The API specifications set down for silica sand used in hydraulic fracturing, or fracing, are demanding. As *Mark Zdunczyk* of Continental Placer explains, suitable US deposits are limited and geology plays no small part in what makes the grade as a frac sand


Courtesy Norsk Hydro.

The facts of frac

IN RECENT YEARS the silica sand (industrial sand) industry has experienced some major changes in the processing and production of its many products. Two changes that the large producers are contemplating are expanding processing and exploring new deposits for frac or proppant sand.

The increased demand for energy, namely petroleum base products and natural gas, has driven oil and gas producing companies to stimulate older wells to increase flows. There are several methods to increase oil and gas flow to the well and, eventually, to the surface. One important method is hydrofracing. This is a combination of frac sand, a viscous gel and other chemicals forced down the well to prop open fractures.

The sands which are suitable for fracing must be from high silica (quartz) sandstones or unconsolidated deposits; well rounded; relatively clean of other minerals and impurities; fine, medium to coarse grain; and mineable.

The US Geological Survey (USGS) reported that the domestic sales of industrial sand and gravel in 2004 increased by about 6% from 2003 sales due to the buoyant construction sector in the USA. Total US production was estimated at 29m. tonnes and valued at about $646m. Only about 8% of production was hydraulic fracturing sand, or 2.32m. tonnes.

In the Rocky Mountain region it is estimated that about 1.1m. tonnes of sand is used annually, leaving about the same amount in the Texas-Oklahoma basin, if all figures and reports are accurate. Other reports indicate that worldwide frac sand usage is about 4.2m. tonnes.

Frac sand specifications

Frac sand specifications are set by the American Petroleum Institute (API). The primary considerations are the physical aspects of the sand. The API recommends specifications on size, sphericity, roundness, crush resistance and mineralogy.

Solubility and turbidity are also required, but a high silica sand is generally insoluble. High silica content sand, sphericity, roundness and crush resistance are the key factors in seeking a good frac sand.

Grain size

The API recommends the sizes as shown in *Figure 1*. The 20-40 mesh or 0.84-0.42mm size fraction is the most widely used size.

Figure 1. Some recognised size classes for proppant sands (adapted from Hoagberg & Koerner-Moore)

Mesh #	8/12	10/20	20/40	70/140
Screen size (mm)	2.38-1.68	2.00-0.84	0.84-0.42	210-105μ
US standard sieves	6	8	16	40
	8	10	20	70
	10	16	30	100
	12	20	40	140
	16	30	50	200
	pan	pan	pan	pan

Note: 90% to fall within size class designation. Not more than 1% of total sample on the first or last sieve in series

Sphericity and roundness

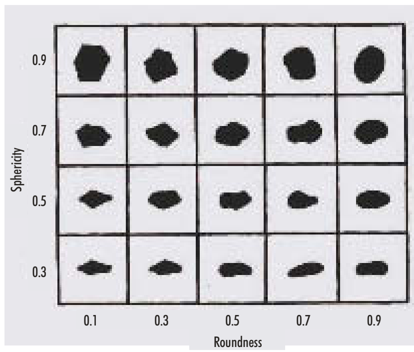
The API standards for sphericity and roundness of a quartz grain are simply an estimate of how closely the quartz grain conforms to a spherical shape and its relative roundness. The grain is assessed using the average radius of the corners divided by the radius of the maximum inscribed circle.

Figure 2 shows a comparison chart which relates to sphericity and roundness. The chart was devised by Krumbein and Sloss in 1955. API recommends sphericity and roundness of 0.6 or larger.

Crush resistance

Crush resistance is the resistance of a quartz grain under compressive loading. This is a function of grain brittleness, which correlates with grain shape, and the internal structure of the grain itself, as well as overgrowths on the grain.

Figure 2. Chart for visual estimation of sphericity and roundness (from Krumbein and Sloss)



API requires silica sand to withstand compressive stresses of 4,000 to 6,000 psi before it breaks apart or ruptures. The tested size range is subjected to 4,000 psi for two minutes in a uniaxial compression cylinder. In addition, API specifies that the fines generated by the test should be limited to a maximum of 14% by weight for 20-40 mesh and 16-30 mesh sizes. Maximum fines for the 30-50 mesh size is 10%. Other size fractions have a range of losses from 6% for the 70-40 mesh to 20% for the 6-12 mesh size.

Solubility

The solubility test measures the loss in weight of a 5g sample that has been added to a 100ml solution that is 12 parts hydrochloric acid (HCl) and three parts hydrofluoric acid (HF), and heated at 150°F (approx. 65.5°C) in a water bath for 30 minutes. The test is designed to determine the amount of non-quartz minerals present. However, a high silica sandstone or sand deposit and its subsequent processing generally removes most soluble materials (eg. carbonates, iron coatings, feldspar and mineral cements). API requires (in weight percent) losses of <2% for the 6-12 mesh size through to the 30-50 mesh size and 3% for the 40-70 mesh through to 70-140 mesh sizes.

Turbidity

Turbidity is the amount of silt/clay sized minerals in the sand sample. Turbidity is generally not a problem because during the processing of frac sand, the material is washed. In some cases, it is attrition scrubbed which eliminates not only the fines but weak and crusted grains as well.

Geology and frac sand

Frac sand must be >99% quartz or silica. Silica sand deposits are commonly mined for use in glassmaking, filtration media, blasting media, ceramic products, and fillers in a variety of other applications.

The silica sand industry in the USA and its deposits are well known. For many years, the larger silica sand companies have literally explored all potential silica sand sites for possible reserves and/or information purposes. In other words, most deposits in the USA have been discovered or, at least, are known to exist. Occasionally, a deposit is rediscovered as market circumstances change. For example, demand may increase in that market area or the sand in that deposit may be suitable for use in a new product.

High purity quartz sands are common throughout the USA. Some deposits are being mined, others have been abandoned, and still others are so remote that transportation costs render them unsuitable commercial sources.

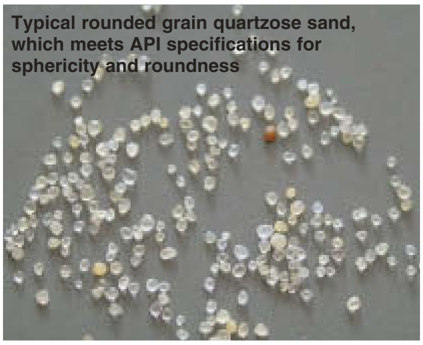
Finally, some deposits have environmental factors that limit mining and which cannot be overcome. Since frac sand has relatively narrow specifications – notably for roundness and sphericity of grains – many deposits in the USA are automatically unsuitable.

The unconsolidated east coast quartzose sands of the USA are geologically young. Those deposits being mined presently in the inner and outer coastal plain provinces have not been reworked sufficiently by geologic processes to acquire rounded grains.

These unconsolidated deposits are generally Cretaceous to Miocene in age (65m. to 2m. years old). Therefore, such deposits can be eliminated for possible frac sand production. The eastern consolidated quartzose sandstones are generally sub-angular to angular in grain shape, or sufficiently quartzitic (ie. interlocking grains) that they cannot be used for frac sand.

Formations such as the Oriskany, Clinch, Pottsville, Antietam, Chickes, Sharon, Sylvania and Berea, to name a few, are all being mined to some extent for silica sand. However, they cannot produce frac sand. These are older geologic deposits that have not been sufficiently worked by geologic processes to contain well rounded grains.

Furthermore, tectonic movements, depositional history, cementation and pitted grains have weakened the quartz grains. As a result, product from these deposits fails the crush resistance test. For example, the Antietam sandstone of Pennsylvania was found to have marginal roundness and sphericity results of almost 6.0. It was considered for use as a frac sand but could not meet the crush resistance test. It has been speculated that tectonic folding


Typical rounded grain quartzose sand, which meets API specifications for sphericity and roundness

of the sandstone exposed in the quarry led to stress on the quartz grains which caused them to become weak.

In the mid-continent, the somewhat friable (loosely cemented) quartz sand of the St. Peter and Jordan formations has long been mined to produce silica sand. Both formations have well rounded sand grains that meet the crush resistance test, as well as the other API tests for a suitable frac sand. These formations are geologically old (Cambrian to Ordovician) and are called supermature. Their deposition involved several geologic processes. The right conditions and sufficient time allowed the removal of weak quartz grains and most impurities before these formations were deposited.

Well rounded grains are the result of either many cycles of transport or intensive abrasion in a specific type of environment. The St. Peter formation has been studied at great length. Some geologists believed that the sand was transported from coastal aeolian (ie. wind blown) and fluvial-deltaic sources (ie. water borne) into the deeper waters of the inner shelf by a combination of shore face and river mouth by-passing mechanisms (Mazzullo & Ehrlich). Whatever its history, the St. Peter deposit has been worked and reworked in order to arrive at the present day grain shape.

The Jordan formation is equally geologically complex in its depositional history. The important factor here is that it is a supermature quartz arenite. The quartz grains have been abraded through fluvial and other high energy geologic processes, and this makes it suitable for frac sand.

Several other sandstones in the USA also produce frac sand. They are: Oil Creek, Oklahoma; the Hickory sandstone, Cambrian Riley formation, Texas; and, to some extent, the Bidahochi formation, Arizona. The Bidahochi formation is relatively young geologically. Therefore, it is used sparingly and in shallow wells.

Grain size variation

Whether the sand deposit is geologically young or old, consolidated or unconsolidated, or has a high silica or low silica content, grain size changes occur. When mining some of the deposits already mentioned, producers occasionally find that they cannot meet the size requirements needed by the customer. In multi-cyclic sandstones such as the St. Peter and Jordan formations, consistency of grain size is difficult to predict. Attempts to relate the size distribution of a sandstone to its depositional environment have had limited success.

Fluvial and tidal sand bodies commonly have upward declining grain size curves. Barrier islands have upward increasing size curves and marine sheet sands may increase or decrease depending upon whether the sand grains migrate shoreward or seaward (Pettijohn, Potter, and Siever).

Frac sand production

Again, specifications seem to determine how frac sand must be mined. The geological variations in frac sand deposits simply determine the product produced. The grain size variations in a deposit sometimes only allow certain size fractions to be produced at the processing plant.

If the silica plant is processing many products, the frac sand gradations may be compromised. For example, the 20-40 and 30-50 mesh grain size fractions can be utilised for many non-frac sand silica products. Therefore, the deposit may yield little 20-40 or 30-50 mesh, as production for other applications leads to lower frac sand output. In addition, poor processing resulting from not regulating the hydro-sizing equipment and screening process can reduce the availability of certain grain sizes.

US frac fundamentals

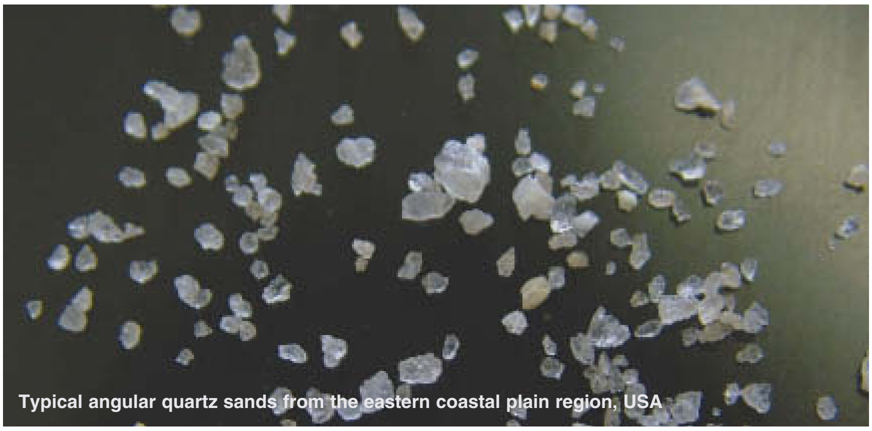
It is likely that in the USA there are only a few geological formations suitable for frac sand production. The strict specifications set by the API renders many high silica sand deposits quite literally useless for this application.

It seems that older quartzose sandstones have a better chance of providing the characteristics of a good frac sand. However, processing can upgrade some deposits if carefully controlled.

With the demand for frac sand increasing, deposit exploration can begin by simply comparing available sandstone formations for their silica content, grain size and roundness/sphericity. Once these have been established, a proper drilling programme can take place with sufficient sampling to perform the required crush resistance test. The deposit may have grain size and roundness, but if it does not meet crush test, then the deposit is of no use for frac sand. Other specifications, such as turbidity, can easily be controlled.

Ten facts of frac

- There is a limited amount of mineable sandstone and unconsolidated sands that meet all specifications set by API
- Geology plays a significant role in whether a deposit will meet API specifications
- Careful mine planning and geological exploration of new and old (already mined) deposits may increase yields of necessary grain sizes
- Some deposits, or more specifically the quartz grains in the deposits, can be upgraded to meet specifications by surface coating the grains
- A cloudy, crusted grain may correlate with fractures within the grain which causes brittleness and, therefore, weak grains
- Most high content quartz (silica) deposits in the USA are known. Exploration should concentrate on these known deposits and their geological equivalents
- Processing sand sometimes causes size distribution problems when making other silica sand products
- Geologically, older sandstones of Cambrian-Ordovician age seem to be the most suitable for frac sand
- Unconsolidated quartzose sands generally cannot meet all API specifications
- As energy consumption of petroleum base fuels and natural gas increases, the demand for frac sand will also increase


Typical angular quartz sands from the eastern coastal plain region, USA

References

American Petroleum Institute, 1995. Recommended practices for testing sand use in hydraulic fracturing operations. API recommended practice 56, 2nd edition.
Hoagberg, R. K. and Koerner-Moore, J. 1980. Silica sand proppants used in well stimulation. Sixteenth Forum on Geology of Industrial Minerals, St. Louis, Missouri.
Krumbein, W. C. and Sloss, L. L. 1963. Startigraphy and sedimentation, 2nd Edition. W. H. Freeman and Co., San Francisco, p. 1 and 2.
Mazzullo, J. M. and Ehrlich, R. 1983. Grain shape variation in the St. Peter sandstone: a record of Eolian and fluvial sedimentation of early Paleozoic cratonic sheet sand. Journal of Sedimentary Research, March 1983, v. 53; no. 1; p. 105.
Pettijohn, F. J., Potter, P. E., and Siever, R. 1972. Sand and sandstone. Springer Verlag, New York, p. 87.

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