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SANDS FOR GLASS-MAKING, WITH ESPECIAL REFERENCE TO OPTICAL GLASS.

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I.—Introduction.

OF the manifold uses to which sand is put none is more important than that for the making of glass. In spite of this fact, most glass manufacturers, like others interested in industries where suitable sand is essential, have done little or nothing towards investigating the reasons for the suitability or otherwise of the sandy materials they use. Economic geologists are equally culpable in not having investigated the resources and characters of the abundant and varied sands, and also related deposits, of this country.

The term "sand" in its popular sense includes many mixed products which are ruled out in the more restricted geological use of the word. The geologist understands by sand an incoherent rock made up of individual mineral grains with a limited range of chemical and mineral composition, but most importantly, having the majority of its grains, which are usually somewhat rounded, lying between certain size-limits. The mean diameter of the grains of a true sand does not rise above 2 mm., or fall below $\frac{1}{25}$ mm. Thus a "very coarse sand" has a high percentage by weight (ideally in each case, 100 per cent.) of grains of diameter 2 mm. to 1 mm., a "coarse sand" of diameter 1 mm. to $\frac{1}{2}$ mm., a "medium sand"

of diameter $\frac{1}{2}$ mm. to $\frac{1}{4}$ mm., a "fine sand" of diameter $\frac{1}{4}$ mm. to $\frac{1}{10}$ mm., and a "superfine sand" of diameter $\frac{1}{10}$ to $\frac{1}{20}$ mm. Each of these size-limits is known as a "grade," and the separation of a deposit into its constituent grades is known as "grading."

Commercially the term "sand" includes materials of varying grades (as for example, moulding "sands") and differing composition; it is also applied to the products obtained by crushing consolidated sandstones and quartzites.

Most sands consist largely of silica occurring as broken fragments of the mineral quartz. The impurities present may consist of grains of other minerals, chemical substances tending to coat and cement the grains together, or as dust, etc., mixed with the deposit.

Upon the varying chemical, mineral, and grade compositions, as well as upon the shape of the grains, the commercial application of sands depends.

Before discussing the particular characters required of sands used in glass-making, a few only of the many uses of sands in industry may be quoted. The farmer lightens his heavy clay soils by the addition of sand, thereby rendering the land more permeable to air, gases and water, warmer, more amenable to working and more easily drained. It is the addition of coarse grade material which is necessary here. If the sands are calcareous, the effect is heightened by the flocculation of the clay particles.

Since sands are usually made up of hard and tough materials, frequently as angular fragments, they are of considerable value as abrasives. Formerly their employment in this connection was almost limited to the housewife's scouring of kitchen utensils, etc., but whilst fine sands are still similarly used as the basis of scouring soaps, the properties are more extensively utilised in the sand-blast applied to cutting, grinding and etching glass, cleaning metal-castings, arming stone-saws, and so forth.

In the process the sand loses its sharp edges and requires periodic renewal.

Closely related are friction-sands, employed not only on polished roads and in frosty weather to reduce slipping, but used frequently to increase the grip of car-wheels upon metal rails. Sands used in this way, besides being hard, tough, and angular, must also be dry and of even grade to slip freely down the feeding funnel. The use of sands in hour-glasses and egg-timers, though not of great commercial importance, depends upon the same properties. A well known geologist when met by the question as to the geological horizon and properties of the sand used in hour-glasses, avoided a confession of ignorance by remarking that it was not the custom to measure geological time with hour-glasses!

Besides being largely employed for building purposes, where angular, fairly coarse sands are mixed with lime to make mortar, sands are mixed with the stiff clays in brick-making in order to reduce the shrinkage and tendency to cracking when the bricks are burnt.

From the point of view of public health, the employment of sands for water-filtration involves important considerations. The sands so used should be well graded, often fairly coarse, should not contain clayey or organic matter, or any amount of lime.

REFRACTORY SANDS.

But by far the most important industrial uses of sand depend upon its power to withstand high temperatures. It is our commonest and most abundant refractory material, and is, therefore, largely used in metallurgical practice. Its silica percentage must then be high, and that of the alkalies and alkaline earths low. The linings, floors, sides, and roofs of kilns and furnaces require highly quartzose sands and sandstones, and the moulds in which the molten metal is cast must similarly be made of highly

refractory "sands" of peculiar grade composition, which will enable them to bind well and stand up against the metal, but will allow ventilation of the casting.

The importance of the question of investigating sands used for glass-making will be realised hereafter. Other commercial applications need not be detailed, but it is interesting to note that just as "flint-glass" is not now made from flint but from sand, so "sand-paper" is often not made from sand, but from powdered glass!

Many uses of sand, for example, in the making of our hour-glasses, as an absorbent for ink before blotting paper was introduced, for the sanding of stone and brick floors, and others, have almost, if not entirely, disappeared.

Just as, chemically, dirt has been defined as "matter in the wrong place," sand may in certain industries be inimical. Among others the agriculturist and traveller fully recognise that it is possible to have too much sand, yet its value around our shores, apart from the commercial aspect, is both æsthetic and protective, and there are few who would join with the Walrus and the Carpenter in weeping over the quantity and sympathize with them when "If this were only cleared away," they said, "it *would* be grand!"

II.—Sands for Glass-making.

A.—IMPORTANCE OF SANDS IN THE PROCESS.

The choice of a suitable sand for use in the making of glass, particularly such special glasses as those for optical purposes, is an important question. Upon the quality or purity of the sand depend the transparency, brilliancy, lustre, and hardness, of the glass, while its uniform density is determined to no small extent by the mechanical composition of the sand. Due regard must be paid to obtaining and treating suitably the sand in order that the "life" and "water-whiteness" of the best glass may be

obtained. For optical glass and best "crystal" only the purest sands can be used.

In the matter of bulk also, the sand is the most important ingredient, constituting 52 to 65 per cent. by weight of the "batch," or mixture of raw materials. The finished product, glass, contains 60 to 75 per cent. of silica, the increase in proportion being due sometimes to the fact that silica is added as felspar to the batch, but usually owing to the loss of gases, such as water, carbon dioxide, sulphur dioxide, etc., during the melting process.

B.—NATURE OF SANDS.

Sands have been produced by the natural breaking down of the rocks which build up the earth's crust. The geological agencies of heat and cold, frost, and rain, are concerned in this gradual shattering of the rocks by chemical and mechanical means. Running water and gravity are continually at work moving the disintegrated material down to lower levels, and eventually to the sea.

The less stable minerals of the rocks decompose and are broken down into soluble salts and fine-grained insoluble residues, whilst the obstinate ones, such as quartz, are loosened from one another. Material of very mixed chemical, mineral, and grade composition, is thus produced, but the sorting action of wind and water soon comes into play. This sorting is controlled by the size and weight of the mineral fragments, the larger and heavier grains soon being dropped, while the fine clayey material is often carried for long distances. While the grading and the sorting of minerals according to density is never perfect, a strong tendency always exists towards simplification. The sediment, in time, comes to consist almost entirely of one mineral and of equal-sized grains.

From the point of view of the production of sands suitable for glass-making, the last factor is an extremely important one. Considering

purity from the standpoint of silica percentage, pure sands are not common in occurrence, nor abundant when found. Great variation occurs in the mechanical (or grade) composition of sediments, and well-graded sands are by no means so frequently met with as we might expect. It is an interesting fact that all the best glass-sands *i.e.*, the purest and best-graded deposits, occur comparatively late in the geological time-scale.

The minerals composing sands may be divided into two groups, the allogenic minerals, derived from older rocks, and the authigenic minerals, which were formed at the time the rocks were deposited or subsequently. We are mainly concerned with the allogenic minerals. Some of the heavy detrital minerals are fixed chemical compounds, others are molecular mixtures which vary somewhat in their composition. Among the latter are such silicates as the pyroxenes, amphiboles, olivines, epidotes, etc.

C.—METHODS OF INVESTIGATION.

For the complete understanding of the characters and properties, and hence the economic uses and value of unconsolidated sediments, we need to know the chemical, mechanical, and mineral composition, and the corresponding three analyses of each sample.

Chemical analyses are carried out by methods familiar to all, the usual procedure in dealing with rocks being followed.¹ Mineral analyses are made in detail by treating the sediment with heavy liquids of densities ranging from 2.56 to 3.3. The minerals such as quartz and feldspar, which usually constitute 98 per cent. or more of a sand, have a density below 2.8, while the iron oxides, ferro-magnesian minerals such as biotite mica, hornblende, augite, epidote, garnets, staurolite, and other heavy minerals (alu-

¹ See for example W. F. Hillebrand. U.S.G.S. Bull. 176 (1900). H. S. Washington. "Chemical Analyses of Rocks;" 1906. New York.

minous silicates such as muscovite mica, andalusite, kyanite, sillimanite, topaz, etc., and also zircon, rutile, etc.) have a density greater than 2.8. Bromoform, mercury potassium iodide solution, cadmium borotungstate solution, and other liquids of density about 2.8, are therefore employed to separate off the heavy crop of minerals which sink in them, from the lighter and much bulkier crop of quartz, etc., which floats. The crop of density, 2.8, usually does not reach over 1 per cent. by weight, but it may range from 0.01 to 4 or 5 per cent. Other methods are employed, including microscopic examination, for the separation and investigation of the individual mineral grains.²

Examination of a glass-sand under the microscope is easily carried out and yields interesting information. A small quantity of the sand may be mounted temporarily in a drop of clove oil upon a glass slip. Owing to the fact that the mean refractive indices of quartz and clove oil are very close to one another, the quartz grains, if they are clean, are almost invisible in ordinary light. A very thin pellicle of clayey or ferruginous matter upon them renders them easily visible, and the extent of iron-staining is thus quickly observed. Felspar, when fresh and unaltered, is similarly only faintly outlined, but when "kaolinised," *i.e.*, decomposed into micaceous and clayey matter, appears dusky. Such an excellent glass-sand as that from Fontainebleau almost disappears on immersion in clove oil. Heavy detrital grains, when they do occur, usually stand out in bold relief, owing to their higher refractive indices.

The mechanical analysis is carried out with a view to finding the sizes of the constituent grains, and the percentage by weight of each grade. The grades in common use are:—

² For details of these methods, etc., see T. Crook in Appendix to Hatch & Rastall "Petrology of Sedimentary Rocks." London, 1913.

Greater than 2 mm. diameter ...				Gravel Grade.		Sand Grade.
" 1 mm. and less than 2 mm. diam.				...	Very coarse sand	
" $\frac{1}{2}$ " " " 1 " "				...	Coarse sand	
" $\frac{1}{4}$ " " " $\frac{1}{2}$ " "				...	Medium sand	
" $\frac{1}{10}$ " " " $\frac{1}{4}$ " "				...	Fine sand	
" $\frac{1}{20}$ " " " $\frac{1}{10}$ " "				...	Superfine sand or Coarse silt	
" " " " $\frac{1}{20}$ " "				...	Silt	Silt Grade.
" " " " Less than $\frac{1}{100}$ " "				...	Clay Grade.	

The oldest and roughest method of making mechanical separations is the well-known one of sifting. The method is, however, inaccurate for scientific work, and if carried out at all, separations should be made with brass or copper sieves having punched round holes of diameter 2 mm., 1 mm. and $\frac{1}{2}$ mm. Below $\frac{1}{2}$ mm. punched holes are not practicable, and squared-holed wire-mesh screens must be used. In all cases it is the mean diameter of the sand-grains which determines what passes the sieves, but in the square mesh sieves the grading is less accurate owing to the greater length of the diagonal of the aperture. Sifting is thus not to be recommended below $\frac{1}{2}$ mm.; separation of smaller grades may be made to a fair degree of accuracy by the use of elutriation. For detailed descriptions of the processes of elutriation in air or water, and the various forms of apparatus devised, reference must be made to the works cited.¹ Briefly put, elutriation depends upon the power of upward currents of air or water of varying velocities to buoy up grains of minerals of different surface areas. It has been found as a result of both calculation and experiment that the final velocity acquired by a small fragment of solid, approximately spherical, when falling freely in a fluid, such as water, depends primarily upon its surface area (and, therefore, upon its mean diameter) and to a less extent upon its density. Subsidence methods have thus been used (and are used in industry

¹ Schoene, E. "Ueber Schlaemmanalyse." Berlin, 1876.

Keilhack, K. "Lehrbuch der praktische Geologie." Leipzig, 4th ed., 1908.

Crook, T. Proc. Roy. Dublin Soc. (Econ.) Vol. I.; pt. 5 (1904), p. 267, and *op. cit.*, p. 349.

Stadler, H. "Grading Analyses by Elutriation." Trans. Inst. Mining and Metall. XX. 1912-13, p. 686.

to-day, *e.g.*, in the preparation of china-clay) to separate sediments into various grades. Such methods are not scientifically accurate, hence the adoption of elutriation, where upward currents of fluid are utilised, equal to or just in excess of the respective falling velocities of the particles of definite grade sizes which it is desired to separate. Water is generally used, and an elutriator consists essentially of one or more cylindrical vessels of known area of cross-section. The velocity of the upward current of water passing through is controlled by the head of water outside (often adjustable) the diameter of the vessels, and the size of the outlet jet. Usually a manometer-tube is attached to the elutriating cylinder to register the pressure and thus indicate the velocity.

A weighed quantity of sediment is placed in the cylindrical vessel, and by the variation in the velocity of the water-current, grading is effected, the respectively smaller grades being carried over, collected, dried and weighed. The various grades are calculated to percentage weights and the results may be expressed graphically.

The apparatus is easily constructed, being made of glass, and should find a place in the laboratory of every glassworks.

III.—Desiderata of Glass-Sands.

A.—CHEMICAL COMPOSITION.

The chemical analysis of a glass-sand should indicate the percentage of silica (SiO_2), alumina (Al_2O_3), iron oxide (expressed as Fe_2O_3), and loss on ignition (H_2O , etc.). It is desirable in sands generally to have a full analysis, but those proposed for use in glass-making should bear little more than a trace of alkalies, lime, magnesia, etc. The silica percentage should be very high, preferably over 98 per cent., which means that the sand must be a pure quartzose deposit. For common bottle-glass the percentage may drop to 95, and for the best quality glass

such as that known as "crystal," used for table-ware and optical glass, the sand should possess 99.5 per cent. or more of silica. Alumina is sometimes desirable in a sand, particularly when it is to be used for the manufacture of refractory ware such as thermometer-glass. Hovestadt mentions¹ that thermometer-glass made in the Thuringian Forest district owes its special quality to certain sand found only in the neighbourhood of the village of Martinsroda. The glass stands repeated melting, blowing and fusing, without change, while ordinary glass, such as that of windows, becomes rough and dull of surface even after short exposure to the flame. The cause of excellence is believed to be due to the 3.66 per cent. of alumina present. In sands free from iron the alumina usually occurs as the mineral felspar. Its presence as clay (hydrated aluminium silicate), either free or as a dust coating quartz-grains, is highly undesirable.

Unfortunately, alumina in a sand usually carries with it other impurities, especially iron and lime, so that it is advisable to use a pure quartzose sand for glass-making and to add the alumina required as such to the batch which is melted up to make glass.

Iron compounds are undesirable in a glass-sand, whether they occur as hematite and limonite coating the quartz, or as detrital mineral grains of magnetite, titanoferrite, or the ferromagnesian minerals enumerated above. The effect is to give the glass a pale-green or yellow colour. By the addition of decolorisers such as manganese dioxide, arsenious oxide, etc., a certain amount of correction may be obtained, and glass practically white or with an exceedingly faint pink tinge be yielded. For the best glass, including optical glass, the iron percentage (estimated as Fe_2O_3) should not exceed 0.05 per cent., but for window and plate-

¹ "Jena Glass," translated by J. D. & A. Everett. MM. & Co., London, p. 21.

glass, chemical apparatus, globes, etc., 0.1 to 0.2 or even 0.3 per cent. may be permitted. Correction for iron by means of decolorisers is inadvisable in the case of optical glass on account of the absorption of light owing to the neutral tint produced.

Sands containing over 99 per cent. of silica and less than 1 per cent. of iron and alumina rarely carry more than a trace of lime, magnesia, titanium, potash, soda, etc. Sands containing any quantities of these compounds are not suitable for glass-making.

B.—MINERAL COMPOSITION.

Just in the same way as valuable mineral products, such as gold, tin, and gems, are concentrated by natural agencies in stream-sands as a result of their high density, and are further concentrated by panning at the hands of the prospector, so the heavy detrital minerals of a sand may vary in proportion to the lighter quartz and felspar, according to the conditions of deposition. Proximity to the source of the heavy minerals, and oscillatory current-action after or during deposition, tend to increase the amount. Taking an average for British sands and sandstones of all geological ages, the percentage weight of mineral grains of density greater than 2.8 is probably about 0.5. In certain very pure sands, sandstones and quartzites, it falls as low as 0.01 per cent.; occasionally it rises in other deposits to 4 or 5 per cent. If a sand is used for glass-making, the percentage of heavy minerals should be low, since iron oxides and ferromagnesian silicates constitute a large proportion of the dense minerals present.

It is now possible to recognise many sands both as regards geological age and locality, from their heavy mineral assemblages. A considerable number of minerals, with much variety of form, size, colour, inclusions and degree of alteration, in their grains, may be met with in

these assemblages, and detailed examination will in most cases serve to indicate whether successive consignments of a sand come from the same bed or pit. Glass-manufacturers, in using the methods of mineral analysis, have in their hands a valuable check on such foreign deposits as Belgian and Dutch sands.

C.—MECHANICAL COMPOSITION.

A perfectly-graded ideal sand would have all its grains of closely the same size, that is, 100 per cent. by weight would lie between two close limits of size (as defined on p. 227).

No natural sands are perfectly graded, but those which most nearly approach the ideal are shore-sands and dune-sands which have been continually winnowed by wind and washed by water. Smaller grains have all been carried far away, and larger ones left behind when the deposits themselves have travelled along the shore. Dune-sands and sea-sands around our coasts to-day, and those formed under similar conditions in past geological ages, may have as large a proportion as 97 per cent. of their grains of one grade size, usually "medium sand" of diameter between $\frac{1}{4}$ and $\frac{1}{2}$ mm.

By subjecting the sands which have proved most successful in glass-making (as well as those which have not) to mechanical analysis, it has been found that the grade is an exceedingly important factor. A few glass-manufacturers who have studied the technique of their work have realised this and placed the question of size of grain on an equality with that of chemical composition. Nevertheless, no systematic work seems to have been done, but it is to be hoped by now that elutriators have been set up in the laboratories of a few glass-works.

In order that the batch containing the sand, alkalies, and other compounds may melt freely, evenly, and as rapidly as possible, at least 70 per cent. of the sand should be of one grade, preferably medium sand of diameter $\frac{1}{4}$ to $\frac{1}{2}$ mm.

The practice in the United States glass industry appears to consist in the use of graded deposits of rather coarser grain than in this country. The presence of coarser fragments than the average in a glass-sand results in these being left unmelted as "stones" while the rest of the batch has become molten "metal." If heating is continued until the "stones" are also dissolved, some glasses are spoilt by the chemical changes which take place, and the fresh gases which are evolved.

Finer material belonging to the clay grade (diameter less than .01 mm.) or silt grade (diameter between .01 and .05 or possibly .1 mm.), whether occurring as thin pellicles on the larger quartz grains, or acting as a bind, is inimical from the glass-making point of view. Clayey material, especially if it is such a pure clay as kaolin or china-clay, is refractory, and clouds the glass. Fine particles also carry with them air-bubbles, from which it is very difficult to clear the metal. If the batch is melted in pot-furnaces, the finer quartzose material (superfine sand, silt, etc.) tends to melt first and sink to the bottom. Subsequent melting of the rest of the batch results in the production of a pot of metal of varying chemical composition and density according to depth, as usually no arrangements are made for stirring the mixture. The variation in density of the metal results in the production of objectionable "wavy" and "cordy" glass upon blowing.

Tank Furnaces.

When tank-furnaces are used, the strong blast of air and gas which plays through the "ports" in the side walls over the bath of metal, carries off the fine material of the sand, and a real loss in bulk occurs, as well as a change in chemical composition of the remainder. The other powdery material of the batch such as soda-ash (Na_2CO_3) melts too rapidly to be lost, but the fine silica dust is more refractory and "blowing-

out" results before it can be melted. The statement that in America glass-making, sand of diameter less than $\frac{1}{80}$ inch burns out in the batch¹ is not borne out by British and Continental practice, where sands of diameter down to $\frac{1}{4}$ or even $\frac{1}{10}$ mm. ($\frac{1}{100}$ to $\frac{1}{250}$ inch) are continually in use. Fine sand of diameter $\frac{1}{4}$ to $\frac{1}{10}$ mm. diameter does not appear to be objectionable—rather the reverse, but it is not easy to find pure and well graded deposits of this character. The important point is that for most glasses, the melting of the batch should be rapid and even.

D.—SHAPE OF GRAIN.

Some disagreement exists as to how far the shape of the grains constituting a sand is of importance in glass-making. Most manufacturers, if they have a preference, lean towards the use of an angular or sub-angular sand. However, sands composed of rounded grains are successfully used for glass-making in the United States.

The most obvious reason for the preference for angular grains seems to be that the grains fuse more rapidly in the batch, the melting proceeding at the corners and edges of the grain. The tendency of the batch to pass freely, quickly and evenly into metal is thus increased.

These remarks do not apply altogether to the making of optical glass, where no danger of blowing out exists, a long period of melting is required, and stirring is always adopted.

E.—OTHER CONSIDERATIONS.

It is necessary that a glass-sand should be dry, for moisture present tends to form bubbles or otherwise spoil the glass or cause variation in its properties (*e.g.* in optical glass). For all special work, the sand, or batch including it, is dried in large ovens.

¹ United States Geological Survey Bull. 285 (1906), p. 454.

Freedom from organic matter should also be ensured, for it usually has a reducing action which is not always desired in glass-making (though coke is sometimes added for that purpose in making common glass, as, for example, where salt-cake is used). Organic matter is burnt out with the water during the roasting in the ovens.

Water and organic matter appear in the chemical analyses under "loss by ignition."

The ideal sand for making the best glass is thus one with practically 100 per cent. silica free from all but the slightest trace of iron, and composed of angular grains of quartz (but not other forms of silica as well) all of the same size. The sand should also be dry and cleared from dust or any clayey coating on the grains. Although not so essential, it is desirable not to have organic matter present.

IV.—British and Foreign Glass-sands.

In the previous section the importance of the information yielded by analyses of glass-sands has been emphasised, and the criteria of a good sand stated. Before passing on to discuss British sands which might satisfy the requirements of the maker of optical glass, it will be instructive to examine in detail the properties of the sand from Fontainebleau which has been so largely used for the purpose in this country. The well-known sand from Lippe, used so extensively in the German industry, will also be described. We may then hope to realise the desiderata of a first-class glass-sand, and know what to look for in any other deposits exploited for glass purposes.

1. FONTAINEBLEAU SAND.

The sand, of Upper Oligocene age (Sables de Fontainebleau, Stampian Stage of the Oligocene), is associated with lignites.¹ To the un-

¹ Revision de la Feuille de Fontainebleau. Bull. Carte Géol. France. No. 122. Vol. 19. (1908-9), p. 7.

aided eye, the sand is a beautiful white, fine, even deposit. All glass-sands should be examined in the field with a hand lens. With such a lens the sand appears to be composed of water-clear quartz, and only here and there a few dark grains are to be seen. Unless the sand has been washed after its arrival at the works (and for all special glasses it is usually washed carefully), a little dirt and occasional specks of black coaly matter may be seen. Such impurities are, of course, adventitious and obtained from trucks and barges in course of transit. The grains have no coating of white clayey matter as many sands have, their white colour being due to the reflection of light from irregular surfaces. They are almost invisible under the microscope when immersed in media such as clove oil, Canada balsam, etc., the refractive indices of which lie very near to that of quartz. The grains are free from the pale yellowish or brownish coating of iron oxide so frequently seen in sands.

CHEMICAL COMPOSITION.

Chemical analyses show that the sand contains 99.65 to 99.97 per cent. of silica, and, therefore, must be composed almost entirely of pure quartz. Only a small quantity of iron oxide is present, hence glass made from the sand is practically water-clear (provided no colouring compounds are added). The alumina percentage is very low, being probably accounted for in the rare grain or two of felspar seen, and in the few heavy minerals present. Lime and magnesia are practically absent.

CHEMICAL ANALYSIS OF FONTAINEBLEAU SAND.

SiO_2	...	...	99.65 per cent.
Al_2O_3	...	...	.21 "
Fe_2O_3	...	...	.04 "
Loss on Ignition	...	...	.16 "
<hr/>			
100.06 per cent.			

H. F. HARWOOD, An.

MINERAL COMPOSITION.

Fontainebleau sand, like many other pure quartzose sands, contains less than 0.1 per cent. of heavy minerals, which is much below the average for all sands. In this heavy crop, of density > 2.8 , the minerals present are clean and fairly coarse in grain. They include magnetite, zircon, rutile, ilmenite, rounded tourmaline in blue and brown grains, staurolite, andalusite, muscovite, kyanite, limonite, etc.

From the chemical compositions of these detrital minerals, it is seen that silica is present in some amount, and that small quantities of iron, aluminium, titanium, magnesium, zirconium and boron occur. The proportion of heavy minerals in the sand is so small that even with the large bulk of sand used for the batch, the aggregate amount of impurities is slight.

MECHANICAL COMPOSITION.

The evenness in grain of a sand (to the eye) has been commented upon, and mechanical analyses determined by elutriation give the following results:—

	$> \frac{1}{4} \text{ \& } < 1 \text{ mm.}$	$> \frac{1}{8} \text{ \& } < \frac{1}{2}$	$> \frac{1}{16} \text{ \& } < \frac{1}{4}$
1.	$< 0.1\%$	70.6%	26.6%
2.	—	70.3	28.3

	$> \frac{1}{16} \text{ \& } < \frac{1}{8}$	$< \frac{1}{16} \text{ mm.}$	Total sand-grade $> \frac{1}{16} \text{ \& } < 1 \text{ mm.}$
1.	2.8%	—	97.2%
2.	0.6	0.8	98.6

1. Obtained by the kindness of Mr. Frank Wood, Managing Director of Messrs. Wood Bros., glass manufacturers, Barnsley.

2. Obtained by the kindness of Mr. G. Jenkinson, Managing Director of the Edinburgh and Leith Glass Co., Ltd., of Edinburgh.

Lastly as regards shape of grains, Fontainebleau sand is made up of grains consistently sub-angular. To what extent the rapid and even melting of the batch depends upon the shape of the sand-grains, is a disputed question, but it is clear that such a sand as that of Fontainebleau, the grains of which are all of similar shape, is preferable to one containing a mixture of angular, sub-angular, and rounded grains.

ECONOMICS.

In addition to the recommendation afforded by chemical purity, evenness of grade, and suitability of size and shape, Fontainebleau sand can be transported cheaply and conveniently to most British glass-making districts. This is partly due to the insular position of Britain, and partly to the fact that the sand can be directly shipped from Rouen, and, without further handling, may be discharged high up the estuaries which notch our industrial areas. In pre-war times it was delivered in Britain at a fairly cheap rate (12s. to 23s. per ton). Owing to the shortage of labour and lack of barges, the price has since risen to as much as 50s. to 60s. per ton.

2. LIPPE SAND.

Two different samples of this famous glass-sand from Dörentrup, Saxony, were subjected to analyses and examination through the kindness of Dr. Walter Rosenhain, Director of the Metallurgical Department, National Physical Laboratory, Teddington.

The sand occurs in deposits of Miocene age, and is associated with rafts of brown coal.¹

In this connection it may also be noted that the valuable glass-sand of Hohenbocka, in

¹ Dritt. Jahresber. des Niedersachs. Geolog. Vereins. 1910, p. 185, also see p. 171, and Zeitschr. der Deutsch Geol. Gesell. Band XL, 1888, p. 310.

Prussia, occurring in Miocene beds, is also associated with carbonaceous layers.¹

Both samples of Lippe sand are beautifully white, of better colour even than that from Fontainebleau. The better sample is finer in grade and remarkably even, while the second is rather coarser. The chemical analyses are as follows :—

	I.	II.
	Per cent.	Per cent.
Silica	99.88	99.73
Al ₂ O ₃	.18	.20
Fe ₂ O ₃	n.d.	n.d.*
Loss on Ignition	.21	.23
	<hr/> 100.27	<hr/> 100.16

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* Separate determinations of Fe₂O₃ gave I. .02 per cent. and II. .03 per cent.

It is said that, such is the remarkable constancy of chemical purity, the sand is guaranteed when sold to contain 99.98 per cent. of silica. The mechanical analysis of the finer and better sample is

> $\frac{1}{2}$ and < 1 mm.	> $\frac{1}{4}$ and < $\frac{1}{2}$	> $\frac{1}{16}$ and < $\frac{1}{4}$
One or two grains.	78.6%	19.9%
> $\frac{1}{16}$ and < $\frac{1}{8}$	< $\frac{1}{16}$ mm.	Total sand-grade > $\frac{1}{16}$ and < 1 mm.
0.4%	1.1%	98.5%

Examination and measurement under the microscope show that the average diameter of the

¹ K. Keilhack, Jahrb, König. Preuss. Geol. Land. 1908. Bd. 29, pt. II., p. 214.

grains is .3 mm. (or perhaps slightly less). They are composed, with the exception of the few detrital minerals, of colourless, clean quartz, sub-angular to angular in shape. The mechanical analysis of the second sample is

$> \frac{1}{2}$ mm.	$> \frac{1}{4}$ and $< \frac{1}{2}$	$> \frac{1}{16}$ and $< \frac{1}{4}$
10.2%	85.8%	1.4%
$> \frac{1}{160}$ and $< \frac{1}{16}$	$< \frac{1}{160}$	Total sand-grade $> \frac{1}{16}$ and < 1 mm.
1.0%	1.6%	97.4%

The grains, which are sub-angular, are similar to those of I. under the microscope, but are, for the most part, nearly $\frac{1}{2}$ mm. in diameter.

The heavy residue of minerals is small in each case (less than 0.01 per cent. by weight), but, as is often the case, was greater in the finer sand than in the coarser.

Sample I. yielded a pretty residue consisting of abundant zircon and red-brown rutile, rather rounded and averaging .12 mm. diameter, together with very large kyanite fragments up to .7 mm. long, and coarse staurolite and tourmaline grains. The staurolite is deep golden-brown in colour, of diameter .2 to .3 mm. The tourmaline occurs in grains up to .3 mm. diameter, of brown, greyish, greenish-blue, and deep blue colour. Magnetite, ilmenite, and leucoxene (.2 to .3 mm. diameter) and limonite occur. Small and non-pleochroic dusky grains of andalusite occur less commonly, and chlorite also was seen.

The second sample yielded a rather coarser residue consisting of abundant pleochroic andalusite (.3 mm. diam.), large yellow, grey-brown, and greenish tourmaline (.3 mm. diam.), deep green hornblende (.2 mm. long), and ilmenite. Staurolite and zircon occurred in small grains,

.05 mm. long. Chalcedony was also seen in the sand.

3. BRITISH SANDS.

There does not appear to be anywhere in the British Isles a sand so suitable, from all points of view, as either the Fontainebleau or Lippe sands described above. This does not mean that sands as pure and well-graded as those cannot be found. The question is one also of persistence and constancy to type, that is to say, the bed of sand must be fairly thick, of constant nature and composition, cleanly divided off from other materials, and of considerable extent. In addition, carriage must be cheap and easy, and the deposits situated near the markets.

Undoubtedly there exist in this country large supplies of sand suitable for good flint-glass work, laboratory glass, some table-ware, plate-glass, etc. These deposits certainly yield quite as good supplies as those imported from Holland and Belgium. A full discussion by the writer of our resources will be found in the forthcoming Memoir of the Geological Survey on Glass-sands.

The fetish of "nothing but Fontainebleau" seems now to have disappeared. The notion that only this sand would serve for a great deal of glass-work has been exploded, but in making the best glass, for the reasons given, it still remains unrivalled.

Very few of the numerous British deposits are of sufficiently high quality to be recommended for the making of optical glass.

The following are suggested as being the best, analyses being given in each case.

AYLESBURY SAND.

Worked by Mr. Joseph Arnold (Offices, 32, St. Paul's Road, Camden Town, N.W.).

The quarries occur at Stone, three miles west of Aylesbury. The sand, which is of Lower Greensand age, is also exposed in the "Wind-mill Pit" but is not worked to any extent.

White seams of very pure sand extend to a depth of about 18 feet, but working is then stopped by water. Peaty and ferruginous bands occur, and since the seams of white sand are not very thick (4 to 6 feet) or persistent, working is rather difficult. It is not easy to ensure that successive consignments conform to the highest standard of purity met with. The whiteness and purity are probably connected with the peaty bands. The colour is good, the best Aylesbury sand being better than Belgian, selected samples being practically equal to Fontainebleau sand. Washing does not improve the colour of the best sand to any extent, but a second quality sand washed free from limonitic and clayey pellets in rotary washing plant is also supplied. The latter sand is pale grey but reddens on burning, whereas the former shows little or no change. The chemical composition of a selected sample is as follows:—

SiO ₂	...	...	99.80 per cent.
Al ₂ O ₃	...	...	.32 ,,
Fe ₂ O ₃	...	...	.03 ,,
Loss on Ignition	...	...	.22 ,,

100.37 per cent.

H. F. HARWOOD, An.

The evenness of grade is a marked feature, the sand in this respect very closely resembling Fontainebleau. The mechanical composition is as follows:

> $\frac{1}{2}$ and < 1 mm.	> $\frac{1}{2}$ and < $\frac{1}{2}$	> $\frac{1}{10}$ and < $\frac{1}{4}$
A few grains only	78.3%	15.0%
> $\frac{1}{100}$ and < $\frac{1}{10}$	< $\frac{1}{100}$ mm.	Total sand grade > $\frac{1}{10}$ and < 1 mm.
5.8%	0.9%	93.3%

The detrital mineral suite is the very marked and characteristic one of the Lower Greensand throughout England. Heavy minerals are fairly abundant (.2 to .3 mm. diam.) and the residue consists almost entirely of coarse angular kyanite, staurolite, and brown and blue tourmaline, together with iron-ores (magnetite, limonite, and altered ilmenite), zircon, rutile, etc.

The sands, after being carted to Hartwell Siding near Aylesbury Station, were put on trucks in pre-war times at 7s. 6d. per ton. At the time of writing the price is 10s. This is rather high, and freight charges increase it to about 15s. or 17s. 6d. by the time it reaches a glass-making district as far distant as the London area or Yorkshire.

SAND FROM GODSTONE, SURREY.

The pit revealing the whitest sand, again of Lower Greensand age (Folkestone Beds), is found half a mile north-west of Godstone Church. The whitest and best glass-sand occurs in irregular patches in more ironstained beds. No great supply of standard material can, therefore, be guaranteed, an unfortunate fact in view of its proximity to London and the Thames. It is also some distance from a railway station. Sand has been sold for glass-making, but never in quantities of more than 90 tons a week, an amount hopelessly too small. It is put on rail at Caterham Station at 6s. 6d. a ton. The bulk of the deposit is worked for building purposes.

The sand suitable for glass-making possesses a white to faint yellow colour, at its best almost equal to Fontainebleau sand. It changes to faint pink on burning. Washing would probably improve slightly some of the second-best sand, which would then serve for white-bottle work. The chemical analysis yields:—

SiO ₂	...	...	99.56 per cent.
Al ₂ O ₃	...	...	.26 "
Fe ₂ O ₃	...	...	.06 "
Loss on Ignition	...	...	.24 "

100.12 per cent.

H. F. HARWOOD, An.

From the point of view of glass-making, the grade analysis is good, being as follows:—

$> \frac{1}{2} \text{ \& } < 1 \text{ mm.}$	$> \frac{1}{4} \text{ \& } < \frac{1}{2}$	$> \frac{1}{10} \text{ \& } < \frac{1}{4}$
0.45%	74.9%	22.6%
$> \frac{1}{100} \text{ \& } < \frac{1}{10}$	$< \frac{1}{100} \text{ mm.}$	Total sand-grade $> \frac{1}{10} \text{ \& } < 1 \text{ mm.}$
1.05%	1.00%	97.95%

In mineral composition, the sand resembles other deposits of the same age, such as those from Aylesbury, etc., described. The list of minerals and descriptions there given holds for the Godstone deposits.

MUCKISH MOUNTAIN SAND, CO. DONEGAL.

The deposit is worked by Sir Pieter Stewart Bam, Ards House, Dunfanaghy. The sand lies on the top and upper slopes of a hill (Muckish Mountain) of quartzite about four miles from the sea and 33 miles N.N.E. of Donegal. The quartzite is of pre-Cambrian age. The sand can be worked very cheaply and brought down to rail or boat by gravity, so that it is hoped that it may be placed on the British market at as low a figure as French and Belgian sands. The purity is high, and the colour a good white. The chemical analysis is as follows:—

SiO ₂	...	...	99.37 per cent.
Al ₂ O ₃	...	...	.36 ,,
Fe ₂ O ₃	...	...	.05 ,,
Loss on Ignition	...	...	.12 ,,
			<hr/> 99.90 per cent. <hr/>

H. F. HARWOOD, An.

No change occurs on heating except in the occasional brown patches which are met with. The latter, although pale-coloured, are objectionable.

The mechanical analysis is as follows:—

> 1 mm.	> $\frac{1}{2}$ & < 1 mm.	> $\frac{1}{4}$ & < $\frac{1}{2}$	> $\frac{1}{16}$ & < $\frac{1}{4}$
1.43%	9.47%	71.3%	17.0%
> $\frac{1}{16}$ & < $\frac{1}{8}$	< $\frac{1}{16}$	Total sand-grade > $\frac{1}{16}$ & < 1 mm.	
0.3%	0.5%	99.2%	

and indicates that it errs on the coarse side, but as most of the larger grains are very loosely cemented compound ones, the fact does not militate altogether against the value of the deposit. The sand has been cleared of finer material by agencies of denudation, although it still rests *in situ* on the quartzite. It contains a very small proportion of heavy detrital minerals, little else but zircon being present. The sand was used by the Irish Department of Agriculture in the reproduction of Waterford Glass for the Cork Exhibition, 1902, and good glass has also been made from it in the London area.

OTHER BRITISH DEPOSITS.

Tables of chemical and mechanical analyses are added, and also notes upon some other British sands which do not reach the standard of the above. These are mentioned in case it should become possible to treat them profitably.

The white sands of the Isle of Wight, which were formerly worked for glass-making, occur chiefly in the Headdon Hill sands and Lower Bagshot beds of Alum Bay and the adjoining area. They suffer from the objections that they contain yellowish ferruginous patches here and there, are not well-graded, and are somewhat inaccessible and awkward to work.

The Lower Greensand of Leighton Buzzard is on the whole rather coarser than that of Aylesbury, but it is possible to select and work beds of finer material. The colour is not so good as that of the latter sand, but the analysis shows greater purity than the colour leads one to expect.

A decomposed sandstone or quartzite from Bethesda, North Wales, has been put upon the market. In parts it yields a very pure sand, but the joint planes which frequently occur are iron-stained, and the deposit is not well-graded. Before being used it would require both washing and screening (see later).

A very pure Coal Measure Sandstone from Guiseley, near Leeds, has been crushed for use as a glass-sand. Whilst being of excellent whiteness and purity, it suffers from the disadvantages of all crushed rocks, and contains material of varying grades, including some amount of dust.

For details of other British supplies of sands suitable for glass of lower quality, the reader is referred to the coming Memoir of the Geological Survey upon Glass-sands.

SPECIAL GEOLOGICAL CONDITIONS.

With a view to realising the geological conditions under which glass-sands occur, and knowing where to look for suitable supplies, it is instructive to draw attention to several salient facts.

The best-graded sands in the British Isles are the dune and shore sands, but these are never pure enough for good glass work. They are used, for example, in the Dublin bottle industry.

Every example of the whitest and best glass sands indicates that the deposit is associated with carbonaceous (planty) matter. Lippe sand occurs with rafts of braunkohle, Hohenbocka sand is associated with carbonaceous layers, Fontainebleau sand with lignites, Aylesbury and Leighton sand with peaty layers. Some of our purest sandstones occur in the coal measures, and, of second-rate sands, the Headdon Hill and Bagshot sands occur with lignites, the Northampton sands (Inferior Oolite) carry plant remains, and the well-known Brora coal of north-east Scotland is associated with white sandstones.

The bleaching of red and yellow sands for a few feet in depth on our heaths is another example of this action. The explanation appears to lie in the reducing action of the planty matter. Ferric compounds are reduced to the ferrous state, and are often carried off in solution by percolating water. Sometimes, however, they remain, and are revealed by the return of the red colour on burning the sand.

Estuarine or lagoon conditions favour the formation of white sands and sandstones. In our search for glass-sands, particularly in the Colonies, we have therefore a valuable indication of the kind of strata in which to look, and the conditions under which we may expect to find the required material. Simplicity of composition and perfection of grading are more likely to be found in deposits of late geological age, as exemplified by the occurrence of the glass-sands of western Europe. It is very improbable that any new and large British supplies of first-class sands will be revealed, but deposits of small extent, at present unknown, probably occur in many cases in proximity to, or along the outcrops of, supplies previously worked.

V.—Treatment of Sands.

A.—WASHING.

Many British sands may be improved by violent agitation with water. The improvement may be threefold; a better grading may result

from the washing off of fine sand and silt grades, the iron percentage may be reduced by the washing off of some of the limonitic coating of the quartz grains or the breaking up of ferruginous pellets, and clayey or dusty matter may be removed.

One outstanding fact, however, remains. It does not appear possible by washing to convert a second or third quality sand into a first quality one. An irreducible minimum of iron-oxide always remains and cannot be washed away.

The washing is usually carried out in this country by means of rotary plant. The sand is fed in at one end of an iron cylinder which is rotated. Water pipes run through the upper part of the cylinder and spray the sand, which is forced down the chamber by a screw-action. The dirty water runs off at the opposite end. The sand is drained and usually is left to dry in the open air. In some cases it is washed twice over.

Although the best sands, such as those from Aylesbury and Fontainebleau, are not improved in the matter of iron-percentage by washing, they are frequently and advisedly treated in this way at the works when they are required for optical and special glass-work. The washing then removes dirt, dust, coal, other organic matter, etc., picked up during transport.

By experimental work with elutriators, etc., washing may be controlled so as to eliminate only the grades which it is desired shall be absent. For example, a current of velocity $3\frac{1}{2}$ mm. per sec. (42 ft. per hour) will carry off all particles of diameter less than .075 mm.

The objection to washing (and the subsequent drying) is the extra expense incurred, this amounting at times, owing to the additional handling and moving necessitated, to 2s. 6d. per ton. Glass-manufacturers naturally prefer washing to be done at the pits, and a clean sand delivered. In this case effective drying must also be carried out at the pit, for carriage cannot be paid upon water.

B. DRYING AND BURNING.

Thorough drying is rarely attempted by exploiters of sands in this country, so has often to be carried out at the glass works. The drying apparatus is usually a form of large oven, but in the United States, tier-dryers, rotary methods, and steam-coils are used.

Apart from the mere improvement in colour as the moisture is driven off, the burning of sand often affords a valuable indication of the approximate amount of iron present. The sands from Lippe, Fontainebleau, Aylesbury, Godstone, and Muckish Mountain among others, show no change, but those from the Isle of Wight, Malton (Yorks.), Lynn, Belgium, Holland, and others, show a slight darkening in grey or brown tints, or a reddening on heating. The change of colour is due to the dehydration of limonite, and consequent formation of iron oxide (Fe_2O_3). The burning registers only the iron present as staining, and not that in the form of iron-bearing minerals, which usually remain unchanged. Black specks of coaly matter, which might otherwise at first sight be confused with magnetite or titanoferrite, then burn out and indicate their organic origin.

C. MAGNETIC METHODS.

Sands bearing a considerable amount of heavy mineral residue are, as previously noted, generally unsuitable. Many of the heavy grains, particularly the oxides and ferro-magnesian silicates, react with the electro-magnet, and may be separated thereby from the quartz. In the United States glass-sands have been freed in this way from magnetite, but it is very doubtful whether such a process would pay in this country.

No chemical methods yet suggested have been both completely effective in cleaning a sand of iron and reasonably cheap at the same time.

D. TREATMENT OF CRUSHED ROCKS.

At the outset it may be pointed out that crushed sandstones and quartzites, or even

crushed forms of silica, such as quartz, have never found much favour with British manufacturers. Similar materials, after suitable treatment, appear to be extensively utilised in the United States. The rock known as the St. Peter's Sandstone, is largely used in this way in the great glass-industry of the Mississippi Basin, but it appears to have been naturally decomposed to some extent, like the Muckish Mountain rock, before it is quarried.

The importance of using well-graded sands especially for optical glass has been emphasized. The crushing of rocks always produces material of all sizes from a certain limit downwards. Mining engineers are still endeavouring to devise a machine that will grind or crush rocks to a fine, even grade without producing dust, which is waste material. The great evil of rock-crushing lies in the quantity of dust produced.

The following table gives a few mechanical analyses of crushed rocks which may be compared with those of Fontainebleau sand. Chemically the rocks are sufficiently pure to make good glass.

Locality.	> 1 mm.	> $\frac{1}{2}$ and < 1 mm.	> $\frac{1}{4}$ and < $\frac{1}{2}$
Port-a-cloy (Irish Silica Co.)	—	3.6%	44.0%
Guiselley*	—	0.1	40.1
Bethesda	2.6	8.6	77.65
Muckish Mtn.	1.43	9.47	71.3

> $\frac{1}{16}$ and < $\frac{1}{4}$	> $\frac{1}{160}$ & < $\frac{1}{16}$	< $\frac{1}{160}$ mm.	Total sand-grade. > $\frac{1}{16}$ and < 1 mm.
30.8%	9.0%	12.6%	78.4%
44.3	9.2	6.3	84.5
8.85	2.3	—	97.7
17.0	0.3	0.5	99.2

* Sifted to 40 mesh.

To produce an effective sand from this crushed material, the fine grades and dust must be washed away with suitably adjusted water currents, the velocities of which have been determined as a result of elutriation experiments. The mixture must also be sifted to remove coarse grades. The cost of quarrying, crushing, and sifting, has generally been already too great to permit of washing also, the price of the unwashed material being prohibitively high even in the neighbourhood where it is produced. Considering also the high freights, it will be seen that it is improbable on these grounds alone, that crushed rocks even with high silica and low iron content, will replace glass-sands to any extent in this country.

The objections to the use of crushed rock-material in the actual manufacture of glass are serious. It has been pointed out that coarse grains produce "stones," and fine dust "blows out," entangles air bubbles, and gives glass which is not of the same density throughout. It is essential for optical glass more than any other that homogeneity should be obtained and defects and bubbles eliminated. As in the case of crushed quartz-crystals themselves, it is also objected by many glass-manufacturers that the metal produced from the crushed material tends to be "cordy," and "wavy," and to remain "sticky" too long during cooling, which also is protracted more than is desirable. Whether this is the result of the mixture of fine grades, of the presence of two allotropic modifications of quartz (for example, α and β forms differing crystallographically and physically) one possibly as matrix, of the different hydration of the silica acting as cement, or of the presence of inclusions in the quartz, is not known. Investigation is now being carried out upon the question. It is noteworthy that the sand obtained from Muckish Mountain, Co. Donegal, Ireland, is a naturally disintegrated pure pre-Cambrian quartzite. It is often difficult to draw the line

between a true sand and such a disintegrated sandstone or quartzite. The mechanical analysis (see table) indicates, however, that it has been fairly well graded, probably a result of percolating waters for a long period, helped by the fact that the original sandstone was also well graded, and most of the cement has since been removed. It contains rather too much coarse material, but this is very friable, and can be rubbed down in the fingers, compound grains thus breaking up. The analysis should be compared with those of Bethesda material, of which the coarse grades will not break up easily, Guiseley, which was supplied sifted to 40 mesh, Irish Silica Co.'s material, etc. Even with washing and sifting the residual rock-particles are distributed over several grades, and the mixture from a crushed rock is still objectionable.

VI.—General Conclusions and Economic Questions.

The literature of glass-making is not large, and that upon glass-sands is almost non-existent. Systematic surveys of the sand resources of countries do not appear yet to have been published, and the returns dealing with glass-sands are very few.¹

Eminently suitable sands of a high degree of purity and in abundant quantities have before the War been imported into this country at a comparatively cheap rate. Most of the supplies came from Holland, Belgium, and France. Indeed, the only sand used for optical glass and table ware was brought from Fontainebleau, near Paris. It should be emphasised that there appears to be no sand in the British Isles equal

¹ The Geological Surveys of the United States and of Denmark have published small notices.

U.S.G.S. Bulletins 285 and 315, and Annual Reports of Mineral Resources 1883 onwards.

Danmarks Geol. Undersög, Ser. 2, No. 16. 1905.

in quality or extent to that from Fontainebleau. Sands have been mentioned in a previous section which are equal in chemical purity and grade composition, but their extent is comparatively small, and successive consignments cannot be guaranteed absolutely true to the best sample. Variability in such an essential raw material is abhorred by glass-makers. Since these foreign supplies were brought by water almost from their home into the estuaries and canals which give access to our industrial areas (often as ballast on the return journey of vessels carrying coal, etc., out) sands were abundant and cheap, far cheaper than railway-carried British material. The result was thoroughly to spoil glass manufacturers, and they smilingly admit it. Consignment after consignment was so true to sample that apparently no need existed for a works-chemist and laboratory. The reasons for the suitability of the sand were not determined. Manufacturers were able to go forward with very little alteration of the batch, and without any apparent necessity for investigation and analysis. British supplies, had they been as pure, extensive, and available, would not have been used on account of their greater cost.

Owing to the War and the consequent dislocation of traffic and shortage of labour and ships, the foreign supplies have been much restricted, and in many cases stopped. In view of the difficulties thus experienced by the glass trade, it behoves us to see whether we must be dependent hereafter upon the foreign supplies, or whether we possess reserves of suitable sands at home or in the Colonies. We cannot ignore the future; foreign supplies, in particular those of Fontainebleau, are not unlimited, nor will they always arrive in this country so cheaply or of so uniform a quality. The output may at any time be restricted for domestic reasons, or a tariff imposed.

The margin of profit on sand is small. Where

a material is used in such large quantities as sand, it must be cheap, and therefore abundant, unconsolidated, easily and cheaply worked, and accessible and conveniently situated. Seams or beds must run very true in composition, and be clearly marked off from other beds or materials. Due consideration must be given to the important question of workability. The factors to be considered in recommending sources of sands for any industry should include the quantity available, the location with respect to fuel supplies and markets, and to transporting routes, road, rail, canal, or sea. The accessibility of deposits in sea-cliffs, on hills, near bogs or marshes, as well as the conditions of quarrying, such as workable depth below ground-level, position of the water-table, thickness of overburden, etc., must be considered. The state of the local labour market also cannot be ignored.

Carriage by road is expensive, and railway freights are even more so. Foreign sands could actually be bought in this country at a price per ton lower than the cost per ton of moving British sands a comparatively short distance. The freights frequently amount to five or six times the cost of the sand at the pit. Canal-traffic must replace rail-transport (unless the tariff of the latter is reduced), if English sand resources are to be developed. Reorganisation and revival of canal-transport must, therefore, take place.

While the imposition of greater import duties upon foreign sands may not be desirable, it may have to be considered. In any case we shall do well to enquire into our Colonial resources of sand, particularly for moulding purposes as well as glass-making. For very special glasses such as optical glass, the variation in cost of sand is small compared with the considerable cost of production. It may be advisable to be independent of foreign supplies and, if suitable sands do not exist in this country, to fetch them in from distant Colonies, bearing in mind the

TABLE OF CHEMICAL ANALYSES OF GLASS-SANDS.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Loss on Ignition.	Age.
Lippe I. ...	99.88	.18	.02	n.d.*	.21	Miocene
Lippe II. ...	99.73	.20	.03	n.d.	.23	"
Fontainebleau ...	99.65	.21	.04	n.d.	.16	Oligocene
Belgium ...	99.38	.30	.02	n.d.	.23	?
Aylesbury, (Arnold's)	99.80	.32	.03	n.d.	.22	Lr. Greensand
Godstone ...	99.56	.26	.06	n.d.	.24	"
Leighton, (Arnold's) ...	99.59	.25	.21	n.d.	.27	"
†Lynn, white ...	98.47	.81	.24	.26	.22	"
+ " washed ...	98.54	.61	.26	.22	.37	"
†South Cave, Yorks. ...	97.64	.181	.089	trace	1.930 & Water	Callovian.
Bethesda, N. Wales ...	99.85	.54	.04	n.d.	.072	?
†Guiseley, Yorks. ...	98.5	1.25	trace	.25	.36	Coal Measures
Muckish Mountain ...	99.37	.36	.05	n.d.	.12	Dalradian

* Where Lime was not determined, only a trace, if any, was present.

† Analyses not carried out in the Imperial College.

MECHANICAL ANALYSES OF GLASS-SANDS.

Diameter of Grains in mm.

	$> \frac{1}{2}$ mm.	$> \frac{1}{4}$ and $< \frac{1}{2}$	$> \frac{1}{16}$ and $< \frac{1}{4}$	$> \frac{1}{16}$ and $< \frac{1}{16}$	$< \frac{1}{16}$	Total Sand Grade $> \frac{1}{16}$ mm.
Lippe L.	one or two grains	78.6%	19.9%	0.4%	1.1%	98.5%
" II.	10.2	85.8	1.4	1.0	1.6	97.4
Fontainebleau	$< 1\%$	70.6	26.6	2.8	—	97.2
Belgian	$< 1\%$	99.3	0.3	0.4	—	99.6
Dutch	0.4	98.5	4.8	1.3	—	98.7
Aylebury (Lr. Greensand)	0.3	85.1	14.5	0.1	—	99.9
Leighton Buzzard (Lr. Greensand)	24.5	74.3	1.0	< 1	—	99.9
Lynn (Lr. Greensand)	—	94.8	4.9	0.2	0.1	99.7
Godstone (Lr. Greensand)	0.6	73.0	25.7	0.2	0.5	99.3
Burythorpe, Yorks. (Callovian)	—	86.0	63.1	0.8	0.4	99.1
Hutton Ambo, Yorks. (")	1.2	91.9	5.6	0.5	0.8	98.7
South Cave, Yorks. (")	—	8.3	90.2	0.7	0.8	98.5
Alum Bay, I. of Wight, (Headon Hill Beds)	—	3.8	84.0	9.7	2.5	87.8
Lymington, Hants (Bagshot)	—	13.5	76.7	9.0	0.8	90.2

Continued on next page.

MECHANICAL ANALYSES OF GLASS-SANDS.—Continued.
Diameter of Grains in mms.

	< $\frac{1}{2}$ mm.	> $\frac{1}{4}$ and < $\frac{1}{2}$	> $\frac{1}{16}$ and < $\frac{1}{4}$	> $\frac{1}{16}$ and < $\frac{1}{16}$	< $\frac{1}{16}$	Total Sand Grade > $\frac{1}{16}$ mm.
Corby, (Northampton Sands) ...	—	1.3	78.5	16.0	9.2	74.8
Charlton, Kent (Thanet Beds) ...	—	16.2	79.6	3.1	1.1	95.8
Hoathley, (Tunbridge Wells Sands) ...	—	23.8	69.7	5.8	0.7	93.5
Levensat, N.B. (Millstone Grit) ...	3.7	88.5	6.0	0.2	1.6	98.2
Workop, (Trias) ...	> 1mm. 2.0 > $\frac{1}{2}$ mm. 6.6	58.65	26.15	4.5	2.1	98.4
Silver Strand, Wicklow (blown sand)	—	92.1	6.4	0.9	0.6	98.5
Bamburgh, (blown sand) ...	—	94.8	4.7	0.5	—	99.5
Spital, Cheshire (Trias) ...	2.2	75.9	17.05	4.85	—	95.15
Muckish Mountain (pre-Cambrian) ...	> 1mm. 1.43 > $\frac{1}{2}$ mm. 9.47	74.3	17.0	0.3	0.5	99.2
Bethesda ...	> 1mm. 2.6 > $\frac{1}{2}$ mm. 8.6	77.65	8.85	2.3	—	97.7
Guiselley (Coal Measures) ...	0.1	40.1	44.8	9.2	6.3	84.5
Port-a-cloy ...	3.6	44.0	30.8	9.0	12.6	78.4
Westport (crushed silica) ...	—	2.6	40.6	88.8	18.0	43.2

principle that the Empire should be self-supporting and the union in industrial and scientific matters between the Mother-country and the Colonies as close as possible.

In the course of the investigation into British resources of sand, with particular reference to glass-making, I have received every courtesy from glass-manufacturers and works-managers, as well as from owners and exploiters of sand-pits and quarries. I therefore express my indebtedness to them, and desire also to record my thanks to Dr. Walter Rosenhain, of the National Physical Laboratory, for discussing many questions with me, and to Dr. H. F. Harwood of the Chemical Department, Imperial College of Science and Technology, who has kindly carried out many of the chemical analyses which form so valuable a contribution to the paper.

Discussion.

DR. ROSENHAIN said it was not often that one had the pleasure of hearing so scientific and yet so practical a treatment of such a subject as that—a subject which to many would appear on the face of it singularly dull and uninteresting. With regard to the historical aspect of the matter, he thought Dr. Boswell had been a little hard on the glass manufacturer, and had ignored the fact that after all the geologists also might have been somewhat to blame for the neglect of the glass sands of this country. Twelve or fifteen years ago he had been engaged on the practical aspect of the question, and when he had sought the help of geologists at the Museum in Jermyn Street and elsewhere they had told him practically nothing, and he had had to spend his own time in going to the various sand beds in the country to find out what our resources were. He was bound to say that the results of his own investigations had been very similar to those arrived at by Dr. Boswell; it was extremely difficult to find in this country any satisfactory substitutes for the

Fontainebleau and other foreign sands. He thoroughly endorsed Dr. Boswell's view that the resources of the outer Empire should be tapped for this purpose, and emphasised his remark that the cost of sand for optical glass making was nothing like so important a factor as in ordinary commercial glass making, even of the better kinds, for other than optical purposes. The great items which went to make up the cost of manufacturing optical glass were fuel, labour, and plant, and, above all, the very small amount of usable glass which was obtained from each smelting. The actual cost of the glass itself was not a vital factor.

From the purely optical point of view, one thing which Dr. Boswell had said was open to criticism, namely, as to grading. The importance of grading was fully recognised by manufacturers of optical glass. While uneven grading undoubtedly tended to create the difficulties Dr. Boswell had referred to, he was not at all certain that in optical glass making that was a serious matter, because the duration of the melting was much longer than in other glass making, and for other reasons, quite apart from the analysis of the glass, stirring was absolutely essential; so that he doubted whether any little inequalities due to unsatisfactory grading would really add much to the difficulty of producing homogeneous glass. He would particularly suggest one point as of importance, namely, that the use of extremely fine grades of material, the use and the introduction of silica in extremely fine forms, was desirable from another point of view, namely, that of rapidity of chemical action, and consequently of rapidity of melting. So much was this the case that he believed certain conscientious manufacturers had begun to grind the whole of their glass materials down in expensive appliances in order to get it down to those finer grades which Dr. Boswell rather condemned in glass sands. Not only that, but the use of precipitated silica had

been suggested, and he was not at all certain that there was not a good deal of foundation for that suggestion from the point of view of furnace economy. Of course, it was necessary to get a certain degree of uniformity, or there would be a waste of the time gained in the rapid melting of the fine materials in waiting for the coarser ones to melt. The question of the possibility of using precipitated silica was undoubtedly an important one, and provided the material could be obtained in sufficient quantity and of sufficient purity, it might solve the whole difficulty so far as optical glass was concerned. He did not think the quantities procurable were sufficient for plate or sheet glass, but for optical purposes it might be extremely useful.

Dr. Boswell had referred to the analyses of sands, and he thought no one would be inclined to quarrel with his strictures on the kind of analyses one met with up and down the country. He did not himself quite understand the analyses Dr. Boswell had shown them on the screen, but as they were not his own it would perhaps be hardly fair to cross-examine him about them. Still, his own impression certainly was that the Lippe sands ran to over 99.5% SiO_2 . The analysis was not quite clear, because there was loss on ignition, and the whole added up to considerably over 100. None the less, the order of the sands dealt with by Dr. Boswell—Lippe I., Lippe II., Fontainebleau, Belgian—agreed with his own observations, so that the variations were probably a matter of presentation only, and did not indicate any real difference. The question of drying was another important matter. One of the great objects of optical glass making was uniformity of composition. If one introduced, say, 60 per cent. of silica, and that varied by one or two per cent., a result was obtained which undoubtedly affected the optical properties of the glass in the fourth decimal place. So that the degree of

drying must either be kept extremely perfect or constant, or the moisture must be estimated carefully every time a batch was made. He was afraid that was almost the only way, because sand varied in moisture even if thoroughly dried. With these few remarks he would leave the subject, although there was a great deal more which could be said. The matter was one of great importance, and he welcomed this, the very first opportunity the Society had had of ventilating the subject on something like a sound scientific basis. (Applause.)

Washing Sand, Emery, etc.

DR. CLAY said that some time ago—he thought just about the time Mr. Crook was making his experiments—he also had made some experiments on the possibility of grading substances like sand by the method of causing a constant flow of water to pass through them, and he had found a difficulty, which no doubt had been experienced by others working in the same field. Owing to viscosity, the water at the middle of the tube travelled with a much higher velocity than the water near the walls of the tube, with the result that the size of the particles falling through a uniform tube with a uniform flow of water was not uniform; the particles falling down the centre of the tube were much larger than those coming down the sides of the tube where the water was travelling more slowly. Possibly by some stirring arrangement, and by repeating the experiment over and over again, or carrying it on, as he understood Dr. Boswell had done, for a long time, the small particles would ultimately be carried up the middle, and only the larger particles would ultimately remain. But if the apparatus was made on a much larger scale, by using the central part of a tube of considerable size, where the viscosity effect would be negligible, a uniform flow of water might be obtained

up through this central part of the tube, and the particles falling through this would be uniform in size. It might thus be an economy to use a larger tube and a bigger volume of water for a shorter length of time. It had occurred to him that the same method of separating substances by a flow of water might be utilised for separating the glass waste obtained in lens grinding and polishing, as ordinarily there was a large waste of emery and carborundum in glass grinding. Of course, the difficulty lay in the fact that the emery particles were not all of one size, and therefore the smaller emery particles would be carried away with the stream which left the larger glass particles behind. To succeed it might be necessary to obtain uniformity of size, first, by means of a sieve, after which the separation of the glass and emery could be effected by this apparatus.

MR. CHALMERS thought the question of the materials to be used in making optical glass was very important indeed, and that some of the methods Dr. Boswell had dealt with would perhaps lead to good results in other branches of the optical industry.

MR. W. SHACKLETON remarked that, although Dr. Rosenhain had mentioned that the availability of British sands for optical glass-making purposes had already been investigated, he (Mr. Shackleton) had no recollection of the results of those investigations having been made public. Possibly the investigations had been undertaken on behalf of a private firm, and their results were not, therefore, available to anyone making subsequent inquiries. The method of elutriation described by Dr. Boswell was, he thought, extremely interesting, and it might be used in a practical way in optical workshops. He had been that morning in the glass-making district of West Lancashire, and he had learnt that they were there using Lancashire sands. He had not noticed any mention of these Lancashire sands in Dr. Boswell's paper.

DR. BOSWELL asked whether the sands in question were used for making optical glass.

MR. W. SHACKLETON replied in the negative; the sands he referred to were used for making plate glass.

DR. BOSWELL said he was aware of the existence of those sands, but in his paper he had confined himself to the question of optical glass sands.

MR. W. SHACKLETON went on to say that he had already approached Dr. Boswell on the subject of giving them a paper at some future time on the subject of the abrasive properties of different sands, and had received a favourable reply. In the large glass works where plate glass was made, sand, of course, was the first material used for grinding; emery came later. The sands used in the St. Helens district were obtained from the Mersey, and at St. Helens there were great heaps of sand dunes which had been collected for over half-a-century. St. Helens, he might say, presented almost the appearance, on its outskirts, of having been "at the Front," and of having been subjected to a series of mining operations. It was said that when the Zeppelins came over there and saw all those sand-heaps, they said, "Oh, some of the others have been here already," so they did not drop any bombs there, and went away again. (Laughter.)

THE PRESIDENT said the mere mention of sand reminded him of one of the most bitter disappointments of his life. When he was a very small boy he had read a book by a very attractive writer, who solemnly stated that the Lord's Prayer was "written on every grain of sand." Well, he had believed it. (Laughter.) He was at that age when one did believe everything one was told. (Renewed laughter.) And when he later discovered that the microscope failed to reveal the Lord's Prayer, written in English characters—because that was what he had fully expected to find—he must admit that

he was for some little time afterwards more or less an atheistical desperado. (Laughter.)

With regard to the question of the purity of sands, he had some figures which might throw some light on the subject. Some years ago he had been in Germany when some very important work was being done on vitreous compounds generally, not only with regard to glass, but with regard to quartz and other substances, and a friend of his who had done a great deal of the work in question had told him a very remarkable fact in connection with it. They had no difficulty in getting sand with a pure silica content of 99.96, and it was very cheap; but it was nothing like pure enough for the particular experimental research upon which they were engaged; and in order to get rid of that .04 per cent. of impurity it was necessary to run the cost up to something like £10 sterling per 11b. weight. The research upon which they were then engaged was a failure, and the cost was many thousands of pounds; but his friend had assured him that during the course of that research they had succeeded in discovering a method of purifying the sand which more than repaid them for the whole cost of the research, and they had obtained the sand, finally, of the necessary purity at a cost of something like 1s. 3d. per lb.

There was one little matter he might mention which he was afraid had not much to do with sand, except that it indicated a method by which sand might be done away with altogether for glass-making. He had the permission of Mr. Swift, whom he was glad to see present that night as a member of the Society, to say that a short time since he had come across a most extraordinary thing in connection with the construction of microscopic objectives of the very best class. He had a lens to repair, made by a very famous German maker, and to his amazement, in warming up one of the component systems, it almost exploded, and went

into a kind of white enamel. Of course, he was at once anxious to know what was the matter, and he had finally succeeded in getting this lens—which was a deeply curved negative lens, cemented between two ordinary glass lenses—analysed when it was found to consist of potash alum. That would seem to indicate very strongly that, at any rate so far as rare glasses are concerned, glasses for which there was very little demand indeed, there was a possibility of a great deal of good work being done by a thorough research amongst natural and artificial minerals, as suggested by Dr. Rosenhain some years ago. If potash alum, for instance, was capable of taking such an important part as it did in apochromatic objectives, it might be found that there were other natural and artificial minerals which might be applied to the same purposes.

Reply.

DR. BOSWELL, in replying on the discussion, said that he should be happy to talk about the abrasives used in glass manufacture a little later, when there was a little more British material available. With regard to Dr. Rosenhain's opening remarks, he thought he had stated very clearly in his paper that geologists were equally culpable with glass manufacturers in not having investigated the glass-making resources of their own country. Geologists did not want to shirk responsibility in the matter in any way, and he hoped he might be pardoned if he had appeared to be too harsh in his remarks on glass manufacturers. At the same time, the latter had admitted that they had been spoilt by the ease with which foreign sands had been obtained, and the cheapness and constancy of those sands. It must also be remembered that Dr. Rosenhain had had experience of one of the most advanced firms, and was himself one of the few really scientific men who had ever gone into the question. As the Hon. Secre-

tary had pointed out, there was, he thought, no published statement of the result of Dr. Rosenhain's investigations as to whether or not there were deposits of British sands suitable for the manufacture of optical glass; and he doubted whether Dr. Rosenhain's firm had thought fit to publish such information for the benefit of all the other optical glass makers. If they had done so there would have been less reason early in the war for calling upon those whom he represented to resolve the difficulties of many of the manufacturers.

He had expected to be hit much harder than he had been when he had consented to come there as a geologist. Geologists had been requested to go into the question of British sand resources, amongst others, and to do what they could to help industry. They had to begin by studying what the glass manufacturers wanted. He himself had had, at the outset, a hopeless ignorance of methods and materials, and he was only grateful to those manufacturers who had given him many pleasant days in their works, enabling him to see, as far as possible, what it was they wanted. But then he had found himself up against the optical glass problem. Glass manufacturers had been very reticent in the past, especially on the question of optical glass, so that the chances of a mere outsider getting information about the processes, and the reasons for the material required, must be very small. That, therefore, must be his excuse if he had made any bad blunders on the optical side. He had not wished to imply that there had been any neglect at all on the part of business men, but he did not think they could carry out such a thorough investigation into British resources as could those whom he represented, who had naturally had to do with such materials for some considerable time.

He had acknowledged in his paper (but had inadvertently omitted to mention it at the meeting) the kindness of Dr. Rosenhain in letting

him have samples of the Lippe sands for analysis. The point he (Dr. Rosenhain) had noticed was quite correct; the mechanical analysis of the Lippe sand showed 1.1 per cent. of material less than 1/100 mm. in diameter; that was estimated by difference, and he could not, and did not, believe that that was clay grade; there was absolutely no clay there. The fact was he had omitted to dry that sand carefully before it was submitted to either chemical or mechanical analysis, and that was undoubtedly where the discrepancy came in; water there was estimated by difference as clay grade. Water also appeared in the loss on ignition in the chemical analysis. He also had it on Dr. Rosenhain's authority that the Lippe sand was guaranteed 99.8% silica when sold. The silica percentage doubtless varied a little with the samples. In the case of the Fontainebleau sand his own analysis showed 99.7 silica, which was an indication that the sample he took was higher in silica than another sample quoted in the tables. He was quite in agreement with Dr. Rosenhain, therefore, on that point. Of course, he ought to have emphasised that in the case of optical glass, where stirring was actually carried on, the question of grading the sand was not so important; he had been speaking in that connection of glass making generally. In the vast majority of British works there were no arrangements for stirring the glass, and therefore grading was essential. But he might mention that there was one firm which was actually grinding the whole of its batch for making chemical glass-ware. It was a very expensive process, and he doubted whether it was worth while.

Elutriation Processes.

With regard to the question of grading, "the proof of the pudding was in the eating," and the fact was the elutriation apparatus did actually grade the sand fairly accurately, and that the

apparent vortex and eddy action did not necessarily affect the grading seriously was shown by examination of the grains under the microscope: there was no great admixture. With regard to the separation of emery and glass, that would be possible, of course, if the emery was uniformly much finer than the powdered glass, or, on the other hand, if the reverse held. Elutriation could also be adopted for separation if the grains of each were of the same size. If, however, there were mixtures of different kinds of particles of different sizes, then elutriation could not be adopted, because the fine emery, which was heavier, would occur in the same grade as the coarse glass. In that case he would suggest their turning to mining engineers' books. It might be possible to "pan" the emery by centrifugal action, or to try separation by means of an oil—he did not know what affinity emery had for oil—or many other methods might be looked into with a view to effecting the object in question. The question of expense would of course come in, but possibly some of the works on ore dressing might give some indication. At any rate, it was a case for experiment, and if some of the mixed material were submitted to him he would be pleased to examine it and report upon methods of examination. In that connection air separation had been used abroad instead of elutriation by water: by putting on a blast, the fine materials which were apt to choke the pipes of furnaces were carried off. He was assured that that method worked in preparing sands for filtration purposes.

He concluded by thanking the members present for their kind reception of his short talk upon glass sands.