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GEOLOGICAL SURVEY PROGRAM
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OIL AND GAS INVESTIGATION 4

REPORT ON REMNANT MATERIALS AT A FORMER SAND AND GRAVEL MINING OPERATION NEAR VEBLEN, SOUTH DAKOTA

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2012

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CONTENTS

Page

ABSTRACT 1

INTRODUCTION 1

Characteristics of hydraulic-fracturing sand 1

Area geology 4

Topography and site description 5

Description of aggregates at the former mine site 5

Boulder piles 7

Mixed-particle size mounds 8

Other aggregate materials 8

METHODS 10

Sample collection 10

Sample analysis 12

RESULTS 14

Field results 14

Particle-size distribution 16

Particle mineralogy 16

DISCUSSION 21

Particle sizes 21

Estimated mineralogy 21

CONCLUSIONS 21

ACKNOWLEDGEMENTS 22

CONTENTS – continued Page

REFERENCES 23

FIGURES

1. Location of mine site #807001, Marshall County, South Dakota 2
2. Silica sand used in hydraulic fracturing 3
3. Surface geology south of Veblen, South Dakota 4
4. View of the mine wall in the northwestern area 5
5. Reclamation boundaries at mine site #807001 6
6. View toward the southwest from the entrance gate 7
7. Boulders of igneous and metamorphic rock compositions 7
8. A cream-colored limestone boulder of sedimentary origin 7
9. Mounds of mixed-particle size material 8
10. View from the “sandbox” sand pit to the southwest 9
11. Railroad ballast pile 9
12. Close-up of the railroad ballast/crushed boulders 10
13. Sample locations superimposed on mine site #807001 11
14. Highly weathered cobble 12
15. White scratch at sample location 2 15
16. Iron oxide precipitation at sample location 6 15
17. Sparse to moderate, ubiquitous, vegetative cover 15
18. Ravine and erosion 15
19. Small gully forming on mine floor 16
20. Sieved, unwashed coarse sand 19

FIGURES – continued Page

21. Sieved, washed coarse sand with individual minerals identified 19

22. Chart for estimating percentage composition of rocks and sediments 20

23. Comparison of sands 22

TABLES

1. Relationship between particle sizes and particle names 3

2. Location and sample information 12

3. Relationship between selected sieve-size numbers, range of particle diameters, and particle names 13

4. Weight and percent of aggregate greater than 2 millimeters in diameter 17

5. Weight of the smaller-than-gravel portions 17

6. Sample portion percentages 18

7. Percent of estimated quartz in coarse sand portions 20

APPENDICES

A. Sample information 24

B. Coarse sand portion (1/2 mm – 1 mm) photographs 34

ABSTRACT

The Geological Survey Program, Department of Environment and Natural Resources, was asked by the Minerals and Mining Program, Department of Environment and Natural Resources, to characterize remnant material from a former sand and gravel mining operation in Marshall County, South Dakota. The purpose of this investigation was to evaluate if some of the remnant material could be considered for use as a source for sand that could be used in hydraulic fracturing.

The former mining operation identified as mine site #807001 by the Minerals and Mining Program was visited by Geological Survey Program staff with the land owner, Mr. Tollefson, on June 12, 2012. With an emphasis on sand-sized material, the most abundant remnants present were found to be large mounds of mixed-particle sizes (silt, sand, gravel, and cobbles). Several samples were collected and analyzed for particle-size distribution and for the presence of significant quartz content.

The results of these two types of analyses indicate that, although some sand sizes commonly used in hydraulic fracturing are present, the mineralogical results are sufficient to eliminate all remnant material for use as a possible sand source for hydraulic fracturing because none of the samples contain more than 50 percent quartz.

INTRODUCTION

This report presents the results of an investigation of an abandoned sand and gravel mining operation for its potential as a source of sand (proppant) for use in hydraulic fracturing. The location of the abandoned operation is in northeastern Marshall County, South Dakota, approximately 3.5 miles south and 1 mile east of the town of Veblen at NW¼ sec. 11, T. 127 N., R. 53 W. (fig. 1). This mine site is identified by the Minerals and Mining Program as mine site #807001.

Characteristics of Hydraulic-Fracturing Sand

Sand consists of particles that are commonly described in terms of their texture, and one measure of texture is particle size. The Wentworth scale is used as a means to standardize particle size terminology. The relationship between the measured diameter of a particle and its name is shown in table 1. For example, a particle with a diameter of ¾ inch or 0.75 millimeter (mm) is called coarse sand. The most common method of measuring sand size is by sieve analysis which is explained in the METHODS section of this report.

Specifications for sand used in hydraulic fracturing are set by the American Petroleum Institute (API). These specifications are briefly summarized in Zdunczyk (2012). There are five primary factors used in selecting sand for hydraulic fracturing: API recommends specifications on particle size (particle diameter), mineralogy (high silica or quartz content), particle sphericity, particle roundness, and crush resistance. The most commonly used sand size is 0.42 mm to 0.84 mm (medium to coarse sand) in diameter, and all silica sand to be used in hydraulic fracturing "must be greater than 99 percent pure silica or quartz" (Zdunczyk, 2012). Figure 2 is a photograph of the Jordan Sandstone, a commercially produced sand for hydraulic fracturing, that is composed almost entirely of quartz, with each grain having high sphericity and high roundness.

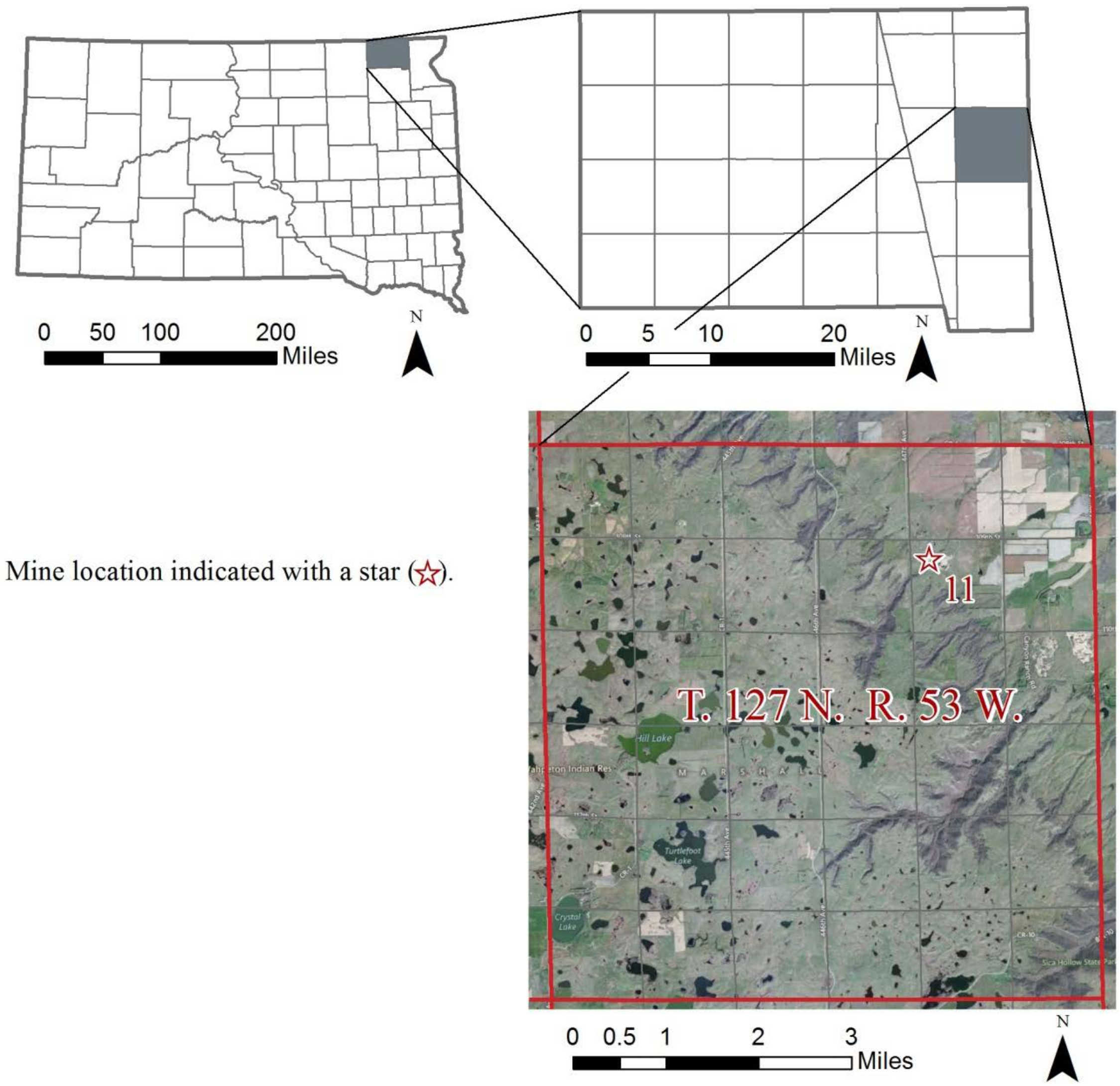


Figure 1. Location of mine site #807001, Marshall County, South Dakota.

Table 1. Relationship between particle sizes and particle names

Size range	Approximate size range (inches)	Particle name (Wentworth Class)
>256 millimeters	>10.1	Boulder
64–256 millimeters	2.5–10.1	Cobble
32–64 millimeters	1.26–2.5	Very coarse gravel
16–32 millimeters	0.63–1.26	Coarse gravel
8–16 millimeters	0.31–0.63	Medium gravel
4–8 millimeters	0.157–0.31	Fine gravel
2–4 millimeters	0.079–0.157	Very fine gravel
1–2 millimeters	0.039–0.079	Very coarse sand
½–1 millimeter	0.020–0.039	Coarse sand
¼–½ millimeter	0.010–0.020	Medium sand
125–250 microns	0.0049–0.010	Fine sand
62.5–125 microns	0.0025–0.0049	Very fine sand
3.90625–62.5 microns	0.00015–0.0025	Silt
<3.90625 microns	<0.00015	Clay
<1 micron	<0.000039	Colloid

Adapted from Krumbein and Sloss (1963)

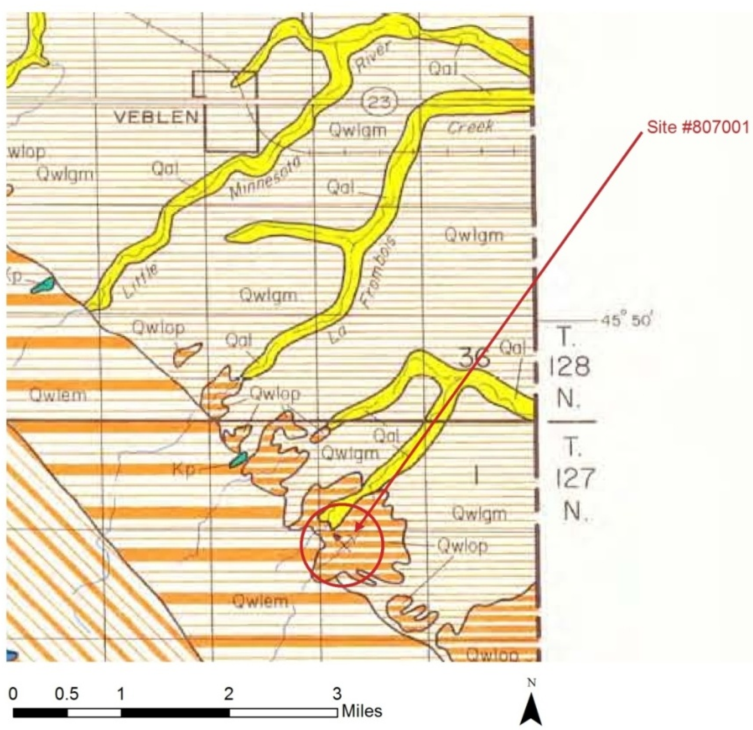
From Marcotty (2012)

Figure 2. Silica sand used in hydraulic fracturing.

Area Geology

The geology of Marshall County was mapped and described by Koch (1975). Figure 3 in this report was adapted from Plate 2 of Koch (1975); it has been cropped to show the surficial geology near mine site #807001. The geologic unit at land surface in the northwestern quarter of section 11 is glacial outwash. By definition, glacial outwash is sediment deposited by water flowing away from a melting glacier.

The minerals and rocks found in glacial outwash reflect the composition of the surface over which glaciers move; as glaciers travel across a landscape, they abrade, pluck, and erode the underlying material. As glacial meltwater carries away some smaller sizes in suspension (i.e., the clay), the remaining heavier material is deposited. Even though glacial meltwater may crudely sort its sediment load by washing away fine-sized material, it does not sort or concentrate individual mineral or rock compositions (i.e., quartz). In the field, the glacial outwash at mine site #807001 ranges in particle size from silt to very large boulders and consists of many kinds of rocks and minerals (fig. 4).



Explanation of map units

Qal	Alluvium
Qwlgm	Ground moraine
Qwlsm	Stagnation moraine
Qwlop	Outwash plain
Qwlem	End moraine
Kp	Pierre Shale

Adapted from Koch (1975)

Figure 3. Surface geology south of Veblen, South Dakota.

Figure 4. View of the mine wall in the northwestern area.

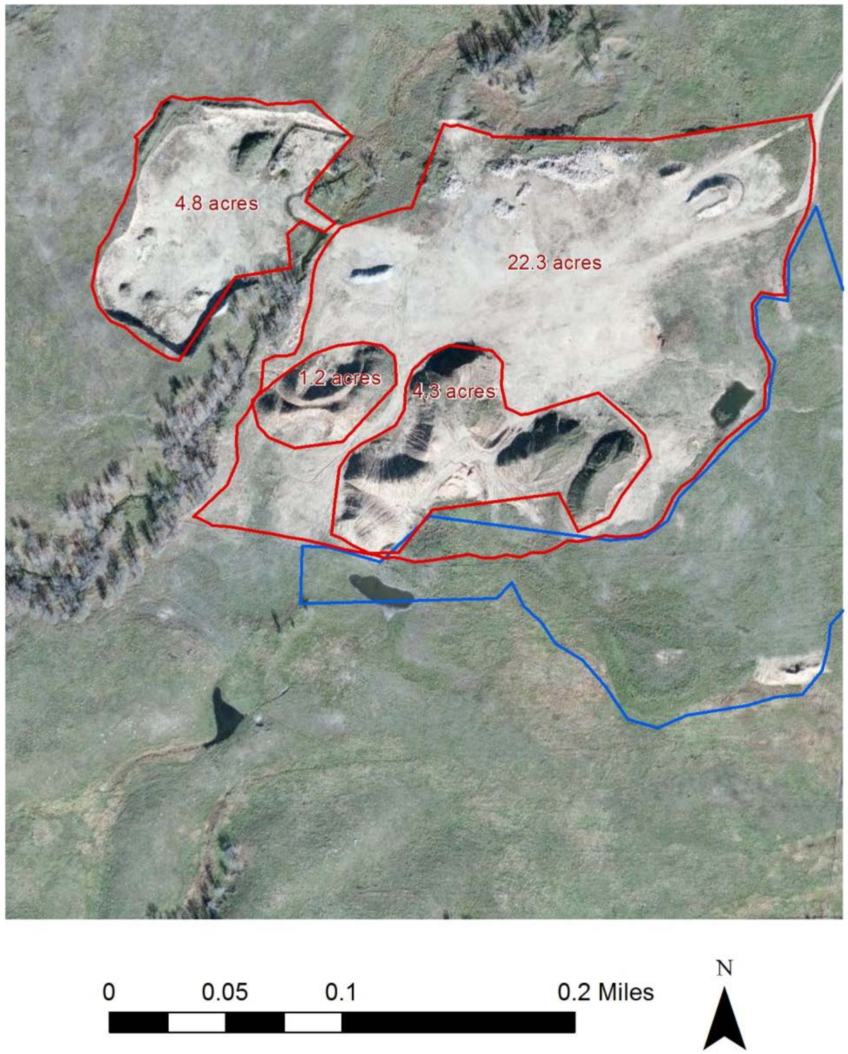
Topography and Site Description

Prior to mining operations, the land surface sloped fairly uniformly to the northeast. The land surface elevation in the northwest quarter of section 11 ranges from 1,564 feet to 1,374 feet. The mine walls are estimated to be 40 feet high (fig. 4). Currently, there are no open pit areas as they have been backfilled and the floor is essentially flat and level. The surface of the floor is covered with a variety of material sizes; mostly gravel, sand, and cobbles.

Large mounds of material from past mining operations rise from the present floor. These mounds are estimated to range from 10 to 60 feet in height. Although the floor is relatively flat, one very small part of the floor is a pit that has been filled with sand.

Description of Aggregates at the Former Mine Site

There are approximately 5.5 acres of processed aggregate in mounds at mine site #807001 (fig. 5). Most reject materials are in piles or mounds that range from 10 to approximately 60 feet high. These mounds were created while the mine site was in operation, presumably as the by-products of size-separation techniques.



Blue line defines reclaimed area. Red lines define areas not yet reclaimed.
Locations for these lines were provided by the Minerals and Mining Program,
South Dakota Department of Environment and Natural Resources.

Figure 5. Reclamation boundaries at mine site #807001.

For the purpose of this investigation, aggregate materials observed at the site were divided into three categories. Figure 6 views the site from the entrance gate of the property, showing the two most abundant types of reject materials in the distance. Several mounds of boulders are visible as a light-colored wedge behind the black cattle. On the left-center side of the photo (in front of the dark-green trees) are numerous mounds of mixed-particle size. Typically, the mixed-particle size mounds support some vegetative cover.

Figure 6. View toward the southwest from the entrance gate.

Boulder Piles

The boulder piles consist of individual boulders that are roughly 3 to 6 feet in diameter. Most boulders appear to be moderately- to moderately-well rounded but are of moderate to poor sphericity. A wide range in rock composition is indicated simply by the many colors and textures of the boulders (figs. 7 and 8). All three major rock-type categories were observed in the boulder piles – igneous, metamorphic, and sedimentary.

Figure 7. Boulders of igneous and metamorphic rock compositions.

Figure 8. A cream-colored limestone boulder of sedimentary origin.

Mixed-Particle Size Mounds

By volume, the most abundant processed aggregate on site is mixed-particle size mounds (fig. 9). The mounds appear to have fairly consistent particle sizes. They all contain clayey silt, sand, and a fair amount of gravel. Cobbles were also observed in the mounds.

Note the trailer for scale

Figure 9. Mounds of mixed-particle size material.

Other Aggregate Materials

Two other types of remnant stockpiles are found on site. Mr. Tollefson identified a pit that has been filled in, as being filled with “sandbox” sand” (fig. 10). He estimates that this former pit measures roughly 80 feet long by 80 feet wide and 3 feet deep. Mr. Tollefson also identified a lone pile of crushed boulders as “railroad ballast” (fig. 11). The size of these crushed boulders ranges from about 6 inches to 1 foot in diameter (fig. 12).

Note the mixed-particle size mounds in the background and the white trailer for scale

Figure 10. View from the "sandbox" sand pit to the southwest.

Figure 11. Railroad ballast pile.

Note the shovel for scale

Figure 12. Close-up of the railroad ballast/crushed boulders.

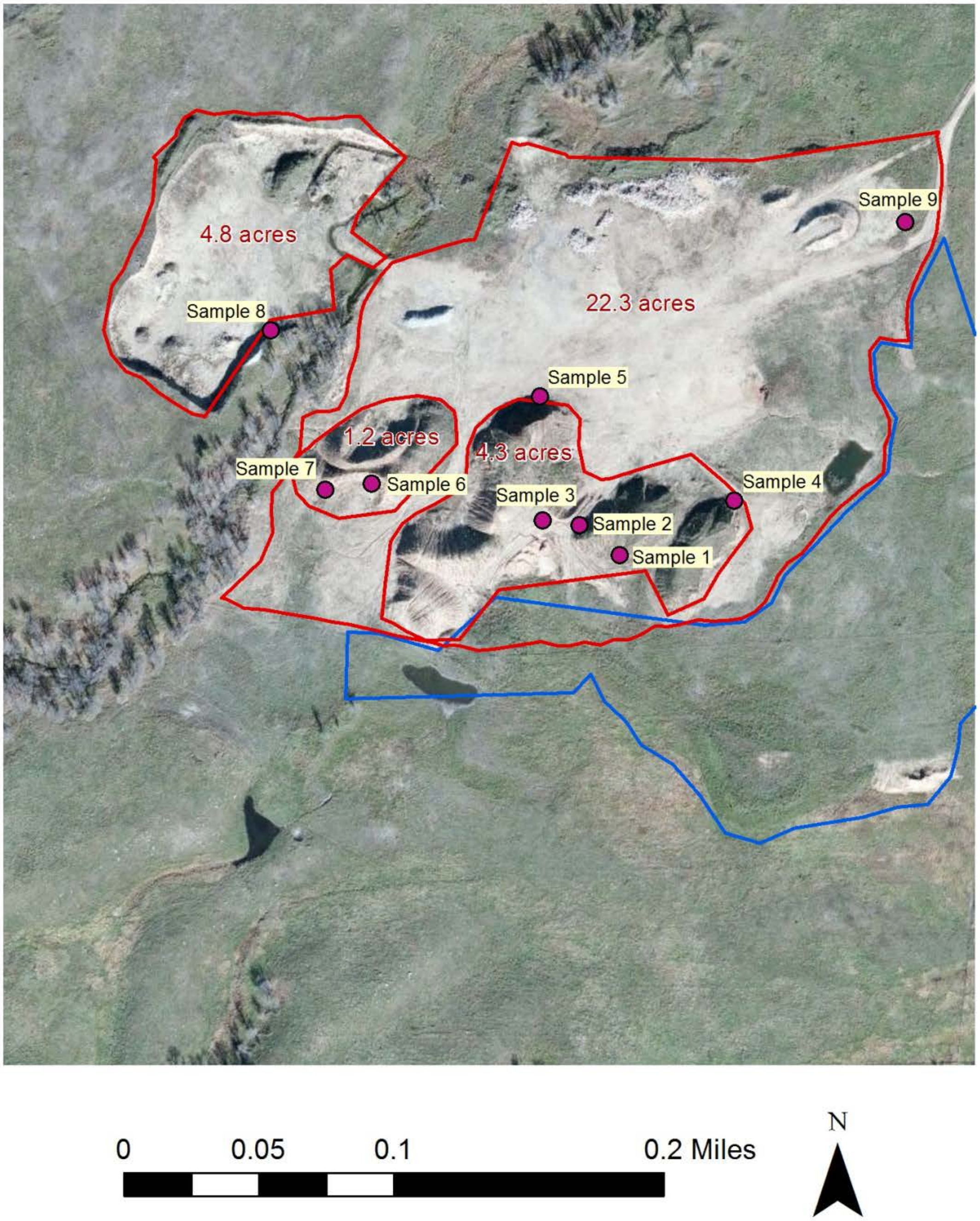
METHODS

Sample Collection

On June 12, 2012, nine sediment samples were collected at mine site #807001 (fig. 13; table 2; app. A). Only materials that had the potential for containing sand were sampled. Cobbles and any larger material were deliberately avoided in the sampling process.

Sample numbers (1 through 9) indicate the location and sequence in which samples were collected. Each sample had its location identified by a Global Positioning Device (GPS). Each sampling site was photographed from a distance as well as up close, with a shovel, back pack, or rock hammer for scale. Approximately 400 to 600 grams of sediment were collected at each sample location and placed in a cloth bag. In the field, each sample was described in terms of color, range of particle sizes, gross mineralogy, and sample reaction to dilute hydrochloric acid. Information about each GPS location (sample number, latitude, longitude, and sampling status) is given in table 2.

Seven samples were collected from mixed-particle size mounds spread across the south end of the area not yet reclaimed. Mr. Tollefson had used a small backhoe to scoop open several sampling locations within these mounds prior to the site visit by the Geological Survey Program, because the mixed-size particle mounds are relatively hard. The backhoe cut to a depth of roughly 2 to 4 feet. This greatly facilitated sampling as the mounds were moderately-well indurated with secondary mineral cements. The seven mixed-particle size mound samples numbers are: 1, 2, 3, 4, 5, 6, and 7.



Blue line defines reclaimed area. Red lines define areas not yet reclaimed. Locations for these lines were provided by the Minerals and Mining Program, South Dakota Department of Environment and Natural Resources.

Figure 13. Sample locations superimposed on mine site #807001.

Table 2. Location and sample information

Sample number	Latitude	Longitude
1	N45° 47´ 59.2″	W97° 15´ 41.8″
2	N45° 47´ 59.8″	W97° 15´ 42.9″
3	N45° 47´ 59.9″	W97° 15´ 43.9″
4	N45° 48´ 00.2″	W97° 15´ 38.6″
5	N45° 48´ 02.3″	W97° 15´ 43.9″
6	N45° 48´ 00.7″	W97° 15´ 48.6″
7	N45° 48´ 00.6″	W97° 15´ 49.9″
8	N45° 48´ 03.7″	W97° 15´ 51.3″
9	N45° 48´ 05.5″	W97° 15´ 33.7″

Two additional samples were collected from other areas. One sample (number 9) was collected from the "sandbox" sand area located in the northeast corner of the area not yet reclaimed. Another sample (number 8) was collected from the talus slope immediately adjacent to the mine wall. This sample is located in the northwest portion of the area not yet reclaimed. The mine walls were not sampled because of safety concerns, so the talus slope next to the mine wall was sampled to represent the unmodified outwash sediment.

During sampling of the talus slope, a cobble of highly weathered, diorite-like grus (weathered rock) was encountered (fig. 14). This indicates the highly weather nature of the sand and gravel at the former mine site.

Figure 14. Highly weathered cobble.

Sample Analysis

Nine samples were examined. Field analysis was completed during the sample collection phase of the study. Additional analyses were completed at the Geological Survey Program's office in Vermillion, South Dakota, during July 2012. Initially, the samples were air dried at room temperature and then weighed to within 0.01 gram. Two types of analyses were completed on all samples; particle-size distribution by sieving, and mineralogical estimation of quartz content by visual interpretation.

Folk’s (1980) sieving technique was followed for particle size distribution analysis. This technique is used to determine the weight percentage of each particle-size class. Sieve sizes were selected to follow standard sediment size definitions (table 3). Eight-inch diameter sieves were used. All sediment portions were weighed to 0.01 gram.

Table 3. Relationship between selected sieve-size numbers, range of particle diameters, and particle names

Sieve size number	Range of particle diameter[1]	Particle name
10	>2 millimeters	gravel and bigger
18	1-2 millimeters	very coarse sand
35	500 microns – 1 millimeter	coarse sand
60	250-500 microns	medium sand
120	125-250 microns	fine sand
230	63-125 microns	very fine sand
pan	<63 microns	silt and clay

Adapted from Folk (1980)

Sieve analysis of the samples involved several steps. First, all samples were sieved by hand to remove the gravel (and larger) components. This was done using a #10 sieve. The resulting sieve portions were weighed, the data recorded, and the portions were bagged, labeled and set aside.

Second, the remaining portion of each sample was shaken through a set of sieves using a mechanized Ro-Tap instrument for 15 minutes. Sieves were stacked incrementally by sieve size opening, with the largest diameter opening at the top of the stack, so the sequence of sieves size numbers were 18, followed by 35, 60, 120, and 230, with a solid pan at the bottom to collect the finest particles. Subsequently, the sieve set was disassembled and the individual sieves were inverted and the contents emptied onto large sheets of aluminum foil. Individual sieve portions were weighed and recorded. Each sample portion was bagged separately and labeled.

Finally, mineral identification and estimation of the percent of quartz was completed using the coarse sand portion (#35 sieve). The coarse sand size was selected for this analysis because it most closely encompasses the most widely used size of sand used for hydraulic fracturing: the 20-40 mesh size, or 0.84-0.42 millimeters (Zdunczyk, 2012).

The sieved coarse sand size portion of each sample was quartered multiple times, until approximately 2-3 grams were obtained. These small portions were placed in aqua-colored weighing boats and photographed using a Leica binocular stereoscope with an attached digital camera. Magnification for the photographs was held constant at 12.5x. Two photographs were taken of each 2-3 gram-sized portion. First, a photograph of the unwashed portion was taken. Second, the same sample was washed in a small amount of tap water and disaggregated by rubbing it with a finger and then the water was decanted. This disaggregation and decantation process was repeated until the decanted water ran clear. Then the second photograph was taken. These photographs were used to visually identify and estimate quartz content.

RESULTS

Field Results

All samples collected in the field consisted of a range of particle sizes and a mixture of lithologies. Sand with clayey silt and a fair amount of gravel was typical. Cobbles were common but were not included in the sample collection. Overall, the samples looked rusty to yellowish-brown in color indicating the presence of small amounts of iron oxide (probably as the minerals goethite and/or hematite). Gross mineralogy included quartz, feldspar, calcite, dark mafic minerals, rock fragments, and lesser amounts of other compositions.

Although some individual sand grains were identifiable, most were coated with too much silt, clay, and/or secondary precipitation to determine their mineralogy the unwashed state. Clear quartz grains were apparent in all samples. In addition, all samples reacted to dilute hydrochloric acid thereby indicating the presence of calcium carbonate (i.e., calcite and/or limestone). Some of the calcite is present as a secondary precipitate cementing particles together, thereby indurating and hardening the mixed-particle size mounds. For example, at two sampling locations, the mixed-particle size mounds were so indurated that white streaks appeared after striking the sampling area with a the rock hammer. These white streaks indicate the presence of calcite (fig. 15). Dark mafic minerals and rock fragment grains were observed in all samples. Trace amounts of iron oxides (mentioned above) are ubiquitous. Secondary precipitation of iron oxide was also observed (fig. 16).

The age of these mounds is not known, however, three indicators illustrate that they have remained undisturbed for several years. First, there is considerable vegetative cover on the mixed-particle size mounds (app. A), as well as across the floor (fig. 17). Second, ravines have either formed and/or incised rather significantly between some of the mixed-particle size mounds (fig. 18). Finally, minor gullies have started to form on the floor (fig. 19). The age of the mounds is relevant because it affects the observed mineralogy of the mounds.

Figure 15. White scratch at sample location 2.

Figure 16. Iron oxide precipitation at sample location 6.

Figure 17. Sparse to moderate, ubiquitous, vegetative cover.

Figure 18. Ravine and erosion.

Figure 19. Small gully forming on mine floor.

Particle-Size Distribution

After sieving, the gravel- and larger-size portions were weighed and the percent of gravel was calculated (table 4). The smaller-than-gravel-size sieve portions of each sample are reported by weight in table 5. The percent of all size portions for each sample are reported in table 6.

Particle Mineralogy

Mineralogical results described in the field were verified using visual interpretation in the laboratory. All samples contained quartz, feldspar, calcite, dark mafics, rock fragments, and lesser amounts of other compositions, including iron oxides.

Every sample has two photographs in appendix B. The first photo shows the unwashed sediment and the second photo shows the washed sediment. Due to the samples being placed in aqua-colored weighing boats, a blue background color is visible in many photographs.

Table 4. Weight and percent of aggregate greater than 2 millimeters in diameter

Sample number	Total sample weight (grams)	Weight of sample portion (grams)	Percent gravel and larger in sample
1	406.44	239.87	59.0
2	386.07	171.47	44.4
3	361.91	196.83	54.4
4	382.32	194.13	50.8
5	420.37	218.83	52.1
6	474.51	208.70	44.0
7	485.49	156.88	32.3
8	514.13	344.34	67.0
9	671.46	121.70	18.1

Table 5. Weight of the smaller-than-gravel portions

Sample number	Particle size, and weight in grams					
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt and clay
1	60.33	49.54	30.26	13.64	6.08	5.27
2	60.71	61.94	48.35	23.63	10.31	8.84
3	59.64	49.15	29.87	13.29	6.66	5.71
4	54.67	58.83	42.51	19.23	7.47	4.78
5	62.58	55.02	38.57	20.8	11.76	11.6
6	75.98	72.68	56.47	31.9	15.45	11.84
7	98.76	100.66	71.07	31.49	13.27	11.89
8	69.3	36.72	26.21	18.01	10.41	8.13
9	170.82	201.99	133.88	29.61	5.39	6.47

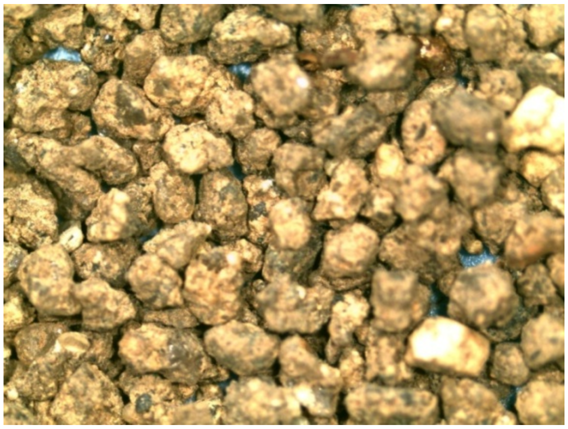
Table 6. Sample portion percentages

Sample location	Sample number	Gravel and larger	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt and clay
Remnant mound	1	59.0	14.8	12.2	7.5	3.4	1.5	1.3
Remnant mound	2	44.4	15.7	16.0	12.5	6.1	2.7	2.3
Remnant mound	3	54.4	16.5	13.6	8.3	3.7	1.8	1.6
Remnant mound	4	50.8	14.3	15.4	11.1	5.0	2.0	1.3
Remnant mound	5	52.1	14.9	13.1	9.2	5.0	2.8	2.8
Remnant mound	6	44.0	16.0	15.3	11.9	6.7	3.3	2.5
Remnant mound	7	32.3	20.3	20.7	14.6	6.5	2.7	2.5
Talus slope	8	67.0	13.5	7.1	5.1	3.5	2.0	1.6
"Sandbox" sand	9	18.1	25.4	30.1	19.9	4.4	0.8	1.0

Regardless of sample location, the mineralogy observed in the unwashed samples in the laboratory was comparable to that determined in the field; it generally remained obscured because clay, silt, and (likely) secondary calcite coat most grains. Clear quartz grains were noted in every sample, as were reddish and grayish grains. The reddish tones were attributed to orthoclase feldspar, iron oxide minerals, and/or iron staining. The grayish grains were silt and clay-coated dark mafic minerals and/or rocks. Rounded limestone grains were sometimes visible.

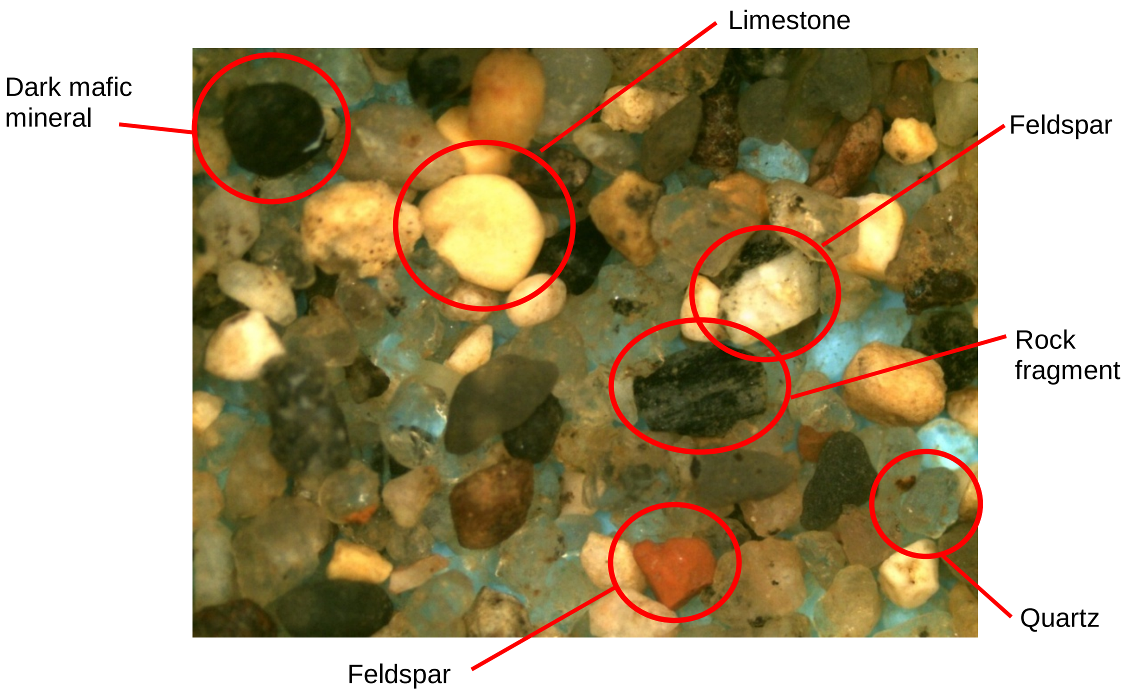
Even after 15 minutes of mechanical sieving, many smaller silt and clay particles remained attached to the unwashed sand grains (fig. 20). It is assumed because of the vigorous reaction with dilute hydrochloric acid, that calcite is the dominant secondary cement. This gives rise to the possibility that some grains may still be cemented together after vigorous sieving which may skew the size-distribution data.

The mineralogy of the washed sample portions is much more obvious. For example, as shown in figure 21, individual minerals present in the "sandbox" sand are readily identified. Figure 21 is representative of the variety of minerals and rocks present in all the samples; clear quartz, feldspars, calcite, dark mafics, rock fragments, and other minerals.



Sample 1; magnified coarse sand; #35 sieve

Figure 20. Sieved, unwashed coarse sand.



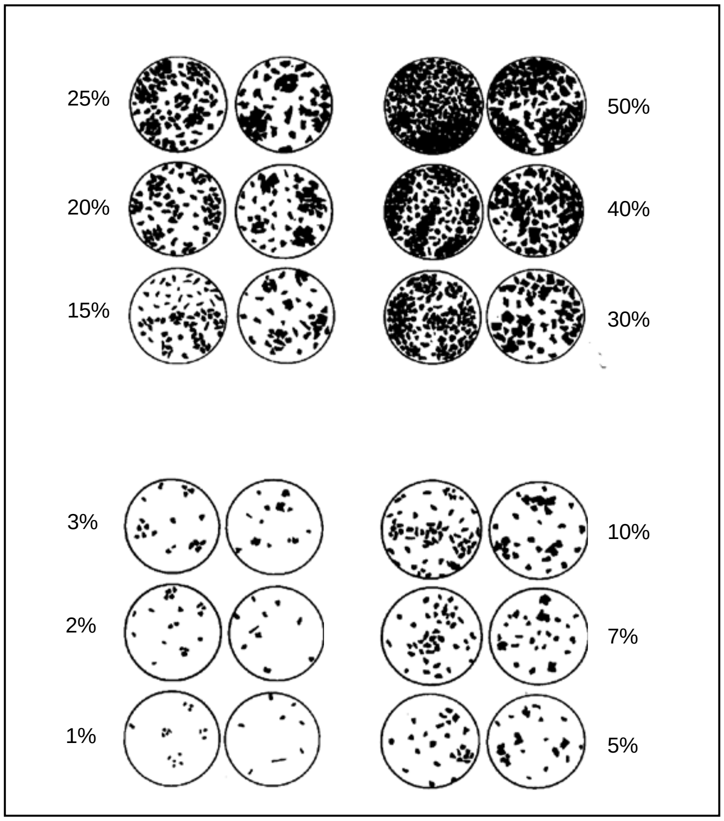
Sample 9 washed and wet; magnified coarse sand; #35 sieve

Figure 21. Sieved, washed, coarse sand with individual minerals identified.

The percent of quartz in the coarse sand portion was estimated from the washed sample portions (table 7). A visual aid used in this determination is provided in figure 22. Most of the washed, coarse-sand portions contain between 25 and 50 percent quartz. Only one sample (number 6) contained 0 to 25 percent quartz. None of the samples contained more than 50 percent quartz.

Table 7. Percent of estimated quartz in coarse sand portions

Sample number	0-25% quartz	25-50% quartz
1		X
2		X
3		X
4		X
5		X
6	X	
7		X
8		X
9		X



Adapted from Compton (1962)

Figure 22. Chart for estimating percentage composition of rocks and sediments.

DISCUSSION

Particle Sizes

All remnant materials consist primarily of sand and gravel. Weight-based sieve analysis results indicate that there is more coarse sediment than fine sediment. For example, with the exception of the “sandbox” sand sample, the percent of gravel is larger than the percent of very-coarse sand, which is larger (plus or minus 1 percent) than the coarse-sand portion, which is larger than the percent of medium sand, and so on, down to the smallest size portion.

The sand size is of particular interest in this study. The combined sand-size portions of the mixed-particle size mound samples indicate a total sand content that ranges from approximately 40 to 65 percent. Gravel constitutes most of the remainder, with silt and clay content only accounting for a total of 2 to 6 percent of the bulk sample weight. The proportions of sand and gravel are slightly different in the “sandbox” sand and the talus slope sample. The “sandbox” sand contains only 18 percent gravel and about 81 percent sand. In contrast, the talus slope sample contains about 67 percent gravel, 13 percent very-coarse sand, 7 percent coarse sand, and 5 percent medium sand. Together, the remaining fine portions account for about 7 percent of the talus slope sample.

Considering only the coarse sand portions, the measured quantities were relatively small. The coarse-sand portions most closely approximate the size that is most commonly used for hydraulic fracturing applications. The amount of coarse sand in the mixed-particle size mound samples ranged from 12 to 21 percent. In the “sandbox” sand sample it was 30 percent. In the talus slope sample it was 7 percent.

Estimated Mineralogy

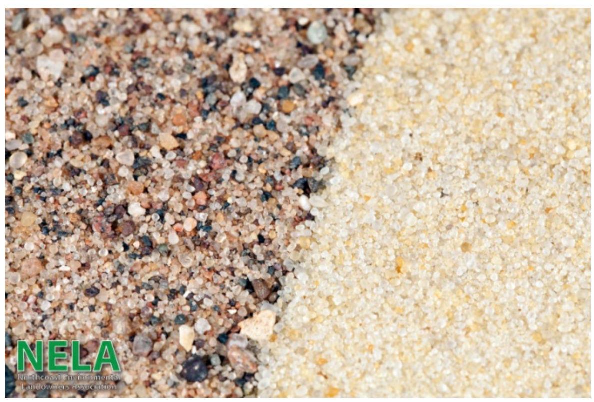
All remnant materials contain quartz, feldspar, calcite, dark mafic minerals, rock fragments, and lesser amounts of other compositions including small amounts of iron oxide (probably as the minerals goethite and/or hematite). The coarse sand portion also contained this same suite of minerals and rocks. The estimated abundance of quartz relative to all other components in the samples was never observed to be greater than 50 percent.

CONCLUSIONS

The purpose of this investigation was to evaluate if some remnant material at the former mining operation identified as mine site #807001 near Veblen, South Dakota, could be considered for possible use as a sand source for hydraulic fracturing. The most abundant remnant materials present were large mounds of mixed-particle size (silt, sand, gravel, and cobbles). A variety of samples were collected and analyzed 1) for particle size distribution using sieve analysis, and 2) for quartz content using visual means to identify and estimate mineralogy.

The results of this study indicate that, although some sand-size material commonly used for hydraulic fracturing applications is present, the necessary quartz content is not present. The amount of quartz only approaches 50 percent in samples collected for this study. However, silica purity of greater than 99 percent quartz is required for hydraulic fracturing applications. Therefore the mineralogical results alone are sufficient to eliminate these sediments for use as a possible sand source for hydraulic fracturing. Based on particle-size distribution and quartz content, it was deemed unnecessary to further evaluate these materials as a potential sand source for hydraulic fracturing applications.

The photograph in figure 23 visually summarizes these concepts. Although the size of the sand appears to be small, the mineralogy (as viewed simply in terms of uniform color) is not. The left side of the picture has multi-colored grains and it is clearly not equivalent in purity to that on the right side. Sand shown on the left is similar in appearance to sand from the Veblen site. Quartz-rich sand used for hydraulic fracturing is shown on the right.



Adapted from Northcoast Environmental Landowners Association (2012)

Figure 23. Comparison of sands.

ACKNOWLEDGEMENTS

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APPENDIX A

Sample Information

<u>Sample 1</u>
Mixed-particle size sample
GPS location N45° 47´ 59.2´´ W097° 15´ 41.8´´

Figure A-1. Sample 1 location.

Figure A-2. Close-up of sample 1 location.

<u>Sample 2</u>
Mixed-particle size sample
GPS location N45° 47´ 59.8´´ W097° 15´ 42.9´´

Figure A-3. Sample 2 location.

Figure A-4. Close-up of sample 2 location.

<u>Sample 3</u>
Mixed-particle size sample
GPS location N45° 47´ 59.9´´ W097° 15´ 43.9´´

Figure A-5. Sample 3 location.

Figure A-6. Close-up of sample 3 location.

<u>Sample 4</u>
Mixed-particle size sample
GPS location N45° 48´ 00.2´´ W097° 15´ 38.6´´

Figure A-7. Sample 4 location.

Figure A-8. Close-up of sample 4 location.

Sample 5
Mixed-particle size sample
GPS location N45° 48´ 02.3´´ W097° 15´ 43.9´´

Figure A-9. Sample 5 location.

Figure A-10. Close-up of sample 5 location.

Sample 6
Mixed-particle size sample
GPS location N45° 48´ 00.7´´ W097° 15´ 48.6´´

Figure A-11. Sample 6 location.

Figure A-12. Close-up of sample 6 location.

<u>Sample 7</u>
Mixed-particle size sample
GPS location N45° 48´ 00.6´´ W097° 15´ 49.9´´

Figure A-13. Sample 7 location.

Figure A-14. Close-up of sample 7 location.

Sample 8

Talus slope sample collected between two large boulders

GPS location N45° 48´ 03.7´´ W097° 15´ 51.3´´

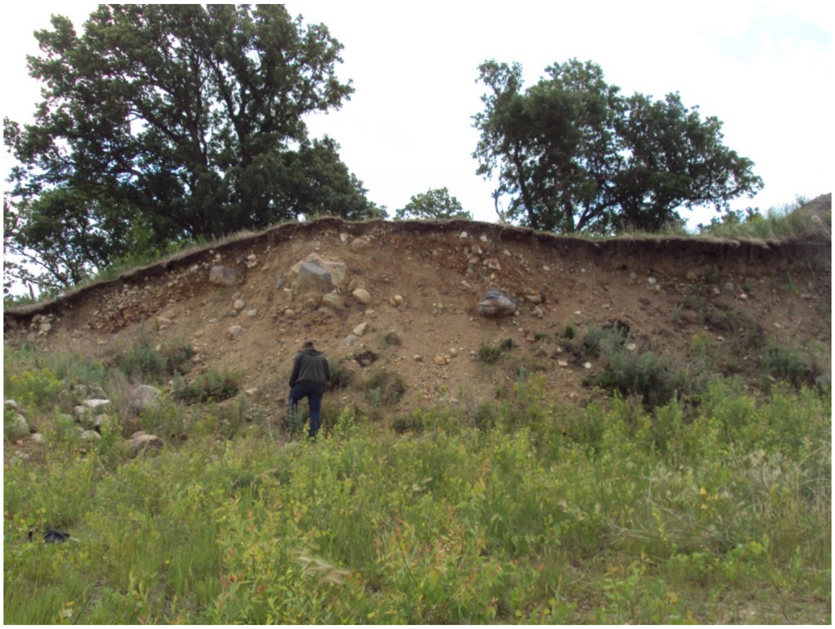

Figure A-15. Sample 8, from the talus slope, was collected between the two biggest boulders.

Figure A-16. Near Sample 8 location.

<u>Sample 9</u>
"Sandbox" sand sample
GPS location N45° 48´ 05.5´´ W097° 15´ 33.7´´

Figure A-17. Sample 9 "sandbox" sand pit in foreground.

Figure A-18. Sample 9 "sandbox" sand location.

APPENDIX B

Coarse Sand Portion (1/2mm – 1mm) Photographs

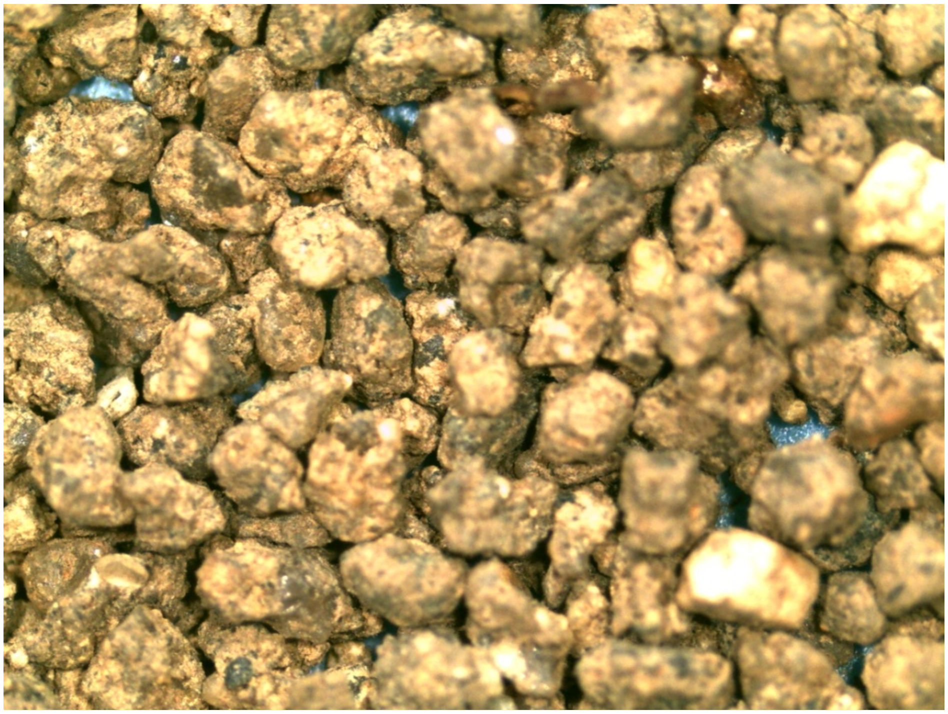

Figure B-1. Sample 1; magnified coarse sand; #35 sieve.

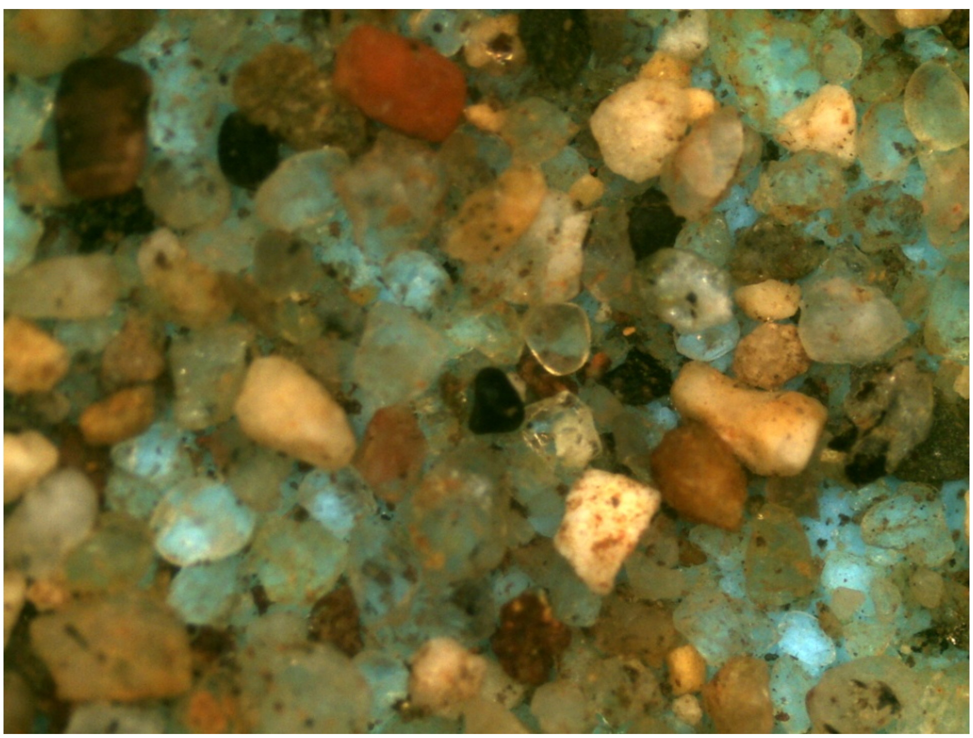

Figure B-2. Sample 1 washed and wet; magnified coarse sand; #35 sieve.

Figure B-3. Sample 2; magnified coarse sand; #35 sieve.

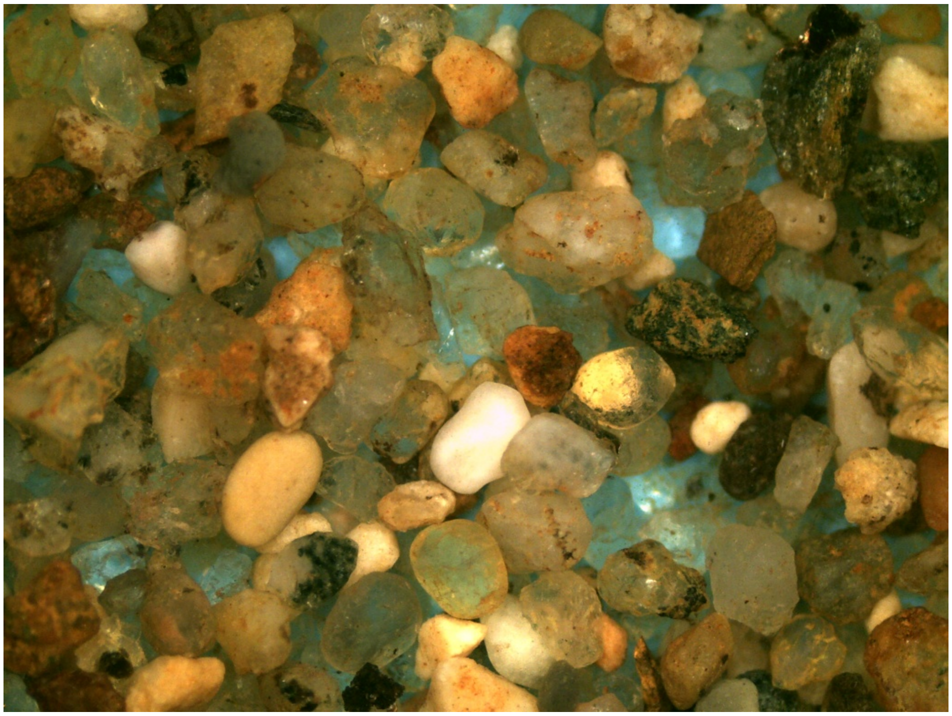

Figure B-4. Sample 2 washed and wet; magnified coarse sand; #35 sieve.

Figure B-5. Sample 3; magnified coarse sand; #35 sieve.

Figure B-6. Sample 3 washed and wet; magnified coarse sand; #35 sieve.

Figure B-7. Sample 4; magnified coarse sand; #35 sieve.

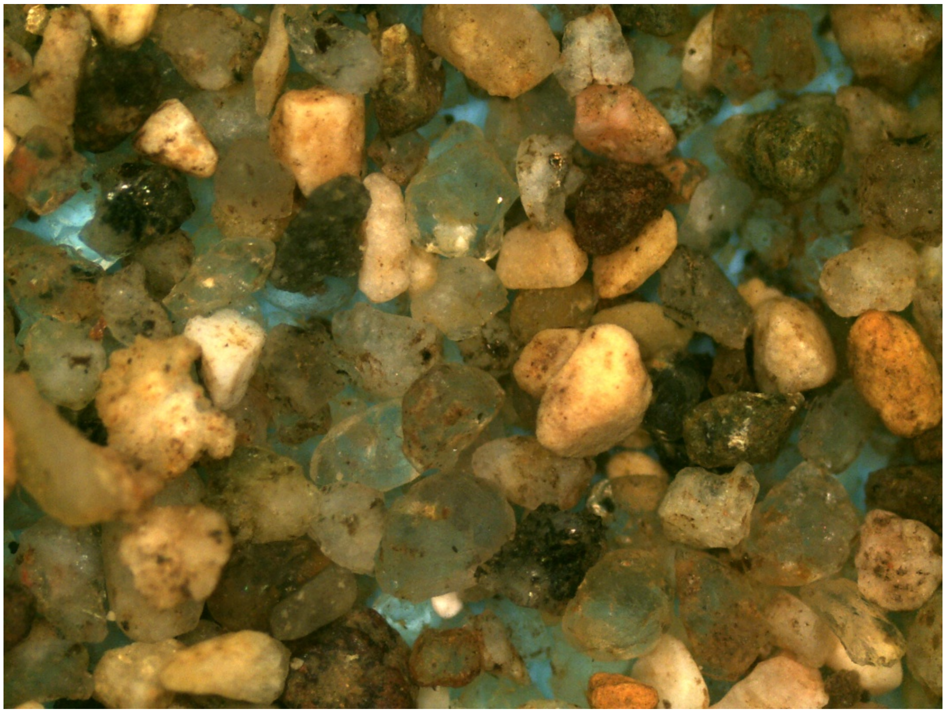

Figure B-8. Sample 4 washed and wet; magnified coarse sand; #35 sieve.

Figure B-9. Sample 5; magnified coarse sand; #35 sieve.

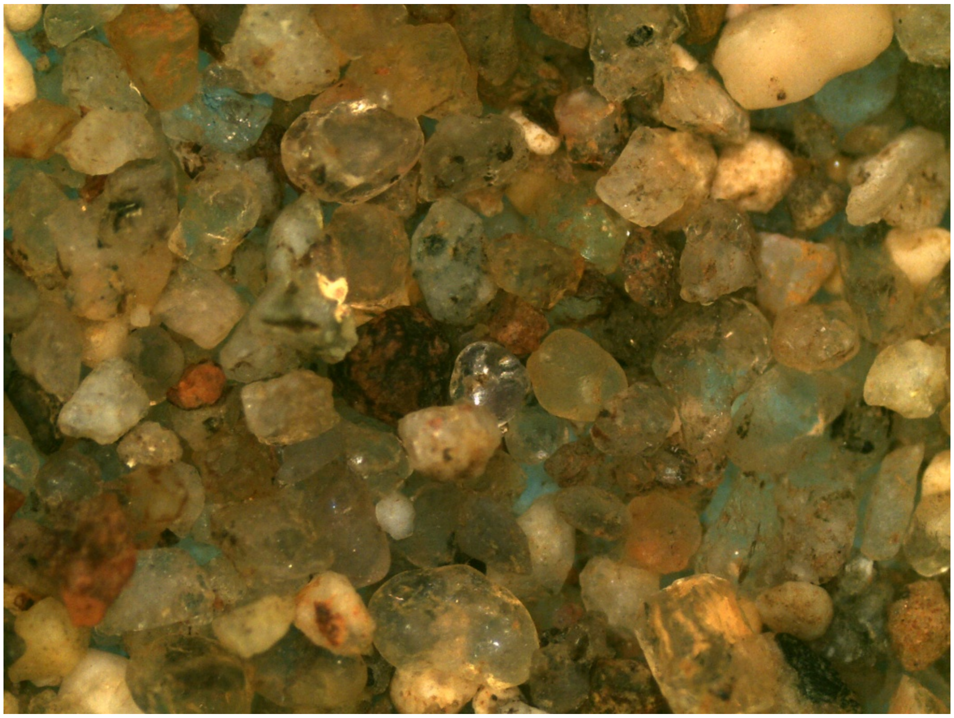

Figure B-10. Sample 5 washed and wet; magnified coarse sand; #35 sieve.

Figure B-11. Sample 6; magnified coarse sand; #35 sieve.

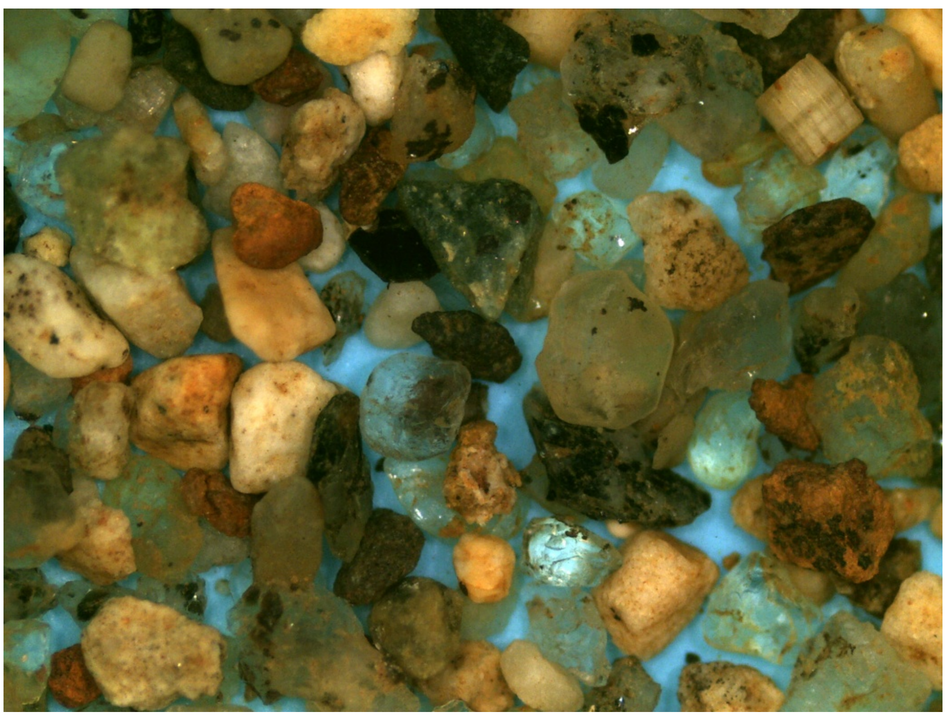

Figure B-12. Sample 6 washed and wet; magnified coarse sand; #35 sieve.

Figure B-13. Sample 7; magnified coarse sand; #35 sieve.

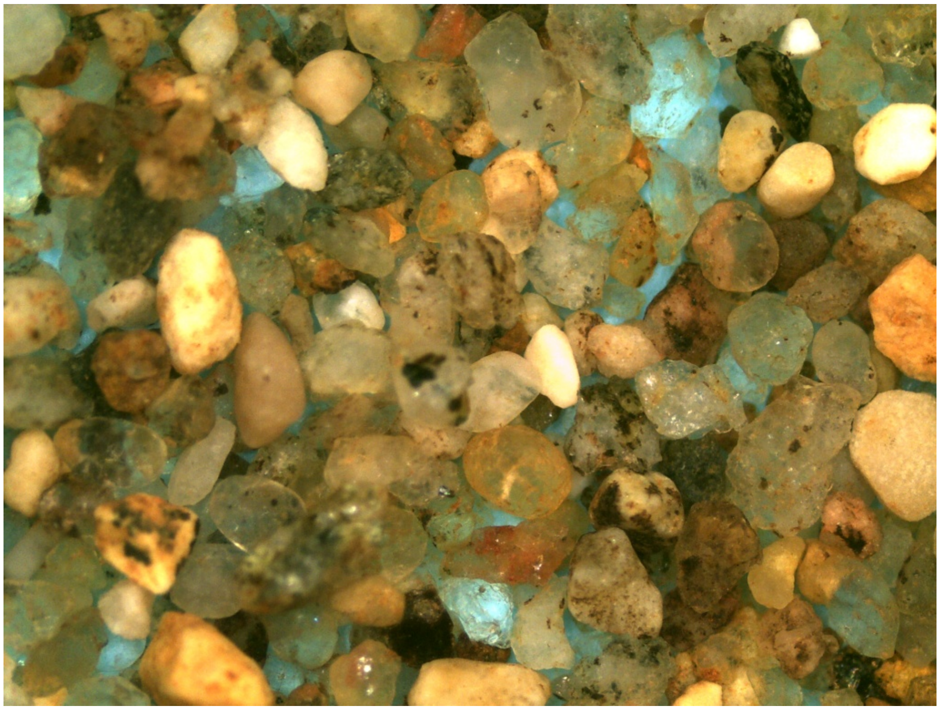

Figure B-14. Sample 7 washed and wet; magnified coarse sand; #35 sieve.

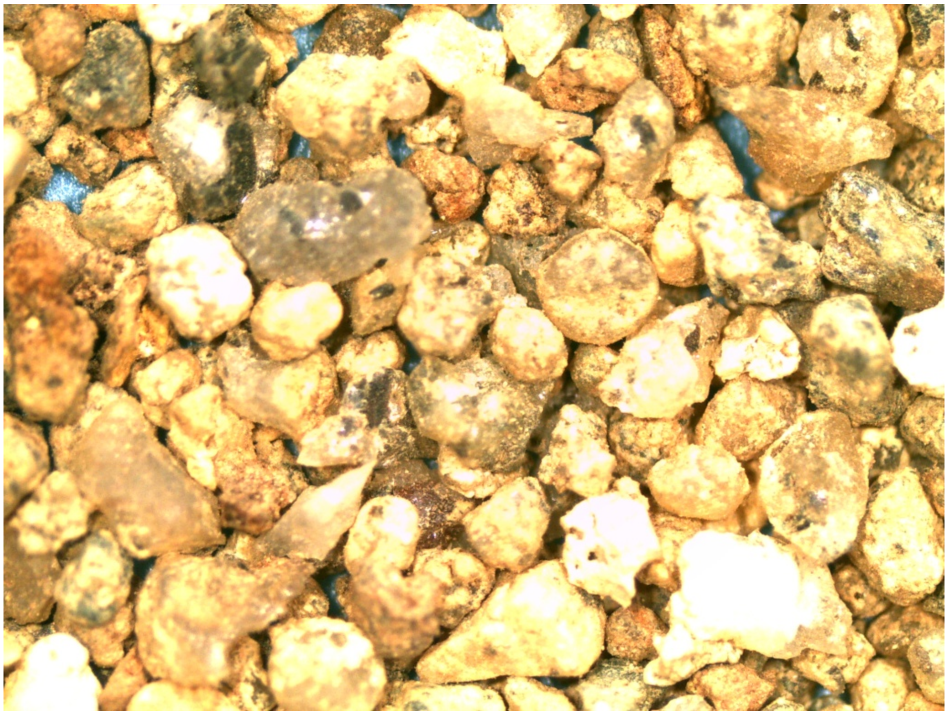

Figure B-15. Sample 8; magnified coarse sand; #35 sieve.

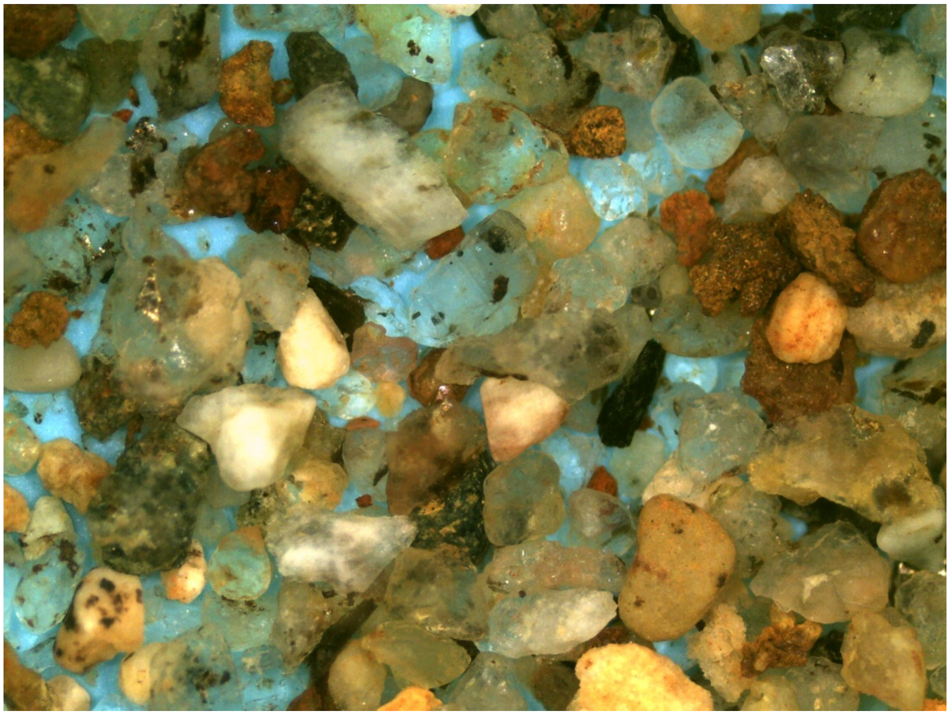

Figure B-16. Sample 8 washed and wet; magnified coarse sand; #35 sieve.

Figure B-17. Sample 9; magnified coarse sand; #35 sieve.

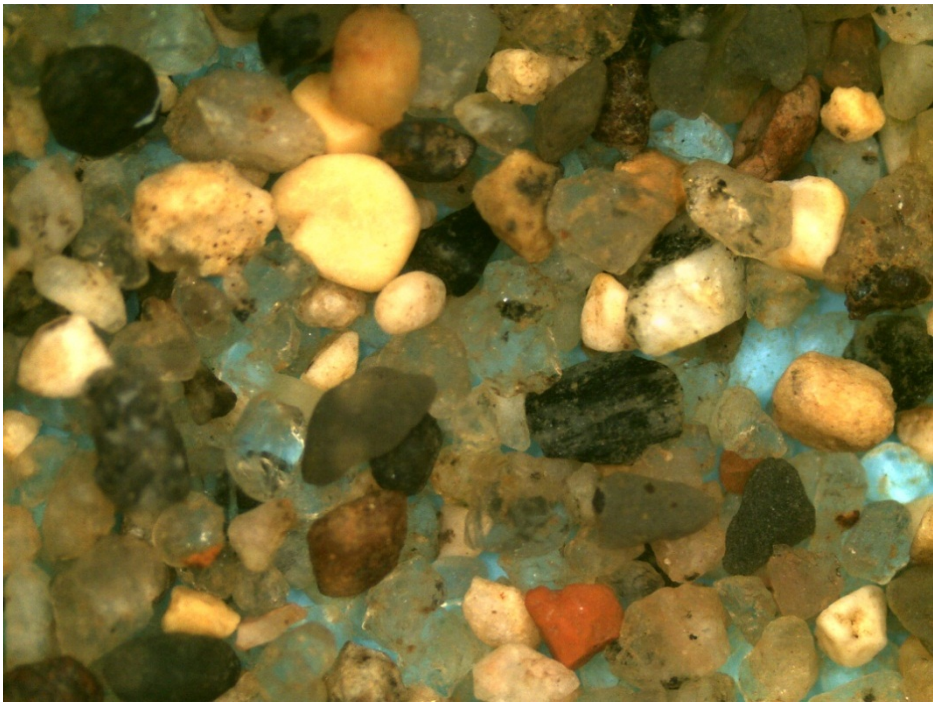

Figure B-18. Sample 9 washed and wet; magnified coarse sand; #35 sieve.