UK FRAC SAND RESOURCES

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ABSTRACT

Although still just a glimmer in the gas man's eye, the prospect of shale hydrocarbon (oil and gas) development in the UK has many companies thinking about the industrial minerals it will require. Chief amongst these is silica sand which is used as a 'proppant' in the hydraulic fracturing, or 'fracking', of shales to help release the gas. The UK has large resources of sand and sandstone, of which only a small proportion have the necessary technical properties that classify them as 'silica sand'. Silica sand is high purity quartz sand that is used for glass production, as foundry sand, in horticulture, leisure and other industrial uses. When used as a proppant to enhance oil and gas recovery it is commonly known as 'frac sand'.

The UK is virtually self-sufficient in meeting its silica sand needs and extracts approximately 4 million tonnes per year from 40 quarries. The resources are varied but most production comes from Carboniferous age sandstones in central Scotland, early Cretaceous marine sands in Norfolk and glaciofluvial sands in Cheshire. As there is currently no production of frac sand in the UK, and the prospect of shale gas recovery becoming a possibility, it is timely to consider where 'frac sand' could be produced. Will supply of silica 'frac sand' be able to meet demand? Will it compete with other applications for silica sand? This presentation will consider those silica sand resources in the UK that may be suitable for 'frac sand' production. It will draw parallels with other industrial applications, notably foundry sand, which shares some common technical requirements such as particle shape and size distribution.

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INTRODUCTION

The UK, along with many other countries, is actively looking at the potential for the production of shale gas. There are resources of shale gas in the UK which have been identified and quantified by the British Geological Survey (BGS), with potential prospects in Northern England, South East England, the Midland Valley of Scotland, Wales and Northern Ireland (Andrews, 2013; Andrews, 2014; British Geological Survey, 2013; Department for Energy & Climate Change, 2012; Monaghan, 2014). Up until now there has been a limited amount of exploration drilling, and exploratory hydraulic fracturing (commonly referred to as 'fracking') has only been carried out in one area, Preese Hall Farm, 5 miles east of Blackpool in Lancashire. Following two minor earthquakes at this site in spring 2011, exploratory hydraulic fracturing was halted amidst much controversy which also focused on the potential threat to the environment, such as ground water contamination. Since 2011, opposition to the development of shale gas resources has grown with many campaigning groups formed, such as Fylde against Fracking and Frack OFF, and demonstrations such as those at Balcombe, West Sussex in the summer of 2013.

The UK Government has maintained its interest in developing shale gas resources, and in July 2014 the Department for Energy and Climate Change (DECC) opened the bidding process for the 14th Landward Licensing Round for companies seeking licences to explore for onshore oil and gas. UK Government Business and Energy Minister Matthew Hancock said “Unlocking shale gas in Britain has the potential to provide us with greater energy security, jobs and growth. We must act carefully, minimising risks, to explore how much of our large resource can be recovered to give the UK a new home-grown source of energy. As one of the cleanest fossil fuels, shale gas can be a key part of the UK’s answer to climate change and a bridge to a much greener future”. It is still early days in the development of a shale gas industry in the UK and there are no guarantees that one will be developed in the near future, if at all.

The UK extractive minerals industry has a role to play in providing minerals that could be used in hydraulic fracturing, such as silica sand which is used a proppant, commonly referred to as ‘frac sand’. Many of the big aggregate companies in the UK are examining their mineral portfolios to determine if and how they can meet the potential future demand for frac sand if the development of shale gas goes ahead. Given that their deliberations are commercially sensitive and are largely publicly unavailable, this paper presents an ‘educated guess’ as to where this frac sand will come from in the UK.

WHAT IS FRAC SAND?

Frac sand is a form of silica sand and is composed mainly of quartz grains. It is used in the hydraulic fracturing process, hence the name ‘frac’ sand. The sand is entrained in water and is pumped under great pressure into the fractures that are simultaneously created in the reservoir rock. The sand is packed tightly into the fractures and props them open (Figure 1). Hence they are also referred to as ‘proppants’. It forms a permeable pathway for the oil and gas to escape from otherwise impermeable rock formations such as shale. Approximately 70% of the proppants used in hydraulic fracturing are naturally occurring silica sand (frac sand). Other types of proppants include resin coated silica sand, and ceramic proppants such as calcined alumina and calcined bauxite.

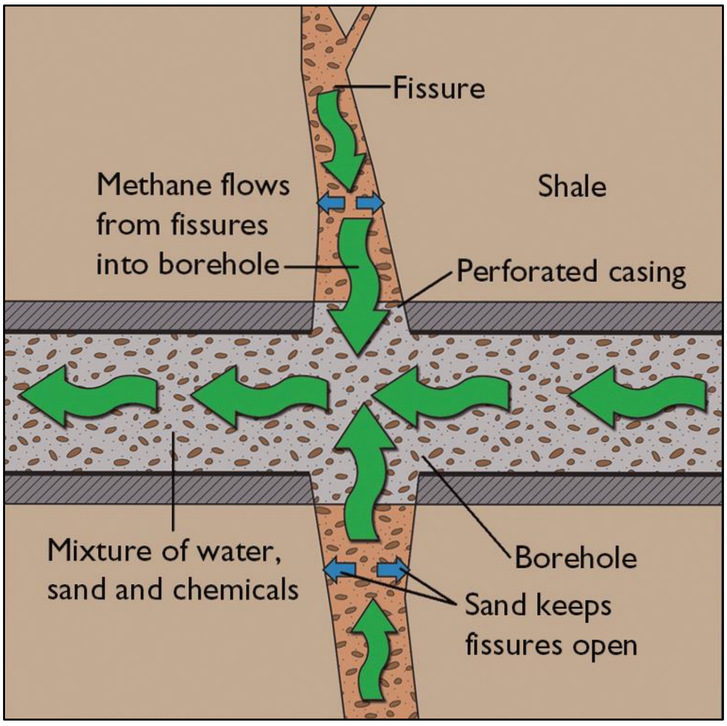

Figure 1. *Hydraulic fracturing of shale to release gas*

The most commonly quoted standard for proppants used in hydraulic fracturing is the *Recommended Practice (RP) 56 for Testing Sand Used in Hydraulic Fracturing Operations* and was issued in 1995 by the American Petroleum Institute (API). This was replaced in 2006 by *API RP 19C for Measurement of Proppants Used in Hydraulic Fracturing and Gravel-packing Operations*. This is the equivalent of the *British Standard (BS) European (EN) International Standards Organisation (ISO) standard 13503-2:2006 + A1:2009 Petroleum and natural gas industries. Completion fluids and materials. Measurement of properties of proppants used in hydraulic fracturing and gravel-packing operations*. The standard covers the testing and specification of those properties that are important for a good quality proppant such as frac sand. Table 1 shows a summary of the properties required for a proppant as specified in the standard.

Property	Limits
Composition	>99% Silica, SiO_2 (Quartz or resin coated quartz) or 100% ceramic
Particle-size	Narrow size-distribution - 90% within specified size ranges e.g. 12 / 20 # (1700 – 850 microns) 20 / 40 # (850 – 425 microns) 40 / 70 # (425 – 212 microns) 70 / 140 # (212 – 106 microns)
Particle-shape	Well-rounded, spherical grains (>0.6 for quartz sand and >0.7 for resin coated sand and ceramic proppants)
Crush resistance	Withstand compressive stress 4000 - 6000 psi (28 - 42 MPa), determined at 10% crush material
Acid solubility	Limits on acid soluble material (<2% ≥30/50, <3% <30/50, <7% for resin coated sand or ceramic proppants)
Turbidity	Limits on clay (<2 microns) and silt (2 - 63 microns) content, maximum turbidity 250 FTU (Formazin Turbidity Unit)
Source: British Standards, 2010	# = mesh size = number of opening per linear inch in a sieve.

Table 1. *Properties of frac sand*

The required particle-size of the sand depends on the intended application. As a rough rule of thumb, coarser sand is used for the production of oil and finer sands for gas, this is because oil is a viscous liquid and therefore requires larger pore spaces than gas in order to migrate out of the reservoir rock. Also, the particle-size distribution required is relatively ‘narrow’, which means that the particles are more or less the same size. The reason for this is to maintain a high permeability so that oil and gas can readily migrate through the sand when it is packed tightly into a fracture in the shale. If the sand has a broader size distribution, i.e. if it is composed of a mixture of relatively small and large particles, the smaller particles would occupy the pore spaces between the larger particles and reduce the permeability of the sand. Table 1 shows some typical particle size distributions for frac sand. One of the most commonly used is 20/40 (Figure 2). This refers to the mesh sizes equivalent to 850 microns (20 mesh) and 425 microns (40 mesh). The mesh size is the number of openings per linear inch in a sieve. The specification requires that 90% of the particles must be between these two sizes. In addition to this, there are also limits on the amount of clay and silt present in the sand, this is measured using a Turbidity test.

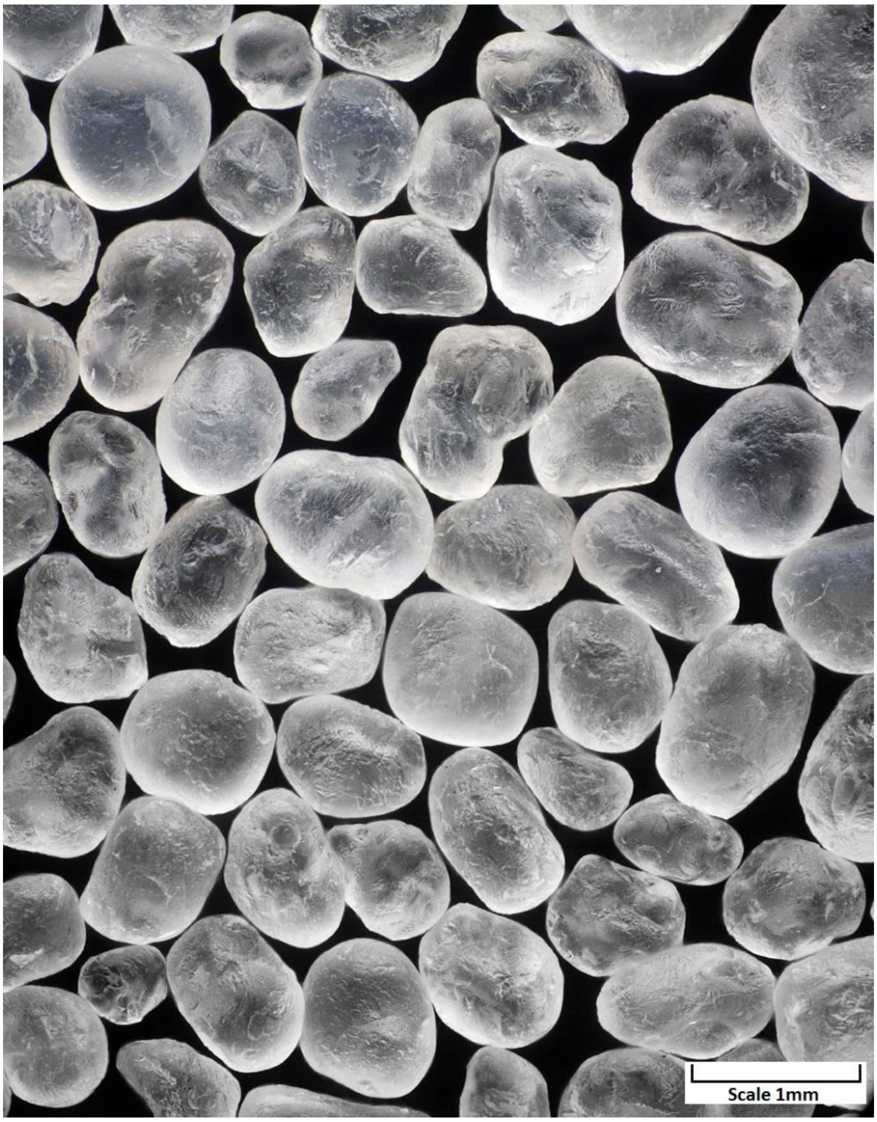

Figure 2. *20/40 grade frac sand, Illinois, USA (Image courtesy of Fairmount Santrol)*

The sand particles must also have a relatively high degree of roundness and sphericity. This is to ensure that the sand particles flow unhindered down the borehole and into the fractures. Also, rounded particles when packed together have a higher permeability than angular or irregularly shaped particles. The roundness and sphericity of the particles can be measured by comparing the shape of sand particles with the well known roundness and sphericity chart as shown in Figure 3 (Krumbein & Sloss, 1963). An average roundness and sphericity of 0.6 is required for naturally occurring silica sand (frac sand), and 0.7 is required for resin coated sand and ceramic proppants.

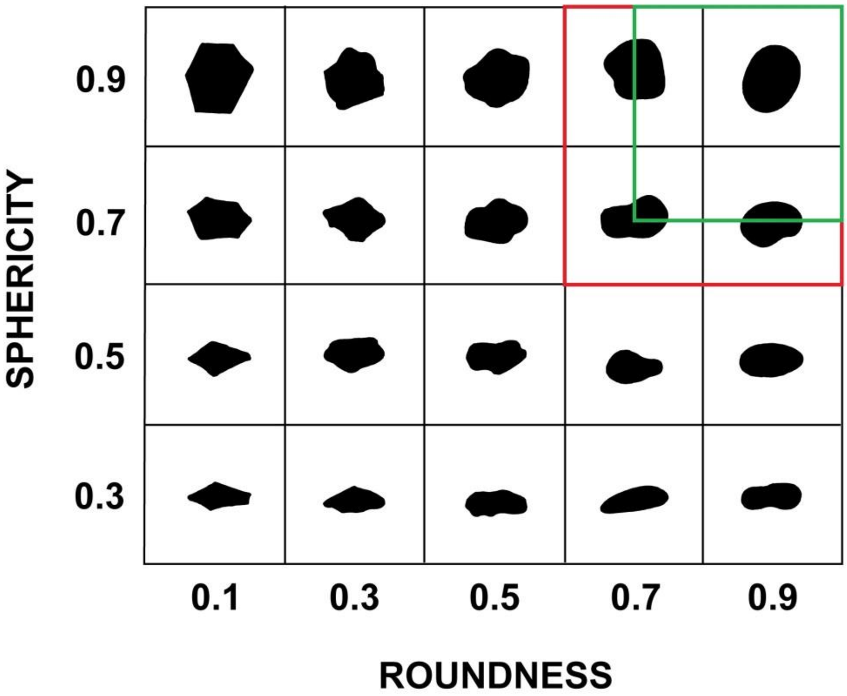

Figure 3. *Chart for visual estimation of roundness and sphericity of sand grains (After Krumbein & Sloss, 1963). The red box shows the limits for frac sand and the green box for synthetic proppants*

The sand must also be capable of withstanding the high pressures found at depths of several thousand meters below the surface. Weak particles will be crushed by the high lithostatic pressures and will fail to keep the fractures propped open. This will lead to a reduction in permeability. Also, the irregular shape of the broken particles and the small fragments created will act to reduce the permeability of the sand even further. Frac sand must withstand pressure up to 4000 - 6000 psi (28 - 42 MPa). As a rule of thumb frac sand is used for lower pressures than resin coated sand and ceramic proppants which can be used for hydraulic fracturing at greater depth.

UK SILICA SAND RESOURCES

Silica sand in the UK is produced for a host of applications including the manufacture of glass and ceramics, as foundry sand, the production of sodium silicate and other silicon chemicals, mineral filler, water filtration, horticulture, and sports surfaces and other leisure uses (British Geological Survey, 2009). The UK is more or less self-sufficient in meeting its silica sand needs. In 2012, silica sand production in the UK was 3.9 million tonnes. Of this total output, 87% was produced in England, 11% in Scotland, 4% in Wales and none in Northern Ireland (Office for National Statistics, 2014).

There are currently 39 silica sand ‘workings’ (Cameron *et al*, 2014) in the UK. It is produced from loosely consolidated sands and weakly cemented sandstones ranging from Recent to Carboniferous in age. The most significant silica sand resources are those of Pleistocene age in Cheshire and of Lower Cretaceous age in eastern and southern England (Figure 4), with each accounting for nearly 40% of total output in England (British Geological Survey, 2009).

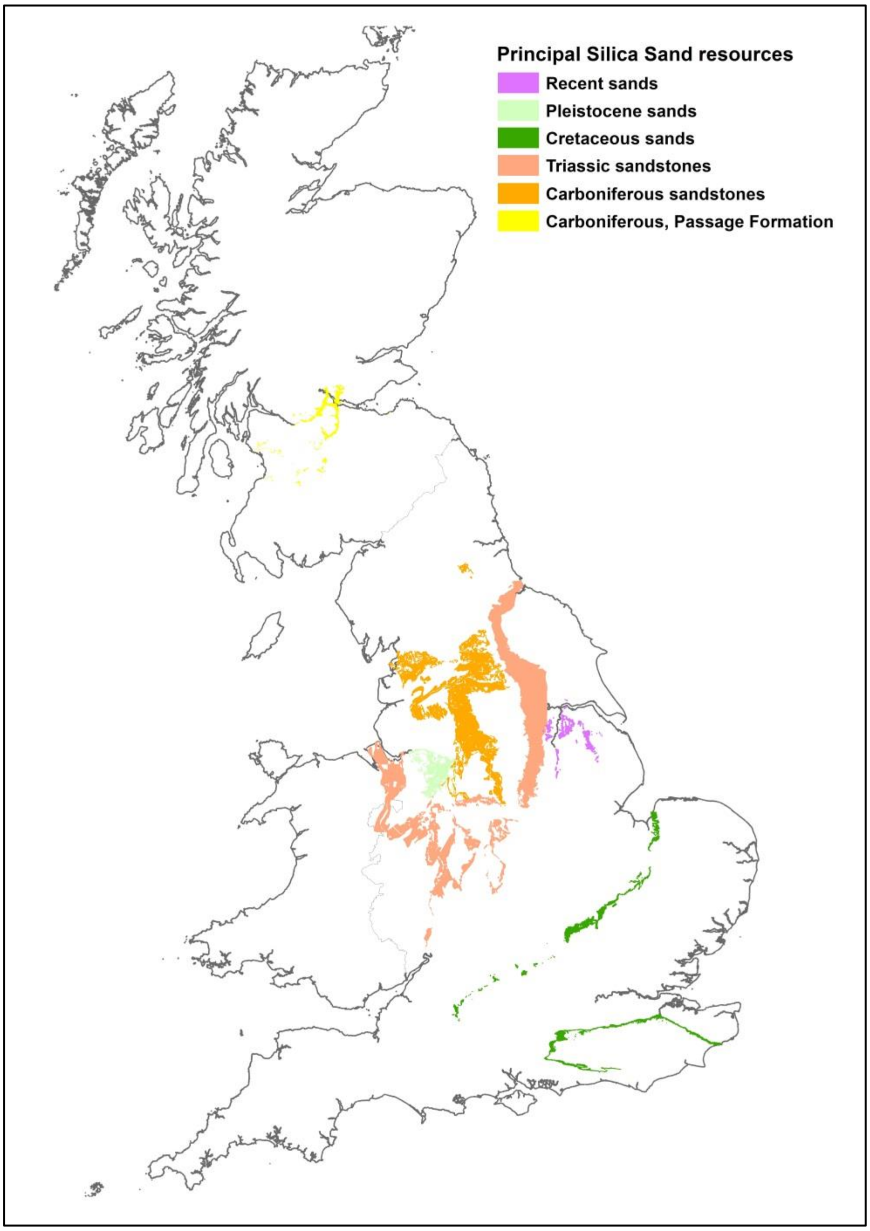

Figure 4. *Principal silica sand resources in the UK*

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In most cases, naturally occurring sand requires mineral processing for it to be upgraded to silica sand (Figure 5). The sand is typically extracted by quarrying, although there is a silica sand mine currently operating at Lochaline in Scotland. The sand is either unconsolidated or forms weakly cemented sandstones which can easily be extracted using front end loaders, bull dozers equipped with rippers or specially designed self-elevating scrapers. At some workings the extraction takes place underwater by suction dredging equipment mounted on pontoons floating on a lagoon. The raw sand is transferred via conveyors or slurry pipes to the processing plant. The sand is processed to remove clay and silt and other non-quartz materials present. This involves washing, attrition scrubbing, screening and other forms of size classification such as hydrocycloning and elutriation. Additional processing may be used such as gravity separation to remove heavy minerals, acid washing to remove surface coatings of iron oxide and other minerals, froth flotation to remove mica and feldspar and high intensity magnetic separation to remove iron-bearing impurities. The sand products are either stored in open air stock piles or they may be dried in kilns and stored undercover to keep the sand dry.

Figure 5. *Silica sand processing plant, Norfolk.*

WHERE WOULD FUTURE PRODUCTION OF FRAC SAND COME FROM?

The silica sand product that is the closest equivalent to frac sand, in terms of its composition and physical properties, is foundry sand (Table 2). Frac sand and foundry sand are both composed of high purity silica sand (greater than 98-99% SiO_2) which consists of well rounded, spherical sand grains with a narrow particle size distribution. Both applications require silica sand with high permeability. In the case of frac sand, this is to allow the migration of gas from the reservoir into the well. For foundry sand, this is to allow the escape of gases generated when molten metal is poured into a foundry mould.

There are 22 silica sand workings in the UK that produce foundry sand and are potential sources of frac sand (Cameron *et al*, 2014). The amount of foundry sand produced in the UK has dramatically declined over the last 15 years. In 1999, 26% (just over a million tonnes) of the silica sand produced was used as foundry sand. In 2012, this had fallen to 9% (340,000 tonnes), a reduction of 700,000 tonnes since 1999 (which is probably due to the declining manufacturing capacity of UK industry as a whole).

Property	Limits
Silica (SiO_2) content	98% minimum
Limits on:	CaO and MgO (to reduce the acid demand value & minimise binder demand)
Particle-size	Range from 0.1 to 0.5mm (100 to 500 microns).
Particle-size distribution	Narrow size distribution (improves permeability)
Grain Fineness	AFS (American Foundrymen's Society) index indicates average grain size. Ranges from 45 to 90 AFS (higher = finer) e.g. 50-60 AFS = 250-220 microns
Particle-shape	Rounded to sub-angular grains with reasonable sphericity are preferred (reduces binder demand, and improves compaction and mould strength)
Sources of information: Society for Mining, Metallurgy and Exploration, 2006; Harben, 2002.	

Table 2. *Properties of foundry sand*

Silica sand resources that are currently worked in the UK to produce foundry sand and are potential sources of frac sand are:

Upper Carboniferous sandstones

The Upper Carboniferous sands produced in Scotland are derived from sandstones which were deposited in a shallow marine environment and form part of a cyclical sequence with siltstones and mudstones (Cameron & Stephenson, 1985). This sequence formed in the Midland Valley of Scotland which was essentially a graben, with the Caledonian Mountains to the north and the Southern Uplands to the south acting as the source of the sediment (Browne *et al*, 1999).

The Passage Formation occurs across the Midland Valley of Scotland (as shown in the map in Figure 4 and the quarry in Figure 6). A thick alternating sequence of fine to coarse-grained sandstone is worked at Levenseat Quarry near Fauldhouse in West Lothian, and Burrowine Moor and Devilla Forest quarries near Kincardine-on-Forth in Fife. The sandstone is friable and easily worked to produce construction sand, foundry sand and specialist sands (Smith *et al*, 2008b). The Passage Formation sandstone appears to be extensive and is likely to remain an important silica sand resource for the UK market in the future (British Geological Survey, 2009).

The Upper Limestone Formation occurs in North Ayrshire, Scotland. The formation is characterised by a cyclical sequence of limestone, mudstone, siltstone and sandstone. A 10m thick sequence of white sandstone occurs within this formation and is worked at Hullerhill Sand Quarry for foundry, construction and horticultural sand (Smith *et al*, 2008a).

Figure 6. *Silica sand quarry, Passage Formation, Fife*

Lower Triassic sandstone

The Nottingham Castle Sandstone Formation, part of the Sherwood Sandstone Group, occurs in Nottinghamshire and south Yorkshire (as shown in Figure 4) and is a thick sequence (approximately 100m) of pinkish-red or buff-grey, medium to coarse-grained sandstone (Figure 7). The sand was deposited by fast-flowing braided rivers in an actively subsiding continental basin. This lead to a thick sequence being deposited, the Sherwood Sandstone Group is over 1000m in some places (Ambrose *et al*, 2014). It is currently worked at Ratcher Hill Quarry 4km east of Mansfield. This quarry is due to be phased out in 2014 and production moved to a new site at Two Oaks Farm Quarry 4km south of Mansfield. The sandstone is friable and easily worked to produce construction sand, sports sand and foundry sand (although there is currently little demand for foundry sand from this working) (Edwards, 1967; Harrison *et al*, 2002).

Figure 7. *Silica sand quarry, Nottingham Castle Sandstone Formation, Nottinghamshire*

Middle Jurassic sandstone

The Scalby Formation occurs in North Yorkshire and is represented by medium to coarse grained, sporadically pebbly, cross-bedded sandstone with thin siltstone and mudstone beds which were deposited in fluvial, deltaic and coastal floodplain environments (Barron *et al*, 2012). The Scalby Formation is up to 60m in thickness. At Burythorpe Quarry near Malton it occurs as a grey to white, fine grained, friable, pure quartz sandstone and is worked to produce foundry sand. This is a small occurrence of sand with only local importance (Kent, 1980; Harrison *et a*l, 2004).

Lower Cretaceous sands and sandstones

Collectively the Lower Cretaceous sands and sandstones of eastern and southern England (as shown in Figure 4) are significant sources accounting for approximately 40% of the silica sand used in the UK.

The Leziate and Mintlyn members occur in west Norfolk (Figure 8) and form the upper part of the Sandringham Sands Formation. The Leziate Member is up to 30m in thickness and consists of pale grey, fine to medium grained cross bedded quartz sand with subordinate bands of silt or clay, plus pyrite nodules and glauconite. The Mintlyn Member is up to 15m in thickness and consists of glauconitic, clayey, grey and green sands with clay-ironstone and phosphatic nodules (Hopson *et al*, 2008). They give rise to the heathland scenery of the Sandringham area. Much of the outcrop is covered by Pleistocene deposits and exposures are rare. It is thought that the sands were derived from Carboniferous sandstones to the west and were deposited in a near shore marine environment adjacent the north-south trending coastline. They are currently worked at Leziate Quarry near King's Lynn to produce glass and foundry sand (Gallois, 1994).

Figure 8. *Stockpile of silica sand, Leziate Member, Norfolk.*

The Folkestone Formation, part of the Lower Greensand Group, occurs around the circumference of the Weald basin in SE England, from Hampshire in the west to Kent in the east (Figure 9). The formation comprises fine to coarse grained, well-sorted, cross-bedded sands and weakly cemented sandstones. It was deposited in a shallow marine, near shore environment and varies in thickness from 0.5m to 85m (Gallois, 1965; Farrant, 2002; Hopson *et al*, 2008). The formation is worked at 5 quarries in Kent and Surrey to produce building sand, foundry sand, industrial sand, and sand for the manufacture of sodium silicate. In addition, there are over 20 quarries that work the Folkestone Formation in Hampshire, Kent, Surrey and Sussex to produce building and concreting sand.

Figure 9. *Dredging of silica sand, Folkestone Formation, Hampshire*

The Woburn Sands Formation, part of the Lower Greensand Group, occurs in Bedfordshire and Cambridgeshire between Leighton Buzzard and Cambridge (Figure 10). This formation was deposited in a shallow marine basin and is typically 30 to 60m in thickness. It mostly consists of fine to medium grained, yellowish, iron-rich and glauconitic, cross-bedded quartz sandstone or loose sand (Sumbler, 1996; Hopson *et al*, 2008). In a small area near Leighton Buzzard, where the Woburn Sands Formation is up to 120m thick, the upper part of the formation contains a layer, up to 20m thick known as the 'Upper Woburn Sands' or the 'Silver Sands'. This consists of white, well-sorted and well-rounded, medium to coarse grained quartz sand (Shephard-Thorn *et al*, 1994). This sand is worked at 10 quarries producing a range of products including building sand, foundry sand, glass sand, horticultural sand and sports sand. In addition, there are 4 quarries that work the Woburn Sands Formation in Bedfordshire to produce building sand.

Figure 10. *Silica sand quarry, Woburn sands Formation, Bedfordshire*

Palaeogene sands

The St. Agnes Formation occurs as an outlier of Palaeogene sand, thought to be of marine origin, overlying Devonian mudstones and sandstones near St. Agnes Head, Cornwall. It is approximately 10m in thickness. The sand occurs interbedded with clay with both being worked at Beacon Pit on a small scale to produce sand for industrial use and pottery clay (Edmonds *et al*, 1975; Walsh *et al*, 1987; British Geological Survey, 1997).

Pleistocene sands

The Chelford Sand Formation, which includes the Congleton Sand, in Cheshire (as shown in Figure as ‘Fluvioglacial sand’) is a significant source, accounting for approximately 40% of the silica sand used in the UK (Figure 11).

The Chelford Sand Formation occurs as irregular sheets of quartz sand which infill troughs in the underlying Triassic Mercia Mudstone Group and is in turn overlain by glacial deposits (boulder clay, sands and gravels). The formation is up to 20m in thickness and consists of white to buff-coloured, well-sorted, well-rounded quartz sand with minor gravel, silt and peat lenses. The sand grains are mostly in the size range 200 to 400 microns with a minor amount of fine sand and very little silt and clay present (McMillan *et al*, 2008). Despite their close association with glacial deposits, the roundness and sphericity of the sand grains is more consistent with an aeolian (‘wind-blown’) origin (Figure 12). It is possible that the sand was derived from sandstones to the west of the Cheshire basin, such as those in the Carboniferous Millstone Grit and the Permo-Triassic Sherwood Sandstone groups (Evans *et al*, 1968; British Geological Survey, 2009). The sand is currently worked at Arclid Quarry near Sandbach, Bent Farm and Eaton Hall quarries near Congleton, and Dingle Bank Quarry near Lower Withington to produce building sand, foundry sand and sand for the manufacture of glass.

Figure 11. *Silica sand quarry, Congleton Sand, Cheshire.*

The Chelford Sand Formation is the only sand to have been used in recent exploratory hydraulic fracturing of shale in the UK. In total, 108.1 tonnes of Congleton Sand and 354.6 tonnes of Chelford Sand were used in five hydraulic fracturing stages at the Preese Hall-1 well, Lancashire in 2011 (Cuadrilla, 2014).

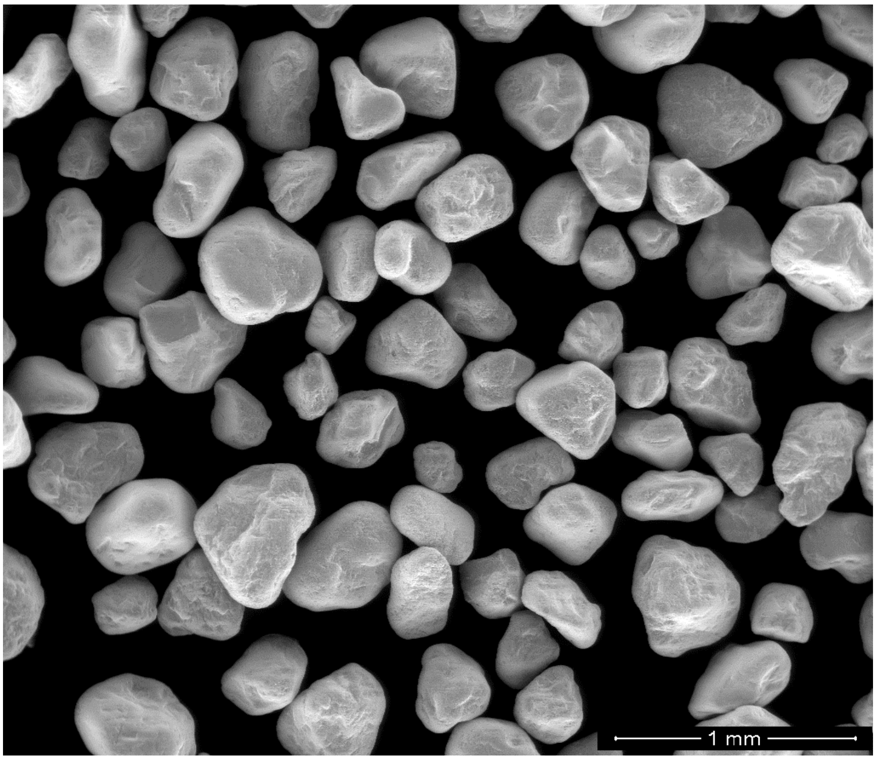

Figure 12. *Photomicrograph of Congleton sand, Cheshire*

The Lowestoft Formation in Suffolk is a chalky till that contains outwash sand and gravels (McMillan *et al*, 2011). It is extremely variable in thickness with a maximum up to 60m in buried valleys. It is worked at Blyth River Pit near Mells to produce building sand, foundry sand and sand for equestrian menage surfaces.

WHAT IS THE FUTURE FOR UK FRAC SAND?

Given that the scale of any shale gas development in the UK is likely to be modest in the near future, it seems likely that the UK has the resources and the production capability to meet the domestic demand for frac sand. The major silica sand producers in the UK, such as Aggregate Industries, Hanson Aggregates, Lafarge Tarmac and Sibelco, are all actively considering the potential to produce frac sand from their existing operations. Initially at least, frac sand production would probably come from increased production at their existing operations rather than new quarries. At this stage it is difficult to predict the amount of frac sand that would be required. The experience from production in the USA is that each well would require in the order of 2000 to 10,000 tonnes of frac sand depending on the length of the well and the number of hydraulic fracturing treatments. In the USA, the amount of silica sand used for hydraulic fracturing has increased dramatically over the last 10 years. In 2003, 1.3 million tonnes were used and in 2013 it was 29.9 million tonnes (United States Geological Survey, 2014). This represents an increase of 2300%.

The following estimates for the amount of frac sand required in the UK is based on the amount of sand used in the exploratory well at Preese Hall 2011 and a DECC commissioned SEA (strategic environmental assessment) (AMEC, 2013). At the Preese Hall well in 2011, 462.7 tonnes of frac sand was used in 8399.2 cubic metres (m^3) of water. Using a bulk density for sand of 1.7 tonnes per m^3 this is equivalent to 272.2m^3 of sand. This gives a volume of 3% sand in the hydraulic fracturing fluid. The DECC SEA (AMEC, 2013) considered the impact of different hydraulic fracturing scenarios. These scenarios considered the impact of 30 to 120 well pads each having 6 to 24 wells, with each well requiring 10,000 to 25,000 m^3 of water for hydraulic fracturing. In addition, it was considered that each well would be re-fractured once during its 20 year lifetime.

As shown in Table 3, the estimated amount of frac sand required for the lowest activity scenario would be 190,000 to 470,000 tonnes and 3 to 7.5 million tonnes for the highest activity scenario. Averaged over the 20 year lifetime of the wells, this represents a demand of approximately 10,000 to 24,000 tonnes of frac sand per year for the lowest activity scenario to 150,000 to 380,000 tonnes of frac sand per year for the highest activity scenario.

Number of pads	**Number of wells per pad**	**Total number of wells**	**Water required (m^3)**	**Sand required (m^3)**	**Sand required (tonnes)**
30	6	180	3,600,000 to 9,000,000	111,340 to 278,350	189,278 to 473,195
	24	720	14,400,00 to 36,000,000	445,360 to 1,113,402	757,112 to 1,892,784
120	6	720	14,400,00 to 36,000,000	445,360 to 1,113,402	757,112 to 1,892,784
	24	2880	57,600,000 to 144,000,000	1,781,444 to 4,453,608	3,028,454 to 7,571,134

Table 3. *Estimation of the amount of frac sand required for different hydraulic fracturing scenarios*

CONCLUSIONS

The UK is actively looking at the potential for the production of shale hydrocarbons (oil and gas). As a result, many companies in the UK extractive industry sector are looking to see how they could meet the potential future demand for frac sand if the development of shale hydrocarbons goes ahead.

The key parameters for frac sand are a high silica content (as quartz), a narrow particle size distribution, sand grains with a high sphericity and roundness, resistance to crushing and a low silt and clay content. Existing sand resources that meet these requirements do exist in the UK, with the closest parallel being those used to produce foundry sand.

The most likely sources for the future production of frac sand in the UK are the Upper Carboniferous sandstones in the Midland Valley of Scotland, the Lower Cretaceous sands and sandstones of eastern and southern England, and the Pleistocene sands of Cheshire.

It is difficult to predict the amount of frac sand that will be required. It depends on the number of wells that are drilled, their length and the number of hydraulic fracturing treatments carried out. Based on the scenarios envisaged as part of a DECC SEA, the amount of frac sand required could be as little as 10,000 tonnes per year or as much as 380,000 tonnes per year. Before this point is reached, many years of exploratory drilling and hydraulic fracturing are needed before the first shale hydrocarbon production goes ahead in the UK.

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