Published at the Instruction of the Ministry of Munitions of War, by the Imperial College of Science and Technology.

A MEMOIR

ON

BRITISH RESOURCES

OF

SANDS SUITABLE FOR GLASS-MAKING,

WITH

NOTES ON CERTAIN CRUSHED ROCKS AND REFRACTORY MATERIALS.

BY

P. G. H. BOSWELL,
A.R.C.Sc., D.I.C., D.Sc. (London), F.G.S.

WITH CHEMICAL ANALYSES BY
H. F. HARWOOD, M.Sc., Ph.D., and A. A. ELDRIDGE, B.Sc., F.I.C.

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PREFACE.

MINUTE study of the sands employed in the manufacture of glass has revealed the fact that the very exceptional qualities displayed by the best of them are not merely those due to chemical composition, but are the outcome of their exact mineralogical nature, and even of the size and shape of their constituent grains.

In nearly all kinds of glass there are certain permissible irregularities in both form and composition of the raw materials which allow the employment of a larger range than had hitherto been suspected. A search in localities where Glass-Sand has been worked in the past, and at other "likely" places, has shown that large supplies are available, and has given indications of directions in which further search might be profitably undertaken. The search cannot be regarded as quite exhaustive—indeed, it is still being prosecuted with vigour,—but it has been thought best not to delay publication, in order to set free as soon as possible the data already collected.

This work embodies the practical results which flow from a series of investigations carried on by Dr. Boswell, with the support of the Imperial College from the beginning and of the Ministry of Munitions in its later stages. Large quantities of material have been accumulating since 1912, every locality described has been personally studied by the Author, and—with the exception of certain Scottish and Irish sands received by favour of the Assistant (for Scotland) to the Director of H.M. Geological Survey, and of the Department of Agriculture for Ireland—only samples collected by himself have been subjected to analysis. The chemical analyses have been made, by kind permission of Professor Baker, in the Chemical Department of the College. They are the work of Dr. H. F. Harwood and Mr. A. A. Eldridge, who have devoted much thought and care to the methods employed. All the mechanical and microscopic analyses and other work have been carried on in the laboratories of the Geological Department. Much assistance in indexing and in the preparation of photographs has been given by Mr. G. S. Sweeting.

Our hearty thanks are tendered to many glass manufacturers and quarry-owners who have given the Author every facility for his work, and have freely discussed with him the technique of glass-making and the economic factors of the industry. We are also indebted for help on the chemical side, both in the discussion of results and in the indication of promising lines of enquiry, to Professor Herbert Jackson, of King's College, London, and to Dr. Walter Rosenhain, F.R.S., of the National Physical Laboratory,

As the study of sands and related sediments has become a matter of pressing national importance, and as this is the first work published on British resources of these materials, it has been thought well to go a little outside the obvious scope of the Memoir in two directions:—

(1) The properties of sands are so varied, and the requirements of the different industries so diverse, that the Author has entered into some detail both on the best methods of investigation and on the most convenient modes of expressing the results thus obtained.

(2) At the same time, the properties of sands suitable for glass-making are in some cases identical with or allied to those useful for refractory purposes, such as steel-moulding, fettling of furnaces, and the making of silica bricks. Reference has been made in passing to properties of this nature, and the applicability of the same modes of enquiry has been indicated.

It should be stated, however, that the sands actually described in Chapter VI. are only a very small fraction of the total number examined and analysed. Hosts of others have been "turned down," either because they were wholly unsuitable or on account of the possession of properties with which the manufacturer has not so far been able to deal. As the chemistry of glass-making advances it is probable that some of these disabilities may disappear—indeed, some of them are all but overcome—and then the large amount of apparently unproductive information obtained and filed by Dr. Boswell will find its use.

W. W. WATTS,

Imperial College of Science and Technology.

November 1916.

CHAPTER I.

Introductory: Uses of Sands.

Of the many mineral resources of Britain none are more abundant or more varied in quality and use than sands. Their utility, in the national economy of this country at least, has never been fully appreciated. Yet the agriculturist, the builder, the glass-maker, the metal-founder, and even the housewife, all turn in their need to the natural sand-resources of the country.

To the man in the street to-day the difference between sands are neither striking nor important. This attitude has, of course, not been shared by those who are concerned with the use of sands in industry, but it is noteworthy that little or no systematic investigation of the special properties of British sands of commercial value has hitherto been attempted.

In many industries the best sand available for the purpose has been found by a lengthy process of trial and error, but the reasons for its suitability or the reverse have rarely been systematically looked into. The inevitable result is that when material of value for some special purpose is no longer available serious delay and inconvenience are caused. Particularly has this been the case in glass-manufacture and in the casting of certain steels, for which the most suitable materials in use up to the present have been certain foreign sands with properties peculiar to themselves. The restriction or stoppage of such imported supplies in war-time, owing to shortage of ships and labour, has set on foot enquiries as to whether suitable sands occur in Britain, and, if so, whether they can be profitably worked.

Such an enquiry necessitates not only a thorough knowledge of the sands themselves, their mode of occurrence and properties, but an investigation into the materials previously in use in each industry, and an attempt to ascertain the reasons for their special suitability. Why, for example, should one moulding-sand "burn on" to the steel poured into a mould and another yield a clean smooth casting; or one sand produce a clear, sparkling, white glass, fit for table-ware or for optical instruments, and another only a poor green bottle-glass?

All sands consist, in the main, of silica in the form of broken grains of crystalline quartz associated with various forms and proportions of impurities, partly impregnating or coating the quartz, and partly in the form of grains or dust of other ingredients. When sand is used as a source of silica, as in glass-making, the most obvious requirement is that it should be as pure as possible and especially free from ingredients which would diminish the utility or beauty of the finished product. For other purposes, however, the "impurities" themselves may give the sand its special value. In certain industries the hardness and shape of the grains are more essential than the composition, and the difference between "angular" and "rounded" grains becomes an important matter. Again, the size of the individual grains, and more particularly the relative proportions of material of different sizes in a sample, has sometimes a bearing on the use of sand: this is spoken of as the "grading" or "grade" of the sand.

In a material used in such large quantities as sand, supplies must be cheap. This means that the sand must be abundant, soft, easily and cheaply worked; that seams or beds must run very evenly in nature and composition, and must be cleanly marked off from other seams or materials; above all, that the market must be easily accessible and carriage cheap and easy.

The term "sand" to the geologist connotes a limited range of chemical and mineral composition, and a definite grade. The term is generally extended to include other minerals than quartz, and is used in commerce for material of varying grades irrespective of composition or angularity. It is also applied to consolidated sandstones and even to hard siliceous rocks which have been crushed for commercial purposes. In this Memoir the most extended commercial application of the term will be taken.

Some Uses of Sands.

Before passing on to discuss the special properties which it is desirable for glass-sands to possess, it will be well to consider briefly how desiderata vary in different industries and applications.

Sands bearing minerals of the rare earths such as monazite, xenotime, thorianite, zircon, etc., are worked for the elements yttrium, zirconium, cerium, thorium, lanthanum, and others, which are used in the manufacture of incandescent mantles and filaments and for refractory paints. Those bearing gems, gold, platinum, cassiterite, and wolfram are similarly worked for the precious materials they contain. Shore-sands, and others such as the East Anglian "Crags," rich in shell-fragments, form an admirable dressing for the land on account of the lime that they yield, which not only provides plant-food but aids drainage by "flocculating" the clay of the soil. This is particularly the case when such sands are near to agricultural country and lime has to be imported from a distance. It is desirable that all coastal deposits should be investigated in this connexion. Even if the sands are not calcareous they render heavy clay soils lighter and more open, breaking them up by the admixture of coarser grade material, and making the land warmer, more permeable to air, gases, and water, more easily drained, and more amenable to working. Here grade, as well as composition, is an important factor.

The use of sand for abrasive purposes depends on the hardness and toughness of its constituents, and on the "sharpness" of its grains. Quartz is not only hard, but, as it has no cleavage, it breaks irregularly and does not easily comminute under wear. It is employed for grinding marble and other stone, plate-glass, and metal. It is also used for arming stone-saws, and in the sand-blast applied to glass-cutting and etching, the cleaning of castings, and innumerable other industrial processes. In this work it soon loses its "sharpness" and requires frequent renewal. In the old days the housewife used a cheap, fine, sharp sand for scouring purposes, now she buys scouring-soap consisting largely of similar fine angular sand bound together with clay, soap, and gum *. "Silver-sand" is a term used for a fairly pure fine white sand, used mainly for scouring and for lightening soil. Samples sold by hardware dealers in London appear, from their mineral composition, to come from the Lower Greensand.

Closely allied to abrasives are friction-sands such as those used to increase the grip of wheels on metal rails. These sands must be not only hard, tough, and angular, but also dry and of even grade to slip freely down the feeding-funnel. Similar sands, which are better if not angular, are used in hour-glasses and egg-timers. A well-known geologist, when faced with the enquiry as to the geological age and characters possessed by these sands, gravely avoided the issue by pointing out that it was not the custom of geologists to measure time with hour-glasses!

The practice of sanding floors has almost died out, but the use of sands for road surfaces and for making road materials is increasing rapidly. Angular sands, free from clay, are utilized in the asphalt industry, the mixture of sand and pitch being of considerable value for road-dressing. The sands utilized are, as far as possible, of local origin; Lower Greensands from Surrey and Bedfordshire, and Portlandian sand from Oxfordshire, have been used.

Large quantities of sand are worked for building purposes. Most sands are suitable for mixing with lime and water to make mortar, and usually each district is able to satisfy its own demands. Shore-sands are, however, avoided on account of the tendency of mortar made from them to "sweat" owing to thin films of deliquescent sea salts being left as a coating on the grains when the sea-water evaporates. These salts are brought to the surface by percolating water, and left on evaporation. A similar effect is observed in the complete breaking up of Chalk fossils collected from spray-beaten cliffs, unless they have been well soaked in fresh water before storing. Building-sands should be fairly angular and not too fine, in order that their grip on the calcareous matrix may be strong, and the mortar truly becomes a miniature concrete.

The clays worked for brick-making are often stiff deposits of almost pure clay. As such they can only be used for making flat tiles and pipes where great strength and adhesion are required. To

* By an order of the German Government in Aug. 1916, the use of sand instead of soap for scouring purposes was made compulsory.

reduce shrinkage and cracking during the drying and firing of bricks, sand is added to the clay and thoroughly mixed with it. A porous brick of good shape and soundness results. Here, again, the grade-composition is a leading factor. Many of the so-called clays in the geological formations of Britain are not true clays, but contain already a variable admixture of sand and are thus really loams. The Glacial brick-earths, the Keuper "Marls," and the London "Clay" are deposits of this character largely employed for brick-making.

Parting-sands, which are usually dry, sharp, fine, quartzose sands, are used in casting and in brick- and pottery-making. In the case of brick- and tile-manufacture, the sand used to "dust" the mould exercises considerable influence on the texture and colour (due usually to oxides of iron) of the surface of the article. The ability to withstand weathering and the æsthetic value thus depend in part upon the sand. In metal-casting, "burnt" moulding-sand from near the surface of previously-made castings is frequently and successfully used as a parting-sand.

In connexion with water-supply, sands are of considerable importance for purposes of filtration. In order that there may be a large proportion of interspace between the grains, the sand should be fairly coarse and its grains preferably rounded, with as large as possible a percentage of grains belonging to one grade. Thus the sand should be free from clay, and of course from organic matter, while the absence of lime is an additional advantage.

The most important commercial uses of sand, those connected with the property of refractoriness to high temperatures, have been left until the last. Silica, of which quartz is the commonest crystalline form (though other allotropic modifications such as tridymite and cristobalite exist), has to be raised to a very high temperature (1650° Centigrade) before effective fusion takes place. Quartzose sands and sandstones bearing a high percentage of silica and no fluxes such as alkalies or alkaline earths are therefore in great demand for the floors, sides, and roofs of kilns and furnaces, and for the bottoms of soaking-pits. Sands of corresponding composition are also required for fettling furnaces (that is, re-coating with silica the baths which hold the molten metal), making crucibles and fire-bricks, and other similar purposes.

"Silica-bricks," used so largely for furnace-work, gas-ovens, and similar purposes where very high temperatures must be successfully withstood, are made from refractory sands. No lime or other alkaline earths, no alkalies, and very little, if any iron, should be present. Highly quartzose sands are therefore required, and a great advantage accrues if such sands possess a "bond" which is itself refractory. As examples may be quoted the kaolin-bearing whitish sands of Devon and Cornwall, associated with kaolinized granite, and the similar deposits of the Mountain Limestone district of Derbyshire and Staffordshire.

Included in the subject of refractories comes the wide and difficult problem of moulding-sands. These vary according to the metal which is being cast, the shape of the mould, and their position with respect to the metal. Thus there are facing- and core-sands in addition to ordinary moulding-sand, and the range in composition is from true sands almost entirely composed of quartz to loams containing no small proportion of clayey bond. The problem of moulding-sands is too large and controversial to be entered upon here, and demands a memoir to itself, but a few points may be emphasized. Difficulties rarely arise as a result of the sand alone in the casting of iron, brass, bronze, or other alloys, where the temperature reached by the molten metal does not exceed 1250° Centigrade. No sand is, however, perfectly refractory for steel-casting, and the surfaces of the mould may have their quartz melted or recrystallized as the mineral tridymite (conversion temperature about 800° C.). To obtain a very refractory sand, high silica-percentage is demanded, and the absence of lime, magnesia, and the alkalies essential. For high-temperature castings ordinary clay must not be present, as it fuses too readily. Kaolin is a very refractory clay, but, unfortunately, it does not, like most ordinary clays, become sufficiently plastic with water to bind the sand well. A binder, either natural such as clay, or artificial, such as oil, gluten, flour, dextrine, treacle, etc., must be present in. or be added to, the sand to bind it together and ensure its standing up firmly in the required shape. At the same time the mould, and particularly the core, must be "open," that is sufficiently permeable to permit the passage of liquids and gases when the hot metal pours into the mould. It is therefore desirable that moulding-sand should contain a good proportion of the medium-grade sand, probably round or subangular grains being best. It should also contain a proportion of a refractory clay to act as a bond, whether or not additional binding material is to be added. The intermediate grades of fine sand and silt are of no value—in fact, they are rather detrimental. The material known to geologists as a clayey or loamy sand most nearly approaches what is required. In addition to refractoriness and suitable mechanical composition and shape of grain, moulding-sands should possess the power of taking up water to the extent of at least 4 to 5 per cent. of their own weight (some take up as much as 10 or 11 per cent.), making when moist a strong "bind." For most purposes they should not become "dead" or dehydrated quickly or entirely after casting. A quantity of fresh sand has always to be added to keep them "alive." Certain other less important conditions must also be satisfied. Reference to the grading of moulding-sands is made again later (see p. 29 and Figs. 5 & 6).

The importance of obtaining suitable sands for the making of glass, and the conditions which such sands must satisfy, are considered in Chapter V. Whereas the chemical composition of a sand for many of the purposes hitherto mentioned is not the most important factor, in the case of glass-making it rises to a position of prime consequence; the mechanical composition is also of great importance, and other features, though far from negligible, sink into a minor position. Thus glass-sands are by no means the most interesting types to a geologist, the criteria being simple and for the most part easy of investigation.

For obvious reasons, the following descriptions and analyses of British sands suitable for glass-making will be of great use to those who urgently require such sands high in silica-content (and therefore highly refractory) in other industries, for example, in the manufacture of silica-bricks, for dry-sand steel-moulding, fettling furnaces, soaking-pits, crucible-making, etc.

In the making of white bricks, pure sands low in iron-content frequently have to be transported considerable distances, when local sands bearing iron-compounds "burn up red." The sands and fuel (of which only a small supply is required) are in this case carried to the clay, but in the glass-industry, sands and other chemicals necessary for the manufacture are generally carried to the fuel, as is often the case with raw materials in other industries.

It is unnecessary to say more upon other uses of sands to justify the claim that the sand-resources of the country should be exhaustively investigated. In conclusion, it may be pointed out that just as "flint-glass" is not now made from flint but from sand alone, so "sand-paper" is often not made from sand but from powdered glass.

CHAPTER II.

The Nature of Sands.

Formation of Sands.—Sands and similar deposits are the result of the gradual breaking down of rocks. The sun's heat, frost, rain, and gravity are among the geological agencies which are chiefly engaged in this work of disintegration and attrition. Fragments of rock, in their continual movement to lower levels, are reduced in size by wear and tear, and broken up into their constituent mineral grains. Chemical, as well as mechanical, action assists in this work. The more easily decomposable minerals rot away, and the more obstinate are loosened from one another. In the decay of minerals the more soluble salts are carried off in solution, while the less soluble yield fine clayey or micaceous material which may be carried in suspension for long distances.

The disintegration of rocks thus results in the production of simple individual mineral grains varying considerably in size. This material is carried downwards towards the sea, and collected at lower levels. In transit it is winnowed by wind and washed by water. Most sands and related sediments are either deposited in water or have been washed down and assorted by water at some time in their history. The sorting is controlled by the size and weight of the grains, coarser grains and denser minerals being dropped down near to the source of supply. This sorting is never perfect, and it is not usual to find in geological strata a deposit made up entirely of material of one size. Nor even do we find, with very rare exceptions, that one grade—sand, silt, or clay—makes up the whole of a single bed. The manner of transport and deposition leads in any one deposit to a mixture of grades which may be valuable or inimical from a commercial standpoint.

A tendency generally exists for the collection in basins of deposit of material which has been brought from many different sources. Working against this tendency towards the production of rocks of mixed grades we have the selective transport and deposition due to currents of air and water. Heavier and larger fragments are dropped first, finer ones are carried farther, and the finest frequently travel long distances before the velocity of the stream is so far reduced that they come to rest. A fairly complete natural grouping therefore takes place, gravel, sand, silt, and mud being found at successively greater distances from their place of origin. But this grading by water or air is not a perfect one; the manner of transport varies accordingly as the small particles are held in suspension, rolled along the bottom, or carried forward by leaps (saltation), and the final deposition depends upon local variation of direction and velocity of the currents, eddies, etc., and upon the precipitating power of dissolved salts.

Sudden arrest of material near to its source, especially where it has been brought down by torrent-action, results in deposits consisting of about equal proportions of coarse and fine grades; they may be termed "non-graded" (see Fig. 7, p. 30). Such a case is exemplified by many of the Cretaceous and Tertiary deposits around the Dartmoor and Cornish granite-masses. Torrential streams of water poured down the slopes and ravines in past ages, rolling pebbles and boulders of granite and limestone, fully charged with grains of quartz, felspar, tourmaline, etc., and milky-white with china-clay from the decomposed felspar of the granite. The sudden checking of their velocity when they reached the still waters of the lakes, the larger sluggish rivers, or the lower ground, caused the bulk of the transported material to be thrown down higgledy-piggledy, all grades mixed, frequently as an alluvial fan.

On the other hand, the continual sorting of sediments along the shore by the action of waves and winds has resulted in the elimination from shore- and dune-sands of both very coarse and fine material. The clay and silt particles are carried far away by wind and water, and the coarse sand and gravel left alone; thus the percentage of medium-sized sand rises very high, and the deposit is almost perfectly graded.

Composition of Sands.—Usually each grain of sand is an individual mineral fragment contributed by the parent rocks which have undergone denudation. While sands are frequently made up of a large variety of different minerals, quartz and, to a less extent, felspar usually constitute more than nine-tenths of their bulk. The chemical composition of the constituent minerals, their proneness to decay, and the compounds resulting from their partial or complete decomposition, are all important factors when the commercial use of the sand is under consideration,

While the grading of sands and the sorting of minerals according to density are never perfect, a strong tendency exists towards simplification, which is helped by the proneness to decay of the less stable minerals. By repeated geological action, sorting again and again, very pure and well-graded sands come to be formed, and it is noteworthy that all the best glass-sands occur in the later geological formations. On the other hand, the ancient Ordovician and Silurian "sands" are usually ill-sorted and very variable in composition.

As a rule, sands contain only a small proportion of the minerals known as the heavy detrital minerals, which possess a density greater than 2·8. These, like quartz, have proved themselves sufficiently stable to withstand decomposition, and their presence is often a useful indication of the source of the sandy material. Most of the common rock-forming minerals occur in sediments in more or less relative abundance. In ordinary sands the proportion of heavy minerals varies from 0·02 per cent., or even less, to 4 or 5 per cent. by weight (the latter quantity in sands of fine or superfine grade only).

The minerals composing sands may be divided into two groups: the allothigenous minerals, derived from older rocks, and the authigenous minerals, which were formed at the time the rocks were deposited or at some later date. We are mainly concerned with the allothigenous minerals. Some of the heavy detrital minerals are fixed chemical compounds, others are molecular mixtures which vary somewhat in their composition. The colour and optical properties vary sympathetically with the chemical constitution. In the latter group are the pyroxenes (augite, etc.), amphiboles (hornblende, etc.), olivines, epidotes, etc.

The chief heavy minerals occurring in sands are the following:—

OXIDES:—Anatase, brookite, rutile (TiO_2). Cassiterite (SnO_2); corundum (Al_2O_3); hematite (Fe_2O_3); limonite ($2Fe_2O_3 . 3H_2O$); magnetite (Fe_3O_4); spinel (oxides of Fe, Cr, Mg, Al, etc.); titanoferrite or ilmenite ($FeTiO_3$); wolfram $(FeMn)WO_3$.

SILICATES:—Andalusite (silicate of Al); augite (metasilicate of Al, Fe, Mg, Ca, Na, etc.); biotite (silicate of Al, H, K, Fe, Mg); enstatite ($MgSiO_3$); epidote (hydrated silicate of Ca, Al, Fe); garnet (silicate of Mg, Ca, Mn, and Fe, Cr, Al); glauconite (silicate of K, Fe); hornblende (metasilicate of Al, Fe, Mg, Ca, Na, etc.); hypersthene $(Mg, Fe)SiO_3$; kyanite (silicate of Al); muscovite (silicate of H, K, Al); olivine (orthosilicate of Mg, Fe); sillimanite (silicate of Al); sphene ($CaTiSiO_5$); staurolite (silicate of Fe, Mg, Al); topaz (fluosilicate of Al); tourmaline (boro-silicate of Al); zircon ($ZrSiO_4$).

Other compounds:—Apatite (calcium phosphate with calcium fluoride or chloride); calcite ($CaCO_3$); monazite (phosphate of Ce, La, etc.); pyrite (FeS_2); pyrrhotite (approximately FeS).

Where older sediments have been broken down to make the new rocks, only the most obstinate detrital minerals, such as iron ores (including ilmenite), rutile, zircon, tourmaline and others, survive, and the proportion by weight is low. When crystalline rocks of igneous and metamorphic origin are subjected to denudation, they yield a rich and highly varied assemblage of minerals. It is noteworthy that most of the heavy minerals occurring in sediments are of metamorphic origin; as examples may be quoted, spinels, garnets, rutile, tourmaline, staurolite, andalusite, sillimanite, sphene, epidote, muscovite, biotite, chlorite, kyanite, and amphiboles (including common hornblende, glaucophane, actinolite, etc.). Igneous rocks appear to provide an assemblage of minerals more liable to decomposition. However, those derived from an area of pneumatolysis are more stable, and include garnets, cassiterite, tourmaline, topaz, andalusite, etc. Minerals derived from other igneous rocks include zircon, rutile, anatase, apatite, brookite, white and dark micas, hornblende, and, less commonly, augite, and a few others.

The mineral constitution of a sediment varies not only with the parent rocks laid under contribution, but with its distance from the source of origin, the grade, and the conditions of deposition.

Unless local concentration is produced by wind- or stream-action, or by the oscillatory effect of currents, the proportion by weight of the heavy crop will decrease the farther we go afield, and the variety will be reduced as minerals prone to decay are eliminated. The exact connexion between mineral composition and grade is not yet thoroughly understood; it is undoubtedly a close one. During the process of deposition, other minerals may be formed through organic agency, among them being glauconite, calcium phosphate, limonite, secondary silica, etc.

Finally, we have those minerals which develop subsequently in sedimentary deposits as a result of alteration of other minerals; a few such are iron oxides, secondary silica, leucoxene, anatase, chlorite, etc.

If the heavy minerals are present in quantity in sands they affect its chemical constitution very considerably. Alumina might be expected to be abundant in a heavy residue, and it is noteworthy that lime is usually low, the lime-bearing minerals, with the exception of some hornblende, pyroxene, epidote, etc., tending to decompose. In sands subjected repeatedly to the action of geological agencies, the latter group of silicates first disappears, then the ferro-magnesian minerals, and, finally, the aluminous silicates, when certain iron ores, zircon, rutile, and tourmaline only survive.

Coating of Sand grains.—On the principle that, chemically, dirt is only "matter in the wrong place," the detrital minerals of a sand may be regarded as impurities when we desire to find a sand pure enough for glass-making. More important, however, are the impurities resulting from decomposition of these minerals and those introduced either during deposition of the bed or subsequently by the action of percolating water. An example of such an impurity is the iron staining in tints of red, brown, and yellow, so widely met with in rocks. Iron oxide (as hematite, Fe_2O_3, or limonite, $2Fe_2O_3.3H_2O$) acts as a coating to the mineral grains and at times cements them together into a compact rock. Other minerals, such as silica itself, clay, fluorspar, barytes, calcite, dolomite, phosphates, etc., also play a cementing rôle. Certain unconsolidated sands, while apparently fairly pure and clean, have a fine dust-like coating of clay or calcareous material deposited upon the grains.

Association with Organic material.—Sometimes organic material such as plant-remains has the effect, either by its acting as a reducing agent or by the production of humic acids, of clearing a sandy deposit of impurities, or of rendering them more easily soluble in percolating water. Some of the purest quartz-sands known to us, remarkable on account of the freedom of the grains from the slightest ferruginous coating, are associated with carbonaceous material (see Chap. VI.). The famous glass-sands of Fontainebleau in France, Lippe in Saxony, Hohenbocka in Prussia, and Aylesbury in England, are apposite examples. The purity of Coal Measure sandstones is interesting in this connexion, and the bleaching, to the depth of a few feet, of the yellow and red sands on our heath-lands is a well-known phenomenon. This question is considered in more detail on p. 66.

Form of Sand grains.—During their progress from the disintegrated parent-rock to their final resting-place, mineral grains suffer continual abrasion. If the habit is needle-like, or the cleavage good, there is a general tendency for rapid fragmentation and disappearance. Brittleness and softness help the speedy reduction in size of grains, but when a soft mineral, such as mica, has a single cleavage, and one so perfect that it is buoyed up, it may travel a long way.

The continual battering of one another to which grains carried by water are subjected results in the wearing down of the sharp edges and angles, and the sands become subangular. Prolonged rolling action produced by currents up and down a shore-line, or repeated action on the same grains through successive geological cycles, may gradually round even quartz sand. Pot-hole water-action in a confined space (*e.g.* under glacier-ice) produces sometimes a beautifully rounded sand. Much more rapidly, however, are sands rounded by the action of wind, when the grains are continually rubbed against one another, or meet other obstacles, with no water present to act as a cushion or a lubricant to reduce friction. Many desert-sands consist of grains which have been rounded in this way, but just as the want of rounding does not imply the absence of desert-conditions, so also its presence may not necessarily be due to wind-action. Sand-dunes, so common around the shores of the British Isles, consist of shore-sands which have been blown up into mounds by wind-action, but that action has usually not been sufficiently prolonged to change the angular or subangular shape of the grains.

Size of Grains.—The sorting effect of water and air upon sediments has been briefly referred to early in the chapter. It is necessary to consider systematically the sizes of the grains constituting sediments and their relative proportions by weight. At the outset it should be repeated that the term "sand" has different signification to the layman and to the geologist. In the above remarks "sand" has been used in its wider commercial sense, and therefore includes related loose deposits bearing some amount of clay and other material in their composition. In its stricter geological use sand is purely a "grade" term, that is, one depending only upon the size of the constituent grains. Although most sands happen to be made up largely of one mineral—quartz,—the real criterion upon which the geologist bases his definition is the high percentage of grains with average diameter between 1 mm. and 0·1 mm. (about 0·04 and 0·004 of an inch). Very coarse sands may have grains up to 2 mm. diameter, and very fine ones down to 0·05 mm., but these are extreme limits. Pebbles of diameter over 2 mm. fall into the grade known geologically as "gravel" (not the commercial term of the building-trades, which connotes a coarse concrete-making bouldery deposit with a good deal of sand and fine clayey "bind"). Particles of diameter less than 0·05 mm. constitute "silts." A further limit, however, exists, and deposits made up of mineral fragments, the diameter of which is less than 0·01 mm. (0·0004 in.) are true "clays" or "muds."

A useful classification of the size-limits or grades is therefore :—

A.	Greater than 2 mm. diam.		Gravel.	
B.	,, ,, 1 mm. ,,	and less than 2 mm.	Very coarse sand.	Sand-grade.
C.	,, ,, ·5 mm. ,,	,, ,, ,, 1 mm.	Coarse sand.	Sand-grade.
D.	,, ,, ·25 mm. ,,	,, ,, ,, ·5 mm.	Medium sand.	Sand-grade.
E.	,, ,, ·1 mm. ,,	,, ,, ,, ·25 mm.	Fine sand.	Sand-grade.
F.	,, ,, ·05 mm. ,,	,, ,, ,, ·1 mm.	Superfine sand or coarse silt.	Sand-grade. / Silt-grade.
F.	,, ,, ·01 mm. ,,	,, ,, ,, ·05 mm.	Silt.	Silt-grade.
G.	....	less than ·01 mm.	Clay or mud grade.	

The letters A, B, C, etc., denoting the various grades are for use in this Memoir only as a means of shortening the expression of the mechanical analyses quoted in later chapters. Thus, a sand consisting of 11·8 per cent. by weight of very coarse sand-grade (>1 mm. & <2 mm. diam.), 44·1 per cent. of coarse sand-grade (>0·5 & <1 mm.), 41·5 per cent. of medium sand-grade (>0·25 & <0·5), 2·2 per cent of fine sand-grade (>0·1 & <0·25), 0·2 per cent. of silt-grade (>0·01 & <0·1), and 0·2 per cent. of clay-grade (<0·01) would be represented thus :—

$$\frac{B}{11{\cdot}8},\ \frac{C}{44{\cdot}1},\ \frac{D}{41{\cdot}5},\ \frac{E}{2{\cdot}2},\ \frac{F}{0{\cdot}2},\ \frac{G}{0{\cdot}2};\ \frac{B\text{–}E}{99{\cdot}6}.$$

CHAPTER III.

Methods of Study of Sands.

For the proper knowledge of sediments, considering both their geological interest and economic value, it is desirable that we should know the chemical, mineralogical, and mechanical compositions of each sample. In the case of sands, each of these three analyses yields interesting and valuable data, and for glass-sands in particular the chemical and mechanical analyses are most important. Although desirable, it is not so essential for commercial purposes that we should also be acquainted with the mineral composition; the knowledge is, nevertheless, of considerable value in special cases and may give an indication of the particular treatment required, of the presence of minerals detrimental to the industry, or enable the user to ensure that successive consignments of sand come from the same quarry or bed.

Chemical Composition.—Since quartz and felspar usually make up the bulk of a sand, and aluminous silicates that of a clay, the silica-percentage generally runs fairly high, reaching in very pure sands and sandstones 98 or 99 per cent. Complete analyses are very desirable, especially of moulding "sands," but where only fairly pure sands are investigated, as in connexion with glass-making, it is often sufficient to estimate silica, iron oxide (as Fe_2O_3), alumina, and water. Other elements will rarely be present in quantities larger than "a trace." If they should be, however, it is highly desirable that even small percentages should be recorded. Their effect in the actual making of the glass is not known, but numerous problems and difficulties have arisen in the processes and have not yet been explained. Small quantities of foreign substances may play a greater part than has hitherto been suspected in determining the character of satisfactory or unsatisfactory glass.

The chemical composition varies according to the amount and character of the cementing material upon the individual grains, but more according to the variety and relative abundance of detrital minerals present. As previously remarked, the heavy detrital minerals are mostly oxides and silicates, but borates, fluorides, phosphates, chlorides, etc., also occur. The total silica estimated in a sand is therefore made up of free silica, that of the quartz grains themselves, and the combined silica of the other minerals. If it is not desired to carry out a complete chemical analysis involving fusion with alkaline carbonates, for glass-purposes the iron-content of the sand may be estimated after digesting the sand with hydrofluoric and sulphuric acids in a lead basin (see footnote, p. 38).

Mineral Composition.—Apart from the determination of the actual species present, the mineral analysis is useful as giving an indication of the relative amount of heavy detrital minerals and the quantity of such lighter minerals as quartz and felspar. The earliest method in use for the purpose of conducting a mineral analysis was that of "panning," so well known to the miner. Gentle agitation of the sand beneath water, combined with a slight rotary movement with a jerking "throw," has the effect of causing the heavier minerals to segregate at the bottom. The lighter constituents above, making the bulk of the sand, are washed off carefully in a gentle water-current. Separation of minerals, such as quartz from gold or cassiterite (tin ore), which are very different in density, is very successful, but for geological investigation, where it is desired to separate minerals of density a little below and a little above 2·8, the method by itself is not suitable. To reduce the bulk of the sediment, and to increase the relative proportion of heavy constituents in order to obtain a larger quantity for qualitative examination, panning is adopted. If carried too far, some of the less dense of the heavy minerals may be washed away with the lighter.

Before being analysed mineralogically, a sediment is sifted free from larger compound grains, and, if necessary, washed clean from clayey matter. The dried sand or silt is then treated with heavy liquids to obtain the small crop of minerals the density of which is greater than 2·8. The proportion of these is usually so small that examination of the untreated sand, etc., only reveals occasional grains. The densities of quartz and felspar, which make up the bulk of sands, vary from 2·54 to 2·76, while those of the more interesting detrital minerals mentioned vary from 2·9 to 4 or more. Quartz, felspars, and certain other light minerals therefore float in a liquid of density 2·8, while the heavy minerals sink. The apparatus required for mineral analysis is very simple. An ordinary funnel (dropping funnels have been used, but the open conical form is perhaps preferable) fitted with a ground-glass tap or rubber-tubing and pinch-clip is all that is required (Fig. 1). The most suitable heavy liquids in use are bromoform (density about 2·84) and Thoulet's (Sonstadt's) solution (mercury potassium iodide in aqueous solution, density from 2·8 to 3·1, according to concentration). The heavy liquid is poured into the funnel and the sediment added, the whole being well stirred at intervals to permit of the easier settling of the heavy grains. When the separation is complete (in practice it is probably never perfectly so), the light grains form a belt at the top of the liquid, there is usually an intervening clear portion, and a sediment of heavy grains occurs below. The latter portion of the sand is tapped off, filtered from heavy liquid, and washed with benzene if bromoform has been employed, or distilled water if use has been made of Thoulet's solution. The light crop is similarly dealt with, the washings in each case being saved and concentrated later over a water-bath or by distillation. Heavy liquids are thus used many times over.

If necessary, the heavy crop may be further separated for diagnostic purposes by magnetic, electromagnetic, electrostatic, rolling, and other methods, and by treatment with heavier liquids, such as methylene iodide (density 3·3) *.

After some practice, many of the tiny heavy mineral grains may be recognized by examination with a high-power hand-lens (× 15 or 20 diameters). For permanent use under the microscope they are mounted in the usual manner in Canada balsam (refractive index about 1·53), and examined in transmitted and reflected light. For rapid temporary examination it is useful to immerse some of the residue in such a medium as clove oil (refractive index about 1·53), but then the mount is not permanent. The minerals are identified by their shape, crystalline form, cleavage, fracture, enclosures, alteration, and such optical properties as colour, refractive index, pleochroism, birefringence, extinction-angle, interference figure (directions-image), twinning, etc. For these mineral characters reference must be made to any good book on rock-forming minerals. The size of the different mineral grains is measured by means of eyepiece and stage micrometers.

Fig. 1 *a*.

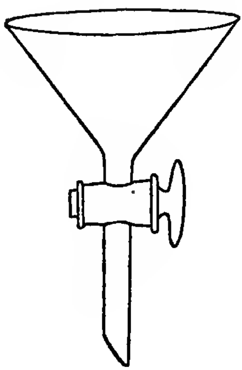
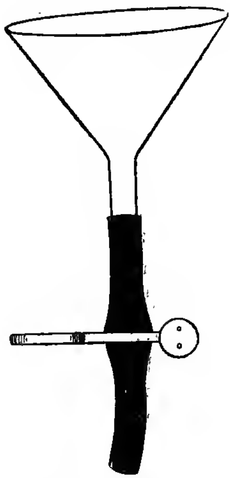


Fig. 1 *b*.



Funnels for separating heavy minerals from sands.

The heavy detrital minerals usually stand out in relief (owing to their higher refractive indices) when examined in balsam or

* T. Crook, "The Systematic Examination of Loose Detrital Sediments," Appendix to Hatch & Rastall, 'Sedimentary Rocks,' London, 1913. Weinschenk (translated by Clark), "Petrographic Methods," New York, 1912, and other works.

clove oil (see Plate II, figs. 2, 3, 4). It is also useful to examine some of the lighter crop in the same way. Since quartz and felspar have refractive indices very near to that of the medium (clove oil or Canada balsam), the grains if fresh and clean have very faint borders in ordinary light (see Plate II, fig. 1). A very slight ferruginous coating on the grains is then easily detected. Grains of a highly pure glass-sand immersed in clove oil almost disappear. Felspar is usually turbid with alteration products consisting of micaceous material or clay (kaolinization).

In certain exceptional cases, where the grading has been well carried out by natural agencies and a good proportion of heavy minerals is present, ordinary sifting will separate, to a remarkable degree, the coarser light minerals and the finer heavy ones which required the same strength of wind- or water-current to transport them. As an example may be quoted the dune-sand from Balgownie Links, near Aberdeen. A mechanical analysis of this deposit yields: Coarse sand 2·0 per cent., medium sand 91·2 per cent., fine sand 3·3 per cent., superfine sand or silt 2·9 per cent., dust, etc., 0·6 per cent.; total sand-grade ($>0·1$ mm. diameter) 96·5 per cent. The portion of diameter greater than 0·25 mm. (medium and coarse sand) consists of quartz and felspar, while that of diameter 0·25 to 0·1 mm. (fine sand) consists almost entirely of heavy detrital mineral grains, epidote, augite, garnets, tourmaline, and zircon being conspicuous.

In very pure sands or sandstones, the heavy crop may be less than 0·01 per cent. in weight, but it sometimes increases to 4 or 5 per cent., as, for example, in some samples of Bagshot Sands, Inferior Oolite Sands, and others. Usually it is found that the coarser the sand becomes the smaller is the heavy crop yielded; silts and fine sands often carry the highest proportion. Estimation of the heavy crop of true clays is very difficult to make, as it has not been possible to obtain a good separation in a heavy liquid of the very fine material which takes a long time to settle.

Complete mineral analysis may, as a rule, be carried out within an hour, that time serving also for the identification of all the important detrital minerals. Mineral analysis is much more rapid than chemical analysis, and yields general information as to the chemical compounds present and their relative abundance. A check upon the chemical analysis and a knowledge of what elements to look for are thus obtained. Chemical, mineral, and mechanical analyses may all be in operation at the same time.

Mechanical Composition.

A mechanical analysis of a sediment seeks to record the various sizes of its constituent grains, and the relative proportion by weight of grains between certain limits of size. These size-limits are known as "grades," and a useful classification has been given in Chapter II. on p. 16.

The general importance of mechanical analyses in industry is only being realized very slowly. Agriculturists have long recognized the value of mechanical soil-analysis; indeed, the methods of work were first introduced in this connexion. Mining-engineers subject their battery-pulps to such analysis in order to determine the efficiency of their machinery, and they use various forms of apparatus designed to separate pulps into grades *. Water-engineers have recognized the importance of the knowledge of relative proportions of certain sizes in coarser sands and gravels in the matter of water-filtration, and the distribution and movement of underground waters †. The significance of the method has been realized to some extent in pottery-work. Not yet, however, have glass-manufacturers, brick-makers, metal-founders, and others fully appreciated the value and importance to themselves of a knowledge of the mechanical constitution of the clays, silts, loams, and sands which form their raw materials. Frequently there has been some realization of the value of the investigation, but crude methods of sifting are often deemed sufficient. That the old order of things is changing is evidenced by the fact that elutriation apparatus has been set up in a few works as well as in a few scientific institutions in this country. Some managers of glassworks have recognized that the grade-analysis of a glass-sand is of as much importance as the chemical composition (provided, of course, that the latter does not fall outside certain limits). Otherwise no scientific investigation as to a suitable mechanical composition has been made, experience being trusted to as a general rule. Usually only sifting through wire-screens has been adopted by sand merchants or manufacturers and founders.

(a) *Screening.*—Sifting or screening may be resorted to for coarse sands, but for fine material the procedure is objectionable both because of liability to contamination and want of accuracy. Moreover, very fine grades cannot be separated by sieves, as the apertures cannot be made sufficiently small. From a scientific standpoint the sifting of sediments through wire-screens with square or rectangular mesh does not give accurate results, since grains of various diameters up to the length of the diagonal of the aperture pass through. It is the mean and not the major diameter of the grains which determines what shall pass the screen. Sifting, therefore, does not guarantee sizing. Where sifting is adopted, round-holed sieves, with the holes punched out and set in 60° triangular spacing, should be used. It is even then questionable whether sifting much below 0·5 mm. (about 0·02 inch) is entirely satisfactory. Smaller holes than 0·5 mm. cannot be punched without difficulty, and 0·25 mm. (0·01 inch about) sieves are therefore wire-screens. The latter mesh is the minimum limit of screening adopted by the writer. In these screens and in the smaller "120 to the inch," supplied by makers, the apertures are square and

* H. Stadler, "Grading Analyses by Elutriation," Trans. Inst. Mining & Metall. xxii. (1912–1913) p. 686.

† C. Slichter, "Motions of Underground Water" (1902) U.S. G. S. Water-Supply Papers, No. 67; King, U.S. G. S. 19th Annual Report, 1897–8, p. 67.

tend to become clogged by use. Contamination thus occurs, especially if the metal of the screens be iron, which inevitably rusts in time. All sieves for scientific work should be made of copper or brass.

Before passing on to a description of the forms of apparatus used in elutriation, a note is desirable upon the standardization of grade-measurements. As in other scientific work, the use of the metric system units is preferable and simplifies all calculations. The grade-sizes adopted in this account are therefore expressed in millimetres, and may be converted to English units if required (25·4 mm. = 1 inch). Screens are frequently made according to English units, 30, 60, 90, etc., meshes to the inch. In the I.M.M. mesh screens (inch-units) the thickness of the wires is equal to the diameter of the aperture, hence, for example, a 120-mesh screen has apertures about ·004 inch in diameter (about 0·1 mm.). In other screens (30, 60, 90 mesh, etc.) this is not the case, the wires being of smaller diameter than the apertures. Accurate grading cannot then be carried out.

A plea must be made for uniformity in the expression of grade-sizes, preferably in millimetres. The brass-screens in use in this country for soil-analysis and other grading work, while often made according to metric units (frequently in Germany) are in nests of 2 mm., 1 mm., 0·5 mm., and 0·25 mm. diameter holes, the last being square wire-mesh, and the others punched round holes. In some of the literature on mechanical analysis of sands, the last mesh-size or elutriation-size is taken at 0·2 mm. diameter instead of 0·25 mm. It is then difficult to institute comparison between analyses. The size 0·25 mm. diameter is adopted here, on account of the exigencies of the apparatus used.

(b) *Elutriation.*—For determining smaller grades of sand, screening should give place to elutriation. The process of elutriation is a classification of particles according to size by means of upward currents of water. The final velocities attained by small grains of a particular mineral of known size, when they are allowed to settle freely in water, have been determined both by calculation and experiment. The results have proved to be remarkably concordant and indicate that the controlling factor in the settling of small particles is surface-area, and not density. The free settling of particles in a liquid is due to gravity, but the velocity attained is reduced by the viscosity of the liquid. The settling of grains of diameter up to about 0·2 mm. thus conforms to a law which has been termed* "the law of viscous resistance." The velocity varies as the square of the diameter of the particle. The settling of grains above about 0·2 mm. diameter is controlled by another law, that of "eddying resistance," where the velocity varies as the square-root of the diameter. Elutriation, however, is concerned

* Stokes deduced the law on purely theoretical considerations. Richards, 'Text-book of Ore-Dressing,' New York, 1909, p. 264.

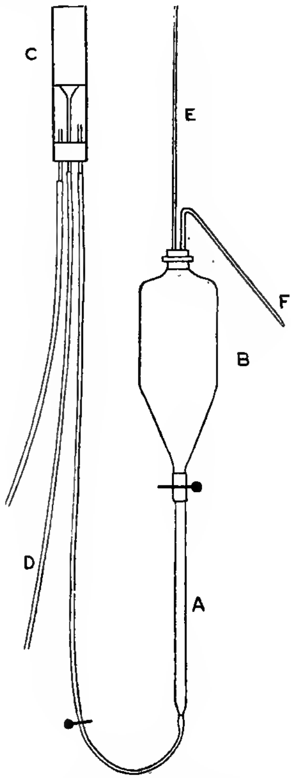
only with separation of grains up to about 0·25 mm. diameter; above that size, sifting is usually adopted. In elutriation the assumption is made, and has been found to be justifiable, that the final velocity of any grain of known size is that of the upward current of water which will just keep the grain in suspension. The process enables us to classify sediments into grades, if desired, down to a limit of 0·005 mm. (about 0·0002 inch) diameter.

The two chief forms of elutriators used by the writer in the investigation of sediments are the Crook pattern and a modification by Stadler of the Schoene type. The former apparatus *, designed by Mr. T. Crook of the Imperial Institute, is simpler to make and work, and enables a mechanical analysis to be made more rapidly than the Schoene, all the grades being separated at once. The apparatus will be best understood from the sketches. The Crook elutriator consists (Fig. 2 & Plate I, fig. 1) essentially of two cylinders, a lower narrow one A and an upper broad one B. In order to obtain a constant rate of flow upwards for the water in these cylinders a small movable reservoir C is used, with an overflow funnel and tube D. The reservoir C can be moved up and down, and a constant head and pressure of water may be obtained in the apparatus when these vary in the water-taps of the laboratory.. The vessel B is fitted with a double-holed stopper through which passes a straight tube E acting as a manometer, and a bent tube F with a jet at the end. The velocity of the upward current of water in A and B is regulated by the size of the jet-opening, and the height of the water-level in C, which may be moved up and down, and is marked by the height to which the water rises in E. For separation of the sediment into sand-, silt-, and clay-grades (1 mm. to 0·1 mm., 0·1 mm. to 0·01 mm., and less than 0·01 mm. diameter) the internal areas of cross-section of the cylindrical parts of A and B must be closely in the ratio of 1 to 50. Convenient sizes are found to be 1·4 cms. diameter for A, and 9·6 cms. diameter for B, in which case to obtain the required upward velocities of the water, of nearly 7 mms. per second in A, and 0·15 mm. per second in B, the jet F is found to be about 1 mm. diameter, and must permit an outflow of nearly 100 c.c. in 90 seconds. The outflow is controlled and varied by movement of C, and when the correct measure is found the height of the water-column in E is marked and should be kept constant. The tube A should be about 30 cms. long with a slight constriction in the drawn-out bottom end (which may also be roughened) to facilitate the grip of the rubber tube upon it. The vessel B is about 14 cms. long in the conical part and 12 cms. long in the cylindrical part. The lower portion of B and the tube A should be of the same diameter and joined by rubber tubing of the same internal diameter fitted with a clip. Another clip is used to cut

* T. Crook, Appendix to Hatch & Rastall, 'Sedimentary Rocks,' London, 1913, p. 349. Apparatus made by Messrs. A. Gallenkamp & Co. Ltd., Finsbury Square, London, J. Moncrieff, Ltd., Perth, and Muller, Orme & Co., 148 High Holborn, London.

off A from C. Other details will commend themselves to the user of the apparatus. A weighed quantity of sediment (10 or 20 grammes) sifted to 1 mm., after being suitably treated if clay is present (boiled with water and deflocculated by the addition of pyrogallol or such an alkali as ammonia or washing-soda) is introduced into B. When the clips are released, the upward currents of water separate the material into grades, the sand-grade from 1 mm. to 0·1 mm. diameter being buoyed up in A, the silt-grade from 0·1 to

Fig. 2.—*Crook's Elutriator.*



A. Lower cylinder for sand-grade.

B. Cylinder for silt-grade.

C. Movable reservoir giving head of water.

D. Overflow tube.

E. Pressure-gauge.

F. Outlet tube and jet.

0·01 mm. diameter being held in suspension in B, and the clay-grade being carried over by the water through F. The last grade may be collected in large jars and allowed to settle. The water may then be decanted off, and the sediment dried and weighed. As it is sometimes necessary, with clayey deposits, to keep the apparatus going for 12 or more hours, until the separation is complete (shown by clear water passing over from B), a very large bulk of water accumulates, and settlement takes much time; moreover, the fine clayey material is difficult to deal with. When separation appears to be complete, the screw-clip between A and B should for a short time be closed a small amount before the grades in A and B are finally clipped off from one another. It is the usual practice, after drying and weighing the separated grades in A and B, to find the grade of $<\cdot 01$ mm. diameter by difference. The proportion of material of diameter >1 mm. may be found by sifting before elutriation. The grading obtained by this apparatus is therefore >1 mm., $>0\cdot 1$ and <1 mm., $>0\cdot 01$ and $<0\cdot 1$ mm., and $<0\cdot 01$ mm. As it is often desirable to know the percentages of fine, medium, and coarse sand, the dried portion of diameter $>0\cdot 1$ and <1 mm. may be subjected to sifting through 0·5 and 0·25 mm. sieves.

In the case of true sands, very little material should be found in B or pass over through F. The height to which a known weight of sand is borne up in A during the experiment gives the observer an idea of the proportion of the coarse, medium, or fine sand-grades. For example, in the elutriation of Fontainebleau sand, a seething mass of grains 10 cms. high, with a sharp upper limit and almost clear column of water above, is seen in A. The sharp upper limit indicates a high percentage of one grade such as coarse sand, medium sand, etc. An indefinite, hazy border, or the complete occupation of A denotes a mixture of grades, and the sand is therefore not of the best for glass-making. Crushed rocks invariably give the latter result.

The great feature of Crook's apparatus is its simplicity and rapidity of working. By adjustment other grades than those >1 mm., $>0\cdot 1$ mm. and <1 mm., $>0\cdot 01$ and $<0\cdot 1$ mm., and $<0\cdot 01$ mm. can be separated. The Schoene apparatus (or its modification here described) enables grades between any desired sizes to be separated, as many as eight or nine grades being obtained if desired. The apparatus requires much more attention, and, since the grades are separated one at a time, a complete analysis of a sediment may take a considerable time (sometimes a week of working days).

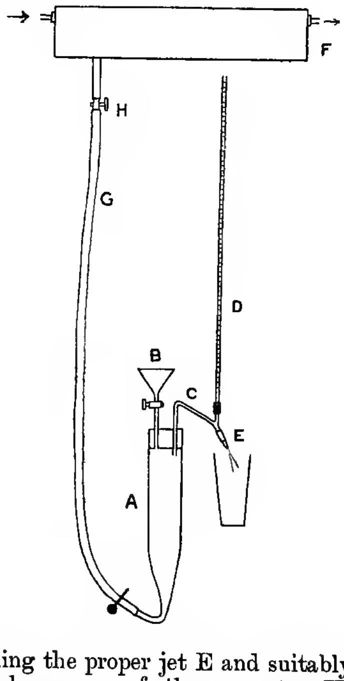
The Stadler modification of the Schoene apparatus * is represented simply in Fig. 3 and Plate I, fig. 2. Essentially it consists of a cylindrical vessel A about 40 cms. long and 9 cms. diameter drawn out and bent round at the bottom, and fitted at the top with a stoppered funnel B, and outlet tube C. The tube C divides into the vertical piezometer tube D which registers the pressure and therefore the velocity of water passing through A, and a jet E. The tank F gives a fixed head of water; the latter passes down the tube G, controlled by a stop-cock H, into A. A short length of glass tubing and a clip are attached to the

* H. Stadler, *loc. cit.* p. 689. Made by Messrs. Griffin & Co., Kingsway, London. Mr. T. Crook suggested a modification of the Schoene apparatus, using jets of varying size, in Roy. Dublin Soc., Econ. Proc. vol. i. pt. 5 (1904) p. 267. On elutriators generally, see Keilhack: 'Lehrbuch der praktischen Geologie,' 1908, 2nd ed., Stuttgart, and Ries: 'Clays, their Occurrence, Properties, and Uses,' 1908, 2nd ed., New York.

lower end of A, which may be fitted with a glass stop-cock. The tube D is about 100 cms. long and is suitably graduated. A series of jets (best made by the operator and standardized with the instrument) with holes from 2 mms. diameter down to an extremely small size (about 0·25 mm.) are fitted in turn at E. Knowing the internal diameter of A, and measuring the volume of water outflowing per second from each jet, we can plot curves and draw up a table showing the jet used and the piezometer reading for all the velocities of water in A we require.

A weighed quantity of sediment, previously treated as described, is washed down through B into A, and separated into grades com-

Fig. 3.—*Stadler's modification of the Schoene Elutriator.*



A. Elutriating cylinder.

B. Intake funnel for sediment.

C. Outlet tube.

D. Piezometer.

E. Variable jet.

F. Tank to provide fixed head of water.

G. Connecting tube for water-supply.

H. Screw-tap.

mencing with the finest, by attaching the proper jet E and suitably adjusting the water-level in D by means of the screw-tap H. To distribute the water-current entering A, shot or mercury may be placed at the bottom. The grades are thus separated one at a time and the procedure is slow, so slow, indeed, as to give time for complete settlement of the finest grades as they come over, and permit decantation and estimation. The grades separated depend on the kind of work. Mr. H. Stadler, of the Royal School of Mines, classifies battery-pulps in a series of grades in a reduction ratio of the weight of a grain of each grade of four to one. For glass-sands, moulding-sands, and general geological work, it is more advantageous to adhere to the classification detailed above, but the apparatus permits the estimation of certain useful intermediate grades ($>0{\cdot}01$ and $<0{\cdot}05$, $>0{\cdot}05$ and $<0{\cdot}1$ mm. etc.).

The relative advantages and disadvantages of the two forms of apparatus cannot be discussed here, but it may be repeated that for work dealing largely with deposits which are essentially sands, Crook's apparatus, combined with careful sifting, is simpler and more rapid in its action. The wide cylinder B in Crook's elutriator may be substituted for the cylinder A in the Schoene apparatus, giving greater accuracy in the separation of the fine grades, while using the latter apparatus.

(c) *Graphical Expression of Results.*—The expression of mechanical analyses in the form of curves brings out contrasts and similarities in sediments more graphically than does the use of space (*e.g.* "strip" or "butterfly") diagrams. Similar graphs have been used for screening-analyses in connexion with water-supply and percolation, in the publications of the United States Geological Survey, and for analyses of moulding-sands in those of the Geological Survey of Denmark. The curves here drawn are to be regarded as approximations only, serving to visualize the lists of figures given in the tables of mechanical analyses. Reference should always be made to the latter. Cumulative percentages by weight of material above the grade-size (marked horizontally) are set off vertically as ordinates. For example, in the curve XW (Fig. 4) representing a specimen of London Clay, about 17 per cent. of the sample is of diameter greater than 0·1 mm. and about 55 per cent. of diameter between 0·1 and 0·01 mm.; the ordinate at the latter grade-size is therefore $17+55=72$ per cent. The horizontal scale adopted is proportional to the logarithms of the diameters quoted, in order to keep the various grades down to clay within the compass of the page.

The curves are plotted from four or five points, with information for intermediate points obtained from microscopic examination.

Horizontality in any part of the curve means the absence of the grade-size corresponding to the distance that such horizontality extends. Verticality in the graph means a considerable percentage of the grade-size corresponding to the position of the vertical portion. In the figures for glass-sands and other similar well-graded sands the verticality is probably greater than represented, but the absence of information as to percentages of intermediate grades prevents more accurate plotting. All the curves eventually turn up at the right-hand end (in the clay-grade portion) when the total reaches, as it must do, 100 per cent. The approach to the upper line may be asymptotic, *i.e.* the particles may gradually become smaller and smaller to vanishing point; but it is more probable that in most sediments a lower limit of size of particle is reached, when the curve turns up thus ——⁄. Probably solution eventually causes the disappearance of tiny particles before they disintegrate mechanically.

Representing the mechanical composition of a sediment as a

Fig. 4.—*Mechanical Analyses of Sediments : Graphical representation.*

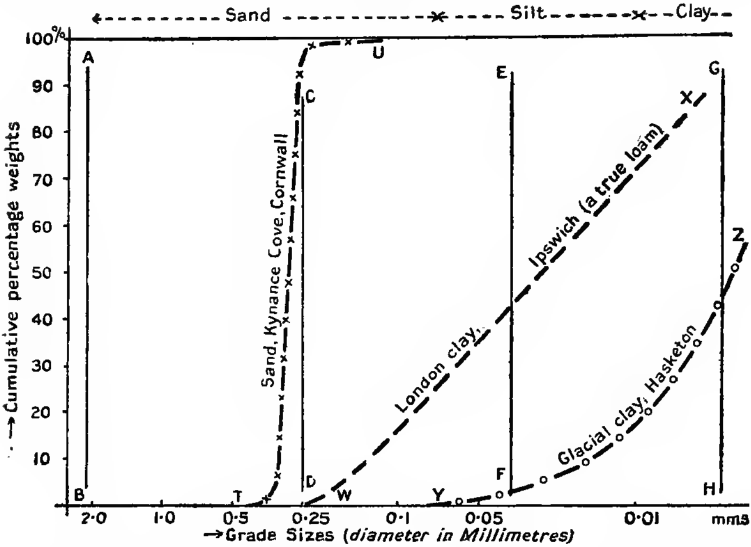
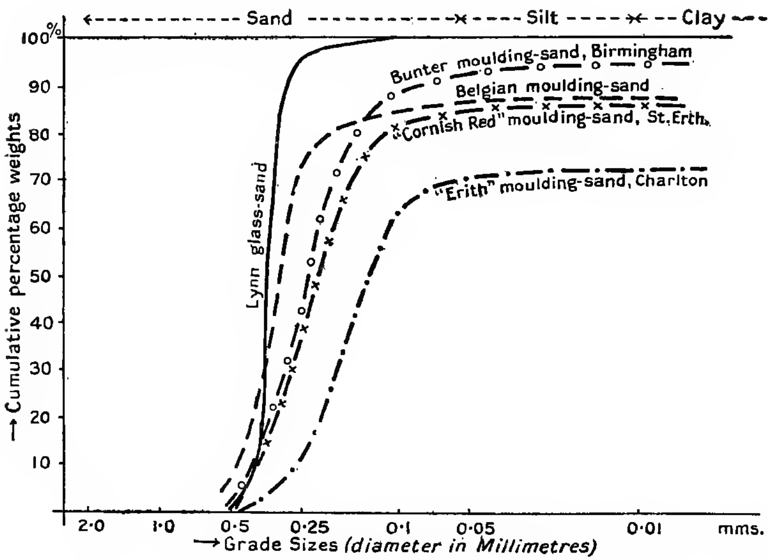
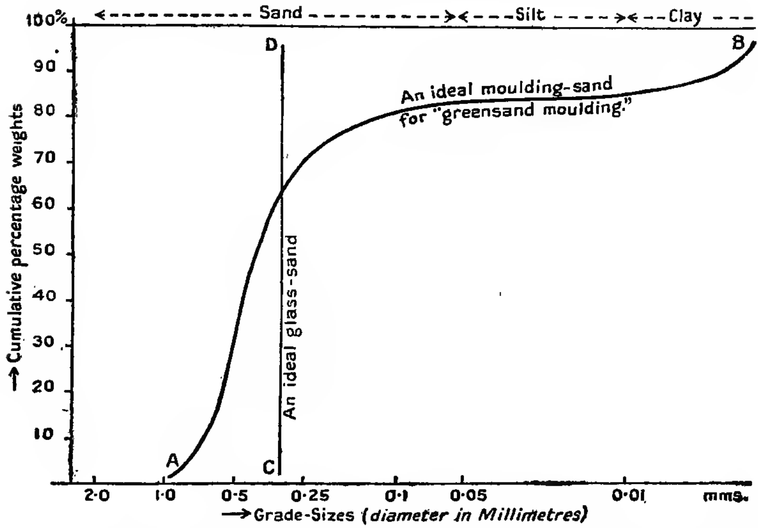


Fig. 5.—*Mechanical Analyses of Sands : Moulding- and Glass-Sands compared.*



curve (Fig. 4) obtained by plotting cumulative percentages of the various grades against the diameter of particles in the grades, we see that a pure gravel, 100 per cent. of diameter not less than about 2 mms., is represented by the vertical line AB, a pure sand of medium grade by CD, a pure silt by such a line as EF, and a pure clay by another vertical line such as GH beyond. Such ideal sediments do not seem to be present in nature. The curves TU, WX, and YZ represent actual British sediments which have been subjected to mechanical analysis. The curve TU is that of a true medium sand from the shore at Kynance Cove, Cornwall, WX is a true loam, worked for brick-making, from the London Clay at

Fig. 6.—*Mechanical Analyses of Sands. An attempt towards representation of Ideal Glass- and Moulding-Sands.*



Ipswich, and YZ is a true clay of Upper Glacial age from Hasketon, Suffolk. These three sediments approach very nearly to the highest perfection to be expected from natural deposits. With them should be compared the curves indicated in Fig. 5, which are of some well-known and successful English moulding-sands. The upper curves, representing the famous "Belgian Red" and "Cornish Red" (Pliocene Beds, St. Erth, Cornwall) moulding-sands, etc., are clearly from their position indicative of coarser sediments than the other represented, which is the well-known "Erith" sand from Charlton (Kent), much finer in grain. In spite of the variation in size of the constituent grains, the proportion of the grades is constant and causes the curves to be remarkably

Fig. 7.—*Mechanical Analyses: Unsorted Deposits.*

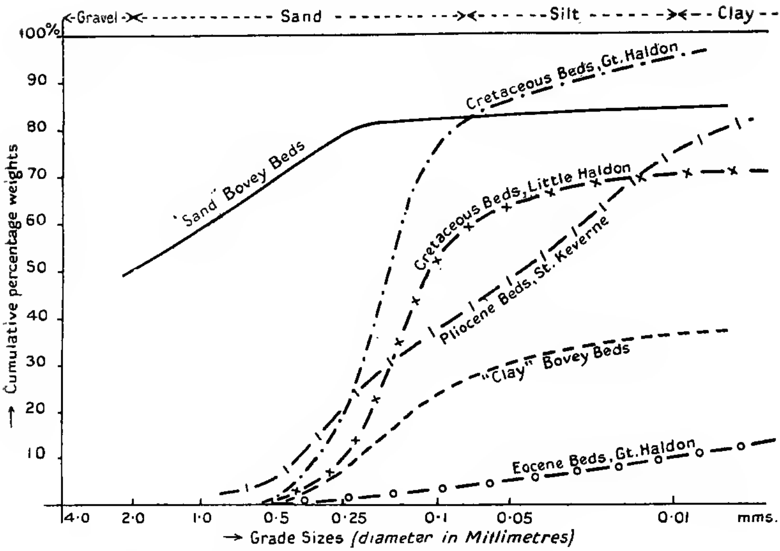
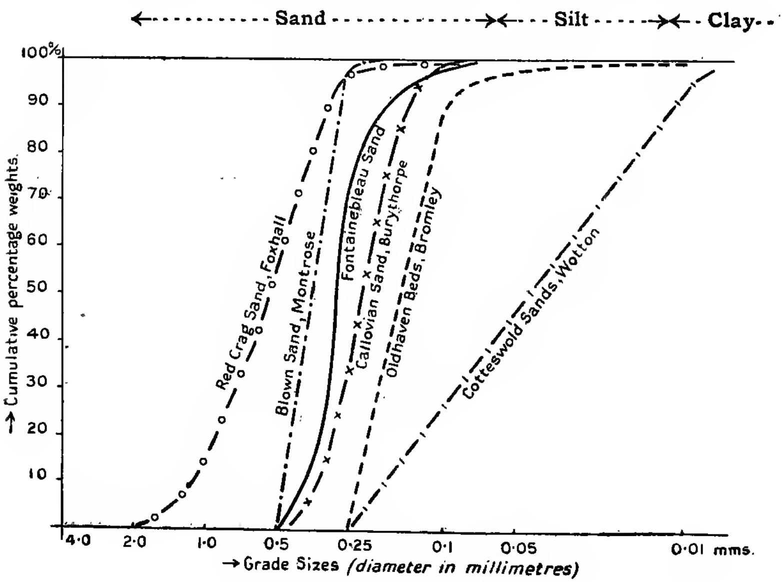


Fig. 8.—*Mechanical Analyses: possible variation in true sands.*



sympathetic. The graph of the "Belgian Red" moulding-sand is seen from the figure to cut across the others, owing to that deposit containing a greater proportion of clay, apparently ferruginous kaolin. Actually it is more nearly the ideal moulding-sand expected on theoretical grounds, *i. e.* one with high clay-grade for bind, and with a good quantity of sand-grade (other than fine sand) for openness and ventilation. The ideal moulding-sand for "greensand moulding" would be graphed as in Fig. 6, AB, the horizontal part of the curve passing over the fine sand- and silt-grades. Some of the Pliocene, Eocene, and Cretaceous Beds fringing the kaolinized granite-masses of Devon and Cornwall approach very closely to this ideal. Moreover, the clay-grade is composed largely of kaolin, the refractory properties of which are excellent. The difficulty to be solved is that of making the kaolin, which is not a very plastic clay, into a good "bind."

On the other hand, a perfect glass-sand should be all of one grade, preferably among those sizes not so desirable in a moulding-sand. In other words, a sand from which glass is to be made should have all its grains of one size, not greater than 0·5 mm. or less than 0·1 mm. diameter. The curve CD (Fig. 6) would represent such a sand.

With these ideal cases should be compared those of Fig. 7, representing such unsorted deposits as those mentioned in Chapter II. The curves in Fig. 8 show the possible variations in grade of British sands, and from a comparison of Fig. 8 with Figs. 9 & 10, page 48 (see also Plate III, figs. 1–5), the special grading of sands for glass-making will be realized. The badly-graded products obtained by crushing rocks are indicated in Fig. 11, p. 71 (see also Plate III, fig. 6).

CHAPTER IV.

Glass-Manufacture.

Literature on Glass-Sands, etc.—Very little appears to have been written in any language upon the important subject of glass-manufacture, and especially in this country is there a dearth of literature bearing upon the problem. Only a small amount, too, of the available literature refers to modern processes and developments. For those interested in the methods used, and those who desire to realize to what extent knowledge of our geological resources may help the trade, the following works may be recommended:—

Glass Manufacture (Constable, 6s.), by Walter Rosenhain, 1908.—A very interesting and simple introduction to all aspects of the work; the raw materials, properties and kinds of glass, furnaces and processes, are treated in a very pleasing way.

The Principlss of Glass-making (G. Bell & Sons), by Powell and Chance. 1885.

Glass. Articles in 'Encyclopædia Britannica,' 11th edition, by Harry J. Powell and W. Rosenhain.

Jena Glass (Mm. & Co.), by Hovestadt; translated by J. D. and A. Everett.

References to other scattered papers, etc., and to French and German literature, will be found in an Appendix to the first work cited above.

Lists of formulæ for various glasses have recently been issued by the Institute of Chemistry *. Others are supplied confidentially.

On the important question of glass-sands, less still has been written; indeed, the literature may almost be said to be non-existent. In very few countries do we know the properties, quantity, and workability of the sand-resources generally, and little of this knowledge concerns glass-sands.

No thorough discussion of the properties and desiderata of glass-sands is known to the writer. Scattered notes are to be found in publications of the Geological Surveys of the United States, Denmark, etc. These are referred to in their appropriate places hereafter.

The dearth of literature upon glass-sands in this country is doubtless due to the fact that before 1914 manufacturers of glass in the United Kingdom used large quantities of foreign sands, notably from France, Belgium, and Holland. The use of such imported sands, frequently to the entire exclusion of

* Proceedings, 1915, Parts ii., iii., & iv.

our own resources, was due to two main causes: in the first place, the sands were generally purer than the obtainable British sands, and, in the second, the cost was less, particularly when foreign sands were brought back as ballast on a boat's return journey. The latter state of affairs arose because the British supplies of sand were frequently situated inland; thus the cost of transport by water from abroad was less than that by rail from one part of the country to another. So little has Britain investigated and relied upon her own resources of sand, that it is not surprising to find a German writer upon glass-making declaring categorically in 1885 that the English sands were iron-bearing, while only those of the Isle of Wight were considered worthy of mention. It is stated that the English obtained glass-sand from France, America, and Australia! * Such statements are hardly correct; for as far back as 1858 Northampton Sands, Ashdown and Tunbridge Wells Sands, Aylesbury sands, Aylesford sands, Lynn sands, Thanet Sands, Bagshot Sands, and others were already in use †.

Tscheuschner, the German writer referred to above, mentions that glass-sands were obtained in France from Maintenon, Fontainebleau, Nemours, and Champagne; and in the German Empire from Nievelstein in the Rhine Province, Hohenbocka in Prussia, and Lemgo in Westphalia.

Raw Materials: Importance of Sand.—The various kinds of glass may be regarded as mixed silicates (and, to a smaller extent, borates) of the alkalies, sodium and potassium, the alkaline earths, calcium, barium, magnesium, etc., and lead, iron, and aluminium.

Probably these silicates, borates, and oxides are in a state of mutual solution in one another; but, just in the same way as much dispute exists among petrologists as to the combinations into which the various elements enter in a natural molten rock-magma (of which a natural glass such as obsidian is only a solidified form), so authorities on the chemistry of glass are by no means agreed upon the actual compounds formed. The geologist is mainly concerned with the fact that the finished product, glass, consists of 60 to 75 per cent. of silica, which is contributed to the raw mixture or "batch" in the form of a sand.

The "batch" or mixture of raw materials such as sand, soda-ash (Na_2CO_3), salt-cake (Na_2SO_4), potash (as K_2CO_3 or KNO_3), limestone ($CaCO_3$), red lead (Pb_3O_4), manganese dioxide (MnO_2), coke or anthracite (C), alumina (Al_2O_3), boric anhydride (B_2O_3), barium carbonate, calcium fluoride, etc., according to the kind of glass required, usually consists of 52 to 65 per cent. by weight of sand. A small amount of silica is sometimes added in the

* 'Handbuch der Glasfabrikation,' E. Tscheuschner (Weimar, 1885), p. 72. Analyses of some English glass-sands are also given in Dralle's 'Die Glasfabrikation,' and of German glass-sands in the 'Sprechsaal Kalendar' (*e. g.* 1916).

† Mineral Statistics: Mem. Geol. Survey (1860, being Part ii. for 1858), p. 374.

form of felspar; but the percentage is increased in the final product (which, when molten, is termed "metal"), as a result of the loss of such gases as SO_2, CO_2, etc. The silica-percentages in some well-known glasses are as follows:—Window 53 per cent., lead flint 53 per cent., soft soda (chemical laboratory ware, X-ray tubes, etc.) 54 to 56 per cent., green bottle 57 per cent., miners' lamps 59 per cent., combustion tubing 60 to 62 per cent., plate 62 per cent., resistance (very like Jena) 63 per cent., soda-lime (Venetian) 73·4 per cent., potash-lime (Bohemian), 71·7 per cent., and so on, the proportions varying somewhat in actual practice.

In point of bulk, therefore, the sand is the most important ingredient, and its properties influence to a large extent the character of the glass obtained.

As emphasizing the bearing of the sand used upon the qualities of the glass, an example given by Hovestadt may be quoted. Thermometer-glass, made in the Thuringian Forest district, owes its special quality to certain sand found only in the neighbourhood of the village of Martinroda. 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. Other sands are believed to be unsuitable, especially the pure sand from Brandenburg. The cause of excellence is believed to be due to the alumina present, which forms 3·66 per cent. (p. 21, Everett's translation).

Colour etc. of the Glass.—Upon the sand depend the transparency, brilliancy, lustre, and hardness of glass. The uniform density of glass, as will be seen in the sequel, is influenced to no small extent by the mechanical composition of the sand. In order that the finished article may have plenty of "life," and the sparkle and "water-whiteness" of the best glass, due attention must be paid to obtaining, and treating suitably, the sand itself.

For optical glass and table-ware ("crystal" and "cut-glass") only the purest sands can be used.

Where the glass is blown or rolled into thin sheets, as in the making of laboratory-ware, lamp chimneys, incandescent electric globes, window-glass, etc., the requirements are not so exacting, but the sand must still be fairly pure. The light passes through only a small thickness of glass, which, although possessing a slight colour when seen in a thick mass (sometimes a faint green due to the small quantity of iron in the sand, at others a faint pink due to manganese which has been added in the form MnO_2 as a corrective to the iron), appears colourless and has plenty of life in the attenuated state. The colour may then be observed by looking at the object "edge-on," that is, through a much greater thickness of material.

While only the merest trace of iron impurity in the sands is permitted for optical and cut-glass, less pure sands containing 0·1 per cent. of Fe_2O_3 may be used for plate- and window-glass, chemical apparatus, globes, etc.

Small quantities of iron or other impurities are sufficient to detract from the lustre of table-ware, or to spoil the power of transmitting light possessed by lenses and prisms of optical glass.

Coloured glasses are prepared in one of two ways, the more common being that of adding a chemical compound to the batch, and thus obtaining a coloured silicate (chromium for green glass, cobalt for blue, etc.), or reduction to a very finely-divided metallic state (copper or gold for ruby glass). The other method is known as "flashing," and consists in covering the surface of colourless glass with a very thin coating of a coloured material (*e. g.*, copper or gold ruby glass, which is opaque when only $\frac{1}{16}$ inch thick). In either case, to obtain purity of colour, it is essential that no amount of impurity such as iron should be present.

The Process of Glass-making.—The manner in which the batch is melted to form the glass has also a bearing on the kind of sand used and its physical properties. Two different processes are adopted. The batch may be placed in open or closed "pots," or crucibles, which stand upon a kind of "false-bottom" in the furnace. This floor is known as the "siege" (Fr. *siège*) and has "ports" or openings in the middle (or in the end and side walls of the furnaces), by which the heated gas and air enter, playing around the pots. The pots are arranged around the periphery of the furnace to facilitate the extraction of the molten "metal" from them as "gatherings" upon the glass-workers' iron rods or blowing-irons. Melting of the batch from the bottom upwards is ensured as far as possible. For ordinary glass-work, open pots are used; but for special ware, impurities are kept out by using crucibles covered with a hood, "gatherings" being taken through a mouth-like opening at the side.

In the tank-furnace, the batch is melted in a long bath or tank constructed from blocks of highly refractory siliceous sandstone. Much larger quantities of material can be dealt with in this way; for, besides the larger capacity, the process is a continuous one, the batch being fed in at one end of the furnace (filling-hole) and the metal being continuously drawn from the other, and cooler, end of the tank (working-hole). Special and best quality glasses cannot be made in this way. The tank is not covered, and the mixture of burning gas and air, forming sheets and jets of flame, enters through ports in the side-walls above the surface of the metal.

The pots are usually made of fire-clay (or of fire-clay mixed with other highly resistant materials), and are very carefully prepared. The floors, sides, and crowns of the furnaces are constructed from highly refractory silica- and fire-bricks (*e. g.*, Dinas, Glenboig, and Stourbridge bricks, etc.), but frequently both pots and bricks are partially melted in the intense heat obtained in the furnace (1500°–1600° C.). Most furnaces are now built on the regenerative principle, by which the issuing hot spent gases are utilized to heat the incoming mixture of gas and air.

For the respective advantages of each kind of furnace, reference must be made to books or glass-workers. Briefly, it may be said that for special glasses, where covering of the metal is essential, when considerable time is occupied in complete fusion and mixture of the constituents, when they must be kept together long enough to combine, and where accurate regulation is required, the pot-furnace is more suitable. When large quantities of less pure glass are required, maximum space and heating are to be utilized, and time saved by continuous working (for pot-furnaces must cool down and be reheated, and pots fail and need renewing) the tank-furnace is best. The level of the metal is kept fairly constant, and therefore convenient for the withdrawal of gatherings, in a tank-furnace; while the glass left in the bottom of a pot frequently becomes "cordy" or "wavy" on blowing, and rarely is as good, or of the same composition and properties, as that already used from the pot.

CHAPTER V.

The Requirements of a good Glass-Sand.

The sand hitherto used in this country for all the best kinds of glass-work is that of Upper Oligocene age from Fontainebleau, near Paris. It is shipped from Rouen and delivered in Britain at a fairly cheap rate. Since the outbreak of war, manufacturers have found considerable difficulty in getting it through, owing to shortage of barges and labour, and the dislocation of trade. Enquiries were therefore made for suitable substitutes from the geological formations cropping out in Britain, with the results given later in this Memoir.

Characters of Fontainebleau Sand.—As a glass-sand, that of Fontainebleau nearly approaches perfection *. If, therefore, we look into its properties in some detail, we may hope to realize the desiderata of a first-class glass-sand, and know what to look for in any other deposits exploited for glass-purposes.

(a) *General Characters.*—To the unaided eye, the sand is a beautiful white, fine, even deposit. With a hand-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 for optical purposes and table-ware 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 appearance being due to the ordinary reflection of light from irregular surfaces. They are almost invisible under the microscope when mounted in media such as clove oil, Canada balsam, etc., the refractive indices of which lie very near to that of quartz (Plate II, fig. 1). The grains are free from the pale yellowish or brownish coating of iron oxide so frequently seen in sand.

(b) *Chemical Composition.*—Chemical analyses (*cf.* Table I.) 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, of course, 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.

* The sand from Lippe, in Saxony, is slightly purer, but Fontainebleau sand, being better known in this country, has been selected for description.

Chemical Analysis of Fontainebleau Sand.

SiO_2	99·80 per cent.*
Al_2O_3	·13
Fe_2O_3	·006
CaO	trace
Loss on ignition	·18
	100·116 per cent.

(c) *Mineral Composition.*—Fontainebleau sand, like many other very pure quartzose sands, contains less than 0·1 per cent. of heavy minerals, which is 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, in irregular black grains;
zircon, in slender prismatic crystals;
rutile, as irregular foxy-red grains;
ilmenite, altering to leucoxene;
tourmaline, blue and brown, in somewhat rounded prismatic fragments;
staurolite, in golden yellow angular grains;
andalusite, as small clear pleochroic grains;
muscovite, in larger flakes;
kyanite, in almost rectangular well-cleaved fragments;
limonite, etc.

From the chemical composition 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, however, that even with the large bulk of sand used for the batch, the aggregate amount of impurities is slight.

(d) *Mechanical Composition.*—The evenness in grain of the sand (to the eye) has been commented upon, and mechanical analyses determined in elutriators like those described in Chapter III. are:

Diams. in mm.	C. >0·5 & <1.	D. >0·25 & <0·5.	E. >0·1 & <0·25.	F. >0·01 & <0·1.	G. <0·01.	C–E. Total sand-grade: >0·1 & <1.mm.
1	<0·1 %	70·6 %	26·6 %	2·8 %	...	97·2 %
2	......	70·3	28·3	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. S. N. Jenkinson, Managing Director of the Edinburgh and Leith Glass Co. Ltd., of Edinburgh.

* In this and other analyses, the silica was estimated by the usual method of fusion with alkaline carbonates, checked afterwards by the use of hydrofluoric acid. The iron was estimated as Fe_2O_3 on 5-gramme samples.

The ordinary commercial chemical analyses of sands (which usually give a total of exactly 100 per cent.!) are of little value for glass-making purposes.

A suitable method of graphical expression is by means of a curve, as in Figs. 8, page 30, and 9, page 48. Practically no grains occur with diameter above 0·5 mm., and very few are below 0·1 mm. diameter (see Plate III, fig. 1).

(e) *Shape of Grains.*—Lastly, as regards shape, Fontainebleau sand is made up of grains consistently subangular. To what extent the rapid and even melting of the batch depends upon the shape of the grains of sand 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, subangular, and rounded fragments.

(f) *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 due to the insular position of Britain, and 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.

Requirements of Glass-Sands.

Up to the present time most manufacturers and writers have been inclined to emphasize the importance of chemical analysis, and to demand a very high standard of purity in the sand. Experimental work carried out since the opening of the war has tended to indicate that fairly pure British sands can be used with success for much good flint-glass work, thus tending to destroy the fetish of "nothing but Fontainebleau." Indeed, a few of the managers who have studied the technique of their work place the question of the evenness of grain of their sands on an equality with, if not above, that of very high silica and very low iron-content. In the manufacture of glass other than that for optical purposes (where exceedingly pure sands are sometimes required) the mechanical analysis is of great importance.

1. *Chemical Analyses.*—From the chemical point of view, sands for glass-making should have a very high silica-content, preferably over 98 per cent., and for the best work over 99·5 per cent.* ; they should have a low iron-content, for the best glass-work below 0·05 per cent. Iron is always present in the heavy detrital minerals, as magnetite, limonite, or ilmenite, or in the form of silicates, etc., but since the heavy crop in a suitable glass-sand is always less than 1 per cent., it is not the iron so present which determines the suitability or otherwise of the sand. Even such a very pure sand as that from Fontainebleau contains a proportion of dense minerals, but its low iron percentage is due to the absence of any

* See chemical analyses in Tables. In addition to these, Hohenbocka sand is said to contain 99·71 per cent., and sand from Nievelstein, in the Rhine Province, 99·97 per cent. of silica.

coating of limonite (hydrated iron oxide) or hematite (Fe_2O_3) upon the quartz grains. This iron staining in sands, which is the cause of the rejection of a large number of English samples, usually exists on the outside of the quartz and felspar grains, but is sometimes seen inside, due to subsequent growth of quartz after deposition of the pellicle of iron oxide. Inclusions of ferruginous material also occur in quartz and felspar, having been caught up and enclosed at the time of their crystallization.

The iron percentage should therefore always be low, but a small amount present in the sand need not render it unsuitable, provided the mechanical analysis is satisfactory, for much good glass-work, such as lamp chimneys, globes, laboratory-ware, etc. The green or yellow colour due to iron may be corrected by the addition of decolorizers (including oxidizing agents or oxygen carriers) such as manganese dioxide, white arsenic (As_2O_3), nickel oxide, selenium, etc.

Glassy rocks, such as obsidian, tachylyte, etc., which are produced by the rapid cooling of igneous magmas, similarly owe their dark green, black, or brown colour to the presence of iron-, alumina-, lime-bearing, etc. compounds. Similar "black" or dark green bottle-glass may obviously be made from impure sands.

In consequence of the demand for a high silica-percentage, the sands used are for the most part almost entirely composed of quartz. The presence of felspar in a glass-sand is desirable for many purposes, but, unfortunately, it usually means an increase in iron and other constituents. The usual method, therefore, of obtaining the required amount of alumina and alkalies is to add pure felspar, alumina, and salts of potassium and sodium to the batch. Sands low in iron are generally very free from other constituents also, rarely containing, except as traces, substances other than alumina. To yield the proportion of alumina required for certain glasses, a sand consisting of 40 per cent. to 60 per cent. of felspar would be required. Such sands, if they are to be free from iron oxide and certain other substances, are very rare, and indeed could only result from the denudation of such a rock as a very pure quartz-porphyry or a pegmatite, with no admixture from any other source. In Chapter IV. (p. 34) the Thuringian Forest sand, bearing 3·66 per cent. of alumina, was mentioned as being especially suitable for the making of thermometer-glass.

Calcareous sands are of frequent occurrence, but are to be avoided. The calcareous material is often sporadic in its distribution. The Fontainebleau deposit is well known to geologists for the beautiful steep rhombohedral crystals made up completely of sand grains, just cemented by calcite into the crystal shape. The sand used for glass-work is selected free from this calcareous material, but occasionally the supplies received in Britain contain a few chalk-cemented balls. These are objected to when found, but usually all the consignments are similar in their purity and remarkably true to sample. Other impurities also tend to occur in calcareous sands; and lime itself is an undesirable constituent in sands used in the manufacture of certain kinds of glass.

2. *Mineral Analyses.*—The mineral composition is useful as giving an indication of the relative amount of heavy detrital minerals present in the sand, and the quantity of quartz and felspar in the lighter crops. Sands with large crops of heavy minerals can only be used for rough bottle-glass, etc. Indications of the presence in quantity of minerals other than quartz are, of course, yielded by the chemical analysis. Mineral analysis is, however, a shorter and less tedious process, and like the spectroscopic examination of sands, reveals the presence of small quantities of the less common elements. Naturally-panned sands—namely, those in which the heavier minerals have been concentrated as a result of oscillation produced by wind- or water-currents—must be avoided, even if, as in some cases, they are white and clean-looking. Iron minerals frequently make up a considerable bulk of a heavy residue. Sometimes, by the combined effects of wind-action and screening by vegetation (as in some of the Irish dune- and beach-sands), a kind of winnowing action takes place and sands may be locally purified from heavy minerals. Most of the British dune- and beach-sands are, however, made up of mineral material derived from many sources, and while yielding interesting mineral assemblages (including micas in English, Scotch, and Irish samples, although Retgers states that these minerals do not occur in Dutch dune-sands) are, in spite of being washed free from some adherent limonite etc., of little use except for green bottle-glass work.

The presence or absence of certain minerals highly objectionable in glass-making may quickly be noted by mineral analysis. Zircon crystals ($ZrSiO_4$) are very undesirable on account of their highly refractory character. They remain undigested in the metal. Titanium minerals such as ilmenite ($FeTiO_3$), rutile (TiO_2) and its isomers, anatase and brookite, are also detrimental to the making of good glass. Titanium is always an objectionable constituent of the metal, and it so happens that ilmenite and rutile, like zircon, are among the most commonly occurring detrital minerals.

3. *Mechanical Analyses* (see p. 23 for description of apparatus, etc.).—Elutriation is carried out on the assumption that the sediment is composed entirely of quartz, or minerals of the same density. Most sediments contain so small a percentage of heavier or lighter minerals, that the error introduced by the latter is less than that due to experimental causes.

Mechanical analyses of glass-sands, including many from abroad which are successfully used in the trade, indicate that the sand should have at least 70 per cent., and, if possible, more than 90 per cent., of one grade, and that this grade should be in most cases medium sand, *i. e.* with diameter between 0·25 and 0·5 mm. (0·01 to 0·02 inch). Although a "medium" sand in the geological sense, it is a fine looking material to the eye. If the true "fine sand" grade, 0·1 to 0·25 mm. diameter, forms the bulk of the deposit, so much the better, but such sands are not abundant in the British Isles. A distribution of the bulk of the sand over these two grades is also not very objectionable, although glass-makers naturally prefer constancy of size. Grains over 1 mm. diameter in a sand reduce its value considerably, and it is best that none should have a diameter greater than 0·5 mm. diameter. If the extra expense is not prohibitive, a pure and fairly well-graded sand may be sifted by screens to rid it of grains over 0·5 mm. diameter. Of the few sands used in glass-making, containing the coarse grade, we may mention that from Leighton Buzzard in Bedfordshire (Lower Greensand). The sand as supplied has been washed, and contains 24·6 per cent. by weight of diameter between 0·5 and 1 mm., and 74·3 per cent. of diameter 0·25 to 0·5 mm. The latter grade is suitable and its percentage is fairly high, but it would be desirable if the other 25 per cent. were of the next smaller, and not the next larger, grade, as in the case of Fontainebleau sand, where $>0·5$ mm. diameter = 0·1 per cent. or less, $>0·25$ and $<0·5$ mm. = 70·6 per cent., and $>0·1$ and $<0·25$ mm. = 26·6 per cent.

If the "batch" is ground fine before being melted the question of grade-size in the sand is obviously not of such moment, and high silica and low iron percentages are the desiderata. Leighton sand was used in this way by one firm making chemical glass-ware, but it is doubtful whether much advantage accrues from the grinding except in the case of the best glass-ware. The extra expense is considerable.

As the tables indicate, there are many British sands of which the mechanical analyses are similar to that of Fontainebleau sand. The regularity of grade of blown-sands in various other parts of the world has previously been commented upon, and the same holds true with British dune- and shore-sands. Although the evenness of these sands, due to selective transportation and deposition of material, renders them very suitable for glass-making, the colour, as previously remarked, shows the presence of too much iron and heavy mineral residues for the sands to be used for other than common bottle-glass. Dutch and Belgian sands imported into this country vary considerably in character. They are uniformly high in silica, some varieties containing pink quartz, and are used for other purposes, as well as glass-making, on account of their refractory properties. The colour and iron-content vary somewhat, but the grade-analysis, although variable, usually shows a high percentage (over 90) of the medium-sand grade. These are good all-round sands, and the nearest English equivalent in mechanical composition is the Lower Greensand obtained from near King's Lynn, in West Norfolk (Sandringham Sands). Many qualities of this sand are supplied, and the best has a colour and low iron-content equal to those of the best Belgian sand, as well as a high percentage (95 per cent.) of the desirable grade. Further notes upon the various qualities will be found under the remarks upon this source of supply.

British sands with a high fine sand-grade include those of the uppermost Thanet Beds from the well-known Charlton pit in Kent, and the Kelloway Beds of Burythorpe, near Malton, Yorkshire.

The fineness of their dominant grade and its high percentage (nearly 70 per cent. diam. $>0{\cdot}1$ and $<0{\cdot}25$ mm.) are advantageous.

In the Tables the cumulative percentage of all the sand-grades ($>0{\cdot}1$ and <1 mm. diameter) is given in a separate column. This should approximate to 100 per cent. for glass-sands, and rarely be less than 95 per cent. The grade of diameter $>0{\cdot}01$ mm. and $<0{\cdot}1$ is best termed the silt-grade, but actually the coarser material of this grade is a superfine sand. It is therefore sometimes desirable to estimate it in two portions: (*a*) superfine sand of diameter $>0{\cdot}05$ mm., (*b*) silt of diameter $<0{\cdot}05$ mm. Certain deposits, for example, are certainly sands, but contain a high percentage of the grade $>0{\cdot}01$ and $<0{\cdot}1$ mm., the grains composing which are mostly above 0·05 mm. diameter. Such are the sands of the Inferior Oolite from Bridport, Midford, Yeovil, the Cotteswolds, etc., which show a remarkable uniformity of grade over a large area.

These Inferior Oolite Sands are unfortunately yellow in colour, contain much iron oxide, and heavy crops of dense minerals. They are occasionally calcareous, but clear rapidly to fine white micaceous sands on warming with dilute acid. Their use for glass purposes is therefore at present ruled out. Sands of this extremely fine grade are rare in the British Isles.

Sands to be used for glass-making should not contain much of the silt-grade. The clay-grade, of diameter $<0{\cdot}01$ mm., certainly should be absent. The percentages shown in the tables were estimated by difference (see p. 25). The figures in this column, therefore, include hygroscopic water (some of the samples were air-dried at first, and all the grades were dried at 100° C. before weighing), dust accumulated by exposure and in transit of the sand, limonite coating on grains in some cases, and films of soluble or other salts (*e. g.* sea salts in the dune- and shore-sands). Probably this grade is practically absent in most cases where it is recorded as less than 1 per cent.

Mechanical analyses of American and Danish glass-sands are appended for comparison.

Such sands as those of Triassic age from Worksop in Nottinghamshire, and Spital in Cheshire, actually contain clayey and silty material (including kaolin). Some of the clayey and dusty matter coats the quartz and felspar grains. The Tables indicate that, although they are fairly clean sands, they are not sufficiently well-graded to be suitable for the making of other than common glass.

The use of pot- or tank-furnaces has an important bearing on the grade of the sand used for the batch. When a poorly-graded sand, containing much fine powdery silica, is used in the batch for a tank-furnace, considerable loss due to "blowing-out" results. The other constituents such as compounds of the alkalies, which may be in the form of fine powder, melt more rapidly, and so are not lost.* A considerably higher temperature must be attained before

* In many works it is found that alkali dust and not silica is carried over into the flues and chokes them. Careful filling of the batch does much to prevent the loss of fine material, but rapidity of filling is essential. Damping the batch has also been recommended.

silica fuses; fine material is therefore carried away by the blast of gas and air before it melts. Not only does a real loss in bulk thus occur, but the resulting composition of the batch is changed. When melting takes place in pots, this loss by blowing-out is obviated. Silica in a fine state of division in a sand is also open to objection on other grounds. Air-bubbles entangled in the fine material are introduced into the metal from which they are removed only with great difficulty. The fine particles melt before the coarser ones, and the resulting metal sinks to the bottom. The density of the metal thus formed is not constant, and varies as the pot is depleted of its contents. If coarse material is present, the batch takes longer to melt, or these remain as undigested or partly digested lumps in the glass ("stones"). The results, therefore, of using non-graded sands are objectionable. The value of such a sand as that of Fontainebleau lies in the way the whole of the batch containing it passes smoothly into the molten condition at almost the same moment. Angularity or subangularity of the grains may contribute to rapid melting.

No arrangements for stirring the metal exist in most furnaces. The result of using imperfectly graded sands is the production of metal of unequal composition, texture, and density, with consequent trouble in working. Clayey materials also tend to cloud the glass, and kaolin itself is highly refractory and formerly rendered a sand containing it unsuitable at once.

The statement in an American publication (U. S. G. S. Bull. 285, p. 454) that sand of diameter less than $\frac{1}{60}$ inch burns out in the batch, giving less glass, is not borne out by British and Continental practice, where so much of the sand used is of diameter less than $\frac{1}{60}$ inch. Sand of 20 to 50 mesh, advocated by American writers, appears to be coarser than British glass manufacturers prefer to use.

4. *Angularity of Glass-Sands.*—The grains composing the sands in general use for glass-making in Britain are angular to subangular in character. Sands containing rounded grains are not popular with some glass manufacturers. The most obvious explanation of the preference for angularity seems to be that the grains fuse more rapidly, the process beginning at the corners and edges, the surface-area being much greater, volume for volume, than that of rounded grains. Some of the Belgian sands are highly angular, having a sharp feel to the fingers. Rapid melting is desirable and saves much time and trouble, and both furnaces and sands are called upon to contribute towards this end.

Sands composed of rounded grains appear to be successfully used for glass-making in America *.

In certain works where flint-glass table-ware and bottles have names and marks etched upon them by sand-blast action, the sand

* United States Geological Survey, Bull. 285, 1906, p. 454. See also Mineral Resources, 'Sand and Gravel' for 1915 and earlier years.

used in the blast as the abrasive is the same Fontainebleau, Belgian, Aylesbury, or Lynn sand as that employed in making the glass. Besides its marked angularity (so that its cutting power may be as great as possible), a sand for etching should be hard and tough. For common purposes a highly siliceous, *i. e.* quartzose, sand is suitable. It must be perfectly dry and of even grade (not too coarse), in order that it may pass freely through the funnels, etc., and not clog the jets and stencil upon the sudden release of pressure. If water-vapour is present the adiabatic expansion and fall of temperature results in its condensation, and clogging takes place.

Variation according to the kinds of Glass produced.—For the commonest glass (bottle-ware, etc.) the mechanical analysis is of prime importance. The sand must be well-graded and composed of suitably-sized grains. Greater latitude than with better-class glasses is permissible in chemical composition. The silica-percentage should still be fairly high, but low iron-content is not so essential: it may vary up to 1 per cent. (as Fe_2O_3). The presence of small quantities of titanium, aluminium, calcium, and alkalies is of little importance.

For all medium-class glass-ware, including the best bottles, chemical ware, globes, chimneys, pressed ware, etc., both chemical and mechanical analyses are of great importance. High silica-content (and for much laboratory-ware, etc., high alumina) and low iron-content are demanded. Other constituents, if present at all, should be in minimum quantity. Good grading is extremely desirable, and the size of grain should not fall outside the limits of 0·5 and 0·1 mm. diameter.

For high-class glass-ware such as optical glass, table-glass (which is afterwards "cut"), and other special glasses, the chemical composition is of prime importance, and the mechanical analysis often, but not always, takes a secondary rank. In the famous cut-glass table-ware industry of the Stourbridge district, the batch is not at the present time ground fine, neither do arrangements exist for stirring the metal; in consequence the grade, as well as the chemical composition, must be of a high standard. For the other ware mentioned, high silica (and at times, alumina) percentages are demanded, and little or no iron should be present. As the batch is often pulverized, and the metal allowed to remain molten for a long period, being usually stirred, crushed rocks and quartz, as well as poorly-graded sands, might be utilized.

Summary: The Ideal Glass-Sand.—A perfect "sand" in the geological sense, that is one composed entirely of grains belonging to one grade, which should not be a coarse one, yields the best material for glass-making, provided, of course, that the chemical composition is suitable. As a general rule, for all kinds of glass-work, the iron oxide (Fe_2O_3) percentage should be low, always under 1 per cent., the higher limit being permissible only for glass for the cheapest class of bottles. As already stated, the sand used for the best varieties of glass, such as optical glass, best flint- and sheet-glass, best Bohemian glass, "crystal" table-ware, etc., should contain at the most only a few hundredths (·02 to ·08) per cent. of iron oxide. Alumina, magnesia, and lime may be present in sands as felspars, ferromagnesian and lime-bearing minerals, and calcareous cement, but are required only for certain glasses. These bases are very refractory and lengthen the time taken for melting. Sands free from them are preferable, both because the bases are required only for refractory glasses, and then must be added in larger quantities, and because the presence of minerals containing them in sand usually means also the presence of a prohibitive quantity of iron.

It is found desirable, therefore, to rely upon the sand only as a source of pure silica, and to add other bases for the purpose of making various kinds of glass desired.

The ideal sand for the best glass-making is one with 100 per cent. silica and composed of angular grains all of the same size, and of the grade known as medium or fine sand. Such a perfect sand has not at present been discovered, but the ideal is approached by a few sands, including those of Fontainebleau in France (99·7 per cent. silica), and Lippe in Germany (99·8 per cent. silica). The latter sand is described in Chapter VI.

CHAPTER VI.

SANDS SUITABLE FOR GLASS-MAKING.

BRITISH SANDS.

The tables of chemical and mechanical analyses, etc., give an indication, in the light of what has been said before, as to how far British sands may be used to replace those imported from abroad. In the first place, there does not appear to exist, anywhere in the British Isles, a sand so suitable, from all points of view, for the making of the best kinds of glass, as those from Lippe and Fontainebleau. The best sand from Aylesbury in Buckinghamshire is equal to Fontainebleau, but is of less extent, and the sands from Huttons Ambo and Burythorpe in Yorkshire, and other places, are certainly as good as the Belgian sand imported. Lynn sand, at its best, is also equal to much of the Belgian material, and is superior to some of the Dutch sand imported. The same remarks apply to Godstone and Reigate sands (Lower Greensand, Surrey), but the deposits are irregular. A large number of British sands, especially dune- and shore-sands, are less pure, but are well suited to the making of common bottle-glass. Mechanical analyses of some representative examples of these are given in a separate table. Sands suitable only for rough green and black bottle-glass are not dealt with here, but a few analyses of them are given in the Tables.

Notes are added upon some of the more interesting of these sands. Analyses and notes upon a few foreign sands are included for purposes of comparison. Mechanical analyses are graphically expressed in the curves of Figs. 9 and 10 (p. 48).

"Aylesbury" Sand.

Worked by Aylesbury Sand Co. Manager, Mr. J. Arnold (Offices, 32 St. Paul's Road, Camden Town, N.W.).

Maps.—Geological: Old Series, 1-inch, Sheet 46 S.W.
6-inch, Buckinghamshire, Sheet 32 N.W.

Situation.—*Lat.* 51° 48′ 22″, *Long.* 0° 52′ 5″ W.

The quarries occur at Stone, three miles west of Aylesbury. The sand is also exposed in the "Windmill" pit, but not worked to any extent.

Formation.—Lower Greensand.

Description.—White seams of pure sand, suitable for flint-glass work, extend to a depth of about 18 feet. 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 ft.) or persistent, working is rather difficult. It is not easy to ensure that

Fig. 9.—*Mechanical Analyses of Glass-Sands : Foreign.*

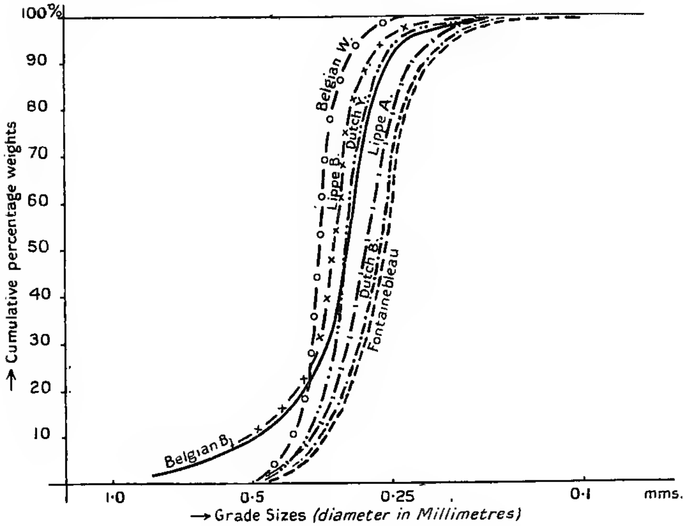
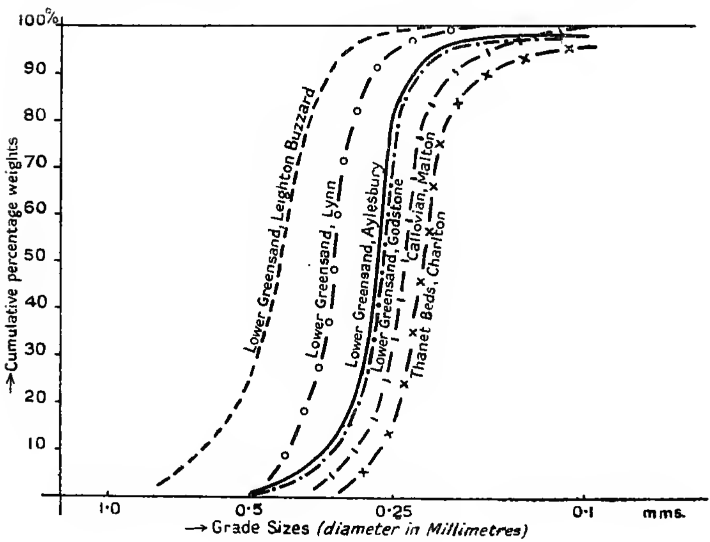


Fig. 10.—*Mechanical Analyses of Glass-Sands : British.*



successive consignments conform to the highest standard of purity met with, and variability is abhorred by glass-makers. The whiteness and purity may be connected with the peaty bands. The colour is good, the best Aylesbury sand being better than Belgian, and selected samples being 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 slightly on burning, whereas the former shows little or no change. The chemical composition is as follows:—

	Best sand.	Washed sand as delivered.
SiO_2	99·80 per cent.	99·39 per cent.
Al_2O_3	·32	·48
Fe_2O_3	·03	·02
Loss on ignition	·22	·13
Total..................	100·37 per cent.	100·02 per cent.

The evenness of grade is a marked feature, the sand in this respect very closely resembling Fontainebleau (see Plate III, figs. 1 & 3). The mechanical composition is as follows:—

$>$0·5 mm., few grains only; $>$0·25 & $<$0·5, 78·3 %; $>$0·1 & $<$0·25, 15·0 %; $>$0·01 & $<$0·1, 5·8 %; $<$0·01, 0·9 %. Total sand-grade, $>$0·1, 93·3 %.

$$\left[\frac{C}{tr.}, \frac{D}{78{\cdot}3}, \frac{E}{15{\cdot}0}, \frac{F}{5{\cdot}8}, \frac{G}{0{\cdot}9}; \frac{C\text{–}E}{93{\cdot}3}.\right]$$

The detrital mineral suite is very marked and is characteristic of the Lower Greensand throughout England. Heavy minerals are fairly abundant (0·2 to 0·3 mm. diameter), 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 (G. C. Railway), were put on trucks, before the war, at 7*s*. 6*d*. per ton. At the time of writing the price is 10*s*. This is rather high, and freight charges increase it to about 15*s*. or 17*s*. 6*d*. by the time it reaches a glass-making district as far distant as London or Yorkshire.

The estimated quantity available in the area is 2 million tons *.

"Leighton Buzzard" Sand.

Worked by (1) Mr. Joseph Arnold, (2) Mr. George Garside, (3) Mr. Gregory Harris.

Maps.—Geological: Old Series, 1-inch, Sheet 46 N.W.
6-inch, Bedfordshire, Sheet 28 N.E.

Situation.—*Lat.* 51° 56′ 15″ to 51° 57′ 10″, *Long.* 0° 38′ 20″ to 0° 39′ 10″ W.

* In each case the estimate of the resources is by the writer, and is to be taken as well within the upper limit.

The sand is worked over a large area north and north-east of Leighton Buzzard. Numerous quarries and old workings occur (Mile Tree, Shenley Hill, Stone Lane, Chance's Quarry, etc.).

Formation.—Lower Greensand.

Description.—The deposits are worked for a variety of purposes, glass-making being subordinate.

Both chemical and mechanical compositions vary considerably. The coarse sands are supplied for water-filtration plant, concrete-making, grinding, etc. The highly ferruginous sand is used for building, and most of the pale-coloured medium-grained sands are worked and washed by the rotary method for foundry purposes, particularly in connexion with steel-work. This is on account of the high silica-percentage, very little felspar occurring. For the most part the sands are neither so pure and free from iron nor of so fine a grade as those of Aylesbury; they are therefore not so well suited for good glass. They are used for the making of pressed glass and laboratory-ware. The iron staining is patchy in its occurrence, and the pale sands are thus impersistent. The whitish sands are again associated with peaty bands.

The chemical composition of one of the samples of glass-sand is as follows:—

SiO_2	99·59 per cent.
Al_2O_3	·25
Fe_2O_3	·21
Loss on ignition	·27
	100·32 per cent.

For the most part, the sands are coarse, passing into fine quartzose and cherty gravels. The latter are screened and used for abrasive purposes, including the grinding of plate-glass. Seams of fine white and grey sand occur, but are not common.

The whitish and pale yellow sands supplied for glass-making are rather coarser than manufacturers like. A typical mechanical analysis is as follows:—

$>0{\cdot}5$ & <1 mm., 24·6 %; $>0{\cdot}25$ & $<0{\cdot}5$, 74·3 %; $>0{\cdot}1$ & $<0{\cdot}25$, 1·0 %; $>0{\cdot}01$ & $<0{\cdot}1$, less than 0·1 %. Total sand-grade, $>0{\cdot}1$ & <1 mm., 99·9 %.

$$\left[\frac{C}{24{\cdot}6}, \frac{D}{74{\cdot}3}, \frac{E}{1{\cdot}0}, \frac{F}{0{\cdot}1}; \frac{C\text{–}E}{99{\cdot}9}\right].$$

The mineral composition is like that of Lower Greensand deposits generally. The description of the mineral assemblage of Aylesbury sand applies here.

The sand is put on boat upon the Grand Junction Canal, or on truck at Leighton Buzzard, at 6*s*. per ton (Arnold), and 6*s*. 6*d*. per ton (Garside).

The available resources are at least 500 million tons.

The Lower Greensand of **Flitwick** (pit $\frac{1}{3}$ mile north of the railway station, worked by Mr. Joseph Arnold) is similar, but less pure. Analyses of this sand are given in the Tables.

"Lynn" Sand.

Worked by Messrs. Joseph Baum & Co., Ltd. (Offices, Silver Street, Leicester).

Maps.—Geological: Old Series, 1-inch, Sheet 65.
6-inch, Norfolk, Sheet 33 S.E.

Situation.—*Lat.* 52° 44′ to 52° 45′, *Long.* 0° 28′ to 0° 29′ E.

The sand is worked over an extensive area at Middleton and Gayton, 3 miles E. of King's Lynn, and numerous scattered quarries occur.

Formation.—Sandringham Sands (Lower Greensand).

Description.—The deposit is fairly persistent and thick, so that large supplies of sand running true to sample can be supplied. Little variation occurs in successive consignments. The sand is won for foundry-work, glass-making, building purposes, etc. The red sands are used for the last-named purpose and also for the making of black-bottle glass. In considering the sands suitable for general glass-making, it should be said that the colour of the best Lynn sand is equal to that of the Belgian, but most is rather darker, three qualities and a washed sand being supplied. Rotary washing-plant is employed. The washed sand has a grey to brown colour. The iron-content is rather higher than that of Aylesbury sand, and on burning there is a marked change to redder or greyer tints. The chemical composition of the best sand is as follows:—

SiO_2	99·23 per cent.
Al_2O_3	·59
Fe_2O_3	·04
CaO	·11
MgO	·02
Loss on ignition ...	·25
	100·24 per cent.

Note.—A duplicate determination of the silica and also of the alumina carried out as a control gave the figures 99·20 % and 0·56 %, respectively.

In mechanical composition the sand is seen to be well-graded, but rather coarser than either Aylesbury or Fontainebleau sand. The curve representing its composition in Fig. 10, page 48, is therefore sympathetic with, but to the left of, those for Aylesbury, etc., sands. Typical analyses yield the following results:—

$>$0·5 & $<$1 mm.—; $>$0·25 & $<$0·5, 94·8 %; $>$0·1 & $<$0·25, 4·9 %; $>$0·01 & $<$0·1, 0·2 %; $<$0·01, 0·1 %. Total sand-grade, $>$0·1 & $<$1 mm., 99·7 %.

$$\left[\frac{D}{94{\cdot}8}, \frac{E}{4{\cdot}9}, \frac{F}{0{\cdot}2}, \frac{G}{0{\cdot}1}; \frac{D\text{–}E}{99{\cdot}7}.\right]$$

The mineral composition indicates rather more felspar than in the other Greensand deposits discussed (note Al_2O_3 percentage in chemical analyses). The heavy detrital mineral assemblage is similar to that of the Lower Greensand generally, but, in addition, occasional garnets are found. The residue is a coarse one, the grains averaging 0·2 mm. diameter. The sand is extensively used for general glass-work, including window- and plate-glass, laboratory-ware, incandescent-lamp globes, chimneys, white and coloured bottles, etc. It has the great advantage of being cheap, the price in 1914 being 2*s*. 9*d*., and the present price 3*s*. 6*d*. per ton on truck at Middleton Station (G. E. Railway) or Gayton Road Station (Midland and G. N. Joint Railway). The sand is also carted to King's Lynn Quay (about four miles) and shipped from there.

The available resources are at least 300 million tons.

Sand from Godstone, Surrey.

Worked by Messrs. Goodwyn & Sons, Granville Chambers, Portman Square, London, W. (owner Sir W. R. Clayton, Bart.).

Maps.—Geological: Old Series, 1-inch, Sheet 6.
6-inch, Surrey, Sheet 27 S.E.

Situation.—*Lat*. 51° 15′ 0″, *Long*. 0° 4′ 0″ W.

The pit revealing the whitest sand occurs half a mile N.W. of Godstone Church.

Formation.—Folkestone Beds (Lower Greensand).

Description.—The whitest and best glass-sands occur in irregular patches in beds more iron-stained. No great supply of standard material can therefore be guaranteed, an unfortunate fact in view of its proximity to London and the Thames area. The pit 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. The bulk of the deposit is worked for building purposes, and some probably reaches London and is sold as silver-sand for soil-dressing and scouring purposes.

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

SiO_2	99·56 per cent.
Al_2O_3	·26
Fe_2O_3	·06
Loss on ignition	·24
	100·12 per cent.

From the point of view of glass-making the grade analysis is good (Plate III, fig. 4). It is as follows :—

$>$0·5 & $<$1 mm., 0·6 %; $>$0·25 & $<$0·5, 73·0 %; $>$0·1 & $<$0·25, 25·7 %; $>$0·01 & $<$0·1, 0·2 %; $<$0·01, 0·5 %. Total sand-grade, $>$0·1 & $<$1 mm., 99·3 %.

$$\left[\frac{C}{0\cdot6}, \frac{D}{73\cdot0}, \frac{E}{25\cdot7}, \frac{F}{0\cdot2}, \frac{G}{0\cdot5}; \frac{C\text{–}E}{99\cdot3}\right]$$

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

The price is 6*s.* 6*d.* per ton on truck at Caterham Station (S. E. & C. Railway).

At **Oxted** and **Limpsfield** in Surrey, about two to three miles east of Godstone, and at other places along the outcrop, the same sands (Folkestone Beds, Lower Greensand) are rather coarser in character, the mechanical composition (see Table II. at end) resembling that of Leighton sand. More iron is present and the sands burn redder, but would be suitable for bottle-glass work. The mineral composition is again typical of the Lower Greensand.

Sand from Reigate, Surrey.

Worked (1) Doods Road Pit: by Mr. A. B. Apted, Doods Road, Reigate; (2) Park Lane Pit: Agent, Mr. H. Sims, Old Town Hall, Reigate.

Maps.—Geological: Old Series, 1 inch, Sheet 8.
6-inch, Surrey, Sheet 34 N.E.

Situation.—Doods Road Pit. *Lat.* 51° 14′ 25″, *Long.* 0° 11′ 0″ W.; Park Lane Pit. *Lat.* 51° 14′ 5″, *Long.* 0° 12′ 45″ W.

The smaller pit, in Park Lane, is situated about $\frac{1}{3}$ mile south-west of the Castle, and the larger, Doods Road Pit, occurs by the northern side of the railway half-way between Reigate and Redhill.

Formation.—Folkestone Beds (Lower Greensand).

Description.—The Reigate sand is similar in age and character to that at Godstone, but the purer parts are of greater extent. The iron staining is distributed in patches, but is never so serious as to prevent the sand being worked for second-quality glass (sheet-glass, pressed ware, laboratory-ware, etc.). The best seams of sand are equal in colour to Fontainebleau sand. The presence of calcareous material in places will probably necessitate washing. The chemical analysis is as follows:—

SiO_2	98·93 per cent.
Al_2O_3	·67
Fe_2O_3	·02
CaO	trace
MgO	none
Loss on ignition	·28
Total	99·90 per cent.

The mechanical analysis indicates:—

>0·5 & <1 mm., 2·7 %; >0·25 & <0·5, 79 %; >0·1 & <0·25, 14·5 %; >0·01 & <0·1, 1·8 %; <0·01, 2·0 %. Total sand-grade, >0·1, 96·2 %.

$$\left[\frac{C}{2\cdot7},\ \frac{D}{79\cdot0},\ \frac{E}{14\cdot5},\ \frac{F}{1\cdot8},\ \frac{G}{2\cdot0};\ \frac{C\text{-}E}{96\cdot2}\right]$$

The grading is rather variable, a gradual passage from coarse to fine sands being frequently observed. The mineral composition is typical of the Lower Greensand. The sands should be worked with care, both from the point of view of grade and iron-content. That the available resources here are very great is indicated by the abundance of caves throughout the Reigate area. Large quantities of cream-coloured sand have been removed from these excavations. Doods Road Pit shows a 40-foot face of sand.

From the Doods Road Pit, selected fine silver sand is put on truck at Redhill Station at 6*s*. per ton (unwashed).

The available resources in the area are over 100 million tons.

Sand from Aylesford, Kent.

Worked by Mr. Silas Wagon, Aylesford.

Maps.—Geological: Old Series, 1-inch, Sheet 6.
6-inch, Kent, Sheet 31 S.W.

Situation.—*Lat.* 51° 18′ 25″, *Long.* 0° 29′ 0″ E.

The pit exhibiting the whitest sand lies immediately N.E. of Aylesford Church. The Nickle pit, ¼ mile W. of the church, contains rather yellower sand (worked by the Nicopits Sand Co., Ltd.).

Formation.—Folkestone Beds (Lower Greensand).

Description.—Whitish sands with a northerly dip are covered in one part of the pit by Carstone. About 12 feet of the sand are worked, but the floor of the pit was covered with water at the time of writing. White chalky matter is often present. The general characters are similar to those of the other Greensand deposits described.

The colour is pale grey to cream, but the sand burns up pink.

The chemical analysis of the best sand is as follows:—

SiO_2	99·06 per cent.
Al_2O_3	·56
Fe_2O_3	·04
CaO	·17
MgO	trace
Loss on ignition	·22
Total	100·05 per cent.

The grading is good, a mechanical analysis being as follows:—

>0·5 & <1 mm., few grains only; >0·25 & <0·5, 83·7 %; >0·1 & <0·25, 16·0 %; >0·01 & <0·1, 0·3 %. Total sand-grade, >0·1 & <1 mm., 99·7 %.

$$\left[\frac{C}{tr.}, \frac{D}{83·7}, \frac{E}{16·0}, \frac{F}{0·3}, \frac{C–E}{99·7}\right]$$

The mineral composition is that of the Lower Greensand generally, tourmaline, staurolite, and kyanite being large and conspicuous in the heavy mineral crop.

The sand is supplied on ship upon the Medway at Aylesford at 8*s*. per ton, and on truck at Aylesford Station (S. E. & C. Railway) at 9*s*. 6*d*. It is used for bottle-making at Queenborough, but would be of service for better glass.

The available resources are 5 million tons.

Sand from Huttons Ambo, near Malton, Yorks.

Worked by High Silica Sands Company, Falconer Chambers, Scarborough.

Maps.—Geological: New Series, 1-inch, Sheet 63.
Old ,, ,, ,, 93 N.E.
6-inch, Yorkshire, Sheet 141 N.E.

Situation.—*Lat.* 54° 5′ 50″, *Long.* 0° 51′ 40″ W.

Greyish and pale yellow sands occur at Sleights and Hutton Bank, and the working is in process of development.

Formation.—Upper Estuarine Series (Lower Oolites).

Description.—The sand is pale grey to white in tint and is slightly improved by washing, which removes calcareous and aluminous material also. Much of the sand carries kaolin, which may be an advantage for certain glasses. For other purposes it is easily removed. One seam of the sand is extremely pure, but most will have to be washed. The sand reddens slightly on burning. A chemical analysis of an unwashed sample is as follows:—

SiO_2	99·04 per cent.
Al_2O_3	·84
Fe_2O_3	·03
CaO	·10
MgO	·18
Loss on ignition	0·19
	100·38 per cent.

Other analyses are given in the Tables.

The mechanical analysis indicates:—

$>$0·5 & $<$1 mm., 1·4 %; $>$0·25 & $<$0·5, 84·9 %; $>$0·1 & $<$0·25, 7·5 %; $>$0·01 & $<$0·1, 4·1 %; $<$0·01, 2·1 %. Total sand-grade, $>$0·1 & $<$1 mm., 93·8 %.

$$\left[\frac{C}{1\cdot4}, \frac{D}{84\cdot9}, \frac{E}{7\cdot5}, \frac{F}{4\cdot1}, \frac{G}{2\cdot1}; \frac{C\text{–}E}{93\cdot8}.\right]$$

The sand is quartzose, felspar being much less abundant than in the Kelloway Beds. In mineral composition the sand does not exhibit a rich variety of minerals, the heavy residue being coarse (averaging 0·2 mm. diameter). Very little magnetite is present, but ilmenite is abundant. Limonite and leucoxene occur. Large red garnets are common, and also tourmaline, staurolite, deep red rutile, and zircon. Grains of serpentine occur rarely. It is hoped that the sand will be delivered at Knottingley and other places in the Yorkshire area at 7*s.* to 9*s.* per ton. It is put on truck at Huttons Ambo at 3*s.* 3*d.* per ton.

The estimated resources are 1 million tons.

Sand from Burythorpe, near Malton, Yorks.

Working given up some years ago.

Maps.—Geological: New Series, 1-inch, Sheet 63.
Old ,, ,, ,, 93 N.E.
6-inch, Yorkshire, Sheet 42 N.W.

Situation.—*Lat.* 54° 4′ 40″, *Long.* 0° 48′ 40″ W.

Whitish sands are exposed in several pits, the chief of which lies near the Fox Cover, and ¾ mile N.W. of Burythorpe Church.

Formation.—Kelloway Beds of the Jurassic.

Description.—As in the case of the country around Leighton Buzzard, Middleton and Gayton, Godstone, etc., the sand supports only a poor heath flora by which its fairly extensive outcrop is vaguely defined. Some years ago it was worked for glass-sand, but the working was given up; it may be re-exploited shortly.

The sand possesses a slight brown tint, due to iron staining, but the best quality is nearly white (cream-coloured). The tint becomes slightly browner on burning, but the original colour, which lies between those of Fontainebleau and Belgian sands, is not improved to any extent by washing, although calcareous material is removed.

The chemical composition is as follows:—

SiO_2	96·79 per cent.
Al_2O_3	1·63
Fe_2O_3	·22
Loss on ignition	·60
Total	99·24 per cent.

Alkalies not determined.

The dominant grade of the sand is smaller than that of foreign sands and other British glass-sands, but this is an advantage, for the deposit is well graded (see Plate III, fig. 5).

In the mechanical composition the grade-percentages are:—

$>$0·5 & $<$1 mm., few grains only; $>$0·25 & $<$0·5, 39·2 %; $>$0·1 & $<$0·25, 59·0 %; $>$0·01 & $<$0·1, 1·0 %; $<$0·01, 0·8 %. Total sand-grade, $>$0·1 & $<$1 mm., 98·2 %.

[C D E F G ; C–E / tr.' 39·2' 59·0' 1·0' 0·8 ; 98·2.]

The grains are mostly subangular clean quartz, but grains of turbid felspar are not uncommon. The heavy residue is abundant and consists of much fine-grained dark material (average diameter 0·1 mm.). In character it most resembles the mineral assemblage of the Inferior Oolite, which is remarkably similar all over its outcrop across England, from the Dorset coast to Yorkshire. Abundant magnetite and ilmenite occur, and colourless to pale brown and pink angular garnet grains (0·12 mm. diameter) make up most of the residue. Rutile is extremely plentiful and zircon is common (both about 0·1 mm. or less diam.). Staurolite and grey-brown tourmaline grains occur. Muscovite is present, but the diameter of the flakes (0·12 mm. diameter) is not much larger than that of the average for the rest of the grains.

The question of transport to the nearest railway station, Malton (almost 5 miles), the high railway freights, and also the distance to the nearest port are serious considerations. The great glass-making area of Yorkshire is, however, near at hand.

Some trial borings and a trial hole have recently been put down a short distance away in Burythorpe Park by the owner. R. B.

Colton Fox, Esq. The best of the sand brought to the surface looks very promising, and subject to an improvement in the economic conditions specified above, development of the area may be expected. (For analyses, see Tables.)

The available resources in the area amount to 3 million tons.

Less pure sands in the Kelloway Beds are worked at South Cave, near the station (by Messrs. T. H. Lyon and Partner, of Scarborough). They are of service for white bottle-glass and much other ware. Similar sands occur at Newbald. At Sancton, near by, white micaceous sands are found in the Estuarine Series.

"Isle of Wight" Sand.

This sand was formerly worked for glass-making and is mentioned in older British and foreign text-books. It has not been worked for some years.

Maps.—Geological: New Series, 1-inch, Special Sheet, Isle of Wight. (Sheets 330, 331, 344, 345.)
6-inch, Hampshire, Sheet 93 S.W.

Situation.—*Lat.* 50° 40′ 0″, *Long.* 1° 33′ 50″ W.

The sand is one of the famous Alum Bay Sands, cropping out in the cliffs about four miles S.W. of Yarmouth.

Formation.—Headon Hill Sands. White sands also occur in the Lower Bagshot Beds.

Description.—The sand is associated with beds of lignite. In places it possesses a good colour, almost equal to that of French glass-sand, and darkens only very slightly on heating. Patches of more ferruginous material, however, occur frequently in it.

The chemical analysis of an average sample of Headon Hill Sand yielded:

SiO_2	96·96 per cent.
Al_2O_3	1·90
Fe_2O_3	·11
CaO	·34
MgO	v. sl. trace
Loss on ignition	·64
Total	99·95 per cent.

So far as its use for glass-making is concerned, the mechanical composition leaves something to be desired.

	C. >0·5 & < 1 mm.	D. >0·25 & <0·5.	E. >0·1 & < 0·25.	F. >0·01 & <0·1	G. <0·01	D–E. Total sand-grade: >0·1 mm.
Headon Hill ...	—	3·8 %	84·0 %	9·7 %	2·5 %	87·8 %
Lr. Bagshot ...	—	8·1	76·2	10·7	5·0	84·3

The mineral composition is similar to that of the Bagshot Beds generally, the abundance of rutile, blue and indigo-coloured tourmaline, and rolled grains of staurolite being noteworthy.

The practice of using this sand appears to have dropped since the 'eighties, probably as a result of the difficulty, from its position, of working it in quantity, the imperfect grading, and the ferruginous patches occurring in it.

Similar whitish sands, but not so pure, are met with in Whitecliff Bay, at the opposite end of the Isle of Wight.

Sand from Charlton, Kent.

Worked by Mr. E. Gilbert; pit owned by Sir Spencer Maryon Wilson, Bart.

Maps.—Geological: New Series, London, Sheet 4.
6-inch, Kent, Sheet 2 S.W.

Situation.—*Lat.* 51° 29′ 10″, *Long.* 0° 2′ 15″ E.

Numerous excavations occur in the district, but sand is actually worked for glass-making at the large pit about ¼ mile N. of the church.

Formation.—Thanet Beds.

Description.—The uppermost few feet of the Thanet Beds at Charlton are worked for rough green bottle-glass manufacture in the London District. The lower portion of the Thanet Beds (which are here seen resting upon the Chalk) is more clayey and is worked for the famous "Blackfoot" moulding-sand ("Erith" sand), which is sent to all parts of Britain and exported abroad (to Stockholm, India, etc.). The sand is coloured pale brown or grey and is suitable only for common bottle-glass. It contains a fair quantity of iron and reddens on heating.

The chemical analysis is as follows:—

SiO_2	95·21 per cent.
Al_2O_3	2·43
Fe_2O_3	·42
CaO	·19
MgO	none
K_2O	·89
Na_2O	·19
Loss on ignition	·88
Total	100·21 per cent.

The mechanical analysis indicates that the fine-sand grade is dominant, as in the Burythorpe deposit:—

>0·5 & <1 mm., —; >0·25 & <0·5, 16·2 %; >0·1 & <0·25, 79·6 %; >0·01 & <0·1, 3·1 %; <0·01, 1·1 %. Total sand-grade, >0·1 & <1 mm., 95·8 %.

$$\left[\frac{D}{16·2}, \frac{E}{79·6}, \frac{F}{3·1}, \frac{G}{1·1}; \frac{D\text{–}E}{95·8}\right]$$

In mineral composition the sand resembles the Thanet Beds generally of the southern outcrop, the detrital minerals being fairly abundant, and occurring in angular grains. Ilmenite (altering to leucoxene) and limonite (0·2 mm. diam.), zircon

(0·1 mm.) and rutile (0·2 mm.) abound, and tourmaline (0·2 mm.), staurolite, ? andalusite, and flakes of muscovite (0·2 mm. diam.) are also found.

Rail and river are near, and the sand is supplied at about 3*s*. 6*d*. to 5*s*. per ton at the pit (1*s*. 6*d*. and upwards per "foot").

Thanet Sand near Rochester is similarly worked for the bottle-industry at Queenborough, Higham, etc.

Dune-Sands and Shore-Sands.

Although some of these sands, the analyses of which are given in the Tables, have been used for bottle-glass, no blown-sand or shore-deposit from the British Isles pure enough (with the exception of that from the Isle of Jura) and in sufficient quantity for the making of flint or better-class glass has yet been seen by the writer. The colour varies from pale grey and brown to deeper tints, and usually darkens considerably on burning. Too much iron is present, and the heavy-mineral crop is frequently large. Commercial electromagnetic separation will hardly clean the sands sufficiently. They are of little use except for "black" glass-work when the industry is located close at hand.

The purest shore-sand met with is that occurring on the western shores of the **Isle of Jura**, and derived from the Dalradian quartzites forming the greater part of the island. This sand is said to have been formerly worked for glass, but it is of limited extent and, although very white-looking, contains 0·7 per cent. of iron oxide (see Tables of Analyses).

The beach-sand from the **Isle of Eigg** is also of fairly good quality, and consists of very clean and colourless angular quartz, mixed with a considerable quantity of dark kaolinized felspar, but it yields a large crop of heavy minerals derived from neighbouring igneous masses (augite, olivine, epidote, garnet, zircon, etc.).

Similar sands from near Dublin (**Sandymount Strand**) have been used in the dark-bottle industry of that city.

Information regarding other sands investigated will be found in the Tables or, incidentally, in the remarks below. Sandstones and quartzites naturally disintegrated or crushed to produce "glass-sands" are discussed in Chapter VII.

Possible sources of Glass-Sands. (With especial reference to England.)

Incoherent glass-sands are not to be expected from Archæan and Palæozoic Rocks. Very pure quartzites occur, but the objections to crushed rocks (see p. 72) and the question of expense almost rule them out. Where very pure rocks have rotted *in situ* and been exposed to washing by rain, etc., glass-sands may be produced. The whitish Cambrian quartzites of the Midlands are not sufficiently pure. Other Cambrian sandstones are less pure still, and the same objection applies to Ordovician and Silurian Rocks.

Nothing suitable seems to occur, nor would it be expected, in Devonian strata.

The Carboniferous Period was one in which very pure sandstones were laid down, the association with much organic matter being here noteworthy. The decomposition of pure sandstones (*e. g.*, in Ireland, near Glasgow, in Yorkshire, etc.) may give suitable sands, but no very good examples have yet been found. Such rocks have, however, been crushed and put upon the market. In some good coloured sandstones the cement is barytes (often derived from Permian deposits above), when crushing hardly pays. The Lower Permian Yellow Sands are often incoherent, but are too deeply iron-stained and calcareous all along their outcrop to be of service.

The pale-coloured sandy beds of the Trias do not appear to be sufficiently well-graded, nor are they very pure. The cementing materials are also objectionable, and the grains are often covered with clayey material. Near **Worksop** the basal Bunter Beds, which rest on the Permian Marls, are in places almost decolorized, possibly by bacterial action. They are worked by Mr. Joseph Turner for building and refractory purposes, and may be used for rough glass. The colour is dirty white, but darkens on heating. The sands contain about 95 per cent. of silica and 0·5 per cent. of ferric oxide. Mechanical analyses show that the deposit is not a well-graded one, and is hardly suitable for other than common glass-making. Too much kaolin-like dust is found. The sands are washed and the colour improved, most of this dust then disappearing. Sifting and washing together render the sand suitable for rough glass-making.

A soft sandstone, of Keuper Waterstones age, occurs at **Higher Bebington**, near **Spital** in Cheshire. It is crushed and sold as a glass-sand and refractory material (by the Executors of Chas. Wells; Agent, Mr. H. A. Walker, Exchange Street East, Liverpool). The price is 6*s.* 2*d.* per ton on truck at Spital Station, and 9*s.* 6*d.* on boat at Birkenhead. The grading is not good, and there is too much of the clay- and silt-grades, made up of kaolin-like material resulting from decomposition of felspars. The grains are in part coated with white material. The colour is about that of Lynn sand, but darkens on heating. The sand is used for glass-making in the bottle industry of Dublin, Belfast, and other localities.

The English Jurassic strata are very variable, and it is possible that sands of great purity not known to us at present may turn up, but their thickness and extent must be limited. The Inferior Oolite "Sands" of the western area (Dorset Coast, Bridport, Yeovil, Midford, Wotton, Cotteswolds, Cheltenham, etc.) are too ferruginous and are occasionally calcareous. In the Northampton Sands and Estuarine Series, beds of whitish sand occur, but are usually calcareous and never very pure. The detrital mineral percentage is also high. Sands are said to have been worked for glass-making about 1860 from Wansford, Apethorpe, Blatherwyke, Burleigh, Caswick*, etc.; but the glass cannot have been of good quality. Analyses of

* Was Caswick a slip for Castor, which is near to the other villages? No village of Caswick is mentioned in British Gazetteers.

sands from Corby, Denford, etc., will be found in the Tables. The Estuarine Series and Kelloway Beds of East Yorkshire have been mentioned as some of the best of English deposits. The Corallian Beds often contain clayey or calcareous sands, and the Portland Sands are too grey or brown and impure for glass-making.

The Cretaceous Period in England gave us certain fairly pure deposits, as, for example, the white sands of the Lower Greensand and the limestone Chalk. The Wealden Beds at the base are rarely free from iron, and some of the paler-coloured beds (Ashdown Sands, Tunbridge Sands, etc.) are cemented with calcareous and ferruginous matter: they are rarely very pure. The Ashdown Sands near Hastings and in the country around Rotherfield, and the Tunbridge Wells Sands at Tunbridge Wells, East Grinstead, Mayfield, and East Hoathly have been worked: reference to these will be found in the Tables. The sands most used for glass-making in England are of Lower Greensand age (Aylesbury, Leighton, Lynn, Godstone, Reigate, Aylesford, etc.); but the great bulk of the deposit is highly ferruginous and unsuitable, and the beds of good quality often impersistent. Glass-sands have been worked also at Bearsted, Hollingbourne, and Aylesford, in Kent, and near Blackgang Chine in the Isle of Wight. Highly siliceous, but less pure and more indurated, beds occur in the Upper Greensand over a wide area from the Isle of Wight to Wiltshire and Kent.

The Tertiary sands are, as a general rule, well-graded. The Thanet Beds are usually too impure, but those of Charlton and other places in Kent have been used for bottle-glass. No very pure sands occur in East Anglia, but the buff-coloured Reading Beds might be used for common green glass. The Bagshot Beds of the London Basin have not all been explored; but some bands, such as the pale sands of St. George's Hill, Weybridge (see Tables), might be used for common glass. The sands from Alum Bay and Whitecliff Bay (Isle of Wight) may vary in grade and chemical composition, and may be suitable at times if the purest portions are workable. Similar beds are said to have been formerly worked on the mainland at Longdown and the New Forest. Whitish sands in the Bagshot Beds are now worked near Lymington and Brockenhurst in Hampshire, and near Creechbarrow and Wareham in Dorset, but are not sufficiently pure for the purpose required (see Tables). Their grading is open to objection. English Pliocene sands are mostly ferruginous, as are almost all glacial, dune-, and shore-deposits. The constituents of the last group of sands have usually a very mixed origin; but if local derivation from decomposing pure sandstones or quartzites can be ensured, suitable sands may be found. Usually, in dune- and shore-sands, current-action tends to defeat this object. Nevertheless, the dune- and shore-sands of the United Kingdom (especially bordering the Archæan areas of Scotland and Ireland) ought to be more thoroughly investigated than they have been. Certain fairly pure glacial sands, which may be improved by washing, occur rarely (Carstairs Kames, near Glasgow, Lancashire, Sudbury in Suffolk, etc.), and more deposits of this age may be found. The glacial sands of Shirdley Hill, near St. Helens, have long been famous on account of their use for the making of window-glass.

Very pure white sandy deposits of doubtful age occur in Flintshire *, Denbighshire, Staffordshire, and Derbyshire †, resting upon or filling hollows in the Carboniferous Limestone. The deposits are usually of small extent, and are of little use for glass-making on an extensive scale, on account of their non-graded character and limited extent. Some of them would be of special value for certain glasses because of their high alumina-content (*e. g.*, 18 per cent.) and relative freedom from iron. (See Brassington, Parsley Hay, and Abergele in Tables.)

The tips of rejected coarse material from the kaolin workings in Devon and Cornwall contain high silica and fairly high alumina-content. The tourmaline could be extracted by electromagnetic means, but the alumina is mostly present as micas, kaolin, and partially decomposed felspar. Some of this may be too refractory for ordinary glass-making. The deposits are poorly graded, containing much coarse quartz and felspar. It is a pity the material cannot be utilized; for sands with a good proportion of alumina are sometimes desirable for glass-work, and a market is badly needed for the rejectamenta from the kaolin-works. The material is utilized for the making of refractory bricks.

A discussion of suitable British glass-sands would not be complete without comparative notes upon some widely-used continental examples. Notes upon a few well-known European glass-sands are therefore appended.

Foreign Sands.

Lippe Sand.

This sand was imported into this country before the war for the making of silica ware; but its use was not extensive. Two different samples of this famous glass-sand from Dörentrup, Saxony, were supplied to me through the kindness of Dr. Walter Rosenhain, F.R.S., Director of the Metallurgical Department, National Physical Laboratory, Teddington, and were subjected to analysis and examination.

The sand occurs in deposits of Miocene age, and is associated with rafts of braunkohle ‡. In this connexion it may also be noted that the valuable glass-sand of Hohenbocka in Prussia, occurring in Miocene strata, is also associated with carbonaceous layers §.

Both samples of Lippe sand are beautifully white, of better

* A. Strahan, 'Geology of the Neighbourhood of Flint, Mold, and Ruthin (79 S.E.),' 1890, Mem. Geol. Survey, p. 119.

† G. Maw, Geol. Mag. 1867, p. 246, and other references.

‡ Jahresb. niedersächs. geol. Ver. 1910, p. 185; and Zeitschr. deutsch. geol. Gesellsch. Band xl., 1888, p. 310.

§ K. Keilhack, Jahrb. K.-preuss. geol. Landesanst. 1908, Band xxix. pt. ii. p. 214.

colour even than that from Fontainebleau. The better sample is finer in grain and remarkably even, while the second is rather coarser. The chemical analyses are as follows :—

	I.	II.
Silica	99·88 per cent.	99·73 per cent.
Al_2O_3	·18	·20
Fe_2O_3 *	n.d.	n.d.
Loss on ignition ...	·21	·23
	100·27 per cent.	100·16 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

$>$0·5 & $<$1 mm., one or two grains; $>$0·25 & $<$0·5, 78·6 %; 0·1 & $<$0·25, 19·9 %; $>$0·01 & $<$0·1, 0·4 %; $<$0·01, 1·1 % † Total sand-grade: $>$0·1 & $<$1 mm., 98·5 %.

$$\left[\frac{C}{tr.}, \frac{D}{78{\cdot}6}, \frac{E}{19{\cdot}9}, \frac{F}{0{\cdot}4}, \frac{G}{1{\cdot}1}; \frac{C\text{–}E}{98{\cdot}5}\right]$$

Measurement under the microscope shows that the average diameter of the grains is 0·3 mm. (or perhaps slightly less). They are composed, with the exception of the few detrital minerals, of colourless clean quartz and a very little felspar, subangular to angular in shape. The mechanical analysis of the second sample is :

$>$0·5 & $<$1 mm., 10·2 %; $>$0·25 & $<$0·5, 85·8 %; $>$0·1 & $<$0·25, 1·4 %; $>$0·01 & $<$0·1, 1·0 %; $<$0·01, 1·6 % †. Total sand-grade: $>$0·1 & $<$1 mm., 97·4 %.

$$\left[\frac{C}{10{\cdot}2}, \frac{D}{85{\cdot}8}, \frac{E}{1{\cdot}4}, \frac{F}{1{\cdot}0}, \frac{G}{1{\cdot}6}; \frac{C\text{–}E}{97{\cdot}4}\right]$$

The grains, which are subangular, are similar under the microscope, but are for the most part nearly 0·5 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.

The former yielded a pretty residue consisting of abundant zircon and red-brown rutile, rather rounded, and averaging 0·12 mm. diameter, together with large kyanite fragments up to 0·7 mm. long, and coarse staurolite and tourmaline grains. The staurolite is deep golden-brown in colour, of diameter 0·2 to 0·3 mm. The tourmaline occurs in grains up to 0·3 mm. diameter, of brown, greyish, greenish blue, and deep blue colour. Magnetite, ilmenite, leucoxene (0·2 to 0·3 mm. diameter), and limonite occur. Small and non-pleochroic dusky grains of andalusite occur less commonly, and chlorite also was seen.

* Separate estimation of iron gave: I. ·02 per cent., II. ·03 per cent. These values are probably too high.

† Hygroscopic water included.

The second sample yielded a rather coarser residue, consisting of abundant pleochroic andalusite (0·3 mm. diam.), large, yellow, grey-brown, and greenish tourmaline (0·3 mm. diam.), deep green hornblende (0·2 mm. long), and ilmenite. Staurolite and zircon occurred in small grains 0·05 mm. long. Chalcedony was also seen in the sand.

Fontainebleau Sand.

The sand, of Upper Oligocene (Stampian) age and associated with lignites *, occurs in considerable quantities at Fontainebleau, near Paris.

The mechanical and chemical composition are given in the Tables, and the general properties are discussed in Chapter IV.

The sand costs upon delivery at British works from 12*s.* to 39*s.* per ton (rising to 50*s.* and 60*s.* through war-difficulties), according to distance brought on rail, an average price being 17*s.* The cost has, of course, increased owing to the war; and for some time after the outbreak of war, as well as again at the time of writing, difficulties existed, due to shortage of labour and ships, in getting it through to England and Scotland.

Belgian Sand.

The sands cost, upon delivery in this country, 4*s.* to 16*s.* per ton. They often arrive as ballast, packing for bottles, etc. Large quantities were sent from the Campine.

Some of the sands are shipped from Rotterdam, and the unequal quality since the outbreak of war leads to the suspicion that some of those now being supplied may be inferior Dutch sands. Much variability in tint and slight differences in mechanical composition occur (see Tables and Fig. 9). The sands may be almost white, a very pale grey, or a marked pale pink, in part due to the presence of pink quartz. Their iron-content is slightly greater than that of Fontainebleau, and they burn to a rather darker pink shade. Washing does not improve the colour noticeably.

One sample from Barnsley Glass-works, which was analysed, proved to have the following chemical composition :—

SiO_2	99·38 per cent.
Al_2O_3	·30
Fe_2O_3	·02
Loss on ignition	·23
	99·93 per cent.

* "Revision de la Feuille de Fontainebleau," Bull. Serv. Carte géol. France, No. 122, vol. xix. (1909) p. 9; and numerous other references.

Mechanical analyses show the following grade-proportions :—

	C. >0·5 & <1 mm.	D. >0·25 & <0·5.	E. >0·1 & <0·25.	F. >0·01 & <0·1.	G. <0·01.	C–E. Total sand-grade: >0·1 & <1 mm.
Knottingley Glass-works.	9·6 %	83·3 %	5·9 %	1·2 %	—	98·8 %
Barnsley Glass-works	<0·1	99·3	0·3	0·4	—	99·6

Quartz, somewhat rounded to subangular, makes up the bulk of the sand ; but cleavage-flakes of felspar are to be seen. The heavy residue is small, and of the type which in Britain characterizes the Pliocene deposits. Among the coarse dense grains are kyanite, andalusite, staurolite, rutile, yellow-brown tourmaline, iron ores, etc.

Dutch Sand.

The prices of Dutch sand have varied considerably in pre-war and present times, the range being from 9*s*. to 23*s*. per ton.

Only a few samples have been analysed. They had a slight grey or brown colour, some darker than Belgian sand, and differed to some extent in grade-percentage (see Tables and Fig. 9). Occasionally the sand is white and equal in quality to that of Fontainebleau.

The chemical analyses of two samples are as follows :—

	Knottingley Glass-works.	Edinburgh & Leith Glass-works.
SiO_2	99·23 per cent.	99·63 per cent.
Al_2O_3	·50	·35
Fe_2O_3	·02	·03
CaO	n. d.	·08
MgO	n. d.	trace
Loss on ignition ...	·22	·19
	99·97 per cent.	100·28 per cent.

The grading composition is indicated by the following results of mechanical analyses :—

	C. >0·5 & <1 mm.	D. >0·25 & <0·5.	E. >0·1 & <0·25.	F. >0·01 & <0·1.	G. <0·1.	C–E. Total sand-grade: >0·1 mm.
Knottingley Glass-works.	0·7 %	68·0 %	30·8 %	0·5 %	—	99·5 %
York Glass works	0·4	93·5	4·8	1·3	—	98·7

The heavy crop is a rich and abundant one, consisting of well-rounded grains 0·15 to 0·2 mm. diameter. The minerals present, besides quartz and felspar, include purple and brown tourmaline, epidote, staurolite, kyanite, red garnet, green hornblende, zircon, andalusite, muscovite, ilmenite and leucoxene, magnetite, limonite, etc.

General Geological Considerations.

With the view of realizing the geological conditions under which glass-sands occur, in order to search for suitable supplies, it is instructive to draw attention to several salient facts. The association of pure white sands with carbonaceous matter has frequently been mentioned in this Memoir. Indeed, it may be said that every example of the better-class glass-sands indicates that the deposit is associated with vegetable matter. Lippe sand occurs with rafts of braunkohle. Hohenbocka sand is associated with carbonaceous layers; Fontainebleau sand with lignites; and Aylesbury and Leighton sands with peaty layers. Some of our purest sandstones occur in the Coal Measures, and, of second-rate sands, the Headon Hill and Bagshot Sands of the Isle of Wight (Alum Bay, Whitecliff Bay, etc.), Dorset, and elsewhere are interbedded with lignites; while the white beds of the Northampton Sands (Inferior Oolite) and the Estuarine Series in Yorkshire are found in deposits carrying plant-remains. The well-known Brora coal in the Jurassic of north-east Scotland is associated with white sandstones. The purest Ashdown Sands (Wealden) often carry plant-remains. The glacial sands of Lancashire, used for the making of window-glass, owe their low percentage of iron to the association with peaty material.

The bleaching of red and yellow sands for a few feet in depth on heaths and by the action of peat are other examples of this phenomenon. The explanation appears to lie in the reducing action of the vegetable 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.

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 (that is, beds containing coal, lignites, peaty matter, etc.) and the conditions under which we may expect to have had deposition of 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 glass-sands in Western Europe. It is very improbable that any new and large British supplies of first-class glass-sands will be revealed; but, in addition to the extension of supplies now being worked, deposits of small extent, at present unknown, probably occur in many cases in proximity to, or along the outcrops of, strata previously worked.

CHAPTER VII.

Special Treatment of Sands and Rocks.

Sands, like many other natural products, can be improved by washing. If the process is carried out effectively, a third-quality sand may be brought up to the rank of second, but it does not produce, in the case of British samples, a first-quality sand. Moreover, the question of extra expense due to washing (and sometimes drying also) and consequent additional handling and movement, is here an important factor, since very large quantities of second- and third-rate sands are used for making glass for lamp chimneys, electric-light globes, flint-glass bottles, window-glass, commoner table-ware, etc., individual firms each using as much as 300 tons of sand a week.

Colour of Glass-Sands—Although in the field a considerable number of sands appear by comparison to be white, it is remarkable how very few have the whiteness of white paper. The colour is frequently a good indication of the relative freedom of the sand from iron oxide. The best English sands are locally white, but usually grey, cream-coloured, or faintly yellow or brown. To realize the true colour, samples may be placed upon white paper or compared with Fontainebleau sand. Small quantities may also be mounted in clove oil and examined under the microscope when the faint yellow, brown, or grey pellicles of ferruginous material are easily visible.

A dark colour is not necessarily an indication of much iron; organic matter, which may subsequently be burnt out, produces this effect. A pink colour may be due to pink quartz and not to iron oxide. Similarly, a glass may be water-white and brilliant, and yet contain no small percentage of iron.

(a) *Washing.*—Hematite-coated grains (like those in Permian and Triassic deposits) cannot be cleaned without very great difficulty, even where the coating is thin and the sand pale-coloured. In the case of sand grains having a thin pellicle of limonite, mere washing by water may improve the quality considerably. Second-class sands from the Lower Greensand of Aylesbury, Leighton Buzzard, and King's Lynn have been improved and made suitable for flint-glass work in this way, but the results are not even then so good as the best of the Aylesbury or Lynn sands as actually found in the quarries. The sands are not improved in the matter of iron percentage by washing. Apart from the question of the increased cost of washing, which is considerable (at least

F 2

6*d*. per ton, but reaching, with the extra handling, as much as 2*s*. 6*d*. per ton), it is doubtful whether any British sand will be consumed at present in large quantities unless it can be used in the same state as it is quarried. This remark does not apply to sand worked for the best glass-making.

Tank-washing has been adopted in this country, but the method in general use is a rotary process. In one form the sand is fed in at one end of an iron cylinder. Water-pipes run through the upper part of the cylinder, which is rotated, and the sand is slowly forced down the cylinder by a worm action. The dirty water runs off to the opposite end. The end portion of the cylinder consists of a screen through which the sand passes free from pebbles, etc. It is then allowed to dry naturally. In other forms the water and sand run off at the same end, and draining is accomplished by passing the sand on to a rotating flanged cone.

Devices are employed to hasten the drying by draining off the water, and sometimes the process is carried out in large ovens (2 tons at a time), but systematic drying plant like that used in America has not yet been introduced. Drying is carried out in the Mississippi valley etc. by the use of tier dryers, rotary methods, or steam coils. Small quantities of dry sand are frequently required in this country in winter time, for use as parting-sand in facing moulds for brick-making, etc. In this case a small oven is built of bricks, a fire lighted within it, and the sand heaped over and around the oven.

Another method of washing adopted abroad is on the principle of acid-scrubbers, the sand being arranged upon tiers of platforms above one another and washed by distributed descending sprays of water.

In some cases the sand is washed twice over to ensure better cleansing. It is often an advantage, especially when washing is adopted in order to cleanse a sand from iron oxide, to have the cylinder much longer than it usually is. Care should be taken to ensure that rotary washing plant is suited to the grade of the sand. If the latter is too fine for the apparatus, much loss will result owing to the carrying off of fine sand in the stream of dirty water.

Washing is resorted to in glass-works and by sand merchants at the pits for cleansing purposes, and can sometimes be made to pay. In the matter of the improvement of the grade of a sand, screening may be combined with washing without much difficulty, and clayey and silty materials may be washed out by suitably controlled streams of water. If an elutriator is set up in the works' laboratory, analysis of the sand or crushed rock will give an indication of the velocity of the stream of water which will carry off all grades below that desired. For certain glasses it is not too expensive to treat local sands on a large scale in water-currents adjusted to this determined velocity. The process, in addition, will clean the sand of dirt and possibly some iron oxide. A velocity of 3·5 mm. per sec. (42 ft. per hour) is the theoretical velocity which will carry away all particles (which can move freely) of diameter less than ·075 mm. The use of a greater velocity than this will be necessary on account of the friction of sluices, etc. and the bulk of sand treated. An air blast may be used, as it is occasionally in engineering practice or for filtration purposes, to clear a sand of fine material. A blast of about 1·5 metres per second (about 4·9 feet per second) will carry off all particles of diameter less than 0·1 mm.

The coating of sea salts around the grains of dune- and shore-sands does not appear to be objectionable for glass-making (as it is when such sands are used for building purposes), similar salts being added in the batch. The sands have the advantage of being well-graded (see Table II.) as a result of repeated sorting by wind and water, but since their colour is not good and they often contain abundant shell-fragments, it is clear that repeated washing of sands will not produce purity without the intervention of living organisms and percolation of water (*cf.*, for example, the patchiness of colour in the red sands of the Permian and Trias due to reduction around organic remains).

(b) *Burning.*—The better-class sands are undoubtedly improved by baking. Water, often an objectionable constituent, is driven off. Organic substances are burnt out, and an improvement in whiteness results. Impurities which have been introduced in transit, *e.g.*, dirt and coal (when the sand is brought back by coal-barges as ballast) are eliminated. For very special work, such as optical glass or finest crystal ware, it is advisable to wash and burn even a very pure sand like that from Fontainebleau.

Burning, therefore, cleans a sand if it has been darkened by included peaty matter, but if the discoloration is due to iron staining in a slight degree, the sand becomes a darker grey, brown, pink, or red colour, the usual change being that from the hydrated oxide, limonite, to the anhydrous oxide, hematite. The effect of burning thus yields in most cases a rough indication of the amount of iron present as staining, that in the heavy minerals, as already stated, usually being of little importance. If the burning is carried on under standard conditions, the temperature being recorded by means of a pyrometer, and the increase in colour compared with known standard materials, an approximate idea of the amount of iron and organic matter present may be obtained. Most of the British deposits under consideration darken on heating, as do also the Belgian glass-sands so extensively used in this country. The latter are almost white, but attain a slightly pinker colour, while Dutch sand becomes greyer. Of the few British deposits which, like Fontainebleau sand, show no change on heating, the following may be mentioned: the best quality sand from Aylesbury and selected Godstone and Reigate sands (Lower Greensand), sand from Muckish Mountain, Co. Donegal, and a sand from Abergele, North Wales (the last two contain ferruginous patches which darken considerably). Pure white sandstones, such as the Coal Measure sandstone from Guiseley, near Leeds, show no change of colour on heating. The Godstone deposit mentioned is irregularly stained with iron. In places a pure sand is found which becomes only a very faint pink upon burning. Some of the white Godstone sand which had been left lying in heaps in the quarry had been thus improved in colour as a result of washing by rain for some time.

Many glacial sands appear to be light-coloured and fairly pure, but on examination are usually found to contain limonite pellets (often representing decomposed iron-bearing minerals). The limonite, the usual calcareous material, and the abundant heavy minerals (a result of the varied sources of their constituents) render them of little value for glass-making. They burn up to a much darker colour.

(c) *Chemical Methods.*—Other processes for the purification of sand from iron are too costly if any great quantity of the sand is required in industry *. Acids only partially clean the sands, even with application of heat. Hydrochloric acid has been used in this way, but the solution of iron oxide is never complete. Nitre-cake (a mixture of acid and neutral sodium sulphates) has been successfully used for dissolving out ferruginous and other compounds from sands. By raising a mixture of the sand with about 2½ per cent. of common salt to a red heat, and afterwards lixiviating with water, complete purification from iron is obtained †. Treatment with sodium hydrosulphide is said to yield the same result at lower temperatures. These methods are much too costly except where pure sand is required for very special work, such as optical glass.

(d) *Magnetic Methods.*—Endeavours to remove objectionable heavy minerals from a sand are not, as a rule, paying propositions. Electromagnetic methods have, however, been applied in the United States of America to the freeing of an otherwise suitable sand from such iron ores as magnetite. Other iron bearing minerals (including silicates, etc.) less permeable to electromagnetic action can be at the same time removed.

If hard rocks, such as well-cemented sandstones and quartzites, are crushed for glass-purposes (see below), magnetic separation must be resorted to in order to free the product from fragments of iron or steel obtained from the rolls or jaws of the crushing-plant. The process is similar to that employed in the preparation of raw materials for the manufacture of pottery. It has not been found necessary to apply this treatment to sand obtained from soft grits and sandstones.

(e) *Grinding or Milling.*—Only for the best glasses for optical purposes is it really advantageous to grind the sand to a fine even

* The largest glass-making firms each use 100,000 to 150,000 tons of sand a year.

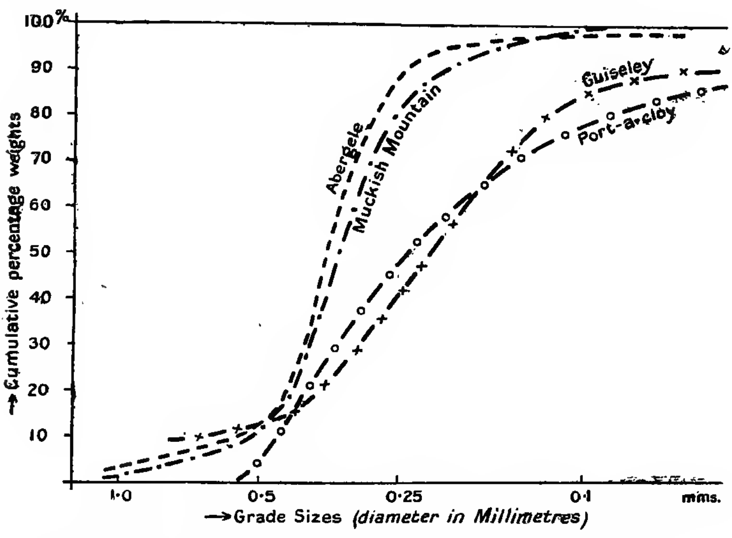
† Patent No. 8495 (1914) by J. G. A. Rhodin, "Improved Means for and Process of Bleaching Sand."

state. Better mixing and more even melting may thus be ensured, but the expense is considerable. The process has been adopted in the making of laboratory glass-ware, but it is doubtful whether any great advantage accrues. The procedure is not always followed in the making of optical glass (washed Fontainebleau sand being used) or in the manufacture of the best "crystal" table-ware, although many of the authorities on glass-making are convinced that a better result is obtained by its adoption.

Crushed rocks.

The consideration of the elimination of finer grades by washing or air blast leads naturally to the question of the suitability of

Fig. 11.—*Mechanical Analyses of Glass-Sands: Crushed Rocks, etc.*



crushed quartzose rocks, which have been placed upon the market as proposed substitutes for glass-sands. At the outset, it may be said that they have never found much favour with British manufacturers, although such materials appear to be extensively used abroad. The great evil of rock-crushing lies in the quantity of dust, which is waste material, produced. Mining engineers are still endeavouring to devise a machine that will grind or crush rocks to a fine even grade without producing slime. So far as glass-making materials go, the above remarks regarding the unsuitability of sand not of even grade apply still more emphatically here. Several pure sandstones and quartzites, of various geological ages from pre-Cambrian to Coal Measures, occur in the

British Isles, and a few have been crushed and exploited. Mechanical analyses of the products are given in the Tables. Sifting is usually carried out at the quarries, and so those coarse grades which are objectionable are eliminated. Large quantities of fine grades and dust are, however, produced, and, in order to yield an effective sand, these ought to be washed away with water-currents of strength calculated as above from elutriation data. It is frequently necessary to remove electromagnetically the iron particles obtained from the crushing-plant. The cost of quarrying, crushing, and sifting has usually been too great to permit of washing also, and the price of the unwashed material is often prohibitively high, even in the neighbourhood where it is produced. Much more is the cost increased by the usual heavy freights, so that there is little likelihood of such materials replacing glass-sands to any extent for ordinary work in this country. High-content of silica, or high alumina if that is desired, low iron, and general purity and angularity are their chief recommendations. Difficulties occur in the use of these crushed rocks. Often it does not pay to wash them, and consequently loss results from the burning out of the fine grade, and unevenness in the "metal" is caused by irregular melting. The fine material carries with it air-bubbles, from which the metal is cleared with great difficulty. 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" or "wavy" and to remain "sticky" too long upon cooling, which also takes a longer time than is desirable. Whether this is the result of the mixture of fine grades, of the presence of two allotropic low temperature forms of quartz, differing crystallographically, one possibly as a cement, of the different hydration of the silica acting as matrix, or of the presence of certain inclusions in the quartz, is not known. Greater heat, or more prolonged melting of the batch, appears to be required when crushed rocks are used *. 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 a disintegrated sandstone or quartzite. The mechanical analysis (see Tables) indicates, however, that it has been 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 (see also Fig. 11) should be compared with those of Guiseley material (which was supplied sifted to 40 mesh), Port-a-cloy Silica, Westport Silica, etc. Even after washing and sifting, the residual

* On the behaviour of the forms of silica, see Fenner, Amer. Journ. Science, vol. 36 (1913) p. 331, and Journ. Wash. Acad. Sc. vol. 2 (1912) p. 471; Wright & Larsen, Amer. Journ. Science, vol. 27 (1909) p. 421, and others.

rock-particles are distributed over several grades and the mixture is still unsatisfactory.

Among decomposed or crushed sandstones and quartzites examined were the following:—

Muckish Mountain Sand, Co. Donegal.

Worked by Sir Pieter Stewart Bam, Ards House, Dunfanaghy.

Maps.—Geological: Old Series (Ireland), 1-inch, Sheet 10.
6-inch, Donegal, Sheet 34.

Situation.—*Lat.* 55° 6′ 20″, *Long.* 7° 59′ 50″ W.

The sand lies on the top and upper slopes of a hill (Muckish Mountain) of quartzite about 4 miles from the sea, and about 33 miles E. of N. of Donegal. It consists of scree material resulting from the decomposition of the quartzite.

Formation.—Pre-Cambrian (Dalradian).

Description.—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 price 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_2O_3	·36
Fe_2O_3	·05
Loss on ignition	·12
	99·90 per cent.

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., 1·43 %; $>$0·5 & $<$1, 9·47 %; $>$0·25 & $<$0·5, 71·3 %; $>$0·1 & $<$0·25, 17·0 %; $>$0·01 & $<$0·1, 0·3 %; $<$0·01 mm., 0·5 %. Total sand-grade: $>$ 0·1 mm., 99·2 %.

$$\left[\frac{B}{1{\cdot}43}, \frac{C}{9{\cdot}47}, \frac{D}{71{\cdot}3}, \frac{E}{17{\cdot}0}, \frac{F}{0{\cdot}3}, \frac{G}{0{\cdot}5}; \frac{B\text{–}E}{99{\cdot}2}\right]$$

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 use of the deposit for glass-making. The sand has been cleared of finer material by agencies of denudation. A large quantity of pure rock is available for crushing, some of it having weathered soft on the surface. The actual quantity of sand appears to be small, but trial workings are at present being made in order to ascertain its extent. It contains a very small proportion of heavy detrital minerals, little else but zircon being present. The sand is now being developed by Sir Pieter Stewart Bam, and was used by the Irish Department of Agriculture in the reproduction of Waterford Glass for the Cork Exhibition, 1902. Good glass has also been made from it in the London area.

Crushed Sandstone from Guiseley, near Leeds.

Worked by The Guiseley Ganister Company.

Maps.—Geological: Old Series, 1-inch, Sheet 92 S.E.
6-inch, Yorkshire, Sheet 202 N.W.

Situation.—*Lat.* 53° 52′ 5″, *Long.* 1° 44′ W.

The quarry lies 1 mile W.S.W. of Guiseley.

Formation.—Coal Measures.

Description.—The purity and high silica-content of certain sandstones of Coal Measure age are well known and the rocks utilized. The Guiseley rock is much shattered, and is washed at the quarries, being supplied at present to the steel industry. It is proposed to crush and sift the rock for glass-making. The sifted product is free from coarse grains, but naturally is spaced over several grades, and contains objectionable fine material. The cost of washing, to rid the sand of the latter, is somewhat prohibitive, the price without washing varying from 15*s.* to 17*s.* per ton even in the neighbouring Yorkshire glass area. However, certain glass manufacturers are trying the sand, which is white, bears only a small quantity of iron, and does not darken on burning. The chemical analysis * is as follows:—

SiO_2	97·45 per cent.
Al_2O_3	1·76
Fe_2O_3	·09
CaO	·13
MgO	v. sl. trace
Loss on ignition	·78
Total	100·21 per cent.

The mechanical composition, after sifting to 40 mesh, is:—

>0·5 & <1 mm., 0·1 %; >0·25 & <0·5, 40·1 %; >0·1 & <0·25, 44·3 %; >0·01 & <0·1, 9·2 %; <0·01 mm., 6·3 %. Total sand-grade: >0·1 mm., 84·5 %.

$$\left[\frac{C}{0\cdot1}, \frac{D}{40\cdot1}, \frac{E}{44\cdot3}, \frac{F}{9\cdot2}, \frac{G}{6\cdot3}; \frac{C\text{–}E}{84\cdot5}\right]$$

The mineral composition indicates very rare felspar, a colourless flake of garnet (?), anatase growing on ilmenite, abundant small red-brown rutile, zircon, limonite, leucoxene, etc.

Samples supplied by The Irish Silica Company from **Port-a-cloy**, Co. Mayo, are also crushed Dalradian quartzite. The iron-content is low, and the sand consists almost entirely of quartz and muscovite (0·5 mm. diam.) with a little rutile, 0·05 mm. diam., chlorite (0·2 mm.), ilmenite, and zircon. Mechanical analysis indicates much variation in the size of the grains.

* An uncrushed sample of rock yields the following analysis:—

SiO_2, 98·93 %; Al_2O_3, ·60 %; Fe_2O_3, ·03 %; CaO, ·24 %; MgO, none; Loss on ignition, ·29 %. Total, 100·09 %.

The greater amount of iron in the crushed sample is therefore presumably due to additional impurity obtained from the crushers.

The material supplied by the Irish Industrial Minerals Company, Westport, consists of very finely crushed quartz from **Achil Island**, but the grading is imperfect and there is much dust. Various grades have been put upon the market.

Among other rocks examined with a view to the possibility of crushing and treating for glass-making purposes are the following: Appin quartzite (Kentallen, Argyllshire), Porthwen (Anglesey) quartz-rock, Twelve Pins and other Connemara quartzites, Carboniferous sandstones from many localities in the Scottish Lowlands, and from Pant du, near Mold, Brora sandstone (Sutherlandshire) and others. None appears to be pure enough to be profitably worked and treated. Crushed, decomposed, or treated materials have been obtained from Eaglescliffe (Co. Durham), Rhes y cae and Talargoch (Flintshire), Stiperstones (Shropshire), and Ballycastle (Co. Antrim). It is hoped that detailed descriptions of these may be given later.

CHAPTER VIII.

Economic Considerations.—General Remarks.

In the development of the national resources of raw materials for glass-making, questions of the cost of working, suitable treatment, and transport play a most important part.

The margin of profit upon sands is small. This and the fact that our large export coal-trade to the Continent enabled foreign sands to be brought back very cheaply as ballast have been mainly responsible for the small development of home resources of sands and allied rocks, and for the lack of investigation into them. The glass manufacturer hitherto has not experimented to any great extent with British sands, and is thus not generally acquainted with their potentialities. Moreover, before 1914 it was by no means certain that the best British sands actually reached the manufacturer. Owing to lack of systematic working, want of proper treatment and careful transport, British materials sent to the glass-making areas have to overcome the prejudice which they previously caused. This state of affairs is now rapidly being remedied, since the cutting off of a considerable proportion of foreign supplies of sand, due to the shortage of labour and shipping caused by the war, has necessitated the systematic surveying and exploitation of British mineral resources.

When brought as ballast or packing for bottles, Belgian and Dutch sands could formerly be delivered in our East Coast estuaries at 4*s*. to 5*s*. per ton. Fontainebleau sand was similarly delivered (although it was not usually brought as ballast) at 10*s*. per ton. These prices were doubled or trebled by the time the sand reached inland glass-making districts, the railway freights on sands being high. Even then the prices were below those of British sands, since the cost of production of the latter was, as a rule, greater.

Since the outbreak of war, partly owing to the greater demand for British materials and partly as a result of certain facilities having been granted which permit cheaper working, British sands are being delivered at a price which will enable them to compete successfully with foreign supplies. This improvement has been effected and a systematic development made possible by the high cost of foreign sands at the time of writing. Fontainebleau sand costs from 20*s*. to 60*s*. per ton, and Belgian and Dutch sands 17*s*. to 23*s*. per ton, according to the position of the glass-making area. Even when prices return to the normal level it will be possible for sand merchants to exploit their deposits if the demand is sufficient and if railway and canal facilities are given. Some British sands have for many years been carried as ballast from one part of the coast to another.

High class glass-sands, such as that of Fontainebleau, have frequently been used in this country in what might be termed a wasteful manner for common glass-manufacture. In certain maritime areas the sand can be obtained as cheaply as a less pure one, and is therefore used. In other areas, rather than have two different sands in use in the same glass-house, entailing possibility of confusion (which is, perhaps unnecessarily, feared), the manufacturer uses the same sand for crystal table-ware and also for commoner glass.

As a result of the importation of foreign sands, many British supplies which were formerly worked have been abandoned. Glass-sand appears to have fallen very considerably in price during the last fifty years, for, in 1858, Aylesbury sand fetched 25*s.* per ton at Aylesbury. In comparison with the present prices of British glass-sands given in the previous chapter, it may be stated that the average price in the United States of America is 4*s.* per ton.

Each of the economic factors will be considered in turn.

Workability.—In recommending sources of sand suitable for glass-making (or, for that matter, any other industry) due consideration must be given to the very important question of workability. Since the margin of profit on sands and gravels is low, attention must be paid to many factors other than those concerned with the actual properties of the sand. Of the latter, the high silica and low iron-content, low heavy-mineral percentage, absence of harmful minerals, the even grade (medium or fine sand), and possibly the shape, are the chief points to be considered. High content of alumina and potash are at times valuable.

In the field occurrence of the sand, due regard must be paid to the quantity available, the location with respect to fuel supplies and markets, and to transporting routes, whether by road, rail, canal, or sea. The accessibility of the deposits—on hills, near bogs and marshes, or in sea-cliffs—as well as the conditions of quarrying (workable depth below ground-level, position of water-table, direction of drainage, thickness of overburden, etc.), and the state of the local labour market have to be considered.

Treatment.—The cost of washing sands is usually about 6*d.*, or perhaps rather more, per ton. The additional handling and moving consequent upon washing, drying, or treating magnetically a sand or crushed rock, raises the cost considerably. Little washing is done in England, and where it is carried on, ordinary draining and air-drying are generally considered sufficient. The question is, of course, one of cost; but washed deposits ought to be dried before being put on rail or on board ship, for carriage should not be paid upon water. Sands have the power of retaining a considerable quantity of water, and their strongly hygroscopic nature should be clearly recognized. When crushing, washing, and drying are carried on, the proximity and price of fuel supplies and the available water-supply are important factors. If the crushing, screening, etc., of pure sandstones and quartzites ever becomes a paying proposition in this country, a considerable quantity of raw materials will be found to occur in the older rocks, especially in Scotland and Ireland. At present, for all but the very best glass-ware, these are ruled out. If a rock which has to be crushed is to be worked successfully, it must be exceedingly good in chemical composition, and fairly accessible.

Such rocks are at times of value for the alumina or the alumina and potash, as well as the silica, which they contain. If they are very hard, subsequent electro-magnetic treatment is necessary, after crushing, to free the sand from particles of steel, etc., derived from the crushers. The cost of electro-magnetic separation is 6*d.* or more per ton, according to local conditions.

Where sandstones and quartzites are disintegrating under atmospheric conditions, working may be carried out profitably, for the crushing, washing, and drying are done by natural means for the exploiter, and the deposit often needs screening only. If such deposits or other glass-sands are situated at a suitable elevation and water-power is available, the use of monitors to wash down the sand may be found advantageous. Gravity will then assist in transport, and the washing may well improve the quality of the product, both as regards mechanical composition and iron-content.

The enormous glass-industry of the Middle Mississippi Basin is supplied by crushing the St. Peter Sandstone, which crops out in the States of Minnesota, Wisconsin, Iowa, Illinois, Missouri, Arkansas, etc. It is blasted, crushed, screened, washed, and dried. The well-known Oriskany sandstone of West Virginia (Berkeley Springs, etc.) is similarly treated. Certain pure quartzites are, it is said, now being crushed and treated in Sweden to provide the sand for the manufacture of the well-known laboratory glass. Before 1914, Fontainebleau and Lippe sands were imported for the purpose.

Transport.—Carriage by road is expensive, and aerial transit, even for short distances and when aided by gravity, does not always appear to be satisfactory, besides being frequently costly. Railway freights upon sand (as well as upon the finished article, glass) should be reduced so as to permit the transportation of English glass-sand over any distance. Glass-sands, being purer, are unfortunately at present subject to a more expensive rate than ordinary sands. Canal-transport should replace rail-transport wherever possible in developing British sand-resources, and must be further revived and reorganized for this purpose, as too few of our deposits are situated near the sea or large rivers.

The levying of greater import duties upon foreign sands may not be desirable, but may have to be considered. As emphasizing this question of the necessity for a revision of freights, if British sands are to be exploited to any large extent, the fact should be noted that certain Continental supplies of glass-sand are larger, more regular and persistent, and in part purer than deposits in our own country.

General Considerations.—As a result of the chemical investigation which has been going forward while this geological enquiry has been in hand, it has been found that a lower standard of purity than hitherto admitted may be permissible in glass-sands. Owing to the paucity of chemists and works' laboratories in the glass-trade generally, little check has been kept upon other raw materials, and these have frequently been found to be impure. It should be possible to obtain the latter in a high degree of purity, and if any latitude is permitted, it should certainly be in the sand, where freedom from iron and casual impurities is more difficult to ensure than in manufactured chemical products. The sand has often been suspected, while the manganese dioxide, red lead, limestone, or even felspar, have been responsible for the iron. On the other hand, by varying the composition of the glass, less pure sands may be used to produce excellent ware, of water-whiteness and great brilliancy. The limit of iron oxide in sands for certain optical glasses may, according to Prof. Herbert Jackson, even reach 0·04 per cent..

The cost of chemical treatment of sand may also not be prohibitive when the manufacture of optical glass is under consideration.

While there are deposits in this country equal in quality to Fontainebleau sand, they do not appear to equal that deposit in extent and maintenance of sample. Our very pure and well-graded sands are of limited extent, but we possess large supplies of sand suitable for flint glasses, soda glasses, laboratory-ware, lamp chimneys, globes, bottles, etc. Suitable sands for black and green bottle-work are common enough, and are widely distributed. The price paid for sands for common glass in many British areas is far higher than it need be.

Good crystal ware has been made from Aylesbury sand, and the application of this sand to good glass-work is steadily growing. Selected samples might well be tried for certain optical glasses *. For such glass the variation in cost of sand is small compared with the considerable cost of production. The price of the sand is therefore not such an acute question, and a highly desirable sand will be obtained at any reasonable price, even where transport is expensive.

Early in this Memoir it was pointed out that sands suitable for glass-making (and therefore carrying a high percentage of silica, or silica and alumina) were of great value to the steel-founder for furnace-bottoms, soaking-pits, moulding-sands, silica-bricks, crucible-making, etc. We must note that the price paid for

* While this Memoir has been in the press, excellent optical glass has actually been manufactured from a number of British sands, many less pure than Aylesbury sand.

such sands by steel manufacturers and founders is usually well in advance of, and sometimes double as much as, that which the glass-maker is prepared to pay. Freedom from iron oxide or a very low percentage of it is not essential to the steel-maker; it is therefore desirable that the best silica-sands should, if possible, be retained for glass-making. Many deposits exist which are of great use as refractories, but are quite unsuitable for glass-making.

Glass manufacturers have been very fortunate in being able to obtain from abroad large and constant supplies of their essential raw material, pure sand, at a comparatively low price. The constancy in grade and chemical composition has enabled them to go forward with very little alteration of batch, and with no apparent need for investigation and analysis. The future cannot be ignored. It must be understood that foreign deposits, in particular those of Fontainebleau, are not inexhaustible, nor is it likely that they will always arrive in this country so cheaply or so true to sample in consignment after consignment as they did before 1914. The output of Fontainebleau sand may at any time be restricted for domestic reasons, or a tariff may be put upon it. It therefore behoves glass manufacturers to investigate the properties of their glass-sands and the questions of suitability or unsuitability of British supplies. More skilled chemists must be employed in the works to investigate not only the finished products and the necessary mixtures for special glasses, but also the chemical and mechanical composition of their raw materials, including sand. The discussion of the uses and nature of sands, and of the methods of study, together with the requirements of good glass-sands, have been expanded in this Memoir with the view of aiding glass manufacturers to investigate sands for themselves. Chemical analysis is familiar to all. Mechanical analysis can be carried out with very little apparatus, which is also such as can generally be blown in the works. Mineral analysis indicates the presence or absence of certain objectionable minerals in glass-making, and will enable the manufacturer to determine, within certain limits, whether his successive consignments come from the same bed or quarry. The last method of work, for example, is sufficient to prove at the present time whether the consignments of sand, which may well vary slightly in chemical or mechanical constitution, are the same Belgian or Dutch sand as that hitherto obtained.

Our Colonial resources of sand, particularly with reference to moulding (or, perhaps, refractories generally) and glass-making, ought to be thoroughly investigated. If it becomes desirable that, for certain special glasses, such as the valuable and important optical glass, the Empire should become self-supporting, it is highly probable that sands of sufficient purity and of suitable grade will be found in the Colonies, and could be shipped home, possibly as ballast. Such sands are said to occur, among other places, in

India, South Africa, and Victoria. The pulps obtained by crushing quartz-rock for extracting gold are often very pure; they accumulate in large quantities, but the remoteness of their location possibly rules them out. A revival of interest has recently taken place in Indian glass-making. The Tertiary deposits of Northern India are of similar age and character to those of Western Europe, which contain such excellent glass-sands. India may, therefore, well be self-supporting in the matter of glass-ware, and, if desired, may provide the necessary pure sands for British optical glass-making. This is one case among many, and serves to emphasize the desirability of further investigation and closer union in industrial and scientific questions between the Colonies and the Mother country.

Table I.—Chemical Analyses of Glass-Sands.

Percentage weights.

Locality.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	Loss on ignition.		
Analyses by Dr. H. F. Harwood and Mr. A. A. Eldridge, Chemical Dept., Imperial College of Science and Technology.							
Foreign.							
Lippe, best	99·88	·18	n. d.	n. d.	·21	Total 100·27 per cent.	Separate determination Fe_2O_3, ·02 per cent.
do. second quality	99·73	·20	n. d.	n. d.	·23	„ 100·16 ,	Separate determination Fs_2O_3, ·03 psr cent.
Fontaineblean, Barnsley Glass Works	99·80	·13	·006	trace	·18	„ 100·116 „	
Belgian, „ „	99·38	·30	·02	n. d.	·23	„ 99·93 „	
Dutch, Knottingley Glass Works	99·23	·50	·02	n. d.	·22	, 99·97 „	
do. Edinburgh & Leith Glass Works	99·63	·35	·03	·08	·19	„ 100·28 „	MgO, a trace.
British.							
Sandymount Strand, Dublin, shore-sand *	84·24	3·61	·47	4·65	4·81	Total 98·24 „	MgO, ·46 ; alkalies, n. d.
Jura, shore-sand	97·89	1·19	·07	·18	·42	„ 99·83 „	„ ·08.
Parsley Hay (High Peak), age?	74·54	18·04	·05	·19	7·24	„ 100·06 ,	„ none.
Brassington , „	90·40	6·56	·18	·16	2·48	„ 99·78 „	„ trace.
Abergele, age?	99·35	·54	·04	n. d.	·36	„ 100·29 ,	
Charlton, Thanet Beds	95·21	2·43	·42	·19	·88	„ 100·21 ,	K_2O, ·89 ; Na_2O, ·19.
Alum Bay, Headon Hill Sands	96·96	1·90	·11	·34	·64	, 99·95 „	MgO, sl. trace.
Aylesbury, Lower Greensand (best)	99·80	·32	·03	n. d.	·22	„ 100·37 „	
„ „ „ (washed)	99·39	·48	·02	n. d.	·13	„ 100·02 „	
Leighton Buzzard, Lower Greensand	99·59	·25	·21	n. d.	·27	„ 100·32	
„ „ , „ (a fine grade)	96·77	1·77	·27	·15	·63	„ 100·24 ,	MgO, ·03 ; K_2O, ·60 ; Na_2O, ·02.
Reigate, Lower Greensand	98·93	·67	·02	traoe	·28	„ 99·90 „	MgO, none.
Aylesford, , „	99·06	·56	·04	·17	·22	„ 100·05 „	MgO, v. sl. trace.

Lynn, Lower Greensand (best)	99·23	·59	·04	·11	·25	,,	100·24	,,	MgO, ·02.
Flitwick, ,, ,,	98·30	·87	·18	n. d.	·47	,,	99·82	,,	
Godstone, ,, ,,	99·56	·26	·06	n. d.	·24	,,	100·12	,,	
Burythorpe Fox Cover Pit, Kelloway Beds	96·79	1·63	·22	n. d.	·60	,,	99·24	,,	Alkalies present, n. d.
Burythorpe Park, Kelloway Beds	97·73	1·41	·06	trace	·32	,,	100·38	,,	MgO, tr.; K_2O, ·74; Na_2O, ·12.
South Cave, Kelloway Beds	94·80	2·93	·13	·14	·47	,,	100·11	,,	MgO, tr.; K_2O, 1·42; Na_2O, ·22.
Huttons Ambo, Upper Estuarine	99·04	·84	·03	·10	·19	,,	100·38	,	MgO, ·18.
Guiseley, Coal Measures	97·45	1·76	·09	·13	·78	,,	100·21	,	MgO, v. sl. trace.
Crofthead, Carboniferous	97·00	2·02	·20	·14	·76	,,	100·12	,,	,, none.
Muckish Mountain, Dalradian	99·37	·36	·05	n. d.	·12	,,	99·90	,,	

In the above analyses, three evaporations with intervening filtrations were made in the determination of the silica, and its purity checked with hydrofluoric acid. Iron was estimated colorimetrically in a separate sample.

Other Analyses:—

Lynn, Lr. Greensand, white	98·47	·81	·24	·26	·22	E. G. McBretney, Analyst.
,, ,, (washed)	98·54	·61	·26	·22	·37	
,, ,, glass-sand	97·4	1·77	·03	...	·8	
, , light brown	97·96	1·39	·26	·31	·08	
,, ,, "oxide," for black bottles	86·28	1·12	3·52	·45	8·25	Alkalies, ·38.
South Cave, Kelloway Beds	97·64	·18	·04	trace	1·93	Water, ·072 per cent. MgO, trace.
Huttons Ambo, Upper Estuarine	94·36	3·68	1·28	0·52	...	
, ,, ,, ,, (washed)	96·4	1·2	0·8	trace	1·0	
Denford, Estuarine Sand	98·22	·98	·30	trace	·60	MgO, trace; alkalies, trace.
Port-a-Cloy silica	75·00	14·83	1·02	trace	3·97	MgO, ·44; TiO_2, 1·09; alkalies (as sulphate), 3·54, [J. H. Davidson, Analyst.
Ballycastle, Co. Antrim	99·12	·61	·05	·02	...	TiO_2, ·05; MgO, ·02; K_2O, ·05; Na_2O, ·08.

* Used for black bottle-glass.

TABLE II. A.—MECHANICAL ANALYSES OF BRITISH GLASS-SANDS.

Percentage weights.

Sand.	B. >1 mm.	C. >0·5 & <1 mm.	D. >0·25 & <0·5 mm.	E. >0·1 & <0·25 mm.	F. >0·01 & <0·1 mm.	G. <0·01 mm.	B–E. Total sand-grade: >0·1 mm.	Colour.	Burning.
Pre-Cambrian:—									
Muckish Mountain	1·43	9·47	71·3	17·0	0·3	0·5	99·2	white.	no change.
Carboniferous:—									
Glenboig, N.B.	...	11·3	82·6	4·3	0·5	1·3	98·2	brown.	darker.
Levenseat, N.B.	...	3·7	88·5	6·0	0·2	1·6	98·2	yellow.	brown.
Crofthead, N.B.	sifted to 1mm.	1·4	67·2	25·4	1·8	4·2	94·0	brown.	much darker.
Trias:—									
Spital, Cheshire (Keuper Watsr-[stones).	...	0·7	81·7	13·6	1·4	2·6	96·0	grey.	darker.
Worksop (Lower Bunter)	2·0	6·6	58·65	26·15	4·5	2·1	93·4	dirty white.	,,
Inferior Oolite:—									
Corby, Lr. white Estuar. sands	...	...	1·3	73·5	16·0	0·2	74·8	cream.	pinker.
Denford ,, ,, ,,	...	...	2·9	92·3	3·0	1·8	95·2	whitish.	pinker.
Huttons Ambo	...	1·4	84·9	7·5	4·1	2·1	93·8	,,	grey.
Kelloway Beds:—									
Burythorpe Roadside pit	...	...	36·0	63·1	0·8	0·1	99·1	browner.	rather greyer.
,, Fox Cover pit	...	few grains only	39·2	59·0	1·0	0·8	98·2	as Belgian sand.	slightly greyer
,, Park	...	...	48·5	50·8	0·6	0·1	99·3	grey.	darker.
South Cave	...	...	8·3	90·2	0·7	0·8	98·5	pale grey.	greyer.
Wealden:—									
Tunbridge Wells	...	...	89·7	5·5	3·8	1·0	95·2	pale brown.	redder.
East Hoathly (Ashdown)	...	...	23·8	69·7	5·8	0·7	93·5	,, ,,	,,
Fairlight (Ashdown)	...	...	83·7	16·1	0·1	0·1	99·8	oream.	,,

Lower Greensand :—									
Aylesbury Windmill pit	...	<0·1	70·3	28·7	0·7	0·3	99·0	almost white.	no change.
,, Arnold's pit (best)	...	0·3	85·1	14·5	0·1	...	99·9	,, ,,	,,
,, as supplied	...	few grains only	78·3	15·0	5·8	0·9	93·3	fairly white.	,,
Lynn best white	...	...	94·8	4·9	0·2	0·1	99·7	as Belgian, grey-brown.	greyer.
,, (washed)	...	1·2	88·0	10·4	0·1	0·3	99·6	grey-brown.	markedly redder.
,, 2nd quality	...	...	73·3	26·0	0·2	0·5	99·3	darker.	redder.
,, 3rd ,,	...	2·6	94·1	2·5	0·2	0·6	99·2	darker still.	darker.
Godstone	...	0·6	73·0	25·7	0·2	0·5	99·3	almost white.	faint purplish pink.
Leighton Buzzard	...	24·6	74·3	1·0	<0·1	...	99·9	as Lynn 2nd.	much redder.
Oxted	...	12·4	86·3	0·9	0·1	0·3	99·6	rather browner.	redder.
Flitwick	...	0·7	83·5	14·6	0·5	0·7	98·8	grey.	darker.
Aylesford	...	few grains only	83·7	16·0	0·3	...	99·7	cream.	redder.
Reigate, Doods Road	...	2·7	79·0	14·5	1·8	2·0	96·2	almost white.	slightly darker.
Hollingbourne	...	...	94·6	4·2	0·8	0·4	98·8	cream.	browner.
Eocene :—									
Charlton (Thanet)	...		16·2	79·6	3·1	1·1	95·8	pale yellow-brown.	darker.
East Wickham (Thanet)	...	...	3·0	76·6	18·6	1·8	79·6	,, ,,	,,
Bromley (Blackheath)	...	...	0·7	86·5	11·8	1·0	87·2	pale brown.	redder.
Lymington (Bagshot)	...	...	13·5	76·7	9·0	0·8	90·2	pale brown.	darker.
Brockenhurst (Bagshot)	...	...	3·8	56·2	37·4	2·6	60·0	,, ,,	
Stoborough (Bagshot)	...	14·9	80·7	1·7	2·1	0·6	97·3	,, ,,	
St. George's Hill (Bagshot)	...	...	77·3	21·2	0·6	0·9	98·5	,, ,,	darker.
Alum Bay (Bagshot)	...	...	8·1	76·2	10·7	5·0	84·3	almost white.	slightly darker.
Alum Bay (Headon Hill Sds.)	...	...	3·8	84·0	9·7	2·5	87·8	,, ,,	,, ,,
Whitecliff Bay (Headon Hill Sds.).	...	...	17·3	60·2	17·7	4·8	77·5	,, ,,	,, ,,

Mechanical Analyses of British Glass-Sands (*cont.*).

Percentage weights.

Sand.	B. >1 mm.	C. >0·5 & <1 mm.	D. >0·25 & <0·5 mm.	E. >0·1 & <0·25 mm.	F. >0·01 & <0·1 mm.	G. <0·01 mm.	B–E. Total sand-grade: >0·1 mm.	Colour.	Burning.
Doubtful age:—									
Brassington	...	1·5	71·4	11·8	2·1	13·2	84·7	almost white.	pinker.
Parsley Hay (High Peak)	...	0·3	20·2	35·7	13·5	30·3	56·2	white.	no change.
Abergele	2·6	8·6	77·65	8·85	2·3	...	97·7	,,	,,
Crushed Rocks:—									
Irish Silica Co., Port-a-cloy	...	3·6 (mica etc.)	44·0	30·8	9·0	12·6	78·4	almost white.	darker.
Guissley Coal Measures	...	0·1	40·1	44·3	9·2	6·3	84·5	white.	no change.
Westport Silica	...	...	2·6	40·6	38·8	18·0	43·2	,,	,,
Dune & Beach Sands:—									
Jura (beach)	...	...	95·8	4·1	0·1	...	99·9	whitish.	grey.
Eigg ,,	...	2·9	94·8	0·2	1·6	0·5	97·9	mottled.	slightly pinker.
St. Ives (beach)	...	{shell-fragments 10·2}	88·8	0·2	0·4	0·4	99·2	{pale brown mottled.	whiter and blacker.
Curracloe, Rosslare (blown)	...	...	89·2	9·6	0·4	0·8	98·8	as Lynn.	redder.
Silver Strand, Wicklow	...	...	92·1	6·4	0·9	0·6	98·5	as Leighton.	,,
Sandymount Strand (shore)	...	0·7 (mica)	31·1	64·9	1·7	1·6	96·7	brown.	darker.
Montrose (dune sand)	...	0·4	96·4	2·5	0·2	0·5	99·3	brown.	darker.
Aberdeen ,, ,,	...	2·0	91·2	3·3	2·9	0·6	96·5	medium brown.	much darker.
Culbin ,, ,,	...	...	76·1	22·2	0·8	0·9	98·3	brown.	slight change.
Bamburgh ,, ,,	...	few small shell-fragments	94·8	4·7	0·5	...	99·5	pale brown.	darker brown.
Hartlepool ,, ,,	...	0·2	96·6	0·9	1·1	1·2	97·7	medium brown.	darker.
Blyth ,, ,,	...	1·3	96·6	0·7	0·2	1·2	98·6	darkish brown.	,,
Lowestoft ,, ,,	few grains	16·0	83·0	0·9	0·1	...	99·9	medium brown.	redder.
Maghera Green	...	...	75·0	15·7	8·0	1·3	90·7	nearly white.	,,
Ballycastle	...	3·3	82·8	12·0	1·1	0·8	98·1	cream.	pale brown.

Table II. B.—Mechanical Analyses of Foreign Glass-Sands.

Sand.	B. > 1mm.	C. >0·5 & <1 mm.	D. >0·25 & <0·5 mm.	E. >0·1 & <0·25 mm.	F. >0·01 & <0·1 mm.	G. <0·01 mm.	B–E. Total sand-grade: >0·1 & <2 mm.	Colour.	Burning.
Fontainebleau—Barnsley Glass Works.	...	<0·1	70·6	26 6	2·8	...	97·2	white.	no change
,, Edinburgh & Leith Glass Works.	...	...	70·3	28·3	0·6	0·8	98·6	white.	,,
Belgian—Barnsley	...	<0·1	99·3	0·3	0·4	...	99·6	almost white.	slightly pinker.
,, Knottingley	...	9·6	83·3	5·9	1·2	...	98·8	slightly grey.	,, ,,
,, Sheffield	0·7	6·5	91·0	1·4	0·4	...	99·6	pink.	slightly redder.
,, Manchester	...	1·1	93·3	4·8	0·4	0·4	99·2	pale pink.	no change.
Dutch—Knottingley	One grain	0·7	68·0	30·8	0·5	...	99·5	slightly grey.	? greyer.
,, York	...	0·4	93·5	4·8	1·3	...	98·7	slightly browner than last.	redder.
,, Edinburgh	...	0·4	94·4	5·1	0·1	...	99·9	white.	no change.
Lippe, best	...	...	78·6	19·9	0·4	1·1 *	98·5	white.	,,
,, 2nd quality	...	10·2	85·8	1·4	1·0	1·6 *	97·4	white.	,,

* Hygroscopic water included.

Table III.—American Glass-Sands*.

Sieve Tests. Approximate percentage weights. Chemical Analyses.

	Over 20.	Passes mesh. 20	40	60	100	SiO	Al_2O_3.	Volatile matter.	Fe_2O_3.	CaO.	MgO.	Total.
Berkeley Springs, W. Va.	...	100	98	25	1	...	...	...	...	...	...	...
Crystal City, Mo. (Pittsburg Plate Glass Co.).	...	100	55	20	1	98·90	·20	·25	·002	·54	·20	100·092
Klondike, Mo.	Small lumps.	100	90	15	1	99·97	...	...	·03	...	...	100·00
Ottawa, Ill.	...	100	100	92	25	99·45	{& Fe_2O_3 0·3}	...	...	·13	trace.	99·88
Utica, Ill.	A few grains.	99+	45	11	3	99·576	·283	...	·0903	·0197	·002	99·971

Table IV.—Danish Glass-Sands†.

(Chemical details also added.) Percentage weights.

Diameter in mms.

...	>1 mm.	>0·5 & <1·0	>0·2 & <0·5	>0·1 & <0·2	>·05 & <0·1	>·01 & <0·05	<·01	Silica.	Iron oxide.
Svendborg, Tertiary Sand	0·2	9·0	53·2	34·6	...	3·0	...	97·5	0·12
Fæno	...	...	1·2	39·2	52·9	4·8	1·9	89·2	0·48
Vejle Fjord, Hvidbjerg	0·9	9·9	41·2	45·7	...	2·3	...	95·9	0·18
„ „ Tyrsbaek	1·1	11·6	53·2	31·2	...	2·9	...	93·4	0·22
Grejs Mølle	1·1	6·8	37·4	50·7	...	4·0	...	94·6	0·18
Grejs Dal, Tertiary Sand	{>2 mm., 5·0 / 31·3}	47·3	15·4	1·0 (<0·2 mm.)		...	...	99·1	0·08
Stilling	...	0·1	21·7	75·9	...	2·3	...	97·5	0·17
Vejle Dal	0·5	31·8	65·6	2·1 (<0·2 mm.)		...	...	98·9	0·14
With these is quoted for comparison :—									
Belgian	...	1·6	80·8	17·2	...	0·4	...	98·4	0·17

[From the above table it does not appear that Denmark is too well supplied with suitable glass-sands of her own.]

* Bull. 285, United States Geological Survey, 1906.

† Dan. Geol. Undersøg. ser. 2, No. 16: N. Steenberg, "Undersøgelser over Nogle danske Sandsorters Anvendelighed til Rudeglas og simplere Hvidglas."

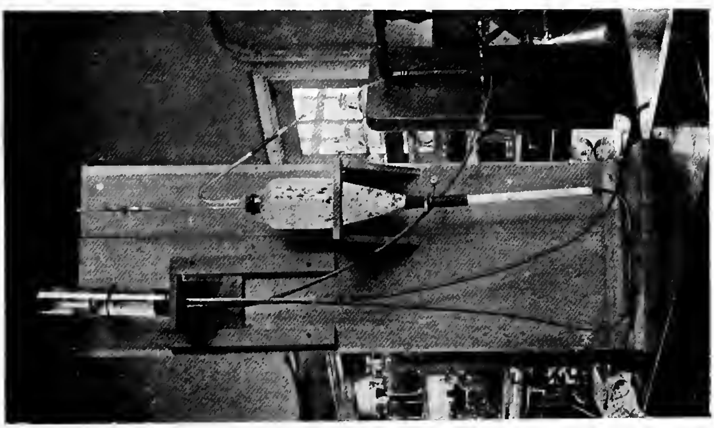


Fig. 1.—Crook's Elutriator.

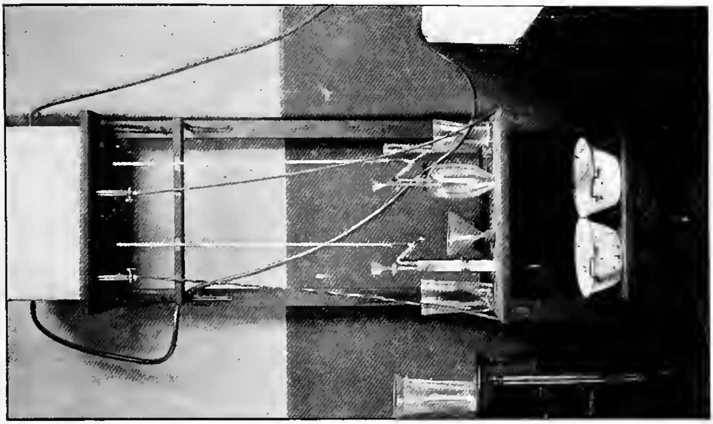


Fig. 2.—Stadler's modification of the Schoene Elutriator.

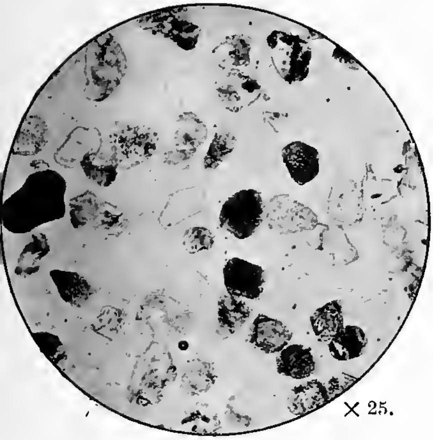


Fig. 1.—Quartz (faint and clear) and felspar (turbid) in a good glass-sand.

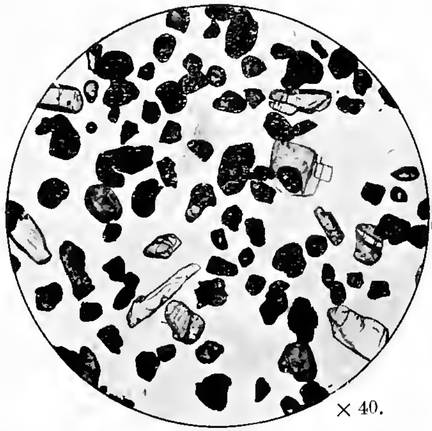


Fig. 2.—Heavy mineral residue from a British glass-sand: kyanite, staurolite, tourmaline, ilmenite, etc.

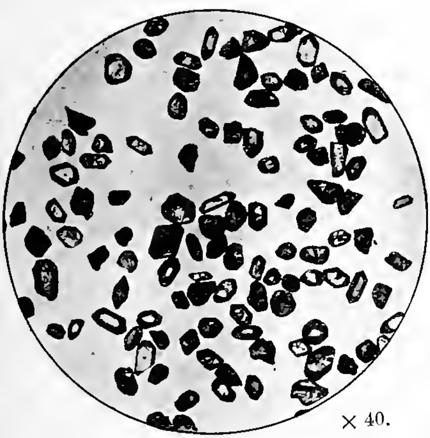


Fig. 3.—Zircon and Rutile: harmful minerals in glass-sands.

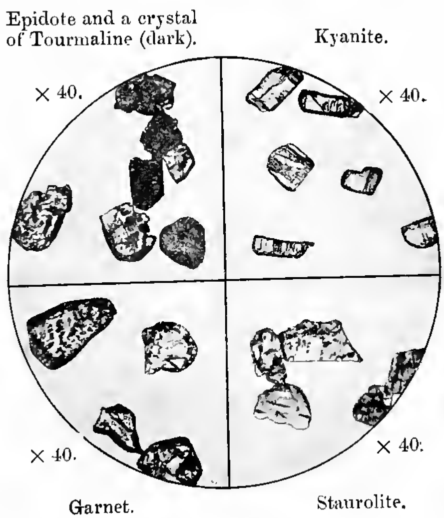


Fig. 4.—Heavy minerals from Sands.

Photomicrographs of Minerals from Sands (transmitted light).

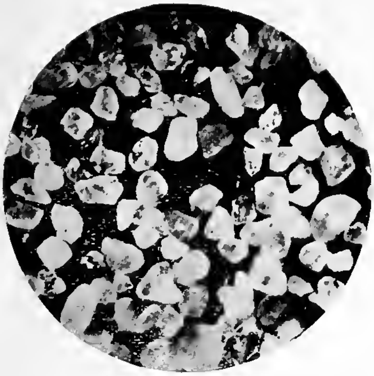


Fig. 1.—Fontainebleau Sand.

Fig. 2.—Lippe Sand.

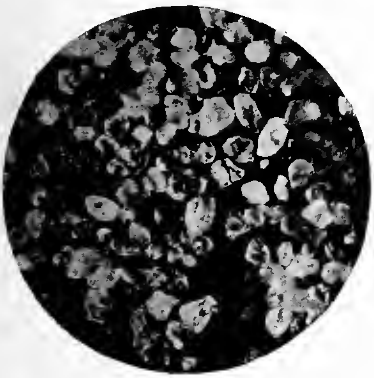


Fig. 3.—Aylesbury Sand.

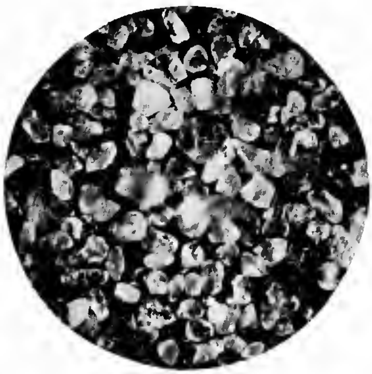


Fig. 4.—Godstone Sand.

Fig. 5.—Burythorpe Sand.

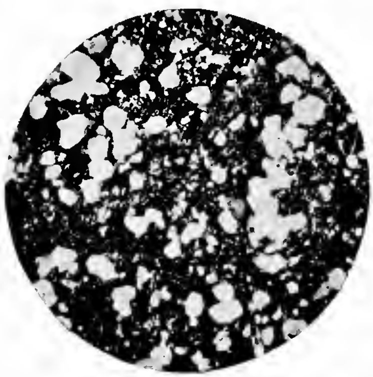


Fig. 6.—Crushed rock : Guiseley.

Photomicrographs of Glass-Sands (reflected light).

INDEX.

Note.—Descriptions of particular Glass-Sands occur on pages marked in black figures.

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