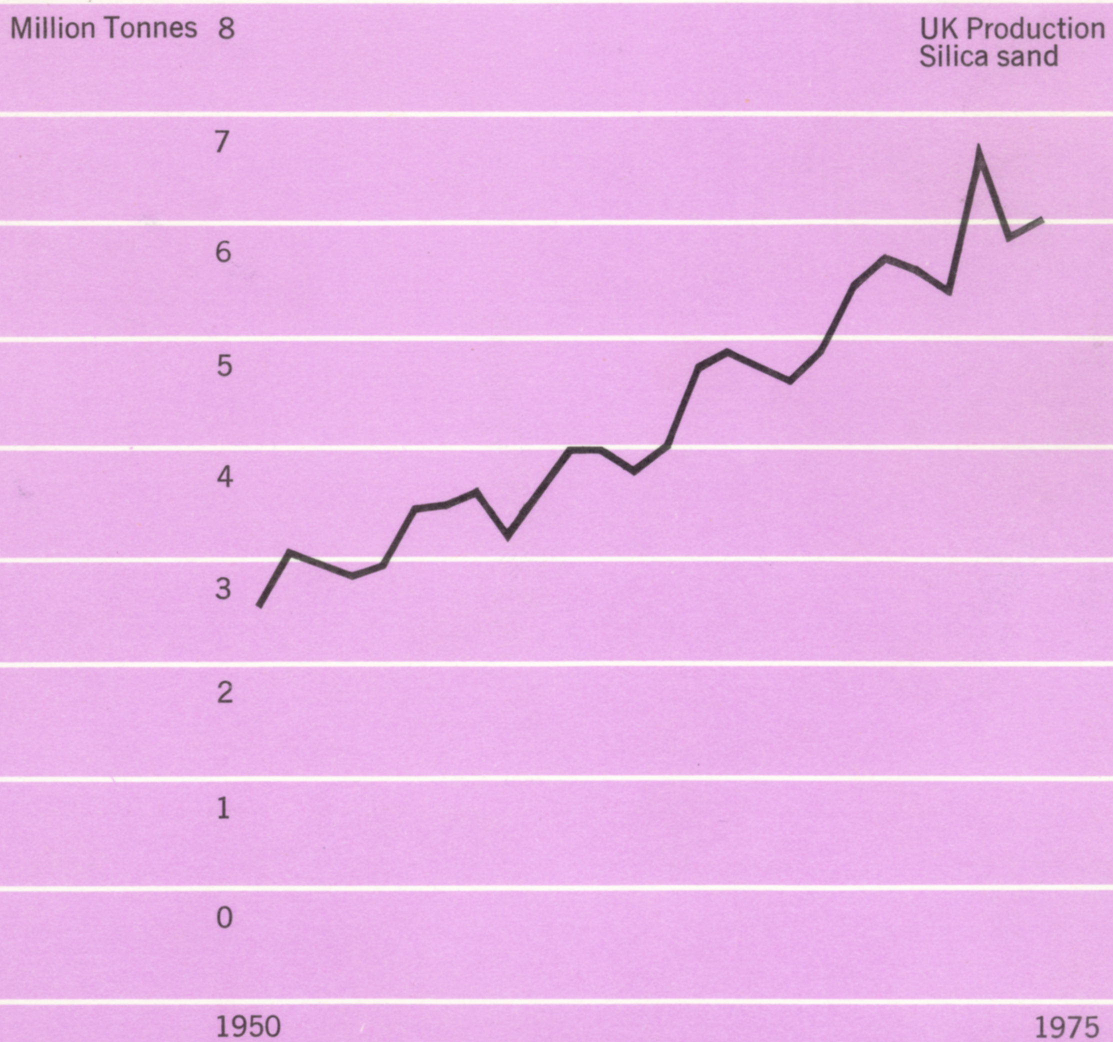
Mineral Resources Consultative Committee

Silica



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Mineral Resources
Consultative Committee

Mineral Dossier No 18

Silica

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London
Her Majesty's Stationery Office

Titles in the series

No 1	Fluorspar
No 2	Barium Minerals
No 3	Fuller's Earth
No 4	Sand and Gravel
No 5	Tungsten
No 6	Celestite
No 7	Salt
No 8	Sulphur
No 9	Tin
No 10	Talc
No 11	Ball Clay
No 12	Slate
No 13	Gypsum and Anhydrite
No 14	Gold
No 15	Mica
No 16	Potash
No 17	Sandstone

Preface

The Mineral Resources Consultative Committee consisted of representatives of interested Government Departments, and specialist advisers. It was set up in 1967 to keep present and future requirements for minerals under review and to identify problems associated with the availability, exploitation and use of mineral resources, both inland and offshore, having regard to competing demands on land use and other relevant factors.

Widespread and increasing interest in the mineral resources of the United Kingdom led the Committee to undertake the collation of the factual information then available about those minerals (other than fossil fuels) which were being worked or which might be worked in this country. The Committee produced a series of dossiers, each of which was circulated in draft to the relevant sectors of the minerals industry. They bring together in a convenient form, in respect of each of the minerals, data which had previously been scattered and not always readily available. These dossiers in updated form are now being published for general information.

Acknowledgments

This dossier has been compiled with the assistance of the Department of Industry and the Department of the Environment. Within the Institute of Geological Sciences the compiler would like to thank Mr D Horne and Mrs J Susskind of the Mineral Statistics and Economics Unit for providing statistical information and members of the field divisions for their comments. The compiler would also like to thank Mrs W Khosla for graphical work and Mr P B Nicholls for bibliographic services. The help of many of the companies listed in the final chapter of this report in providing information and advice, and giving access to their operations is gratefully acknowledged, as is also the assistance of representatives of the glass, foundry and refractory industries.

Metric units are employed throughout this document except where otherwise stated. In most cases this has necessitated the conversion of originally non-metric data. The units and conversion factors used are as follows:

millimetres (mm)	=	inches x 25.4
metres (m)	=	feet x 0.3048
kilometres (km)	=	miles x 1.609344
hectares (ha)	=	acres x 0.404686
grammes (g)	=	troy ounces x 31.1035
kilogrammes (kg)	=	pounds x 0.45359237
tonnes (1000 kg)	=	long tons x 1.01605
cubic metres (m^3)	=	cubic feet x 0.028317

Contents

Illustrations

Summary

Silica crystallises in several forms, the most common polymorph being quartz which occurs abundantly in nature as a major rock-forming mineral. The other principal crystalline forms of silica are tridymite and cristobalite, which, although uncommon in nature, are present in commercially fired products as they are produced by heating quartz at high temperatures. Micro-crystalline forms of silica are not covered by this report.

The principal commercial sources of silica in the United Kingdom are 'silica sands' and 'silica rock'. Silica or quartz sands are produced from sand and weakly cemented sandstone deposits ranging from Carboniferous to Holocene (Recent) in age. Production is, however, mainly confined to a few superior quality sands, notably those of Pleistocene age in Cheshire and of Lower Cretaceous age in Norfolk, Surrey, Kent and Bedfordshire. Holocene sands and Carboniferous sandstones are also locally very important. Silica sand is used principally for foundry moulding purposes and in glassmaking, about 3.3 million and 2.2 million tonnes, respectively, being produced for these purposes in 1975, representing about 90 per cent of the total output. Silica sands have numerous other industrial applications which are based not only on chemical purity but also the physical properties of the sand, such as grain-size distribution and grain shape. Silica rock is produced from hard, compact quartzitic sandstones and quartzites and is used in the manufacture of silica refractories, principally silica bricks. There has been a very marked decline in the production of silica rock in the United Kingdom since the Second World War due to changes in refractory and steelmaking technology and the output of silica rock in 1975 was only 42,000 tonnes compared with 625,000 tonnes in 1949. Silica rock production is now confined to Carboniferous quartzites and quartzitic sandstones in South Wales with one remaining operation in Durham.

Both silica sand and silica rock are won by opencast quarrying, the one exception being the Loch Aline mine in north-west Scotland where a bed of high purity sandstone, underlying Tertiary basalts, is mined by pillar and stall techniques. Processing of silica sands is of varying complexity and for most foundry sands and sands used in the manufacture of flat glass and coloured glass, consists largely of washing and sizing. Sand of purity sufficiently high for the manufacture of colourless glass without significant processing is rare in the United Kingdom, the only suitable deposit being that at Loch Aline in Scotland. Elsewhere the sand has to undergo extensive processing involving acid leaching and froth flotation.

The United Kingdom is nearly self-sufficient in silica sand and imports, which amounted to 145,000 tonnes in 1976 with a cif value of £1,535,000, came principally from Belgium and comprised high quality glass sand. The United Kingdom exported 54,000 tonnes of silica sand in 1976 with a cif value of £548,000. Imports and exports of quartz and quartzite are small, amounting to 3,600 tonnes valued at £612,000 and 328 tonnes valued at £24,000, respectively, in 1976.

Silica sand production in the United Kingdom is dominated by one company, British Industrial Sand Limited, which accounts for over 70 per cent of foundry and glass sand production. There are a significant number of other producers, the largest being Hinckley's Limited, Pilkington Brothers Limited, Sand Developments (UG Glass Containers) Limited, Buckland Sand and Silica Company Limited and Tilling Construction Services Limited. The silica rock quarrying industry is now a fraction of its former size and consists of only six small operations.

Definition and mode of occurrence

Oxygen and silicon are the two most abundant elements in the earth's crust and they occur in combination as free silica (SiO_2) or combined with other elements to produce the important silicate minerals which are the main constituents of rocks. Silica is polymorphic, that is, it can occur in different crystalline forms with the same chemical composition. The principal crystalline forms of silica are quartz, tridymite and cristobalite of which quartz is by far the most abundant comprising some 12 per cent of the earth's crust and occurring as an essential component of many sedimentary, igneous (especially granitic) and metamorphic rocks. The most important commercial sources of quartz are arenaceous sedimentary rocks and their metamorphic equivalents, and less commonly vein quartz and pegmatites. Tridymite and cristobalite occur only rarely in nature in certain volcanic rocks but as they are produced by heating quartz at high temperatures they are present in many manufactured siliceous products. There are also a number of high-temperature, high-pressure polymorphs of silica, such as coesite and stishovite. Silica also occurs in non-crystalline or micro-crystalline forms such as opal and chalcedony and such varieties as flint and chert.

The basic structure of the crystalline forms of silica is the SiO_4 tetrahedron in which a silicon atom is surrounded by four oxygen atoms, each oxygen atom being shared with another silicon to produce a three dimensional framework of SiO_4 tetrahedra. Quartz heated above 1470°C gradually converts to cristobalite, which, in turn, if heated in the range 870° – 1470°C slowly converts to tridymite. The conversions take place only slowly, because the Si-O-Si bonds have to be broken and rearranged; conversion is assisted by the presence of impurities or mineralisers. The changes are not easily reversible as both high temperature forms of silica are relatively stable down to room temperature. Conversion is accompanied by thermal expansion, the densities of quartz, cristobalite and tridymite being 2.65 g ml^{-1}, 2.33 g ml^{-1} and 2.27 g ml^{-1}, respectively. This fact is important in the manufacture of silica refractories, which consist of cristobalite and tridymite, and care is needed to ensure that adequate transformation to the high temperature polymorphs has taken place during firing to minimise any after expansion during service.

The polymorphs of silica exhibit both low and high temperature forms. At room temperature quartz exists in the low temperature or α-form but on heating it instantaneously inverts to β-quartz at 573°C. This change is reversible and below the inversion temperature, β-quartz reverts immediately to α-quartz. Similarly, cristobalite inverts at 220°-280°C; the inversion temperatures of tridymite are complicated, however, and have not been established with certainty. Inversion, particularly for quartz and cristobalite, is accompanied by a marked change in their thermal expansion coefficients, resulting in the thermal shock sensitivity of silica bricks below 600°C which may cause spalling or cracking unless care is taken in the heating up schedule of the furnace (Fig 1).

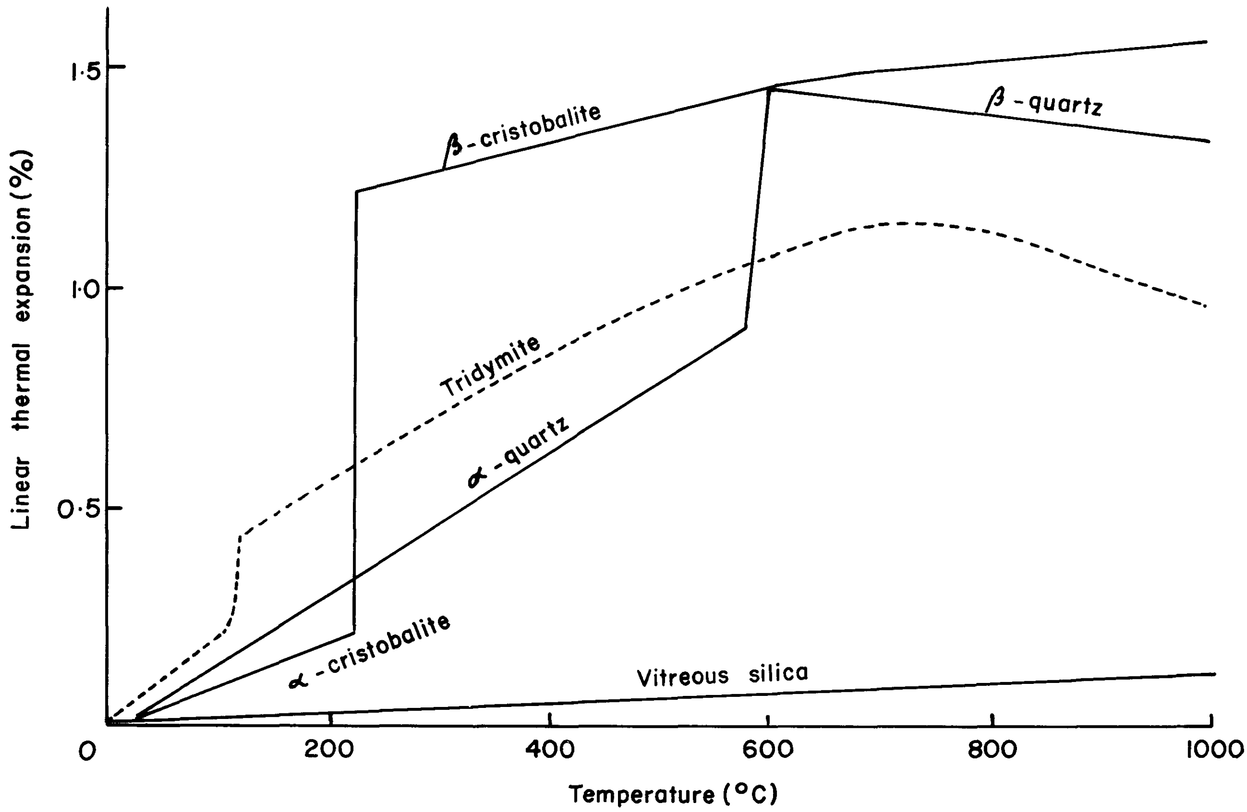

Fig 1 Thermal expansion properties of the principal forms of silica.

When silica is heated above its melting point (1710^{o}-1730^{o}C), and cooled rapidly, a glass is produced known as vitreous silica (fused silica). In commercial practice, however, temperatures of $1{,}800^{o}$ to $2{,}000^{o}$C are required to produce a workable glass. This has a very low thermal expansion coefficient (0.54×10^{-6} deg. C^{-1} between 0^{o}-1000^{o}C) compared with the other forms of silica, and has a high resistance to thermal shock. It can be subjected to rapid and extreme temperature changes without danger of breakage.

The sources of silica which are of economic importance in the United Kingdom and which are covered by this report, include 'silica sands', produced from unconsolidated sand and friable sandstone deposits, and 'silica rock' produced from compact quartzites and quartzitic sandstones. The occurrence, exploitation and utilisation of non-crystalline or partially crystalline forms of silica, such as flint and diatomaceous earth, are not covered by this report. The use of quartzite and sandstone as a source of aggregate and building stone has been covered in the *Sandstone* dossier.

Silica sand

The term 'silica sand' is used in industry to describe a commodity which contains a high proportion of silica in the form of quartz, and is marketed for purposes other than construction work, principally for foundry moulding purposes and in glassmaking. The term 'industrial sand' is often used synonymously. Silica sand, which can be produced both from sands and crushed sandstones, is therefore defined by end application as well as by geological or mineralogical criteria.

Quartz is both chemically and physically resistant (hardness 7 on Mohs' scale) to erosion and is concentrated during sedimentary processes thus being the principal constituent of arenaceous sedimentary rocks together with variable amounts of feldspar, mica, rock fragments and clay minerals. Other, accessory, minerals are present only in minor or trace amounts.

Natural sands rarely contain more than 95 per cent quartz and deposits containing only 80 to 85 per cent quartz are sometimes beneficiated to produce high quartz concentrates suitable for glass manufacture. It is impracticable, however, to define a silica sand by a minimum silica or quartz content as many sands are capable of beneficiation whether by simple washing and size classification, or more complex chemical treatment. Naturally-occuring, clean, white, well-sorted*, essentially monomineralic quartz sands needing no treatment are rare.

Most marketable silica sands contain a minimum of 95 per cent SiO_2, although for some applications, even in glass manufacture, a lower silica content is acceptable provided that the other mineral components of the sand are compatible with the particular end use. The presence of feldspar, for example, is often an advantage in glass manufacture, since it is a normal ingredient of the glass batch. The term 'silica sand' is usually restricted to essentially clay-free sands, although naturally-bonded mounding sands containing significant amounts of clay are covered by this report.

Mineralogical and chemical purity are by no means the sole criteria by which silica sands are defined and their physical properties, i.e. grain-size distribution and grain shape, may be equally important. Sands are clastic sediments with grain sizes variously defined in the range 0.0625 mm to 2 mm or 4 mm. For most commercial applications, however, silica sands are required to be well-sorted and with one or two notable exceptions e.g. water filtration sands, most commercial silica sands have grain-size distributions within the range 0.5 mm to 0.1 mm. The extent to which a poorly-sorted sand can be sized to produce a product within this range will depend not only on the inherent properties of the sand itself but on the opportunities for marketing the rejected fines and oversize material. However, since transport costs form an important part of the delivered price of the mineral, a poorer quality sand may be worked and the higher processing cost accepted where the deposit lies close to a major market.

Sands are derived from the weathering and erosion of igneous and metamorphic rocks and pre-existing arenaceous rocks and are deposited in a variety of environments from terrestrial to deep ocean by marine, fluvial, glacial and aeolian processes. The nature of sand deposits is greatly influenced by the type of rock from which they are derived and the distance the material has been transported from its source. Sediments stemming from the weathering of crystalline rocks tend to have a higher feldspar and heavy mineral content than those derived from arenaceous strata, reworking of which can eliminate less stable minerals such as feldspar, thus enriching the quartz content of the sand to produce a purer deposit. The depositional environment itself may also have a considerable bearing on the suitability of a sand for use as silica sand. For example, aeolian sands are usually well-sorted and have rounded grains, whereas glacial and fluvio-glacial sands are generally poorly-sorted, have angular grains and are much more variable in composition. The deposition of sands in shallow, current-swept waters characteristically produces well-sorted essentially clay-free sands. Variation in grain size distribution and quality do occur in sand deposits, however, and this may lead to problems in maintaining a uniform plant feed without discarding much waste. Normally, when evaluating a deposit, detailed borehole programmes are required to determine the quality and variability of the sand.

*A well-sorted sand is one which consists of grains of approximately the same size and the term well-graded is sometimes used synonymously by geologists, although it is used by civil engineers to imply quite the opposite sense. The term well-sorted is, therefore, used throughout this document.)

Silica rock

The term 'silica rock' (or 'silica stone') is an industrial term used to describe a hard, compact, even-grained rock consisting essentially of quartz from which silica bricks and other silica refractories are manufactured. In petrographic nomenclature the rocks include quartzitic sandstones, in which the detrital grains are cemented by secondary silica, and quartzites in which the detrital grains have been recrystallised or recemented by metamorphism (metaquartzites) or diagenetic changes (orthoquartzites). Originally the term 'ganister' was applied to a number of fine-grained, highly siliceous seatearths, rarely more than a metre or so thick, which occur near the base of the Lower Coal Measures (Westphalian A) in the Sheffield district, the best quality ganister lying beneath the (Halifax) Hard Bed (or Ganister) Coal. The rock is hard and compact, and composed of subangular quartz grains cemented by secondary silica and was formerly used in silica brick manufacture. The term is used rather loosely by the refractories industry, however, to refer to any highly siliceous rock, including ground mixtures of quartz and refractory clay used for lining furnaces and ladles. Apart from the presence of streaks of carbonaceous matter ('pencil' ganisters), compositionally ganisters are similar to other silica rocks, the main difference between them being their mode of occurrence. The term 'silica rock' appears, however, to have been firstly introduced to distinguish quartzites and quartzitic sandstones from ganisters. Siliceous seatearths which contain significant amounts of clay matrix are sometimes referred to as 'bastard' ganisters.

Uses and specifications

Silica sands have numerous industrial applications; by far the most important are for foundry moulding purposes and in the manufacture of glass. About 3,348,000 tonnes and 2,147,000 tonnes respectively, were produced for these applications in 1975, accounting for 90 per cent of total output.

Foundry sand

Silica sand is used as a mould and core-making material in the production of over 95 per cent of iron, steel and non-ferrous metal castings. Most is used in the production of iron castings output of which amounted to 3 million tonnes in 1975 as against only 0.27 million tonnes of steel castings.

Two basic types of foundry sand are produced; naturally bonded moulding sand, which contains sufficient clay to give the mould strength without the addition of a bonding agent, and clay-free silica sand (washed foundry sand), which requires the addition of a bonding agent, either clay (usually bentonite) or a chemical. Most metal is cast in 'greensand' moulds consisting of a mixture of sand and clay to which water is added to allow sufficient plasticity to develop for the mould to be formed and retain its shape while the metal is being cast. Naturally bonded moulding sands were formerly extensively used for this purpose but have gradually been replaced by clay-free silica sand to which a clay bonding agent such as bentonite is added and which imparts the necessary plasticity to the sand when water is added and the mixture milled. These sands are known as synthetic moulding sands. Naturally bonded and clay-free silica sand may be blended to produce a semi-synthetic moulding sand. Since the early 1950s, chemical bonding agents have been used increasingly, including sodium silicate, oil and various resin binders, which are bonded or hardened *in situ* by heat or chemical action. Chemically bonded sands are conducive to greater production rates, economy in use of skilled labour in mould and core-making, greater accuracy and intricacy of design and improved surface finish. The properties of clay-free silica sands can be controlled much more easily than those of naturally bonded sands. The replacement of naturally bonded sand by synthetic clay-bonded sand and more recently the wider use of chemical binders has brought about a considerable increase in use of silica moulding sands at the expense of the naturally bonded sand (Fig 2). The decline in the naturally bonded moulding sand industry is not, however, truly reflected in the graph since, excepting 1975, recent recorded output is believed to be too high.

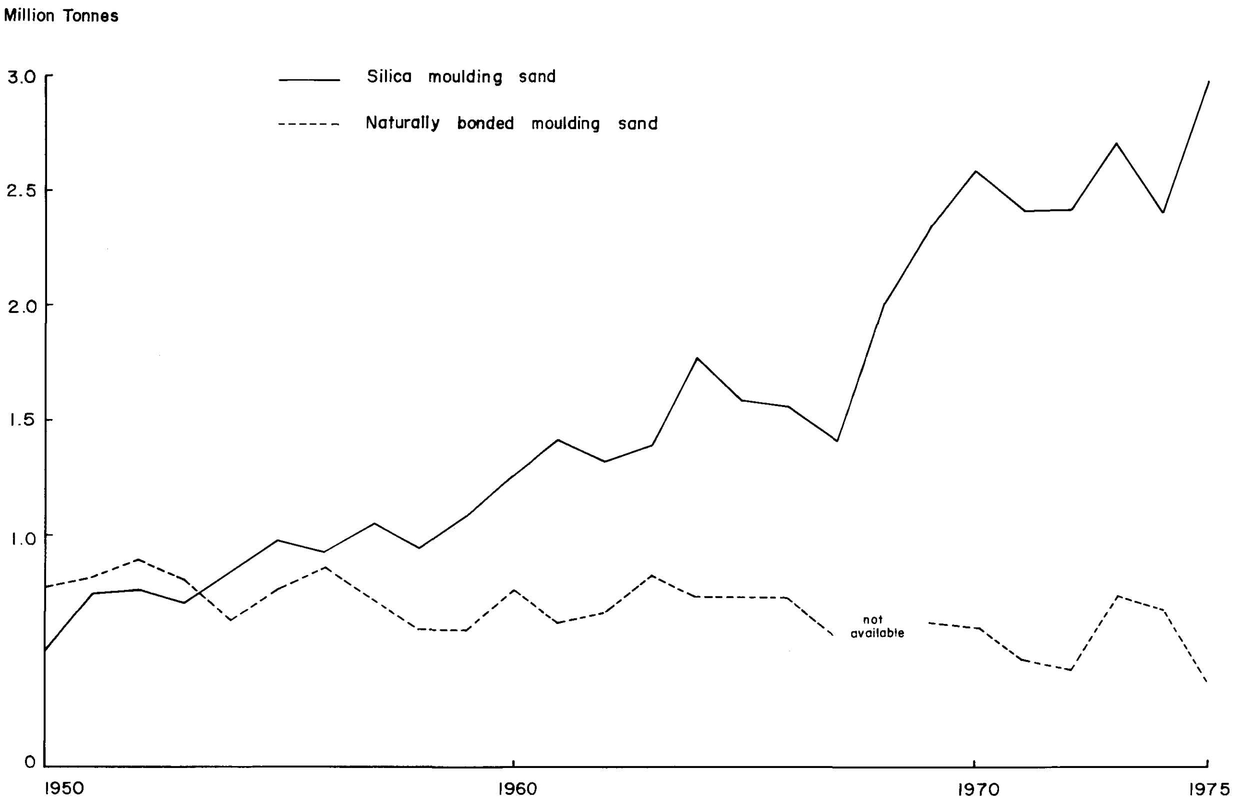

Fig 2 Great Britain: Production of silica and naturally bonded moulding sands, 1950-1975.

The physical and chemical requirements of foundry sands vary according to the metal being cast, the type of binder being used, the size of the casting and the position of the sand in the mould, for example, whether it is used as a facing sand or in core-making. There are no precise specifications for moulding sands, although the Steel Castings Research and Trade Association has published a *Tentative Acceptance Specification (No.6) for Dried Silica Sand,* for use in casting steel.

Most impurities reduce the refractoriness of a silica sand, so that for steel casting, where temperatures of 1580°C to 1650°C are attained, a high purity sand is required. The silica content should not, in general, be less than 96 per cent. For iron and non-ferrous castings, however, lower temperatures are involved and refractoriness is not so important. Nevertheless, a minimum silica content of 95 per cent is often required and the type of contaminating material present is also important as the presence of significant clay, alkalis, and calcium and magnesium oxides can reduce the effectiveness of the acid catalysts in resin bonded systems and thus lower the bond strength. The effect of these impurities can be obtained by determining the pH and acid demand values of the sand. For bentonite, oil and sodium silicate bonded sands small amounts of residual clay (up to 1 per cent) can be tolerated and may act as a key to the binders and help the breakdown of the mould after the metal has been cast. The sand should be essentially clay-free if a resin binder is used, however, as fine sand and clay increase binder requirements and can lead to considerable increases in costs. The clay content of a foundry sand (A.F.S. clay content) is expressed as the -20 micron fraction. (N.B. In sedimentary petrography practice the clay fraction is normally expressed as particles finer in size than 2 microns).

Quartz exhibits an instantaneous expansion on inversion from the α to β form at 573°C. This may cause distortion of the mould and casting. Zircon, olivine and chromite sands exhibit thermal expansion properties much lower than those of quartz sand and may also be used for facing cores and moulds. These alternatives are expensive, however, and the deficiencies of quartz sands in this respect can usually be overcome by the use of additives capable of accommodating the expansion.

A knowledge of the grain-size distribution of a foundry sand is of fundamental importance in controlling the permeability of the mould or core, the surface finish of the casting produced and the strength of the mould. Good permeability is required in a moulding sand to allow the gases generated during casting to escape through the mould and not into the metal where it would cause defects in the metal surface. Permeability decreases as sands become finer and the grain-size distribution wider. Finer sands are, however, more resistant to metal penetration and erosion and produce better surface finishes. There is a trend towards the acceptance of finer sands.

The series of British Standard sieves normally used for determining the grain-size distribution of a foundry sand are listed in Table 1, together with some typical grain-size distributions of foundry sands.

Table 1 Typical grain-size distributions of some washed foundry sands

		Wt percentage retained		
B S Sieve	*Aperture size (Microns)*	*Coarse*	*Medium*	*Fine*
16	1,000 (1mm)	0.1	0.0	0.0
22	710	0.7	0.0	0.0
30	500	4.0	0.1	0.1
44	355	20.2	3.6	0.3
60	250	44.5	43.2	1.8
72	212	19.9	32.7	4.8
100	150	9.1	17.7	45.0
150	106	1.1	2.2	41.5
200	75	0.3	0.3	3.2
<200	<75	0.1	0.7	3.3

In order that foundry sands should develop a high strength on compaction and exhibit good permeability they should be well-sorted with most of the sand grains falling on three or four adjacent sieves. The fineness of a foundry sand is conveniently expressed by its grain fineness number or AFS (the American Foundrymen's Society) number. The generally accepted method of calculating this number is shown in Table 2, which is a version of the American method slightly modified to suit British Standard sieves. The number gives a useful indication of the average grain size of a foundry sand but not the distribution of the sand grains. It can only be used satisfactorily in comparing the average grain size of well-sorted sands. The smaller the number the coarser the sand and most foundry sands have grain fineness numbers in the range 45 to 95, with the majority in the range 45 to 60.

Table 2 Method of calculating grain fineness number

BS Sieve No.	*% retained*	*Sieve factor*	*Product*
16	0.0	10	0
22	Trace	16	0
30	0.1	22	2.2
44	3.6	30	108.0
60	43.2	44	1,900.8
72	32.7	60	1,962.0
100	17.7	72	1,274.4
150	2.2	100	220.0
200	0.2	150	30.0
<200	Trace	300	0
TOTAL	99.7	–	5,497.4

The product is obtained by multiplying the percentage retained by the preceding BS sieve no. (the sieve factor).

$$\text{Grain fineness no.} = \frac{\text{Total product}}{\text{Total percentage of retained grain}} = \frac{5497.4}{99.7} = 55$$

Grain shape is an important property in a foundry sand and all grains must exhibit a high sphericity and platy and acicular particles must be absent. Roundness, which refers to the sharpness of the edges and corners and is independent of shape, is also an important criterion. Foundry sand grains are described visually as rounded, sub-angular or angular. Very well rounded sands are rare in the United Kingdom and most of the foundry sands produced are composed of rounded to sub-angular grains. Rounded sand grains flow more easily, giving more uniform and dense compaction than angular grains, as well as better grain contact and higher strength properties when bonded. The surface area of individual grains increases with angularity (for the same mean diameter) and with the fineness of the sand, so that the quantity of binder required must be increased to give the same bond strength between angular grains. The specific surface area of a sand ($cm^2 g^{-1}$), determined by an air permeability method, gives some indication of binder requirements and this is important where expensive chemical bonding agents are being used. With a relatively cheap clay bond angularity is less important. The surface area of a medium foundry sand (about AFS 60) is in the range 130 to 160 $cm^2 g^{-1}$ and for a fine foundry sand (about AFS 100) about 200 $cm^2 g^{-1}$.

Glass sands

Most commercial glasses contain between 60 and 80 per cent SiO_2, the source of which is silica sand. Soda-lime-silica glass, containing about 72 per cent SiO_2, is used in the production of glass containers and flat glass which account for over 90 per cent of the glass manufactured today. Total production of glass in the United Kingdom amounted to 2.8 million tonnes in 1975.

Unlike the foundry industry, where the physical properties of a sand are the most important factor, glass manufacturers are principally concerned with the chemical composition. Since most sands used in glassmaking require beneficiation, the mineralogy of a sand and the form in which the impurities occur is also of great importance. Specifications for glass sands vary considerably depending primarily on the type of glass to be produced and to some extent on the requirements of the glass manufacturer. The main applications of glass sand are in the manufacture of colourless glass (flint glass) containers, flat glass (float, sheet and rolled plate or patterned glass) and coloured (amber and green) glass containers, the silica content of the sand used ranging between

99.5 and 92.0 per cent, depending on the particular application. The physical requirements of the various grades of glass sand are similar, a narrow grain-size distribution being required, as the presence of oversize material and fines can cause difficulties in the melting and refining process. Most of the sand grains should fall in the range 125 to 500 microns, although it is claimed that finer (and angular) sands melt with a lower energy requirement. The problems of utilising fine sands in the batch might be overcome by pelletisation thus greatly increasing available raw material. According to the Glass Manufacturers Federation the grain-size distribution of glass sands for container and flat glass manufacture should be as follows:

	Cumulative
Retained on 16 BS mesh (1000 microns)	Nil
Retained on 22 BS mesh (710 microns)	0.25% max
Retained on 30 BS mesh (500 microns)	5% max
Passing 120 BS mesh (125 microns)	5% max
Passing 170 BS mesh (90 microns)	Nil

Similar size distributions are required for tableware, crystal and borosilicate glass manufacture.

In colourless glass manufacture iron oxide is the most undesirable impurity, particularly if it occurs as discrete particles and is not uniformly distributed. Other heavy minerals, particularly chromite and ilmenite, are also undesirable because they are refractory and insoluble in the glass and produce black specks. For colourless glass container manufacture an Fe_2O_3 content of less than 0.030 per cent is specified although sands with 0.040 per cent Fe_2O_3 are often used. Decolourisers are usually added to colourless glasses whatever their iron content but there is a limit at 0.05 to 0.06 per cent Fe_2O_3 beyond which glasses cannot be decolourised successfully.

In sand for flat glass manufacture 0.10 per cent Fe_2O_3 is acceptable whilst 0.25 per cent Fe_2O_3 or more is normally present in coloured container glass so that the presence of iron oxide in the sand can be advantageous since it contributes to the colouring medium. For large continuous glassmaking processes, however, consistency is probably the most important chemical criterion and the more mineralogically heterogeneous the sand the greater the problems of control. As alumina, soda and potash are normal consitituents of the glass batch the presence of feldspar in the sand may be economically advantageous. The sources of British glassmaking sands are shown in Fig 3 and some typical chemical analyses of colourless glass sands in Table 3.

Table 3 Typical chemical analyses of British colourless glass sands

	Wt %			
	1	*2*	*3*	*4*
SiO_2	99.75 - 99.85	99.65 - 99.75	99.0	99.74
Al_2O_3	0.05 - 0.10	0.10 - 0.15	0.6	0.09
Fe_2O_3	0.009 - 0.013	0.021 - 0.030	0.040 - 0.043	0.026
CaO	0.01	0.01	0.04	0.01
MgO	0.01	0.01	*n.a.*	0.04
Na_2O	0.01	0.01	0.03	0.10
K_2O	0.005	0.01	0.30	0.01
TiO_2	0.01	0.02	*n.a.*	0.06
Cr_2O_3	0.0003	0.0004	0.0004	0.0002
Loss on ignition	0.05	0.10	0.10	0.06

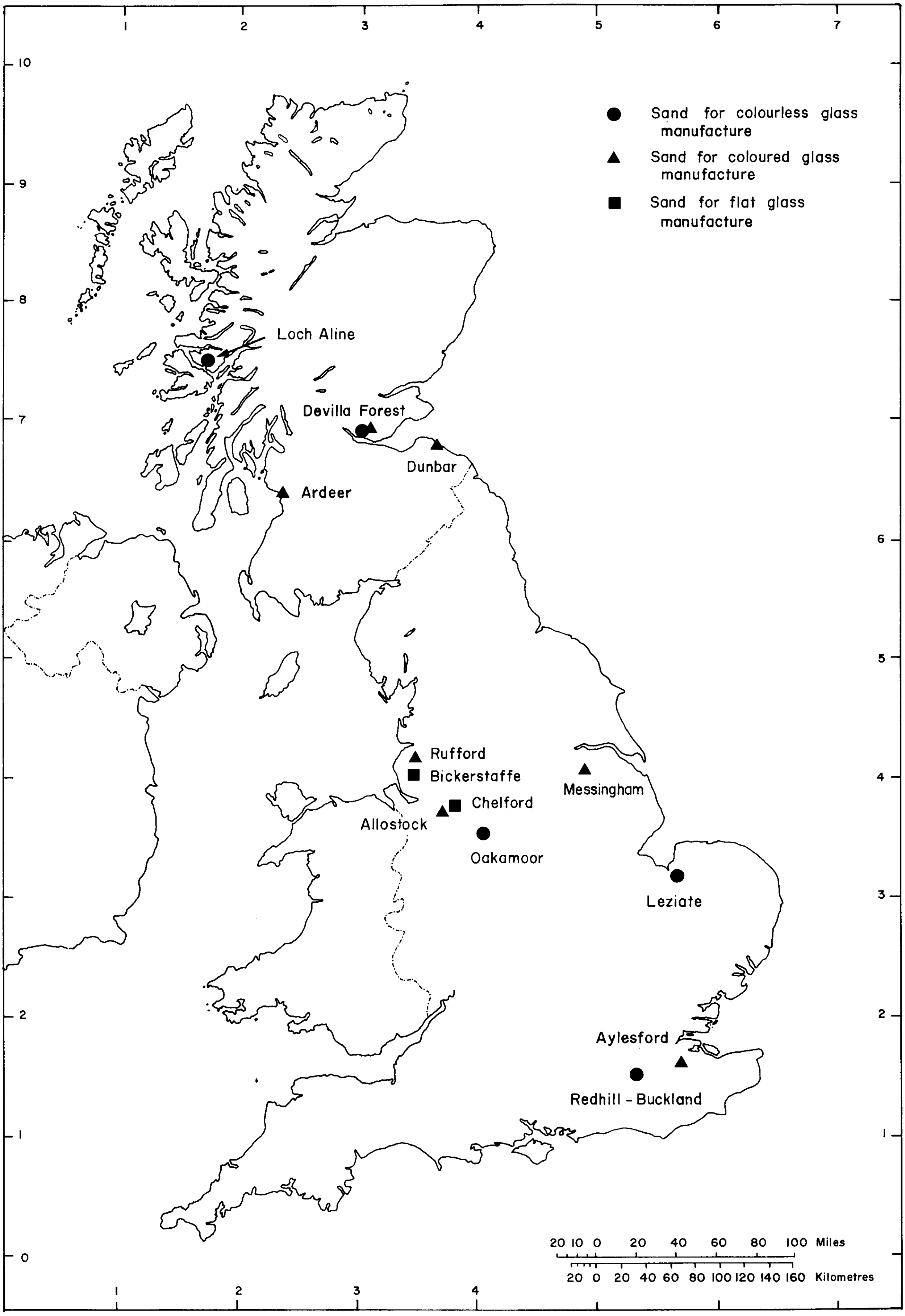

Fig 3 United Kingdom sources of glassmaking sands in 1976.

Table 3 (continued)

	5	*6*	*7*	*8*
SiO_2	98.3	99.0 - 99.3	99.5	97.5
Al_2O_3	0.8	0.35 - 0.4	0.1	1.3
Fe_2O_3	0.038	0.030 - 0.035	0.040	0.105
CaO	0.05	0.07	0.05	0.1
MgO	*n.a.*	Trace	*n.a.*	*n.a.*
Na_2O	0.1	Trace	0.1	0.1
K_2O	0.5	0.15	0.1	0.6
TiO_2	*n.a.*	0.03	*n.a.*	*n.a.*
Cr_2O_3	0.0010	*n.a.*	0.0004	0.0010
Loss on ignition	0.2	*n.a.*	0.1	0.2

n.a. not available.

Sources:

COLOURLESS GLASS SANDS

1 Loch Aline. Grade B. Upper Cretaceous. Tilling Construction Services Ltd.
2 Loch Aline. Grade C. Upper Cretaceous. Tilling Construction Services Ltd.
3 King's Lynn. Lower Cretaceous. British Industrial Sand Ltd.
4 Buckland. Lower Greensand. Buckland Sand and Silica Co Ltd.
5 Oakamoor. Millstone Grit. British Industrial Sand Ltd.
6 Devilla Forest. Passage Group (Millstone Grit). Sand Developments (UG Glass Containers) Ltd.
7 Redhill. Lower Greensand. British Industrial Sand Ltd.

FLAT GLASS SAND

8 Chelford White. Chelford Sand. Pleistocene. British Industrial Sand Ltd.

N.B. Chemical analyses of some coloured glass sands are shown in Tables 9 and 14.

Specifications for glass sand for colourless glass (flint glass) manufacture are given in BS 2975: 1958 'Sand for making colourless glasses'. Three grades of sand are defined by chemical composition and grain size, according to the product.

		Min SiO_2 %	*Max Fe_2O_3* %	*Max TiO_2* %	*Max Cr_2O_3* %
Grade A	Fine-grade optical glassware	99.5	0.008	0.030	0.0002
Grade B	High-grade domestic and decorative glassware	99.5	0.013	(a)	0.0002
Grade C	General colourless glassware including containers	98.5	0.030	(a)	0.0006

(a) not specified.

Specifications which generally supersede BS 2975:1958 and cover a more comprehensive range of glass sand grades were published by the Glass Manufacturers Federation in July 1974. These are preferred specifications and a reasonably wide variation in acceptable standards is allowed, although a consistent composition is of overriding importance. Specifications for certain types of glass are shown below:

	Min SiO_2	*Max Fe_2O_3*	*Max Cr_2O_3*
	%	%	%
Opthalmic glasses	99.7	0.013	0.00015
Tableware, crystal and borosilicate glass	99.6	0.010	0.0002
Colourless glass containers	98.8	0.030	0.0005
Coloured glass containers	97.0	0.25	–
Clear flat glass	99.0	0.10	–

For coloured and flat glass manufacture the minimum silica content is not critical and higher values for Fe_2O_3 may be acceptable, depending on the colour of the glass manufactured, and providing consistency is maintained.

Loch Aline is the only source of sand in the United Kingdom suitable for high-grade domestic and decorative glassware, which includes crystal glass, tableware and borosilicate glass for laboratory and scientific ware, chemical plant and domestic ovenware. Total demand for this grade of sand is between 150,000 and 200,000 tonnes a year, the major proportion of which is imported from Belgium. Natural sands are rarely of purity sufficiently high to be used in the manufacture of optical glassware, for which ground vein quartz with less than 10 to 15 ppm Fe_2O_3 is imported. Sands imported from Europe are used, after further processing, in the production of ophthalmic glasses. A minimum of 99.7 per cent SiO_2 is normally required for ophthalmic glass with less than 0.013 per cent Fe_2O_3, 1 ppm of such trace elements as copper, cobalt, chromium and nickel and 3 ppm of vanadium. Similar quality sand is required for the manufacture of translucent vitreous silica, United Kingdom supplies for which are obtained from the Miocene sand deposits near Fontainebleau in France.

Silica sand used in the manufacture of glass fibre falls into two categories. For glass fibre insulation wool, fine sand with a maximum of 20 per cent greater than 250 microns is suitable. It should have a minimum SiO_2 content of 94.5 per cent and maximum Fe_2O_3, Al_2O_3 and total alkali contents of 0.3 per cent, 3.0 per cent and 2.5 per cent respectively. For continuous filament glass fibre reinforcement, ground silica with a maximum of 3 per cent more than 45 microns, and chemical requirements conforming with those for colourless glass container manufacture are used but the alkali content should be low, about 0.5 per cent or less.

High quality silica sand is used in the chemical industry for the manufacture of sodium silicate. A silica content in excess of 99.5 per cent, with less than 0.05 per cent Fe_2O_3 and 0.4 per cent Al_2O_3 and not greater than 20 ppm Mn is preferred. The bulk of the sand grains should fall in the range 1 mm to 0.15 mm. Sodium silicate glass is produced by the fusion of silica sand and sodium carbonate at about 1300°C. It differs from ordinary glass in that it is soluble in water and for most of its industrial applications it is used in aqueous solution. By varying the relative proportions of Na_2O, SiO_2 and water a wide range of products can be produced, with applications in many sectors of industry. Present United Kingdom consumption of silica sand for sodium silicate manufacture is about 110,000 tonnes a year.

High quality quartz crystals exhibit the piezoelectric effect and both natural and cultured crystals are used for electronic frequency control or selection and to a much lesser extent for optical purposes. Cultured quartz crystals, produced by dissolution and hydrothermal growth have almost entirely replaced the use of natural quartz crystals in the United Kingdom. 'Lasca', the Brazilian term for fragments of clear quartz crystal, and high purity vein quartz are used as nutrient in the growth of cultured quartz crystals. Substantially 'water clear' high purity (>99.98 per cent SiO_2) quartz crystal (fusing grade 'lasca') is also used in the manufacture of transparent vitreous silica. Formerly most of the supplies of lasca were obtained from Brazil but because of very large price increases supplies are being sought elsewhere. Transparent vitreous silica may also be produced by the hydrolysis or oxidation of a volatile silicon compound and the subsequent fusion of the silica thus formed. The material is then referred to as synthetic vitreous silica.

Refractory uses

With rapid changes in refractory and steelmaking technology the importance of silica, which was a very important refractory material, has declined markedly since the late-1950s. Nonetheless, the manufacture of silica refractory bricks remains the most important application for high silica rock produced in the United Kingdom today. The first significant production of silica bricks was from the Millstone Grit of South Wales (the Dinas rock of the Vale of Neath) in 1856, but shortly afterwards ganister from the Lower Coal Measures of the Sheffield area was also being utilised. The rapid decline in the use of silica bricks was initially due to the change from 'acid' to 'basic' operating practice with open hearth steel furnaces. Acid open hearth furnaces, which were lined almost entirely with silica and fireclay bricks with a fritted layer of silica sand forming the floor, were used for refining hematite iron but this type of furnace has been of only minor importance since before the last war and is now no longer in use. Basic open hearth furnaces operate with silica roofs but a further decline in demand for silica bricks resulted not only from the replacement of the open hearth furnaces by LD or basic oxygen and electric arc furnaces, which require basic linings, but also from the use of basic and high alumina bricks in the roofs of basic open hearth and electric arc furnaces. Silica, which reacts readily with a basic slag, cannot be used in the basic steelmaking process.

Development of indigenous natural gas and the consequent decline of the carbonising industry also contributed to the fall in demand for silica bricks, although ovens for the production of blast furnace coke represent an important market for silica bricks today. Silica bricks are also used as glass tank refractories and for lining the hottest parts of hot blast furnace stoves (used to provide preheated air to the blast furnace), where, because of the higher temperatures now being used, they have replaced fireclay refractories in recent years.

The chemical requirements for a silica rock for silica brick manufacture are a minimum SiO_2 content of 97 per cent, and preferably more than 98 per cent, Al_2O_3 less than 1 per cent and preferably less than 0.5 per cent, and alkalis less than 0.2 per cent. For super-duty bricks the alumina and alkali content of the rock must be low, although authorities differ on the exact levels. Alumina less than 0.5 per cent and combined alumina and alkalis less than 0.7 per cent, or less than 0.5 per cent combined alumina, titania and alkalis have both been quoted. The need for silica bricks to withstand higher working temperatures and have longer lives in open hearth furnace roofs resulted in the temporary introduction of the super-duty brick in the mid-1950s which increased the need for very low alumina silica rock. The presence, therefore, of alkali bearing aluminosilicates such as feldspar and mica is particularly undesirable as they will reduce the refractoriness of the brick.

Chemical purity is by no means the sole criteria by which the suitability of a particular rock for silica brick manufacture is determined. To prevent after expansion during use, a high conversion of quartz to cristobalite or tridymite is required and to ensure adequate transformation, silica bricks are fired in batch type kilns at about 1450°C for long periods in order that they attain specific gravities of between 2.30 and 2.35. Pure silica converts only slowly, but it has been found that raw materials containing a proportion of chalcedonic silica have faster conversion rates and thus reduce fuel consumption. However, the presence of small amounts of mineralisers also speeds up conversion, for example, lime and iron oxide assist conversions to cristobalite and tridymite, respectively. The problem of producing a refractory brick with a long working life is also dependent on a low porosity. A hard, compact rock in which the individual sand grains are cemented by secondary (preferably chalcedonic) silica, to give a high bulk density rock with a low porosity, is desirable. Coke oven bricks do not need to possess the same degree of purity, but a dense, low porosity rock is still preferred for their manufacture. The particle-size distribution of the rock after crushing can also have a marked effect on the porosity of the brick and a 45 per cent coarse (3.35 mm to 0.5 mm), 10 per cent medium (0.5 to 0.18 mm) and 45 per cent fines (0.18 mm to flour), size distribution is consistent with a low porosity brick.

The main advantages of silica bricks are that they do not shrink at temperatures up to their melting point (1710°C – 1730°C), they are resistant to thermal shock above 600°C and can be used under load up to 1650°C or even 1700°C for super-duty bricks. Ultimately, however, it was found not to be possible to improve further their performance and with higher operating temperatures being used this has led to the introduction of basic roofs for open hearth furnaces and high alumina bricks for electric arc furnace roofs.

Imported raw materials have also been used in silica brick manufacture, including 'Findlings quartzite', a compact quartzite with a chalcedonic cement produced in Federal Germany, and 'silcrete', a micro-crystalline or chalcedonic quartzite produced in South Africa. Today only Swedish quartzite is imported for silica brick manufacture.

Highly siliceous clays and synthetically blended sand/clay mixes, with silica contents of between 88 and 93 per cent, are used in the manufacture of fired semi-silica or siliceous bricks. Siliceous bricks are produced from the naturally bonded 'Pocket' silica sand deposits of Derbyshire. Production of siliceous bricks amounted to 20,100 tonnes in 1975. The use of sand slinging techniques in the production of the monolithic linings for steel ladles for large production units is a relatively new and expanding use. The sand must contain sufficient clay, between 20 and 30 per cent, for it to retain its strength until the first batch of steel has been introduced, at which stage the surface of the sand fuses and glazes over. The grain-size distribution of the sand must be consistent with close packing and in order that the sand be refractory a kaolinitic clay is preferred. Naturally bonded Belgian sand has been widely used for this application, but synthetically produced sand/clay blends from indigenous sources are now being used. Chemical and physical requirements specified by the British Steel Corporation are shown in Table 4.

The 'Pocket' silica sands of Derbyshire, blended with siliceous clay from the Jurassic Upper Estuarine Series of Northamptonshire, form the most important source, but fine silica sands and silty clays from the Lower and Upper Estuarine Series, respectively, are also employed. The same sand/clay mixes are also chemically bonded to provide unfired bricks for lining the bottoms of steel ladles.

Table 4 Specification for ladle sands

	Wt %		*Wt %*
SiO_2	85-90	+18 BS sieve	2
Al_2O_3	6-9	−18 +150 BS sieve	40-55
Fe_2O_3	1-2	−150 BS sieve +6 microns	20-35
TiO_2	0.5-1.0	<6 microns	18-32
CaO	<0.5		
MgO	<0.3		
Alkalis	<0.1		

Moisture content 8.0-9.0%
Refractoriness 1620°C minimum

The fine sands and silty clays of the Lower and Upper Estuarine Series are also used, together with quartzitic gravel, in the production of patching and ramming compounds for lining cupola furnaces and foundry ladles. This material is generally referred to as 'ground ganister', United Kingdom production of which amounted to 21,700 tonnes in 1975. Ground silica rock from 6 mm to dust, bonded with boric acid, is used in the production of silica ramming mixes for lining electric arc induction furnaces. Silica sand is also used by the iron and steel industry for lining the troughs in which molten slag and iron run, and for casting pigs of iron. Siliceous clay or silica cement may be used for lining landers, the inclined channels which convey molten steel from the furnace tap-hole to the ladle. Silica sand or ground silica rock are raw materials for the production of silica cements, and sand and quartzite gravel are used as a flux in iron-making to balance the lime/silica ration of the blast furnace burden. High quality silica is not essential.

Other uses

High purity silica sands are used in the manufacture of ceramics. Ground silica sand is used chiefly in non-porous bodies such as porcelain and vitreous china, and also in frits, glazes and enamels. The problems associated with its use in earthenware bodies has now been largely overcome by calcining the sand to cristobalite with a constant specific gravity of 2.34 ± 0.02. In this respect it has successfully replaced calcined flint in wall tile manufacture. Silica flour is also used as an inert filler in rubber and plastics, in a variety of pharmaceutical products and in the manufacture of asbestos cement.

Silica sands have also a number of applications where a narrow grain-size distribution is necessary. Sands ranging from BS 6-14 mesh (2.80 mm – 1.18 mm) to BS 16-30 mesh (1.00 mm – 0.50 mm) are used as filtration sands for water and sewage treatment, one of the main grades being BS 8-16 mesh (2.00 mm – 1.00 mm) with a maximum of 10 per cent retained on BS 8 mesh and a maximum of 5 per cent passing BS 16 mesh. A narrow size distribution is required to produce a high permeability and, therefore, high flow rate through the filter. As the filter beds are cleaned by back washing the presence of coarse and fine particles would lead to uneven sedimentation reducing the efficiency of the filter bed. Essentially monomin-erallic quartz sands are required and they should be chemically inert, free of clay, organic matter, friable and platy particles, and consist of rounded to sub-angular grains. The most important source of water filtration sands produced in the United Kingdom is the Lower Greensand near Leighton Buzzard. The Passage Group sandstones at Levenseat in Scotland are also a source.

Standard sands are defined by the British Standards Institution for various testing purposes. Most standard sands are produced from the Lower Greensand near Leighton Buzzard and are exported to many parts of the world for testing purposes. For example, the standard sand for testing Portland cement (BS 12: Part 2: 1971) is specified as a thoroughly washed and dried white sand from Leighton Buzzard. Its loss of weight on extraction with hot hydrochloric acid must not be more than 0.5 per cent. All should pass a 0.850 mm BS test sieve but not more than 10 per cent by weight should pass 0.600 mm. This is the major standard sand for export. Similarly, a standard sand for mortar testing (BS 4551: Part 2: 1970) should be a natural (uncrushed), thoroughly washed and dried silica sand, free from active surface materials, and the various fractions (*see* below) should be derived from the Lower Greensand of Leighton Buzzard and the Lower Estuarine Series near Elton in Cambridgeshire.

	Fraction	*Source*
A	(2.36 mm to 1.18 mm)	Lower Greensand, Leighton Buzzard
B	(1.18 mm to 600 microns)	Lower Greensand, Leighton Buzzard
C	(600 microns to 300 microns)	Lower Greensand, Leighton Buzzard
D	(300 microns to 150 microns)	Lower Greensand, Leighton Buzzard
E	(150 microns to 90 microns)	Lower Estuarine Series, Elton, near Peterborough

Closely-sized sands are used by the petroleum industry to improve the permeability of reservoir rocks by pumping a mixture of sand and liquid down the well under such pressure that the rock is fractured. When the pressure is reduced the liquid drains away leaving the sand grains to hold the fractures open, thus substantially improving the original permeability of the rock and increasing the oil flow. Closely-sized sands of various grain-size distributions are employed, depending on geological conditions, some of the principal grades being 4.76 mm to 2.38 mm, 2.38 mm to 1.41 mm, 1.68 mm to 0.841 mm, 0.841 mm to 0.42 mm, and 0.42 mm to 0.25 mm. The sands should be of a high purity (>98 per cent SiO_2), washed and dried and essentially free of fines and acid soluble matter; the grains should also be well-rounded and have high compressive strengths because of the very large lithostatic pressures they have to withstand.

Clean, washed silica sands have numerous other applications which include sand-facing for bricks, roofing tiles and roofing felt; external rendering and rough-casting; the production of specialised concrete products, floor mixes and coloured facing sands; in sulphate resistant cement manufacture; as extenders in fertilisers; for turf and track dressings and general horticultural purposes; in sandblasting, stone sawing and polishing; and for golf course bunkers and sand pits. Clean washed, uniformly sized sands with size distributions mainly in the range 355 to 180 microns, are used in coal washing plants using the now obsolescent Chance dense medium process. Well rounded sands with grain-size distributions in the range 600 to 300 microns are used in air-fluidised sand beds for nursing purposes.

Sand mixed with 6 to 7 per cent lime and subjected to steam pressure at 174^{o}C is used as the source of silica in the manufacture of calcium silicate (sand-lime) bricks. Although relatively high purity silica sands are used and a broad grain-size distribution is desirable, a fairly wide tolerance is acceptable in terms of chemical purity.

Clean, well-sorted sands are used as the fine aggregate in the production of hot rolled asphalt, although a high purity is not required. Production of sand for asphalt and calcium silicate brick manufacture is included in official production statistics for building sand.

Silicon carbide, often known by its trade name 'carborundum', is produced by heating a mixture of silica sand and metallurgical coke in an electric furnace. The process requires large amounts of electrical energy and is not used in the United Kingdom, although silica sand from Loch Aline is exported to Scandinavia for this purpose. The sand usually employed should contain 99 to 99.5 per cent SiO_2 with only traces of phosphorus, lime and magnesia, although a small amount of alumina is permissible. It is usually required to pass a BS 22 mesh (0.71 mm) sieve with no fines passing BS 150 mesh (0.106 mm).

White silica sand was formerly used extensively in the manufacture of scouring powders but, because of the health hazard associated with free silica, it has been replaced by feldspar.

Quartzite pebbles are used as ball mill grinding media for grinding ceramic raw materials and pigments. Indigenous sources are not exploited and present requirements are imported. Flint grinding pebbles are, however, hand picked from beaches near Lyme Regis and are also produced as a by-product of sand and gravel working at Dungeness and the Crumbles, near Eastbourne. Flint pebbles are also imported from France. Quartzite and silex (chert) blocks for lining ball mills are all imported and there is no production of siliceous mill liners in the United Kingdom. However, microgranite mill liners are produced in North Wales.

In a number of countries lump silica in the form of vein quartz or quartzite has a major application in the production of silicon, ferrosilicon and other silicon alloys. These products are manufactured in electric furnaces and are energy intensive, silicon requiring 13,000 to 14,000 kWh/tonne (4.68 to 5.04×10^{10} joules*) and 75 per cent ferrosilicon 9,000 to 11,000 kWh/tonne (3.24 to 3.96×10^{10} joules), so that production is generally confined to countries with supplies of cheap electric power. The United Kingdom is entirely dependent on imports (Table 5), at considerable cost to the balance of payments, but if electric power were made available at special rates (as in the case of the aluminium producers) a considerable demand for high purity lump silica would arise. For example about 2 tonnes of quartz are required for the production of one tonne of 75 per cent ferrosilicon. Some potential also exists for the export of lump silica to countries such as Norway with large silicon and ferrosilicon industries.

Specifications are for a hard, clean quartz or quartzite with size limits in the range 20 mm to 150 mm. Fines must be kept to a minimum and the rock should have high thermal shatter resistance and not decrepitate on heating. Chemical purity is important, and for silicon manufacture the silica content should be as high as possible, normally at least 99.5 per cent, with Al_2O_3 less than 0.15 to 0.2 per cent, Fe_2O_3 less than 0.1 per cent, and CaO and TiO_2 as low as possible. Slightly less stringent specifications are acceptable for ferrosilicon manufacture but Al_2O_3 should be less than 1.0 per cent, and preferably lower than 0.6 per cent, and Fe_2O_3 less than 0.6 per cent. Phosphorus, sulphur and arsenic should be present in negligible amounts. Because of the presence of aluminosilicates, such as feldspar, quartzite is rarely of a purity sufficiently high to be used in silicon manufacture and vein quartz is normally employed.

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*1 kWh = 3.6×10^6 joules.

Table 5 United Kingdom: Imports and exports of silicon and ferrosilicon, 1972-1976

	Year	*Imports* Tonnes	*Imports* Cif value £ thousand	*Exports* Tonnes	*Exports* Fob value £ thousand
Elemental silicon					
(other than high purity)*	1972	16,229	2,684	317	48
	1973	22,411	4,371	1,422	322
	1974	20,467	7,890	3,592	1,721
	1975	14,611	7,060	701	418
	1976*(p)*	19,903	10,185	1,373	675
Ferrosilicon					
Total	1972	120,155	9,789	291	31
	1973	118,251	11,183	446	49
	1974	77,447	22,488	3,604	957
	1975	117,199	38,406	1,199	348
	1976*(p)*	112,331	28,309	1,224	331
of which containing	1972	98.469	8,532	200	24
55% or more by weight	1973	95,426	9,624	249	32
of silicon.	1974	62,525	20,307	3,175	874
	1975	105,180	29,140	946	278
	1976*(p)*	97,942	25,626	725	204

(p) provisional

*Minor amounts of high purity silicon metal are used in the electronics industry. A variety of other silicon ferro-alloys are also imported.

Source: H.M. Customs & Excise

Lump silica is also used as a flux in the production of elemental phosphorus by the electrothermal route, the silica reacting with the CaO content of the phosphate mineral producing a calcium silicate slag. A SiO_2/CaO ratio of between 0.8:1 and 0.9:1 is required in the furnace charge. High purity silica, usually quartzite, is not essential and a minimum silica content of 94 per cent is acceptable, although iron oxide is particularly undesirable and should be less than 1 per cent since the iron reacts with phosphorus to produce ferro-phosphorus thus tying up the valuable element in a low-value end product. The silica should not decrepitate on heating and is normally added to the charge in about 65 mm lumps. Phosphorus production is energy intensive, about 13,000 k Wh/tonne (4.68 x 10^{10} joules) being required, and although the element was almost continuously produced in the United Kingdom from the late 19th century, with a break in the period 1919 to 1932, production was finally abandoned in 1969 because of high energy costs. The Hartshill Quartzite at Nuneaton was formerly used as a flux.

Pyrogenic silica, a high purity silica of extremely fine particle size (0.006 to 0.02 microns), has been produced in some countries from fluosilicic acid which is a by-product of the manufacture of wet-process phosphoric acid. Pyrogenic silica is used in small quantities for many different applications such as in improving the viscosity and thixotropy of unpolymerised polyester and epoxi plastics and as an additive to paints, printing inks and colours.

Resources

United Kingdom resources of sand and sandstone are extremely large but only a very small proportion possess the desired physical and chemical properties to be classed as silica sand, consequently most sands need to be upgraded before use. Theoretically at least it would be possible to produce acceptable grades of silica sand from many sands and sandstones in Britain but the viability of upgrading inferior quality sand will depend ultimately on whether it can compete in price with existing sources of supply.

The general distribution of potential silica sand bearing strata in the United Kingdom is well known, but detailed information on their bulk physical/chemical properties and amenability to upgrading is not generally available. Although it is possible that new deposits of high quality sand might be discovered at depth or intercalated with superficial deposits, it seems likely that following the trend of the past 30 years, the future supply of silica sand will depend on the increasing use of mineral processing techniques to upgrade sand to the required specifications.

Table 6 Stratigraphical distribution of the major resources of silica sand in the United Kingdom

			Estimated proportion of total output %
Holocene (Recent)		Wind blown sands, including those of late Pleistocene age Shirdley Hill Sands	17
Pleistocene		Interstadial Congleton and Chelford sands Fluvio-glacial sands	35
Palaeogene-Neogene (Tertiary)		'Pocket' silica deposits of Derbyshire Barton Beds (a) Bracklesham Beds Bagshot Beds Thanet Beds	<1
Cretaceous	Upper Cretaceous —	White Sandstone (Loch Aline)	30
	Lower Cretaceous: Lower Greensand	Folkestone Beds Woburn Sands Sandringham Sands Spilsby Sandstone *(a) (b)*	
	Lower Cretaceous: Hastings Beds	Ashdown Beds *(a)* Tunbridge Wells Sand *(a)*	–
Jurassic		Kellaways Beds Lower Estuarine Series	<1
Permo-Triassic		Bunter Sandstone (Lower and Upper Mottled Sandstone)	5
		Lower Permian Basal Sands *(a)*	–
Carboniferous		Millstone Grit (including Upper Limestone and Passage groups in Scotland and Cefn-y-Fedw Sandstone) Fell Sandstone Group *(a)* Ballycastle sandstone *(a)* Kildress sandstone *(a)* Calciferous Sandstone Measures	12

(a) Formations not worked for silica sand
(b) Partly of Jurassic age

At present, industry relies on only a few superior quality sands, notably those of Pleistocene age in Cheshire and of Lower Cretaceous age in Norfolk, Surrey, Kent and Bedfordshire. These account for over 60 per cent of national output. Late Pleistocene and Recent (Holocene) sands in Lancashire, Merseyside, Humberside and Scotland, and Carboniferous sandstones in Staffordshire and the central valley of Scotland make up the greater part of the remaining output (Fig 4 and Fig 5). The main geological formations in which silica sands occur are shown in Table 6.

These deposits represent a very large resource of potentially workable silica sand and it is difficult to foresee any future shortage occurring for lack of available material in the ground. However, the continuity of availability depends on a number of other factors, the most important among which is the adequacy of planning permissions. Accessible reserves of silica sand can only be taken to comprise those deposits which are both economically exploitable at present and for which planning permission for extraction has been obtained.

The distinction between silica sand and some building and asphalting sands is sometimes difficult to make and the latter can be and, in some cases, are used, as foundry sands and in coloured glass manufacture, where a high purity sand is not essential. Similarly, the separation of the required sand fraction from a sand and gravel operation may be feasible, as has recently been proposed for a Pleistocene sand and gravel deposit near Colchester in Essex. Much depends on the economics of the individual operation which, because of high transport costs,is largely dependent on the proximity of a market, and also on whether a uniform product can be guaranteed.

The geological distribution of high silica rocks in the United Kingdom is summarised in Table 7. Comprehensive and representative analytical data on their quality is not generally available, although some data has been published by the Institute of Geological Sciences[1]. Resources of silica rock and ganister for silica refractory manufacture were examined during the two World Wars[2,3,4]. In 1948 Davies[5] concluded that resources of high quality quartzite suitable for silica brick manufacture were limited. Scottish quartzites were not examined during this survey but during the mid-1950s preliminary investigations were carried out by the Scottish Council for Development and Industry and by the United Steel Company Limited, although the results of this survey have not been published. Moinian, Dalradian and Cambrian quartzites were investigated along with vein quartz deposits and the Tertiary quartz pebble beds in the Grampian region. The quartzites are generally highly variable in quality, although the Cambrian Basal and Pipe-Rock quartzites and certain Dalradian quartzites in the Loch Leven area gave the most promising results, but although many samples had alumina contents of less than 1 per cent, few had less than 0.5 per cent. A bulk sample from a selected site failed a full scale industrial test owing to explosive splintering during firing. However, the demand for silica refractories has declined markedly since the mid-1950s and any future demand for high silica rock in Scotland is unlikely to be for silica brick manufacture.

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1. *Rep. No.* 69/1, *Inst. geol. Sci.,* 1969.
2. *Mem. geol. Surv. spec. Rep. Miner. Resour. Gt Br.,* 1920, Vol. 6.
3. *Mem. geol. Surv. spec. Rep. Miner. Resour. Gt Br.,* 1920, Vol. 16.
4. *Wartime Pamph. No.*7, *geol. Surv. Scotl.,* 1945.
5. *Trans. Br. Ceram. Soc.,* 1948, Vol. 47, No.2, pp. 53-79.

Table 7 Stratgraphical distribution of the major quartzite and quartzitic sandstone resources of the United Kingdom

Pliocene		Quartz pebble beds	Grampian region
Jurassic		Quartzitic sandstone, Moor Grit	North Yorkshire Moors
Triassic		Bunter Pebble Beds	Midlands
Carboniferous		Ganisters, Lower Coal Measures	South and West Yorkshire
		Quartzitic sandstones and ganisters, Millstone Grit and Lower Coal Measures	Northern Pennines
		Quartzitic sandstones	East Cheshire and north Staffordshire
		Cefn-y-Fedw Sandstone	North Wales
		Basal Grit, Millstone Grit	South Wales
		Quartz conglomerate, Calciferous Sandstone Measures	North of Glasgow
Ordovician		Stiperstones Quartzite	Salop
Cambrian		Basal and Pipe-Rock quartzites	North-west Highlands
		Hartshill Quartzite	Nuneaton, Warwickshire
		Wrekin Quartzite	Salop
	Dalradian	Durn Hill Quartzite	Portsoy, Grampian region
		Binnein Quartzite, Appin Quartzite	Loch Leven area
		Islay Quartzite	Islay and Jura
		Newtonstewart Quartzites	Northern Ireland
Precambrian	Moinian	Scaraben Quartzite	Helmsdale, north-east Scotland
	Mona Complex	Holyhead Quartzite	Anglesey
		Small vein quartz deposits	Highlands of Scotland, Lake District, Snowdonia and northern Pennines.

A potential application for lump quartz or quartzite is in the manufacture of silicon and ferrosilicon. Very high purity quartz is required for silicon manufacture and it is unlikely that a quartzite would have a sufficiently low alumina content. Massive vein quartz would be a more likely source but such deposits are small in the United Kingdom and generally situated in remote areas. The vein quartz deposit at Dalwhinnie in the Grampian Highlands has been worked intermittently in recent years for use in external rendering. The deposit is variable in quality, although in places of high purity (SiO_2, 99.7 per cent; Al_2O_3, <0.2 per cent; Fe_2O_3, 0.01 per cent) but reserves are small and have been estimated at only 40,000 tonnes.

The use of Scottish quartzites for ferrosilicon manufacture is a possibility, either for export or for use domestically if the necessary plant were established. Ready access to sea transport may, therefore, be an important factor. The Cambrian Basal and Pipe-Rock quartzites form the most extensive outcrop, extending in a narrow belt from Skye to Whitten Head on the north coast of Scotland. Most of the outcrops are comparatively inaccessible, however. The Basal Quartzite, although purer than the Pipe-Rock Quartzite, has a variable and locally high feldspar content. It's alumina content is too high for ferro-silicon manufacture. Metamorphic quartzites are not abundant in the Moinian, the main occurrence being confined to the Scaraben Quartzite near Helmsdale (Table 8). Within the Dalradian, quartzites are common, although of variable quality, but the Binnein Quartzite, which occurs in the Loch Leven area at Kinlochleven and Caolasnacon, appears to have the highest quality (Table 8) and is readily accessible.

Table 8 Partial chemical analyses of bulk samples of Scottish metaquartzites

	Wt%				
	1	*2*	*3*	*4*	*5*
SiO_2	98.46	98.40	99.10	98.50	97.80
Al_2O_3	0.91	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Fe_2O_3	0.19	0.16	0.08	0.09	0.09
CaO	0.06	*n.a.*	*n.a.*	*n.a.*	*n.a.*
MgO	0.11	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Na_2O	0.07	0.02	0.02	Nil	Nil
K_2O	0.20	0.25	0.11	0.23	0.49
TiO_2	0.06	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Loss on ignition	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*

1 Scaraben Quartzite. Moinian. Helmsdale. Bulk sample over 9 m. 275 m east of the summit of Beinn Dubhain.

2 Binnein Quartzite. Dalradian. West of Kinlochleven. Bulk sample over 14 m.

3 Binnein Quartzite. Dalradian. North-west of Kinlochleven. Bulk sample over 8 m.

4 Binnein Quartzite. Dalradian. South-west of Kinlochleven. Bulk sample over 4.5 m.

5 Binnein Quartzite. Dalradian. Caolasnacon. Bulk sample over 7 m.

Source: *Wartime Pamph. No.7, geol. Surv. Scotl.*, 1945.

Robertson Research International Limited, on behalf of the Highlands and Islands Development Board, have examined a number of potentially high quality quartzites including a detailed investigation of the Cambrian Basal and Pipe-Rock quartzites at Portnancon on the west side of Loch Eriboll.[1,2,3]. Initial surface sampling was encouraging but in depth higher alumina contents were encountered due to the greater abundance of feldspar. Four million tonnes of quartzite averaging 96.5 per cent SiO_2 and 1.7 per cent Al_2O_3 were outlined, but the quality is below that required for ferrosilicon manufacture. The higher quality material is produced by the leaching of feldspar within a metre of the surface. The Basal Quartzite at Achnashellach was also found to be too impure, as was the Islay Quartzite on the west coast of Jura, south of Inver Cottage. The Scaraben Quartzite, near Helmsdale and the Binnein Quartzite at Loch Leven were considered by Robertson Research International Limited as the most worthy of further investigation.

The British Aluminium Company Limited have investigated the Binnein Quartzite in the Kinlochleven area and preliminary results indicate that large tonnages of quartzite exist with much of the material containing over 98 per cent SiO_2 and less than 0.6 per cent Al_2O_3.

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1. An appraisal of the Portnancon quartzite, Durness. Report No.663, 1971.
2. A preliminary appraisal of high-grade quartzite deposits of the Crofter Counties. Report No.693, 1972.
3. A quartzite deposit in southern Jura. Report No.789, 1972.

The Holyhead Quartzite on Anglesey was formerly exploited for silica brick manufacture but output is now confined to the production of aggregate. Large reserves of quartzite exist on Holyhead Mountain, in close proximity to a good harbour, but the chemical purity of the rock is very variable and pockets of higher quality quartzite are irregularly distributed. Quartzite presently produced at the Twr quarry has a silica content of 93 to 94 per cent but material with 98.7 per cent SiO_2 and 0.8 per cent Al_2O_3 was formerly worked for silica brick manufacture.

Other than some impure quartzites e.g. the Cambrian Hartshill Quartzite of Nuneaton, used as a source of aggregate, virtually the whole of past and present production of silica rock has come from quartzitic sandstones, quartzites and ganisters of Carboniferous age. The quartzites and quartzitic sandstones of the Basal Grit of the Millstone Grit of South Wales, the Cefn-y-Fedw Sandstone of North Wales and certain quartzitic sandstone horizons within the Millstone Grit and Lower Coal Measures of Durham have provided the bulk of the silica rock produced since the Second World War. The most important ganisters were those underlying the Middle Band, Hard Bed, Hard Bed Band and Whinmoor Coals near the base of the Lower Coal Measures (Westphalian A) in South Yorkshire and ganisters within the Millstone Grit (Namurian) and Lower Coal Measures (Westphalian A) of Durham. However, because of their limited thickness and the high cost of extraction the importance of ganisters declined after the First World War and few true ganisters have been worked since the Second World War for silica brick manufacture.

At Meltham, near Huddersfield, the silicified top of the Huddersfield White Rock (Millstone Grit), which passes upwards into a ganister giving a workable thickness of up to 3 m, was, however, worked until the mid-1960s.

CARBONIFEROUS

Lower Carboniferous

In the Midland Valley of Scotland, at Milngavie and Strathblane, to the north-east of Glasgow, a quartz conglomerate with intercalated beds of sandstone is worked principally to provide coarse quartz gravel and sand which is sold as good quality concrete aggregate. The finer sands, which are highly siliceous (Table 9), although somewhat angular in shape, are sold for foundry sand and a number of other applications. The conglomerate lies at the base of the Calciferous Sandstone Measures and immediately overlies the Clyde Plateau Lavas. The pebbles consist principally of rounded, pinkish to white quartz up to about 65 mm in diameter. Although no chemical data are available, their silica content is probably high and these deposits may be a potential source of lump silica.

Parts of the Fell Sandstone Group of the Lower Carboniferous of Northumberland are potential sources of high silica sand, although they are remotely situated. From Redesdale northwards through the Rothbury Forest to Berwick-upon-Tweed, the Group is between 240 m and 300 m thick, and consists essentially of well-sorted, fine-grained sandstones. The sandstones are extremely friable and on crushing, milling and washing produce a silica sand containing about 96-98 per cent SiO_2, the grains being somewhat angular in shape. Similar white sandstones are known, but not worked, at Kildress in Co. Tyrone and Ballycastle, in Co. Antrim.

Index to Figure 4

1	Strathblane	
2	Milngavie	
3	Drumcavil	
4	Gartverrie	
5	Dullatur	
6	Kilwinning	
7	Harthope	
8	Halkyn Mountain (Chert)	
9	Llanarmon	
10	Tir Celyn, Minera	
11	Mynydd-y-Gareg	
12	Allt-y-Garn	
13	Cennen	
14	Cefn Cadlan	
15	Hensall	
16	Mansfield	
17	Bramcote	
18	Kinnerton	
19	Wittering	Lower Estuarine Series
20	Elton	Lower Estuarine Series
21	Corby	Lower Estuarine Series
22	Burton Latimer	Lower Estuarine Series
23	Pickworth	Upper Estuarine Series
24	Stamford	Upper Estuarine Series
25	Kingscliffe	Upper Estuarine Series
26	Burythorpe	Kellaways Beds
27	South Cave	Kellaways Beds
28	Borough Green	
29	Wrotham	
30	Aylesford	
31	Hamble	
32	Wareham	
33	Linford	Thanet Beds
34	Friden	Tertiary 'Pocket' Deposits
35	Brassington	Tertiary 'Pocket' Deposits

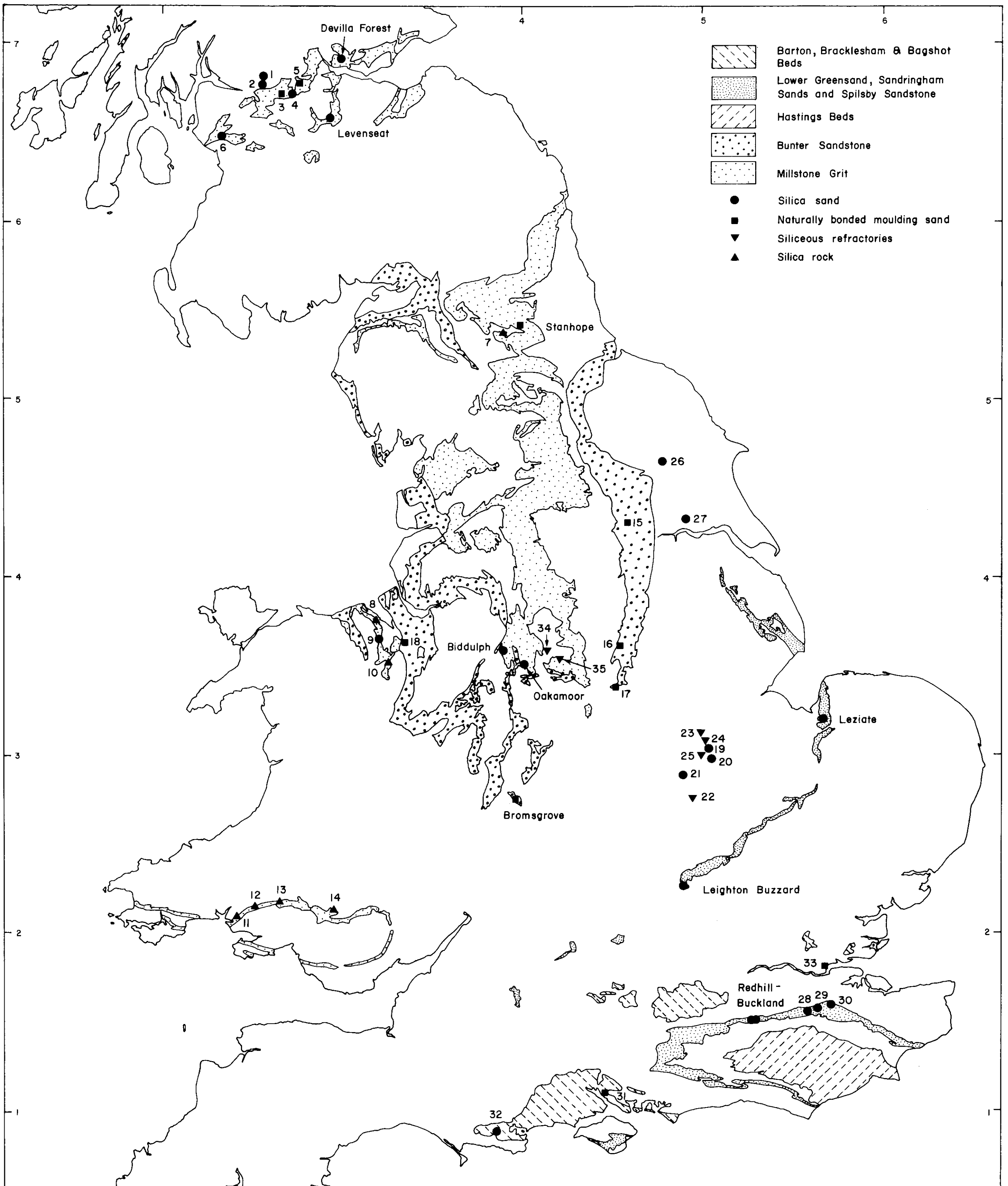

Fig 4 Distribution of silica sand and silica rock operations in sedimentary formations of Carboniferous to Tertiary age.

Millstone Grit

Arenaceous rocks, which vary considerably in thickness, purity and texture, form only part of the Millstone Grit. Coarse-to fine-grained, friable, feldspathic sandstones are most common but compact quartzites and quartzitic sandstones also occur and consitute the major producing source of silica rock today, although they were formerly of much greater importance. The Millstone Grit is also an important source of silica sand and despite a relatively high proportion of impurities (up to 20 per cent), mainly clay derived from decomposed feldspars, and iron oxide, it is possible to upgrade the sands, in certain areas, to meet the specifications of the glass and foundry industries.

In Staffordshire, the Rough Rock, which is about 30 m thick and contains up to 15 per cent clay and over 0.5 per cent Fe_2O_3, is exploited at Oakamoor and Biddulph. Crushing, grinding, fines rejection and acid leaching at Oakamoor, improve the quality of the sand sufficiently for it to be used in colourless glass manufacture and for ceramic purposes. At Biddulph washed sand is used in the production of sodium silicate and for a range of miscellaneous uses. The sand grains from both sites are generally too angular for use as foundry sands. A chemical analysis of sand from Biddulph is shown in Table 9.

Beds of white, friable, quartzitic grits and sandstones within the Millstone Grit near Pateley Bridge in Nidderdale and Greenhow Hill in Wharfedale have been investigated as potential sources of silica sand. Grain-size distributions vary considerably, but some of the sandstones have size distributions similar to foundry sands, although the grains are angular. The sands which have silica contents varying between 98 and 99 per cent, are reported to be suitable for colourless glass manufacture.

Deeply rotted and friable sandstones (often referred to as 'rotten-rock') suitable for naturally bonded moulding purposes, occur at a number of localities in central Scotland and are produced from the Upper Limestone Group* at Dullatur and Drumcavil in Strathclyde. Similar, coarse, rotted sandstones in the Millstone Grit of Durham and south Northumberland were formerly extensively exploited in the fell country between the Wear and Tyne, mainly to the north of Wolsingham, but only two quarries near Stanhope remain operating. They contain up to 20 per cent clay and can be easily crushed and milled to form naturally bonded moulding sands of sufficient refractoriness to be used for steel foundry work. A soft, white to creamy white sandstone within the Upper Limestone Group near Kilwinning in Strathclyde has been worked as a source of foundry sand in the past but it is now used for plastering and external rendering.

Some of the quartzitic sandstone beds within the Millstone Grit of the northern Pennines are sufficiently pure and compact to be used in the manufacture of silica bricks. Only one quarry, at Harthope in Weardale, now remains in operation, although formerly Durham was an important source of both silica rock and ganister. At Harthope a sandstone bed some 6 m thick beneath the Upper Felltop Limestone is worked. The typical composition of selected rock is shown in Table 10.

*The Millstone Grit in Scotland incorporates the Limestone Coal Group, Upper Limestone Group and all but the extreme upper part of the Passage Group

Table 9 Typical chemical analyses of washed silica sands produced from Carboniferous sandstones

	1	*2(a)*	*3*	*4*	*5*
			Wt %		
SiO_2	97.70	86.74	99.00	98.5-99.0	98.9
Al_2O_3	0.65	4.60	0.53	0.4-0.5	0.55-0.56
Fe_2O_3	0.64	2.08	0.070	0.12-0.20	0.14
CaO	0.04	0.84	0.01	0.1	<0.01
MgO	0.02	0.58	0.04	Trace	0.01
Na_2O	0.01	0.03	0.05	Trace	0.01
K_2O	0.07	1.01	0.07	0.2	0.04
TiO_2	*n.a.*	0.34	0.09	0.04	0.04
Loss on ignition	0.92	3.00	0.20	*n.a.*	0.32
Grain Fineness Number	60	57	50	*n.a.*	46

(a) Naturally bonded moulding sand after crushing and grinding, only.

n.a. Not available.

Sources:

1 Calciferous Sandstone Measures, Milngavie. Strathclyde. Amalgamated Quarries (Scotland) Ltd. Data Sheets on Foundry Sands. Institute of British Foundrymen, 1974.

2 Rotten-rock, Millstone Grit, Stanhope. Durham. Thos. W. Ward Ltd. Data Sheets on Foundry Sands. Institute of British Foundrymen, 1974.

3 Millstone Grit (Passage Group), Levenseat, Lothian. British Industrial Sand Ltd.

4 Millstone Grit (Passage Group), Devilla Forest, Fife. Coloured glass sand. Sand Developments (U.G. Glass Containers) Ltd.

5 Millstone Grit, Biddulph, Staffordshire. Hinckleys Ltd.

In the Midland Valley of Scotland the Passage Group is extensively exploited as a source of foundry and glass sand. Fine, white, quartzose sandstones are worked at Levenseat, near Fauldhouse in the Lothian Region, mainly for foundry purposes, although the sand has also been used in glass manufacture in the past. Similar sands are produced from the Passage Group at Glenboig, near Coatbridge. At both these operations the sandstones are merely crushed, milled and washed but at the Devilla Forest operation, near Alloa, Passage Group sandstones are, in addition, acid leached to produce a sand which is suitable for colourless glass manufacture.

Table 10 Chemical analyses of refractory grade silica rocks of Carboniferous age

	1	*2*	*3*	*4*
		Wt %		
SiO_2	98.08	98.80	97.5	97.66
Al_2O_3	0.68	0.31	0.9	0.82
Fe_2O_3	0.80	0.34	0.5	0.20
CaO	0.10	*n.a.*	*n.a.*	0.04
MgO	0.02	*n.a.*	*n.a.*	0.08
Na_2O	0.07	0.18	0.03	0.16
K_2O	0.11	0.05	0.15	0.12
TiO_2	0.05	*n.a.*	0.1	0.15
Loss on ignition	*n.a.*	*n.a.*	*n.a.*	0.35

n.a. Not available

Sources:

1 Selected chert. Cefn-y-Fedw Sandstone. Halkyn Mountain, Clwyd. DSF Refractories Ltd.

2 Selected quartzite. Basal Grit, Millstone Grit. Cennen quarries,Black Mountains. Dyfed. W J Dore.

3 Selected quartzitic sandstone. Millstone Grit. Harthope quarry, Weardale, Durham. British Steel Corporation.

4 Selected quartzitic sandstone, Cefn-y-Fedw Sandstone. Tir Celyn quarry, Minera, Clwyd. Romag Refractories Ltd.

The Cefn-y-Fedw Sandstone of North Wales includes sandstones, grits, shales and cherts. Many of the sandstones are of relatively high purity and where they consist of compact, haid quartzitic sandstones or quartzites, as for example in proximity to the Bala and Minera faults, have in the past been extensively worked for silica brick manufacture. However, they have alumina contents in excess of 0.5 per cent and have been produced at only one quarry, near Minera in recent years. Friable, fine-grained, white quartzose sandstones with intercalations of silty clay are, however, exploited for both silica sand and siliceous clay east of Llanarmon. On Halkyn Mountain the Cefn-y-Fedw Sandstone consists of interbedded shales and cherts, which are worked principally as a source of fill, although small quantities of washed and selected chert are used in silica brick manufacture. A typical chemical analysis of selected chert suitable for refractory manufacture is shown in Table 10.

The Basal Grit of the Millstone Grit cropping out on the north side of the South Wales Coalfield has been a major source of silica rock in the past and still provides the bulk of United Kingdom output today. Silica rock is currently produced in south-east Dyfed on Mynydd-y-Gareg near Kidwelly, Allt-y-Garn near Carmel, Cennen in the Black Mountains north of Glanaman and at Cefn Cadlan near Penderyn on the Powys-Mid Glamorgan border. The Basal Grit consists of a variable succession of white and iron-stained quartzites and quartzitic sandstones, with thin quartz conglomerate beds and occasional interbedded shales and very infrequent thin coal seams. In places quartzose sands have been formed by the solution of the siliceous cement. West of Llandebie, the Basal Grit is underlain by the so called Plastic Clay Beds which comprise thin siltstones interbedded with white or yellow-brown siliceous clays. These beds are worked at Allt-y-Garn for use in lining cupola furnaces and ladles and in jointing silica bricks. The quartzites are somewhat variable in quality both from bed to bed and within the same bed and selective quarrying is required to produce a consistent product. The best grades of stone have an alumina content in the range 0.3 to 0.5 per cent. A partial analysis of quartzite from Cennen quarries is shown in Table 10. The Basal Grit exhibits comparatively steep dips (20^{o}-30^{o}) and, particularly in the west, has a narrow outcrop.

West of the Vale of Neath, and more especially in the Brecon Beacons and Black Mountains National Park in south-east Dyfed, large-scale collapse of the Basal Grit into solution-enlarged fissures or caverns in the underlying Carboniferous Limestone has given rise to saucer-like accumulations of silica sand and associated siliceous clays. Some of the sands are of high purity (more than 99 per cent SiO_2) and have been worked in the past. Their possible exploitation for glassmaking has been considered but they are relatively inaccessible and variable in composition. Similar but much smaller deposits occur in the Carboniferous Limestone of Clwyd.

PERMIAN AND TRIASSIC

Lower Permian Basal Sands

The Lower Permian Basal Sands, a weakly cemented aeolian sandstone, which in places overlie a breccia, extend in a belt from South Shields to Mansfield. The sands were formerly mined in Yorkshire beneath a cover of Lower Magnesian Limestone for iron and non-ferrous foundry work, but they are poorly-sorted and relatively impure.

Bunter Sandstone

The Permo-Triassic Bunter sandstones are the most important source of naturally bonded moulding sands in the United Kingdom and in the past have been widely worked. The sands contain appreciable amounts of feldspar and are not sufficiently refractory for steel foundry purposes and thus are used principally for iron casting.

In the West Midlands the Bunter consists of red, soft sandstones, known as the Lower and Upper Mottled sandstones, separated by a more compact and coarse-grained sandstone, the Bunter Pebble Beds, which contains layers and lenses of pebbles mainly of quartzite and vein-quartz. The Bunter Pebble Beds are worked as a source of concrete aggregate and available information suggests that some of the quartz gravels contain between 92 and 95 per cent of silica. The same formation, but here called the Budleigh Salterton Pebble Beds, occurs in south Devon. In the East Midlands no Upper Mottled Sandstone is developed and northwards into Yorkshire the distinction between the Lower Mottled Sandstone and Pebble Beds is lost so that the Bunter Sandstone is indivisible.

The Lower and Upper Mottled Sandstones are variable in composition and many are too coarse for foundry purposes. They are generally well-sorted, contain rounded grains and have clay contents of up to 10 to 15 per cent. They are therefore used as naturally bonded moulding sands. However, relatively clay-free Bunter Sandstones are also produced for foundry purposes.

The Lower Mottled Sandstone is worked as a source of naturally bonded moulding sand at Kinnerton in Clywd, at Bramcote near Nottingham and to the east of Mansfield, an important centre of production where washed clay-free sands are also produced. The Upper Mottled Sandstone of the Bromsgrove area is, however, the most important source of naturally bonded moulding sand and was formerly extensively exploited in the neighbourhood of Kidderminster and Wombourne. A small output is still recorded near Stourbridge. The Bunter Sandstone east of Knottingley is worked for naturally bonded moulding sand, and small outputs are recorded from a number of other localities. Minor quantities of naturally bonded moulding sands are produced from the Triassic sandstones in the Lagan Valley of Northern Ireland.

In the western part of Vale of Glamorgan massive white to pale green, quartzose sandstones of Rhaetic age were formerly worked as a source of refractory sand.

JURASSIC

The Lower Estuarine Series of the Middle Jurassic which occurs discontinuously throughout central England from Grantham to Banbury, has a maximum thickness of 7.6 m, although only some 3 m to 4 m is generally worked. The formation consists principally of pale grey, white and cream sands and grey to lilac tinted silts and silty clays. Although locally of high purity (Table 11), the sands are very fine-grained. Their use is thereby restricted to facing the moulds for non-ferrous casting, where smooth surface finishes are required, and more importantly to blending with silty clays from the Upper Estuarine Series and quartzitic gravels from the Trent valley, for the production of siliceous patching and ramming materials for cupola furnaces and ladles. Examination of silty clays from the Upper Estuarine Series near Kingscliffe in Northamptonshire, by the Mineralogy Unit of the Institute of Geological Sciences, showed the clays to consist of 70 to 75 per cent silt fraction with less than 3 per cent sand. Quartz is the main constituent of the silt, although some clay minerals overlap into the finer silt sizes. The clay fraction consists of a mixture of interstratified montmorillonite - vermiculite, kaolinite and, possibly, a degraded mica. Fine-grained cream and white sands of the Lower Estuarine Series are worked at Corby for lining the runners or channels in which iron and slag flows from the blast furnace.

In Yorkshire one of the most prominent of the deltaic sandstones of the North Yorkshire Moors is the Moor Grit, which occurs at the base of the Scalby Formation of the Middle Jurassic. The Moor Grit is up to 12 m thick and consists of a quartzose sandstone, highly siliceous in places, which was formerly crushed and washed for foundry sand. The more compact parts of the formation were formerly worked for silica brick manufacture. Sand for glassmaking was extracted during the First World War from the Scalby Formation at Hutton's Ambo near Malton.

Table 11 Typical chemical analyses of Jurassic siliceous clay and washed silica sands

	Wt %			
	1	*2*	*3*	*4*
SiO_2	84.6	97.3	97.80	96.60
Al_2O_3	7.42	1.60	0.83	1.76
Fe_2O_3	1.52	0.20	0.25	0.76
CaO	0.28	0.06	0.02	0.12
MgO	0.15	*n.a.*	0.01	0.30
Na_2O	0.05	0.20	0.01	*n.a.*
K_2O	0.30	0.30	0.34	*n.a.*
TiO_2	2.19	*n.a.*	0.38	*n.a.*
Loss on ignition	3.12	0.40	0.20	0.28

n.a. not available

Sources:

1 Silty clay, Upper Estuarine Series, Kingscliffe, Northants, Kingscliffe Super Refractories Ltd.

2 Silica sand, Lower Estuarine Series, Wittering, Northants. British Industrial Sand Ltd. Grain Fineness Number 96.

3 Silica sand, Kellaways Beds, Burythorpe. North Yorks. Siminco Ltd.

4 Silica (white) sand. Lower Estuarine Series, Wansford, Cambs. The Nene Barge & Lighter Co Ltd.

Silica sand for shell moulding purposes is produced from fine-grained sands within the Kellaways Beds at Burythorpe, near Malton. The same horizon is quarried at South Cave in Humberside principally for use in cement manufacture. Naturally bonded moulding sand was produced until recently from Corallian strata near Pickering in North Yorkshire.

LOWER CRETACEOUS

Lower Cretaceous strata include some of the main sources of silica sand in the United Kingdom. Although sands of variable quality occur throughout much of its outcrop, clean, well-sorted, and occasionally very pure, white quartz sands are produced from the Sandringham Sands and Lower Greensand. Typical chemical analyses of silica sands produced from Lower Cretaceous strata are shown in Table 12.

Hastings Beds

The Hastings Beds consist of a succession of fine-grained, soft sandstones, silts and clays which crop out in the central part of the Weald. They contain relatively pure, white quartzose sandstones at a number of horizons within the Ashdown Beds and Tunbridge Wells Sand. The Ashdown Beds were formerly exploited at Fairlight, near Hastings, as a source of glass sand and, laterly, foundry sand but operations ceased in the mid-1960s. Silica sand has been reported in the Ashdown Beds at a number of other localities and small quantities of very fine-grained foundry sand have been produced from the uppermost Ashdown Beds at Reading Street near Tenterden. A high silica content (98.77 per cent) is recorded for the Ardingly Sandstone within the Tunbridge Wells Sand at Ashurstwood, near East Grinstead, which is believed to have been exploited during the last century.

Sandringham Sands

At Leziate, to the east of King's Lynn in Norfolk, pale-coloured and greyish-white, cross-bedded quartz sands comprise the Leziate Beds of the Sandringham Sands formation. These are worked on a large scale to their maximum thickness of 30 m to 35 m for glass and foundry purposes. The operation is one of the largest in the United Kingdom with an annual output of about three-quarters of a million tonnes and constitutes the largest single source of sand for colourless glass. Different grades occur as distinct horizons, the low iron glass sand being overlain and underlain by medium and fine-grained foundry sands, respectively. The Leziate Beds attenuate southwards towards Downham Market and extend northward to Hunstanton. The formation was formerly worked at Snettisham, Dersingham, Roydon Common and Blackborough End.

Spilsby Sandstone

Part of the Spilsby Sandstone* of the Lincolnshire Wolds is a potential source of silica sand. It is about 25 m thick at the southern end of the Wolds but thins gradually northward to 12 m at North Willingham and 7.6 m at Claxby beyond which it thins more rapidly and is discontinuous. At its most northern outcrop, near Elsham, the Spilsby Sandstone is well-sorted with a relatively high silica content, but farther south its quality deteriorates.

Lower Greensand

The Folkestone Beds, which form the uppermost sub-division of the Lower Greensand of the Weald, consist largely of weakly consolidated, clean, well-sorted, iron-stained quartz sands. However, clean, white silica sands, generally containing more than 97 per cent SiO_2, occur as discontinuous beds and lenses at a number of horizons and are worked in the Buckland, Redhill and Godstone area of Surrey, principally for glass and foundry purposes, and near Borough Green, West Malling and Aylesford in Kent, principally for foundry sands. Similar, although less extensive deposits occur in the western and southwestern part of the outcrop principally near Midhurst, although these sands are worked mainly for construction purposes.

Near the village of Heath and Reach to the north of Leighton Buzzard in Bedfordshire, beds of white, cross-bedded silica sand up to about 10 m thick occur at the top of the Lower Greensand (Woburn Sands) beneath an over-burden of Gault clay and boulder clay. They overlie less pure building sands. The sands vary considerably in quality and grain-size distribution, but certain horizons are characterised by coarse, rounded grains. The sands are worked for a variety of applications including foundry sands, water filtration media, horticultural uses, turf dressings and white concrete. Lower quality sand is sold for building sand and for the manufacture of calcium silicate bricks.
The small silica sand quarry at Stone, near Aylesbury in Buckinghamshire, is now abandoned and being reclaimed. Clean, well-sorted quartz sands occur within the Lower Greensand near Compton Bassett in Wiltshire.

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*Partly of Jurassic age

Table 12 Typical chemical analyses of washed silica sands produced from Lower Cretaceous sands

Wt%

	1	*2*	*3*	*4*	*5*
SiO_2	99.50	98.4	98.70	99.10	98.6
Al_2O_3	0.16	0.81	0.34	0.44	0.2
Fe_2O_3	0.073	0.34	0.19	0.074	0.8
CaO	Nil	0.20	<0.10	0.03	0.04
MgO	*n.a.*	0.07	0.05	*n.a.*	0.02
Na_2O	Trace	0.12	*n.a.*	0.03	Trace
K_2O	0.01	0.03	0.05	0.15	0.04
TiO_2	0.1	0.07	0.10	0.04	0.02
Loss on ignition	0.16	0.31	0.39	0.20	0.20
Grain Fineness Number	61	56	52	60	–

n.a. not available

Sources:

1 Folkestone Beds. Redhill, Surrey. British Industrial Sand Ltd.

2 Folkestone Beds. Borough Green, Kent. Hall Aggregates (South East) Ltd.

3 Woburn Sands. Heath & Reach, Bedfordshire. Buckland Sand and Silica Co Ltd. Data Sheets on Foundry Sands. Institute of British Foundrymen. 1974.

4 Sandringham Sands. King's Lynn, Norfolk. British Industrial Sand Ltd.

5 Woburn Sands. Heath and Reach, Leighton Buzzard. Bedfordshire. BS 14/25 grade. George Garside (Sand) Ltd.

UPPER CRETACEOUS

At Morven, in the Highland region of Scotland, a pure white sandstone is exposed on both sides of Loch Aline within the Upper Cretaceous White Sandstone beneath Tertiary Plateau Basalts. Since the Second World War sandstone has been mined on the west side of Loch Aline as a source of high quality glass sand, as well as for a number of other purposes, and is the highest purity silica sand known in the United Kingdom (Table 3). The White Sandstone is 10 m thick, within which the main bed of pure, white, friable sandstone is 3 m to 7.5 m thick.

In the same area, other occurrences of white, Upper Cretaceous sandstone have recently been examined by Robertson Research International Limited, on behalf of the Highlands and Islands Development Board, and have been found to be of a quality similar to that of the Loch Aline material. Significant tonnages may be present. If they prove to be of commercial interest the deposits would have to be worked by underground methods, and their remoteness would add significantly to costs. White sandstone up to 12 m thick crops out on the eastern side of Loch Aline, but its easterly extent beneath the basalt is unknown. A north-south trending fault with a downthrow to the west is present between 350 m and 780 m east of the sandstone outcrop, and east of this fault there may be rapid variation in the thickness of the sandstone bed. North of Loch Aline at Beinn na h-Uamha and Beinn Iadain, white sandstones occur in Mesozoic and Tertiary outliers overlying the Moine Series. The sandstone is poorly exposed but appears to be of high quality in places and resources are extensive, although the area is very inaccessible. On Mull the horizon is generally absent or of negligible thickness and is of a quality inferior to that at Loch Aline.

TERTIARY

Sands of Tertiary age which were formerly worked extensively in Southern England are now of only limited importance. The Thanet Beds occur in a small area of south-east London, north Kent and Essex and were formerly an important source of fine-grained naturally bonded moulding sand which was worked near Charlton and Erith. The famous Erith Loam, containing between 10 and 20 per cent clay, was produced in small quantities for both the home and export market until early 1976. Similar sand within the Thanet Beds at Linford, Essex, is marketed as a naturally bonded moulding sand.

The Bagshot Beds, which consist of clean, generally fine-grained bright yellow and greyish-white sands with impersistent beds of clay, were formerly worked for silica sand in Hampshire, Surrey and Essex. The beds are fairly extensive in the Hampshire Basin but exploitation is currently confined to the production of closely-sized, coarse-grained, resin-coated sands near Wareham in Dorset.

The Bracklesham Beds are worked as a source of naturally bonded moulding sand at Hamble in Hampshire. Some of the purer sands within the Barton Beds have been worked for silica sand in the New Forest and clayey sands have also been worked in the same area for naturally bonded moulding sand.

Fine, silty and clayey sands associated with the ball clays of the Bovey and Petrockstow Basins may be suitable for refractory lining applications. Small quantities of silica sand associated with refractory clays are produced for local foundry purposes from a small Palaeogene outlier at St. Agnes Beacon in Cornwall.

Pliocene quartzitic gravels occur in north-east Grampian region principally near Turriff and Fyvie to the west of Peterhead. The gravels have a variable composition but very pure quartzite pebbles with more than 99 per cent silica predominate in some areas, for example at Fyvie. Flint pebbles are also abundant, the gravel occurring in a white sandy matrix. The pebbles range in diameter from 12 mm to 200 mm, are generally well-rounded and are highly spheroidal to ellipsoidal in shape. These deposits are worthy of investigation as they appear to have potential as a source of lump silica and possibly of grinding pebbles.

Silica sands and clays occur as 'Pocket Deposits' in deep hollows in the Carboniferous Limestone of Derbyshire and Staffordshire. The hollows were formed by solution and the deposits are composed of Triassic sand, some of which has probably been reworked in Tertiary times. The sands, which may be white, although many are stained various shades of brown and red, are coated with kaolinite producing a naturally bonded sand with highly refractory properties. They are utilised in a variety of refractory products.

QUATERNARY

Silica sands of Pleistocene and Holocene age are the most important sources of foundry sands in the country and are also used in coloured and flat glass manufacture.

Pleistocene

Glacial and fluvio-glacial sands and gravels are widely distributed throughout the United Kingdom and extensively worked as sources of aggregate, but their variable composition, grain-size distribution and grain shape generally precludes them as sources of silica sand. Important exceptions do exist, however, either because of the occurrence of pure Pleistocene sands such as those in Cheshire, or where the opportunity exists for removing the desired size fraction as a co-product of a sand and gravel operation.

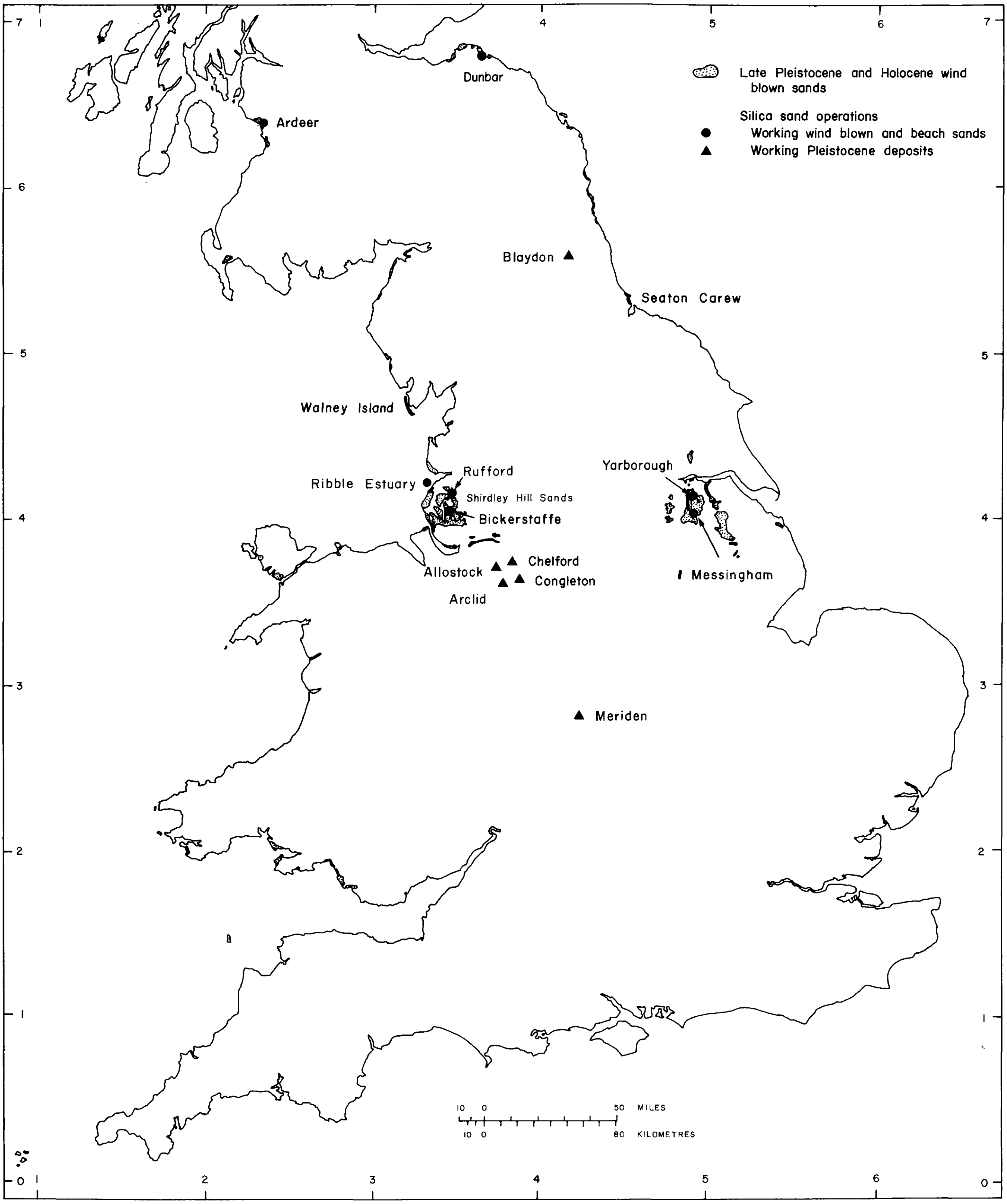

Fig 5 Distribution of silica sand operations in Quaternary deposits.

In the Cheshire Plain, in the area between Congleton and Sandbach extending northwards to Chelford, sands deposited during an interstadial period are the most important single source of foundry sand in the country and are extensively exploited. The sands occur as a somewhat irregular sheet with a partially dissected upper surface, in places filling glacial valleys or troughs in the underlying Lower Boulder Clay or Keuper Marl. The quarrying operations are centred around Congleton and Chelford. The Congleton and Chelford sands, which are similar in quality although the latter is purer and coarser, are highly valued as foundry sands because they are extremely well-sorted, contain little silt and clay impurities, consist of relatively well-rounded grains and have silica contents of about 96-97 per cent. A selection of chemical analyses is shown in Table 13. The Congleton Sand is pale yellowish brown due to a limonitic coating on the sand grains. Some of the Chelford Sand is whiter (Chelford White Sand), has a lower iron content and is suitable for flat glass manufacture (Table 3).

The Congleton and Chelford sands rest on patches of Lower Boulder Clay or directly on Keuper Marl. They are overlain by the impurer Gawsworth Sand and by the Upper Boulder Clay. The deposits are at least 30 m thick in the east but thin in a westerly direction. The homogeneity of the Congleton and Chelford sands and the roundness of the sand grains are unlike fluvio-glacial sands and it has been suggested that they may have been transported by wind from the Pennine area and subsequently re-sorted by water.

Table 13 Typical chemical analyses of some washed silica sands of Pleistocene age

	Wt %						
	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	97.3	96.20	97.00	94.76	94.30	96.60	95.56
Al_2O_3	1.23	1.05	1.63	2.29	2.22	1.97	1.73
Fe_2O_3	0.18	0.35	0.15	0.42	1.42	0.31	0.55
CaO	0.04	0.18	0.11	0.16	0.20	0.13	0.10
MgO	0.04	0.09	*n.a.*	0.16	0.04	*n.a.*	0.05
Na_2O	0.10	0.10	0.14	0.13	0.14	0.16	0.17
K_2O	0.75	0.99	0.74	1.52	0.49	0.87	1.32
TiO_2	0.03	*n.a.*	0.06	*n.a.*	0.17	0.08	0.12
Loss on ignition	0.34	*n.a.*	0.26	0.37	0.80	0.38	0.92
Grain Fineness Number	60	60	58	55	60	60	*n.a.*

n.a. not available

Sources:

1 Congleton Sand. Marsh Farm Quarry, Cheshire. Hinckley's Limited.

2 Congleton Sand. Arclid Quarry, Cheshire. Bathgate Silica Sands Limited. Data Sheets on Foundry Sands. Institute of British Foundrymen. 1974.

3 Chelford Sand. (Foundry sand). Cheshire. British Industrial Sand Limited.

4 Meriden Quarry. Warwickshire. Tilling Construction Services Limited.

5 Blaydon Quarry. West Midlands. Tilling Construction Services Limited.

6 Congleton Sand. West Heath. Cheshire. British Industrial Sand Limited.

7 Fourways quarry, Oakmere, Cheshire. Tilling Construction Services Limited.

At Allostock, a sand very similar to the Congleton Sand and probably representing a fluvio-glacial delta derived from it, is worked as a source of sand for coloured glass manufacture, building and asphalting. At the Fourways quarry, Oakmere, glacial sand, primarily worked for building sand, has been used for coloured glass manufacture and also as a foundry sand. An analysis of the sand is shown in Table 13.

Fluvio-glacial sands are worked near Meriden in the West Midlands for foundry sands. Coarse aggregate and concreting sand are screened from the deposit, and the clay content is removed by washing, attrition scrubbing and hydrosizing. At Blaydon, in Tyne and Wear, fluvio-glacial sands are similarly treated to produce foundry sands, although in this case froth flotation also is used to remove coal particles. Fluvio-glacial sands are worked in a number of other areas for local foundry use, for example, at Creeting St Mary in Suffolk.

During the course of sand and gravel surveys, the Mineral Assessment Unit of the Institute of Geological Sciences, has identified clean, well-sorted sands underlying glacial sand and gravel in mid-Essex, particularly between Colchester and Braintree.

Fluvio-glacial sands are worked on a small scale for foundry sand at Portadown (Lough Neagh) and Kilkeel, Co. Down in Northern Ireland.

Holocene (Recent)

Recent wind-blown dune sands and somewhat older, even perhaps late Pleistocene sands such as those occurring in Lancashire and Humberside, are an important source of material for both the glass and foundry industries.

The Shirdley Hill Sands of western Lancashire are very uniform in both composition and grain-size distribution and have been extensively exploited in the Rainford – Ormskirk area for use in the St Helen's glass industry for the manufacture of flat and coloured glass. The deposits may be up to 3 m to 4 m thick but for flat glass manufacture only the top 0.5 to 1 m of purer sand directly beneath the topsoil is taken. A typical analysis of the topmost Shirdley Hill Sand is shown in Table 14. The sand has a high alumina content due to the presence of feldspar, but as this mineral is a normal addition to the glass batch, its presence is advantageous. The Shirdley Hill Sand is also worked at Rufford for coloured glass manufacture.

Similar wind-blown sands, some of which were re-deposited by water, occur in Humberside between Kirton Lindsey and the Humber, banked up against Lincoln Cliff and spread over the lower ground to the west, where they mask Jurassic rocks over a large area. The sands are brown, due to limonite coating the grains, and contain organic matter as peaty layers. They are extensively worked for foundry sands and coloured glass manufacture at Messingham, where they are on average about 2.5 m thick, and were formerly exploited at Haxey. Around Scunthorpe the sands, which are up to 7 m thick with a silica content of about 90 to 92 per cent, are removed as overburden prior to the extraction of the Frodingham Ironstone. Some of the sand is utilized for balancing the lime-silica ratio in the blast furnace burden and also for lining troughs and for casting pigs of iron.

Dune sands, which in places are still in the process of formation, occur at numerous localities in Britain. They cover extensive areas adjacent to the Merseyside and Lancashire coast and were formerly worked near Southport, where the sands are very uniform in composition, well-sorted and consist of well-rounded grains. A relatively low silica content of about 90 to 93 per cent and appreciable amounts of feldspar restricted their use to the lower temperature field of iron castings. The dunes are no longer worked because of amenity considerations, but beach sands are produced from below high-water mark on the Horsebank on the southern side of the Ribble Estuary. These sands are washed and subjected to froth flotation to remove shell debris, as lime is a serious impurity in foundry sands in which chemical binders are used.

Table 14 Typical chemical analyses of late Pleistocene and Holocene sands

	Wt %				
	1(a)	*2(b)*	*3(c)*	*4(a)*	*5(b)*
SiO_2	96.8	94.8-95.3	95.1	95.60	92.0-92.8
Al_2O_3	1.5	2.15-2.35	1.9	2.29	2.8-3.0
Fe_2O_3	0.125	0.33-0.37	0.8	0.21	1.25-1.45
CaO	*n.a.*	0.15-0.20	0.24-0.5	0.15	0.35-0.45
MgO	*n.a.*	0.10-0.15	0.14	*n.a.*	0.25-0.30
Na_2O	0.2	0.25-0.30	0.26	0.15	0.60-0.75
K_2O	0.8	1.0-1.2	0.97	1.00	0.65-0.75
TiO_2	*n.a.*	0.10-0.12	0.08	0.09	0.20-0.30
Loss on ignition	0.3	0.3-0.6	0.5	0.47	0.5-1.2

(a) washed sand *(b)* as dug *(c)* after froth flotation
n.a. not available.

Sources:

1 Shirdley Hill Sand. Bickerstaffe. Pilkington Brothers Limited (Flat glass).

2 Shirdley Hill Sand. Rufford. Rockware Glass Limited (Coloured glass).

3 Beach Sands. Ribble Estuary. The Southport Sand Co Limited (Foundry sand).

4 Late Pleistocene to Holocene wind blown sands. Messingham. British Industrial Sand Limited (Foundry sand and coloured glass).

5 Dune Sand. Ardeer. Rockware Glass Limited (Coloured glass).

Dune sands also occur in other parts of Britain, for example, on Walney Island in Cumbria, at Seaton Carew in Cleveland, in South Wales and at many other localities. Dune sand is worked in West Glamorgan mainly for asphalting although smaller quantities are used by the Port Talbot steelworks and for foundry purposes. At Ardeer, in the Strathclyde region of Scotland, dune sands are worked for coloured glass manufacture and for foundry purposes. Dune sands are also worked for coloured glass manufacture west of Dunbar.

In Northern Ireland the limited working of silica sand (foundry sand) is almost entirely confined to superficial deposits, either dune and beach sand or fluvio-glacial sand. Resources of foundry sand in Northern Ireland were recently investigated by the Geological Survey of Northern Ireland* but no high quality natural sands of Quaternary age where found, although it might be possible to produce better quality sand if processing could be justified.

OTHER SOURCES

During the extraction of china clay very large quantities of waste sand are produced (on average some 20 million tonnes annually) of which only a very small part is subsequently used. The bulk is tipped in large conical or tabular dumps which are characteristic features of the china clay producing areas of south-west England. Their composition is variable but they consist principally of angular quartz grains with varying amounts of feldspar, tourmaline and micaceous residues. Grain sizes range between 9mm and 0.075 mm but 70 per cent by weight is above 0.3 mm. The high cost of transport to the major markets is the main factor limiting their use and, like many natural sand and sandstone deposits, they would additionally have to bear the costs of substantial upgrading before they would be considered acceptable by the glass or foundry industries. The angular shape of the quartz grains would be a limiting factor to their use as foundry sand.

**Rep No.* 72/8, *Inst. geol. Sci.*, 1972.

Land use

As with the extraction of other minerals there is conflict between silica sand working and amenity and environmental considerations. The total area covered by permissions for surface mineral working and mineral waste tipping in respect of silica and moulding sand, where work was in progress or had not yet commenced was at 1 April 1974, as 3899 hectares of which just under a half had not yet been affected. Table 15 shows the situation in the more important counties; this does not include workings where silica sand is extracted as a by-product of another mineral e.g. sand and gravel.

Table 15 Mineral working/waste tipping permissions for silica and moulding sands as at 1st April 1974

Hectares

	1	*2*	*3*	*4*
Lancashire	–	20	20	1035
Merseyside	12	528	540	117
Bedfordshire	–	259	259	300
Norfolk	–	400	400	–
Cheshire	–	220	220	51
Kent	–	122	122	49
Derbyshire	12	45	57	78
Humberside	6	45	51	51
Surrey	1	80	81	18
Staffordshire	16	44	60	39
Others *(a)*	11	164	175	176
Total	58	1927	1985	1914

Source: Results of the 1974 Survey of Derelict and Despoiled Land in England.

(a) Includes Berkshire, Cambridgeshire, Cumbria, Hampshire, Hereford and Worcester, Northamptonshire, Nottinghamshire, Suffolk, North, South and West Yorkshire.

1 Area affected by spoil heaps and tips, plant buildings and lagoons not shown in (2).

2 Excavations and pits.

3 Total (1) and (2).

4 Area not yet affected.

N.B. Comparable statistics are not available for the rest of the United Kingdom.

Although workings and plant can be visually obtrusive, planning conditions are such that most workings are required to be adequately screened during their operational life and restored in accordance with a plan approved by the Local Authority. Many workings in unconsolidated and loosely consolidated sands which generally form relatively low relief, extend below the water table and lakes are formed. As these are usually scenically attractive and as insufficient inert fill is available to restore the land, they may be used for recreational purposes, as nature reserves or reservoirs. They nevertheless represent a significant change in the character of the original land surface. Some operations, such as those working the Shirdley Hill Sands, can be progressively restored as extraction proceeds, albeit at a slightly lower level, but this is possible only if sufficient suitable fill is available to keep pace with extraction. Filling itself may cause problems, particularly by generating extra traffic.

Noise from silica sand workings is rarely a major problem unless the quarry, or more particularly the processing plant, is situated close to residential areas. Blasting is only rarely required since most deposits are in loosely consolidated sands. Considerable traffic is generated at the major works by vehicles either delivering the finished product or bringing sand in from the quarry for processing, although wherever possible this is done by conveyor belt. However the glass industry, a large consumer, is concentrated at a relatively small number of factories and a large proportion of the sand is delivered by rail. On the other hand because of the wide distribution of foundries, this industry tends to be served by road transport. The output of the Loch Aline mine is transported by ships with capacities ranging from 600 to 2,500 tonnes; sand for the United Kingdom market is shipped to Ardrossan, Glasgow and Runcorn for final delivery by lorry. Messingham sand for the Yorkshire glass industry is transported in barges by river.

Except for some of the few 'Pocket' silica sand operations in Derbyshire, which are relatively small, existing silica sand operations lie outside the National Parks, although some are situated in areas of high landscape value close to Areas of Outstanding Natural Beauty. The Lower Cretaceous deposits of Surrey, Kent and Norfolk are typical examples, but there will be a continuing demand to work the resources of high quality sand in these areas.

Silica sand is a mineral of national importance as a basic raw material, especially for the glass and foundry industries. High quality sands occur in relatively few areas and as a result these sands are intensively worked leading to a high concentration of workings in various stages of operation and restoration in fairly restricted areas. There are planning difficulties, therefore.

In such established silica sand producing areas as Cheshire, Norfolk, Surrey and Bedfordshire, for example, high capital investment in processing plant does not permit much flexibility in the source of raw material which must be close to plant to eliminate high transport costs.

The future supply of silica sand depends on the adequacy of planning permissions rather than any potential shortage of raw material in the ground. In this context, Cheshire County Council, recognising that the county is the most important source of washed foundry sand in the country (accounting for over 50 per cent of total output in 1975), has ensured that adequate supplies of silica sand are safeguarded by maintaining a 'County Reserve' with planning permission of 10 to 15 years supply at estimated future production rates. The silica sand industry, however, regard a minimum of 30 years planning permission as necessary.

Price

In general, dried foundry sands and colourless glass sands had ex-works prices in the range £3.50-£4.00 a tonne in 1976, whilst naturally bonded foundry sands and coloured glass sands were about £1.50 a tonne. Bagged silica sands (100 kg bags) for foundry and other purposes were considerably more expensive being generally of the order of £10-£15 a tonne, and resin coated sands about £40 a tonne or more. The cif values of imported high purity sands from Belgium, the Netherlands and France were £11.3, £20.1 and £19.2 per tonne, respectively, in 1976.

The cost of silica sand forms a small part of the total manufacturing cost of glass and castings. In general, this probably ranges between 1 and 3 per cent depending on the type of glass or casting being produced and in the case of castings the type of metal and process used.

Silica sand is a high bulk/low cost commodity and transport costs, therefore, are an important part of the delivered price of the mineral. Hence, in addition to their superior quality and the ease with which they can be extracted, the Congleton and Chelford sands are an important source of supply because of their proximity to the main foundry markets in the West and East Midlands and West and South Yorkshire. Nevertheless, some silica sands, particularly colourless glass sands and Cheshire foundry sands, are transported considerable distances; for example, Redhill glass sand is transported by rail to South Wales and north-west England, and Cheshire foundry sands by road to South Wales, north-east England and Scotland. The expansion of the container glass industry in central Scotland and its decline in the London area has had a significant effect on the national pattern of demand. An expansion of glass sand production in northern England in closer proximity to the glass industry in this area may be a future trend.

The price of silica rock for refractory manufacture was £2.50 to £3.00 per tonne, ex quarry in 1976.

Technology

Silica sands are produced from two main types of deposit in the United Kingdom, unconsolidated, or weakly consolidated sands, and sandstone, which has to be crushed and milled to liberate the individual sand grains.

With the single exception of the Loch Aline mine in the Highland region of Scotland silica sand is won from opencast quarries, either wet or dry, by dragline excavators, suction dredges, face shovels, scrapers or front-end loaders, blasting or ripping being required only in the harder sandstone deposits such as the Millstone Grit. In many instances a number of different grades of sand are produced from a single quarry by selective quarrying of distinct horizons. Sand is usually transported from the face to the processing plant by conveyor belt, whilst sandstone is transported by lorry. Excavations range in depth from a maximum of about 35 m in sandstone deposits to a mere scraping of the top metre or so, as is the case with the Shirdley Hill Sands. The overburden may vary from a thin covering of topsoil or alluvium, to greater thicknesses of boulder clay, Gault and inferior quality sands. At Leighton Buzzard, for example, up to 20 m of boulder clay and Gault are removed in some areas to extract as little as 3 m to 5 m of sand. At Loch Aline the high purity sandstone, which ranges from 3 m to 7.5 m in thickness, is mined beneath Tertiary basalts using conventional pillar and stall techniques. Extraction rates of 70 per cent are achieved. The sandstone is drilled, blasted and loaded into articulated dumpers for transport to the surface.

Depending on their end use the processing of British silica sands is of varying complexity, but is aimed at improving the physical/chemical properties of the sand, largely by adjusting the grain-size distribution by removing undersize and oversize material, and removing contaminating impurities in the sand or from the surfaces of the individual sand grains.

Naturally bonded sands are only crushed and milled but processing of most foundry sands consists of the removal of oversize material by screening and fines by elutriation. Attrition scrubbing is sometimes carried out to remove impurities such as clay and iron oxides from the grain surfaces. At Blaydon, in Tyne and Wear, a selectively quarried fluvio-glacial sand is further subjected to flotation to remove coal particles. Despite somewhat higher processing costs the sand can compete in certain local markets with sand from Cheshire, because of the higher transport costs incurred by the latter. Similarly, beach sands produced in the Ribble Estuary are subjected to flotation to remove shell debris.

Most foundry sands are dried in rotary or fluidised bed driers to a moisture content of less than 0.5 per cent and cooled before delivery, generally by bulk tanker, if heat sensitive binders are to be employed. Addition of the bonding agent is normally undertaken at the foundry but silica sands with grain fineness numbers in the range 60 to 110, are resin-coated for shell moulding purposes at three quarries. The sand grains are coated with a thin layer of phenolformaldehyde resin, in the range 2-6 per cent, as well as a catalyst, and the free-flowing sand delivered to the foundry. When the sand is poured over the surface of a heated pattern the resin near the pattern fuses and then polymerises producing a thin rigid shell (the mould or core) around the pattern, which accurately conforms with its dimensions and has a smooth finish. Excess sand can be removed and used again. United Kingdom production of resin-coated sand is about 280,000 tonnes a year.

Prior to the Second World War the bulk of the sand requirements for colourless glass manufacture were met by imports from Belgium, the Netherlands and France. British sands were unable to compete with the combination of their high purity, requiring virtually no processing, and low price, which was possible because of easy access to waterborne transport and low shipping costs. The first processing plant in Britain designed for more than simple washing was installed at King's Lynn in 1935. The suspension of supplies from Europe during the Second World War stimulated the installation of further beneficiation plant for glass sand at Redhill. The Loch Aline deposit was also brought into production during this period. After the war, imports resumed but higher transport costs have kept imports down to around 170,000-200,000 tonnes in most years, although latterly imports have been somewhat lower, because of the installation of further glass sand processing facilities in central Scotland.

Only the Loch Aline deposit is of purity comparable to the sands of Miocene age on the mainland of Europe and all the sands produced in the United Kingdom undergo some form of beneficiation to improve their quality for the manufacture of colourless glass. The Loch Aline sand is subjected only to washing and attrition scrubbing, but sands from the Lower Cretaceous of Surrey and Norfolk and the Millstone Grit of Staffordshire and the Central region of Scotland, are subjected also to froth flotation and acid leaching.

There are, however, considerable differences in the chemistry and, therefore, mineralogy of the sands used in glass manufacture in the United Kingdom. With the exception of the Loch Aline deposits, sands from the Lower Cretaceous are the highest in purity having high quartz contents (about 96 per cent) and clay contents of only 1 or 2 per cent. They may have low iron contents (<0.08 per cent Fe_2O_3 after washing), which is present mainly as the iron-bearing heavy minerals ilmenite, hematite and magnetite, although some limonite occurs as a surface coating of the quartz grains. The Folkestone Beds in Surrey have lower alumina and iron contents than the Sandringham Sands in Norfolk. The Millstone Grit currently exploited is more variable in quality, having a high clay content (up to 20 per cent) and higher iron and alumina contents (0.10-0.15 per cent Fe_2O_3 and 0.5-0.8 per cent Al_2O_3 after washing) than other sources of sand for colourless glass. The iron oxide generally occurs as a surface coating on the sand grains giving the rock a brownish or even reddish colouration in some places. The Passage Group sandstones worked in Scotland have a somewhat higher purity than their counterparts worked in England.

The main differences between the beneficiation of the Millstone Grit and Lower Cretaceous sands is that the former has to be crushed and milled to reduce it to a sand, and is subjected to a hot acid leach rather than a dilute acid wash. In both cases the milled sand is screened to remove oversize material, and fines, including clay, are removed by hydrosizers. Attrition scrubbing is then normally carried out in either an acid or alkali environment to remove clay and iron oxide coating the sand grains. To remove the remaining iron oxide coating on the sand grains a hot sulphuric acid leach is used in the case of sands from the Millstone Grit, whereas for Lower Cretaceous sands a mild acid wash in cold, dilute sulphuric or hydrofluoric acid in the presence of a reducing agent,either sodium or zinc hydrosulphite, has been successfully applied. Hot hydrochloric acid was until recently used at Oakamoor in Staffordshire but operating difficulties were experienced and hot sulphuric acid is now employed. Froth flotation to remove heavy minerals, in particular iron bearing minerals and chromite, is also used in the processing of the Lower Cretaceous sands, although it may not be necessary where particularly high quality sand is encountered in the quarry. Acid leached sand from the Millstone Grit may also be subjected to froth flotation. Finally the sand slurry is dewatered and the glass sand is supplied with a moisture content of about 4-5 per cent.

The ease with which impurities, in particular iron oxides, can be removed from a sand (or sandstone) is an important factor in determining its potential value for glass manufacture, and will depend on how the impurities occur, whether as discrete heavy minerals, as a surface coating of the sand grain by iron oxide and clay, or as inclusions within the sand grains. Iron oxide present in pits and joints in the grain surface are much more difficult and costly to remove than a mere surface coating of a smooth grain, whereas sand grains with inclusions of impurities may be too costly to beneficiate to required specifications.

Sand for flat glass and coloured glass manufacture undergo no form of chemical treatment, but are merely washed and graded. Thorough blending of the Shirdley Hill Sands from the numerous workings is required to ensure a consistent feed for flat glass manufacture. In the case of the Chelford Sand the fraction above 0.3 mm is kept as low as possible to minimise the content of coarse (heavy) minerals, such as chromite, which are insoluble in molten glass and can produce specks in the product. Coloured glass sands may be washed, but in some cases the sand is used 'as dug' or after screening to remove organic matter.

The likelihood that high purity metamorphic quartzites and hard quartzitic sandstones could be used as alternatives to silica sand in the production of colourless glass is remote. Crushing and grinding costs would be high and any impurities present would be difficult to liberate and remove.

There is a general trend towards the use of higher quality grades of sand with consistent properties, not only for the glass industry but now also for the foundry industry. Processing is likely to continue to be of increasing importance and a major factor in the future supply of sands to industry, particularly as escalating transport costs make distant sources of supply economically less attractive.

In the Leighton Buzzard area sands with closely defined size distributions are produced from the Lower Greensand for a variety of specialised applications. The raw sands are washed, dried and screened to remove the coarse sizes used in water filtration and are further screened to produce more closely defined grades. Only some 7 to 10 per cent of the sand as dug contains grains of the required size for water filtration, the fine sands being sold for other purposes.

At Oakamoor part of the output is retained for conversion to cristobalite by calcining the sand in a rotary kiln. A 97 per cent conversion is achieved at a specific gravity of 2.34 ± 0.02. Both silica sand and cristobalite may be finely milled and micronised to produce various grades of silica flour.

Silica rock quarrying is now on a small scale and it is unlikely that any of the operating quarries will have an output of much over 15,000 tonnes a year. Quartzite has to be drilled and blasted, and processing consists only of crude screening to produce a +150 mm product and simple washing to remove adhering clay impurities. For consistently high quality rock to be supplied to the silica brick manufacturers selective quarrying and blending is essential. Washing, crushing, grinding and blending are undertaken by the silica brick manufacturers.

Production

Great Britain is a large producer of silica sand, total production amounting to about 6 million tonnes in 1975. Output of silica sand in Northern Ireland is not separately recorded but is thought to be insignificant, having been estimated at about 18,000 tonnes in 1970[1]. Production of moulding and silica sands (including glass sand) in Great Britain has been separately recorded since 1950, and in the period 1950-1976 production totalled 119 million tonnes. Production of 'moulding and pig bed sand' has been officially recorded since 1923. Production of silica sands (or industrial sands as they are now recorded in the official production statistics) by end use in Great Britain for the period 1950-1976 is shown in Table 16, and by end use and county for 1975 in Table 17.

Table 16 Great Britain: Production of silica sands, 1950-1976

Thousand tonnes

	Glass sand	*Foundry sand*		*Other industrial uses*	*Total*
		Naturally bonded moulding sand	*Silica moulding sand*		
1950	739	766	481	607	2,593
1951	851	825	743	685	3,104
1952	763	895	758	613	3,029
1953	740	819	716	607	2,882
1954	829	639	832	678	2,978
1955	1,106	760	973	635	3,474
1956	1,104	856	931	624	3,515
1957	1,059	714	1,043	838	3,654
1958	1,044	593	941	671	3,249
1959	1,000	592	1,070	998	3,660
1960	1,171	770	1,253	841	4,035
1961	1,153	631	1,419	836	4,039
1962	1,161	671	1,320	711	3,863
1963	1,245	833	1,395	597	4,070
1964	1,418	742	1,781	876	4,818
1965	1,390	736	1,596	1,214	4,936
1966	1,462	725	1,558	1,058	4,804
1967	1,446	558	1,415	1,260	4,679
1968	1,529	*n.a.*	2,009	*n.a.*	4,920
1969	1,589	622	2,352	987	5,550
1970	1,670	602	2,592	918	5,782
1971	1,777	452	2,420	996	5,645
1972	1,769	411	2,437	861	5,478
1973	2,394	731	2,704	946	6,775
1974	2,221	676	2,394	699	5,990
1975	2,147	368	2,980	644	6,139
1976*(p)*	2,368	315	2.539	355	5,577

(p) Provisional

Sources: Department of the Environment, 1950-1972.
Business Statistics Office, 1973-1976.

1 *Rep, No.* 72/8, *Inst. geol. Sci.*, 1972.

Table 17 Great Britain: Production of silica sand by end use and county, 1975

<table>
<tr><td></td><td colspan="3">Thousand Tonnes</td></tr>
<tr><td>County/Scottish region</td><td>Foundry sand including naturally bonded</td><td>Other industrial uses including glass manufacture</td><td>Total</td></tr>
<tr><td>Cumbria, Durham, Tyne and Wear, Humberside, North Yorkshire, South Yorkshire</td><td>236</td><td>322</td><td>558</td></tr>
<tr><td>Derby, Leicester, Northampton, Nottingham</td><td>120</td><td>72</td><td>192</td></tr>
<tr><td>Cheshire, Lancashire, Merseyside</td><td>1,785</td><td>604</td><td>2,389</td></tr>
<tr><td>Cambridge, Norfolk, Suffolk, Bedford</td><td>391</td><td>612</td><td>1,003</td></tr>
<tr><td>Hampshire, Kent, Surrey, Essex, Greater London</td><td>310</td><td>493</td><td>803</td></tr>
<tr><td>Cornwall, Avon, Wiltshire, Clwyd, Dyfed, West Glamorgan</td><td colspan="2">95</td><td>95</td></tr>
<tr><td>Hereford and Worcester</td><td>194</td><td>–</td><td>194</td></tr>
<tr><td>Stafford, West Midlands</td><td colspan="2">431</td><td>431</td></tr>
<tr><td>Highland, Fife, Lothian, Strathclyde</td><td>207</td><td>267</td><td>474</td></tr>
<tr><td>Total Great Britain:</td><td>3,348</td><td>2,791</td><td>6,139</td></tr>
</table>

Source: Business Statistics Office.

During the period 1950 to 1975 total production of silica sand showed an average annual growth rate of 3.4 per cent, while the corresponding growth rates for glass sand and silica moulding sands were 4.25 per cent and 6.25 per cent, respectively.

Total glass production in the United Kingdom amounted to 2.8 million tonnes in 1975. Assuming an average SiO_2 content of 70 per cent for the glass, consumption of glass sand would have been about 2 million tonnes in 1975 of which about 5 per cent was imported. This compares reasonably well with glass sand production (Table 16); the small difference might be accounted for by glass fibre and sodium silicate glass production, which are thought not to be included in the total glass production figure. Production of sand in 1975 for the manufacture of colourless and coloured glass containers and flat glass is estimated to be about 1.0, 0.4 and 0.5 million tonnes, respectively. Silica sand of colourless glass sand quality is also used for other applications, for example, in the ceramics and chemical industries. Total United Kingdom production of high purity sand in 1975 was probably about 1.3 million tonnes.

Production of silica rock and ganister in Great Britain has been separately recorded from 1903 to 1949 and 1967 to the present, except that from 1929 to 1940, silica sand for refractory purposes was included under this heading.

Table 18 Great Britain: Production of silica rock and ganister, 1925-1949 and 1967-1975

Thousand tonnes

Year		*Year*	
1925	357	1944	526
1926	343	1945	479
1927	578	1946	697
1928	519	1947	587
1929	558	1948	626
1930	451	1949	625
1931	394		
1932	379		
1933	454		
1934	541		
1935	586	1967	167
1936	648	1968	107
1937	726	1969	160
1938	610	1970	238
1939	750	1971	148
1940	908	1972	121
1941	443	1973	102
1942	588	1974	79
1943	582	1975	42

Source:

1925 – 1937	Mines Department.
1938 – 1949	Ministry of Fuel and Power.
1967 – 1972	Department of the Environment.
1973 – 1975	Business Statistics Office.

Since 1967 some silica sand and siliceous clay production has been recorded with silica rock, and silica rock production for non-refractory use, amounting to 3,100 tonnes in 1975 (probably for aggregate), is also included.

The decline in silica rock production for silica brick manufacture is reflected in Table 19.

Table 19 United Kingdom: Production of silica refractories, 1960-1975

Thousand tonnes

Year		*Year*	
1960	241.5	1968	57.3
1961	193.9	1969	69.8
1962	133.6	1970	71.9
1963	113.7	1971	61.0
1964	130.1	1972	47.4
1965	112.9	1973	50.4
1966	81.0	1974	44.3
1967	57.3	1975	40.6

Source: National Federation of Clay Industries.

Overseas trade and consumption

The United Kingdom is not entirely self-sufficient in silica sand. Imports, chiefly of high purity glass sand, are used primarily in the glass industry for the manufacture of higher quality glass containers, as well as crystal, borosilicate and optical glasses, translucent vitreous silica and for blending to improve the quality of the feed in the manufacture of colourless glass containers. The continuing imports suggest that Loch Aline sand is not competitive with Continental supplies in some parts of the country because of the high transport costs incurred by its remoteness.

Imports of silica sand have remained relatively constant, although they have declined somewhat in recent years (Table 20), but with expanding domestic production have accounted for a decreasing proportion of total United Kingdom consumption. Imports and exports of silica sands are included in the United Kingdom Tariff and Overseas Trade Classification for 1976 under the heading 'Natural sands of all kinds, whether or not coloured, other than metal-bearing sands – natural sands for industrial uses (founding, glass-making, ceramics manufacture and the like) – code number 2505-1045'.

Table 20 United Kingdom: Imports of silica sand, 1950-1976

	Quantity (tonnes)	*cif value £*
1950	152,035	291,152
1951	213,136	463,934
1952	160,386	312,259
1953	162,738	307,884
1954	163,357	308,555
1955	184,477	356,763
1956	221,742	465,533
1957	214,085	490,488
1958	245,364	532,982
1959	284,766	622,370
1960	305,994	716,068
1961	224,381	522,346
1962	190,352	452,266
1963	200,068	521,677
1964	211,250	574,954
1965	206,792	589,327
1966	245,591	669,723
1967	204,141	613,314
1968	215,525	678,822
1969	222,631	759,661
1970	202,895	818,968
1971	171,420	819,108
1972	161,493	711,233
1973	208,468	1,084,102
1974	177,187	1,508,935
1975	132,170	1,430,854
1976	144,906	1,535,280

Source: H.M. Customs and Excise.

Details of United Kingdom imports of silica sand in the period 1970-1976 are shown in Table 21.

Table 21 United Kingdom: Imports of silica sand by country, 1970-1976

	1971	*1972*	*1973*	*1974*	*1975*	*1976*	*Average cif value per tonne £*
			Tonnes				
From:							
Belgium-Luxembourg	134,434	123,482	145,995	148,603	119,278	116,119	11.3
Netherlands	20,823	19,954	22,014	3,820	2,893	2,252	20.1
Irish Republic	7,442	12,120	31,869	11,356	3,551	22,065	0.94
France	4,754	3,829	6,057	4,096	3,500	2,424	19.2
USA	1,585	865	1,710	2,255	976	641	128.2
Fed.Rep.Germany	312	263	508	4,322	559	374	36.3
Other Countries	2,070	980	315	2,735	1,413	1,031	14.9
Total	171,420	161,493	208,468	177,187	132,170	144,906	10.6

Source: H.M. Customs and Excise.

Typical chemical analyses of two grades of imported Belgian sand produced by Sablières et Carrières Réunies SA, the major Belgian producer with operations at Mol east of Antwerp and at Maasmechelen in the province of Limburg

	Wt %	
	1A	*M. a. M.*
SiO_2	99.2	99.5
Al_2O_3	0.25	0.09
Fe_2O_3	0.033	0.022
TiO_2	0.05	0.05
CaO	0.05	0.05
MgO	0.01	0.02
K_2O	0.07	0.04
Na_2O	-	-
Loss on ignition	0.31	0.20

Source: Rockware Glass Ltd.

United Kingdom exports of silica sand have increased substantially in recent years (Table 22). The destinations in 1975 are shown in Table 23.

Table 22 United Kingdom: Exports of silica sands, 1965-1976

	Tonnes	*Fob value (£)*
1965	48,503	181,947
1966	43,794	219,351
1967	47,951	226,722
1968	41,576	260,044
1969	48,747	302,263
1970	41,001	460,227
1971	38,741	346,087
1972	56,772	399,316
1973	74,969	1,102,152
1974	100,446	2,313,865
1975	69,841	1,034,590
1976	53,505	547,644

Source: H.M. Customs and Excise.

Table 23 United Kingdom: Exports of silica sand by major country and value, 1975

	Tonnes	*Fob value(£)*	*Average fob value(£) per tonne*
Irish Republic	25,059	221,908	8.8
Norway	14,226	166,976	11.7
Sweden	10,655	38,055	3.6
France	4,237	3,118	0.7
Fed.Rep.Germany	3,759	153,603	40.8
Belgium-Luxembourg	3,368	132,629	39.4

Source: H.M. Customs and Excise.

The Loch Aline mine, with nearly 50 per cent of the mine output exported, probably accounts for the major proportion of total exports to the Irish Republic, Norway and Sweden. The high value exports to the Federal Republic of Germany and Belgium-Luxembourg probably consist of resin-coated foundry sands exported from King's Lynn. Sands are also exported to some 55 other countries for use in water treatment plants, for cement and mortar testing, ceramic and foundry applications. The low unit value exports to France seem unlikely to be a true silica sand.

Small quantities of quartz and quartzite are imported and exported. Over recent years this trade has been recorded in the Tariff and Overseas Trade Classification under a number of different headings, but in 1976 these headings were as follows:

Quartz (other than natural sands); quartzite, including quartzite not further worked than roughly split, roughly squared or squared by sawing –
Quartz, ground or powdered; quartzite –
Quartz, ground or powdered 2506 1089
Quartzite –
Crude, roughly split or roughly squared 2506 1203
Other 2506 1349
Other –
Quartz, other than ground or powdered –
Crude, roughly split or roughly squared 2506 1477
Other 2506 1609

Trade in quartz and quartzite during the period 1972 to 1976 is shown in Table 24.

Table 24 United Kingdom: Imports & exports of quartz and quartzite, 1972-1976

<table>
<tr><th></th><th>1972</th><th>1973</th><th>1974</th><th>1975</th><th>1976</th></tr>
<tr><td></td><td colspan="5">Tonnes</td></tr>
<tr><td>Imports</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite</td><td>694</td><td>650</td><td rowspan="2">3,757</td><td rowspan="2">2,468</td><td>732</td></tr>
<tr><td>Ground and powdered quartz</td><td>3,746</td><td>4,915</td><td>1,724</td></tr>
<tr><td>Unground quartz</td><td>4,833</td><td>2,826</td><td>2,951</td><td>1,059</td><td>1,128</td></tr>
<tr><td>Total quartz and quartzite</td><td>9,273</td><td>8,391</td><td>6,708</td><td>3,527</td><td>3,584</td></tr>
<tr><td>cif value</td><td>£210,698</td><td>£225,221</td><td>£385,406</td><td>£452,588</td><td>£611,916</td></tr>
<tr><td>Exports</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite</td><td>46</td><td>7</td><td rowspan="2">783</td><td rowspan="2">64</td><td>24</td></tr>
<tr><td>Ground and powdered quartz</td><td>122</td><td>32</td><td>201</td></tr>
<tr><td>Unground quartz</td><td>91</td><td>189</td><td>1,941</td><td>50</td><td>103</td></tr>
<tr><td>Total quartz and quartzite</td><td>259</td><td>288</td><td>2,724</td><td>134</td><td>328</td></tr>
<tr><td>fob value</td><td>£14,202</td><td>£35,043</td><td>£47,395</td><td>£10,541</td><td>£24,362</td></tr>
</table>

Source: H.M. Customs and Excise.

Details of imports for 1975 are shown in Table 25.

Table 25 United Kingdom: Imports of quartz and quartzite by country, 1975

Country of consignment	*Quartz, ground and powdered; quartzite (2506 0247)*			*Other (2506 0368) (Unground quartz)*		
	Quantity	*Value*	*Average value*	*Quantity*	*Value*	*Average value*
	Tonnes	*£ cif*	*£/tonne*	*Tonnes*	*£ cif*	*£/tonne*
EEC						
Belgium-Luxembourg	406	14,610	36.0	35	6,924	197.8
France	160	17,077	106.7	24	3,480	145.0
Germany F.R.	103	3,737	36.3	166	105,551	635.8
Irish Republic	-	-	-	18	1,035	57.5
Italy	616	44,809	72.7	40	3,225	80.6
Netherlands	41	11,659	284.4	-	-	-
Sweden	450	16,188	35.9	-	-	-
Norway	428	10,486	24.5	-	-	-
Portugal	60	2,844	47.4	565	25,628	45.4
USA	204	43,962	215.5	48	21,145	440.5
Yugoslavia	-	-	-	60	10,920	182.0
Czechoslovakia	-	-	-	4	1,994	498.5
S. Africa	-	-	-	10	1,156	115.6
India	-	-	-	6	2,872	478.7
Republic of Korea	-		-	17	1,383	81.3
Brazil	-	-	-	54	100,728	1,865.3
Others	-	-	-	12	1,175	97.9
Total	2,468	165,372	67.0	1,059	287,216	271.2

Source: H.M. Customs and Excise.

Imports are used in the manufacture of optical glassware, vitreous silica, piezoelectric quartz,refractories, ceramics and grinding pebbles and for non-industrial purposes such as decorative stone.

About 90 per cent of total United Kingdom production of silica sand is consumed by the foundry and glass industries and demand for silica sand is, therefore, closely linked with activity in these two industries. Consumption of glass sand has shown an average annual growth rate of 4.25 per cent during the period 1950-1975 and it seems likely that this general trend will continue unless there is a wider use of recycled waste glass and/or glass containers. There is no major problem to recycling waste glass so long as it is free from contaminants and sorted by colour, although to use a wholly waste glass feed can create technical problems. About 20 per cent of the present feed for glass container manufacture consists of recycled waste glass ('cullet') most of which comes from within the glass works itself and for which the composition is known. Since it appears far cheaper to use glass sand than collect, sort and clean waste glass from domestic refuse (over 1.3 million tonnes of glass are discarded annually in domestic refuse) it seems unlikely that waste glass recovery will have any major effect on future glass sand demand in the foreseeable future. However, research into the technical and economic feasibility of recovering glass as a by-product of the total recycling of domestic refuse is being carried out by the Warren Spring Laboratory and a prototype plant is being built at Doncaster for this purpose. The process involves sizing, air classification, selected comminution and either froth-flotation or optical sorting to produce a mixed glass product which has been found suitable for green bottle glass manufacture.

The wider use of returnable bottles could also have a significant effect on future glass sand demand. There are no other practical substitutes for glass sand, but plastics, paper and metals are alternatives to glass as packaging materials. In general, however, they would be more expensive and there would be considerable customer resistance to their use in some applications.

Demand for silica moulding sands has increased although the total quantity of castings produced by the iron founding industry has remained fairly constant at around 3.5 million tonnes, annually. This increase has come about by the introduction of new foundry processes and the greater use of chemically bonded sands. The increasing cost of silica sand, concern over future supplies because of environmental pressures, and the problem of disposing of the used sand are causing the foundry industry to give greater attention to recovery and re-use. Clay-bonded sands, with the addition of a small amount of new sand and clay binder, are recycled, but reclamation of chemically bonded sands is much more difficult and requires considerable investment in plant. Organically bonded sands are more easily reclaimed than inorganic, particularly sodium silicate systems, but as yet the effect on total consumption of foundry sands has been small. With the wider adoption of reclamation, the industry expects foundry sand consumption to stabilise in future years.

There appears to be no acceptable alternative to sand for use as a mould and core-making medium, principally on the grounds of cost, although imported zircon, olivine and chromite sands substitute for some applications, particularly in the production of heavy steel castings and as facings for moulds and cores to provide better casting surfaces. These minerals are more refractory than silica sand and do not exhibit the same thermal expansion problems, but they are used only for specialised applications because of their higher prices.

Industry

There are a large number of silica sand producers in the United Kingdom, most of the major producers being members of the Silica and Moulding Sands Association, a trade association whose general objectives are to promote the welfare and protect the interests of the silica sand industry. British Industrial Sand Limited, a member of the Hepworth Ceramic Holdings Group, accounts for some 70 per cent of the total glass and foundry sand production. The location of the company's main quarries and plants, in order of size, are listed below:

Location	*Geology*	*Major applications*
Chelford, Congleton Cheshire	Pleistocene	Foundry and flat glass sands
King's Lynn, Norfolk	Sandringham Sands, Lower Cretaceous	Colourless glass and foundry sands
Messingham, Humberside	Late Pleistocene to Holocene	Foundry and coloured glass sands
Oakamoor, Staffordshire	Millstone Grit, Carboniferous	Colourless glass, ceramics, silica flour
Redhill, Surrey	Folkestone Beds, Lower Cretaceous	Colourless glass and foundry sands
Levenseat, Lothian	Passage Group, (Millstone Grit), Carboniferous	Foundry sands
Allostock, Cheshire	Pleistocene	Coloured glass, building and asphalting sand
Dullatur, Strathclyde	Upper Limestone Group, Carboniferous	Foundry sands (naturally bonded)
Wittering, Cambridgeshire	Lower Estuarine Series, Jurassic	Foundry sands

Hinckley's Silica Sands Limited is the second largest producer, with foundry sand production based on Pleistocene deposits near Congleton and silica sand for chemical and a variety of miscellaneous uses from the Millstone Grit at Biddulph in Staffordshire. Kingscliffe Super Refractories Limited, a subsidiary of the Hinckley's Group, produces fine silica sand and silty clay for refractory purposes from the Lower and Upper Estuarine Series of the Middle Jurassic at Kingscliffe in Northamptonshire. Pilkington Brothers Limited works Shirdley Hill Sands in the Rainford-Ormskirk area for use in flat glass manufacture at their St Helens factory, and Sand Developments (UG Glass Containers) Limited, a subsidiary of United Glass Limited, produces colourless and coloured glass sands and foundry sands from Passage Group sandstones at Devilla Forest in Central region, Scotland.

Buckland Sand and Silica Company Limited works the Lower Greensand near Reigate, for colourless glass and foundry sands and the company's subsidiary, Bedford Silica Sand Mines Limited, produces foundry sands from the Lower Greensand near Leighton Buzzard.

Tilling Construction Services Limited produces foundry sands from fluvio-glacial deposits at Blaydon in Tyne and Wear, and Meriden in the West Midlands. The company acquired the Loch Aline Mine in 1972 and this is now operated by a subsidiary, Tilcon Loch Aline Limited, with an annual output of about 100,000 tonnes.

Joseph Arnold and Sons Limited and George Garside (Sand) Limited exploit the Lower Greensand near Leighton Buzzard for the production of specialised grades of sand, particularly for use in the water and sewage treatment fields.

The major silica sand producing operations, other than those operated by British Industrial Sand Limited, are listed below:

Company	*Location*	*Geology*	*Applications*
Amalgamated Quarries (Scotland) Ltd	Milngavie, Strathclyde	Calciferous Sandstone Measures, Carboniferous	Aggregate and special uses
Joseph Arnold and Sons Limited	Leighton Buzzard, Beds	Lower Greensand, Cretaceous	Special uses
Bathgate Silica Sands Ltd	Arclid, Cheshire	Pleistocene	Foundry sand
Bedford Silica Sand Mines Ltd	Leighton Buzzard, Beds	Lower Greensand, Cretaceous	Foundry sand
British Steel Corporation	Scunthorpe, Humberside	Recent	Running sand Pig-bed sand Addition to blast furnace burden
British Steel Corporation	Corby, Northants	Lower Estuarine Series, Jurassic	(as above)
Buckland Sand & Silica Co Ltd	Reigate, Surrey	Lower Greensand, Cretaceous	Colourless glass and foundry sands
R. Clarke Ltd	Hensall, North Yorks	Bunter Sandstone, Triassic	Foundry sand (naturally bonded)
Thos. Dodd Moulding Sand Quarries Ltd	Kinnerton, Clwyd	Lower Mottled Sandstone, Permo-Triassic	Foundry sand (naturally bonded)

Company	*Location*	*Geology*	*Applications*
DSF Refractories Ltd	Friden, Derbyshire	'Pocket' Silica Deposits, Tertiary	Siliceous refractories
Stanley N. Evans Ltd	Bromsgrove, Worcs	Upper Mottled Sandstone, Triassic	Foundry sand (naturally bonded)
George Garside (Sand) Ltd	Leighton Buzzard, Beds	Lower Greensand, Cretaceous	Specialised uses
T.E. Gray & Co Ltd	Kettering area, Northants	Lower Estuarine Series, Jurassic	Siliceous refractories
Hall Aggregates (South East) Ltd	Borough Green, Kent	Lower Greensand, Cretaceous	Foundry sand
" "	Linford, Essex	Thanet Beds, Tertiary	Foundry sand (naturally bonded)
Hinckley's Ltd	Congleton area, Cheshire	Pleistocene	Foundry sand
" "	Biddulph, Staffordshire	Millstone Grit, Carboniferous	Special uses
Hoben Quarries Ltd	Brassington, Derbyshire	'Pocket' Silica Deposits,Tertiary	Siliceous refractories
Hobson Bros	Stanhope, Durham	Millstone Grit (Rotten-rock), Carboniferous	Foundry sand (naturally bonded)
Hugh King Ltd	Ardeer, Strathclyde	Holocene	Foundry and coloured glass sand
" "	Kilwinning, Strathclyde	Upper Limestone Group, Carboniferous	External rendering and rough casting
Kingscliffe Super Refractories Ltd	Kingscliffe, Northants	Lower Estuarine Series, Jurassic	Siliceous refractories
Mansfield Standard Sand Co Ltd	Mansfield, Notts	Lower Mottled Sandstone,Permo-Triassic	Foundry sand
B. Mullen & Sons Ltd	Dunbar, Lothian	Holocene	Coloured glass sand
The Nene Barge & Lighter Co Ltd	Elton, Cambs	Lower Estuarine Series, Jurassic	Siliceous refractories
Olley (Wrotham) Ltd	Wrotham, Kent	Lower Greensand, Cretaceous	Foundry sand
Pilkington Brothers Ltd	Bickerstaffe area, Lancashire	Shirdley Hill Sands, Holocene	Flat glass sand
C H Pinches & Sons Ltd	Bromsgrove, Worcs	Upper Mottled Sandstone, Triassic	Foundry sand (naturally bonded)
Quartzag Ltd	Strathblane, Strathclyde	Calciferous Sandstone Measures, Carboniferous	Concrete aggregate, miscellaneous uses
Rufford Sand Co Ltd	Rufford, Lancs	Shirdley Hill Sands, Holocene	Coloured glass sand
Sand Developments (UG Glass Containers) Ltd	Devilla Forest, Central region	Passage Group (Millstone Grit), Carboniferous	Colourless, coloured and foundry sand.

Company	*Location*	*Geology*	*Applications*
Sandell's Loam and Gravel Co Ltd	Hamble, Hants	Bracklesham Beds, Tertiary	Foundry sand (naturally bonded)
Siminco Ltd	Burythorpe, North Yorks	Kellaways Beds, Jurassic	Foundry sand
Southport Sand Co Ltd	Southport Sands, Merseyside	Beach sands, Holocene	Foundry sand
Spencer Bros	Brassington, Derby	'Pocket' Silica Deposits, Tertiary	Siliceous refractories
Peter D Stirling Ltd Ltd	Drumcavil, Strathclyde	Upper Limestone Group, Carboniferous	Foundry sand (naturally bonded)
" "	Gartverrie, Strathclyde	Passage Group (Millstone Grit), Carboniferous	Miscellaneous uses
J. Stoddart and Sons Ltd	Llanarmon, Clwyd	Cefn-y-Fedw Sandstone (Millstone Grit), Carboniferous	Special uses
Tilling Construction Services Ltd	Blaydon, Tyne and Wear	Pleistocene	Foundry sand
" "	Meriden, West Midlands	Pleistocene	Foundry sand
Tilcon Loch Aline Ltd	Loch Aline, Highland region	Upper Cretaceous	Colourless glass sand
Thos. W. Ward Ltd	Stanhope, Durham	Millstone Grit (rotten-rock), Carboniferous	Foundry sand (naturally bonded)
The Wareham Ball Clay Company	Wareham, Dorset	Bagshot Beds, Tertiary	Foundry sand
West of Scotland Sand Co Ltd	Kilwinning, Strathclyde	Upper Limestone Group, Carboniferous	External rendering and rough casting
Wettern Bros Ltd	Aylesford, Kent	Lower Greensand, Cretaceous	Glass, foundry sand and miscellaneous uses
John Williams (Cinetic Sand) Ltd	Bromsgrove, Worcs	Upper Mottled Sandstone, Triassic	Foundry sand (natural)

Producers of highly siliceous, silty clays used in the manufacture of siliceous refractories are listed below:

Producer	*Quarry Location*	*Geology*
Adamix (Kingscliffe) Refractories Ltd	Kingscliffe, Northants	Upper Estuarine Series, Jurassic
GR-Stein Refractories Ltd	"	"
Kingscliffe Super Refractories Ltd	"	"
T.E. Gray & Co Ltd	Pickworth, Leics	"
The Nene Barge & Lighter Co Ltd	Kingscliffe, Northants	"
Williamson Cliffe Ltd	Stamford, Lincs	"

The silica rock quarrying industry is now only a fraction of its former size and only six operations now exist. These are listed below:

Producer	*Location*	*Geology*
British Steel Corporation	Harthope, Durham	Millstone Grit, Carboniferous
Cefn Cadlan Quarries Ltd	Penderyn, Powys	Millstone Grit, Carboniferous
D.T. Evans	Carmel, Dyfed	Millstone Grit, Carboniferous
D.T. Jones	Kidwelly, Dyfed	Millstone Grit, Carboniferous
Llanelli Plant Hire Co Ltd	Black Mountains, Dyfed	Millstone Grit, Carboniferous
Romag Refractories Ltd	Minera, Clwyd	Cefn-y-Fedw Sandstone, Carboniferous

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