Upton House
Market Street
Charlbury
Oxford OX7 3PJ
tel 01608 810374
fax 01608 810093
e-mail info@gwp.uk.com
www.gwp.uk.com

A STUDY OF SILICA SAND QUALITY AND END USES IN SURREY AND KENT

FINAL

For

KENT AND SURREY COUNTY COUNCILS

MARCH 2010

GWP Consultants LLP
Registered No. OC326183
Registered Office: Upton House, Market Street, Charlbury, Oxfordshire OX7 3PJ

CONTENTS

FIGURES

APPENDICES

A STUDY OF SILICA SAND QUALITY AND END USES IN SURREY AND KENT

1. EXECUTIVE SUMMARY

1.1 Project Brief and methodology

Quarries in Kent and Surrey produce sand from the Cretaceous age Folkestone Formation for both general construction purposes (building, concrete and asphalt sand) and for a wide range of specialist uses. A small number of these quarries produce high purity silica sand which supplies the glass, chemical, ceramics and foundry industries. Kent and Surrey County Councils have recognised that there is a need for information, obtained independently of the operating companies, relating to the quality of sand required by different end uses and the availability of suitable sand in existing sites or elsewhere for these specialist uses. Such information will be used in assessing proposals for the development of silica sand quarries, particularly where potential sand extraction affects environmentally sensitive locations.

GWP Consultants was commissioned by Kent and Surrey County Councils to carry out a study with the following general aims:

(i) to establish the physical and/ or chemical properties that are required for the different end uses of silica sand;

(ii) to determine whether sands in the Folkestone Formation traditionally worked as building sands display these properties and could be used instead of silica sand, either 'as worked' or after processing;

(iii) draw conclusions as to whether the end uses of silica sand identified could only be satisfied from the traditionally worked outcrop of silica sand;

Specific questions have also been raised relating to the quality and quantity of sand used by the Celcon Blockworks in Kent, the quality of sand at existing sites in Kent and the proposed extension to North Park Quarry in Surrey.

Unlike building sand, sand for industrial and other specialist uses may be transported considerable distances from quarry to market. In order to appreciate the importance of silica sand production in Kent and Surrey in the national context, the regional distribution of silica sand quarries and the principal markets served have been reviewed. Specialist end-uses for sand, their physical and chemical requirements and main markets in the UK were investigated through a review of literature, contacting trade organisations and other experts, and through discussions with both end-users and producers. Finally the geology, end uses, production and market information have been drawn together to present an overview of the nature and controls on the production of silica sand and sand for specialist uses in Kent and Surrey and to establish the importance of the production in the national context.

1.2 Silica Sand terminology

There is some ambiguity in the use of the term '*silica sand*' which is often used interchangeably with '*industrial sand*', reflecting the traditional uses of high purity white sand in the glass, ceramics, foundry and chemical industries. Sand is also used in a great variety of other products for which the chemical and physical requirements vary widely. To avoid ambiguity and for the purpose of this report, it is recommended that the general term 'specialist sand' is used to encompass processed or unprocessed sand marketed for a wide range of specialist end uses and that the sand resources of the Folkestone Formation are divided up as follows:

(i) **Specialist Sand**

a) *Industrial Sand*	Uses including glass, foundry moulds, chemicals, ceramics, aircrete, bricks and tiles, paint, adhesive, grout, roof felt
b) *Non-construction aggregates*	Uses including equestrian sand, sports and leisure sand, horticultural sand.

(ii) ***Construction aggregates*** -

Uses including mortar, plastering and rendering sand (often called building sand), concrete sand, asphalt sand and fine granular constructional fill. The suitability of sand for a particular construction end use is determined principally by the grain size distribution.

It is suggested that unprocessed sand is only termed 'silica sand' if it is of sufficient purity that it might be processed economically to satisfy the requirements of end uses having demanding compositional and/or colour requirements, which cannot be met from other natural raw materials. Whether the potential of a silica sand resource can be economically realised will depend on a complex set of factors including the size of the reserve; available processing plant; the practical, economic and environmental feasibility of processing the sand; the market conditions and the strategic interests and requirements of the operating company.

1.3 Production of silica sand in the UK and Southeast region

In 2008, the UK production of specialist industrial and non-construction sand was 4.777Mt of which 40% was used in glass manufacturing, 9% in the foundry industry, 25% for other industrial uses and 26% in agricultural, sports, leisure and horticulture sectors. The UK is self sufficient in silica sand with the exception of the highest grades required for crystal glass and some electronic and scientific uses, which are no longer available from UK sources.

Sand with the appropriate physical, chemical and mineralogical properties for industrial use is found in a relatively small number of areas of the UK. Glass sand is currently supplied by eight quarries in the UK, of which three are in Scotland. Two major quarries, Moneystone in Staffordshire and Dingle Bank in Cheshire, which supply the float and container glass industry, will be closing within the next 5 years as consented reserves are depleted. Both sites are operated by Sibelco and it is anticipated that capacity will largely be taken up by remaining sites operated by that company.

After closure of these two sites, the only currently operating quarries in England which will have sufficiently high grade sand to supply colourless container and float glass manufacture are North Park Quarry in Surrey and Kings Lynn Quarry in Norfolk. The glass industry in Scotland is supplied from quarries in Fife and West Lothian where resources of high grade sand are believed to be extensive.

In 2008 the southeast region accounted for 642,000t or 13.4% of the total UK production of specialist sand (National Monitoring Statistics). North Park Quarry (Sibelco) is the only site in the region currently producing glass sand. In 2008 North Park Quarry was supplying 18% of the UK supply of sand for coloured glass and 5% for float glass. At that time they were anticipating an increase in 2009 to 17% of the UK supply for float glass.

North Park Quarry and Tapwood/Park Pit, operated by Hanson, are the only suppliers of sand with a sufficiently low Alumina content (Al_2O_3) for the production of Sodium Silicates – a basic raw material for a large number of manufacturing industries.

The southeast region supplied 21,000t of sand to the foundry industry in 2005, a small proportion of the national production which is dominated by Cheshire Quarries. The proportion of sand used for non-industrial uses in the southeast is high compared to the national rate. In 2007 41% of sand production identified in monitoring statistics as silica sand was reported to be for non-industrial use.

1.4 End Uses of Sand

1.4.1. High Grade silica sand

Approximately 1.63Mt of sand from the Folkestone Formation is excavated annually in Kent and Surrey (survey of producers) of which approximately 61% is building, concreting and asphalt sand or general fill, 23% is used for industrial manufacturing processes and 16% for other non-construction uses in the sports, leisure, agriculture and horticulture sectors. The suitability of sand for different uses is determined by the quality of the sand in terms of:

- Chemistry – typically the grade is determined by the iron content of the sand in the ground.
- Grading or grain size – unprocessed sand may be suitable for a limited range of uses. Washing and sizing greatly increases the possible product range. Very fine grained sand may have limited use.
- Colour – for some industrial end uses and many sport and leisure uses off white or light coloured sand is preferred. Very low iron sands naturally are white or off-white.

The most stringent chemical requirements are for the glass and chemical industries. In order to produce sand of the required purity after processing, the initial iron content of the sand quarried must be approximately 0.13% iron oxide (Fe_2O_3) or lower. Sand of this quality is found at North Park Quarry and in the proposed extension area at Pendell Farm. Similar quality sand is also exploited at Tapwood / Park Pit Quarry. Sand is washed, sized and the iron content further reduced by magnetic separation or froth flotation.

An intrinsic property of the sand of the Folkestone Formation is the low content of alumina (Al_2O_3) which is essential in the manufacture of sodium silicates. Silica sand from Surrey is reported to be the only sand used by sodium silicate producers in the UK.

Sand for the foundry, water filtration and aircrete industries has slightly higher minimum requirements for iron. Some paints, fillers and grouts require a white sand to give a consistent colour, high reflectance or brightness. The chemical grade required for ceramics depends on the end use. These processes, with the exception of sand used as a filler aggregate in aircrete, require high purity washed and graded silica sands. Additional beneficiation is not generally carried out to reduce iron content further.

1.4.2. Other Specialist Uses of sand

Naturally light coloured sand is used for a variety of uses for which there is no chemical specification. Light colour, low fines and durability are important characteristics for sand used in brick facing, dry jointing sand, roofing felt, ornamental stone, white mortar and grouts.

Washed and processed sand is used for construction and maintenance of golf and bowling greens, tennis courts, winter sports pitches, equestrian surfaces, golf bunkers, jump and play pits, and artificial sports surfaces. There are no specifications for the chemical composition of sand for these uses, however detrimental effects of the iron oxide that forms cement and coatings in the sand of the Folkestone Formation include: staining; a tendency to break up on use causing increased dust; drainage problems; and problems in the waxing process for coated equestrian sand products. As a consequence, light coloured sand is preferred.

At the top end of the market, sports and leisure sands need to meet increasingly tightly defined grading specifications. Sites with washing and classifying plants are able to produce a wide range of consistent products and design products to match requested specifications. North Park Quarry and Park Pit supply the high end of the equestrian sand market with fine, white sand produced as a by-product of glass sand production. Equestrian sand is produced from washed and unwashed sand at other sites in Kent and Surrey.

Coloured sand is principally used unwashed as building sand or asphalt sand and washed as concrete aggregate. It is also used for soil blending and brick body manufacture. It is likely that this more iron-rich sand may be also washed and sized to produce acceptable sand for some end uses such as top dressing, rootzone and artificial sports surfaces.

1.5 Conclusions

1. Currently there are 14 quarries excavating sand from the Folkestone Formation in Kent and Surrey of which 8 produce mainly construction aggregates. At Wrotham, Aylesford, Nepicar, Tapwood / Park Pit and North Park Quarries specialist sand forms most or all of the production.

2. A survey of operators indicates that approximately 40% of the production from the Folkestone Formation is specialist products and non-construction aggregates, of which some 60% is reported to be used in industrial processes.

3. North Park Quarry in Surrey is one of the most important suppliers of container and float glass sand in the UK with production expected to increase towards the processing plant capacity over the next few years as sites elsewhere in the UK close.

4. North Park Quarry and Tapwood / Park Pit Quarries in Surrey are the only current UK sources of silica sand of suitable composition for the sodium silicate industry which supplies silica products to a wide range of manufacturing industries in the UK.

5. The requirements for very high grade, low iron silica sand in the glass, chemical and ceramics industries can only be met where the iron content of the sand in the ground is naturally low or can be lowered sufficiently and economically through processing. The number of active sites where this characteristic is present is very limited in Surrey and Kent.

6. The production of high value specialist sand relies on processing to improve quality and grain size distribution profile. Lack of processing facilities inevitably leads to the loss of value of the sand as high specification products cannot be achieved.

7. Lack of washing and processing plant may be due to environmental restrictions for the protection of groundwater, to a lack of a sufficient reserve base or to market interests of the operating company.

8. Sand currently sold for construction purposes could, with appropriate processing, be suitable for some non-construction markets and industrial uses.

9. In Surrey there are unlikely to be additional resources of high grade silica sand in the Folkestone Formation outside the currently identified area between Godstone and Reigate. In Kent, glass sand production has taken place in the past in the Hollingbourne and Bearsted area and records suggest that the area east of Maidstone should be investigated for potential silica sand production.

10. The silica sand in Surrey and Kent includes an unusually high quality resource. Any developments which affect the production of silica sand in this region will have implications and repercussions for the production of silica sand in other areas and on the costs, supply and quality of raw materials going to manufacturing industry, and in particular the chemical and glass industries.

2. INTRODUCTION

2.1 Scope of report

Silica sand has traditionally been produced at sites between Maidstone and Aylesford in Kent and Godstone and Reigate in Surrey from units within the Upper Cretaceous Folkestone Formation. Three sites in Kent (Wrotham Quarry, Aylesford Quarry and Nepicar Quarry) and two sites in Surrey (Tapwood/Park Pit Quarry and North Park Quarry) have been identified by Surrey and Kent County Councils as producers of silica sand. Two of these sites, Wrotham in Kent and North Park Quarry in Surrey have less than 5 years of consented reserves remaining and potential extension areas which lie partly within Areas of Outstanding Natural Beauty (AONB).

Surrey and Kent County Councils have recognised that there is a need for an independent source of information relating to the suitability of silica sand at sites in both counties for specialist end uses, and to use this as a framework with which to assess claims by operators regarding quality of sand that are used to promote sites for further development.

GWP Consultants (GWP) was commissioned by Kent and Surrey County Councils to carry out a study of silica sand with the following aims:

(i) to establish the physical and/or chemical properties that are required for the different end uses of silica sand;

(ii) to determine whether sands in the Folkestone Beds traditionally worked as building sands display these properties and could be used instead of silica sand, either 'as worked' or after processing; and

(iii) to draw conclusions as to whether the end uses of silica sand identified could only be satisfied from the traditionally worked outcrop of silica sand.

In addition, to consider the following background to issues relating to individual sites namely:

- the suggestion in a recent planning application by Hanson that sands at Nepicar Farm, Squerrey's and Ightham Pits are of lower quality than those at Wrotham and Aylesford;
- the origin and use of silica sand by the Celcon blockworks at Borough Green; and
- to assess the quality of the potential resource at Pendell Farm and whether the same market can be supplied from elsewhere, including Chilmead Farm.

Silica sand is recognised as a nationally scarce resource with production concentrated in a relatively small number of sites around the UK. Unlike building sand, which has a more local or regional market, silica sand is transported considerable distances from quarry to market within the UK and overseas. It is appropriate therefore to set silica sand production in Surrey and Kent into the national picture and Section 3 of this report is an overview of the UK silica sand industry.

The report is divided into six further sections.

- Sections 4 and 5 address the quality requirements of the main markets for silica sand in the UK.
- Section 6 summarises the methods of processing used by industry to produce marketable end products.
- Section 7 discusses briefly the geological background to sand resources in Kent and Surrey and the characteristics that make the sand from this formation an important silica sand resource.

- Section 8 documents the active and potential sites producing silica sand in the counties, the quality of sand and the range of products produced.

- Section 9 presents concluding statements with respect to the aims and objectives of the project.

An explanation of the indices used to classify silica sands is included in the Appendices together with a glossary of terms and selected sources of information.

Information used in the preparation of this report has been provided by most of the main producers of silica sand, specialist sand and building sand in the counties. Further information has been sourced from end users, specialists, trade associations and literature/internet searches. For reasons of commercial confidentiality producers have not supplied a detailed breakdown of production by product type and in some cases have asked that details of markets and customers remain confidential.

2.2 Definition of silica sand

There is some ambiguity in the use of the term '*silica sand*' which is often used interchangeably with '*industrial sand*' (*eg*. BGS Mineral Planning Factsheet September 2009) reflecting the traditional uses of high purity white sand in the glass, ceramics, foundry and chemical industries. MPG15 states

'*Silica sand is an essential raw material for the glass and foundry casting industries, as well as in other industries such as ceramics and chemicals manufacture and for water filtration purposes.*'

However MPG15 also recognizes that not all silica sand is of sufficiently high grade for these industrial end uses and states that

'*Within the general definition of silica sand, there are certain high grade materials which, wherever possible, should be reserved for industrial end-uses which require such sand and for which there is no readily available alternative*.'

Sand is used in a great variety of products and the term silica sand in its broadest sense encompasses sand used in the leisure, sports and horticultural sectors in addition to a wide range of industrial uses. The significance of the end use rather than the nature of the sand in the ground is recognised by the BGS (British Geological Survey) which has defined silica sand as sand

'*used for applications other than construction aggregates and which are valued for their physical and chemical properties*'.

The BGS Mineral Planning Fact Sheet (January 2006) identified silica sands as:

- Used for applications other than construction aggregates
- Valued for their physical and chemical properties, unlike construction sand which is valued for physical properties
- Having a high silica content with low levels of deleterious impurities

The 1993 Kent Minerals Local Plan (KMLP) recognised that '*the distinction made between silica sand and building sand from sources in the Folkestone Beds is based primarily on their end-use applications, rather than on an absolutely fundamental difference between the two materials "in the ground"'. 'The distinction between potential silica sand and building sand is not precise. Building sand resources in the Folkestone Beds may be considered as potential sources of silica sand, although silica sand operations are likely to be located at sites where the required grades can be produced economically*'.

The chemical and physical requirements of end-uses vary widely, the most important properties being grain size and grain size distribution (grading), grain composition, grain shape, grain strength, colour and staining behaviour. Markets often have very specific requirements for one or more of these properties, and such sands are generally marketed as 'specialist sands' that include non-construction aggregates, specialist construction uses and industrial processes.

The raw material for specialist sand ranges from high grade white or 'silver' sand through to more impure sands which, when processed, fill a market need for a particular grading of sand. Unlike building and concreting sand, which have a relatively local market, specialist sand may be transported considerable distances from quarry to market within the UK and sometimes overseas. Government monitoring statistics (Business Monitor PA1007) divide sand production (excluding sandstone) into Industrial Sand and Sand and Gravel for Construction. These comprise:

Industrial Sand	• Sand for foundry uses • Sand for glass manufacture • Sand for other industrial uses • Sand for agriculture, horticulture and leisure uses
Sand and Gravel for Construction	• Building sand for use in asphalt • Building sand for use in mortar • Concreting sand • Gravel (details not relevant here) • Other sand and gravel fill

It should be noted that PA1007 does not use the term '*silica sand*'. Sand for agriculture, horticulture and leisure uses has only been included as a separate entity in the statistics since 2004. Until this time production for these sectors was included in 'other industrial uses'. The distinction between industrial and non-industrial uses of silica sand has led to the perception among some groups that non-industrial uses are 'wasting' a valuable national resource. An understanding of the complexity of market requirements for sand and the capabilities and limitations of processing to design and alter the characteristics of the natural sand is important in assessing to what extent this perception is valid.

The largest proportion of the sand quarried in the Folkestone Formation is coloured sand used for construction aggregates. A small proportion of the same quality of sand from the Folkestone Formation is used for non-aggregate uses – notably in soil blending and brick manufacture. White, cream, buff and pale yellow sand is used in a large and diverse range of products, many of which have well defined specifications for grading (grain size), chemistry, mineralogy and colour which are addressed in Section 4 of this report.

For the purpose of this report, it is recommended that the general term 'specialist sand' is used to encompass processed or unprocessed sand marketed for a wide range of specialist end uses. These specialist end uses are divided into sand for industrial purposes and sand used as a non-construction aggregate in leisure, sports, agriculture and horticultural applications.

(i) **Specialist Sand**

a) ***Industrial Sand*** including glass, foundry moulds, chemicals, aircrete, bricks and tiles

b) ***Non-construction aggregates*** including equestrian sand, sports and leisure sand, horticultural sand.

(ii) **Construction aggregates** including mortar, plastering and rendering sand (often called building sand), concrete sand, asphalt sand and fine granular constructional fill. The suitability of sand for a particular construction end use is determined principally by the grain size distribution.

It is suggested that unprocessed sand is only termed 'silica sand' if it is of sufficient purity that it might be processed economically to satisfy the requirements of end uses having demanding compositional and/or colour requirements, which cannot be met from other natural raw materials. Whether the potential of a silica sand resource can be economically realised will depend on a complex set of factors including the size of the reserve, available processing plant, the practical, economic and environmental feasibility of processing the sand, the market conditions and the strategic interests and requirements of the operating company.

3. THE UK SITUATION

3.1 UK production statistics

Mineral production statistics for 2008 (Office for National Statistics) are the latest national monitoring statistics available. In 2008 the total UK production of industrial and other non-construction sand (PA1007 Table 1) was 4.777Mt with the greatest proportion supplying the glass industry. The breakdown of this sand production into main market sectors for 2008 is as follows:

- 40% (1.93Mt) glass
- 9% (0.443Mt) foundry moulding sand
- 25% (1.186Mt) other industrial uses
- 26% (1.216Mt) agricultural, horticultural and leisure

88.1% of the total production was from England and 13.4% from the Southeast Region (comprising Berks, Bucks, E Sussex, Hants, Isle of Wight, Kent, Oxon, Surrey, W Sussex, London). Data for individual counties and regions are incomplete because of commercial confidentiality. Actual production figures for individual sites are generally confidential although intended production rates can be obtained from recent planning applications published on MPA or planning portal web sites.

Production figures for 2008 were slightly lower than for 2007, caused by a fall in the use of sand in the foundry industry by 84,000t and in the horticulture, leisure and sports sectors by 58,000t. Use in the glass industry and other industrial sectors was little changed. The breakdown of production figures is more complete for 2007, the important East of England region being excluded from ONS regional figures for 2008. Figure 1 below generated from ONS data shows the regional breakdown of industrial and other non-construction sand production in 2007.

The North West region is currently the most significant producer of industrial and other non-construction sand. Past data indicate that almost all of this production is from Cheshire. The East of England has the second largest annual production – in approximately equal proportions - from the Leziate area near Kings Lynn and from the Leighton Buzzard area in Bedfordshire. In 2008 the production from Bedfordshire was 500,000t.

The Northwest Region, dominated by Cheshire, has consistently been the largest producing region over the last 10 years. Available regional data is shown in Figure 2 below. The Southeast region has accounted for between 12 and 15% of UK production, of which currently about 23% comes from Kent and the bulk of the remainder from Surrey, with some undisclosed production from production from Hampshire, Oxfordshire, Berkshire and West Sussex.

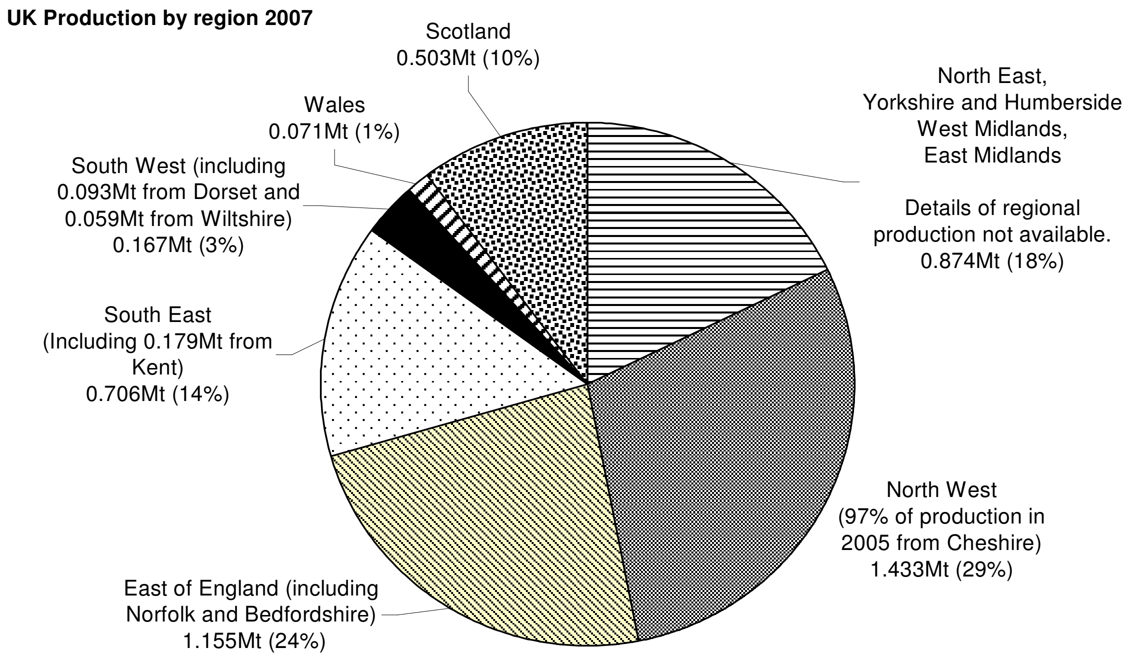


Figure 1. Production of industrial, agricultural, horticulture and leisure sand in 2007 by region (ONS)

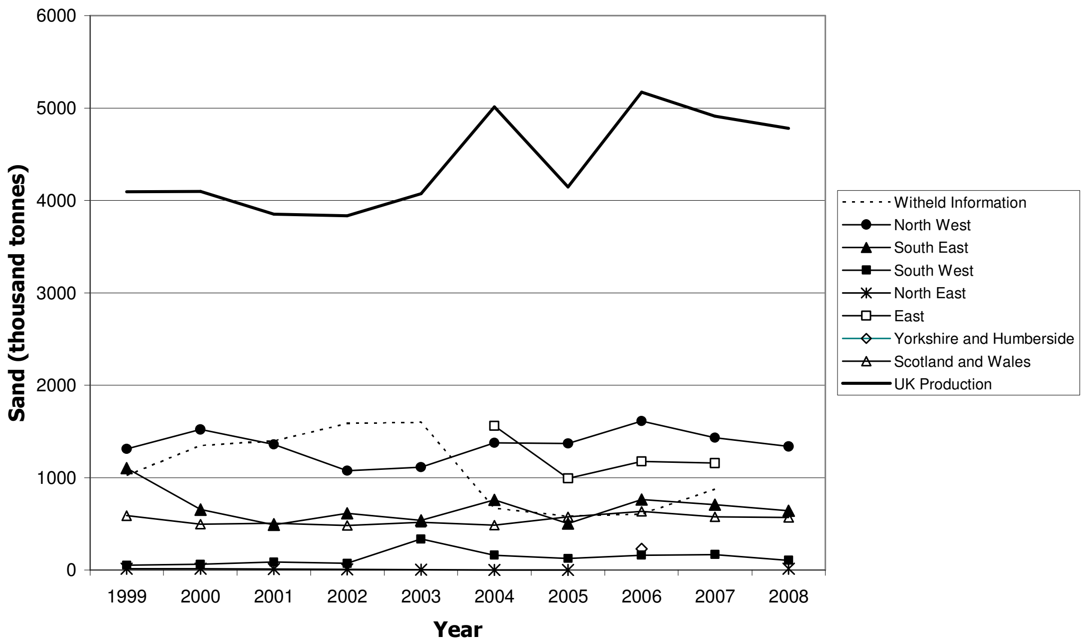


Figure 2. Production of industrial, agricultural, horticulture and leisure sand 1999-2008 by region (ONS)

Figure 3 shows the production of silica sand by end use since 1999. Over this period the production of sand for the glass industry has risen in part due to two new float glass plants which were commissioned in Yorkshire in 2003 by St Gobain and Guardian Industries. The use of sand in the foundry industry has fallen steadily and now accounts for 443,000t, less than half the tonnage used in 1999. The decline in the use of sand in the foundry industry mirrors the decline in the industry itself which in 1980 used almost 3Mt of silica sand.

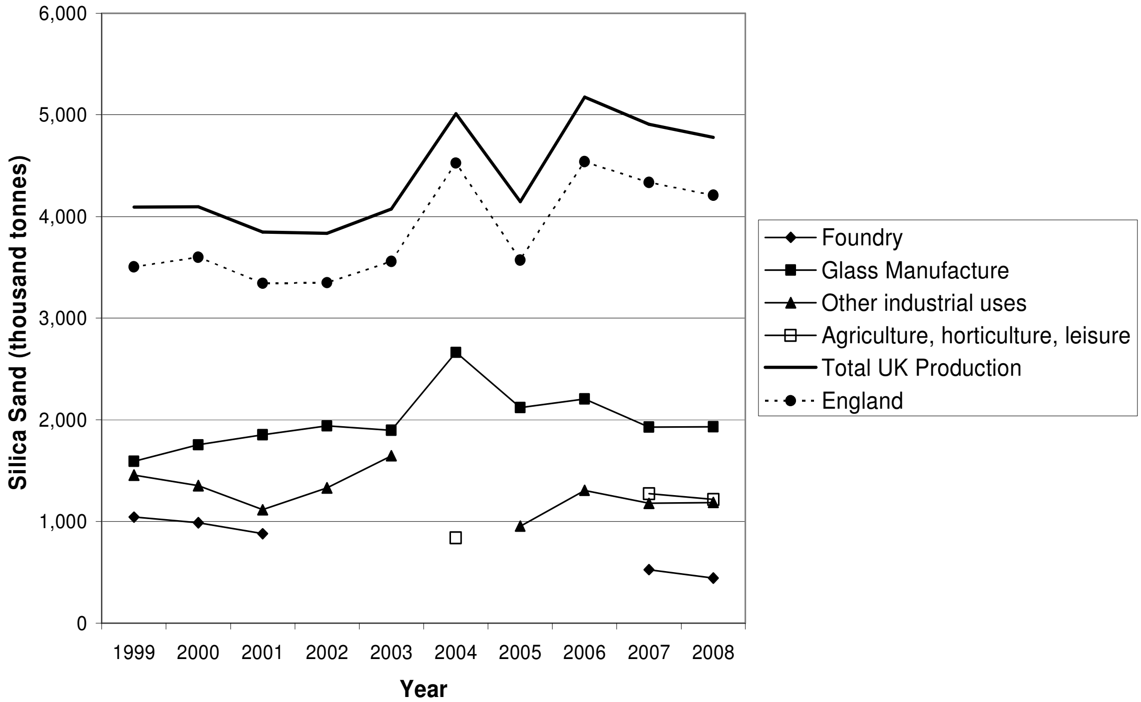


Figure 3. UK Production of industrial, agricultural, horticulture and leisure sand by market sector 1999-2008 (ONS)

Production data for sand used in the agricultural, horticulture and leisure sectors has only been identified separately in government statistics since 2004. The proportion of production from the English regions going to these non-industrial uses has increased from 17.6% in 2004 to 26% in 2008. However, in the Southeast region the proportion has remained at a consistently high level since 2004; in 2007 41% of sand production was reported to be for non-industrial use.

The UK is a net exporter of industrial and non-construction sand. However the value of imported sand has generally exceeded that of exported sand. In 2006 388,440t was exported with a value of £6.402million, while 190,800t was imported at a value of £9.234 million (source BGS Mineral Planning fact sheet 2006). With the closure of the Lochaline Mine in 2008 all very high purity silica sand is now imported.

3.2 Occurrence of silica sand in the UK

Sands possessing physical, chemical and mineralogical properties that make them valuable for industrial and other specialist uses are found in a relatively small number of areas of the UK. The distribution of major silica sand producers supplying the glass industry and the location of the main glass producers in the UK is shown in Figure 4. The principal quarries and end-uses of sand they supply are listed in Appendix 1.

Silica sand in the UK comes from different geological formations with very different geological histories and consequently grading and composition vary from site to site and within each site. The product range is designed through processing and blending to optimise the use of the mineral and minimise the waste. Processing is discussed further in Section 6. Silica sand from one quarry cannot necessarily be substituted for sand from another quarry in the same process and some geological horizons are better suited to particular end uses. The major areas of production are outlined briefly below.

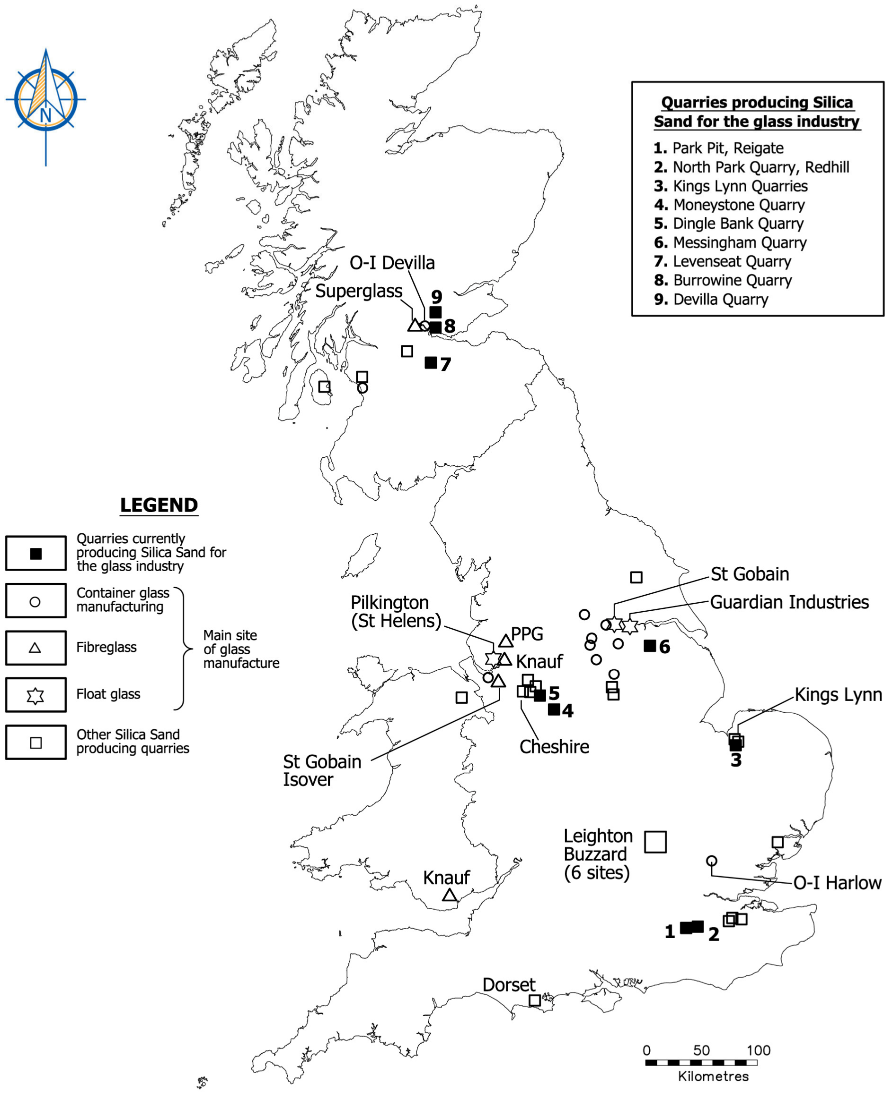


Figure 4. Location of major silica sand quarries and glass manufacturing sites

Bedfordshire

A number of quarries in the Leighton Buzzard area of Bedfordshire produce specialist sands from the Lower Cretaceous Woburn Sand Formation. The Woburn Sands are a complex series of variable sand including high purity white and off-white 'silver sands' and coloured ferruginous sand processed for lower specification uses. The silver sand is best developed in the Heath and Reach area north of Leighton Buzzard where it remains a source of foundry moulding sand. Historically the silver sand has been used for glass production but none supplies the glass industry today. Consented reserves still remain at LB Silica Sands Bryant's Lane site and additional sites have been proposed by industry to increase the availability of this quality of sand. South of Leighton Buzzard a sequence of distinctive ferruginous, fine to coarse sands known as the Red Sand is exploited for a wide variety of specialist end uses at Pratts Quarry (Sibelco) and Grovebury Quarry (Aggregate Industries/Garside). At the latter, a large proportion of production is used for construction sand – a reflection of the core interests of the parent company.

Processed sand is sold to the sports and leisure sand market and a range of other uses including horticulture, rootzone and top dressing, resins, tiles and bricks, foundry moulding sand, grouts, brick facing and industrial fillers. The area is an important producer of building sand which is produced from the same quarries as specialist sands. In the more ferruginous units it is the grading (grain size) rather than the chemistry that distinguishes sands suitable for specialist uses after washing and processing from the finer grained building sands, supplying markets in which the colour and light staining is acceptable.

This area is the traditional supplier of coarse grained, well rounded screened sands for water filtration media (BGS Mineral Planning fact Sheet 2006), although it is understood that suitable grades are imported into the areas to make up shortages in locally produced sand grades.

The annual output of specialist silica sands from Bedfordshire was estimated as *c* 460,000t in 2003 by Cuesta Consulting. Since that time additional reserves have been consented but more recent production figures are not available.

Cheshire

The Pleistocene age glacial sands of Cheshire are a major source of silica sand. The Chelford Sand is worked at Dingle Bank Quarry in Cheshire, which is the major supplier of sand to the Pilkington float glass works in St Helens. Two types of sand are produced, white sand for glass production and overlying Gawsworth Sand which is suitable for sports, horticultural and construction applications. It is understood that before an extension of 460,000t was approved in 2006/7 for an additional 4 years working of glass sand, this site was due for closure in 2010. With the limited extension the site is due to be restored by 2015 (source WBB Non technical summary March 2005). No replacement for this site has been proposed and the supply of sand to the Pilkington plant will have to be taken up by other quarries – possibly Levenseat in Scotland or Leziate in Norfolk.

The Congleton sands have a higher iron content than the Chelford Sand and are not used for float glass production, although some sand is supplied for glass fibre and coloured glass manufacture. These quarries are major producers of sand for the foundry industry. Sand is worked at three sites – Arclid, Bent Farm and Eaton Hall. Potential extension areas to Arclid and Bent Farm Quarries were identified in the Cheshire County Council Minerals Issues and Options document published in September 2007.

Dorset

Production of specialist sand from Dorset was 93,000t in 2007 (ONS Industrial, agricultural, horticultural and leisure) where the Tertiary Poole formation is worked primarily for building sand. Sand is used in glass fibre manufacture and for leisure uses including equestrian sand. Experts for the British Horse Society advise that Warmwell Quarry produces an equestrian sand that meets their grading and colour requirements. Light coloured, buff sand is produced at other sites where specialist sands are a minor product. No details about individual sites are available.

Essex

The only site producing silica sand in Essex is Martell's Quarry at Ardleigh near Colchester operated by Garside Sands (Aggregate Industries). The consented production is 84,000tpa of which *c* 54,000tpa is silica sand from the Quaternary Lowestoft Formation Gravel and the remaining production is construction sand and gravel. A recently granted planning permission has extended the consented reserve life to 2026, and a further two potential quarry extension areas have been identified. Ardleigh produces graded water filtration sand with rounded grain shapes for UK utilities, domestic and industrial markets and for export. Other uses include fillers in specialist plaster, resin bonded decorative surfaces and pathways, horticulture and sports sands.

Kent and Surrey

Silica sand and other specialist sand products are produced from the Upper Cretaceous Folkestone Formation which is a regionally important source of building sand. Non-construction sands are produced in variable quantities from many of the sand quarries, but form the principal product at two sites in Surrey, Park Pit/Tapwood Quarry and North Park Quarry and major products at three others in Kent, Wrotham, Nepicar and Aylesford Quarries. Both Surrey sites have a history of production of low iron sands for the glass industry. Sibelco stated in 2008 that North Park Quarry was providing 18% of the UK supply of sand for coloured glass manufacture and 5% of sand for colourless container manufacture. Sibelco at that time was anticipating increasing the supply of sand for float glass during 2009 to 17% of UK production. The capacity of the processing plant at North Park Quarry is *c* 500,000-600,000tpa which is expected to be reached by the end of 2010 when Moneystone Quarry closes.

Lincolnshire

Messingham in Lincolnshire produces *c* 200,000tpa of silica sand from a Pleistocene blown sand deposit. Typical iron contents are 0.2-0.25% Fe_2O_3 which is too high for flint glass and the principal market is the coloured container glass industry. In a recent planning application for an 11 year extension of operations, Sibelco stated that the site supplies 5% of all UK silica sand production for industrial use and 10% of all silica sand used in the glass industry. Other products include float glass polishing, foundry moulding sand, horticulture and fertiliser.

Norfolk

Sibelco operates a large quarry complex in the Lower Cretaceous Leziate Beds near Kings Lynn. A planning permission for extension of the quarry and extraction of 600,000-650,000tpa (unprocessed) over a 12 year period was granted in 2007. The quarries produce sand for flint and float glass, tableware and foundry use.

Approximately 50% of the output from King's Lynn Quarry is transported by rail. Three areas of search and two small allocation sites, one being an extension to the existing quarry, have been put forward in the Minerals Site Allocations Issues and Options Document on the Norfolk CC website. Areas of search are constrained by SSSI/RAMSAR designations.

Staffordshire

Moneystone Quarry (Oakamoor), which was producing *c* 430,000tpa of silica sand in 2006, is due for closure by the end of 2010 after withdrawal of an application by Sibelco (WBB). The site works the Carboniferous age Rough Rock Sandstone. The quantity of impurities is brought down to levels acceptable for colourless container glass and ceramics by gravity separation and hot acid leaching (BGS Mineral Planning fact Sheet). In the calcination plant, sand is converted to cristobalite in a high temperature rotary kiln. Cristobalite is used by the ceramic and investment casting industries for its thermal properties, or ground to flour for use as a white filler in a range of industrial applications.

The production from Moneystone Quarry, which supplies container glass manufacturers in Yorkshire and Merseyside is likely to be absorbed by higher production rates at some or all of the remaining Sibelco sites, including North Park Quarry. The intentions of Sibelco with respect of the production of cristobalite after the closure of Moneystone Quarry are not known.

Yorkshire

There are two silica sand quarries in Yorkshire, Burythorpe Quarry operated by the Yorkshire Mineral Company, and Blubberhouses Quarry near Harrogate. Blubberhouses was mothballed in 1991 after only 3 years of production of high grade sand used in the manufacture of clear glass. Mineral extraction is consented until 2011 although there are large proven reserves, reported to be approximately 35Mt with potential for additional resources in the area. The quarry lies within the Nidderdale AONB and adjacent to and partly within the North Pennine Moors Special Protection Area (SPA) and Special Area of Conservation (SAC). In 2007 Blubberhouses Quarry was identified as a preferred site for silica sand production beyond 2011 by North Yorkshire County Council.

Burythorpe Quarry, operated by Yorkshire Mineral (formerly known as Burythorpe Silica Sand Products, Ltd) produces resin coated sand for foundry applications, sand for ceramic applications and sports, leisure and construction markets.

Scotland

In 2007, Scotland supplied 10% of industrial, agricultural, horticultural and leisure sand produced in the UK (ONS) and 13% of sand for the glass industry. Most of this production comes from medium to coarse grained sandstones of the Carboniferous age Passage Formation worked at Devilla and Burrowine Quarries in Fife and Levenseat Quarry in West Lothian. The sandstone is white, grey and pale yellow friable sandstone which is easily quarried and processed for a range of industrial, leisure and construction applications. The sand has the coarse grading and purity required by water filtration media. All three sites produce sand for the glass industry, supplying container glass manufacturers in Scotland and Yorkshire.

Burrowine, operated by Fife Silica Sands submitted a Planning Application for an extension in 2008 which at the time of writing is still awaiting a decision. The Planning Application reports a reserve of 30Mt representing a life of over 60 years at maximum plant capacity of 450,000tpa. The site currently produces *c* 250,000tpa. The quality of sand at Burrowine is reported to be high with minimal processing required to produce sand for colourless glass production.

Devilla Quarry, owned by O-I produces sand for the O-I Alloa glass container plant which uses most of the quarry production. The sand is acid leached to reduce the iron content for clear glass production.

Levenseat Quarry in West Lothian is operated by Sibelco. The 1952 permission is valid until 2041 and covers 320 hectares of land. A 12 hectare extension was approved in 2004. The 2003 Planning Application gives principal uses as water filtration, rootzones for sports and horticultural products, resin sands for the foundry industry and sands for commercial flooring, specialist calcined sands used in road markings and fluidized bed sands used for waste incinerators. The worked sandstone units are not as high purity as those at Devilla and Burrowine, however current operations are also producing some sand suitable for clear glass manufacture which supplies glassworks in Fife. A rail loading facility at Levenseat has recently received planning permission (Source Silica sand: Geology and mineral planning factsheets for Scotland BGS 2007).

Small quantities of specialist sand for leisure, sport and horticultural applications are produced from sandstones within the Carboniferous Upper Limestone Formation at Hullerhill (Hugh King Ltd.) in North Ayrshire. At Tarmac's Douglas Muir Quarry near Glasgow moulding sand is produced as a by-product of construction aggregate from a hard, white Carboniferous conglomerate.

The highest purity silica sand in Britain occurs in the Cretaceous Lochaline White Sandstone Formation on the west coast of Scotland. The sandstone is a laterally extensive sandstone up to 12m thick which was mined underground at Tarmac's Lochaline mine until 2008 when it closed. The sand was processed to lower the iron content to less than 0.014% Fe_2O_3 with 99.8% or more SiO_2. Sand was used in clear container glass production, manufacture of silicon carbide abrasives and borosilicate glass for scientific, chemical and domestic products. Extensive proven reserves remain at the site.

The BGS Mineral Planning Factsheets comment that the Passage Formation has the potential to become an increasingly important source of silica sand to the UK market. The purity and grading varies between beds with the potential to supply a wide range of products.

4. QUALITY SPECIFICATIONS FOR INDUSTRIAL END USES OF SILICA SAND

4.1 Glass

4.1.1. Glass Production in the UK

There are four main sectors in the glass industry in the UK.

- **Container glass:** manufactured at 6 sites in the UK in Merseyside, Yorkshire, Scotland and Harlow in Essex. 2.2Mt of container glass, predominantly for bottles and glass, was produced in 2006 (source British Glass).
- **Flat glass** produced by 3 manufacturers in Yorkshire and Merseyside. Production in 2006 of 1.1Mt was mainly for the architectural and automotive industries. The UK is a net exporter of flat glass.
- **Fibre glass** produced by 4 manufacturers. The production from this sector was approximately 250,000t in 2006.
- **Glass for specialist uses** including medical, optical, lighting, laboratory and crystal. Production in 2006 was 0.169Mt.

The bulk of production is sodium silicate glass manufactured from *c* 60-75% silica sand (or including a component of recycled glass) fused with a flux of soda ash (Na_2O) and lime at temperatures of 1,450^{o}C or greater. Other materials are added depending on the desired properties. The presence of iron oxide, which will colour the glass green or brown, is most critical in determining whether the sand is suitable to make clear or coloured glass. Other substances are added to give colour, improve optical properties or increase resistance to corrosion or heat. Common additives include:

- lead increases brilliance and weight and make the glass softer and easier to cut and engrave;
- boric oxide increases resistance to chemical corrosion and thermal and electrical resistance. Borosilicate glass is used in the chemical industry and heat resistant products such as cooking plates;
- barium increases the refractive index;
- cerium is added to absorb infrared rays;
- metallic oxides give colour; and
- selenium is used as a decolourizer.

Container glass

There are 6 major manufacturers in the UK: O-I has a manufacturing plant at Harlow, Essex; Allied Glass in Leeds; Beatson Clarke in Rotherham; Quinn Group in County Fermanagh and Rockware and Stolzle Flaconnage Ltd in West Yorkshire (source Brit Glass). Manufacture of glass packaging uses a large amount of recycled glass cullet. O-I, which produces *c* 500,000t of glass products a year, sources some 85% of green glass, 40% of amber and 50% of colourless glass output from cullet (source: Packaging News 3 July 2007). The availability of cullet can be very variable and the glass industry competes with other users of cullet such as recycled aggregate and drainage and filtration media. Most UK production is of clear containers, while imports are generally coloured (principally wine) bottles. This combined with recycling strategies which have moved to mixed collections has limited the colourless cullet available in the UK and the ability of recycled glass to replace some of the high grade sand used in the industry. Trends in manufacturing and marketing which affect the raw material requirements include:

- increasing the supply of colourless cullet through better control of colour sorting. This may reduce the demand for silica sand raw materials;
- trials of reduced weight bottles and other containers have been carried out (Source WRAP);
- maximising use of cullet by increasing the proportion of coloured glass used in the manufacture of clear glass containers, adding decolourants to achieve the required colour and addressing customer perception of the acceptable colour (source WRAP 2006);
- a backlash against plastic containers, which are seen as environmentally unfriendly, in favour of glass, which is infinitely recyclable and is seen as more environmentally friendly.

Flat Glass

There are 3 flat glass manufacturers in the UK: Saint Gobain Glass (UK) Ltd in Eggborough, Yorkshire; Pilkington UK Ltd based in Lancashire, and Guardian Industries UK Ltd in Yorkshire. Production is dominated by architectural and automotive glass.

Glass is produced by either the float glass process in which a sheet of glass is made from floating molten glass on a bed of molten tin, or the rolled glass process for producing patterned glass. Recycled glass may be used in the process if composition is carefully monitored. The March 2008 (Wrap/Environment Agency) specification for cullet suitable for flat glass manufacture identifies three types:

- clear soda lime silica window glass;
- less than 5% lightly tinted flat glass (bronze, green, blue and grey); and
- flat glass with highly transparent thermal insulating coatings.

The Saint Gobain plant sources 30% raw material from recycled glass, thus reducing its raw material requirement by 50,000t pa. (source The Manufacturer August 2006).

The melt composition may be varied depending on the end use. For example, Pilkington market an ultra-clear float glass with a very low iron content for prestigious building projects, furniture and manufacture of photovoltaic modules (source Pilkington website). Sibelco has indicated that the high purity sand needed for these specialist uses is mostly imported.

Fibre Glass

One company, Pittsburg Plate Glass (PPG), produces continuous filament glass fibre used in thousands of applications including plastics, electronics and light weight products including composite blades for wind turbines. PPG reports that its factory in Wigan will be turning manufacturing entirely to wind energy, long-fibre thermoplastics, and high-pressure pipe industries, with manufacturing for other markets going to China. The quality of raw material required will depend on the nature of the end product.

There are three major manufacturers of glass fibre insulation in the UK: Knauf Alcopor, St Gobain Isover and Superglass (source WRAP) at four sites (see Figure 4). Insulating fibre production is linked to the building industry and the UK has been a net importer (*c* 80,000t in 2006). UK production may increase in the future with new plant capacity planned. Glass wool is made from either borosilicate glass or Ca-Na silicate glass. The recycling of glass from buildings, flat glass, car glass and containers is increasing and, according to WRAP, approximately 50% of the raw materials can be replaced by recycled glass. The proportion currently is approximately 33%.

Specialist Glass

Specialist glass includes optical glass in cameras, microscopes, glasses and other optical instruments and optic fibres used for telecommunications. Resistance to chemical corrosion and temperature is required by laboratory glasswear which is usually borosilicate glass. Domestic use includes glass ceramic cooking hobs, light bulbs, cathode ray tubes and liquid crystal display screens. There are numerous small specialist producers of glass in the scientific, technical and decorative sectors. Some of the larger producers in this category are listed below;

Decorative lead glass: Dartington Crystal Ltd., Devon; Gretdale Ltd., Cumbria; Langham Glass, Norfolk; Royal Brierley Crystal, West Midlands; Tudor Crystal, West Midlands.

Specialist: Biochem Glass (Apparatus) Ltd, Buckinghamshire; Nazeing Glass Works Ltd, Hertfordshire; Poulten & Graf Ltd, Essex;

4.1.2. Specification of silica sand raw material

Chemistry

The requirements of the raw materials depend on the glass produced. There are no current industry-wide specifications or recommendations for the quality of silica sand. The 1988 standard BS2975 included recommended limits for the composition and grading of glass sand for 7 specified grades of glass.

These were omitted from the revised British Standards (BS2975-1:2004, BS2975-2:2008) and, in practice, major manufacturers and suppliers set up partnerships using BS 2975 as guidance for physical and chemical testing methods that may be used when selecting a sand and auditing supply quality (Margaret West personal communication). An example of a specification for flint glass sand from Surrey is included in the table below and it can be seen that it does not meet the very low iron requirements for the specialist Grades A, B and C. Very high purity silica sand is no longer produced in the UK.

Grade of glass (BS2975:1988 superceded)		**SiO_2%**	**Fe_2O_3%**	**Al_2O_3%**	**Cr_2O_3%**
Optical and opthalmic	**A**	99.7	0.013	0.2	0.00015
Tableware and lead crystal glass	**B**	99.6 (+/-0.1)	0.01	0.2 (+/-0.1)	0.0002
Borosilicate glass	**C**	99.6 (+/-0.1)	0.01	0.2 (+/-0.1)	0.0002
Colourless container ('flint')	**D**	98.8 (+/-0.2)	0.03 (+/-0.003)	nominal (+/-0.1)	0.0005
Clear flat glass	**E**	99.0 (+/-0.2)	0.1 (+/-0.005)	0.5 (+/-0.15)	
Coloured container glass	**F**	97.0 (+/-0.3)	0.25 (+/-0.03)	nominal (+/-0.1)	
Insulating fibres	**G**	94.5 (+/-0.5)	0.3 (+/-0.05)	3.0 (+/-0.5)	
Manufacturers specifications for silica sand from Kent/Surrey					
flint glass (colourless containers)		99.69	0.032 (max 0.035)	0.09	0.0003 (max 0.0007)
coloured containers		99.70	0.080	0.14	0.002

Critical chemical and mineralogical parameters that can detrimentally affect the glass include:

- titanium and chromium minerals which may melt if fine enough and will colour the glass;
- larger grains of refractory minerals such as chromite and rutile will not melt and cause flaws in the glass leading to fractures. This is a serious problem in float glass and

manufacturers such as Pilkington carry out routine and frequent testing of raw materials to spot contamination before it affects the production; and

- aluminium, magnesium, calcium and the alkalis (sodium, potassium) levels affect the melting properties and should be kept at consistent levels.

The purity level of silica sands is generally judged by the iron content. Coloured container glass can tolerate the highest iron levels, for example sand from Sibelco's Messingham site, which supplies glass for coloured containers, has typical iron contents of 0.2-0.25% Fe_2O_3.

Acceptable iron content for sand supplied to flat glass manufacturers is considerably higher than that required for clear container (or flint glass). The exceptions to this will be some specialist flat glass products which require a very low iron content. The float glass process is somewhat flexible in the chemistry of the raw materials as long as consistency is assured. Some colour in most flat glass can be tolerated. The cost of transport may be the decisive factor in deciding whether to source silica sand from a higher grade, more distant site, or from a slightly lower grade but more local site.

Grain size and grading

Glass manufacturers require a narrow range of grain sizes to ensure an even and consistent melt. Larger grains will melt more slowly than smaller grains and may remain unmelted causing 'stones' in the final product. Finer grades are more likely to carry refractory and iron oxide mineral grains. A typical specification for glass sand requires 92% between 0.5mm and 0.125mm, with a maximum of 3% between 0.5mm and 0.71mm and no fraction greater than 0.71mm or less than 0.063mm. Typical grading of glass sands is shown in Figure 5.

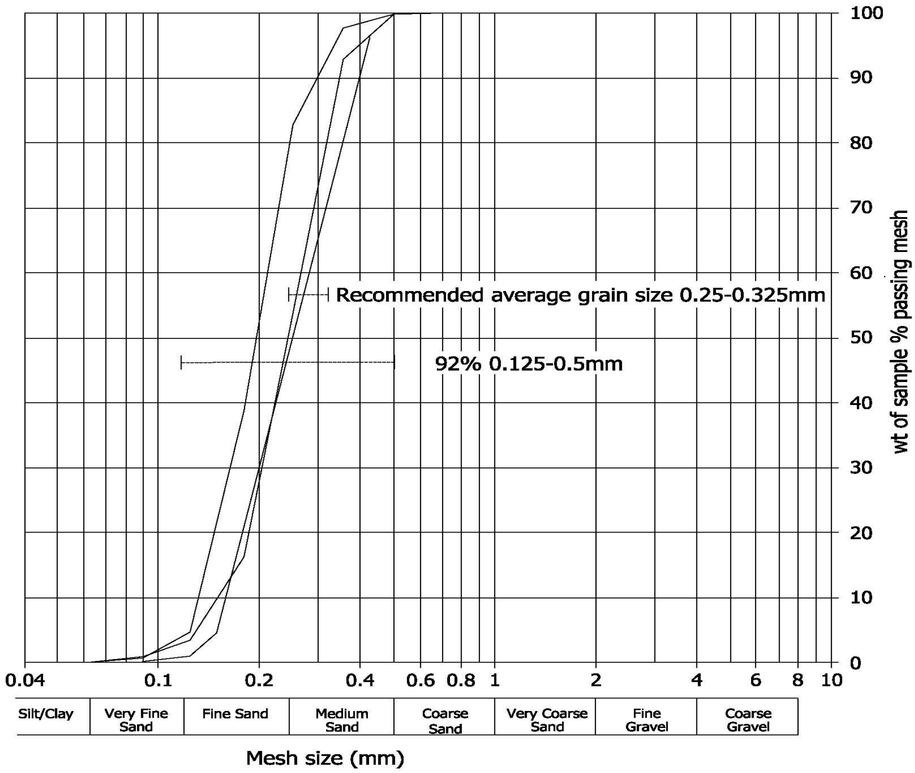


Figure 5. Typical grading curves for processed glass sand from the Folkestone Formation.

4.1.3. The Supply of sand for the glass industry

The glass industry is the largest consumer of silica sand in the UK but only a small number of quarries produce sand which meets the high specifications of the industry. The highest purity sand is needed by crystal glass and optical glass manufacturers. At present there is no source of very high purity sand in the UK and supplies, which comprise a relatively small volume, are imported.

Quarries that produce sufficiently high grade sand for the float and container glass industries are shown in Figure 4.

Sites producing sand for the glass industry are:

In England:

- North Park Quarry in Surrey (Sibelco);
- Tapwood (Park Pit) Quarry in Surrey (Hanson);
- Moneystone Quarry in Staffordshire (Sibelco);
- King's Lynn Quarry, Leziate in Norfolk (Sibelco);
- Messingham Quarry in Lincolnshire (coloured glass only) (Sibelco); and
- Dingle Bank Quarry in Cheshire (Sibelco).

In Scotland:

- Burrowine Moor Quarry in Fife (Fife Silica Sands Ltd);
- Devilla Forest Quarry in Fife (O-I);
- Levenseat Quarry in West Lothian (Sibelco).

All sites currently producing glass sand in England, with the exception of Tapwood / Park Pit in Surrey, are operated by Sibelco (it is believed that Tapwood / Park Pit Quarry is not supplying sand for glass manufacture currently). Levenseat Quarry in Scotland is also owned by Sibelco. O-I owns Devilla Quarry, which supplies its glass container plant in Alloa. Processing is essential at all these sites to produce the grades and composition of sand required for the glass industry. Even after extensive processing only North Park Quarry, Kings Lynn, Moneystone and Tapwood / Park Pit Quarry in England have sufficiently high grade (low iron) sand to supply flint glass (colourless container) manufacture.

The investment costs of installing processing plant require a significant reserve base – probably in the order of 10-15 years. With the exception of Scotland, it is possible that few new sites may be identified with sufficient resources to justify the capital expenditure of installing the necessary processing plant. New sites are usually linked to existing processing plant.

4.1.4. Summary

1. The glass industry is the largest consumer of silica sand in the UK. Silica sand raw material used in the glass industry requires:
   - a narrow grading – produced from natural sands through screening and sizing;
   - demanding specifications for chemical composition principally determined by the type of glass manufactured; and
   - consistency – particularly in the float glass process
2. Colourless container glass (flint glass) requires the highest grade silica sand produced in the UK with Fe_2O_3 less than 0.035%. According to industry only North Park Quarry and Tapwood/Park Pit in Surrey together with Leziate in Norfolk and Moneystone are capable of producing sand of this quality in England. Scotland has considerable potential for future high grade silica sand production.
3. Two additional sites in England, Messingham and Dingle Bank, produce silica sand for coloured container glass and float glass respectively. Glass for the highest

specification specialist uses such as optical glass requires very high purity sand which is not available in the UK.

4. The potential for use of recycled glass is high but limited by the supply of suitable cullet. Manufacturers are actively seeking to increase the amount of recycled glass used where possible. Recycling of flat glass is problematic due to practical difficulties of retrieving glass from buildings.

5. Within the next few years the closure of two major suppliers of glass sand, Dingle Bank and Moneystone will require replacement of the production from existing sites. The total production of these two sites is over 500,000tpa, of which an undisclosed amount is for the glass industry.

4.2 Foundry Moulds

4.2.1. Foundry production in the UK

The South East of England, and specifically the Weald, was an area in which iron production and casting, based on the availability of ironstone and charcoal, was practised since early mediaeval times. In the UK ferrous sector, the iron casting industry was at its peak of over 4m tonnes per year in 1964, and since then it has declined steadily. Between 1971 and 2000 it reduced in size by 71.1% and this trend has continued. In the same period there was a decline in the production of cast steel of 62.8%. In the non-ferrous sector over the same period there were declines in the production of cast copper by 76.3% and cast zinc by 71.5%. Only aluminium (27% increase) and magnesium, which is often alloyed with aluminium (40% increase), showed increased demand, due in a large part to the aerospace industry located in the south and southwest of England.

Sales of silica sand to the foundry industry have steadily decreased with the decline of the engineering industry. About 11% of all silica sand sold in 2007 was used for the foundry market. Today, foundries in the South East produce ferrous and non-ferrous castings and the region is the second largest producer of non-ferrous castings after the West Midlands, with a number of large suppliers to the aerospace industry. In the United Kingdom the remaining large ferrous foundries are located in the North, close to traditional centres of heavy industry and iron making.

Over time the foundry industry has recognised that high quality silica sand, processed to specific physical and chemical quality standards, is essential for the production of consistently high quality castings to very close tolerances. The main advantage of silica sand in foundry work is its low cost, availability and high melting point (1610°C). The sand is mixed with a natural or synthetic binder to produce a mould that retains shape and strength when metal is poured and cooling.

4.2.2. Sand casting processes

Sand casting accounts for approximately 70% of castings made in the UK and is still the most popular casting method due in part to the wide range of component sizes that can be produced and metal alloys that can be used. The process is also fast and less expensive than other systems. The most common two main methods of producing sand moulds are the traditional greensand process and chemically bonded sand.

Greensand process

The greensand mould is made by packing a mixture of silica sand, *c* 10wt% bentonite clay, 2-5% water and *c* 5% coal dust around a pattern. If the mould is dried at a temperature just above 100°C (212°F), the majority of the free moisture will be removed giving the mould increased strength and rigidity. This is called the dry sand process and is traditionally used in the manufacture of large, heavy castings. Once the sand has been packed, the pattern is removed to form a mould into which the metal is poured. Once cooled, the mould is broken away from the metal component. Greensand can be reused repeatedly, reducing the need for new sand.

Bentonite and clay can be replaced by special oil binder, as in the commercial products Petrobond and Mansbond. The absence of water means that there is less venting of steam from the mould and finer grain sizes can be used. Oil bonded sand is used in the same way as greensand but produces better results with non-ferrous metals.

Chemically bonded sand

Chemically bonded sand systems produce castings with a superior surface finish and better dimensional accuracy than conventional greensand castings. The binder resin is designed to harden quickly and typically an acid catalyst is used to speed up the setting process.

The process uses fine-grained, high purity sand that contributes a smooth surface and dimensional accuracy to moulds, cores and therefore to the castings. In conventional greensand moulding the use of such fine sand is precluded because it would dramatically reduce mould permeability. This has the effect of retarding the escape of air and mould gases, causing castings containing gas defects. The resin system has no added water and permits a much thinner mould or 'shell' which allows any volatiles to escape more easily.

4.2.3. Specification of raw materials

The characteristics needed by sand to give the mould dimensional and thermal stability at elevated temperatures and a good quality surface finish are:

- suitable particle size and shape and grading;
- chemically inert with molten metals;
- not readily wetted by molten metals
- freedom from volatiles that produce gas upon heating;
- economically available;
- consistent purity and pH; and
- compatibility with binder systems.

The particle size, shape and grain size distribution have very significant effects on the quality of the mould, the presence of defects and the quality of the surface finish of the product. A foundry may use several sand grades to achieve the best effect and the most cost effective solution.

Grain Shape:

Sphericity: The surface area of sand grains decreases with increasing sphericity. This affects the amount of binder needed**.** High sphericity is a desired property of foundry sand.

Rounded sands: Rounded sands offer excellent permeability and good flow characteristics but unbonded they have poor interlocking strength and compactability. In a bonded state sand requires less binder.

Angular sands: Angular sands give lower permeability but higher interlocking strength when unbonded. In a bonded state they require more binder to cover the higher surface area and achieve the same binder coating thickness and bonding strength.

Sub-angular sands: Sub-angular sands with good sphericity give the best overall characteristics, combined with a low demand for binder. They have intermediate permeability, interlocking strength and fines generation. Foundries may use sands with different grain shapes depending on the specific properties required.

With handling and reuse of moulding sands, the angular and sub angular grains tend to become more rounded as their sharp corners extremities are broken off. This causes fines to be produced, which lowers the permeability of the sand. Dilution sand is added to counteract the increasing fines content.

Grain size and grading

The overall or average grain size of the casting sand affects the quality of the finish. A fine sand will produce a finer finish and may be used if fine detail is needed. However, fine sands have poorer flow characteristics resulting in poor packing. A coarse sand will give a rougher surface finish as the metal will penetrate into the mould, but has a lower binder demand than finer sand. In practice more expensive finer silica sand may be used at the face of the mould to take fine detail with coarser sand as the backing sand.

In organic binder systems, the proportion of sand finer than 0.09mm should be minimised as it increases binder requirements and finer grain sizes have little additional beneficial effect on the quality of the finish. However in greensand, a broader grading is more favourable to give good packing, a good mould strength and density (source SAMSA website). Two commonly quoted indices of grain size are the AFS or Grain Fineness Number and AGS or average grain size (see Appendix 4). AFS is commonly included in the product name, for example CN HST50 is foundry sand with typical AFS of 50 from Congleton. Figure 6 shows grading curves for sands that are marketed as moulding sand from Congleton in Cheshire, traditionally the most important source of foundry sand in the UK.

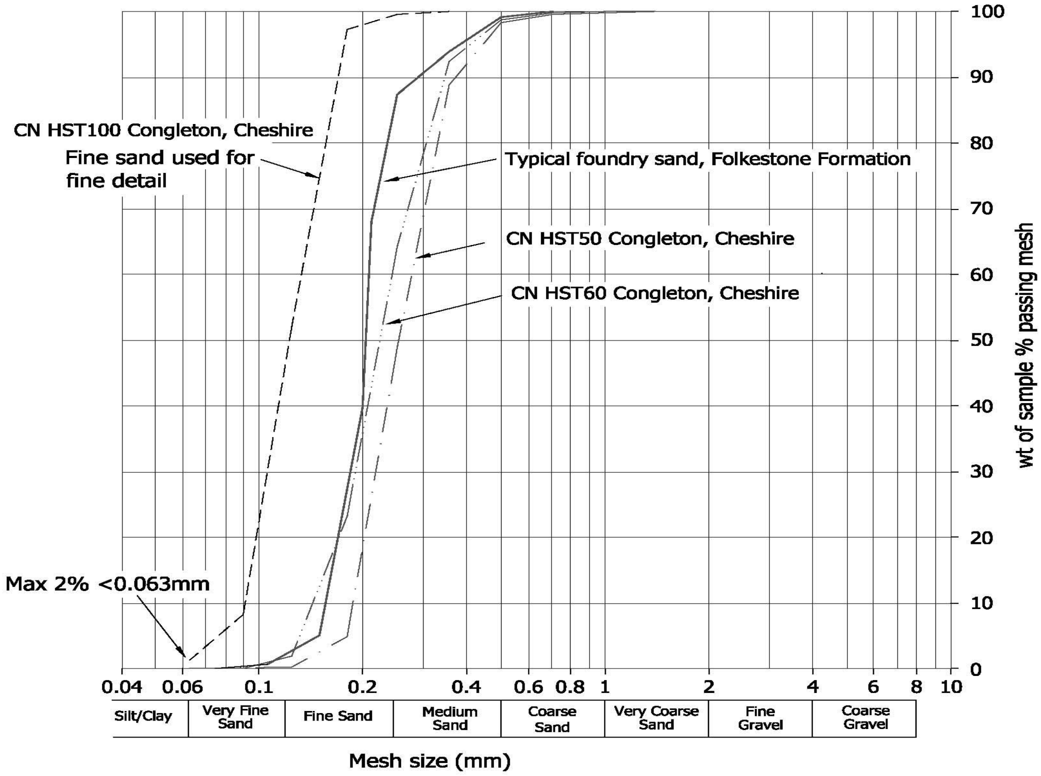


Figure 6. Grading curve of three grades of moulding sand from Congleton and a typical foundry sand from the Folkestone Formation

The grading of the sand will depend on the application, however the grade of sand used is usually a compromise between a good surface finish, the binder requirement and sometimes cost. Sands will typically have the following grading characteristics (The Foundryman's Handbook, 11^{th} ed);

AFS	50-60
AGS	220-250 microns
Maximum fines content	2%
Maximum Clay content (<20 microns)	0.5%
Size spread	95% on 4 or 5 screens

Chemistry and composition

The chemical composition is an indicator of the refractoriness of the sand. The Foundryman's Handbook (11 ed.) specifies the following limits on the chemistry of the sand:

SiO_2	95-96%	minimum
LOI	0.5% max	linked to presence of organics
Fe_2O_3	0.3% max	iron reduces the refractoriness of the sand
CaO	0.2% max	affects the acid demand (binder systems)
Na_2O+K_2O	0.5% max	reduces refractoriness
Acid demand to pH 4	6ml max	affects use of acid catalyst in binders

Chelford Sand used for greensand and resin bound sand typically has the following composition:

SiO_2 97.1%, Fe_2O_3 0.1%, Al_2O_3 1.6%, K_2O 0.73%, Na_2O 0.15%, CaO 0.10%

The composition of the sand can affect the catalyst requirement of cold-setting acid catalysed binders. Acid catalysts may be absorbed by alkali minerals, including carbonate shell fragments and sands with acid demands greater than 10-15ml are not suitable for use with acid catalysed binders.

Recycling foundry waste sand (foundry sand)

It is standard practice to reuse moulding and core making sands, especially those used in the greensand process. In use, the sand becomes contaminated with traces of metal and its physical and chemical properties gradually deteriorate, so residual sand is routinely screened before being returned to the system for reuse. As the sands are repeatedly used, the particles eventually become too fine for the moulding process and the "spent" sand must be replaced with fresh sand. This "spent sand" is typically black in colour, and contains a large amount of fines. It is either disposed of to landfill or, increasingly, used as a recycled material for which there is now a large secondary market. Various end uses for foundry sand and potential recycling routes have been investigated by WRAP and others including hot rolled asphalt, concrete block making, cement manufacture, brick manufacture, aircrete, road base construction and roof felting.

The UK foundry industry is estimated to use and dispose of, over one million tonnes of waste foundry sand per year (distinct from the silica sand raw material), with most of this coming from the Midlands and South and West Yorkshire. Some larger foundries reject over 1000 tonnes per month. Foundries actively seek markets for their foundry sand in order to minimise the cost of disposal and to ensure that solutions other than landfill, which is now costly, are possible. At many foundries space for foundry sand storage on site is limited and, depending on production, quantities of generated waste may exceed the volume of storage facilities. Small foundries, such as many of those in the southeast of England, do not usually produce enough spent sand to develop a market and the cost of landfilling this sand can be considerable.

4.2.4. *Summary and supply in SE England*

1. The typical requirements for a sand used for greensand or chemically bonded moulds are:

    - SiO_2 >95-96%;
    - Fe_2O_3 < 0.3%;
    - CaO <0.2%;
    - AGS 0.22-0.25mm;
    - AFS 50-60 depending on application;
    - Sub rounded to sub angular grain shape, or more rounded in chemically bonded moulds.

2. In practice foundries develop systems and mixes which suit the application and budget. Chemically bonded and oil bonded sand can use much finer sand than traditional greensand and are used to produce fine detail in the casts.

3. Silica sand used for foundry purposes is usually washed and supplied dry. For resin coating, the sand may be supplied within a specified temperature range or the setting time in the foundry plant may be affected.

4. The silica content required is lower than pre-processed glass sand and consequently sand for foundry use may be produced from higher iron sand at the same sites as glass sand. Typical grain sizes are slightly finer than for glass sand and the two end uses do not appear to overlap in their specifications.

5. Sand suitable for the foundry industry is widely available from many of the silica sand producers. Two sites in Kent, Aylesford and Wrotham, sell dried sand to foundries. North Park Quarry in Surrey sends sand to Double Arches in Bedfordshire to be dried and sold as part of the Sibelco product range. Other sites in Kent undoubtedly have sand that would be suitable for this end-use, but do not have the processing plant to produce the correct grain size distribution and dry the sand.

6. Sites in Bedfordshire, Cheshire, Norfolk, Yorkshire, Nottinghamshire and Scotland also produce moulding sand.

4.3 Aircrete

4.3.1. *Aircrete (AAC) manufacture in UK*

Aircrete blocks are produced by five companies in the UK: Tarmac (Topbloc), Hanson Building Materials (Thermalite), H+H Celcon, Quinn (Quinn Lite) in Fermanagh, Northern Ireland and Thomas Armstrong (Airtec) at Catterick in North Yorkshire. In 2007 aerated concrete accounted for 30% of all concrete blocks produced in the UK (dense concrete blocks accounted for 41% and the remainder were made with lightweight aggregate - source statistics.gov.uk).

Manufacturing Process:

Autoclaved aerated concrete (AAC or aircrete) is a widely used lightweight construction material characterised by a low density cellular texture generated by chemical reaction during the manufacturing process. There are two basic recipes for aircrete:

- Cement, lime and pulverised fuel ash (PFA)
- Cement, lime and fine silica sand (usually milled to a fine grain size)

Fine silica sand and PFA are sources of reactive silica. Non-milled silica sand may be added to give additional density to the block and is reported to increase the strength of the reaction.

The raw materials are mixed with water to form a slurry which is poured into large steel tanks. Aluminium powder is added last causing an exothermic reaction, reacting with alkalis to create bubbles of hydrogen gas forming the aerated structure. The mixture rises to fill the tanks and sets to a firm consistency which can be cut. Blocks are cut into the desired size using wire cutters and cured by steam under pressure at 180^o to 200^o in large autoclaves. The curing converts the raw materials into a stable crystalline mineral structure (Tobermorite) with 60-85% of air by volume.

The raw material mix used affects the density and strength of the product and can be changed to suit the application. The overall characteristics of the blocks compared to concrete blocks include good water resistance (pores are not interconnected), resistance to frost damage and sulphate attack, low density, ease of handling and cutting, good thermal insulation, potentially high content of waste or recycled material, ease of handling and cutting.

Sand used for aircrete blocks is exempt from the aggregates levy as it is chemically incorporated into the product.

4.3.2. *Specification of sand raw material*

Technical and quality experts of major manufacturers were contacted for details of their manufacturing process and requirements for silica sand. The specifications for silica sand where sand represents the main source of reactive silica is more stringent than for non-reactive silica forming a minor component.

Iron

Enquiries made of aircrete producers and the findings of the literature review suggest that there is no data regarding any adverse chemical effects of iron. Iron oxide may be more undesirable in light coloured products such as Tarmac Toplite.

Oates (1998) considered Fe_2O_3 to be inert in the manufacturing process. However, if sand is a major raw material, variability in its composition will affect the proportion of active components and cause reduced consistency in the product. The presence of inert compounds may also prevent complete reaction by shielding reactive components. A major manufacturer specifies a maximum of 1% Fe_2O_3 in sand with actual values between 0.2 and 0.5% from sand with an overall SiO_2 of 98%. The price of raw materials, particularly between washed and unwashed sand, was given as an important factor in using some lower grade sand. One manufacturer reported that sand with *c* 4% Fe_2O_3 was trialled unsuccessfully.

Clay

Clay has a considerable detrimental effect on the progress of the reaction. Two major manufacturers quoted different maximum silt/clay content of 1% and 5% in milled (reactive) silica. Clay content increases the water demand during milling and increases the processing costs.

Chemical composition -

One manufacturer has provided the following specification for chemical properties of silica sand:

- SiO_2 > 90%
- Sulphate and sulphide each < 1%
- Alkalis expressed as Na_2O <0.3%
- Chloride <0.5%
- Cr <0.0005%

- Organic material <1%
- Montmorillonite and illite <1%. Up to 2% kaolinite can be tolerated.

4.3.3. Aircrete production in Southern England

Aircrete manufacturing plants are located at Linford in Essex (Tarmac Topbloc), Borough Green (H+H Celcon) and Grays in Essex (Hanson Thermalite).

All three companies were contacted for details of raw materials and manufacturing processes. Hanson Thermalite uses PFA as a source of reactive silica and has no requirement for silica sand. Tarmac (Topbloc) produces different ranges of product including light coloured blocks with no PFA content. The silica content is supplied by sand sourced from quarries in Kent. Celcon H+H in Borough Green uses predominantly PFA from Kingsnorth and Tilbury power stations and includes only about 5% or less of unmilled silica sand in the feed. Higher strength blocks are produced by increasing the proportion of cement in the mix. It was the opinion of Celcon that the sand quality currently used was not critical to the process. The site uses an estimated 100,000tpa of PFA, the principal benefits of PFA are:

- No additional milling costs.
- Cheaper raw material.
- Use of a waste product – more environmentally friendly than using primary aggregates.
- Currently sufficient supplies are available.

The factory at Borough Green is capable of replacing the PFA with sand if problems arise with supply of PFA. From the experience of other manufacturers sand used as the main source of silica needs to have Fe_2O_3 less than 1% and preferably less than 0.5%. Undoubtedly sand from a number of sites in Kent would meet these levels both processed and unprocessed. The level of clay in the sand may limit the use of unwashed sand from some sites.

4.3.4. Summary

1. Sand from Kent supplies 2 major aircrete manufacturers in the Southern England.
2. Sand performs two principal roles in aircrete each requiring different quality specifications.
3. Tighter compositional specifications apply for reactive silica – requiring sand with low iron and clay content. Specifications are not as rigorous as for glass sand but washed sand with low clay content is needed, particularly if the sand is milled.
4. There is little available information on the tolerances of the aircrete process to increased impurities in non-reactive silica– in particular Fe_2O_3 – in raw materials.
5. Grading has not been identified as an important consideration. Reactive silica is generally milled.
6. Sand having a low iron content, from sites where there is no washing plant are likely to be suitable for processing to provide an adequate quality of non-reactive silica sand. Clay and iron content (in fines) may be unacceptably high for milling without washing. For cost reasons, one aircrete manufacturer prefers to use unwashed sand from Kent instead of washed sand, however the fines content of the unwashed sand used in this way is low.
7. Raw material combinations are very different from one manufacturer to another and sand that is used by one manufacturer may not be suitable in a different process or mix.

4.4 Water filtration and treatment

4.4.1. Sand filtration systems

Water treatment is an important but relatively low volume consumer of silica sand in the UK. Sand filtration is used in public water supply and waste water treatment, water supply and environmental monitoring boreholes, industrial water treatment, swimming pool filtration systems, aquaria and aquaculture. Replacement materials, such as Advanced Filtration Media AFM, made from recycled glass are beginning to directly challenge the market for silica sand. Entec estimated that in 2003 the market for filter media in the UK was some 40,000-60,000t for rapid gravity and pressure filtration systems which comprised *c* 80% of installations.

Sand filtration in water treatment is usually used in combination with other filtration and purification systems such as carbon adsorbtion, sedimentation, flocculation, coagulation, disinfection and biological methods. Sand filtration is often the final stage of treatment before water is released. There are three principal methods, slow sand filtration, rapid sand filtration and continuous sand filtration.

Slow sand filters are non-pressurised systems which have been typically used for municipal waste water treatment. The filter medium consists of a bed of fine sand supported on a bed of gravel and coarser sand layers. As waste water lying above the filter percolates downwards, a layer comprising algae, bacteria, fungi and other organisms develops in the top few millimetres of the filter. Dissolved organic material and particles are trapped by this layer and in the underlying sand by both physical and biological processes. When the filtration medium becomes clogged, the surface is scraped off and a new organic layer forms, until a minimum depth of filter is reached, at which time new sand is applied.

Rapid filtration allows more flexible flows and uses coarser grain sizes allowing faster flow rates. Water flow through the filter media is effected either downward by gravitational force or by pumping under pressure. The advantages of rapid filtration are greater throughput and a smaller filter surface area. The higher flow rates prevent an organic layer from forming and filtration is not as efficient as the slow filter system.

Continuous filtration is a more recent development in which the dirty water or effluent is introduced at the base with filtration taking place upwards. Dirty sand at the base is continually taken out, cleaned and replaced at the top while cleaned water leaves from an overflow.

4.4.2. Specification of sand filter media

The sand filter layer may be a single grading throughout or multilayered. The choice of filtration medium depends on the application, the type and quality of the water to be treated, the throughput required, the quality of water to be achieved, the space available and the processing cost. Filter media used for treatment of drinking water must meet basic specifications for composition and grading set out in BS EN 12904:2005.

Grading and grain size

BS EN 12904:2005 sets out the parameters used to specify a silica sand or gravel used in treatment of water for drinking. Filter sand is specified in two ways:

- by the effective size d_{10}, the uniformity coefficient U with maximum 1.5, and the minimum size d_1 (see Appendix 4); or
- by the particle size range and mass fraction of oversize and under size particles. The maximum total proportion of oversize and undersize varies depending on the application – 5% in multimedia filters, 10% in single media filters and 15% in support layers.

Filter sands are generally tightly graded medium to coarse sands. Slow filtration uses a finer grain size than rapid filtration with typical effective size of 0.15-0.35mm and uniformity coefficients of l.8-3.0. Rapid sand filters typically have an effective size greater than 0.55mm and uniformity coefficient less than 1.5. Filter sand is usually sold by reference to the BS mesh sizes:

BS Grades	Size Range (mm)	Effective size d_{10} (mm)
16/30	0.50 - 1.10	0.54 - 0.71
14/25	0.60 - 1.20	0.63 - 0.85
10/18	0.85 - 1.70	.
8/16	1.00 - 2.00	1.05 - 1.27
6/14	1.20 - 2.80	.
6/10	1.70 - 2.80	.
5/8	2.00 - 3.35	2.00 - 2.70

Figure 7 shows a series of Leighton Buzzard sands suitable for rapid filtration systems and a finer grained slow filtration sand (Handbook of Filtration Media 2002). A coarse sand product from the hindered settlement classification plant at one of the main silica sand sites in the Folkestone Formation is shown for comparison. The effective size of the sample from the Folkestone Formation is *c* 0.3mm, too fine for a rapid filter media.

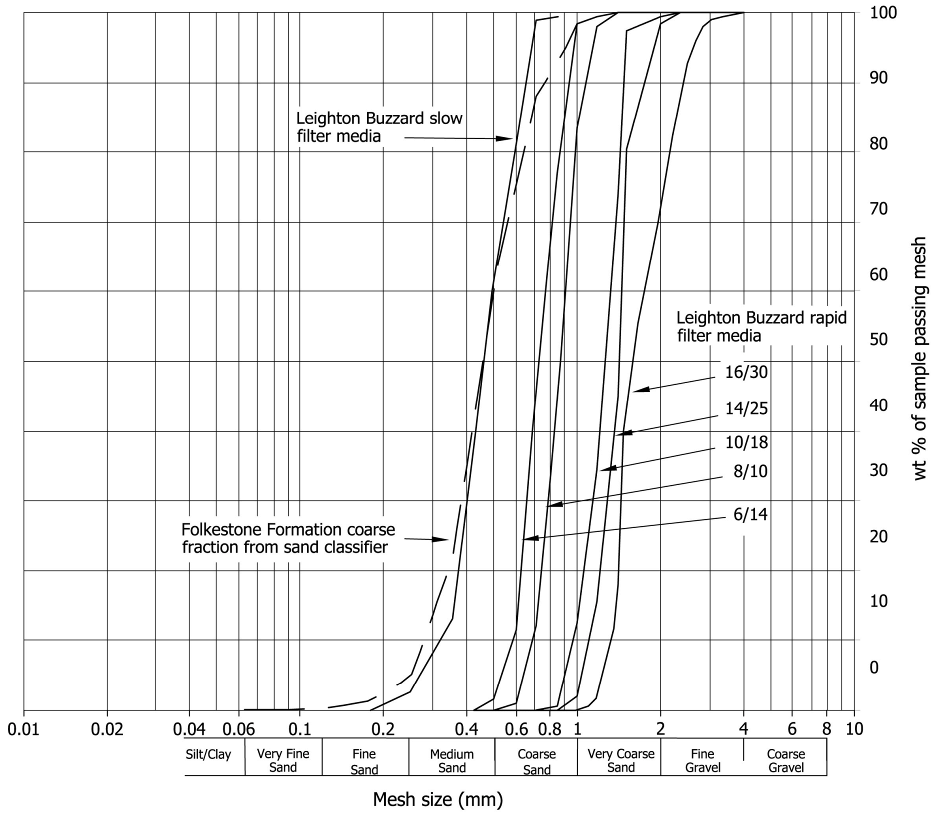


Figure 7. Typical grading curves of filtration sands

Grain shape

The main source of filtration sand in the UK is Leighton Buzzard, traditionally favoured because of the rounded grain shape in the Cretaceous Woburn Formation. Grain shape affects the way the sand particles settle into the filter bed, the proportion of pore space and therefore the performance of the filter. The sphericity of the Leighton Buzzard sands illustrated in Figure 7 is 0.85 (where a sphere is 1.0).

Chemistry

BS EN 12904:2005 sets out minimum purity requirements for silica sand or gravel used in treatment of water for drinking. Three types of filter media are identified in BS EN 12904:2005 which should be referred to for full details. Some of the typical values for the different types of media are set out below.

Type 1	minimum 96% SiO_2, maximum acid soluble material 2%, less than 2% Fe_2O_3 and other limits on Al_2O_3, CaO, K_2O and Na_2O.
Type 2	minimum 80% SiO_2, maximum acid soluble material 2%, less than 10% Fe_2O_3 and other limits on Al_2O_3, CaO, K_2O and Na_2O.
Type 3 d_{10}<2mm	minimum 80% SiO_2, maximum acid soluble material 5%, less than 2% Fe_2O_3 and other limits on Al_2O_3, CaO, K_2O and Na_2O.
Type 3 d_{10}>2mm	minimum 80% SiO_2, maximum acid soluble material 10%, less than 2% Fe_2O_3 and other limits on Al_2O_3, CaO, K_2O and Na_2O.

Typical chemistry of filter sand marketed by PFL Water Filtration Media are shown below:

	Filter sand
SiO_2	97.0-99.8%
Fe_2O_3	1.0-1.5%
Al_2O_3	0.5%
K_2O	0.02%
LOI	0.05%
Acid solubility	1%

4.4.3. *Sources and Alternatives*

The principal sources of filter sand in the UK are the Woburn Sands of the Leighton Buzzard area and Martells Quarry at Ardleigh in Essex. The Woburn Sands naturally contain coarser units than the Folkestone Formation. Washing and classification produces a range of products at the coarse end of the grain size with narrow overlapping grading.

The Folkestone Formation is generally too fine grained to produce the popular gradings for filter media. A small quantity of coarser sand may be available from time to time as a by-product of glass sand production but with an effective size too fine for rapid filter media. The grain shape is not as rounded as that from the Woburn sands or from Martells Quarry in Essex.

The limited distribution of suitable sand means that reuse of sand and use of recycled products should be maximised to extend the life of the natural filter sand resource. New products made from recycled glass, such as Active Filtration Media (AFM) from Dryden Aqua, are being developed and tested. Early evidence suggests that AFM can replace sand in filters for swimming pools, water treatment plants *etc* and in water treatment filters. Research is continuing into the efficacy of recycled sand and other materials for these uses.

4.4.4. *Summary*

1. Particle size is critical to the performance of filter media. Production of filter media requires suitable processing facilities to wash and grade sand.

2. Most filtration systems require a narrow coarser grading than can be supplied from the sites in Surrey and Kent. Coarser gradings represent only a small proportion of

production, usually as a by-product of processing of high grade (glass grade) production from which the >0.5mm fraction is excluded.

3. The trend in Europe and probably also in the UK is towards recycled glass filtration media which have been shown in some tests to have a superior performance in water treatment than silica sand.

4.5 Chemical Industry

Silica sand is one of the basic raw materials for the production of a huge range of silica based products and underpins other chemical and manufacturing industry in the UK. Sodium silicates are a versatile range of soluble compounds, produced from soda ash and silica sand, marketed as glassy clear or powdered solids or as liquid. They are used in the production of soaps, detergents, adhesives, foundry moulds, corrosion control and metal repair, zeolites, glaze and enamels. Silica gel is a highly pure, porous solid made by acidifying sodium silicates and is used for its desiccant and absorbtion properties in the food and cosmetic industries and in cat litter. Precipitated silica, formed from silica gel is widely used in plastic and rubber to increase tensile strength to improve hardness, abrasive and tear resistance. A major market is in fuel efficient tyres which are now standard in the EU. Precipitated silica acts as a thickener and rheological agent to improve flow in a wide variety of products including cosmetic lotions, paints, coatings and adhesives.

The two main manufacturers of Na-silicates have been contacted of which PQ in Warrington, formerly part of Ineos, is the largest, employing 300 personnel directly. The chemistry of the raw materials is critical to the production process at the PQ plant. If alumina (Al_2O_3) is present to a significant degree in the raw materials, insoluble Al silicates are formed. This causes very serious operational problems with the filtration system and may lead to a complete process shutdown. The most important specification of silica sand feed for the process is a maximum of 0.1% Al_2O_3 (100ppm). Limits are also placed on other trace metals and alkalis.

The PQ Plant Manager has reported that considerable effort has gone into testing sands from other UK and overseas sources for suitability in the manufacturing process, including sand from Cheshire and from the now closed Lochaline Mine in Scotland. High grade sand from Belgium is used at significantly greater expense for production of low-iron silicates for electronic applications. However for the main Na-silicate production only sand from North Park Quarry and Park Pit Quarry in Surrey meet the specifications and performance required. *It is the opinion of the PQ Plant Manager that using sand imported from Belgium or elsewhere will increase costs of production to such a degree that it would no longer be competitive with manufacturing plants (including other PQ plants) in Europe and elsewhere where the transport costs are lower.* For a competitive manufacturing industry it is also important to be able to source raw materials from more than one supplier. PQ in Warrington is supplied by both Hanson and Sibelco from their sites in Surrey.

A second Na-silicate manufacturer supplied the following information about their specifications for raw materials:

- Maximum total Al, Fe, Mg and Ca oxides should be 0.3% in the Na-silicate, of which solids make up 45%.
- The final product is white and must have less than 150ppm Fe_2O_3, therefore the main requirement for the silica sand is a very low iron content. One sand supplied has a declared iron content of 0.05% Fe_2O_3.
- In the process a low alumina in the raw materials not so critical since alumina is added to produce the end product, however the maximum total oxide specified for the Na-silicate must not be exceeded.
- The silica sand must be damp with about 5% moisture to suppress dust (PQ also require a maximum moisture content of 6%.

It was also emphasised that this manufacturer *only uses silica sand from Surrey*, this being the only source of acceptable sand. The silica sand supplied to the chemical industry undergoes the same processing at the quarry as glass sand using selectively excavated sand of equal or slightly lower purity than for clear container 'flint' glass.

4.6 Ceramics

Finely milled Silica is a major component of both the body and glaze of most ceramics including sanitary ware, tableware and tiles. Silica reduces shrinkage on drying and firing and affects the strength, rigidity and porosity. Silica sand when calcined (heat treated) is converted to cristobalite, which is a higher temperature, whiter form of silica more suitable for use in ceramics materials and glazes. The Coefficient of thermal expansion is 4 times greater than quartz in the temperature range from 20°C to 300°. The low expansion and contraction of crystobalite helps to stabilise the glaze.

Typically sand should have a silica content above 97.5%, <0.55% Al_2O_3 and <0.2 Fe_2O_3. The chemistry and colour requirement of the raw material will depend on the products and the highest grade silica sand (glass grade) is used for many applications. Sand used in the manufacture of glazed products may have higher iron contents if opaque glazes are used, for example in wall tiles.

4.7 Brick manufacture and other uses in the construction industry

Bricks are produced by mixing ground clay with water, forming the clay into the desired shape followed by drying and firing. The mineralogy of clays used for brick manufacture in the UK is highly variable and processes are adopted which best suit the raw materials available. The behaviour of clay during forming, firing and cooling is controlled by the composition of the raw materials and the proportion of the main mineral components quartz, kaolinite, montmorillonite and micas in addition to subsidiary and minor components. Some clays, including London Clay and Gault Clay, experience a high shrinkage rate on drying before firing. To counteract this, sand is added as a low shrinkage dilutant. Recycled material may be added but with implications for the appearance of the final brick. Weald Clay and Wadhurst Clay are the main brick clays now used in Kent and Surrey. These have a naturally high free silica content and sand addition is not generally needed. Gault Clay and London Clay are no longer used significantly in brick production. Brickearth, a wind blown Pleistocene deposit naturally high in silica, was used to produce the distinctive yellow bricks seen throughout London. A small production of these 'London Stock' bricks remains in Kent.

Sand is also used to provide bulk to the brick body. The grain size distribution of sand will affect the degree of bulking, while the colour of the sand will affect the colour of the final brick. Building sand may be used in manufacture of red bricks. Industry sources have indicated that consistency of colour and grading, and security of adequate supply is vital for quality control and to maintain reasonable colour matching of bricks over time. As-dug sand washed or unwashed sand rather than blended sand tends to provide a more reliable and consistent raw material, avoiding the consequences of changing processing plant.

The most common method of production is by extrusion in which homogenised plastic clay is extruded through a die to produce a column of clay. This is then cut up to the desired size before drying and firing. Alternatively bricks may be formed using moulds either as part of an automated process or for hand made bricks. Sand is used to coat the interior of the mould box facilitating the release of the brick and giving the surface a desirable texture.

Facing bricks make up the greatest proportion of bricks produced in the UK. They are produced with a wide range of colours and surface textures to give a building its aesthetic appearance. Typically facing sand is mixed with a colourant or with a glass flux which lowers the melting temperature of the sand so it can bond to the brick surface. The colour of the sand and its behaviour on firing will affect the appearance of the bricks. Light coloured washed sand from Surrey and Kent quarries with a high proportion of medium to coarse sand such as GS5 from North Park Quarry have been used. A significant iron content will result in a coloured surface. Consistency is vital in the large scale automated manufacturing process.

Calcium silicate bricks are made from sand and lime with sufficient water to enable the mix to be moulded and then hardened by exposure to steam under pressure. Hydrated calcium silicate is formed from the sand and lime and creates a very strong and permanent bond. Calcium silicate bricks are made from 90% sand. Coloured sand will produce different coloured brick – white sand (high silica) is needed for a light coloured brick. Pigments may also be added. Calcium silicate bricks are no longer produced in the south of England.

Kiln dried silica sand is commonly used for dry sand jointing for flexible block pavements, when small element pavers are used and where mortar jointing is not required for decorative pavements and patios. The function of the sand is to provide a strong interlocking joint between the pavers. Sand must be dry to flow correctly when brushed into joints. The grading should conform to BS7533:Part 3 with 85-99% passing 1mm mesh, 55-100% passing 0.5mm and less than 2% fines (<0.063mm). Sand will normally be washed to achieve this specification. Light coloured sand is preferred for the aesthetic appearance but not necessary. Some colour matching with the paving may also be desirable. Water penetration of the joints can lead to erosion of the laying course and failure of the pavement. The sand may be treated with liquid polymer to give a more impermeable but still flexible surface.

Light coloured sand is also used in the manufacture of artificial stone for architectural and ornamental products where matching to natural stone is often required. Silica sand is used as part of proprietary damp proof membrane systems such as Hydraseal.

Light coloured or white sand may be used before or after processing to match historical sand/lime mortars in restoration projects.

4.8 Coatings, fillers, plastics, rubber and adhesive industries

Quartz and cristobalite forms of silica produced as silica flour are used widely in paints, plastics polymer compounds, rubber, sealants, putty and adhesives as a filler to create bulk and to provide resistance against abrasive actions and chemical attack. For these products the white colour of high grade powdered silica sand gives a high brightness, reflectance, durability and chemical inertness.

Uses of silica flour include:

- an abrasive in gels in the metal finishing industry
- calcium silicate insulation boards
- frits for colours and glazes for the ceramic industry
- filler in resin systems including tile adhesive and silicon rubber
- filler in paint in marine applications
- filler in acid resistant paint
- additive in resin cements for restoration of pier legs, sea defences etc..
- abrasive in brake linings to remove glaze and rust from discs/drums
- filler in artificial roofing slate
- void filler in silica based refractories

Uses of crystobalite flour include:

- Methyl methacrylate (perspex) sinks, etc.. filled with approximately 60% cristobalite flour
- Tile adhesive and grouts
- Paint including paint for white lines.
- Silicon rubber – mouse balls, keyboards etc..
- Resin systems

(source Sibelco – Moneystone Quarry Planning Application June 2006)

Other uses of un-milled silica sand include: thermal grouts for ground source heat pump installations where sand is mixed with bentonite; non-slip flooring, as filler or abrasive in resin and epoxy systems.

It is believed that Sibelco sends sand from North Park Quarry to Moneystone plant for milling and processing for high grade end-uses of silica flour and cristobalite.

Where the use does not require a white colour, silica sand may potentially be substituted by ground recycled glass in many applications.

4.9 Other industrial uses

Food Industry

High purity silica flour is added to food products as an anti caking agent separator. Products such as corn chips are dusted with silica flour to increase their shelf life and prevent adhesion of the chips. Alternatively precipitated SiO_2 is manufactured from sodium silicate and used for the same purpose but with an enhanced level of purity. It is uncertain whether food-grade silica is produced from Surrey or Kent.

Refractory

Silica sand is used to manufacture synthetic mullite ($3Al_2O_3 . 2SiO_2$) which is widely used as a refractory in the steel, glass and ceramics industries. New products are being developed in engineering, coating technology (source CERAM). In the UK, DSF Refractories produces mullite from andalusite (aluminium silicate) and alumina. Silica sand is a major component of refractory bricks used in the ceramics industry. It is uncertain whether sand for these end uses is supplied by Quarries in Kent or Surrey.

Metallurgical

Silica sand is used in the manufacture of ferro silicon, an alloy with a silicon content between 15% and 90%. Ferro silicon is used in the production of carbon and stainless steels. One useful by-product of the production processes is silica fume, which is later added to concrete mixes to improve compressive and bonding strength. The specification of quartz and quartzite provided by the industry manufacturing ferro-silicon is as follows:

Constituent	Ideal content as % of weight
SiO_2	98% minimum
Al_2O_3	1.5% maximum
Fe_2O_3	0.5% maximum
P_2O_5	0.1% maximum

The bulk of the world's production comes from India, China and the USA and the market for UK silica sand in this sector is small.

Oil Industry.

Special grades of silica sand, called fracturing sand, are used by the oil industry. A slurry of suitably sized sand grains is pumped at very high pressures down oil wells to fracture oil bearing strata to improve the flow of oil. Washed and graded high silica quartz sand with a grain size of between 0.84 and 0.42 millimetres and rounded and spherical grain shapes is used. Fracturing sand is not produced in the UK.

5. SAND USED AS NON-CONSTRUCTIONAL AGGREGATE

5.1 Sport surfaces

5.1.1. General

A thorough review of the requirements of sand for sports surfaces has been published by the Sports Turf Research Institute (STRI), and this publication should be consulted for details. A summary of the conclusions pertinent to this report are included here. Sand is used in the construction and maintenance of games pitches (football, rugby, field hockey), golf courses and cricket pitches and golf bunkers. Sand producers in Kent and Surrey (and elsewhere) are using the STRI recommendations to design compliant blends using the published grading envelopes.

The mix design is usually a compromise between good drainage and aeration imparted by a coarser grain size and moisture retention which is favoured by a finer grading.

5.1.2. Winter games pitches

Sand is used in the construction and maintenance of winter games pitches (rugby, football and hockey). Sand dominated root zones provide a porous well drained structure to the soil. The sand prevents loss of permeability on compaction during use and in poor weather thus avoiding subsequent waterlogging of the surface. A winter top dressing of sand is applied to maintain the permeability and drainage and give a firm dry playing surface.

The recommended grading envelope for sand in root zones and top dressing is shown in Figure 8.

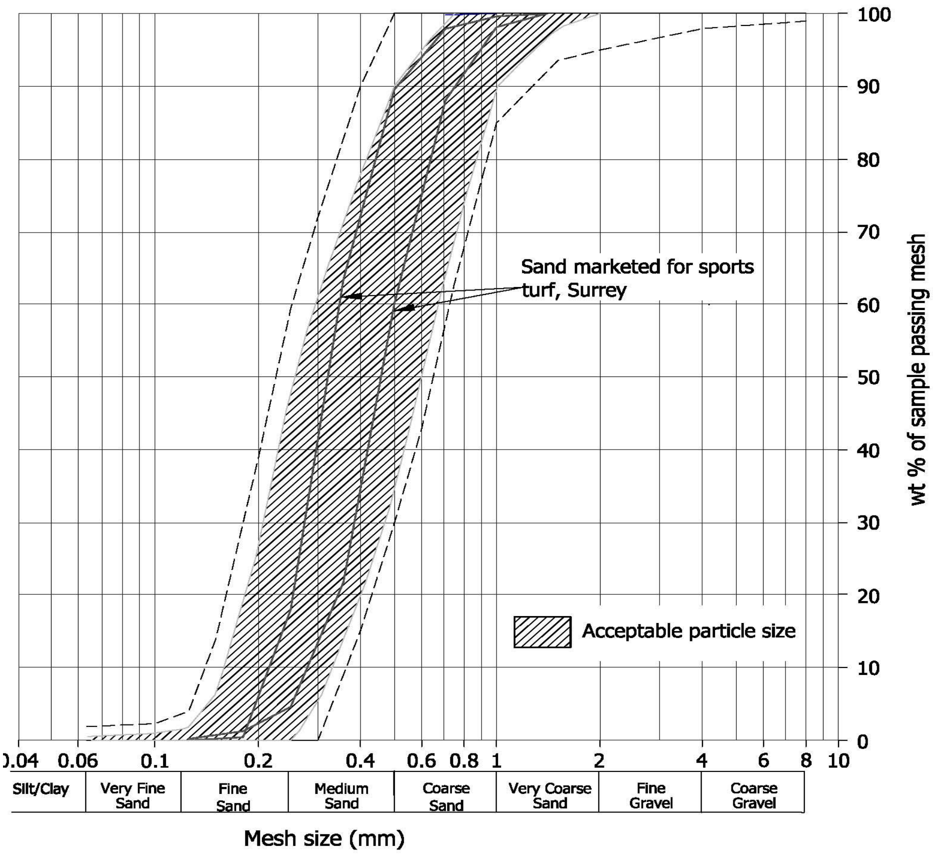


Figure 8. Recommended grading limits for sports turf sand (STRI)

The size range is relatively narrow with grading predominantly between 0.15 and 1.0mm. Ideally the grading curve of the sand should fall within the recommended envelope except when only a light top dressing is applied, in which case the sand should lie on the coarse side of the envelope. Pure sand root zones should be on the finer side of the range to avoid stability problems and excessive drying of the surface.Sands with sub rounded to subangular grains are preferred because they give a better stability to the surface than round grains, while angular sands may suffer excessive compaction and damage turf roots.

Football pitches use between 1,500 and 3,500 tonnes of silica sand in their sub-strata, mainly to provide a firm, water permeable and easily flattened bed for the upper strata of turf. Good quality washed sand is desirable for minimising the proportion of fine and very fine gradings, however it is not necessary to use non-staining sand for this purpose.

5.1.3. Golf and bowling greens

Most golf courses use a root zone mix that conforms to USGA 2004 recommendations which require a minimum of 60% of the mix (including soil or organic material) to be 0.25-1.0mm *i.e.* medium to coarse sand. Up to 20% of the mix should be 0.15-0.25mm. There should be less than 10% very fine sand (0.15mm), silt and clay; and less than 3% 1.0-3.4mm. Ideally none should be greater than 2mm.

On fine lawns a top dressing is applied thinly a number of times to avoid excessive amounts on the surface. If the root zone is sandy, the top dressing should match it as far as possible to maintain continuity. If the ground is in poor condition with excess thatch or poor drainage, the recommendation is to apply larger quantities.

The STRI recommended grading envelope for sand is shown in Figure 9. Sand with high fine content or grain size greater than 2mm should be avoided. Rounded to subangular grain shapes are preferred.

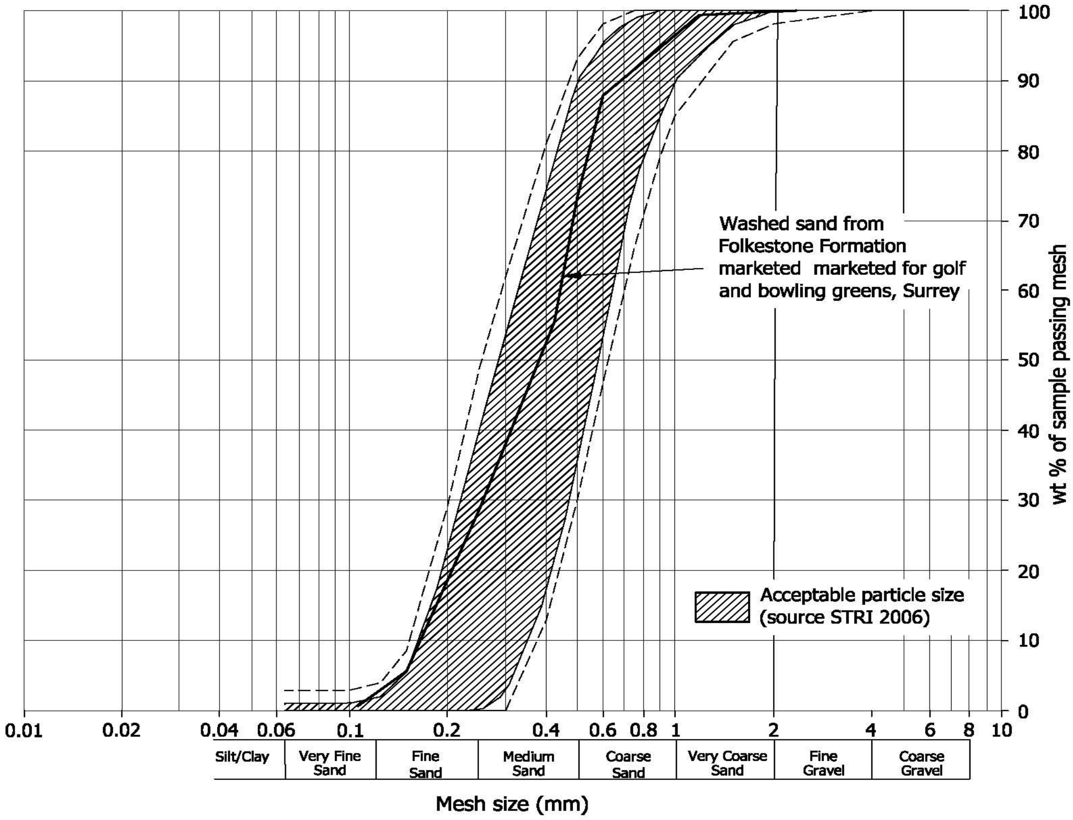


Figure 9. Recommended limit of grading for sand used for golf and bowling greens (STRI).

5.1.4. Golf bunker sand

General recommendations for bunker sand include:

- The sand should be free draining to avoid clogging and water logging.
- Very fine material is likely to be blown around in the wind and should not be used.
- The sand should be compatible with the top dressing in case of chipping onto the surface.
- Fines may cause crusting on the surface increasing maintenance.
- Rounded grains cause a low angle of repose in bunker sand, poor compaction, loose footing and also increase the risk of the ball to plug (be buried on impact). Angular to subangular grains are preferable.
- Light coloured, non-staining bunker sands are generally preferred for aesthetic reasons.

The silt and clay fraction should be less than 3%, The range is very similar to the recommendations for golf and bowling greens, with most of the sand between 0.2mm and 1mm with D50 = 0.3-0.6mm. Golf bunker sand is generally white or off-white. The grading overlaps with, but is generally coarser than glass sand and there is potential for production of bunker sand as a by product of glass sand processing. Bunker sand from North Park Quarry is marketed as RH(Bunker) by Rufford (a Sports and Leisure marketing company owned by Sibelco) and RH30 by Banks Amenity. Cream to light yellow GS5 from Tapwood / Park Pit is marketed by Hanson and others for the same purpose. Not all bunker sand comes from recognised silica sand quarries. Grundon market two bunker sands, a yellow/orange washed sand from Frithend Quarry in Hampshire, and a buff/white sand from Henham Quarry in Suffolk (source Grundon.com).

5.2 Equestrian surfacing

5.2.1. General

Sand is still the most popular surfacing material for arenas, maneges, gallops and race courses, generally in combination with other natural, manufactured or recycled materials. A wide range of surface materials are marketed, in particular at the higher end of the market. Quarries in Kent and Surrey are major suppliers of sand for equestrian surfaces to specialist design and installation companies, wholesalers and private users. Information from the companies contacted indicates that sand from Surrey is extensively used for preparing equestrian surfaces in the South East, other British regions and overseas.

There are no general specifications or recommendations for sand used in equestrian surfacing materials. The principal requirement is to provide a sufficiently firm riding surface. A surface that is too soft (rides deep) may cause strain injuries. However both equine and rider injuries can result from surfaces that are too hard and the surface should provide sufficient cushioning to minimise concussive injuries to horses legs and injury to riders in a fall.

Other factors which are more or less important depending on the nature of use and which are affected by the quality of the sand are:

- Good drainage. This is achieved in the design of the foundation and drainage measures beneath, however clay or silty material in the sand may block drains if the foundation surface design is inadequate.
- The surface should minimise kickback, which results when the sand surface is dislodged by the rotation of the hoof and flies backward. It is a particular concern in racing when sand flies into the faces of horses and riders behind.
- Consistent performance is important as the sand surface tends to deteriorate with time through compaction and breakdown of sand grains. The condition of the beds in

outdoor applications is also dependent on weather. The sand surfaces of indoor facilities need more maintenance to maintain adequate moisture levels.

- Non-staining.
- All weather performance to provide an acceptable surface in all anticipated temperature conditions. Moisture in sand will freeze forming at first 'lumpy' concretions composed of ice and sand and then a completely frozen sand bed dangerous for both horses and riders.
- Cost effectiveness – surface chosen to suit budget
- Durability
- Low dust
- Ease of maintenance

5.2.2. Surface Materials

There has been extensive research leading to a wide variety of materials and surface designs. There are a large number of suppliers marketing a range of sand-based surfacing materials which fall into five general groups:

(i) *Untreated sand*. Untreated sand needs to be watered to maintain the surface, which may freeze in the winter when surface frost needs to be broken up. This sand is susceptible to weather conditions becoming too firm when wet and too soft when dry. Sand drains quickly and dries out causing the surface to soften, which increases the risk of dust formation. It is important to water the surface to keep the surface sufficiently firm and to minimise dust. Over time fines will increase with use as grains abrade. This is likely to be the lowest initial installation cost option if there is a local source of sand but may be a false economy if frequent replacement is required. Also, sand tends to compact over time. A layer of sand greater than 10cm may ride too deep.

(ii) *Untreated sand mixed with fibres, rubber or other recycled material*. These blends mimic turf and stabilise the surface giving a firmer ride compared with sand alone. Fibres or additives such as silica gel may help to maintain the moisture level.

(iii) *Coated sand mixed with fibres, rubber or other recycled material.* This reduces the need for watering

(iv) *Natural materials.* Sometimes wood chips are layered over a bed of sand. Similarly leather offcuts from the shoe industry are used.

(v) *Artificial materials* Rubber may also be used as a covering over sand. Recycled rubber tyres can cause blackening of hoofs.

5.2.3. Installations

All weather race courses and gallops:

There are 5 all weather race tracks in England, four of which (Lingfield, Wolverhampton, Kempton Park and Great Leighs (Essex)) use Polytrack, a wax coated sand supplied by Martin Collins Surfaces and Footings LLC (MCSF) of Lamborne in Berkshire. Southwell in Nottinghamshire uses Fibresand – a mix of clean, washed, uncoated sand and synthetic fibres. The Fibresand is widely reported to give a softer surface ('heavier going') than the Polytrack surface. Similar specifications are needed for gallops and training tracks.

Jumping and Dressage arenas

Frequent high impact use such as competition arenas require well designed installations and generally use high specification surfacing materials. For private use, a lower cost option is often chosen.

5.2.4. *Sand specification*

There are no published recommendations for sand used in equestrian surfaces. Manufacturers and designers of equestrian installations and experts advising the British Horse Society have been consulted. Three factors produce a good equestrian sand:

Grading – fine to very fine sands form a non-abrasive surface that compacts well to form a firm surface. The very fine grain size drains well but compared with coarser sand loses moisture less slowly in dry weather conditions. It is recommended that the silt and clay fraction below 0.063mm is negligible to maintain permeability and prevent waterlogging. Fines can also block drainage below the surface. Sand which is used for coated products should have low fines which will ball up in the coating process, use more wax and may produce a substandard product. In order to reduce the fines, equestrian sand is usually washed. Some manufacturers of coated product need dry sand from the quarry – only Wrotham and Aylesford currently have drying plants in Kent and Surrey.

Grain shape – angular to subangular grains with a low sphericity are favoured and provide a good compaction. Rounded sand grains are not recommended. Sand with rounded grains forms a softer surface than an equivalent graded sand with angular grains. The importance of the grain shape decreases with grain size. The Folkestone Formation typically comprises sands with subangular to subrounded grains.

Colour – Light coloured sand is usually required by users. Staining of horses' hooves by the sand surface is undesirable, particularly in shows and competitions. Staining is usually caused by iron oxide dust abraded from the coating of sand grains. This will also add to dust and fines problems and is undesirable.

5.2.5. *Sources of Equestrian Sand*

The quality of sand marketed as equestrian sand in Kent and Surrey is very variable and reflects the range of end-users, from high specification competition surfaces through to private arenas. Nationwide suppliers of high specification sand-based surfacing for the top level show jumping and dressage market and the major all-weather racing tracks have been contacted about the specifications and sources of supply of sand. Experts for the British Horse Society have identified the following sites as currently producing suitable quality sand:

- Park Pit / Tapwood and North Park Quarry in Surrey,
- Wrotham in Kent,
- Kings Lynn in Suffolk,
- Congleton in Cheshire,
- Burythorp in Yorkshire and
- Levenseat Quarry in Scotland.

Two quarries in Dorset, Binnegar and Warmwell were also mentioned as producing acceptable quality sand. The Leighton Buzzard silica sands, also from the Cretaceous Lower Greensand are composed of rounded grains, making them unsuitable for top level equestrian events.

Each of the sites in Kent and Surrey works silica sands for industrial purposes and employs washing and classification plant. The two sites in Surrey carry out additional processing to improve sand composition for use in glass manufacturing and other industrial processes. The equestrian sand comprises the finer fractions separated before additional beneficiation and not used in the main industrial sand products. The sands are naturally low in iron and provide desirable colour characteristics. The three quarries mentioned supply the higher end market and are sold at premium prices. The product from North Park Quarry is marketed as RH Fines (moist) by Rufford and a typical grading comprises 53.2% fine sand (0.125-0.25mm) and 39.7% very fine sand (0.063-0.125mm). There is also a market for lower specification sands for less frequently used facilities. These are supplied in part from other quarries where a desirable colour is present but a lack of processing means that grading can only be controlled through selective quarrying and screening.

5.2.6. Summary

1. Equine and rider safety is the highest priority. High end users such as competition arenas, race tracks install high specification surfaces which use the highest quality sand products. Whether the surfacing material is coated or not, the qualities required are angular to sub angular grain shape, grading less than 250 microns with low fines content. Iron cement or coating is undesirable because of colour staining and fines production with use.

2. Washed fine to very fine grained sands are used for the high end market and are recommended by designers and installers for all sand based surfaces.

3. Three sites in Kent and Surrey have been identified by major manufacturers and installers as producing high specification sands, Wrotham, Park Pit / Tapwood and North Park Quarries.

4. Unwashed sands have a significant local market.

5.3 Other Sports and Leisure Sand

5.3.1. Play and Jump Pits

Sand for play areas should conform to BS EN71-Part 3 and BS EN1177:2008. Sand is normally non-staining, preferably with a grain size maximum of 1.25mm and with a high proportion of fine sand. Building sand may cause unacceptable staining. There is no specified grading for playpit sand. Rufford market RH65 from North Park Quarry for play and jump pit sand. The typical grading of this product is 0.7% between 0.5mm-1mm, 41.5% between 0.25mm-0.5mm, and 53.7% between 0.125mm and 0.25mm. A playpit and jump sand marketed by CML has a coarser grading with 27.2% between 0.5-1mm and 55.5% 0.25-0.5mm and 10.5% between 0.25mm-0.15mm.

5.3.2. Synthetic Sports Pitches

Dry sand is used for sand filled and sand dressed artificial sports pitches. The grading used are similar to those preferred for golf course top dressing - that is with grading between 0.25mm and 1.0mm. There is no general specification, although manufacturers of surfaces may recommend a particular quality of sand. Sand is not required to be white, and some colour might be preferable.

Rufford do not market a sand for synthetic surfaces from North Park Quarry – this may be because sand needs to be dry and suitably graded can be sourced more locally to the drying plant at Double Arches near Leighton Buzzard. Dry sand from Chelford is marketed by Rufford for the same purpose. Two sites in Kent, Wrotham and Aylesford have dryers and could produce sand for artificial surfaces. It is not known if sand is sold into this market from either of these sites.

5.4 Horticulture

Horticultural sand is used to improve drainage in compacted and waterlogged lawns, as top dressing to improve heavy clay soils by preventing clay particles sticking together, and as a growing medium. It can also be used as an additive to seed sowing compost. Horticultural sand is sold washed and in general coarser grain sizes will give better drainage. Building sand is not normally suitable because of the retention of the finer grain sizes. The sand may be sold at 5mm, 4mm or 3mm down *etc*.

Horticultural sand does not need to be silica sand, although white sand may be used for aesthetic reasons. As well as being mixed with soils to improve their porosity and drainage sand is used by the industry as a medium for display of plants whereby the soil surface of potted plants is covered with white or coloured sand and also as a drainage medium beneath potted plants being nurtured for sale.

Turf farmers also use sand as a substrate to achieve good drainage and easy separation from the subsoil when lifting the turf for transplanting.

6. SAND PROCESSING

6.1 Overview

The quarry operator aims to optimise the use and value of the sand and minimise waste through use of processing plant appropriate for the nature of the material in the ground, the intended range of end uses and the financial circumstances. Some or all of the following processes may be employed:

- screening to remove oversize and coarser grade;
- washing to remove fines fraction;
- classification of sand to produce the grade ranges;
- physical cleaning of sand particles by attrition;
- removal of contaminants by physical or chemical means.

In quarries producing construction aggregates, sand of the Folkestone Formation may be dry screened and blended to produce a consistent product or washed to reduce the fine fractions for concrete sand. Dry screening may be the only option if there is no consent for washing, if processing water is unavailable or for economic reasons. Processing plant suitable for high grade glass sand production is a multi million pound investment. New plant is unlikely to be installed without the expectation of a significant reserve life, probably in the order of 15 years.

6.2 Washing

Washing plant, usually including one or more hydrocyclones, removes the silt and clay fines at a designed cut off grain size (fines are defined as <0.075mm fraction and may include very fine silica sand). In a hydrocyclone fines rise up the vortex to an overflow and larger grains descend and discharge at the bottom. The capacity of a hydrocyclone is limited by the discharge capacity. High solid loads will increase the viscosity of the discharged slurry and the discharge forms a rope-like stream of thick slurry rather than the desired umbrella-shaped stream. A cluster of hydrocyclones may be used to achieve the required output. Fines may be discharged to a settlement lagoon or filter press for dewatering.

6.3 Classification

Most of the specialist end uses of silica sand require a tighter grain size grading profile than building or concrete sand. However aggregate sites may also classify sand before reblending in order to maintain consistent gradings in the products. There is a wide variety of modern processing plant that will accomplish this to varying degrees of precision and flexibility, but there are three principal techniques which may be used in combination with each other; screening, hydrocyclones and hydrosizers.

Hydrosizers or screens may be used for the 0.5mm maximum grain size cutoff required for glass sand. Hydrosizers are hindered settling devices in which a current of water is introduced to expand the sand slurry into a state of teeter. In the state of teeter, heavier grains move to the bottom where the water velocity is higher and lighter particles move to the top where the water velocity is lower. The hydrosizer produces good grading cut off and fewer fines in the sand than a hydrocyclone. If used in series, a range of well controlled graded sands can be output. The FLOTEX density separator and the Linatex T Classifier are both in use at sites in Surrey and Kent.

6.4 Attrition scrubbing

Attrition scrubbing involves the physical interaction between sand grains in two opposing slurry flows with a solid concentration for maximum particle impact is 70-89%. The power consumption and therefore running costs of this type of system is high. Attrition scrubbing is used to remove coatings from silica grains for high grade end uses such as glass. The removal of the natural coating material will create fines which then are removed through physical or chemical means.

6.5 Removal of contaminants

Contaminants which are not desirable in glass sand include refractory minerals such as chromite and titanium oxides. Iron may be present as individual particles of iron oxides or sulphides, or as staining and surface coating on the sand grains. Free iron particles can be removed by gravity separation, flotation or magnetic separation. Removal of iron staining can be more difficult and is usually accomplished by hot or cold leaching in sulphuric acid. The method is effective but requires expensive chemicals and has environmental implications. An alternative method of removing iron oxide coating in appropriate circumstances is by attrition scrubbing. If contaminant particles are enclosed in sand grains, the iron content may not be reduced sufficiently by further physical or chemical treatment.

Separation of iron oxide and heavy minerals is carried out by gravity separation, froth flotation or increasingly by magnetic separation. Gravity separation by spirals is a widely used and cost effective method of separation of heavy minerals. Slurry, with or without added water, flows down a spiral trough under gravity, causing high density particles to migrate to the centre, where they are removed to a concentrate channel. Several passes are usually necessary to achieve the desired reduction in heavy mineral content..

Froth flotation separation is based on surface chemistry. Additives are used to adhere to the heavy minerals making them hydrophobic. An acid environment ensures that sand grains are not affected. The heavy minerals will stick to air bubbles allowing them to be removed as froth overflow from the flotation tanks. Water is usually neutralised before discharge. Disadvantages are high reagent costs, potential environmental effects of discharging reagents and less control over the process than other methods.

Magnetic separation is seen as a more environmentally friendly separation method. Rare earth magnets have low running costs compared to flotation. Typically two passes are required to reach the target composition, however up to four passes may be required. The method, unlike gravity separation, cannot separate non-magnetic heavy minerals such as rutile (a titanium oxide). The following typical results from magnetic and gravity separation are reported by Outokumpu for silica sands from Europe and America.

(source outokuputechnology.com)	Silica Sand 1 (Europe)	Silica Sand 1 (USA)
Feed % Fe_2O_3	0.085	0.089
Gravity Spirals 1 pass % Fe_2O_3	0.038	0.066
Gravity spirals 2 passes % Fe_2O_3	0.033	0.049
Magnetic separation 5tph/m, at least 2 passes % Fe_2O_3	0.014	0.039

There are two silica sand processing plants in Surrey; Sibelco at North Park Quarry operates a new magnetic separator while Hanson at Tapwood / Park Pit use froth flotation. Both sites are capable of producing flint glass sand at 0.035% Fe_2O_3 or below, depending on the feedstock. Sibelco (WBB) previously operated a froth flotation plant at Homethorpe. When this plant was closed and processing relocated to the North Park Quarry a magnetic separation system was chosen after extensive trial work due to concerns about groundwater protection.

6.6 Drying

Some silica sand and fine aggregate products are delivered dry, this includes most foundry sands and glass sand. Most leisure, sporting and horticultural uses do not require dry sand, with the exception of wax coated equestrian sand. Drying is very expensive and not carried out at all silica sand sites. Some sand from North Park Quarry is sent by road to Leighton Buzzard for drying at another Sibelco site.

6.7 Further processing for specialist use

Ground silica or silica 'flour' is a raw material for the manufacture of ceramics, fillers, fibreglass, refractory bricks. Quartz may be converted to Cristobalite at high temperature in a kiln. Sibelco produce silica flour and ground cristobalite from plant at Moneystone Quarry.

7. GEOLOGY AND NATURE OF THE RAW MATERIAL

7.1 Geology and distribution of active quarries

7.1.1. The Folkestone Formation

Silica sand in Kent and Surrey occurs in the Cretaceous Folkestone Formation, a highly variable sequence of fine, medium and coarse, weakly cemented sand which forms the upper division of the Lower Greensand. Large scale cross bedding is typically evident in most exposures with the very common development of layers iron 'hard pan' or carstone (iron oxide cemented sandstone) and ferruginous veining. The Folkestone Formation is underlain by fine to coarse, argillaceous, glauconitic sands of the Sandgate Formation which are not worked for aggregate but contain Fullers Earth horizons which were extensively worked in the Redhill area. West of Dorking the Bargate Beds form the lowest part of the Sandgate Formation. This is a distinctive fine to medium grained, generally calcareous, buff to brown sand with 'doggers' of calcareous sandstone, the Bargate Stone – a local building stone.

The Folkestone Formation dips northwards in Surrey, swinging round to a north easterly dip east of Sevenoaks The overlying Gault Clay forms a limit to the northern development of excavations in the Folkestone Formation, most notably at North Park Quarry in Surrey and Wrotham Quarry in Kent. The sub crop of the Folkestone Formation and the location of active quarries is shown in Appendix 2.

The Folkestone Formation is widely worked for building sand. The characteristic orange-brown colour is caused by pervasive iron oxide staining or weak cement. Buff, pale yellow to white sand is recorded in active and abandoned quarry workings from Dorking to Ashford, but is particularly well developed between Buckland and Oxted in Surrey and Borough Green and Aylesford in Kent where they have been extensively exploited for silica sand. Historic excavations for glass sand continue east of Maidstone.

7.1.2. Surrey

Between Farnham and Dorking the subcrop of the Folkestone Formation is narrow, dipping up to 30^{o} to the north. Working quarries at Runfold South, Homefield and Albury expose a sequence of large scale cross bedded sands. Sand has been described as typically '*well rounded, well sorted, clean, fine to medium grade with sporadic coarser pebbly developments'*, with medium to coarse grained sands in the highest beds (Lake and Shephard –Thorn 1985). Ferruginous sandstone is common. No silica sand is produced from this area where the quarries are principally selling building sand. In 1972 white sands were exposed in Mears Pit and Redland's Pit , Runfold. This sand was formerly worked for foundry use but was considered too impure and clay rich at that time for modern quality requirements. Currrent exposures of white sand are not known, however communications with the producer has indicated that cruuently only construction sand is being produced.

West of Reigate white, low iron sands occur in the lower part of the Folkestone Formation and are worked for silica sand at Tapwood Quarry and formerly at Park Pit. 1.5km west of Park Pit quarry, the white sands are absent at Reigate Road Quarry and in the Common Field extension to the south. East of Reigate the upper part of the Folkestone Formation has been very intensively worked for silica sand, most recently by Sibelco (WBB) at Mercers East Quarry (now restored). The lower part of the Folkestone Formation in this area has been identified as a source of building sand (Preferred Area P) in the emerging Surrey Mineral and Waste Development Framework (MWDF). Preliminary chemical testing for the owner of the adjacent Chilmead Farm, suggests that the sand present may also be suitable for industrial uses.

East of the M23, silica sand is worked in North Park Quarry where highest grade white sands developed in the upper part of the Formation, with higher iron sand below. The silica sands are extensively 'veined' with ironstone. Eastwards the lithologies are variable with brown ferruginous sands predominating but with white sand horizons locally such as at Moorhouse Pit.

7.1.3. Kent

Near Brasted white sandstone, about 10m thick, was worked in underground galleries. The 1969 memoir records a variable sequence of white, pink, buff, brown and orange sands in a pit near Ightham. The first substantial thickness of white sand recorded going east from Sevenoaks is at Borough Green where *c* 8m of white cross bedded sand are described in the memoir. Boreholes drilled through the Gault Clay south of the M26 in the Nepicar area identified 16m of orange and brown sands above 18m of light yellow fine grained sand with over 60% below 125 microns.

From Wrotham Quarry eastwards the presence of white sands is more consistent. Buff and brown cross bedded sand overlies white sand at Wrotham Quarry and Ryarsh Quarry (closed). West of Maidstone at Aylesford the thickness of the Folkestone Beds is *c* 55m. The 1963 geological memoir describes yellowy white, fine grained sand with occasional ironstone lying below iron-rich sandstone with lenticular ironstone. Fine white sands occurred at a deeper level.

Sand was worked for glass manufacturing at Aylesford from the 17^{th} century through to the early 20^{th} century, after which it produced building sand and sand for the foundry industry. Wrotham Quarry (formerly Olley's Pit) was formerly worked for coloured glass sand. The BGS Memoir records a series of surface and underground workings of white sand eastwards from Maidstone where steeper dips are related to monoclinal folding and associated faulting. At Newnham Court Farm immediately north of Maidstone 35' (10.7m) of white sand dipping 10^{o} was worked at the surface and underground. Near Birling House also on the northern edge of Maidstone 40' of sand was exposed of which the lowest bed seen was fine grained white sand, overlain by *c* 10m of cross-bedded, sometimes 'gritty' or 'pebbly'white and yellow sand with lenticular ironstone developed to the top. Glass sand was worked here, the underground excavations have partly collapsed. East of Bearsted Church glass sand was also worked partly underground in caves. At Hollingbourne the glass sand was too deep to quarry from the surface and 'hard white sand' was mined underground from horizontal adits going into the hillside often from quarries (source Kent Underground Research Group). Boswell (1917) gives the following description of sand in caves at Bearstead and Hollingbourne, ' the sands are similar in character to those of the same age at Aylesford, Godstone and Reigate ...' chemical analysis of the cream coloured sand showed 0.04% Fe_2O_3 and 0.31% Al_2O_3.

The geological memoir records white sands in numerous small disused quarries east of Hollingbourne. At Hothfield Common near Ashford, white, fine grained sand was recorded in a small outcrop. At Lenham, east of Charing, fine to medium grained sands with common iron staining and iron pan are worked by Brett Aggregates for construction sand. The memoir records very fine grained, almost white sands in overgrown quarries at Lenham Heath. At Charing Quarry, an active site operated by The Brett Group, fine to medium white to pale yellow sand is worked for building and asphalt sand. The Folkestone Formation is *c* 50m thick in this area.

Eastwards from Ashford there is little mention of white or light coloured sand in the Geological Memoir. The Folkestone Formation thins to c 18m at Folkestone where it comprises coarse-grained, yellowish sand with occasional bands of glauconitic sand. A borehole at Westwell, between Ashford and Charing, intersected 'fine to medium-grained greenish grey sand with glauconitic grains and some mica' with 'medium to coarse pebbly sand to the base, in total *c* 36m thick.

There are few active quarries east of Maidstone where there may be potential for investigating the resources of sand for specialist applications in the Folkestone Formation.

7.2 Characteristics of the Folkestone Formation

The principal characteristics of the sand that affect the end use potential are grain size and particle size distribution (grading), silica content, proportion of silt and clay, the amount of iron oxide cement or coating on the sand grains and grain shape. These will control secondary properties such as of porosity, permeability, coating requirements, processing costs, aesthetic value and chemical purity of the products.

Very little systematic information is publicly available on the properties and characteristics of the sands of Folkestone Formation. The sands are a highly variable sequence of fine, medium and coarse poorly cemented ferruginous sands. The amount of iron coating and cement determines the colour of the sand. Work by Richards and Barton on a limited number of non-representative samples concluded that clay mineral and iron oxide cement may form up to 10% of the *in situ* sand. Cement was present in all samples including those taken from the high grade 'silver sands' at Reigate. Under the microscope, *in situ* sand grains are interlocking and interpenetrating and long straight and concave-convex grain boundaries are found in the loose grains. This results in a variable grain shape from well rounded to angular. The same work identified detrital grains of iron oxides and glauconite with no or trace feldspar (aluminium silicate).

No operators have provided as dug grading analyses of silica sands and it is not possible to systematically compare construction sand grading with silica sand. Figure 10 shows the grading envelope for as dug building sand from a site in Surrey. The site produces no silica sand. Typical building sand from other sites including Wrotham fall within or close to the same envelope. Fine silica sand is known to occur at depth from Nepicar to Aylesford and possibly beyond. The quality of this sand is not known, however the Memoir records fine sand was worked for glass in the bottom of Aylesford Quarry up to the 1970s. Figure 10 shows the grading envelope of two horizons of silica sand from boreholes in the Ightham-Nepicar area. A large proportion of the fine sand would fall below the 0.125mm cut off grain size for glass sand.

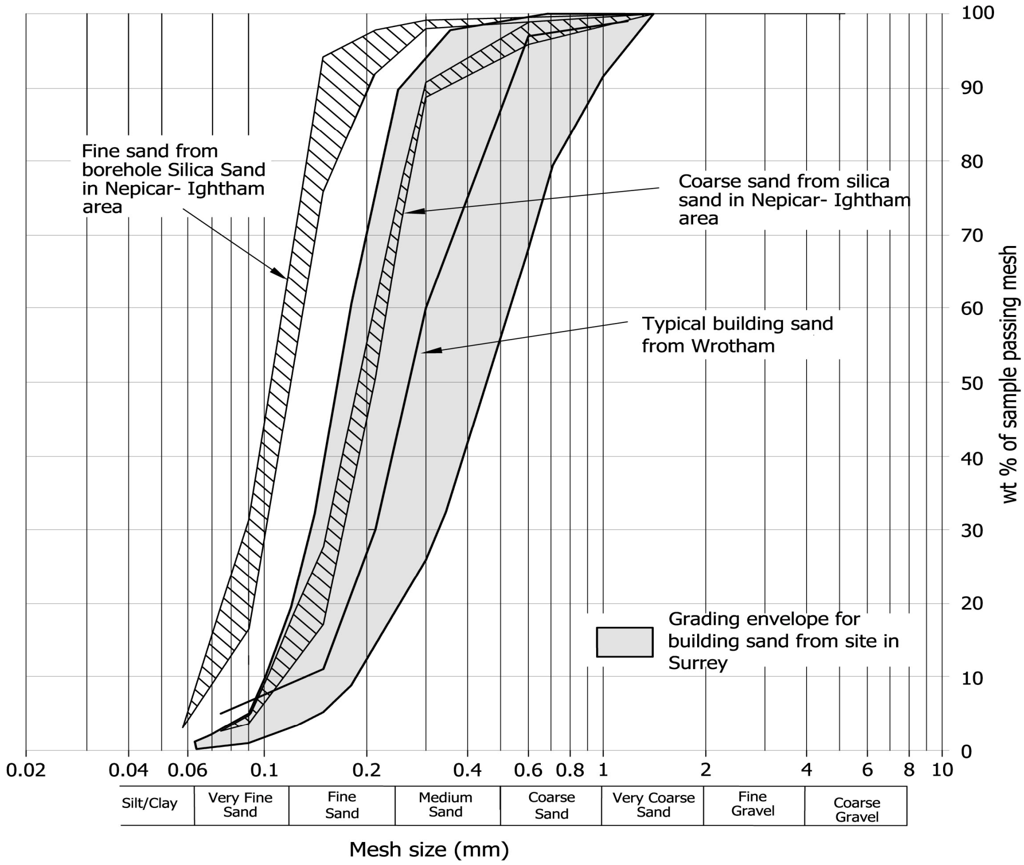


Figure 10. Grading envelope for building sand and silica sand.

8. PRODUCTION AND MARKETS IN KENT AND SURREY

8.1 Output of sand from the Folkestone Formation in Kent and Surrey

End uses for the sand of the Folkestone Formation can be divided into three broad groups:

- Construction aggregates – concrete, plastering and mortar sand, asphalt sand, granular bulk fill forming the bulk of the production from Surrey and Kent. End use determined by grading.
- Non construction aggregates – including leisure, sport and horticultural uses. Grading, colour and non-staining characteristics important to end uses.
- Industrial sand – used in industrial or manufacturing processes. End use depends of composition, consistency and grading.

Operators of quarries in the Folkestone Formation in Kent and Surrey were asked to provide production information based on these three categories. A further breakdown by by-product group was not possible due to the confidential nature of the information.

Currently there are 14 quarries in the Folkestone Formation in Kent and Surrey of which all except Tapwood Quarry produce construction aggregate. In 8 of these sites, construction aggregates comprise all or the major part of production. At Wrotham, Aylesford, Nepicar, Tapwood and North Park Quarry sand for industrial use forms most or all of the production.

Information has been supplied for all sites except Homefield, Runfold South and Albury. which between them supply a limited amount of construction aggregates. For the sites for which information was received, a total of *c* 1.63Mt of sand is excavated annually from the

Folkestone Formation, of which approximately 61% is reported to be sold as construction aggregates, 23% for industrial uses and 16% for non-construction aggregates. The latter, including the leisure, sport and horticulture markets, accounted for approximately 40% of the total non-construction production. These figures are generally in line with the PA1007 monitoring statistics for the southeast region (see Section 3.1). Active sites in Kent and Surrey are listed below.

Quarry	Operator	Processing	Product
Kent			
Addington (Wrotham) Sand Pit	Hanson	washing, classification, drying	Construction sand, industrial, non-construction aggregate
Aylesford Sand Pit	CEMEX	washing, classification, drying	Construction sand, industrial sand
Nepicar Farm	J J Clubb	dry screening	industrial, construction, non-construction
Borough Green Sand Pit	Borough Green Sandpits Ltd	dry screening	Construction sand, (non construction aggregate)
Greatness farm (Sevenoaks)	Tarmac	Washed and unwashed product	Construction sand, non construction aggregate, industrial
Lenham Quarry (Shepherds Farm)	Brett Group	dry screening	Construction sand (minor non construction aggregate)
Charing Quarry	Brett Group	dry screening	Construction sand
Surrey			
Tapwood/Park Pit	Hanson	screen, classification, froth flotation	Industrial, non construction aggregates
North Park Quarry	Sibelco	screen, classification, magnetic separation	Industrial, non construction aggregates, Construction sand
Reigate Road	J J Franks	dry screening	Construction sand
Moorhouse Sandpit	Titsey Estates	washed, dry screened and as-dug products	Construction sand, industrial, non construction
Homefield	Chambers Runfold	dry screening	Construction sand
Runfold South	SITA	dry screening	Construction sand
Albury Sandpit	SITA	dry screening	Construction sand

The main industrial sand uses are in the glass, chemical, foundry and aircrete industries. Significant industrial plants supplied by silica sand from the region include the O-I container glass works in Harlow, Essex – the only major glass plant in southern England, and a major aircrete manufacturing plant.

The low aluminium content of sand from the Folkestone Formation makes it a particularly valuable resource for the production of Sodium silicates.

Non construction aggregates are produced from some sites as a secondary product of building sand excavation, or as a by-product of processing industrial sand. Quarries are important and nationally significant for the production of equestrian sand, sand for sports and leisure purposes – exporting to other regions and occasionally overseas. Both silica sand and non-silica sand are used for horticultural processes. Sites to a greater or lesser degree, depending on the processing plant available, are able to design products with 'custom' characteristics and thus create niche markets in response to market trends and specifications.

8.2 North Park Quarry and Pendell Farm

8.2.1. Background

North Park Quarry, operated by Sibelco, works high grade silica sands west of Oxted in Surrey. Sibelco proposed an area of possible future silica sand resources in open farmland between North Park Quarry and the M23. An area of approximately 96ha has been identified by Surrey County Council for inclusion as a preferred site (Pendell Farm) for future silica sand extraction in the Surrey Mineral and Waste Development Framework (MWDF). At the time of writing Sibelco, the operator of North Park Quarry, is preparing a Planning Application for part of the identified area, much of which lies within the Surrey Hills AONB. Due to land ownership issues, the proposed area of excavation lies approximately 750m west of the limit of current quarry workings.

8.2.2. Geology

The Folkestone Formation dips northwards and is overlain by Gault Clay in the northern part of the site. The highest grade, lowest iron flint and colourless glass sand lies in the upper part of the Folkestone Formation below the Gault Clay. The greatest recoverable thickness of this sand is therefore on the northern, down dip side of quarry where the depth of working may in some locations be limited not by the geology but by the level of the water table. It is understood that Sibelco propose only to work above the water table in Pendell Farm.

The northern extent of excavation is limited by the thickness of clay which increases rapidly northwards towards the M25 Motorway due to a steepening dip and rising topography. A stable long term slope in Gault Clay is *c.* 9-11^{o} (1 in 5h to 1 in 6h) without engineered solutions. Consequently a 20m high un-buttressed Gault Clay slope requires a width of at least 100m (or more if the topography is rising). Sand with a higher iron content lie below the high grade sand and are worked on the southern (up dip) side of North Park Quarry.

Geological investigations by Sibelco (and seen by GWP) show that the proposed Pendell extension area has similar geology to the current site with low iron sands present across the area but possibly with a lower percentage of the higher iron sands due to the position of the site in relation to the Folkestone Formation outcrop.

8.2.3. Sand quality

In North Park Quarry the high grade sand is not homogeneous and control of the grade of sand going to the processing plant is maintained through frequent face sampling and chemical analyses. Sand with different iron contents are stockpiled separately and may be blended with other sand depending on the product required. Small variations in the chemistry of the sand may change the end grade of sand that can be produced. In order to retain flexibility several faces may be worked at anyone time.

Average chemical analyses of sand from boreholes (1m samples) indicates Fe_2O_3 (iron content is the principal indicator of quality) between 0.05 and 0.08% in both the current permitted area and in the proposed extension area. Higher iron sands occur at or south of the proposed excavation limit. Chromium values are also consistently low, below 0.001%. The Surrey silica sand quarries are reported by the BGS to be 'unusual in having a low alumina contents (<0.1% Al_2O_3) making then suitable for the manufacture of sodium silicates' (BGS Mineral Planning Factsheet). Analyses of washed but otherwise unprocessed sand from North Park Quarry and seen by GWP show consistently very low alumina values, typically 0.09% and generally less than 0.2%Al_2O_3. Alumina is probably contained within clay or feldspar grains. Washing will remove most of the clay particles, but feldspar has both a density and grain size similar to that of quartz and is not easily separated by processing. In comparison typical analyses from Leziate (Kings Lynn) and Moneystone quarries have 0.65% Al_2O_3, and from Messingham has 1.6-2.4% Al_2O_3 (source CDS Consultants).

8.2.4. Processing and products

The aim of processing is to produce consistent products with the grading and composition suitable for the intended end uses.

Sand from the Folkestone Formation comprises quartz grains with a variable amount of iron staining and iron cement. This has a number of detrimental affects depending on the intended end use, principally:

- the coating and cement breaks up on handing and use producing staining iron oxide fines;
- the iron content of the sand is too high for use in high specification products, and
- the colour is not acceptable.

As dug sand will rarely have a suitable grading or chemistry to be used directly for glass production in an automated modern manufacturing process. Sand needs to be processed to produce a consistent product with the correct grading and to reduce the content of impurities.

Grading analyses of washed sand supplied by Sibelco indicate that the coarse and fine size cuts from hydrosizing may comprise up to 25-30% of the washed low iron sand with the consequence that sand with a grading suitable for glass manufacture may form *c* 63-68% of the total volume of low iron sand dug from the ground. The proportion is a function of the relationship between the natural sand grading and customer requirements.
The range of coarser and finer by-products of the processing for glass sands generally have found uses in a wide range of market sectors including a strong demand for horticulture, leisure sport and equestrian sands. There is a small market for playpit sands with a similar grading to glass sands but may not have a suitable chemical composition. The production of this type of product from North Park Quarry is not known but it is likely to be only a small volume. A simplified flow chart illustrating the processing at North Park Quarry is shown below.

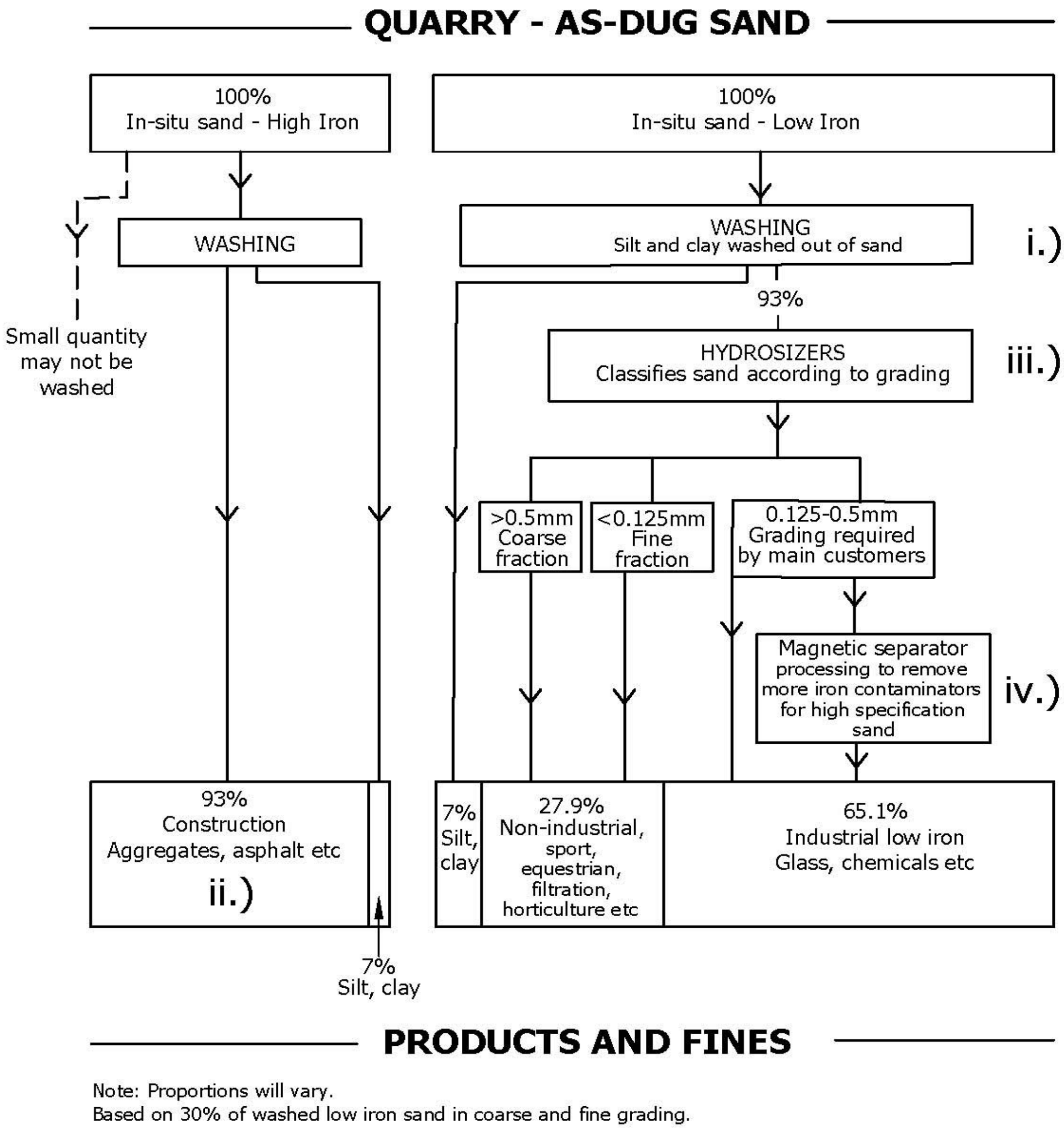


Figure 11. Simplified diagram representing stages of processing at North Park Quarry

(i) Almost all sand is washed to remove the clay content which may form 10% or more of the as-dug sand (typical 7%). The clay is dewatered and used in restoration.

(ii) Washed high iron sand is sold for asphalt or construction use and represents approximately 30% of production. These may contain oversize or undersize fractions from glass sand production. Sand may also be used for soil blending.

(iii) Washed low iron sand is screened to separate grains larger than 1mm then pumped as a slurry to density separators (hydrosizers) in which the sand grains are classified by size. Sizing is set to give gradings of the main product of between 0.5mm and 0.125mm. Coarse and fine sand grades are produced as by-products of the classification. These have limited use in industrial processes as they rarely meet the grading requirement. The proportion of the feed which is suitable for glass sand after sizing depends on the grading of the feed. However the products from hydrosizing are of a consistent grading. The chemistry of the sand at North Park Quarry is such that the sand may be suitable for coloured container glass without further processing.

(iv) Further reduction in iron contamination is carried out by passing the sand slurry through a high intensity magnetic separator. At North Park Quarry the relationship between the feed chemistry and the product is very well controlled. The typical reduction in iron content after processing for different product grades is shown in the following table.

Product	**Typical feed Fe_2O_3 %**	**Typical product Fe_2O_3 %**
Coloured glass	0.13%	0.09-0.1%
Na silicate	0.08%	0.05%
Float glass	0.075%	0.04-0.05%
Colourless container glass	0.06%	0.035%

8.2.5. Sand Resource

In 2007 WBB Minerals supplied borehole locations and thicknesses of 'industrial' (low iron) and 'non-industrial' (high iron) sand at each borehole location. Based on this information, GWP have estimated that some 6.4Mt of industrial sand and 2.5Mt of non-industrial may be recoverable from the area identified by Sibelco between North Park Quarry and the M23. Of this some 2.95Mt of industrial and 0.65Mt of non industrial sand was estimated to be recoverable from the area of the pending Planning Application. These quantities are subject to the design of quarry slopes, minimum working levels, geological modelling based on detailed borehole information, assessment of quality, waste *etc*.

By reference to Figure 11 and 8.2.4 above it can be seen that some 65% of low iron sand, an estimated *c* 4.18Mt in the whole Preferred Area, might constitute sand which is further treated by magnetic separator for the glass, chemical and other specialist industrial processes. The remainder, some 2.25Mt, represents finer and coarser fractions separated during processing and which have a variety of uses as non-construction aggregate in the sport, leisure and horticulture in addition to industrial uses such as filtration sand.

The resource estimates should be reassessed in the light of design and geological information provided by Sibelco in the pending Planning Application documents.

8.2.6. Markets

The processed sand is high in silica and low in iron and other impurities making it an ideal raw material for glass manufacture. A proportion of the sand has iron contents low enough after processing to make colourless container glass (flint). North Park Quarry is one of only 4 quarries in England that has the raw chemistry and processing capabilities to produce flint glass sand. Park Pit in Surrey is nearing completion with no identified extension area and Moneystone Quarry will close at the end of 2010. The other site (Sibelco's King's Lynn Quarry) is understood to have around 10 years of permitted reserves of glass sand). Scottish Quarries, including Sibelco's Levenseat Quarry also produce flint glass sand.

Low alumina is required in silica sand used by the sodium silicate industry and is a characteristic of North Park Quarry and Hanson's Park Pit Quarry. Sand from this area is transported to the main customers in the NW of England and elsewhere in the UK.

North Park Quarry currently provides a significant proportion of silica sand for both the float glass and flint and coloured container glass industry in addition to other industrial and non-industrial uses. Future quarry closures mean that production of colourless container glass sand in England may be concentrated in only two main sites – Kings Lynn and North Park Quarry.

The North Park Quarry plant capacity is *c* 500,000-600,000tpa which is expected to be reached after 2010 when Moneystone Quarry closes.

8.2.7. Other potential resources of silica sand

An area of *c* 12.7ha between Nutfield Marsh and Chilmead Farm south of the former Mercers Farm East silica sand quarry, has been identified by SCC as a Silica Sand Search Area. Samples from 6 boreholes drilled in 2006 were tested by Sibelco and shown to be a 'high quality silica deposit', *ie* suitable for industrial purposes. Sibelco have indicated that the sand is a high quality silica sand comparable to that found at their North Park Quarry. Preliminary assessment of the site by GWP, based on limited data, suggests that the site might have a resource of between 1.4 and 2.5Mt. The quantity of recoverable sand is subject to environmental, geological, quality and market assessments. No estimate of silica or specialist sand resources has been supplied by the owner or by Sibelco.

To the east of Chilmead Farm lies the Mercers Farm Preferred Area P which occupies *c* 37ha of open fields between the M23 motorway and Nutfield Marsh. The site has been proposed for aggregate production, however part of the resource is likely to be of similar quality to the adjacent Chilmead Site. It is understood that the potential yield of silica sand or other specialist sand from Mercers Farm has not yet been assessed by the owner or by Sibelco.

8.3 Park Pit/Tapwood Quarry

8.3.1. Geology and production

Hanson currently produces silica sand from Tapwood Quarry north of the A25 and east of Buckland Village. Sand is piped under the road to the processing plant at Park Pit Quarry. Park Pit, now exhausted, worked sand from the lower part of the Folkestone Formation. The sequence was described in the 1988 planning application for extension of working to Tapwood.

- Gault Clay
- Upper sands suitable for building and construction uses
- Silty clay up to 10m thick
- Clean medium to coarse, white to pale yellow silica sand becoming finer and more iron rich with depth
- Sandgate Beds

At Park Pit Quarry the upper part of the lower sand was worked for silica sand for the glass industry while the lower less pure sands produced foundry, asphalt and construction sands. The high grade horizon continues into Tapwood Quarry where currently only silica sand is produced. The consented maximum annual production rate of the Park Pit plant is 180,000t. The actual annual rate of production and the quantities of different products produced is confidential.

8.3.2. Processing and products

The sand is screened in the quarry before being pumped as a slurry to a Flotex hydrosizer. Coarse sand greater than 0.25mm and fine fractions less than 0.125mm are separated to leave a tightly graded main product between 0.125 and 0.25mm. Hanson advise that the sand is selectively excavated in the quarry to produce the products of different purity.

A number of different sand grades are marketed. GS1 and GS2 are main products that are chemically treated to lower iron content suitable for glass sand and the chemical industry, GS2 being slightly higher in iron. Hanson report that feed with 0.06-0.07% Fe_2O_3 can be processed to 0.03% suitable for flint glass and feed with 0.1% Fe_2O_3 can be reduced to 0.05% Fe_2O_3 suitable for the chemical industry. This suggests a slightly greater efficiency than the current processing plant at North Park Quarry operated by Sibelco. Hanson also advise that the sand at Tapwood is low in alumina a key requirement for the production of sodium silicates.

GS5 is a coarse grained 0.25-2mm by-product of the production of GS1 and GS2 suitable for a variety of sport, leisure and horticulture uses. The grading is also suitable for filtration media. Washed fines also represent the fine by-product of production of GS1 and GS2 and, like GS5, the quantity produced depends on the production of the main high grade products.

Sand excavated and not of high enough purity to produce GS1 or GS2 on processing is graded to produce a range of products for the leisure and sports industry. Hanson have developed a number blended and graded sands to comply with various specifications for sports sands and for niche markets through consultation with end users.

Under the 1999 Planning Consent, restoration for both Tapwood and Park Pit Quarries is due by June 2010. However, Hanson comment that available reserves in Tapwood indicate that a further time extension may be required in order to fully exhaust them. Hanson submitted a potential extension to Park Pit into the fields east of Shag Brook for inclusion in the Surrey Mineral and Waste Development Framework (MWDF). The site was included as PMZ60 in the *Assessment of potential mineral zones for extraction of sand and gravel in Surrey* from SCC in 2004 and SSPMZ3 in the document *Surrey Minerals Plan Preferred Option Silica Sand April 2008.*

The geology is inferred to be similar to that in Park Pit *i.e.* silica sands overlying lower grade foundry, asphalt and construction sand, however detailed geological assessment has not been carried out. The site is subject to a range of environmental issues and is not being carried forward as a Preferred Silica sand site by SCC in the MWDF. No other extension to the site has been proposed. The only alternative site currently with processing plant capable of producing sand for clear container glass and for the silicate chemical industry is Sibelco's North Park Quarry and the potential extension into Pendell Farm.

8.4 Aylesford Quarry

Aylesford Quarry has until recently produced both construction sand and silica sand from above and below the water table. The remaining reserves lies almost entirely below the water table and CEMEX have advised that future production will be predominantly silica sand worked by dredger. Sand as raised is, according to CEMEX staff, almost white. The change from construction sand to silica sand at lower levels is believed to be a real change in the nature of the geological horizons. A similar sequence below the Gault Clay is seen at Wrotham Quarry some 6km to the west.

CEMEX have provided examples of grading analyses of as raised silica sand and processed sand. The as dug sand has a tight grading with 94% between 0.5mm and 0.25mm (D50 0.275mm, AGS 0.3mm, AFS 50). Control of grading and quality of feedstock is generally more difficult in below water workings than in dry operations, for example in North Park Quarry and Tapwood, where horizons of different purity sand are selectively excavated. Further analysis is needed to characterise the chemistry and variability of the Aylesford reserve and its potential for high grade end uses.

The plant is a Linatex hindered settling system in which the sand grade produced is controlled by changing the water pressure and therefore the teeter point or cut-off grade between the fine and coarse output. Aylesford has one of only two dryers in the southeast (the other being at Wrotham) allowing the site to supply industrial processes that require dry sand. Total production from the site in 2008 was *c* 190,000t of predominantly construction sand from above water due to development in one particular area of the site and was not typical of production at the site (source CEMEX).

The major end use of silica sand has been for aircrete manufacture in the southeast. Cement additive and foundry sand are also important markets. Subject to analysis of the remaining reserves, a wider market for sand from Aylesford may be identified. Non construction aggregates have formed only a very small part of past production. CEMEX advise that existing markets will be maintained and new opportunities are constantly sought.

8.5 Addington/Wrotham Quarry

8.5.1. Geology and production

Wrotham Quarry (previously also known as Addington) works a shallow dipping sequence comprising *c* 10-12m of building sand above c 10m of cream coloured industrial sand. The site is worked dry and the floor level is constrained by a 3m separation from the water table. The boundary between building and industrial sand is very well defined change in colour accompanied by the development of a discontinuous ironstone horizon. The industrial sand appears more homogeneous than silica sand horizons currently exposed in quarries in Surrey and Kent with little ironstone veining or staining. Selective excavation in the quarry is not necessary to maintain consistent quality.

In 2008, Hanson submitted a Planning Application for a small extension of the working to the northeast giving the industrial sand an extra 3.5 years of life at an expected annual production rate of 72,000t. Planning Permission was granted on 8 June 2009. Proposed rates of construction sand production are slightly higher at *c* 92,000tpa but rates fluctuate significantly from year to year.

8.5.2. Processing

After washing to remove silt, the main product and fine fractions are separated by four Linatex T-separators. A further grading W75 is produced by spreading the fine fraction of the feed sand. The greater proportion of the sand is dried on site for industrial end uses. The sand separation plant is different from North Park Farm and Park Pit, as there is no coarse graded sand within the deposit. Some design of products to customers' specifications is accomplished through blending, but the flexibility of the processing plant is not as great as at the Surrey sites.

8.5.3. Markets

The current markets for dry silica sand from Wrotham include the foundry industry, roofing felt, grouts and sealants. Moist sands of similar grading are sold for top dressing, sport, equestrian and leisure uses. Dry sand is also used for wax-coated equestrian sand. Some very fine sand produced from a distinct part of the quarry is processed without drying for other parts of the leisure and equestrian markets.

Sand is not currently sold for glass or sodium silicate manufacture although Hanson believe that the quality of current products may meet the requirement for coloured container glass without additional beneficiation (acid leaching, magnetic or gravity separation). A chemical analysis of the main W60 product seen by GWP has 99.79% SiO_2, 0.09% Fe_2O_3 and 0.13% Al_2O_3. This is only slightly higher than the typical specification for amber sand provided by a major container glass manufacturer (0.08% Fe_2O_3) and within the range of processed coloured glass sand supplied by Sibelco for North Park Quarry. The grading curve of this product is also similar to typical glass sand.

Further analyses are needed to assess the consistency of the sand and the potential response to further processing. It does not appear that the sand is sufficiently pure to produce flint glass sand, however the target 0.05% Fe_2O_3 for Na silicates may be attainable with further processing (North Park Farm achieves a reduction from 0.08% to 0.05% with additional magnetic separation of impurities). The low alumina content of the sands, as at North Park Quarry and Tapwood, set those sites apart from other silica sand sites elsewhere in the country and is critical for the sodium silicates industry. Further analyses would be needed to prove the consistency of the chemistry and the suitability for Na-silicate production. The single analysis available shows has an alumina content slightly higher than the maximum specified by the manufacturers.

For Hanson, an extension to Wrotham of sufficient reserve life to justify installation of additional processing plant (unavoidably impinging on the AONB) may represent a valuable replacement for some of the customer base currently served by the Park Pit/Tapwood site which is nearing the end of its life. The potential for the sand at Wrotham to supply the same market as Tapwood needs to be assessed.

8.6 Nepicar Quarry

Nepicar Quarry lies c 2km south west of Wrotham/Addington quarry, which is located north of the M20. Immediately west is Borough Green Quarry and some 800m further west is the Celcon Aircrete plant and Ightham Quarry. The site does not have consent to work below the water table or to use water in processing. J J Clubb reported in 1999 that the minimum silica content of silica sand at Nepicar is 98% .

The owners of the site advise that the sand is variable and selective excavation and blending is carried out to produce consistent products. Sand is sold into all three sectors, construction, non-construction aggregates and for industrial purposes. Details of the markets for sand from Nepicar is confidential, however the website of J J Clubb Ltd. offers silica sand for arenas, maneges and exercise paddocks, bunker sand, brick making sand and root zone sand. It is assumed that most of these products come from Nepicar Quarry.

8.7 Borough Green Quarry

At Borough Green Quarry (Borough Green Sandpits Ltd) building sand lies above cream, white and pink silica sand. Currently the site only produces building sand with very little silica sand available in the current excavation. The operators expect further silica sand to be exposed in the northern extension area. The principal markets for the low production of silica sand is for animal bedding, which is preferred by some farmers as a longer lasting alternative to straw, and for horse maneges.

The 2007 planning application identified fine grained white silica sand with low fines content (1.1%) and 100% less than 0.5mm in the extension area. The total estimated tonnage of this material is 50,000t in a total estimated reserve of 736,000t of sand. A similar sequence was found during investigations north of Nepicar Farm as part of the 1996 Application by Rugby Cement to extend the Gault clay workings with deepening into the Folkestone Formation. The site will continue to be worked dry and as such no further silica sand can be released.

8.8 Sevenoaks Quarry

Sevenoaks Quarry, operated by Tarmac, is the easternmost and only active site of a series of large sites between the A224 and M26 from that have quarried the Folkestone Formation sands from above and below the water table. In a recent planning application the following sequence was identified:

1. Gault clay
2. Up to 25.5m of pale brown, silty fine to medium sand with thin coarse sandstone up to 25.5m
3. 10-12m of orange brown, fine to medium sand with layers of sandstone

4. >15m of dark red brown, slightly silty fine sand with occasional sandstone and ironstone lenses

The annual production of *c* 300,000t is mainly for construction aggregate supplying mortar, building and asphalt sand across Kent, Surrey and London. As-dug sand is used for mixing with soils on site for root zone blends and top dressing for sports turf and with imported compost to make soils for restoration projects. No chemical analyses are available, however the upper, lighter coloured divisions recognised on site would probably be suitable for other non-construction uses after washing and processing. The main interest of the parent company in construction aggregates will to a large extent determine the marketing of sand from Sevenoaks Quarry.

8.9 Moorhouse Quarry

Moorhouse sandpit produces a range of grades and colours of sand which the quarry manager advises are not considered to be silica sands. The site is permitted until 2030. Just under half of the production is dry screened sand suitable for building and asphalt sand, the remainder is split approximately equally between washed sand suitable for plastering and rendering, and as-dug sand. Dry screened and washed sand is used in brick and tile manufacture. Both screened and washed sand is blended with soil on site for rootzone, topdressing and soil improvers. Plastering, rendering and asphalt sand is also produced. None of the products have chemical specifications.

8.10 Charing and Lenham Quarries

Charing and Lenham Quarries are both operated by the Brett Group and produce principally construction aggregates for mortar and asphalt. Lenham Quarry was bought from Hanson Aggregates in 2005 at which time reserves were approximately 2Mt with permission until 2025. The production at that time was some 90,000tpa (source Brett press release). The company report that both sites have white strata that supply non-construction aggregates for bunker and equestrian sand. Much of the sand goes to bagging plants and the eventual end-use is not always known. Direct sales of non-construction sand are a very small percentage of the output of the quarries. Sand is dry screened at both quarries and no washing is carried out.

The geology of the two sites is similar although details of quality variations are not available. Brett report that the sand at Charing Quarry is fine to medium grained, white, pale grey to yellow cross bedded sand with local coarser, more iron-stained sand. The coarser sand is used as construction fill or as restoration material. At Lenham, iron staining is not as prevalent as at Charing. Coarser sand is again used as restoration material.

The potential for marketing specialist sand is limited by the processing available and to some extent by the strategic interests of the operating company, the core business of whom is supplying the construction industry. Coarse sand horizons, which are not widely developed in sand quarries in the Folkestone Formation, may have the potential for producing graded sands for specialist uses after washing and for blending with finer sand to increase the range of products. Sand from Lenham and Charing is probably suitable for a range of industrial and non-industrial specialist uses which would require selective excavation, washing and sizing to supply a range of products for high end markets. Chemical analyses of the sand are not available and a detailed investigations would be required before any potential for supplying high grade silica sand can be determined.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Quality requirements of specialist end uses of sand from Surrey and Kent

9.1.1. General

Approximately 1.63Mt of sand from the Folkestone Formation is excavated annually (survey of producers). Of this approximately 61% is building, concreting and asphalt sand or general fill. Of the remainder, 23% is used for industrial manufacturing processes and 16% for other non-construction uses in the sports, leisure, agriculture and horticulture sectors. The suitability of sand for different uses is determined by the quality of the sand in terms of:

- ***chemistry*** – typically the grade is determined by the iron content of the sand in the ground. High grade sand is low in iron (Fe_2O_3).
- ***Grading or grain size distribution*** – the grading of a natural sand may be suitable for a limited range of uses. Washing and sizing greatly increases the possible product range, usually by separating the coarser and finer fractions from the main product. With the exception of clean, white or off-white sand (see below), very fine grained sand is normally suitable for a very limited range of uses.
- ***Colour*** – for some industrial end uses and many sport and leisure uses, off-white or light coloured sand is preferred. Very low iron sands are naturally white or off-white.

The most stringent chemical requirements are for the glass and chemical industries which require levels of iron in the silica sand supplied between 0.1% and 0.035% Fe_2O_3. Natural levels of iron in the highest grades of silica sand in Surrey have to be further reduced by magnetic separation or froth flotation to reach these levels. Sand for the foundry industry, water filtration and aircrete have slightly higher minimum requirements for iron.

An intrinsic property of the sand of the Folkestone Formation is the low content of alumina (Al_2O_3) and other oxides after removal of clay by washing. This is essential in the manufacture of sodium silicates. Silica sand from Surrey is the only sand accepted by the main sodium-silicate manufacturers in the UK.

Some paints, fillers and grouts require a white sand to give a consistent colour, high reflectance or brightness. The grade required for ceramics depends on the enduse and may be as low as that for colourless glass. These processes, with the exception of sand used as a filler aggregate in aircrete, require high purity washed and graded silica sands.

Other industrial processes, most of which supply products for the construction industry, use light coloured sand either washed or with naturally low fines. Sports and leisure sands have grading requirements which are usually met by washing and sizing the sand. A combination of low fines, light colour and non-staining properties are desirable. North Park Quarry and Park Pit supply the high value end of the equestrian sand market with fine, white sand produced as a by-product of glass sand production, however equestrian sand is produced from washed and unwashed sand at other sites in Kent and Surrey.

There is no available chemical information for the typical sands from the Folkestone Formation that are used for construction aggregates, however analyses of washed 'high iron' sand at North Park Quarry provided by Sibelco indicate that iron contents in brown and orange sand between 0.13 and 0.4% Fe_2O_3 may be typical. Building sand from another site, with iron content of 4%, has been unsatisfactorily tested for aircrete manufacture. The chemistry of unwashed and washed sand from the Folkestone Formation is likely to be very variable. In Leighton Buzzard (Bedfordshire), brown iron-rich sand is washed and graded to produce acceptable sand for sports surfaces including artificial turf. It is probable that sand currently quarried as building sand from the Folkestone Formation in Kent and Surrey could be processed in the same way for these markets in which colour may not be a significant consideration.

While some additional processing beyond that currently employed may be able to raise the grade of some 'high iron' sand into the range of iron suitable for coloured glass manufacture, the greatest value in adding further processing (such as attrition scrubbing) is likely to be in increasing the production of the higher grades for colourless glass and chemical raw material.

The importance of chemistry, grading and colour for the main specialist end-uses of sand is summarised in the table below.

Summary of typical quality requirements for specialist sand

		Typical Chemical requirement for processed sand	Typical Range of Grading	Other
INDUSTRIAL				
Glass	Colourless container	<0.035% Fe_2O_3	0.125-0.5mm	No fines (<0.063mm)
	Float Glass	0.04-0.05% Fe_2O_3	0.125-0.5mm	No fines (<0.063mm)
	Coloured container	0.09-0.1% Fe_2O_3	0.125-0.5mm	No fines (<0.063mm)
	Fibreglass (insulating fibre)	<0.3% Fe_2O_3 (varies)	silica flour (varies)	
Sodium silicate		<0.05% Fe_2O_3,<0.1% Al_2O_3	0.125-0.5mm	White , limits on combined oxides (Al, Fe, Mg, Ca)
Foundry moulding sand		<0.3% Fe_2O_3	graded	Dry, <2% fines
Aircrete		>90% SiO_2, <1% Fe_2O_3	NS	Low clay content
Water Filtration		yes - depends on end use	tightly graded	Coarse to very coarse grades
Ceramics (whiteware, tableware, tiles)		>97.5%SiO_2, <0.2% Fe_2O_3	silica flour varies)	White but specifications depend on end products
Fillers, coatings, adhesive, rubber, paint		NS	varies	White, off white colour requirement depends on end use
Facing Bricks - surface		NS	as required	Light colour low iron, light coloured sand for facing bricks
Bricks - body		NS	NS	Composition will affect colour of brick
Dry sand jointing		NS	<1mm	Dry, <2% fines, light colour preferred.
Roofing Felt		NS	NS	Clean, low fines for hard wearing surface
Artificial Stone		NS		Light colour usually required
SPORTS LEISURE HORTICULTURAL				
Bunker Sand		NS	0.2-1.0mm	White /off white non-staining, <3% fines
Sports Pitch top dressing/rootzone		NS	0.15-1.0mm	Low fines
Golf and bowling greens		NS	0.15-1.0mm	Low fines, conform to USGA specifications
Equestrian		NS	0.063-0.25mm	Light colour fine grained, non-staining, low fines
Jump/play sand		NS	varies	Light colour non-staining, low fines
Synthetic sports pitches			0.25-1.0mm	Dry
Soil improvers		NS	NS	No colour requirement, low fines (washed or unwashed)

NS = no specification

9.1.2. *Specialist sand - production of high grade silica sand*

The principal markets for sand from Surrey and Kent that require the highest purity, low iron sands are:

- glass manufacture;
- chemical industry, in particular the manufacture of sodium silicates; and
- silica flour and cristobalite for the ceramics and other industries.

The range of iron content of processed sand currently produced for these uses at two Surrey sites is approximately 0.1% Fe_2O_3 to 0.035% Fe_2O_3. In order to produce sand of the required purity with the existing plant, the initial iron content of the sand quarried must be approximately 0.13%Fe_2O_3 or lower. Sand of this quality is found at North Park Farm and in the proposed extension area at Pendell Farm. Similar quality is also exploited at Tapwood Quarry/Park Pit. The iron content in the product is maintained by:

- Selective excavation, stockpiling and blending of different grades of sand in the quarry;
- washing and hydrosizing to remove silt and clay and some of the heavy minerals; and
- removal of iron-bearing minerals through magnetic separation (North Park Quarry) or froth flotation (Park Pit).

It is possible that sand with slightly higher iron contents could be processed to give the low levels of iron needed and the production of the highest grades could be increased. This would require additional processing plant to that already in use, such as attrition scrubbing which physically removes iron coatings on sand grains. The benefits of increased production of higher grade sand must be balanced against the costs of running such an energy intensive process.

Sand used for glass manufacture requires a narrow grading of particle sizes between 0.125mm and 0.5mm which is obtained through washing and size classification of the sand. In addition to North Park Quarry and Park Pit Quarry, three sites in Kent, Wrotham Quarry, Aylesford Quarry and Sevenoaks Quarry, have processing plant capable of sizing and classifying sand. Two of these sites, Wrotham Quarry and Aylesford Quarry, have a past history of glass sand production. No chemical test results are available and it is not possible to assess the suitability of sand from these sites to supply high grade silica sand for current market requirements.

Wrotham Quarry is worked dry and the consistency and uniformity of the sand is evident in the exposed faces. Aylesford Quarry is now flooded and worked by dredger. Identification of high grade horizons and control of feedstock grade is more complex in wet working. Sevenoaks Quarry principally produces sand for the construction industry. Geological reports seen by GWP have not identified white sand horizons and chemical analyses of the lighter coloured horizons are not available. However it is probable that suitable processing would enable a range of specialist sands to be produced from the site. The main commercial interests of the operators of both Aylesford (Cemex) and Sevenoaks (Tarmac) quarries are in the production of construction aggregates.

Nepicar Quarry is the only other quarry in Kent with a significant reported production and reserve of silica sand. No chemical analyses of the sand are available and the potential as a high grade raw material is unknown. The sand is reported to be variable and to require selective excavation to maintain consistency of the product. The site does not have consent for washing or working below the water table and consequently processing is limited to dry screening.

9.1.3. *Specialist sand for other industrial uses*

A wide variety of industrial and manufacturing processes use silica sand and specialist sands. With the exception of the industries discussed in 9.1.2, these generally have wider tolerances for chemical composition. The principal industrial end uses for sand from Kent and Surrey are:

- foundry moulding sand;
- filtration media (North Park Quarry);
- aircrete;
- brick, floor and roof tile manufacture;
- filler in grouts, sealants, cement-based admixtures;
- ornamental artificial stone; and
- specialist construction aggregate uses (including lime mortar, dry sand jointing)

The market requirements vary depending on the manufacturing process and final product. Silica sand is used for a combination of its light colour and low fines in many processes for which washed sand is usually, but not always, required. Nepicar Quarry has no washing facilities, but a significant proportion of the output goes to industrial uses. Subject to selective excavation, sand from Nepicar is suitable for, among other uses, brick facing and aircrete manufacture.

The foundry industry is still an important market for sand from Surrey and Kent despite the significant contractions of the foundry industry in recent years. The principal requirements are a high silica content for maximum refractoriness, and a suitable grading. Sand is normally supplied to the foundry hot after kiln drying, limiting the market for this application to those sites with drying plant. Both Wrotham and Aylesford Quarries have drying plants and supply foundry sand, while sand from North Park Quarry is transported to another Sibelco site in Bedfordshire for drying. Sand for foundry use is usually washed, however a market for lower cost unwashed silica sands has been identified by foundries supplied by Kent and Surrey Quarries. The recommended maximum iron content for foundry sand is 0.3% Fe_2O_3 (Foundryman's Handbook). It is probable that with washing and perhaps other treatment some sand currently excavated for construction sand could meet these requirements. At North Park Quarry, some sand which does not meet the cut off grade for glass sand is suitable for foundry sand.

Aircrete manufacture is an important market for sites in Kent. Most of the sand supplied is washed, however if the fines content is naturally low, unwashed sand may be preferred because of lower costs. The iron content of the sand is not reported to be important in the manufacturing process – typical iron content of sand supplied to a major manufacturer is 0.2-0.5% Fe_2O_3 with a maximum acceptable value of 1% Fe_2O_3. However coloured sand, when forming a major proportion of the raw materials, may be detrimental to the appearance of the final product. As with most large scale industrial processes, consistency of the raw materials is critical in maintaining quality control. The Celcon block works at Borough Green uses PFA for reactive silica and only a small proportion of sand. Celcon advises that, while sand forms a minor part of the raw materials, the composition and colour is not important and could be supplied by a number of the local quarries. If the manufacturing plant were to convert to using a higher proportion of sand in the mix, the chemistry and variability of the sand may become a more important consideration.

Sand is supplied for the manufacture of facing bricks by several quarries in Kent and Surrey, not all of which are recognised silica sand producers. The colour of the sand affects the colour of the final brick and sand is selected accordingly. A light colour and an ability to withstand abrasion without producing fines is preferred in other specialist products for the construction industry.

9.1.4. *Specialist sand for non-construction aggregates*

Sports and leisure sands need to meet increasingly tightly defined grading specifications to satisfy the high end (high value) market. Sites with washing and classifying plant are able to produce a wide range of consistent products and design products to match requested specifications. There are no specifications for the chemical composition of sand for these uses, however detrimental effects of the iron oxide that forms cement and coatings on the sand grains in the Folkestone Formation include: staining; a tendency to break up on use causing increased dust; drainage problems; and problems in the waxing process for coated equestrian sand products. As a consequence, light coloured sand is preferred. Although naturally light coloured sands are preferentially excavated for these uses, it is likely that more coloured and iron-rich sand may be washed and sized to produce acceptable sand for some end uses such as top dressing, rootzone and artificial sports surfaces.

Both North Park Quarry and Tapwood/Park Pit Quarry sell white sand into the equestrian, sports and leisure markets that are effectively by-products of the high grade silica sand production. The classification plant at both sites is used to separate the fractions lying between 0.125 and 0.5mm as the main product and feed for further processing. The coarser fraction is marketed for leisure, sport, water filtration and horticultural use. The finer fractions have found a niche market for equestrian sand which, to some extent, has become a benchmark quality in the industry. The production of this sand will depend on the production of the main high grade products.

At Tapwood/Park Pit, sand not reaching the feedstock quality for the high grade end use is also graded and blended for the sport and leisure market.

Tight control over grading is not as easily achieved by dry screening and the products are likely to be sold to a slightly different market. In addition to Nepicar Quarry, several sites where construction sand is the principal product dry screen light coloured sand which is sold to the equestrian, horticultural or agricultural market.

These end uses do not require high grade silica sand. However it is probable that some sites have sand which, with processing, would meet the requirements for industrial sand uses. Without the reserve base to justify investment in processing such sand will continue to be produced for lower value uses.

9.2 Surrey

Current processing plants at North Park Quarry and Tapwood/Park Pit Quarry in Surrey require a maximum iron content in the feedstock of 0.13% or lower to produce glass sand. Additional processing may raise this limit slightly. However, the increased value of the product would have to be balanced against the increased processing costs. The main benefit of additional processing is likely to be increasing the proportion of sand suitable for colourless glass production, chemicals and ceramics.

The investment needed to install appropriate processing plant for producing high grade glass sand is considerable and a substantial reserve base would be required. In Surrey, North Park Quarry will have the only processing plant once Hanson's Park Pit plant is closed. A resource of approximately 6Mt of silica sand has been identified by Sibelco between North Park Quarry and the M23 (Pendell Farm) which site investigation has shown is of similar quality to that in the current quarry. This is approximately 10 years production for the current plant at the anticipated increased production rate.

Potential resources have also been identified at Chilmead Farm and, by extrapolation, are inferred to extend into the adjacent Mercers Farm (Preferred Area P in Surrey MWDF), both some distance from the current processing plant. Preliminary summary information suggests that some of the sand present may be suitable for high grade uses once processed. Chilmead Farm represents approximately 2-3 years production at the North Park processing plant. No further areas of search have been identified in this area, which has been heavily worked. Similarly west of Reigate, no further areas for silica sand production are under consideration. West of the Reigate Road Quarry, Betchworth, no occurrences of light coloured sand are recorded in the BGS memoirs and all active quarries produce construction aggregate. There would appear to be no further potential for high grade silica sand production west of Betchworth.

9.3 Kent

In Kent, at least two active quarries have the potential for production of high grade silica sand; Wrotham Quarry and Aylesford Quarry. Both sites require further investigation and chemical analyses to assess whether sand could meet the same market requirements as North Park Quarry and Tapwood/Park Pit in Surrey. Wrotham Quarry has produced sand for coloured glass in the past.

West of Wrotham, the quality of sand appears to be more variable, requiring selective excavation in Nepicar and Borough Green. The quality of sand at Sevenoaks Quarry is also uncertain. Restrictions on working depth at Wrotham and sites to the west may have sterilised higher grade sand, however no chemical analyses are available to identify potential high grade deposits.

At Wrotham, Ryarsh and Aylesford quarries, construction aggregates occur at the top of the Folkestone Formation with silica sand below. Aylesford is not restricted by the water table, and sand in the floor of the pit previously worked for glass sand may be recoverable. A review of the geology, extent and quality of the silica sand in this area is beyond the scope of this report. Historical evidence indicates that glass sand was excavated as far east as Hollingbourne, much of it from underground galleries. Further east, white through pale grey to yellow sands are found at Charing Quarry and there may be potential for additional production of sand for non-construction aggregate or industrial uses in this area.

9.4 Kent and Surrey in the National Context

Alternative sources of silica sand for colourless container glass manufacturing are in Kings Lynn and Scotland. The BGS has identified unexploited resources and the greatest potential for future growth is in Fife and Midlothian in Scotland.

A suitable, comparably priced alternative to silica sand from the Folkestone Formation for the production of sodium silicates in the UK has not been identified by the sodium silicate manufacturers contacted for this study. The requirements may be met by imported sand with possible implications for quality control, cost to the chemical industry and onward customers, as well as potentially threatening the future of sodium silicate production in the UK.

Other industrial, sporting, equestrian and leisure markets are also supplied by silica sand producers elsewhere in the country. In some cases (for example in Leighton Buzzard) washing of sand removes iron impurities sufficiently to market sand for artificial sports surfaces, top dressing and other uses. The grading characteristics and proportion of coarser grain sizes is critical in identifying suitable sand.

9.5 Concluding remarks

Within the Folkestone Formation a wide range of sand products is produced from white through off-white, beige to orange sand horizons. The quality of sand and its suitability for end uses is determined by chemistry (generally iron content), colour and grain size distribution. It is recommended that the general term 'specialist sand' is used to encompass processed or unprocessed sand, including 'silica sand', marketed for a wide range of specialist end uses. These specialist end uses are divided into sand for industrial purposes (including some specialist applications in the construction industry) and sand used as a non-construction aggregate in leisure, sports, agriculture and horticultural applications.

It is suggested that unprocessed sand is only termed 'silica sand' if it is of sufficient purity that it might be processed economically to satisfy the requirements of end uses having demanding compositional and/or colour requirements, which cannot be met from other natural raw materials. These end uses include glass, chemicals, ceramics, foundry moulding sand and water filtration sand. Other uses, which may require white silica sand but have no general chemical specifications include white grouts, mortars and cement. Sport and leisure sand (notably equestrian sand) may be produced as a by product or co-product of high grade silica sand operations but, in general, grading and colour requirements can also be satisfied from processing the more abundant light coloured sand and building sand. Sites that lack processing plant have less flexibility in product range than those with the capability to produce washed and graded sand.

Whether the potential of a silica sand resource can be economically realised will depend on a complex set of factors including the size of the reserve, available processing plant, the practical, economic and environmental feasibility of processing the sand, the market conditions and the strategic interests and requirements of the operating company. Accordingly factors other than the colour, grading and chemistry of the sand may lead to potentially high grade silica sand being excavated and sold for other lower value uses.

Potential for producing high grade silica sand from lower grade sand

The requirements for very high grade, low iron silica sand in the glass, chemical and ceramics industries can only be met where the iron content of the sand in the ground is naturally low or can be lowered sufficiently and economically through processing. The number of sites where this characteristic is present is very limited in Surrey and Kent.

It is very unlikely that general building sand can be processed to produce high grade glass sand economically or in an environmentally acceptable manner. It is, however, probable that sand currently worked for other specialist uses could be processed to a quality suitable for coloured glass if processing plant were available. Comprehensive physical and chemical testing of sand is necessary to assess the potential of a site for high grade sand production.

Potential of construction sand for specialist uses

It is probable that sand currently sold for construction purposes could, with appropriate processing, be suitable for some non-construction markets and industrial uses. The production of construction or non-construction sands from lower grade sand at any one site is an interaction between a number of factors in addition to the quality of the sand including: the core market of the operating company; available processing plant; identified reserves and resources balanced against the costs of new or upgraded processing plant; environmental considerations; synergies with other companies operating from the same site or nearby; and market conditions and dynamics.

Construction sand is currently used either unprocessed or washed, for soil blending and for brick manufacture in sites where construction aggregate is the main product.

In order to use the resources efficiently, sites with high grade (low iron) sand will market sand within the consented reserve which does not meet the chemical or grain size specifications for the main product for end-uses for which there is a market at that time. Both Sibelco and Hanson have created markets for the finer and coarser by-products of the production of glass-grade sand which, in the case of equestrian sand, has become an industry standard.

Acceptable, non-staining, fine to very fine equestrian sand is unlikely to be produced by washing and grading building sand. However, within the variations of the Folkestone Formation, lighter coloured sand may produce acceptable equestrian sand from processing non-glass grade sand.

Current situation in Surrey and Kent

Silica sand produced at North Park Quarry and Tapwood/Park Pit are unusually low in alumina (Al_2O_3) compared to silica sand quarried elsewhere in the UK. The main producers of sodium silicates in England have advised that Surrey is the only area they have identified that can economically supply sand of suitable chemistry.

The Folkestone Formation in Surrey and Kent forms a single resource area for silica sand and specialist sands supplying regional and national markets. Surrey is a major supplier of silica sand to the glass industry. However, consented reserves for both sites supplying the highest grade sand will be exhausted within 5 years. For one of these, Tapwood/Park Pit Quarry, at the time of writing, there is no planned extension and the site and processing plant will close.

For the other, North Park Quarry, a resource area with a potential life of approximately 10 years has been identified by the operator, Sibelco, much of it within the Surrey Hills AONB. Additional potential resources have been identified for a further 2-3 years or more at Chilmead.

The production of high value specialist sand relies on processing to improve quality and grading profile. Planning or environmental restrictions on the use of washing plant (as at Nepicar Quarry), or lack of processing facilities for other reasons, inevitably leads to the loss of value of the sand as high specification products cannot be achieved.

There is no imminent shortage of the raw material for specialist sand (excluding glass and chemical-grade sand) in Kent with several large operating quarries producing a range of industrial, leisure and sports sands in addition to building sand. Sites with limited processing facilities may serve a demand for lower cost sand. In Surrey, specialist sand is produced as a by-product or co-product of the production of high grade silica sand at North Park Quarry and Tapwood/Park Pit.

Potential future sources of high grade silica sand production

In Kent, there may be potential for producing high grade sand as a replacement for the output from Tapwood/Park Pit. Aylesford, operated by CEMEX, has a large consented reserve extracted from below water, and suitable classifying and drying plant but the chemical suitability of the sand for high grade uses is not known. Historical sources indicate that the site may contain sand suitable for glass manufacture. Additional processing plant is probably needed to increase the purity of the sand.

Wrotham, operated by Hanson, has a relatively small consented reserve of unproven quality (chemistry) in terms of high grade uses but a past history of production for coloured glass manufacture.

The potential of alternative deposits elsewhere in the Folkestone Formation, and outside areas constrained by national environmental designations could be fully explored. In Surrey there are unlikely to be additional resources of high grade silica sand in the Folkestone Formation outside the currently identified area between Godstone and Reigate. In Kent, glass sand production has taken place in the past in the Hollingbourne and Bearsted area and records suggest that the area east of Maidstone should be investigated for potential silica sand production. Significant resources would need to be identified at any new site to justify investment in processing plant.

Significance of Surrey and Kent in the UK context

North Park Quarry currently supplies sand for colourless and coloured container glass and for float glass manufacture. With the imminent closure of Moneystone Quarry in Staffordshire, only three sites in England will have the capability to supply silica sand of sufficiently high quality for the colourless container glass market – Kings Lynn in Norfolk, North Park Quarry and Tapwood / Park Pit, of which the latter is also reaching the end of its reserve life. Quarries in Fife and West Lothian in Scotland may have the potential to replace some of this production. Similarly, production from these sites will also need to replace the supply to float glass manufacturers currently sourced from Dingle Bank Quarry in Cheshire. Any further reduction in UK capacity may put a strain on the ability of the industry to produce a full range of products to meet customers' requirements, and may encourage importation of sand.

Deposits in Surrey are the only current UK source of silica sand of suitable composition accepted by sodium silicate manufacturers in the UK and this forms the basic raw material for a wide range of manufactured products.

The Folkestone Formation in Surrey and Kent includes an unusually high quality silica sand resource. Any developments which affect the production of silica sand in this region will have implications and repercussions for the production of silica sand in other areas and on the costs, supply and quality of raw materials going to manufacturing industry, and in particular the chemical and glass industries.

GWP CONSULTANTS
March 2010

APPENDIX 1

Major sites producing Silica Sand in the UK

Appendix 1
Major sites producing silica and specialist sand in the UK

County	Site	Operator	Geological Unit/Formation	Uses
Bedfordshire	Grovebury Road, Leighton Buzzard	Aggregate Industries (Garside Sands)	Upper Cretaceous Woburn Sands Formation	Construction sand (concrete), sports, water filtration, brick manufacture and specialist industrial applications
Bedfordshire	Munday's Hill, Leighton Buzzard	Aggregate Industries, Garside Sands	Upper Cretaceous Woburn Sands Formation	Specialist and building sand
Bedfordshire	Pratts Quarry, Leighton Buzzard	Sibelco	Upper Cretaceous Woburn Sands Formation	Filtration, chemical, boiler sand, sports, horticulture, brick facing, adhesives, resins, specialist roofing tiles, foundry.
Bedfordshire	Chamberlain's Barn, leighton Buzzard	Sibelco	Upper Cretaceous Woburn Sands Formation	Construction, horticulture, rootzone, sports surfaces, brick facing.
Bedfordshire	Nine Acres Quarry, Leighton Buzzard	Sibelco	Upper Cretaceous Woburn Sands Formation	Sports, equestrian and agricultural, fillers and adhesives, resins and grouts, specialist facings
Bedfordshire	Bryants Lane/Reach Lane	LB Silica Sands	Upper Cretaceous Woburn Sands Formation	Sports, horticulture, foundry, building sand
Cheshire	Arclid	Bathgate Silica Sands Ltd.	Quaternary Congleton Sand	Foundry, fibreglass, ceramics, fillers, plastics, sports, horticulture
Cheshire	Bent farm	Sibelco	Quaternary Congleton Sand	Foundry sands, construction sand, sports sands, equestrian sands
Cheshire	Dingle bank	Sibelco	Quaternary Chelford Sand	Colourless glass sands, construction sands, top dressing, rootzones, horticulture, mineral filler sands, water filtration sands
Cheshire	Eaton Hall	Tarmac	Quaternary Congleton Sand	Foundry sands, resin coated foundry sands, paving sands, sports turf sands, rootzone, topdressing, sand/soil/fertilizer mixes, play-pit sands, cement manufacture sands, equestrian, concreting sand
Cornwall	Beacon Pit	W J Doble	Tertiary St Agnes Formation, silt sand and gravel	Blast cleaning, building, foundry, refractories
Dorset	Warmwell	Bardon Aggregates (Aggregate Industries)	Tertiary Poole Formation	Industrial sand, equestrian, construction sand
Durham	Weatherhill (Millstone)	Hobson Brothers Ltd.	Carboniferous Stainmore Formation	Foundry moulding sand (naturally bonded)
Essex	Martells	Aggregate Industries, Garside Sands	Quaternary sand and Gravel Lowestoft Formation	Industrial, water filtration, sports, horticulture
Kent	Addington/Wrotham	Hanson Aggregates	Createaceous Folkestone Formation	Building, foundry, industrial, sports, equestrian
Kent	Aylesford	CEMEX	Createaceous Folkestone Formation	Industrial, foundry, construction
Kent	Nepicar farm	J Clubb Ltd.	Createaceous Folkestone Formation	Industrial, sports, leisure
Lincolnshire	Messingham	Sibelco	Quaternary Blown sand	Coloured glass sands, top dressing, rootzones, sports sands, equestrian sands, construction sands, horticulture
Norfolk	Mintlyn Wood (Kings Lynn)	Sibelco	Cretaceous Leziate Sand, Sandringham Sand Formation	Foundry
Norfolk	Wicken South (Kings Lynn)	Sibelco	Cretaceous Leziate Sand, Sandringham Sand Formation	Float and container glass, foundry moulding sand

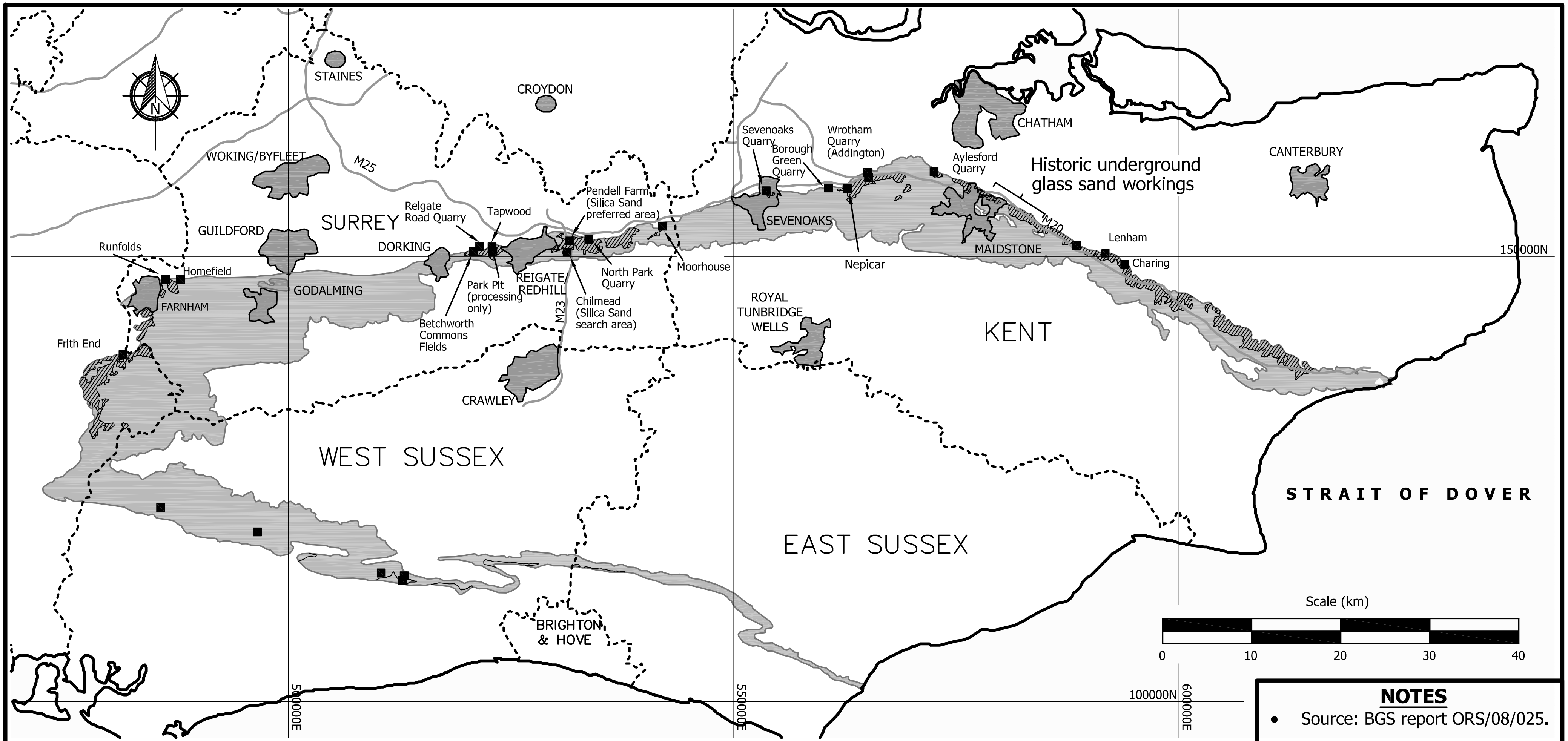
Appendix 1
Major sites producing silica and specialist sand in the UK

County	Site	Operator	Geological Unit/Formation	Uses
North Yorkshire	Burythorpe	Burythorpe Silica Sand Products Ltd.	Jurassic Scalby Formation, Ravenscar Group	Foundry moulding sand, ceramics, sport,leisure, construction.
Nottinghamshire	Mansfield (Ratcher Hill)	Mansfield Sand Co. Ltd.	Triassic Nottingham Castle Sandstone Formation, Sherwood Sandstone Group	Foundry moulding sand (naturally bonded), industrial, sports
Nottinghamshire	Warsop (Oakfield Lane)	Mansfield Sand Co. Ltd.	Triassic Lenton and Nottingham Castle Sandstone Fms, Sherwood Sandstone Gp	Foundry moulding sand (naturally bonded)
Staffordshire	Hurst	Biddulph Sands	Carboniferous Rough Rock, Millstone Grit Group	Industrial, horticultural
Staffordshire	Moneystone (Oakamoor)	Sibelco	Carboniferous Rough Rock, Millstone Grit Group	Glass, silica flours, cristobalite sands and flours, construction, sports, horticulture
Suffolk	Blyth River Pit	Bardon (Midlands) Ltd.	Quaternary sand and Gravel Lowestoft Formation	Building sand, foundry sand
Surrey	North Park Quarry	Sibelco	Cretaceous Folkestone Formation	Coloured and clear container glass, sodium silicate, foundry moulding sand, asphalt and mortar sands, rootzones, horticulture, mineral fillers
Surrey	Tapwood/Park Pit	Hanson Aggregates	Cretaceous Folkestone Formation	Industrial, sodium silicates, sports and leisure
Worcestershire	Sandy lane	Veolia Environmental Services	Triassic Wildmoor Sandstone, Sherwood Sandstone Group	Foundry (naturally bonded)
Fife	Burrowine Moor Quarry	Fife Silica Sands	Carboniferous Passage Formation	Colourless and coloured glass, filtration, specialist construction, leisure, equestrian
Fife	Devilla Forest	O-I	Carboniferous Passage Formation	Glass
North Ayreshire	Hullerhill Sand Quarry	Hugh King & Co.	Carboniferous Upper Limestone Formation	Building, foundry, industrial
West Lothian	Levenseat	Sibelco	Carboniferous Passage Formation	Glass, foundry moulding sand, construction sand, top dressing, rootzones, horticulture, equestrian, sports, water filtration

Note: uses may not be full range of products available
Quarries producing non-construction aggregates and/or industrial sand as subsidiary to construction sand may not be included
Sources Including: Directory of Mines and Quarries 2008. British Geological Survey, SAMSA, Planning Application submissions

APPENDIX 2

Location of active silica sand and building sand quarries, SE region



NOTES

- Source: BGS report ORS/08/025.

LEGEND

■	Active quarry
(grey shading)	Lower Greensand subcrop { Folkestone Formation, Sandgate Formation, Hythe Formation, Atherfield Clay
(hatched area)	Areas identified as bedrock sand resource areas by the BGS

Version	Revision and compilation notes	Date
A	Final	02.11.2009

GWP consultants

Upton House
Market Street, Charlbury
Oxfordshire OX7 3PJ
United Kingdom
tel +44 (0)1608 810374
fax +44 (0)1608 810093
e-mail info@gwp.uk.com
web www.gwp.uk.com

earth & water resources

GWP Consultants LLP. Registered No. OC326183.
Registered Office: Upton House, Market Street, Charlbury, Oxfordshire OX7 3PJ. UK

Client: Kent County Council

Project: Silica Sand Study

Locations of active sand quarries in the Folkestone Formation, SE region

Date	Drawn	Checked	Scale
02.11.2009	IB/EMB/LS	IB	Not to scale

Drawing Ref	Drawing No	Version
SILISAND0907	Appendix 2	A

APPENDIX 3

Glossary

APPENDIX 3 – GLOSSARY

Aircrete	Aerated Concrete, typically produced as lightweight blocks
Autoclave	Industrial autoclaves are large pressure vessels with full-diameter fast-opening doors, used to process parts and materials at high temperature and pressure.
Binder	A material, natural or artificial, used to bind separate particles together or facilitate adhesion to a surface.
Carbon Adsorption	The adhesion of a carbon to the surface of a solid or liquid. Adsorption is often used to extract pollutants by causing them to be attached to such adsorbents as activated carbon or silica gel.
Cretaceous Age	a geologic period within the Mesozoic era that comprises lower and upper epochs from about 146 to 65 million years ago.
Feldspar	Feldspars ($KAlSi_3O_8$ - $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$) are a group of rock-forming silicate minerals which may be found as grains in sandstones depending on the source of sediment.
Ferruginous	Containing iron
Flint Glass	Synonymous with colourless container glass – requiring the highest purity silica sand produced from UK silica sand quarries.
Float Glass	90% of the world's flat glass is produced by the Float Glass Process (also called the Pilkington Process) in which a stream of molten glass is continuously spread onto a bath of molten metal giving flat and very smooth ribbons of glass. The production line, which may be up to 250m long from furnace to cooling and cutting, is in continuous operation.
Glauconite	a green mineral consisting of hydrated silicate of potassium or iron or magnesium or aluminum; found in greensand.
In situ	being in the original position; in situ sand is sand in the round and un-dug.
Meteoric water	Groundwater that originates in the atmosphere and reaches the zone of saturation by infiltration and percolation. Most groundwater is meteoric in origin.
Reserve	A mineral reserve is the economically mineable part of a measured or indicated mineral resource demonstrated by at least a preliminary feasibility study.

Resource	A concentration (or occurrence) of material of economic interest in or on the earth's crust in such form, quality and quantity that there are reasonable and realistic prospects for eventual economic extraction.
Silica Sand	A sand in which a very high percentage of the particles are made up of SiO_2 and in which there are very few organic or inorganic impurities.
Tobermorite	A form of calcium silicate - Ca5Si6O16(OH)2.4(H2O).
Zeolites	Zeolites are microporous, aluminosilicate minerals commonly used as commercial adsorbents.

Abbreviations

AAC	Autoclaved Aerated Concrete
AFS	American Foundrymen's Society
AFS AGN	AFS Average grain number
AGS	Average grain size
BGS	British Geological Survey
MPA	Mineral Planning Authority
PFA	Pulverised Flue Ash
SAMSA	Silica And Moulding Sand Association. (The trade federation for producers of special sands)
STRI	Sports Turf Research Institute
USGA	Governing bogy of golf in the USA that sets standards and specifications for golf course construction and maintenance that are also followed worldwide.
WRAP	Waste and Resources Action Programme *(U.K. non-profit recycling advocate)*

APPENDIX 4

Determination of indicators of grain size, shape and grading distribution commonly used for descriptions of silica sand

APPENDIX 4

DETERMINATION OF INDICATORS OF GRAIN SIZE SHAPE AND GRADING DISTRIBUTION COMMONLY USED FOR DESCRIPTIONS OF SILICA SANDS

A4.1 Grading (Grain size distribution, particle size distribution)

The proportion of particles of different sizes is critical to many end uses of silica sand. This is determined by sieve analysis.

Sieve analysis

The sample is passed through a standard series of sieves of decreasing mesh size. The weight of material retained on each sieve is measured and the proportion of the whole sample is calculated. From the % retained, the proportion of the sample that passes that mesh, *i.e.* has a grain size diameter smaller than the mesh opening, is calculated to give the % passing. The percentage passing is plotted against the mesh size to give the grading curve. Mesh size is normally plotted on a log scale.

A4.2 D Number and Gradation Index

D Number

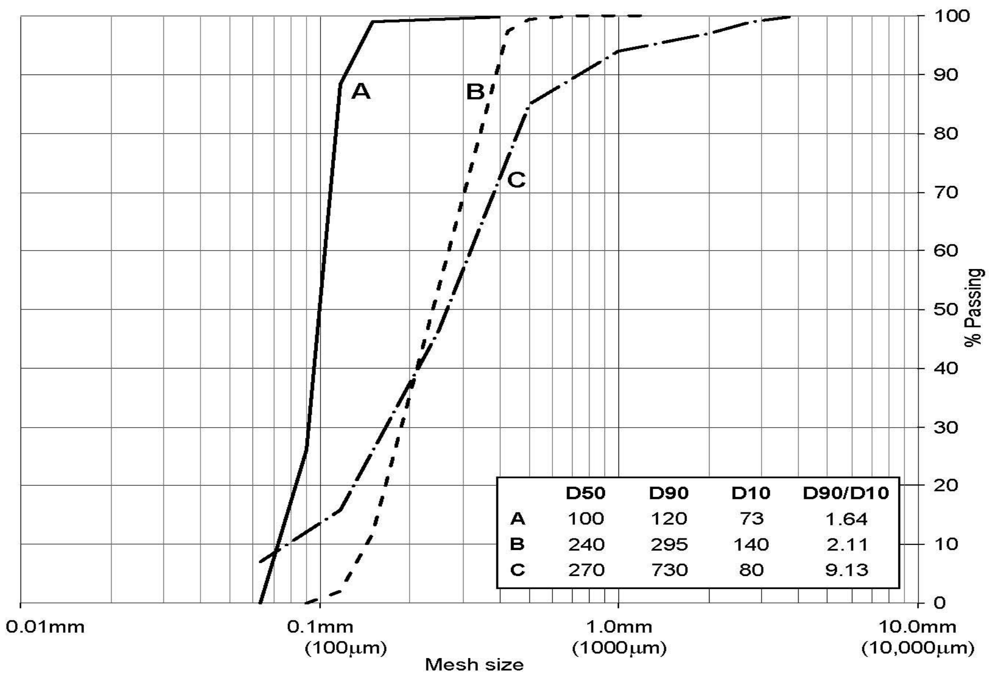
The particle size at which a given cumulative percentage of grains passes, for example D20 = 235 microns indicates that 20% of material is smaller than 235 microns. D10, D90 and D50 are parameters that are often used to assess sand and specify gradings for particular end uses. Note that lower case is also used particularly in specification of filter media (eg d_{10}).

D50 is the median grain diameter, used to indicate the overall coarseness of the sand.

Gradation Index D90/D10

The gradation index is the ratio D90/D10. It gives an indication of the spread of particle sizes, or uniformity, and the amount of interpacking that might be expected in the sand. A high D90/D10 indicates a wide spread of particle size and a high potenial for interpacking – filling in the void space between larger grains with smaller ones – and therefore potential permeability and drainage problems if, for example, it was used for sports surfaces (note this is different from the Uniformity index used to specify filter media).

Sands with similar D50 can have very different D90/D10. The figure below shows grading curves of three sands. Sand A is a fine to very fine sand with D50=100 microns and 80% between 73 microns and 120 microns. The narrow grading is shown by the low gradation index of 1.64. Sand B has a narrow grading but is coarser than A with D50=240. Sand C has a similar D50 to Sand B but with a much grater spread in gain size shown in the Gradation index of 9.13.



A4.3 AFS GFN (shortened to AFS) American Foundry Society Number

AFS Number is a measure of the average grain size of a sand. It has traditionally been used by the foundry industry and is frequently included in silica sand product names for other end uses (eg HST50 – is a foundry sand from Congleton with AFS 50). The number increases with increasing fineness of the sand. The AFS is usually calculated from the results of sieve analysis using US Standard (ASTM E11-61) sieves or BS Standard Metric series sieves (BS410:1976) using a factor for each sieve. The worked example below shows how the AFS is calculated the 300

The percentage of the sample that is retained by each sieve is multiplied by a factor which is different for each sieve. The total of the products is then divided by 100 to give the AFS GFN. The factor is the sieve size of the previous sieve. For those ISO apertures for which there is no BS mesh size the equivalent ASTM size is used.

BS Sieve (microns µm)	**% retained on sieve**	**Multiplier**	**Product**
16 (1000µm)	0.10	10	1.0
22 (710µm)	0.20	16	3.2
30 (500µm)	1.40	22	30.8
44 (355µm)	9.40	30	282.0
60 (250µm)	40.10	44	1764.4
72 (212µm)		60	
85 (180µm)	44.00	72	2640.0
100 (150µm)		86	
120 (125µm)	4.60	100	395.6
150 (90µm)	0.20	120	24.0
200 (63µm)	0.00	150	0.0
PAN (-63µm)	0.00	200	0.0
Total	100.0		5141
		AFS	**51.4µm**

A4.4 Average grain size

The average grain size is now calculated using metric sieve sizes. The lower the value, the finer the grain size, but it gives no indication of the grading of the grains. The product of the percentage of the sample retained on each sieve and a multiplier is divided by the total proportion retained on those sieves. Moulding sands generally have AGS 220-250.

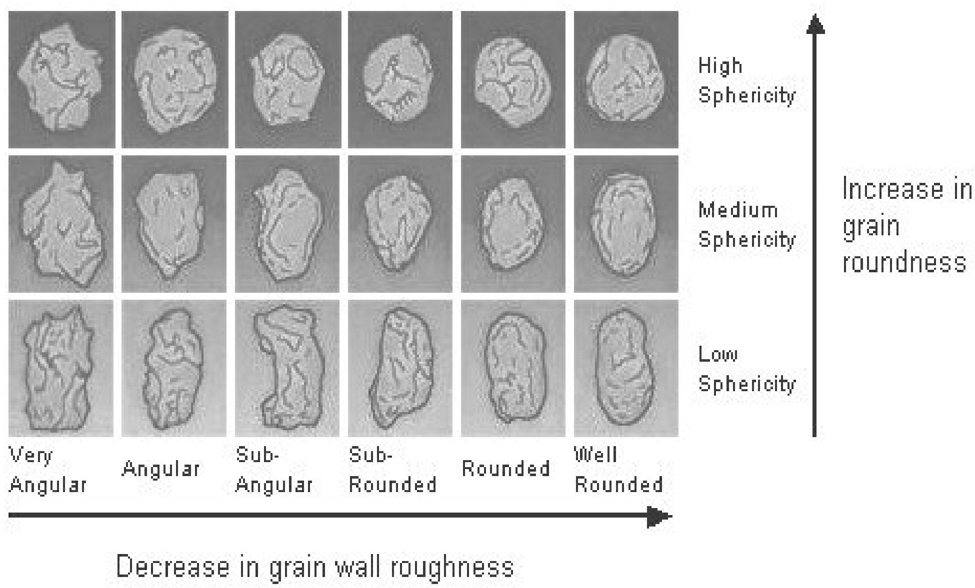
A4.5 Grain shape

The grain shape is normally described by its sphericity and angularity.

Sphericity measures how close the shape is to a sphere

Angularity is the surface irregularity. Particles with a smooth surface are described as round.

The particles are examined visually under a microscope at x25 magnification and compared to a standard chart.



A4.6 ADV Acid Demand value

The acid demand value is a measure of the amount of alkali material, particularly limestone ($CaCO_3$) shells and dolomite (Mg, Ca carbonate), that will absorb acid catalysts in foundry moulds. An acid demand greater than 6ml indicates a high level of acid catalyst will be needed. values greater than 10-15ml would be considered unsuitable for acid catalysed binder systems.

A4.7 Specification of Filter Media

Effective size (d_{10} also D_{10})

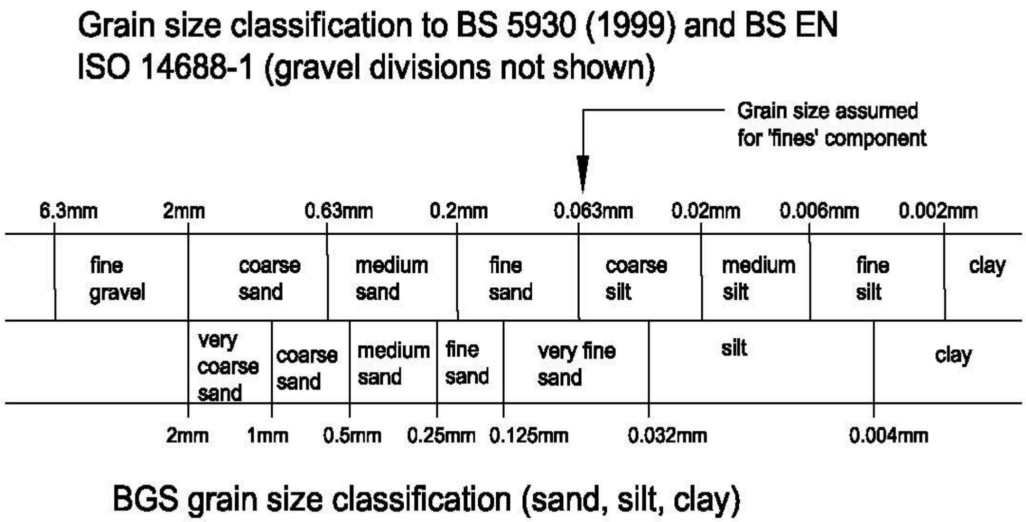
The mesh size at which 10% of grains passes, for example an effective size of 0.3mm means that 10% of material is smaller than 0.3 mm.

Uniformity Coefficient (U)

The ratio d_{60}/d_{10} . Also K and d_{90} are sometimes used to denote the Uniformity coefficient. The lower the coefficient, the more uniform is the grading and the less variable the grain size. This is seen as a steeper grading curve.

A4.8 Grain size classification

Two schemes of grain size classifications are generally used (see below) but there are also exceptions and variations. BS 5930 and the new BS EN 14688-1 standards classify particle size based on field identification for geotechnical purposes based on properties that can be tested rapidly in the field. Sand is defined as particles between 0.063mm and 2mm. It is current practice in the quarrying industry, and defined in the latest European Standards, to consider all grains below 0.063mm as 'fines', the proportion of excavated material that is lost on washing. previous British standards defined material passing 75 microns as 'fines' and some in some grading analyses the finest mesh used is still this size.



The BGS division of sand includes very coarse sand and very fine sand categories and includes particles down to 0.032mm (32 microns) as very fine sand. This is the finest particle size that can be seen with a hand lens, however not relevant to aggregate or silica sand processing in practice.

In the USA the USGA defines the minimum grain size as 0.053mm. This may have implications in some specifications for sands used in the construction and maintenance of golf courses.

APPENDIX 5

Sources of information

APPENDIX 5 SELECTED SOURCES OF INFORMATION

Section 3

- Mineral extraction in Great Britain, Business Monitor PA1007. Office for National Statistics. www.statistics.gov.uk
- UK Minerals Yearbook 2009. BGS 2009
- Bedfordshire Silica Sand Study, 2006/2007. Cuesta Consulting Limited. February 2008. For Bedfordshire County Council.
- BGS Mineral Planning Fact Sheet: Silica Sand. 2006
- Silica Sand: Geology and mineral planning fact sheets for Scotland. BGS 2007
- Proposed Extension to existing silica sand operations with progressive restoration, Messingham Quarry, North Lincolnshire. Planning Statements. Sibelco 2009.
- Borough of Kings Lynn and West Norfolk. C/2/04/2034: Grandcourt Farm. Extension to silica sand extraction operations with progressive restoration: WBB Minerals. Report by Director of planning and transportation. 5 May 2006.
- Smart, J.G.O et. al., 1966. Geology of the country around Canturbury and Folkestone. Memoir for sheets 289, 305 and 306. BGS.
- Ellison R A, Williamson I T, Humpage A J., 2002. Guildford. Explanation for Sheet 285. BGS
- Worssam, B.C., et. al., 1963. Maidstone. Memoir for sheet 288 BGS.
- Dines, H.G. et al.,1969. Sevenoaks and Tonbridge. Memoir for sheet 287. BGS
- Cheshire Minerals Development Framework. Site specific policies and allocations – Mineral issues and Options September 2007.
- The proposed extension (12ha) to silica sandstone extraction operations with progressive restoration. Levenseat Quarry, Near Fauldhouse, West Lothian. Non-Technical Summary 2003. WBB.
- The Proposed Extension to Silica Sandstone Extraction Operations with progressive restooration. Moneystone Quarry, Whiston Eaves Lane, Staffordshire. Non-technical summary 2006. WBB Minerals.
- Sevenoaks Quarry, Planning Application for extension of extraction area and continued operation of existing processing and associated manufacturing plant. Tarmac 2008

Section 4

- Colourite Project – Maximising Cullet Additions in the Glass Container Industry. Glass Technology Services Ltd, Wrap February 2006.
- Waste Protocols Project. Specification for flat glass cullet used in flat glass manufacture Wrap/Environment Agency March 2008.
- BS2975:1988 Methods of sampling and analysis of glass-making sands.
- BS2975-1:2004 Sampling and analysis of glass-making sands Part 1. Methods for sampling and physical testing of glass making sands.

- BS2975-2:2008 Sampling and analysis of glass-making sands. Part 2: Methods for chemical analysis.
- UK Glass manufacture 2008 A mass balance. Envirowise.

- Foseco Non-Ferrous Foundryman's Handbook.
- Filtration sand
- PFL Water Filtration Media website pflfiltermedia.com
- Natare Corporation website www.natare.com
- BS EN12904:2005 Title: Products used for treatment of water intended for human consumption
- Water treatment Unit Processes. David G. Stevenson.
- Handbook of water and wastewater treatment technologies. Nicholas Cheremisinoff. Butterworth and Heineman 2002.
- Advanced Filtration Media (AFM): Clean water market analysis. WRAP Research and development report GLA2-020 Entec 2003.
- Alternatives to sand in drinking water treatment. Mark Watts, WRC
- BS EN 12904:2005 Products used for treatment of water intended for human consumption Silica sand and silica gravel.
- biosandfilter.org
- Handbook of filtration media. 2nd ed. D.B. Purchas and K Sutherland. Elsevier. 2002.
- Southeast Regional Assembly: Southeast Plan – Review of mineral supply and demand. Economic Minerals Programme Commissioned Report CR/06/147. BGS
- Freeman, I.L., 1964. Mineralogy of Ten British Brick Clays. Clay Min. Bull. vol 5, pp 474-485.
- BS 7533-3:2005 Pavements constructed with clay, natural stone or concrete pavers. Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements ISBN 0580 467767

Section 5

- SAND AND SAND MIXES - from Horse and Hound website article published 6 Oct 2005
- Forge Magazine June 2008. Biomechanics – surfaces and their effect on locomotion and shoeing, Kathy Carter.
- Personal communications from Mr David Woods and Mr J Lovett-Smith: Consultants to British Horse Society, Softtract Ltd., Michael Collins Ltd., Equestrian Surfaces Direct. Sibelco, Hanson Industrial Sand, Unidentified Sand Producer.
- Rootzones, sands and top dressing materials for sports turf. Dr Stephen Baker, STRI 2006.

Section 7

- Boswell, P.G.H., 1917. A supplementary memoir on British resources of sands and rocks used in glass-manufacture. Longmans.
- Lake, R.D., and Shephard-Thorn, E.R., 1985. The stratigraphy and geological structure of the Hog's Back, Surrey and adjoining areas. Proc. Geol. Ass., 96 p7-21.
- Richards, N.P., and Barton., M.E., 1999. The Folkestone Bed sands: microfabric and strength. Quarterly Journal of Engineering Geology, 32, p21-44.