INVESTIGATION OF SAND RESOURCES IN NORTH DAKOTA: SEDIMENTOLOGICAL CHARACTERIZATION OF SURFICIAL SAND DEPOSITS FOR POTENTIAL USE AS PROPPANT

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NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
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On the cover: Photomicrograph (25x) of eolian sand from the Denbigh Dunes area (Sample No. 3 this report) in northeastern McHenry County, North Dakota.

Executive Summary

An investigation into the potential use of sands found in North Dakota as natural proppants for use in the hydraulic fracturing of oil and gas wells in the Williston Basin was conducted during the 2009-2011 biennium. The intent of this investigation was to characterize selected sand sources for potential use as proppants by using applicable testing methodologies recommended for the testing and evaluation of natural sands as proppants as published by the International Organization for Standards (ISO), the American National Standards Institute (ANSI), and the American Petroleum Institute (API), and current oil and gas industry engineering practice. Selected sand samples were obtained from private landowners, members of the sand and gravel producing industry, and by the N.D. Geological Survey (NDGS) from sand sources across North Dakota (Figure 1) in the Oahe Formation (Holocene), Coleharbor Group (Pleistocene), and Bullion Creek Formation (Tertiary). Ten samples, representing a broad variety of sand types found in the state were submitted for testing and characterization for potential use as natural proppant sands (Table 1). Test results included the: determination of grain-size distribution via sieve analysis on bulk (Figure 2) and selected sized samples, determination of sand crush resistance and HCL-HF acid solubility, determination of particle shape factors of individual grain sphericity and roundness, sand sample turbidity, and sand density determinations including bulk and apparent (i.e. specific gravity) densities. Overall, testing indicated fines, the percent loss on sample prepatory wash from bulk samples, from 4.1 to 30%. Testing and analysis results on eight prepared 30/50 and two 40/70 sized samples indicated crush resistance values ranging from <2,000 to 5,000 psi, HCL-HF acid solubility ranging from 5.9 to 56.8%, average sphericity and roundness values of 0.6 and 0.56, respectively, ISO mean particle diameters ranging from 0.239 to 0.465 mm, median particle diameters ranging from 0.236 to 0.455 mm, turbidities ranging from 8 to 85 FTU, with bulk densities ranging from 75.5 to 91.7 pcf with an average specific gravity of 2.63 g/cm^3. Four of the ten samples tested reported percent clusters at ~1/100 (Table 2). XRD mineralogy on five of the ten samples reported total clays ranging from 1 to 14% with smectite being the dominant clay mineral (Figure 3). Total silicates range from 81 to 98% with quartz ranging from 45 to 68%. Total carbonates range from 1 to 16% with dolomite ranging from 4 to 10%, and iron minerals reported from trace amounts up to 1%.

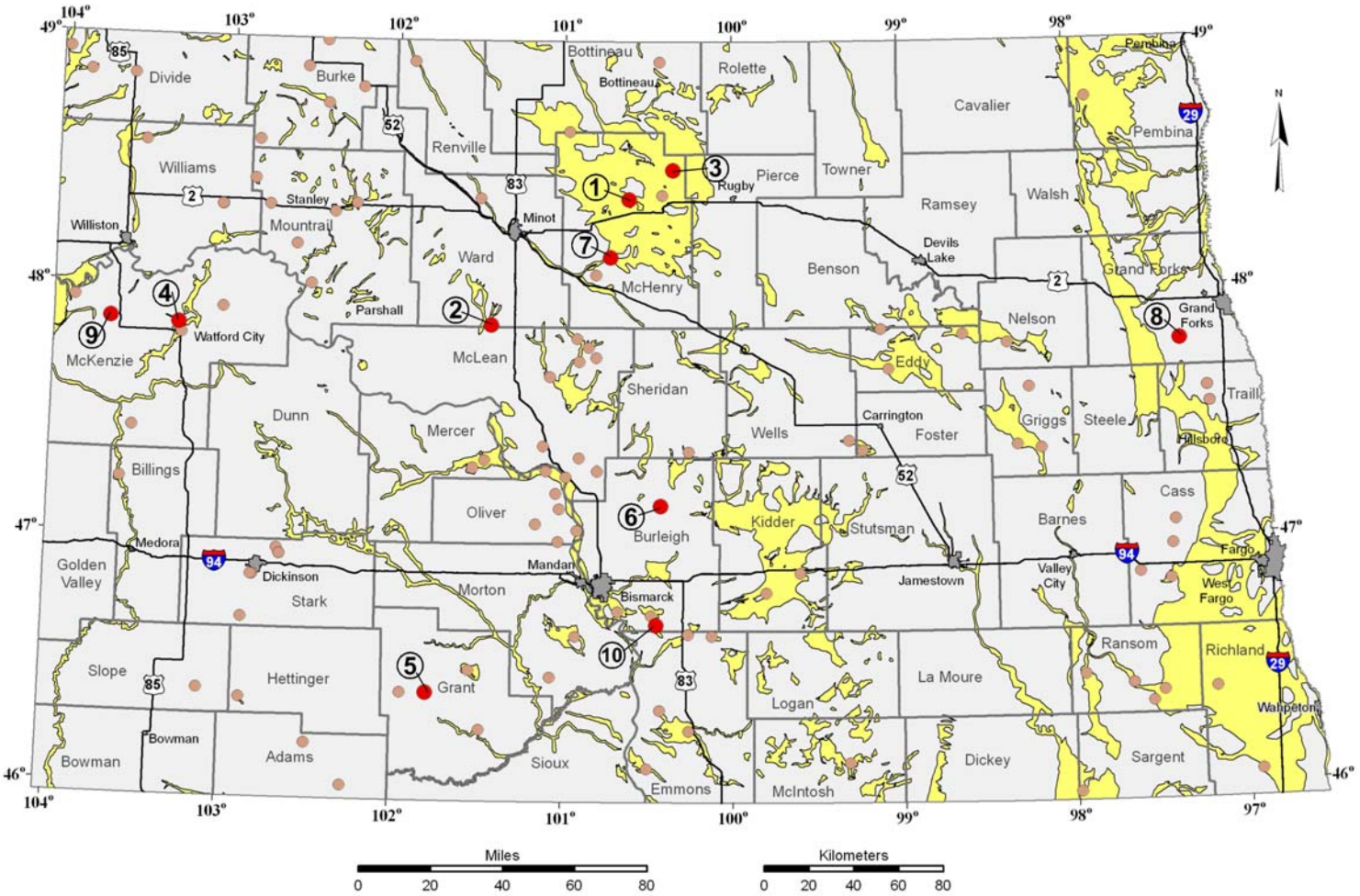

Figure 1. Locations of N.D. surficial sand resources (yellow) along with the locations of sand sources sampled throughout the state (brown circles) as a part of this investigation along with the locations of selected sand samples submitted for testing and characterization for potential use as proppant (numbered red circles).

Table 1. Location and Description Summary of Selected Sand Samples Submitted for Testing.

No.	County	Location (T., R., Sec.)	Geologic Map Unit	Geologic Map Unit Description
1	McHenry	156-77-6	Qod	Windblown Sand (Holocene)-Well-sorted, medium sand with obscure bedding; poorly developed paleosols common; as thick as 30 feet (10 meters); knobby topography consisting of inactive transverse or longitudinal dunes nearly obliterated by more recent blowouts.
2	McLean	151-84-33	Qcrh	Collapsed river sediment-(Holocene to Pre-Wisconsinan)-Moderately well sorted cross-bedded sand and plane-bedded gravel, including sediment of melt-water and other rivers; as thick as 100 feet, faulted and contorted supraglacial sediment with hummocky topography.
3	McHenry	158-75-28	Qtou	Sand of the Oahe and Older Formations, Undivided (Holocene to Pliocene)-Windblown sand of the Oahe Formation, as thick as 10 feet, and sand of older formations with an undulating wind-scoured surface.
4	McKenzie	150-99-1	QTu	Quaternary and Upper Tertiary Sediment, Undivided-Largely river sediment; includes upper Quaternary terrace, fan, and pediment derived material such as sandstone, silicified wood, and concretions and Pliocene(?) to middle(?) Quaternary clay, silt, sand, and gravel composed of rounded pebbles and cobbles of quartzite and porphyry derived from the Black Hills or Rocky Mountains; as thick as 300 feet.
5	Grant	134-88-31	Tb	Bullion Creek Formation (Paleocene) - Yellow-Brown silt, sand, clay, sandstone, and lignite; river, lake and swamp sediment as thick as 600 feet.
6	Burleigh	142-77-10	Tb	Bullion Creek Formation (Paleocene) - Yellow-Brown silt, sand, clay, sandstone, and lignite; river, lake and swamp sediment as thick as 600 feet.
7	McHenry	154-78-29	Qcrf	Uncollapsed River Sediment-Flat-bedded sediment of gently sloping plains and terraces, commonly with braided-channel scars
8	Grand Forks	150-52-29	Qcew	Wave-Eroded Glacial Sediment-Glacial sediment with flat to gently undulating topography resulting from wave erosion; covered by a thin gravel lag in places.
9	McKenzie	151-102-35	Qcdn	Draped Glacial Sediment-Thin glacial sediment draped over and only slightly modifying the non-glacial topography existing before the last glacial advance.
10	Burleigh	137-77-30	Tc	Cannonball Formation (Paleocene)-Olive-brown sand, shale, and sandstone; marine shoreline and offshore sediment; as thick as 400 feet.

Geologic map unit descriptions from the Geologic Map of North Dakota (Clayton et. al., 1980).

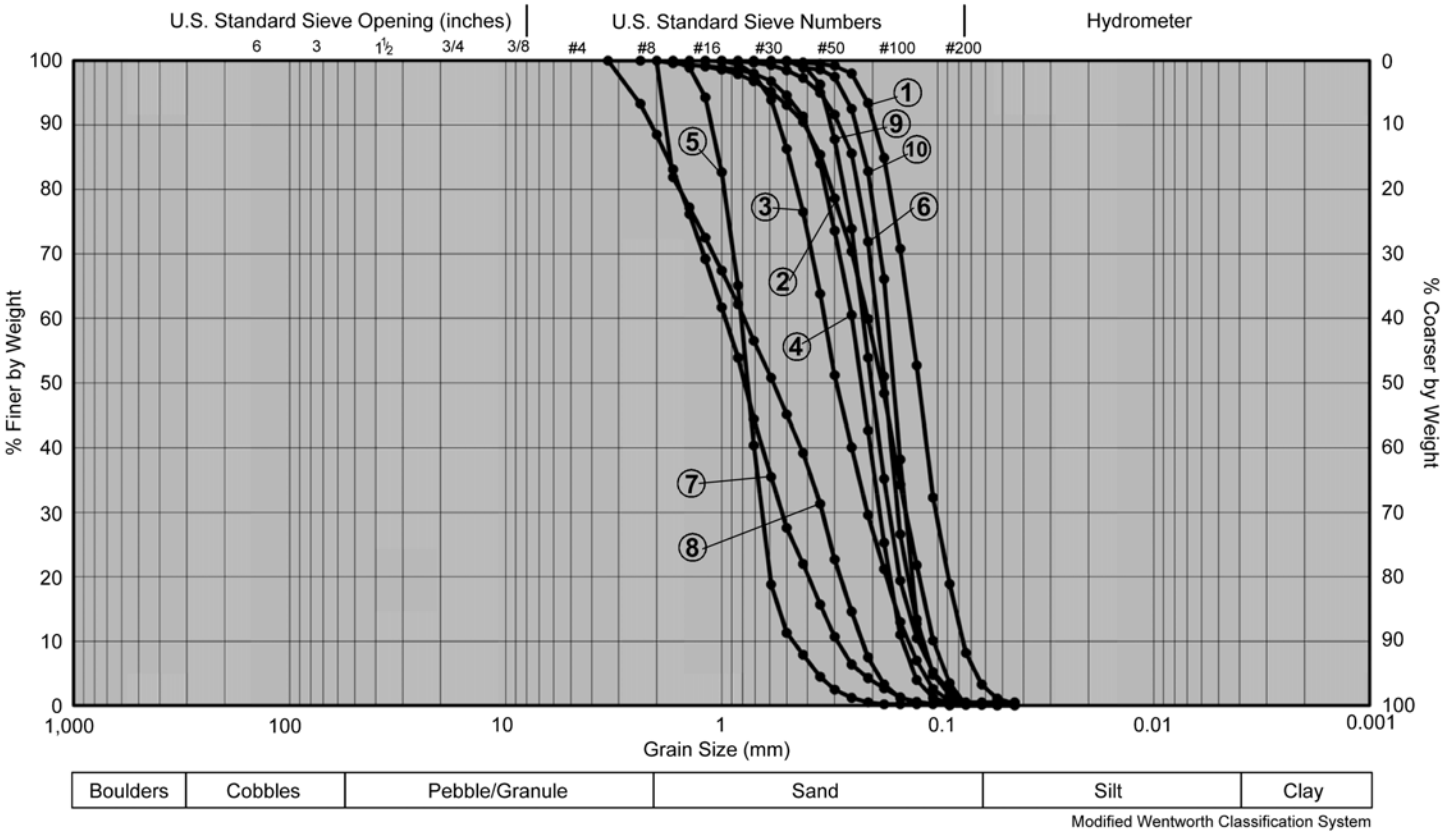

Figure 2. Bulk sample grain-size distribution curves for the ten N.D. sand samples tested and characterized for potential use as proppant. Each curve is labeled with the corresponding sample number.

Table 2. Proppant Testing Analytical Summary - Selected Sands in North Dakota

Sample No.	Tested Size Cut	Crush Resistance (K-Value)	Acid Solubility (%)	Sphericity	Roundness	ISO Mean Particle Dia. (mm)	Median Particle Dia. (mm)	Turbidity (FTU)	% Clusters	Bulk Density (g/cm^3)	Bulk Density (pcf)	Specific Gravity (g/cm^3)
1	40/70	<2K	16.6	0.6	0.5	0.239	0.236	85	~1/100	1.23	76.8	2.58
2	30/50	4K	6.4	0.7	0.6	0.394	0.386	8	NIFC	1.44	89.9	2.63
3	30/50	5K	6.4	0.6	0.5	0.428	0.418	18	NIFC	1.44	89.9	2.65
4	30/50	2K	10.7	0.6	0.6	0.388	0.380	20	NIFC	1.33	83.0	2.63
5	30/50	5K	5.9	0.6	0.6	0.465	0.455	16	NIFC	1.47	91.7	2.62
6	30/50	<2K	56.8	0.6	0.6	0.383	0.374	36	~1/100	1.07	66.8	2.68
7	30/50	4K	17.1	0.6	0.6	0.443	0.433	25	~1/100	1.41	88.0	2.67
8	30/50	4K	13.7	0.6	0.6	0.421	0.411	28	~1/100	1.41	88.0	2.64
9	30/50	<2K	7.9	0.6	0.5	0.367	0.362	10	NIFC	1.32	82.4	2.62
10	40/70	<2K	8.9	0.6	0.5	0.245	0.243	72	NIFC	1.21	75.5	2.61

K-Value is defined as the highest stress level which proppant generates no more than 10% crushed material, rounded down to the nearest 1,000 psi.

FTU = Formazin Turbidity Unit.

NIFC = No clusters observed in field of count.

pcf = pounds per cubic foot.

Proppant testing services were provided by Stim-Lab, Inc., Duncan, Oklahoma. Current testing specifications and recommendations for natural sand proppants, characterized for use in the hydraulic fracturing of oil and gas wells, are summarized below and include the following parameters:

Grain-Size Distribution (Sieve Analysis) - It is recommended that a minimum of 90 percent of tested sand fall between designated sieve sizes, meaning that for a 30/50 sized sand, 90 percent would pass the coarser primary sieve (i.e. the No. 30 sieve), and be retained on the finer secondary sieve selected (i.e. the No. 50 sieve). All selected sized samples (i.e. 40\70, 30\50) tested met this criterion.

Crush Resistance - A sand samples resistance to crushing is an important characteristic in comparing different types of proppant sand and is performed by subjecting a particular sand sample to a predetermined level of stress and measuring (in percent by weight) the amount of crushed material (i.e. fines) generated in a two inch diameter piston-crushing cell. A crush resistance K-value is determined as the highest stress level at which no more than 10% crushed material is generated (rounded down to the nearest 1,000 psi). Reported K-values are all dominantly less than 5K with five samples (No.1, 4, 6, 9 & 10) returning values of 2K or less. For a natural sand proppant sized at 30/50 it is recommended that no more than 10% fines are generated, when subjected to an applied stress of 4,000 psi. For a natural sand proppant sized at 40/70 it is recommended that no more than 8% fines are generated, when subjected to an applied stress of 5,000 psi. Samples 2, 3, 5, 7 & 8 met this criterion.

Acid Solubility - Evaluation of the solubility of sand in a 12-3 hydrochloric (HCL)-hydrofluoric (HF) acid gives a measure of the amount of undesirable and potentially deleterious "contaminants" present such as: carbonates, feldspars, iron oxides, and clays that are found in the sand. It is recommended that for sands sized in the range from 6/12 to 30/50 contain no more than two percent (by weight) HCL-HF soluble constituents, and for sands sized in the range from 40/70 to 70/140 contain no more than three percent (by weight) HCL-HF soluble constituents. None of the samples tested met this criterion.

Sphericity and Roundness (Particle Shape Factors) - Natural sands used in the hydraulic fracturing of oil and gas wells are recommended to have particle sphericity and roundness values of 0.6 or greater as determined by visual-manual comparison of sand grains under the microscope or through evaluation of suitable photomicrographs. Sample Nos. 1, 3, 9, and 10 were near but did not meet this criteria. Percent clusters are recommended to be less than 1\100 within the field of count.

Turbidity - The amount of suspended clay, silt, or finely divided organic sediment in water is a measure of a sands turbidity. It is recommended that natural sands used as proppants have turbidity values no greater than 250 Formazin Turbidity Units (FTU). All samples tested met this criterion.

Mineralogy - In order to provide an understanding of overall mineralogical character of tested sand that is being evaluated for use as a proppant, a qualitative mineralogical analysis by X-ray diffraction (XRD) methods is recommended (Figure 3). Evaluations of relative peak heights are to be used to estimate the amount of clays present, in addition to the reporting of any minerals found at levels above about one percent. For comparison, quartz percentages for Ottawa "white" type sands are commonly around 99%.

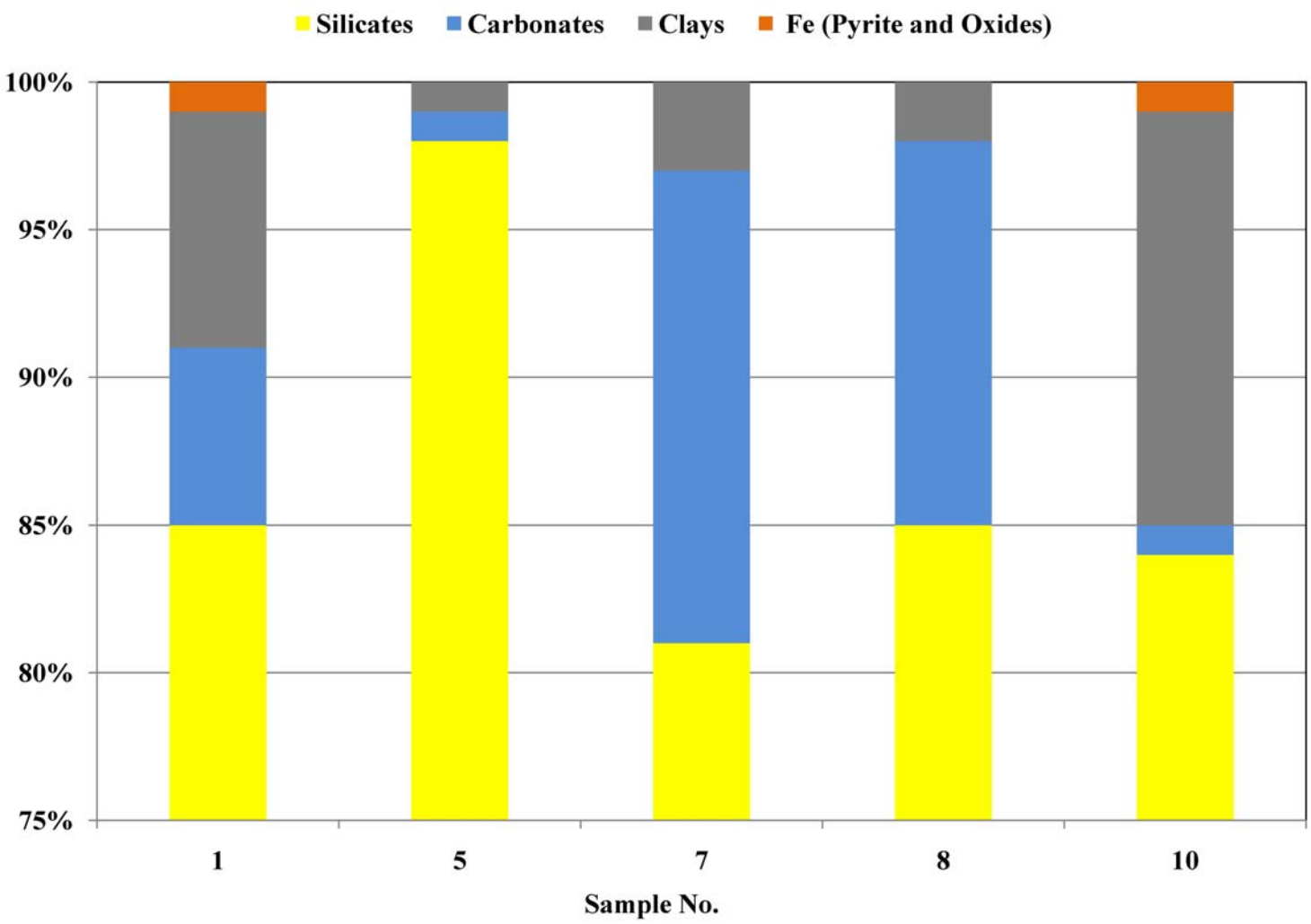

Figure 3. Bulk mineralogical composition of selected sand samples as determined from X-Ray Diffraction (XRD) analyses.

Based on the results of the sand testing and characterization work completed during this investigation, it is concluded that the production of usable quantities of natural sands from tested sources for use as proppant, would likely require several mechanical processing and chemical refinement steps (with anticipated high amounts of bulk volume loss) in order to produce viable amounts of natural sand proppant. The information contained in this report will be beneficial in the continued characterization and evaluation of sand (and gravel) resources for use in other industrial applications. It should be noted that the consideration of a "multiple markets approach" in the development of North Dakota's mineral resources is beneficial and fosters good stewardship of our natural resources.