Potential Use of North Dakota Sand and Clay for Natural and Manufactured Proppants

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The overwhelming success of the Bakken/Three Forks oil play in North Dakota can be greatly, if not wholly, attributed to the advances in hydraulic fracturing of "tight" reservoir rock. As part of the hydraulic fracturing process, proppants (commonly natural sands and manufactured ceramic spheres) are used to keep the fractures that are created open for the enhanced flow of oil and gas from the fractures into the wellbore. A typical hydraulic fracturing stimulation operation in the Bakken in North Dakota requires anywhere from 100 to 500 tons of proppant per well: roughly 150 tons on average. The North Dakota Geological Survey has been investigating North Dakota's sand and clay resources in an effort to better characterize deposits that could potentially be used as proppants. Specifically, we are attempting to locate useable deposits of sand (and potentially clays) for hydraulic fracturing and other industrial sand applications in the Williston Basin.

Sand (and gravel) is widespread throughout North Dakota, although most is in the glaciated part of the state, where it is found in glaciolacustrine beach deposits, glaciofluvial (outwash) and modern stream deposits, and early to mid-Holocene dune fields. Most of the sand and gravel currently mined in North Dakota is used in construction and road building.

Synthetic proppants are manufactured from a variety of materials and include aluminosilicate ceramics derived from the sintering of bauxite (aluminum oxide) and kaolinite. As part of our study, therefore, we are also looking at some of North Dakota's kaolinitic clays as potential raw materials for the manufacture of ceramic proppants.

Progress of Investigation

Over 100 sand locations were sampled from across the state for this study (fig. 1). We have identified the leading sand deposits based upon grain size, sorting, and roundness. Detailed sedimentological and engineering analyses are planned for the best candidate sands.

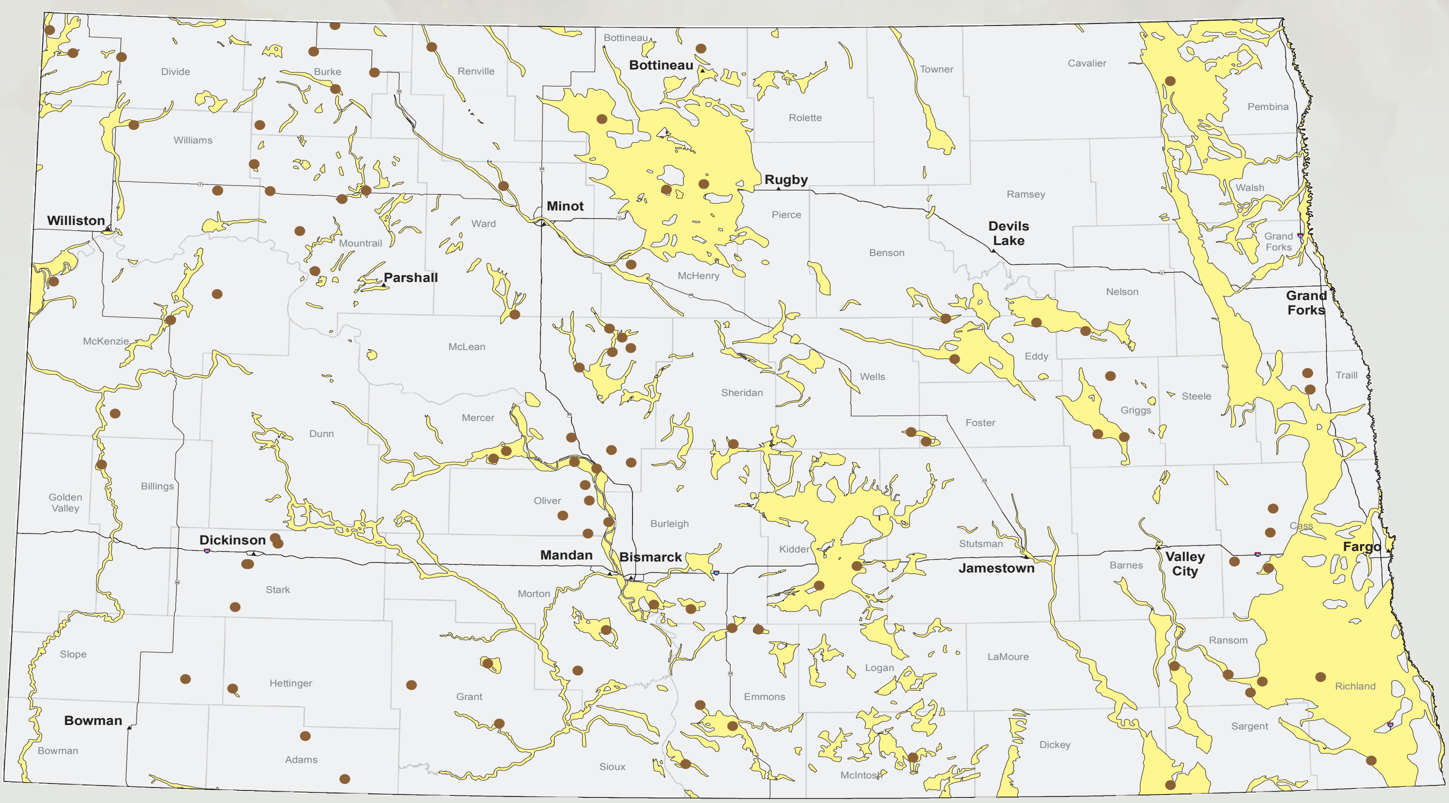

Figure 1. The sand and gravel resources of North Dakota (yellow) and locations of sand samples (brown dots) collected for possible use as proppants for the hydraulic fracturing of oil wells in the Bakken and Three Forks plays in the Williston Basin (modified from Anderson, in press).

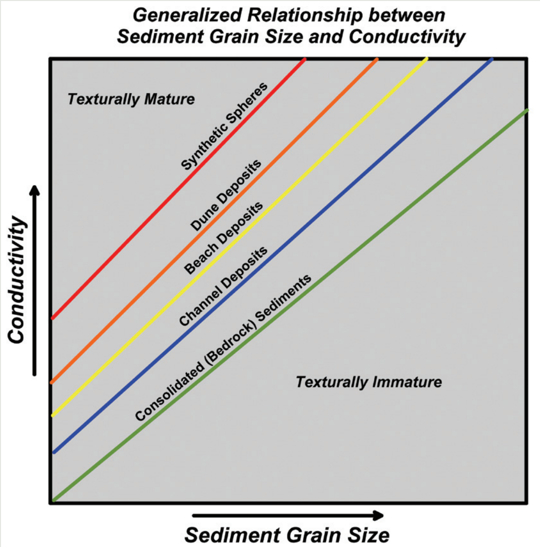

Figure 2. Generalized relationships between grain size and conductivity (permeability) of a sediment (modified from Shepherd, 1989).

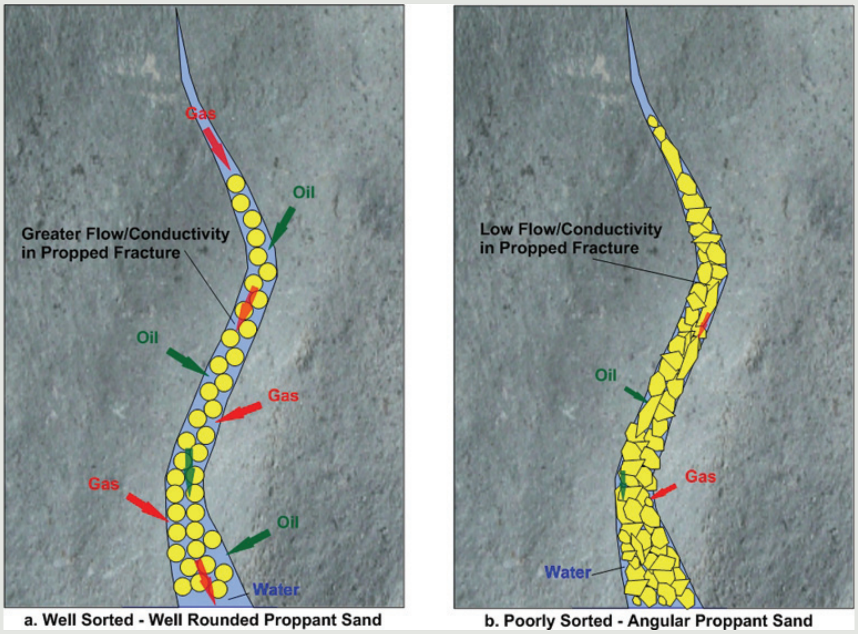

Figure 3. Schematic of an open "propped" rock fracture with proppant placed within the aperture of the fracture. Proppants that are more consistent and well-rounded as in **(a)**, allow for greater interconnected pore space and facilitate a larger amount of flow (higher permeability) of oil and gas out of the reservoir rock and into the fracture(s) and wellbore. Proppants that are less consistent and have poor shape factors as in **(b)**, (higher degrees of angularity) tend to pack better but result in less interconnected pore space and lower permeabilities, which results in less flow of oil and gas into and through the fracture.

Members of North Dakota's sand and gravel-producing industry are also participating in this evaluation, and several producers have submitted sand samples for consideration. The results of this study will be communicated to industry through publication of the investigation results in 2011.

We are also characterizing these samples for use in other industrial sand applications including well completion materials (filter & gravel packs), filter media, and foundry practices. The production of industrial sands as viable economic deposits generally requires materials that are usually more consistent in character, are available closer to the land surface, and require minimal processing (screening and washing). Having a better understanding of some of the characteristics of our state's sand and clay resources is advantageous to both industry and the people of North Dakota.

Proppant Characteristics

Proppants are characterized by what they are; that is, their physical properties, and how they perform (in bulk) within the fractured oil & gas reservoir; in other words, their ability to enhance and facilitate flow (permeability) in a propped fracture. Permeability may be thought of as the rate (distance per unit time) at which a fluid (oil, gas, water) can move through a particular sediment or rock. It is commonly measured in cm/sec, feet/day or the darcy, after French engineer Henry Darcy, whose pioneering work on fluid flow led to the discovery of the law that is named after him (Darcy, 1856). Texturally mature sediments generally have higher permeabilities (fig. 2) than less texturally mature sediments. As a relevant everyday example here in North Dakota, the Bakken Formation exhibits permeabilities in the micro (10^{-6}) darcy range (Nordeng, oral commun., 2010). By comparison, oil and gas reservoirs worldwide typically have permeabilities ranging from 5 to 500 millidarcies (Selley, 1998). The only way to liberate oil and gas from a "tight" reservoir like the Bakken is by hydraulic fracturing (fig. 3).

Geologic factors such as reservoir depths, temperatures, and pressures all relate to a proppant's ability to withstand fracture closure within the reservoir. The closure strength is the amount of strain that can be taken up by the proppant before it fails to keep the induced fractures open during production from the reservoir. When natural proppants fail, particularity when used in the Bakken Formation, individual sand grains may actually fracture under the high stresses and temperatures within the formation/reservoir (Vincent, 2010a & 2010b). These kinds of geologic factors are critically important to understand when designing fracing operations where significant reservoir depths, temperatures, and closure stresses are anticipated.

Figure 4. Outcrop of the St. Peter Sandstone near Ottawa, Illinois. The higher degrees of sorting and mineralogical maturity of these Ordovician-age white "Ottawa" deposits allow for their economical production for use as proppants and in other industrial applications.

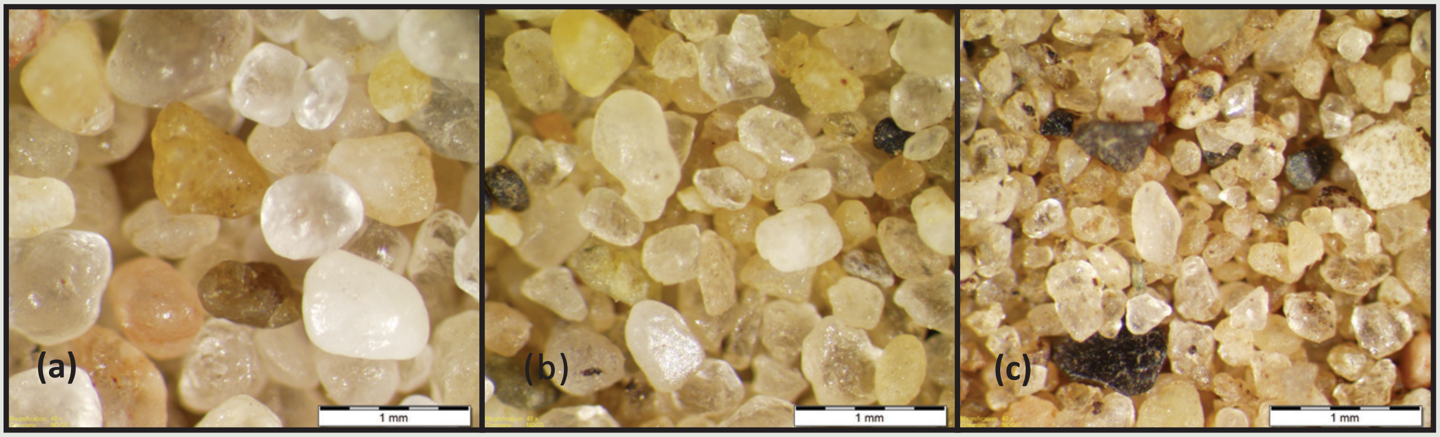

Figure 5. Photomicrographs of **(a)** an out-of-state proppant sand currently in use in the Williston Basin, **(b)** a North Dakota sand processed for use as a proppant, and **(c)** dune sand from Pembina County. All images are at 40x magnification.

Natural Proppants

Most natural sand proppants are sourced as two types: "white" and "brown." "White" or Ottawa sands (referring to their primary source area around Ottawa, Illinois) (fig. 4) are mined in parts of the upper Midwest from quartz-rich Cambro-Ordovician sandstones that are characterized by their exceptionally high degrees of purity and textural maturity. These sands were originally deposited in a shallow marine environment where geologic factors such as weathering, erosion, and repeated refinement in the surf zone have resulted in texturally mature sandstones that are composed almost entirely of quartz. "Brown" or Brady sands are found in deposits located in Texas. Because they are somewhat mineralogically and texturally less mature than Ottawa sands, Brady sands are washed during processing to remove impurities such as clays and feldspars. Natural sand proppants (figs. 5a and b) are used mainly in shallow operations where fracture closure stresses in the reservoir rock are relatively low.

Because North Dakota's sand deposits are so geologically young, they are much less mature, both mineralogically and texturally, meaning that they consist of compositionally more varied, less rounded, less well sorted grains than most sands commonly used in hydraulic fracturing. Potential proppant sands will most likely be found in the better-sorted deposits, which tend to be of windblown origin, like the Denbigh or Pembina Dunes (figs. 5c and 6); or fluvial sediments where geologic processes have selectively removed some of the coarser and finer grained sediments (for example, a sand bar).

Figure 6. Sand dune from the Pembina Dunes in northeastern North Dakota. Small-scale wind ripples are visible on the exposed dune surface, indicative of recent wind activity.

Synthetic or Manufactured Proppants

Synthetic, or manufactured proppants are designed to perform under specific reservoir conditions (high pressures and temperatures coupled with high fracture closure stresses) and can be engineered to perform more favorably in hostile reservoir conditions than natural proppants. Specialty aluminosilicate ceramics, made from sintered blends of bauxite and kaolinitic clays, are one example (fig. 7). Several North Dakota clays, including those from the Bear Den Member of the Golden Valley Formation are being evaluated as potential candidates for the manufacture of these types of ceramic proppants. The Bear Den Member of the Golden Valley Formation is a multi-colored kaolinitic claystone that outcrops in several localities throughout Dunn, Mercer, Morton, Mountrail, and Stark Counties in western North Dakota (fig. 8). The Bear Den Member has been used for decades in the manufacture of bricks by the Hebron Brick Company (Murphy, 2009).

One of the key drivers in proppant selection and use is cost. Natural proppants, when appropriate and available, arguably provide a more cost-effective solution than a custom-designed and shipped synthetic or manufactured proppant. However, since there may

Figure 7. Photomicrograph of sintered bauxite ceramic proppant spheres used in the hydraulic fracturing of oil reservoirs. The uniformity of individual particle shapes combined with higher material strengths, specific gravities, and thermogenic resistance have resulted in the extensive use of ceramic proppants (including this one) in Bakken reservoir-related hydraulic fracturing and refracturing applications.

be a bit more variability in the character of a natural proppant, it may prove difficult to predict expected well performance from frac to frac, or within multiple fracs in a given well.

Development of Proppants in North Dakota

Whether or not a particular deposit of sand or clay can be utilized as a source for proppants, depends on several additional factors, including the proximity of deposits to locations where hydraulic fracturing is taking place, and the degree of natural beneficiation in the deposit; that is, how many natural cycles of refinement the deposit has been exposed to over time. For example, if the deposit is texturally and mineralogically mature, there will be less processing required to produce a given amount of marketable material (fig. 9). This also plays into costs, as the less effort one needs to put into the refining of the deposit, the less money is spent bringing the material "up to spec" and down the road to market. One current market-related aspect that is interesting (and timely) is the fact that, across the nation, the availability of proppant sands from their principal source areas appears to be declining as developing gas plays in the eastern U.S. increase their demand. In addition, ceramic proppants will most likely continue to be imported into the Williston Basin from overseas markets, as more and deeper oil and gas development occurs across the nation (Besler, oral commun., 2010).

Figure 8. Outcrop of the colorful Bear Den Member of the Golden Valley Formation in Dunn County. The Bear Den Member is found in several areas in the heart of the ND portion of the Williston Basin and is known to contain intervals rich in kaolinite (Murphy, 2009).

Since most, if not all, of the currently available natural sand resources are being shipped east for the stimulation of oil and gas reservoirs in Appalachia (especially the Marcellus Shale in Pennsylvania and New York), operators in the Williston Basin may be willing to take what is most readily available and economical as a bit of a frac-design/well production trade-off. Some have suggested that overall production from Bakken wells stimulated with ceramic proppants may be as great as 30% higher than those stimulated with natural (sands) proppants.

Overall, North Dakota's sand, and possibly clay resources, are locally abundant, readily available, and contain a sufficient variety of mineralogical character to allow for a diverse array of potential industrial applications. Creativity in end use, facilitated by producers in industry, will drive the development of North Dakota's sand and clay resources. With an estimated need of 3 million or more tons* of proppants (around a couple of billion dollars at today's prices!) to support full development of the Bakken, gaining a better understanding of our possibilities for the production of natural and manufactured proppants is prudent and beneficial for all of North Dakota.

Figure 9. A sand and gravel processing operation in northern Burleigh County. This plant produces materials for a number of industrial applications in North Dakota.

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* Roughly 60 million cubic yards or the volumetric equivalent of filling the tower of the North Dakota state capitol twenty-six times!