feet from the top of bed No. 2.

Analyses of samples of sand from partial section on Oil Creek.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
A20	.07	.185	6.86	.0518	87.46	.012
A21	.014	.179	.275	.021	99.267	.005
A22	.028	.255	2.075	.0771	95.94	.008
A23	.056	.277	5.925	.0645	88.947	.034
A24	.14	.383	11.225	.0699	79.357	.0098
A25	.056	.214	4.755	.0427	91.21	.0053
A26	.056	.284	.225	.0355	99.19	.0011
A27	.084	.146	.225	.0445	99.34	.0029
A28	.084	.162	.94	.028	98.058	.0084

Size of grains in samples of sand from partial section on Oil Creek.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
A20	2.18a	5.71	27.49	37.48	24.9	2.22	99.98
A21	2.78	15.97	43.02	25.51	12.72	.03	100.03
A22	2.53	22.32	47.5	20.59	7.04	.04	100.02
A23	5.19	7.51	20.64	28.63	36.48	1.54	99.99
A24	10.01a	14.89	34.67	21.93	15.33	3.15	99.98
A25	1.6	13.55	45.88	25.31	12.41	1.24	99.99
A26	3.85	24.89	38.75	25.68	6.42	.43	100.02
A27	4.9	33.18	35.18	17.25	9.34	.17	100.02
A28	3.96	19.97	39.6	22.68	13.29	.47	99.97

a. Most of this can be mashed up finer between the fingers.

Mill Creek section (No. A5).— The last section studied in the southern belt is on Mill Creek in sec. 32, T. 3 S., R. 5 E. The structure in this section is slightly complicated and the thickness of the different beds could be only approximated, as the dip of the rocks varies from 30° to 90° and in a few places are slightly overturned. No attempt was made to deal with the upper beds because they are poorly exposed. The following section was made:

Partial section of the Simpson formation on Mill Creek.

		Glass sand.	Total.
		Feet.	Feet.
Middle Beds.	22. Impure sandstone, with shale and limestone interbedded		10
	21. Massive, white sand	15	15
	20. Irregular sandstones		4
	19. White sand	2	2
	18. Impure sand		4
	17. White glass sand	12	12
	16. Limestone		22
	15. Impure sandstone		5
	14. Pure white sand	45	45
	13. Impure sandstone		10
	12. Shales and limestones, with two thin ledges of sandstone..		505
	Lower Beds.	11. Thin seams of shale, limestone, and sandstone . . . . .		27
10. Good white sand		30	30
9. Impure sand and shale			10
8. Good glass sand		15	15
7. Sandstone with thin seams of shale and limestone			20
6. Shale and limestone			650
5. Impure sandstone, with interbedded shale and limestone			11
Basal Beds.	4. Solid, massive, white sandstone of good quality	50	50
	3. Rather impure sandstone, good only for bottles		11
	2. Massive, white sand, apparently of good quality	13	13
	1. Sandstone grading downward into shaly limestone		5

No samples from the Mill Creek section were taken because the nature of the exposure renders the obtaining of representative samples rather difficult. The location of the deposits with respect to transportation facilities, and the rugged character of the country renders the utilization of these deposits unfeasible.

The following table gives a summary of the results obtained from the five sections made at different localities in the Southern Belt area, the thicknesses being given in feet:

Section.	Horizon.	Phillips Creek.		Cool Creek.		Crusher.		Oil Creek.		Mill Creek.		Average thickness of glass sand.	
		Total thickness.	Thickness of glass sand.	Total thickness.	Thickness of glass sand.	Total thickness.	Thickness of glass sand.	Total thickness.	Thickness of glass sand.	Total thickness.	Thickness of glass sand.	Average thickness of sand horizon.	Average thickness of glass sand.
Upper Beds.		69	18	91	91?	197	58	65	?	?	?	105	55
Middle Beds.		167	66	83	53	54	42	248	115	129	74	136	70
Lower Beds.		174	12	97	67	100	86	45-100	?	102	45	108	53
Basal Beds.								101	76	90	63	95	70

Although the ledges are almost on edge and many sharp exposures were seen where the streams have cut their way across the beds, yet it was impossible in every case to determine the exact thickness of the sand or to judge its quality definitely. As an example the upper beds are not prominent in the southeast part of the belt and in the sections on Oil Creek and Mill Creek the beds are concealed beneath the soil and hence the quantity and quality of the sand could not be determined, although indications are that they contain as much sand which is of as good a quality as that shown in the other sections. In the last two sections the basal beds stand out the most prominently. They occur locally in the western end of the belt, and usually outcrop as a thin ledge of sandstone containing a large per cent of lime.

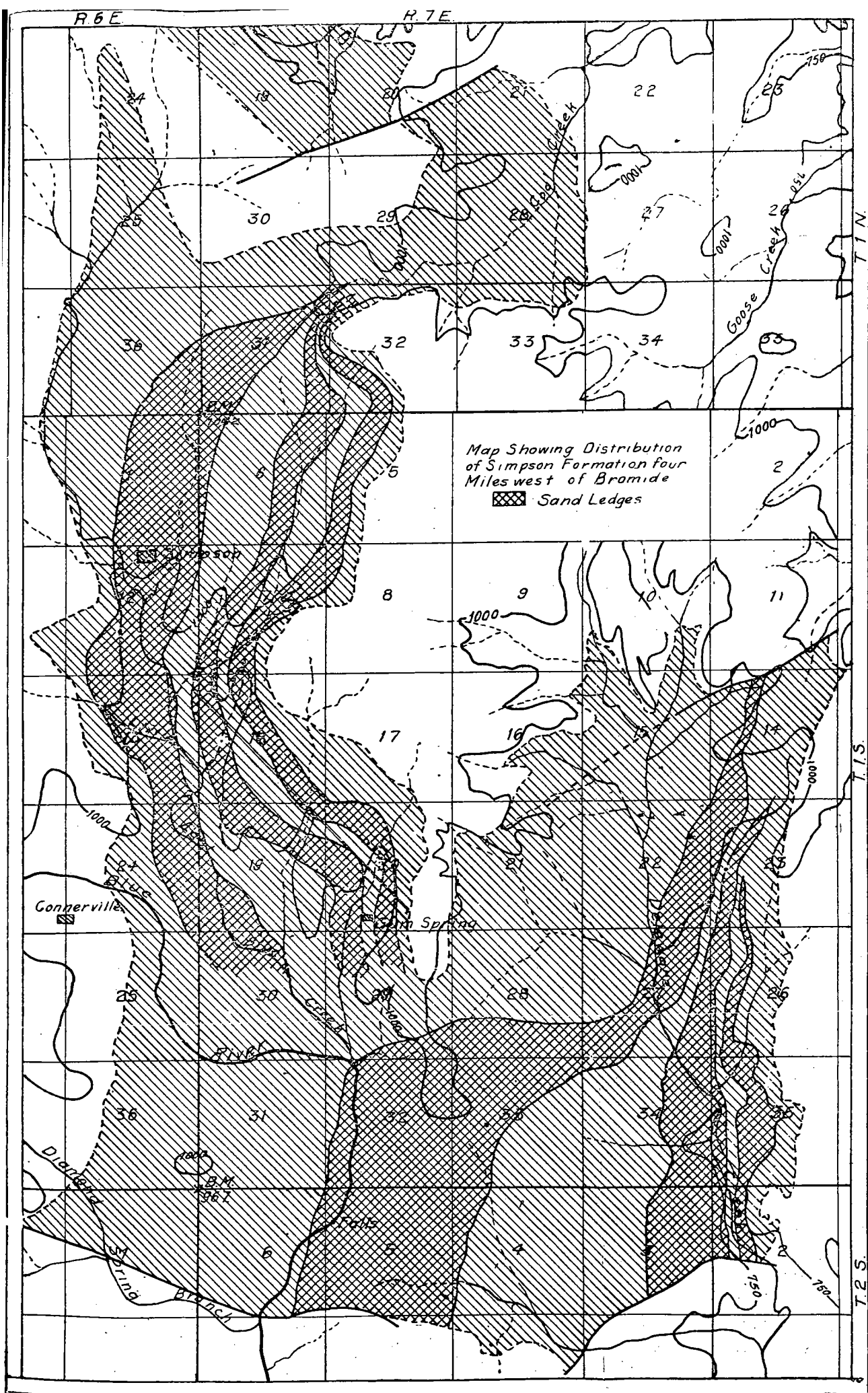
None of the horizons are constant, but the variation in the total thickness in the different localities is partly due to the arbitrary division lines separating the sand ledges from the limestones and shales above and below; since in most cases there is a more or less gradual gradation from one to the other.

Delaware Creek Area.

General features.—The Delaware Creek area consists of the greater part of T. 1 S., R. 7 E., with an arm which extends north into T. 7 N., R. 6 E. The outcrop in T. 1 S., R. 7 E., is approximately square and occupies an area of about 25 square miles, while the arm to the north is about 5 miles long and 3 miles wide, making a total area of about 40 square miles (Pl. II).

The glass sand of the Delaware Creek area is comprised in the Simpson formation. This occurs in a comparatively flat basin, bounded on the east and north by the rounded knobs of the Viola limestone, and on the west by the rolling plateau of the Arbuckle limestone. The general slope is to the east. On the south side where the formation is 5 miles wide the dip is about 3° east, while in the northwest, where it is 3 miles wide, the dip is about 10° to the east. In section 29, and for 3 miles to the northeast, the width of the outcrop is not so great and in places is not more than one-half mile. The dip in this vicinity is 20° to 45° to the southeast.

As shown on the map of the region, a fault occurs in the northeast part of the area, the lower horizon of the Simpson being faulted into contact with the Viola limestone. This fault coupled with erosional features causes a tongue of



R.6 E.

R.7 E.

Map Showing Distribution of Simpson Formation four Miles west of Bramide
[Cross-hatched symbol] Sand Ledges

Connerville

Sam Spring

Goose Creek

Diablos Spring

T.1 N.

T.1 S.

T.2 S.

Viola to protrude 3 miles southward, dividing the Simpson outcrop. The basal beds are exposed along the western border of the Simpson formation and along the stream in the extreme southern part of sec. 15, T. 1 S., R. 7 E. The lower beds have wide outcrops in the valley and to the east of Blue River. In the western part of the area also the lower beds are widely exposed along Little Blue Creek. This area is probably continuous with the wider area to the southward but it is not mapable. The middle and upper beds outcrop between Little Blue Creek and the Viola limestone to the eastward.

Considerable crumpling in the members of the formation is seen in the east-central part of sec. 29, T. 1 S., R. 4 E., where the dip suddenly increases. The crumpled area is small and, beginning in the north-central part of sec. 29, and continuing northward, there is no irregularity in the arrangement of the members of the formation, and the four horizons of sand except in that portion of the area north of the base line are well exposed.

The large deposits of glass sand in the Delaware Creek area cannot be developed at present, because there are no transportation facilities. The nearest means of transportation is a branch line of the Missouri, Oklahoma, and Gulf Railroad. It is reported that plans are being laid to extend the branch line from Bromide on to the northwest. Unless these plans materialize, the large deposits of good glass sand in this region must remain undeveloped. The four miles intervening between Bromide and the sand bluffs along Delaware Creek is comparatively smooth and the road could be built at moderate cost. None of the glass sand deposits of this area, except those in the extreme northwest part, are inaccessible, but there is very little probability that any of it will be developed except the glass sand bluffs along Delaware Creek, since these are more accessible and contain an inexhaustible supply of easily workable sand and are near water.

Occurrence and character of sands. — The glass sand in the Simpson formation in the Delaware region occurs in four beds or series of beds which are very similar in most respects to those found in the sections on Mill Creek, Oil Creek, Phillips Creek, and near Crusher.

The *basal beds* are found resting on the Arbuckle limestone along the western border of the Simpson formation. In the northwest part of sec. 36, T. 1 S., R. 6 E., the outcrop runs northeastward and disappears under Blue River and ap-

parently the beds do not again appear until in the north-central part of sec. 22, T. 1 S., R. 7 E. The prevailing evidence is that the bluff of sand north of the school house in the southern part of sec. 15, T. 1 S., R. 7 E., is a part of the basal beds, since it occurs about 660 feet stratigraphically underneath the lower beds as in the sections on Oil Creek and Mill Creek; and since the characteristics of the sand ledge and the immediately overlying limestone and shale are similar to those in those sections. The beds extend to the southwest a short distance and disappear. The sand in this area is inconveniently located for development.

The basal beds were not mapped in any of the areas studied because with only a single exception, which is noted above, the beds wherever they occur at all are always found outcropping on top of the exposed Arbuckle limestone.

On the bluff mentioned above occurring in sec. 15, T. 1 S., R. 7 E., the following succession was observed (*section No. B1*):

	Feet.
2. Limestone and shale	25
1. Sandstone, base not exposed	18

The analyses below show the quality of the sandstone, sample B1 coming 2½ feet; B2, 7 feet; and B3, 14 feet from the top:

Analyses of samples of sand from section No. B1.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
B1 .....	.112*	.228	.135	.0453	99.388	.0027
B2 .....	.154	1.6	.112	.059	97.986	.0041
B3 .....	.168	.242	.135	.099	99.256	.004

Size of grains of samples of sand from section No. B1.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
B1 .....	.12	8.74	54.82	20.02	15.51	.82	100.03
B2 .....	.27	1.94	36.35	36.17	24.27	1.03	100.03
B3 .....	.62	7.88	37.17	30.42	23.22	.71	100.02

The boundary lines of the outcrop of the *lower beds* are somewhat indefinite. The beds are apparently separated into two divisions. The upper part passes east of Pilgrim Chapel and an exposure on a small branch in the northeast part of section 33 shows it to be about 10 feet thick. The top 2½ feet is almost black with carbonaceous material, but

this is only a local occurrence, since in the other exposures of this ledge the carbonaceous material is not prominent. The lower division passes to the west and north of Pilgrim Chapel. In the northeast of sec. 5, T. 2 S., R. 7 E., it is divided into several thin beds of sandstone interstratified with thin layers of limestone. Sample B 4 was taken from one of these beds which is 2½ feet thick.

Analysis of sample of sand from N. E. 1-4 sec. 5, T. 2 S., R. 7 E.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
B4	.434	.596	.175	.065	98.592	.0082

Size of grains of sample of sand from N. E. 1-4 sec. 5, T. 2 S., R. 7 E.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
B4 .....	.95	3.56	20.12	31.1	41.62	2.64	99.99

The quality of this sand together with its thickness and location makes it infeasible for working.

A sand bed is exposed in the bank of a small ravine 200 yards southeast of the center of section 32. The thickness of the sand is unknown, but there is probably 10 feet of it, as a 10 foot exposure on the same ledge is shown 460 yards north and about 50 yards east of the center of section 27.

On the south the entire lower beds outcrop over most of sec. 5 and the eastern part of sec. 6, T. 2 S., R. 7 E., and extend just across Blue River to the west. The general direction is to the northeast and the beds pass under the Viola limestone in the north-central part of sec. 14, T. 1 S., R. 7 E.

The outcrop of the *middle beds* begins in the east-central part of sec. 3, T. 2 S., R. 7 E., and runs north to the north-central part of sec. 23, T. 1 S., R. 7 E., where they disappear by pinching out or by faulting. They parallel those of the upper beds but are not nearly so conspicuous, since Delaware Creek crosses them and a good part of the sand is concealed in sections 27 and 34. Along the west side of the outcrop the sand is found in several small knobs which are capped by outliers of the limestone that separates the upper and middle beds. This limestone formerly extended over the area now occupied by Delaware Creek and passed under the upper beds to the east. The removal of this limestone by Delaware Creek has exposed portions of the sand east of the original outcrop. The sand in this locality is not so accessible as is that in the upper beds and no good fresh ex-

posures were seen. In the eastern part of sec. 27, the outcrop leaves the valley and frequent exposures are seen from this point northward. Two hundred and seventy yards east of the northwest corner of sec. 26, 6 feet of white, friable sand of the middle beds is exposed (sample B5). The base of the sand is not seen but indications are that it lies several feet below the base of the exposure. It must be borne in mind that in the five sections of the Simpson, in the southern area above discussed, where the thickness could be more or less accurately determined, the middle beds show from 42 to 115 feet of glass sand.

Analysis of sample from sec. 26, T. 1 S., R. 7 E.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter
B5	.056	.277	.11	.068	99.406	.0014

Size of grains of sample from sec. 26, T. 1 S., R. 7 E.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
B5	.7	10.8	51.8	21.1	14.	1.5	99.99

As may be seen from the above analysis this is a very pure sand and only lacks transportation facilities to make it valuable.

The *upper beds* outcrop along the east side of the area. Beginning in the west-central part of sec. 2, T. 2 S., R. 7 E., they run almost due north and disappear either by faulting or by pinching out 480 yards west and 355 south of the center of sec. 23, T. 1 S., R. 7 E. The width of the outcrop varies from 100 to 500 yards and in sections 26 and 35 the outcrop is prominent and only a few small ravines cut the surface; while in section 2 the beds are less prominent and Delaware Creek has deposited alluvium over a good part of them.

Limestone caps the beds and forms a rather prominent ridge on the east side of their outcrop, while the limestone and shale on the west side that separate the upper and middle beds are frequently eroded down by small streams cutting their way across to Delaware Creek, and in most of these places the sand is covered with the soil. In a few small areas sand from the upper beds has been deposited over the limestone and shale in these localities and gives the surface the appearance of one of the series of sand beds. A sufficient number of rounded limestone knobs remain, however, to enable one to determine the boundaries of the sandstone horizons.

The following section from the glass sand bluff of Delaware Creek, 355 yards east and 255 yards north of the southwest corner of sec. 35, T. 1 S., R. 7 E., gives an estimate of the quantity of glass sand in the upper beds and the analyses show the quality:

Partial section of upper beds of Simpson formation on sec. 35, T. 1 S., R. 7 E. (No. B2.)

	Glass sand. Feet.	Total. Feet.
9. Limestone and impure sandstone capping bluff		10-25
8. Massive, white, friable sand...	21	21
7. Thin, irregular, siliceous limestone containing a large per cent of iron		1/2
6. Sand similar to No. 8 in appearance	4	4
5. Siliceous limestone		3
4. White, friable sand	4	4
3. White sandstone, rather hard	2	2
2. White, friable sand	5	5
1. Impure sand and thin layers of shale and limestone.....		16

Analyses of samples from a partial section of Simpson formation in sec. 35, T. 1 S., R. 7 E.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
B6	.126	.464	.31	.0246	98.82	.01
B7	.182	.551	1.35	.0337	96.81	.0091
B8	.406	.61	1.512	.088	96.184	.012
B9	.07	.163	7.5	.03	86.287	.0064
B10	.112	.141	4.125	.0282	92.377	.0042

Size of grains of samples from a partial section of Simpson formation on sec. 35, T. 1 S., R. 7 E.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
B6	1.6	8.4	24.2	23.1	38.12	4.6	100.02
B7	2.58	12.61	35.16	25.4	23.02	1.24	100.01
B8	2.69	13.55	40.1	22.545	18.82	2.22	99.978
B9	1.76	35.59	44.2	12.42	5.41	.62	100.
B10	1.6	13.25	50.2	20.5	12.27	2.2	100.02

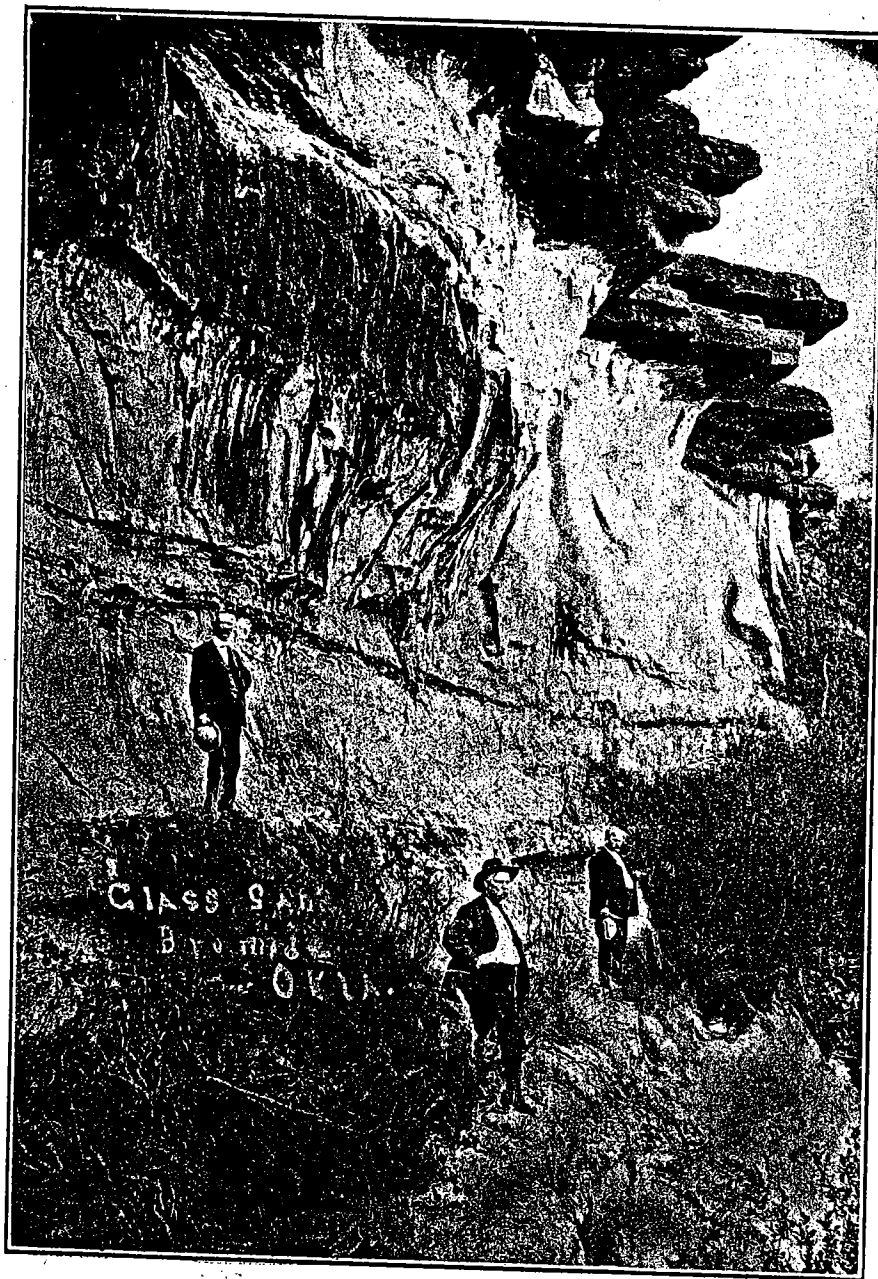


Plate III.

The bluff of sand outcrops for about 100 feet along the east bank of Delaware Creek and sufficient water for washing out the impurities of the sand is found at the base of the bluff (Pl. III). The outcrop is capped with several feet of limestone, the dip of which is about 10° to the east. The 21-foot bed of sand in this bluff is sufficiently pure, according to the amount of impurities allowed for different grades of glass as shown in table on page 11, for any but the best grades of glass. There are several places in the two miles on north from this bluff, where by the removal of a few feet of surface soil, deposits of sand as good as the above may be opened up at a small expense. In fact there is very little of the upper beds in the three miles that cannot be easily worked, except on the south side in section 2, where Delaware Creek has deposited alluvium over a large part of the beds. These deposits on the north, however, are not so conveniently located since there is no water near them.

Roff Area.

General features.—This area extends eastward from Roff through the east central part of T. 2 N., R. 4 E., and onward to the eastern limit of T. 2 N., R. 5 E. The outcrop of the Simpson formation forms a belt from one-half to one and one-half miles wide (Pl. IV). Between this area and the Delaware Region to the southeast most of the Simpson is faulted out and in the northeast part of T. 2 N., R. 6 E., it is entirely gone and the Viola limestone is brought down into contact with the Arbuckle limestone.

The Simpson formation in the Roff area occurs in a narrow valley between the Viola limestone on the north and the Arbuckle limestone on the south. It is almost on edge. Little relief is shown, except that the limestone between the middle and lower beds forms a low ridge near the middle of the outcrop, the sandstone beds lying in narrow valleys on either side.

In the western part of sec. 14 a fault cuts out most of the formation. All of the upper and most, if not all, of the middle beds are faulted out. Another fault on the south in secs. 23 and 24 limits the formation in that direction. Along this fault the basal, and in most places the lower, beds have been faulted up and eroded away. Between Roff and Fitzhugh the Simpson is concealed beneath a formation of sandstone and shale of Carboniferous age.

Occurrence and character of sand.—The glass sand in the Simpson formation in the Roff region also occurs in four

series of beds but for reasons given later, it is probable that only the basal beds will be developed in the near future.

The *basal beds*, resting as they do directly on the Arbuckle limestone, outcrop just to the north of it in the Roff area. In the creek bottom east of Roff the outcrop widens out and the sand is found underlying the south half of secs. 17 and 18. In the southwest part of sec. 18 the ledge swings to the south and outcrops to the east of Roff and in a short distance disappears under the sandstone and shale of the Carboniferous.

The St. Louis and San Francisco Railroad passes over a portion of the basal beds in sec. 18 and with little expense a spur can be run to any other part of the remainder in the two sections. The sand is overlaid by 2 to 6 feet of alluvial soil which may be removed at low cost.

A small quarry has been opened up in the bank of the creek on the south side of sec. 18. From this a sample of sand was obtained which gave the following results:

Analysis of sample of sand from basal horizon near Roff.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
C1	.28	.988	.13	.032	98.24	.229
C1a	.252	.59	.09	.028	98.872	.104

Size of grains of sample of sand from basal horizon near Roff.

Mesh.							Pan.	Total.
	40	60	80	100	200			
No.								
C1	1.74	17.	36.58	22.58	20.785	1.35	100.035	

In the above analysis C1 was unwashed, while C1a was washed, by simply putting the sample in water, letting it remain an hour, draining and drying. The results of the analysis show that most of the impurities may be removed by washing. As Blue Creek does not run the year round, the supply of water would have to be secured from wells or reservoirs.

A carload of this sand was tested by Mr. M. W. Conway, Superintendent of the Tulsa Glass Company, at the plant of the company. The results show that the glass made from this sand is of a better quality than that made from the sand his plant received from the St. Louis region.

Since the sand is accessible to transportation and is of a good quality, the remaining factor that determines its value is the amount of sand in the deposit.

The thickness of the basal beds in secs. 17 and 18 has not been determined, since they are covered in the creek bottom and no structure is seen at this point. The beds are sharply exposed, however, in the northwest corner of sec. 22, and show that they are comprised of three divisions. The bottom 35 feet is composed of massive sand, the next 28 feet is shale, limestone, and sand, and the top 35 feet is massive sand. The surface of these beds is weathered so that fresh samples could not be obtained.

It is unlikely that the thickness of the basal beds has changed materially in the distance between secs. 22 and 19. If this is true and if the quality is as good as shown in the above analysis either one of the 35 foot beds contains a vast amount of good sand.

The *lower beds* are found outcropping along the south side of the limestone ridge that separates them from the middle beds. Their location and extent are shown in the accompanying map (Pl. IV). The conditions found in the upper and middle beds also prevail here and consequently the sand is not workable.

The *middle beds* parallel the upper and pass under the Carboniferous near the northwest corner of sec. 16. The same conditions found with reference to the upper beds obtain also in the middle beds.

The *upper beds* are exposed for a distance of about 1½ miles northwest and southeast. On the east side they are faulted out in the southern part of sec. 14 and on the west they pass under the Carboniferous area near the half-section line on the north side of sec. 16. The beds are almost on edge in places and are hardly traceable. They are prominent near the center of this section and slight exposures are seen in the ravine running east. The sand in the beds can never be worked at a profit because in addition to its being buried beneath several feet of soil, drainage conditions are bad and the beds are on the edge in the bottom of the ravine.

From the above considerations it will be seen that the sand in the lower, middle, and upper beds of the Roff area is not of the highest value. While no analyses are given conditions of quarrying with respect to stripping, drainage, and attitude of the beds render the deposits valueless under present conditions. With respect to the basal beds conditions of quarrying with respect to stripping, drainage, grade, and while, as stated above, the amount of sand present could not be precisely determined such evidence as

could be obtained indicates a large amount occurring under rather favorable conditions.

Hickory Area.

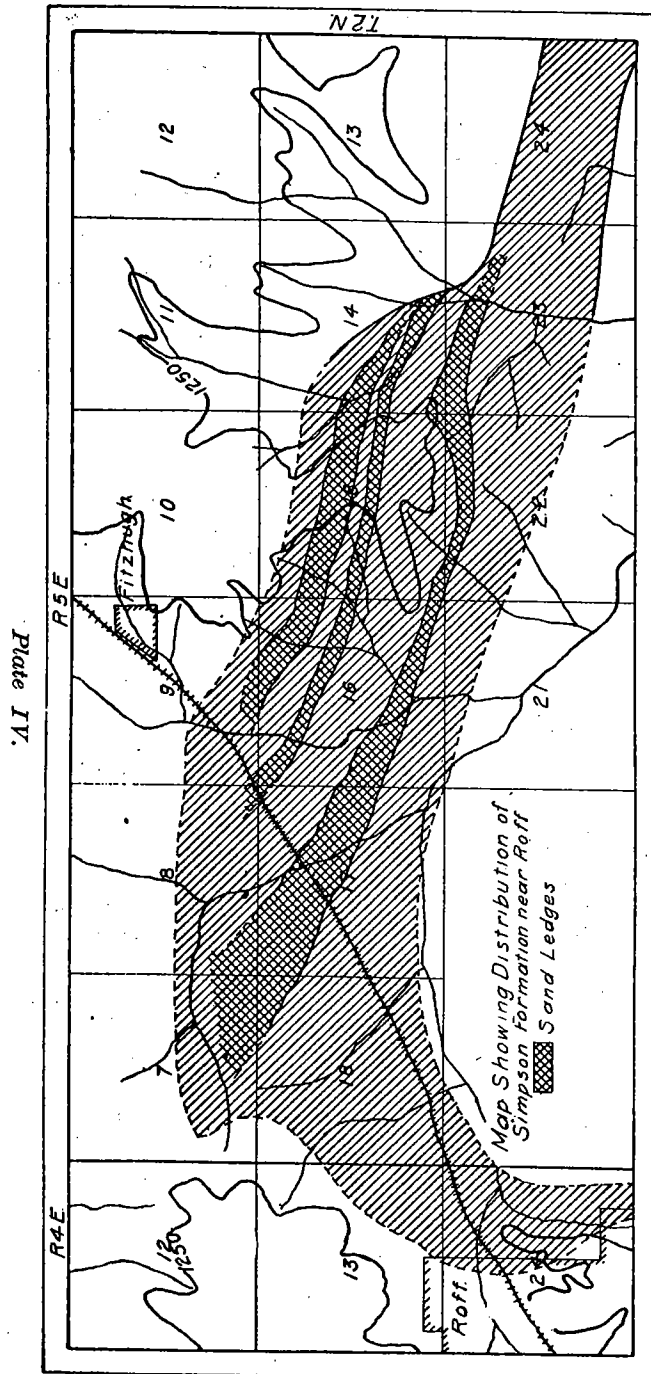
General features.—This area, comprising about seven square miles, is located near the center of T. 1 N., R. 4 E. The village of Hickory on the St. Louis and San Francisco Railroad is located on the east border of the area.

The exposed area of the Simpson formation is here bounded on the north, east, and south by the Arbuckle limestone, and on the west it is limited by sandstone and shale of Carboniferous age. Faults limit the area on every side except the west and one fault traverses the area in the north-central part. This faulting, coupled with poor exposures renders the determination of the amount of sand present and the stratigraphic position of the beds unsatisfactory. The Simpson formation outcrops in this area in a comparatively flat basin which is only slightly dissected by Mill Creek and its small tributaries.

Occurrence and character of sands.—A bed of sand outcrops along the north line of secs. 14 and 15. A sharp exposure is seen about 250 yards southwest of the half-mile stone on the north side of the latter section. At this place it is 25 feet thick. Sample D1 is a representative of the top 15 feet, and D2 of the bottom 10 feet. The hard siliceous limestone capping the sand bed dips 10° to the north. The bed is not prominent at any other place. To the west the bed is covered in the bottom of Mill Creek, and to the east it runs in a little valley and is covered by several feet of surface soil that has been washed down from the ridge on the north. The prospects for the development of this bed are unfavorable, because it is not easily accessible and only the top 15 feet is sufficiently pure to be used.

In the little valley just south of the cotton gin in Hickory another thin bed is found. This also is covered with surface soil. Its thickness is unknown but the evidence obtainable indicates but a few feet. The sand contains a large per cent of impurities but most of these may be removed by washing. Wells dug in the south-central part of secs. 14 and 15 show several feet of white sand, but since this occurs 50 feet or more beneath the surface it is valueless.

Along the north and south sides of the area the fine-grained, generally friable sandstone of the basal beds has been altered to a quartzite. This alteration is often observ-



ed in the basal horizon and is prominent at Roff, Mill Creek, and the other localities where the beds are sharply exposed. This alteration is apparently due to solution and the re-deposition of secondary silica between the grains and is a result of weathering.

The following analyses show the character of the sand in the area:

Analyses of samples of sand from near Hickory.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
D1 .....	.112	.11	2.637	.04	94.56	.486
D2 .....	.056	.097	16.27	.098	70.554	.32

Size of grains of samples of sand from near Hickory.

No.	Mesh.	40	60	80	100	200	Pan.	Total.
	D1 .....	.88	4.35	29.86	27.91	34.74	2.24	99.98
D2	5.91	14.54	32.12	24.24	19.45	3.72	99.98	

Mill Creek Area.

This area includes two detached parts which for purposes of discussion will be conveniently designated as the lower and upper parts respectively.

The *lower part* consists of a relatively narrow band extending from the north-central part of T. 2 S., R. 4 E., eastward across Mill, Rock, and Pennington creeks into the west-central part of T. 2 S., R. 6 E. Its continuity is broken in several places by faults. From the western limit eastward to Rock Creek the basal and lower beds are faulted out. In the narrow strip between Rock and Pennington creeks only the upper beds are present, the other three being faulted out. At the extreme eastern end of this part of the area the entire Simpson formation is present, but it is poorly exposed and few details could be obtained.

In that part of the lower area lying west of Rock Creek the middle and upper beds are exposed, but they are not accessible and therefore are not of any present value, except in sec. 18, T. 2 S., R. 5 E., where the St. Louis and San Francisco Railroad crosses the upper and a portion of the middle beds. West of the railroad both series of beds are exposed. They contain approximately the same amount of sand as the middle and upper beds in the Southern Belt and the quality of the sand is as good as in that area, and in addition to the

accessibility of the sand, little stripping is required.

The *upper part* of the Mill Creek area lies in the north-west corner of T. 2 S., R. 5 E., being roughly semi-circular in outline and embracing an area of about 2½ square miles. Only the basal beds are present, the others being eliminated by faulting. About one-half mile northeast of the town the sand outcrops in low bluffs along the banks of a small ravine for three to four hundred yards. From one of the bluffs several tons of sand have been removed. At this place 15 feet of sand is seen, the base not being exposed, but the indications are that the bed continues several feet below the base of the exposure. The quality of the sand is shown by the following analysis:

Analysis of sample of sand from one-half mile northeast of the town of Mill Creek.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
E1 .....	.35	.56	.065	.188	98.782	.008

Size of grains of sample of sand from one-half mile northeast of the town of Mill Creek.

No.	Mesh.	40	60	80	100	200	Pan.	Total.
	E1 .....	.16	2.38	24.34	32.18	37.52	3.4	99.99

These beds lie one-fourth mile from the St. Louis and San Francisco Railroad, and since practically no grading will be required to run a spur out to the beds they are easily accessible.

Good exposures of the basal beds are also seen in a small creek 1½ miles east of town. The sand here is of the same quality as that northeast of town. It is accessible and the St. Louis and San Francisco Railroad has a spur out to some gravel beds southeast of Mill Creek which passes within three-quarters of a mile of the sand deposits.

Nebo Area.

General features.—This area derives its name from Nebo Post Office which is situated near the western border. It consists of approximately 12 square miles and is located principally in T. 2 S., R. 3 E. It extends south a short distance in T. 3 S., and northeast a short distance into R. 4 E. It is roughly rectangular in outline being approximately 6 miles long north and south and 2½ miles wide east and west (Pl. V).

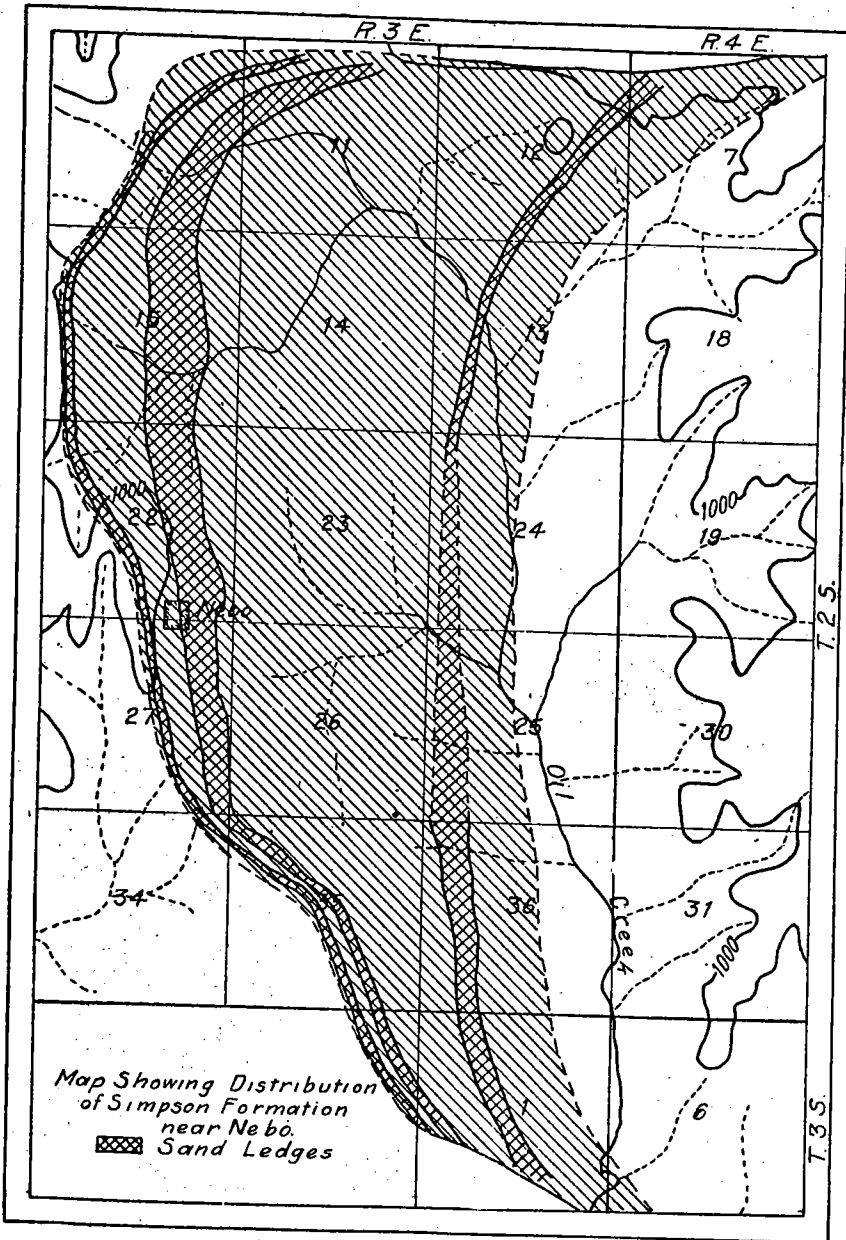


Plate V.

In the vicinity of Nebo the Simpson formation outcrops in the wide, flat valley of Oil Creek. In the eastern half of the area the formation is concealed beneath a thick mantle of soil.

At Wyatt on the southeastern extremity of the area the outcrop of the formation has been cut off by a fault. In the northeast also it is terminated by a fault. In the central part of the area the dip is about 10° to the west while to the north and south it is somewhat greater but very variable.

Occurrence and character of sand. — The workable glass sand in this region occurs in the lower, middle, and upper beds. The basal beds for the most part are concealed beneath the alluvium of Oil Creek. An exposure in the southeast part of sec. 36 shows 60 feet of impure sand. As has been mentioned, the area is of low relief and there are no bluffs or sharp exposures of either the middle or upper beds. For this reason no samples were taken from these beds. But in the south-central part of sec. 36 a ravine cuts at right angles across the lower beds giving a fresh exposure. Along this ravine the following section was made:

Section of lower beds in sec. 36, T. 2 S., R. 3 E.

	Glass sand. Feet.	Total. Feet.
8. Massive, white sand, similar to No. 1	33	33
7. Impure sandstone		15
6. Shale, limestone, and sandstone..		30
5. Massive, white sandstone	41	41
4. Impure sandstone		4
3. Massive, white sandstone	30	30
2. Impure sandstone		4
1. Massive, white sandstone	23	23

The dip could not be determined accurately as the rocks were slightly crumpled. The rocks just below the sand beds show a dip of 21° to the west and the thickness of the beds was calculated on this basis.

A composite sample gathered from different places in Nos. 1, 3, 5, and 8 in the section above gave the following analysis:

Analysis of sample of sand from lower beds in sec. 36, T. 2 S., R. 3 E.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
F1	.014	.136	.15	.077	99.49	.008

Size of grains of samples of sand from lower beds in sec. 36, T. 2 S.
R. 3 E.

Mesh.	40	60	80	100	200	Pan.	Total
No.							
F1 .....	.41	6.96	33.31	34.12	24.83	.39	100.02

Although the outcrop is in a flat level region, it is surrounded by a rough hilly country, and is almost an isolated area. The nearest transportation facilities offered is the Gulf, Colorado, and Santa Fe Railroad, 4 miles west. On account of the rugged character of the country it is altogether unlikely that any railroad will be built to it in the near future.

Sulphur Area.

The Sulphur area lies south and southeast of the town of Sulphur being located almost wholly in T. 1 S., Rs. 3 and 4 E. It is rather sharply subdivided, chiefly by faulting, into three smaller divisions, which may be designated as a, b, and c, which are shown in the accompanying map (Pl. VI).

Division a is located in the southeastern part of the general area and lies in the southwest corner of T. 1 S., R. 4 E., but extends also about one-half mile south into T. 2 S.

On the north the Simpson formation is faulted against the Arbuckle limestone and on the south it is faulted into contact with the Caney shale and Glenn formation. A small fault occurs on the west side, but does not affect the beds of sand. Although the Simpson formation contains a large quantity of good glass sand, yet because it is inaccessible it cannot be worked at present. The beds are not prominent and no bluffs or sharp exposures were seen. They are largely covered with surface soil washed down from other members of the formation.

Division b is located in the east-central part of T. 1 S., R. 3 E. The accompanying map gives the distribution of series of beds and the extent of their outcrops. On the north and west the Simpson passes under the Franks conglomerate. On the south it is cut off abruptly by a complex fault. Eastward it is limited by the Arbuckle limestone.

The surface of this division is broken and hilly and several sharp exposures of the beds are seen along the steep banks of the ravines. Although these beds contain a large amount of pure sand which can be easily worked, yet in all probability they will not soon be reached by railroad and are therefore without value at present.

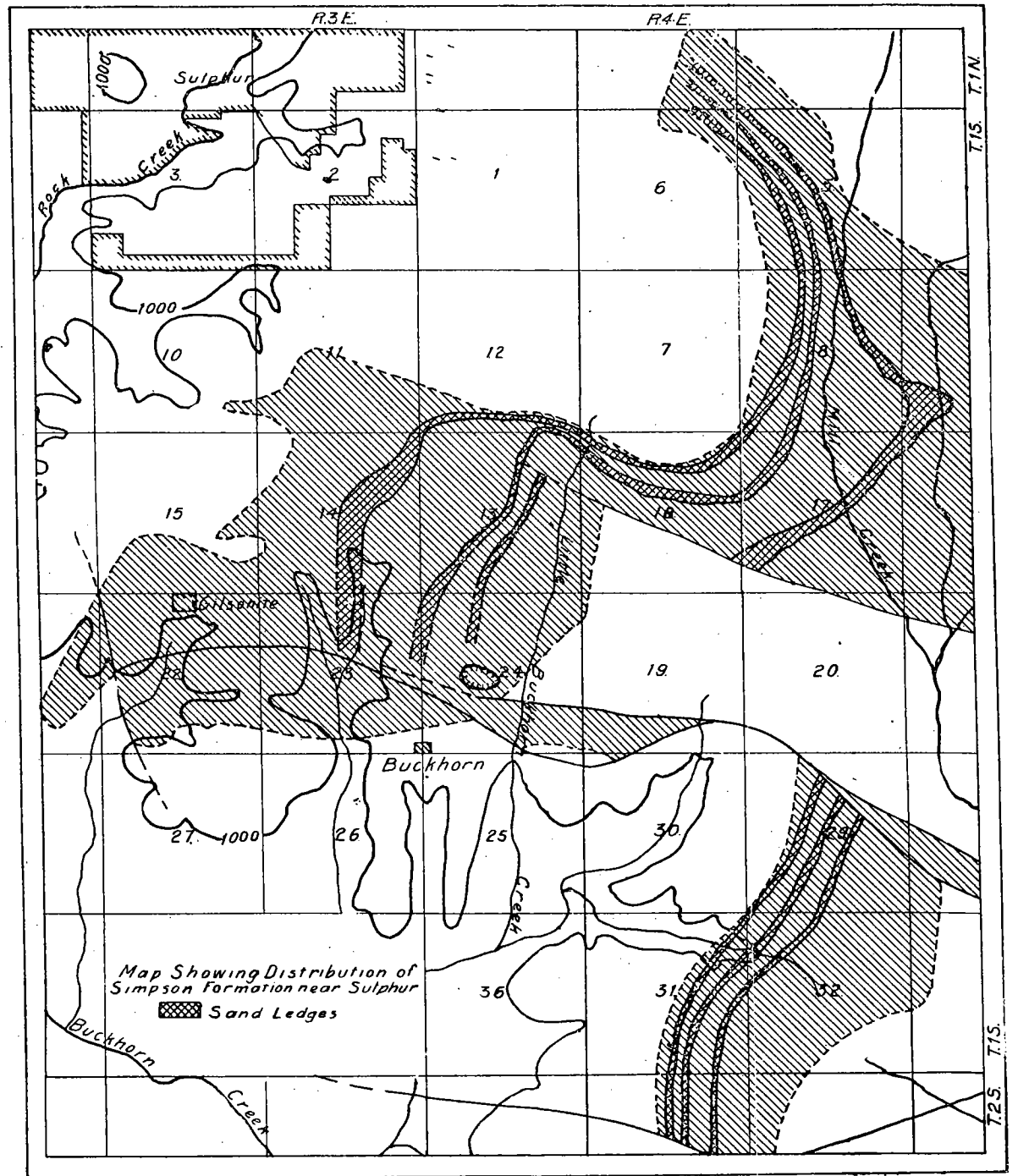


Plate VI.

Division c lies in a crescent shape in the northeast part of T. 1 S., R. 4 E., and is really a continuation of Division b. On the west the area is bounded by the Viola and on the south by the Arbuckle limestone. On the northwest the Simpson passes beneath the Franks conglomerate. The surface of the area is level and the beds do not stand out prominently. They stand on edge and are covered by surface soil. All things considered they cannot be worked at a profit at present.

The basal part of the Simpson extends 7 miles to the east beyond the limits of the accompanying map. The formation lies nearly horizontal and the basal beds of sandstone, after being mixed with the surface soil, contain too large a per cent of impurities to be used for anything but the poorest grades of bottles. Although crossed by the St. Louis and San Francisco Railroad these beds, on account of the valuable deposits elsewhere in the Arbuckle Mountains, are without value at present.

Davis Area.

This area is located on the northeast slope of the Arbuckle Mountains in the valley of the Washita River. The exposures occur in three separate localities; on Coburn Creek, on Falls Creek, and on the Dougherty anticline.

On *Coburn Creek* (called also Colbert Creek) 5 miles southwest of Davis, the Simpson formation outcrops on the northeast slope of the mountains west of Washita River. Coburn Creek and its tributaries have deeply dissected the region so that it is very rugged, rendering it almost inaccessible.

The area is on the northeast limb of the Arbuckle anticline and the rocks dip in general 60° to 90° to the northeast, but are much folded and faulted. The Simpson formation is exposed in the western part of the area, dips northeast beneath the Viola limestone, reappears by an anticline, again dips northeast beneath the Viola to reappear along the southern end of a north-south fault, the rocks on the west and south sides respectively having dropped.

In the Coburn Creek exposures as in the Davis area in general the Simpson is much thinner than in other parts of the mountains. This is because the basal beds of sand and a considerable part of the basal limestone and shale are absent. The formation on the whole is more siliceous than in other places, and the upper and middle beds of sand are thicker than usual. The sand is of good quality and occurs

in large quantities, but it is of no present value, because the region cannot be easily reached by railroad, owing to the rugged surface of the country.

The second subdivision of the Davis area is best seen on *Falls Creek* on the west side of the Washita River, 6 miles due south of Davis. A long, narrow, faulted strip of the Simpson formation outcrops in the southeastern part of this area northwest of Dougherty. The Simpson formation here is faulted against the Arbuckle limestone on the southwest resulting in a long narrow outcrop extending northwest-southeast between the fault and the outcrop of the Viola limestone. The middle and upper beds only are exposed. Although a large quantity of good glass sand is exposed in this area and is only a mile from railroad, it is not probable that it will be soon developed owing to the fact that the Washita River intervenes between the deposit and the railroad.

The third part of the Davis area is in the central part of sec. 21, T. 1 S., R. 2 E., where a narrow band of the Simpson extending northwest-southeast, is exposed along the axis of the *Dougherty anticline*. The northwest end is adjacent to the Gulf, Colorado, and Santa Fe Railroad. The beds dip at a high angle. The sand is of good quality, and occurs in large quantities in the upper and middle beds. Only a part of the lower beds is present. Although the topography is somewhat rough and a few small streams traverse the formation, yet large amounts of the sand may be given transportation facilities, which is the chief factor in determining the value of the glass sand deposits in the Arbuckle Mountains.

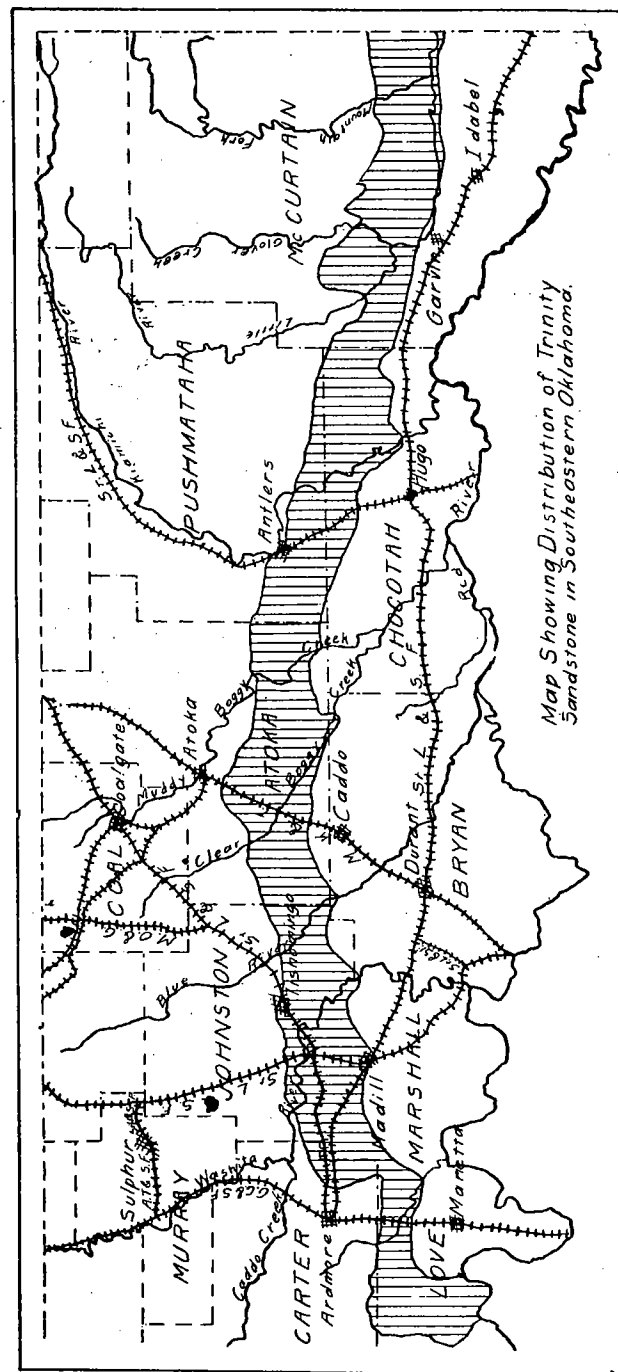
SOUTHEASTERN OKLAHOMA.

Trinity Sand.

General Features.

The second area in which glass sand occurs in quantity in Oklahoma is in the southeastern part of the State. The formation containing it is known as the Trinity sandstone which is the basal formation of the Cretaceous system exposed in this area. The other formations from the Trinity up are the Fredericksburg, Washita, Dakota and Colorado.

The Trinity sandstone enters Oklahoma from Texas just west of Marietta and extends north and east to near Ardmore, thence generally eastward into Arkansas, outcropping as a broad band five to fifteen miles wide along the southern base of the Arbuckle and Ouachita mountains



Map Showing Distribution of Trinity Sandstone in Southeastern Oklahoma.

(Pl. VII). It is bordered on the south by the Fredericksburg formation composed of limestones and shales which form a north-facing escarpment due to the fact that they are more resistant than the underlying sandstones of the Trinity.

Mr. Robert T. Hill separates the Trinity of Texas into three divisions. The lowest is referred to as the basal sand or the Travis Peak formation. It is composed of a series of sandstones and conglomerates several hundred feet in thickness. The middle division is a calcareous formation consisting of limestone interstratified with marly clays. The Poluxy sand forms the upper division and is composed principally of cross-bedded pack sand. The characteristics of these divisions continue into Oklahoma with the exception of the Glenn Rose formation which becomes dominantly a sandstone.

Mr. Pierce Larkin, who has done considerable work on the Trinity in Oklahoma, summarizes it as follows:

"It consists principally of more or less unindurated sand. There also is much clay present which is usually quite arenaceous. None of these sand and clay members are continuous over large areas, but are usually cross-bedded and interstratified with lenticular beds, rarely more than 30 feet in thickness. The sand often grades into clay in very short distances, and it is rare indeed that one would be able to follow a ledge of either sand or clay for more than a mile without finding its character changed or entirely altered."

The heterogeneous composition of the Trinity shows constantly changing conditions of deposition and indicates that the formation was laid down near shore in shallow water, as the deposits laid down in deeper waters are subject to more gradual and less frequent changes. The presence of both salt and gypsum, abundance of lignite, silicified wood, and dinosaur remains are other facts which indicate the shallowness of water at the time the Trinity was laid down.

Localities.

In the study of the sands of this formation no attempt has been made to map in the beds or even to give their exact location. Among the localities that are accessible to transportation facilities the following have been studied: North of Marietta, near Durwood, at Russet, at Madill, north of Caddo, and south of Antlers.

7. Unpublished thesis in library of the State University of Oklahoma.

Overbrook and Marietta.—The Trinity is exposed on the Gulf, Colorado, and Santa Fe Railroad between Overbrook and Marietta, where some thick beds of sandstone occur. On a small tributary of Little Hickory Creek one-fourth mile west of Greenville a sand bluff 25 feet high is exposed. The base is not shown (fig. 2). The top 15 feet of the bed is represented by sample G1, and the bottom 10 feet by sample G2, analyses of which are given below. The sand is of a brownish gray color and the grains are sub-angular and fairly uniform in size although rather small. The bed is covered with about 3 feet of surface soil which can be



Fig. 2.—Ledge of glass sand 4 miles south of Overbrook.

removed easily. This is an excellent location as it is only about 500 yards from the railroad and a spur could be run to the bed with very little grading.

The outcrop of the bed extends for considerable distance up and down the ravine and the beds show little or no cross-bedding. The dip is apparently very gentle to the southeast. The upper 15 feet contains such a large per cent of iron that it is unfit for anything but bottle glass. The grains are angular but too small to produce the best results. The 10 feet at the bottom is sufficiently pure for the manufacture of some of the better grades of glass. The quality of this sand may be improved, as a large per cent of the impurities can be removed by washing.

On the south bank of Little Hickory Creek about one-half mile east of the bluff just described and about 50 yards above the railroad crossing 25 feet of sand are exposed in a bluff. In appearance the sand here is the same as that in the bluff farther west, but as the base of this bluff is covered by sand which has fallen from the top, no fresh sample could be obtained. The sand in this bed is easily accessible and only about 3 feet of the loose surface soil need be removed.

Within the next mile to the south other bluffs of sand having the same appearance as that at Greenville are exposed. Furthermore, to the eastward are still other bluffs but these latter are not near any transportation facilities and were not closely inspected.

Analysis of samples of sand from near Greenville.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
G1	.42	1.88	.22	.04	96.988	.28
G2	.21	.73	.105	.032	98.878	.132

Size of grains of samples of sand from near Greenville.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
G1	1.01	5.71	9.75	3.56	73.05	6.90	99.98
G2	.5	1.65	18.10	24.5	51.52	2.75	100.02

Durwood.—There is a large quantity of sand near the village of Durwood on the St. Louis and San Francisco Railroad, and the Chicago, Rock Island, and Pacific Railroad east of Ardmore. The surface of the land is rolling or even rough, and the soil sandy, the whole being typical of a sand-hill country. There is a 17-foot bed of sand exposed on the south bank of a small creek about 1 mile

northeast of Durwood, analyses of which are given in sample G3 below. About 20 feet of impure sand and surface soil lies above this 17-foot bed. The exposure is easily accessible and the railroad is only one-half mile distant. A spur could therefore be built to this exposure at a very low cost.

Analysis of sample of sand from near Durwood.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
G3	.322	.75	.105	.025	98.593	.123
G3a	.133	.497	.105	.021	99.077	.085

Sample G3a is the same sand as G3 after being washed by immersion in water 1 hour.

Size of grains of sample of sand from near Durwood.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
G3	1.5	6.61	25.31	23.3	40.79	2.5	100.01

A 20-foot bluff of sand is exposed in a small ravine about 2 miles southeast of Durwood. The upper 15 feet is too impure for glass sand. The 5 feet at the base is represented by sample G4, analysis of which is given below. In this are thin layers of coarse-grained sand containing a large per cent of iron and carbonaceous material. The base of the sand is not exposed. This bluff is not readily accessible on account of the rugged character of the country.

Analysis of sample of sand from 2 miles southeast of Durwood.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
G4	.112	.468	.115	.052	99.123	.04

Size of grains of sample of sand from 2 miles southeast of Durwood.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
G4	2.68	57.4	27.58	7.03	5.34	.01	100.04

Russet.—A ledge of sand 15 feet thick, sample G5, is exposed in a ravine one-half mile south of Russet and one-fourth mile southeast of the Chicago, Rock Island, and Pacific Railroad. While the region as a whole is very rugged, a narrow ravine leads from the railroad to the deposit, rendering it accessible. It is underlain by yellow clay and covered by three feet of surface soil.

Analysis of sample of sand from one-half mile south of Russet.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
G5	.126	.174	.07	.057	99.496	.022

Size of grains of samples of sand from one-half mile south of Russet.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
G5	.1	3.45	66.11	18.3	12.32	.25	99.98

The chemical and physical analyses show this to be a good grade of glass sand. The per cent of impurities is small and the grains are subangular and transparent.

Exposures similar to that near Russet are seen just below Randolph near the St. Louis and San Francisco Railroad. Another occurs near Teller, and still others are reported near Tishomingo, Milburn, and Filmore, on the Chicago, Rock Island, and Pacific Railroad.

Madill.—One-half mile northwest of the public square in Madill is a sand bluff 75 yards long and 25 feet high. It is capped by from five to ten feet of surface soil. The 10 feet of sand at the top of the exposure is reddish brown and contains too many impurities for glass. The next 10 feet is represented by sample G6. Crossbedding and irregular deposition are seen in the whole bluff. Portions of the 10 feet are made up of lenticular pockets of almost pure, white sand. Around these pockets are little seams of impure yellowish sandstone. At the base of the bluff occurs a greenish blue sandy clay. The bluff is only a short distance from either branch of the St. Louis and San Francisco Railroad and can be reached easily. From this bluff the sand extends to the south and underlies almost the entire town of Madill. The following analysis shows the character of the sand.

Analysis of sample of sand from near Madill.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
G6	.154	.636	.1	.061	98.89	.08

Size of grains of sample of sand from near Madill.

No.	Mesh.						
	40	60	80	100	200	Pan.	Total.
G6	.95	1.85	27.35	27.45	40.29	2.12	100.01

Caddo to Atoka.—Along the Missouri, Kansas, and

Texas Railroad from a point 4 miles north of Caddo north nearly to Atoka are several good exposures of sand in the railroad cuts. The following section of Trinity between Atoka and Caddo is given by Mr. Larkin.⁸

Section of Trinity from Caddo to Atoka.

No.	Description	Feet.
No. 1.	yellow clay with local lenses of conglomerate containing large waterworn boulders	10
No. 2.	grayish yellow, sandy clay which grades downward through many thin lentils of course, waterworn, and angular gravels	30
No. 3.	fine conglomerate in beds of gray sandy clay	30
No. 4.	yellow and brown pack sand	10
No. 5.	yellow, sandy clay	10
No. 6.	gray, sandy clay with yellow streaks	40
No. 7.	hiatus, bottom land	80
No. 8.	yellow clay streaked with red and containing lenses of gray indurated sandstone	40
No. 9.	grayish yellow clay, sandy at the base	20
No. 10.	reddish yellow sand in matrix of clay	20
No. 11.	hiatus, valley of Davis and Boggy Creek	80
No. 12.	grayish white sand	20
No. 13.	blue, arenaceous clay streaked with yellow	10
No. 14.	reddish, yellow sand cross bedded	12
No. 15.	grayish, blue sand with clay matrix	12
No. 16.	green colored arenaceous clay	22
No. 17.	pack sand reddish brown with iron stone concretions at the base	8
No. 18.	grayish yellow clay red in places and containing occasional lenses of sand	32
No. 19.	blue arenaceous clay with lenses of white sand	10
No. 20.	yellow pack sand	10
No. 21.	yellow clay changing into white sand, much cross-bedded, then into yellow sand in matrix of fine yellow clay in one of which was found the dinosaurian coracoid	40

8. Op. cit.

No. 22.	yellow clay arenaceous in places....	12
No. 23.	arenaceous clay grayish yellow clay iron stone concretions present with it	15
No. 24.	reddish, gray sand with unidentified species of Gryphaea and Ostrea.....	12
No. 25.	grayish yellow sand in matrix of clay very argillaceous in places.....	32
No. 26.	yellow clay streaked with blue sand in places	6
No. 27.	yellow pack sand cross bedded.....	10
	Total	633

The Trinity in this region is characteristically a composite of sand and clay. Usually there are no sharp boundaries between the sand and clay beds, the gradation being gradual from one to the other. In places, however, irregular changes take place, both vertically and horizontally. At other places the sand gives way horizontally to the clay which continues for some distance and then suddenly becomes again predominantly sand.

In the long cut $1\frac{1}{2}$ miles north of Tushka on the Missouri, Kansas, and Texas Railroad, 5 to 20 feet of sand is exposed. Some of this is pure white sand, but it occurs in small lenticular pockets and is not in sufficient quantity to be worked.

One-half mile south of Tushka there is another cut similar to the above. White sand is also found here in small pockets. The deposit on the whole is cross-bedded, lenticular, and contains a large per cent of impurities.

In the big cut $2\frac{1}{2}$ miles north of Caney as much as 30 feet of sand is exposed, and the irregular character seen in the other cuts is in evidence at this place also. From one of the lenticular pockets sample G7 was taken. This pocket is the most prominent exposure seen between Atoka and Caddo and is about 50 feet long and 10 feet thick.

Analysis of sand from railroad cut \approx 1-2 miles north of Caney.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
G7	.098	.152	.04	.056	99.507	.117

Size of grains of sand from railroad cut \approx 1-2 miles north of Caney.

No.	Mesh.	40	60	80	100	200	Pan.	Total.
	G7	2.05	2.47	24.11	25.35	42.75	3.25	99.98

The grains are subangular and transparent.

Goodland to Antlers.—A few pockets of white sand were seen in the Trinity along the St. Louis and San Francisco Railroad between Antlers and Goodland but such evidence as could be obtained indicates that the purer grade of sand does not occur in sufficient quantity. Boring might reveal a considerable quantity of good sand but it would doubtless be in pockets and hence too uncertain in quantity to warrant being quarried at present.

Summary.

From the above discussion of the several localities of the Trinity it will be seen that in several places commercial quantities of good sand occur. The deposits at Greenville, northeast of Durwood, and at Madill are readily accessible. It should be noted, however, that the beds of sand extend east and west along the strike from the exposures described in each case, the details of the several localities being given to show the general character and manner of occurrence of the glass sand in the Trinity as a whole. Other localities might be cited in which the deposits would compare favorably with those described.

Silo Formation.

Glass sand has been reported in the Silo formation which outcrops in Marshall, Bryan, and Choctaw counties, south of the Washita formation, but a study of this formation fails to substantiate this report. The Silo is composed of sand and shales very much like those of the Trinity, but are more regular.

A 20-foot bed of sandstone runs east and west, north of *Durant*. It outcrops on the bank of a creek about one-half mile northeast of the Normal School building. The bed is capped with 3 feet of surface soil. Underneath this surface soil 2 feet of coarse-grained sand occurs. The next 8 feet is represented by sample H1, the analysis of which is given below and shows the sand to be suitable for the poorest grades of bottles. The lowest 12 feet runs high in iron and cannot be used for any grade of glass. South of Durant only an occasional thin bed of sand is seen. These contain too large a per cent of impurities to be classified as glass sand.

Analysis of sample of sand from Durant.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
H1	.868	1.222	.105	.021	97.192	.516

Size of grains of sample of sand from Durant.

Mesh.	40	60	80	100	200	Pan.	Total.
No.							
H1	1.25	1.3	6.85	17.45	71.47	1.65	99.97

TAHLEQUAH AREA.

General features.—The third area in which glass sand occurs in quantity in Oklahoma is in the northeastern part of the State in the northeast corner of T. 17 N., R. 22 E., 5 miles northeast of Tahlequah along Illinois River (Pl. VIII). The surface of this region is very rugged. The Illinois River and its tributaries have cut deep gorges through the hard limestone and cherts which occupy the surface, into the softer rocks beneath. The meanderings of the Illinois River add another obstacle in the way of the development of these deposits.

The region has been studied and mapped in detail by Taff⁹. The following formations are described:

The *Burgen sandstone*, consisting of massive brown sandstone 50 to 100 feet thick lies at the base of the series. It is this formation that carries the glass sand. Above the Burgen sandstone occurs the *Tyner formation*, 60 to 100 feet thick, which is composed of brown sandstone and thin siliceous limestone and chert above; and brown, thin-bedded and flaggy sandstone and greenish shale below. Above the Tyner formation and lying unconformably upon it occurs the *Chattanooga formation* 0 to 45 feet thick which consists of a black shale with a sandstone at the base. The Chattanooga is succeeded by the *Boone formation* 100 to 300 feet thick consisting of chert and cherty limestone. The Boone formation occupies the surface over wide areas in the upland in the vicinity of Tahlequah and on both sides of the Illinois River.

Occurrence and character of sand.—Mr. Taff in the Tahlequah folio, page 2, describes the Burgen sandstone, which carries the glass sand, as follows:

“The Burgen sandstone is a massive, moderately fine-grained light brown rock. The beds are thick and planes of stratification are usually indistinct. The rock consists of nearly pure siliceous sand of rounded grains, with a matrix scarcely sufficient to cement them together.

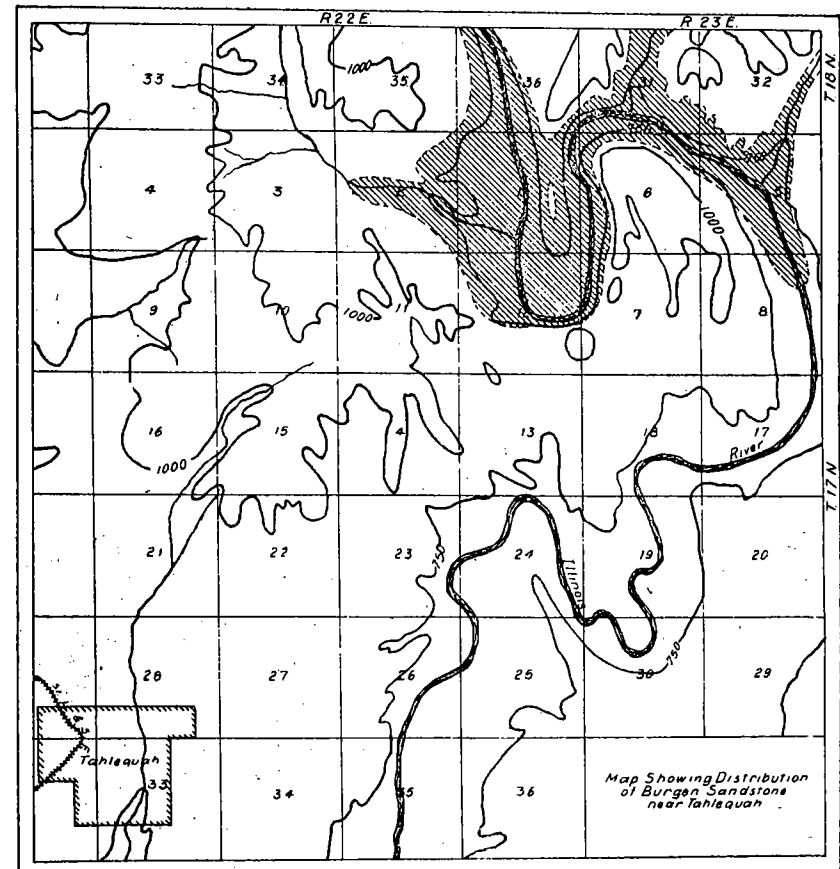


Plate VIII.

9. Taff, Joseph A., Tahlequah folio (No. 123), Geol. Atlas U. S., U. S. Geol. Survey, 1905.

"In natural exposure the rock breaks readily under the stroke of the hammer, crumbling into loose sand. The formation varies in thickness from a thin stratum to beds aggregating more than 100 feet. It is exposed in the Tahlequah quadrangle in but a single area, on the Illinois River northeast of Tahlequah where it rises in bluffs to a height of nearly 100 feet, and the base is not exposed. The full thickness, therefore, is certainly not less than 100 feet."

The Burgen sandstone is correlated with the St. Peters sandstone which is one of the principal glass sand bearing formations in Minnesota, Wisconsin, Iowa, Illinois, and Missouri.

The workable sand of the Burgen sandstone in this area occurs in a 50-foot bluff which is exposed for one-fourth mile along the north bank of the Illinois River in the southwest corner of sec. 31, T. 18 N., R. 23 E. (fig. 3). Sample 11 was taken from different places in the bluff and is a fair representative of the sand.

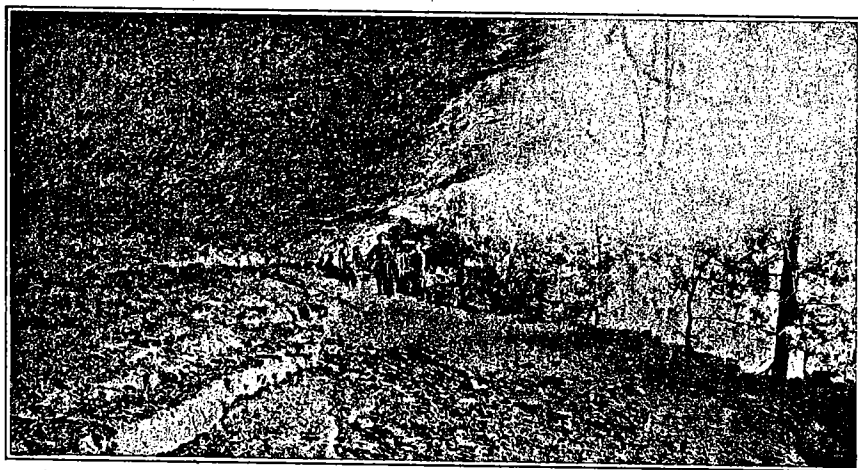


Fig. 3.—Ledge of sand in the Burgen sandstone 7 miles northeast of Tahlequah.

Analysis of sample of sand from the Burgen sandstone 5 miles northeast of Tahlequah.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
11	.14	.32	.18	Trace	99.22	.0028

Size of grains of sample of sand from the Burgen sandstone 5 miles northeast of Tahlequah.

No.	Mesh.	40	60	80	100	200	Pan.	Total
	11	3.85	22.14	40.92	18.75	13.25	1.07	99.98

While this sand shows by its analysis that it is high grade, its remoteness from railroad and the high cost of constructing a spur to the deposit, together with the fact that a heavy capping of limestone occurs above the sand renders it improbable that development will take place in the near future. However, it is reported that construction of a railroad through this region is being contemplated. If the road should be constructed and pass close to the deposits, their value would be greatly enhanced.

AVAILABLE LIMESTONE.

Although frequent reference has been made to limestone beds in the several regions and especially in the Arbuckle Mountain region, a brief statement as to available limestone at this point in the discussion will add clearness.

Associated with the sand beds of the Simpson formation are numerous beds of limestones many of which are relatively pure but some are highly siliceous grading vertically into sandstone or shale. The pure limestone beds are easily accessible and are thick enough to afford cheap and abundant supply of lime. Furthermore, the Viola and Arbuckle limestones are always well exposed in close proximity to the sand deposits. It should be noted, however, that, as shown by the analyses, many of the beds of sand in the Simpson formation already contain approximately the requisite amount of lime. The percentage of lime in these beds seems to be very constant for considerable distances along the strike. This condition will then obviate the necessity of adding lime to the batch.

Overlying the Trinity sand in the southeastern Oklahoma is the Goodland limestone, which affords an adequate supply of lime in that region.

In the vicinity of Tahlequah the Pitkin limestone and various beds in the underlying Fayetteville formation are widely exposed, usually outcropping in bluffs. At the base of the Boone formation also is a thick bed of pure limestone with a maximum thickness of about 30 feet. The upper part of this same formation is composed of about 35 to 50 feet of relatively pure limestone beds.

Throughout northeastern Oklahoma in general where an abundant supply of cheap gas is available, are numerous beds of good limestone, ranging up to 100 feet in thickness, well exposed and easily accessible to transportation facilities.

PRESENT CONDITIONS OF GLASS INDUSTRY IN OKLAHOMA.

Glass plants.—The glass sand industry is in its infancy in Oklahoma. At present there are six plants in operation, namely: The Tulsa Glass Company, at Tulsa; The Neodesha Bottle and Glass Company, at Tulsa; The Graham Glass Company, at Okmulgee; Bakers Brothers' Window Works, at Okmulgee; and two other small plants, one at Bartlesville and the other at Avant.

The Tulsa Glass Company produces lamp chimneys, lantern globes, gas globes, soda fountain tumblers, and one to five gallon water bottles. They employ 150 people with an annual pay roll of \$75,000. Their capacity is 12-3 tons a day.

The Neodesha Bottle and Glass Company produces bottles and globes of all kinds and sizes. They employ 200 men with an annual pay roll of \$240,000. The daily capacity of the plant in finished products is 21 tons.

The plant of the Graham Glass Company at Okmulgee is devoted to the manufacture of beer and soda bottles in light green glass by special bottle machines. They employ 80 men.

The Baker Brothers' plant at Okmulgee manufactures window glass and the small plant at Bartlesville is devoted to the manufacture of bottles and that at Avant to the manufacture of chimneys.

The sand used in these plants is obtained from the Pacific and Crystal City fields near St. Louis, Missouri. A sample of the sand used by the Neodesha Bottle and Glass Company which is obtained from the Cavern Rock Company at St. Louis, gives the following results:

Analysis of sample of sand from Cavern Rock Company.

No.	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SiO ₂	Organic matter.
J1	.112	.938	.145	.027	88.645	.02

Size of grains of sample of sand from Cavern Rock Company.

No.	Mesh..						Total.
	40	60	80	100	200	Pass.	
B4	.95	3.56	20.12	31.1	41.62	2.64	99.99
J1	10.44	48.71	29.16	7.26	4.23	.17	99.97

The grains are irregular in size and only the smaller ones are sub-angular. The larger grains are rounded.

Conclusions.—A study of the analyses of the samples of sand taken from the glass sand deposits in Oklahoma shows that Oklahoma contains inexhaustible quantities of sand which is a better grade than that obtained from the Missouri fields by the Oklahoma plants.

In addition to the better quality of sand, cheaper freight rates can be obtained. M. W. Conway, superintendent of the Tulsa Glass Company, was offered a rate of five cents a hundred from the Roff sand deposits in the Arbuckle Mountains to Tulsa. At the present time the rate on the sand from St. Louis to Tulsa is 12 cents a hundred. Since the glass sand deposits of Oklahoma are accessible and are of as good quality and much nearer to the glass plants in Kansas and Oklahoma than the glass sand deposits in Missouri, there is little reason why Kansas and Oklahoma should not be supplied with Oklahoma sand.