Conference on the Silica Sand Resources of Minnesota and Wisconsin

October 1-3, 2012
Earle Brown Heritage Center, Brooklyn Park, MN

Field Guidebook

Organized by

PRC Guidebook 12-01
Field Guidebook on the Silica Sand Resources of Western Wisconsin

Organizational Sponsors
Precambrian Research Center at UMD - www.d.umn.edu/prc
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Cover Photos: Upper left – Processing plant at Great Northern Sands, New Auburn, WI, photo supplied by Aaron Kent; Upper right – Mining operation at Preferred Sands Woodbury (MN) pit, photo by John Litsenberger; and lower left & lower right – facilities at Preferred Sands operation in Blair, WI, photos by Kent Syverson
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## Trip Route

![Map of the trip route](image-url)
FIELD TRIP SCHEDULE

Wednesday, October 3 – Field Trip on Silica Sand Resources of Western Wisconsin
Letters in parentheses refer to location pins on Trip Route map (p. 2)

7:30 AM        Depart Earle Brown Heritage Center (A)
8:45 AM       Stop at Menomonie Walmart; pick up people parking cars (H)
8:50-9:45    Drive to New Auburn via Hwy 25N/76E
9:45-11:15  Great Northern Sand mine & processing plant; coffee & donuts provided (C)
11:15-11:35  Drive to EOG Resources mine site via DD, 64, DD; go past several sand mines
11:35-11:50  EOG Resources mine site drive-through
11:50-12:10  Drive to EOG processing Plant, Chippewa Falls
12:10-12:40  EOG processing plant (D)
12:40-12:45  Drive to Irvine Park, Chippewa Falls
12:45-1:30    Lunch stop Irvine Park, Chippewa Falls
              Examine Paleozoic cores and hand samples
1:30-2:40     Drive to Blair
2:40-4:20     Preferred Sands mine and processing plant; refreshments provided (E)
4:20-4:40     Drive to Arcadia
4:40-5:20     Jordan Sandstone exposure on Hwy 93 (south of Arcadia) (F)
5:20-6:10     Drive to Eau Claire; drop off people near I-94 jct. (G)
6:10-6:40     Drive to Menomonie; drop off people at Walmart parking lot (H)
6:45-8:00     Drive to Earle Brown Center; sandwiches and refreshments on bus
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Field Trip Hosts

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Field Trip Sponsors - $750

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BARR
Paleozoic age bedrock layers of quartzose sandstone in the central midcontinent of North America (Figs. 1, 2) have been mined since the 1800’s to supply “silica sand” for use in a number of industrial applications. They are well known as some of the most mineralogically pure sandstone on Earth, greater than 95 percent of the sand grains are the mineral quartz (Fig. 2). The recent rapid expansion of silica sand mining in the region is driven by demand for proppant used in the process of hydrofracturing for oil and natural gas. Several attributes make the silica-rich sandstone layers in the central midcontinent, especially parts of Minnesota, Wisconsin, Illinois and Iowa, particularly desirable. Not only are they composed mostly of quartz, a mineral known for being of high-strength and relatively inert, the grains are especially well-rounded, well-sorted, relatively coarse-grained, and are poorly cemented (Fig. 2C). Furthermore, extraction and transport is relatively easy because the sandstone layers are at or near the land surface across aerially large footprints, and road and rail networks are well-developed. Today’s field trip will provide participants with an opportunity to learn about the silica sand mining industry of this region, with visits to mines, processing facilities, and bedrock exposures and cores of quartzose sandstone.

All or parts of four geologic formations in this region have attracted most of the interest for silica sand mining; in ascending stratigraphic order they are the Mt Simon, Wonewoc, Jordan, and St Peter Sandstones (Fig. 1B). This guidebook overview provides the general geologic context for these silica sand-rich layers, beginning with current views on the origin of their unusual, sheet-like geometry, as well as extreme textural and mineralogical maturity. We also provide information on where these layers are potentially economically extractable, describe geologic and landscape conditions that influence accessibility for mining, and summarize some of the textural characteristics that are pertinent to their demand as a proppant.

GEOLOGIC ORIGIN OF SILICA SAND-RICH FORMATIONS

The silica sand-rich bedrock layers of the central midcontinent region have attracted the interest of geologists for over a century. They are often viewed as enigmatic, differing from other, more common sedimentary rock formations (e.g. Dott et al., 1986, 2003 for summary). One unusual feature is their widespread, yet thin, sheet-like geometry, with individual layers typically less than about 150 ft. thick, yet extending hundreds of thousands of miles across the midcontinent. The extreme textural and mineralogical maturity is also uncommon: the bulk of each formation is sandstone that is composed of greater than 95% grains of quartz that are relatively well-sorted, well-rounded, and spherical.
The origin of these unusual features is part of a geologic history that extends back to over 500 million years ago, when sea level was much higher than today and as a result a shallow ocean covered much of the North American continent (Fig. 3). Only the cratonic interior, the central and highest part of the continent, remained above sea level most of the time. This area corresponds to today’s central Canada and northernmost United States. Sand, silt and clay sized particles were carried by wind and in rivers across the cratonic interior to the oceanic shoreline. For long periods of time this shoreline occupied a position approximating today’s southern Minnesota, Wisconsin, and northern Iowa region. Shallow ocean currents sorted this sediment, forming a “texturally graded shelf” (Figs. 3, 4) (Runkel et al., 1998, 2007). On this shelf the coarsest sand, composed mostly of quartz grains, was laid down in the shallow water of the shoreface (including the beach), where currents were strongest. Finer-grained, feldspathic sand, silt and clay sized particles were carried seaward to deeper water, especially during strong storms. Even farther from shore, beyond the distance and depth to which sand, silt and clay were carried, particles of calcium carbonate slowly accumulated on the sea floor.

Figure 1. Distribution and stratigraphic context for the silica sand-rich bedrock in the central midcontinent. (A) Greatly generalized map across part of Minnesota, Iowa and Wisconsin showing extent of Paleozoic bedrock with quartzose sandstone layers that are mined for silica sand. Also shown are the locations of active and proposed silica sand mines. The location of the Wisconsin mines is based on a July 2012 map posted at WisconsinWatch.org by the Wisconsin Center For Investigative Journalism. The Minnesota locations are compiled by the authors of this guidebook paper. For both states, the status of sites changes at a relatively rapid pace, and thus this map is intended to be only a general illustration of the distribution and density of mines as expansion of the industry occurs. (B) Stratigraphic column of Paleozoic bedrock for the shaded region shown in (A), highlighting the four formations that are most commonly mined for silica sand; the Mt Simon, Wonewoc, Jordan and St Peter Sandstones. (Modified from Mossler, 2008)
The layers of different types of Paleozoic sedimentary bedrock that stretch across this region today were formed when sea level, and therefore the depth of the ocean, changed through time. Changes in sea level led to changes in the position of the shoreface, moving it back and forth across much of southern Minnesota and Wisconsin multiple times (Fig. 5) (Runkel et al., 2007). Each time the shoreface migrated back and forth, it left behind a “trail” of sand. In this way, each of the silica sand-rich formations present today represents one or more major migrations of the shoreline across this region hundreds of millions of years ago.

Most of the Paleozoic formations of this region are not composed mostly of silica-rich sand (Figs. 1, 5). They formed during conditions of higher sea level, when the quartzose, sandy shoreface was north of today’s southern Minnesota and Wisconsin. For example, the Eau Claire Formation was deposited when sea level was high enough that much of southern Minnesota and Wisconsin were the site of deep-water accumulation of feldspathic, very fine sand, silt and clay. When sea level was even higher, particles of calcium carbonate accumulated, forming today’s limestone and dolostone, such as parts of the Oneota Dolomite and St Lawrence Formation.

Figure 2. Typical exposures and disaggregated grab sample of silica sand from the Paleozoic bedrock of the central midcontinent. (A) outcrop of St Peter Sandstone along the Mississippi River in St Paul, Minnesota, (B) outcrop of Jordan Sandstone along St Croix River near Stillwater, Minnesota. (C) The dominant component of the Mt Simon, Wonewoc, Jordan and St Peter Sandstones consists of fine to coarse-grained, well-rounded, high-sphericity grains of quartz such as these grains from a core of the upper part of the Wonewoc Sandstone collected in St Paul, Minnesota.
The unusually widespread, yet thin geometry of the quartzose sandstone layers of this region is believed to mostly reflect somewhat unusual conditions in this part of North America hundreds of millions of years ago (Runkel et al., 2007). The ocean floor sloped seaward at a very low gradient, with the transition from the beach to water depths of a few tens of feet likely occurring over long distances of a hundred miles or more. In such conditions even relatively small changes in sea level led to the shoreface moving very long distances. As a result of these long migrations of the shoreface, some layers of quartzose sand were deposited hundreds of miles beyond today’s southern Minnesota and Wisconsin, although in most places they remain deeply buried. An additional factor explaining the sheet geometry of these layers is that this part of the continent was only very slowly subsiding (“sagging”) which allowed for only a relatively thin layer of shoreface sand to accumulate in any one place.

The various interpretations posed to account for the extreme maturity of these silica-rich sandstone formations is best summarized by Dott et al. (2003). An important clue to the origin of mineralogical maturity is contained within the finest-grained sandstone layers of Paleozoic bedrock, which are feldspathic rather than quartzose. Odom (1975, 1978) showed that this very fine grained sandstone is rich in potassium feldspar, but has only a trace amount of plagioclase, even though plagioclase was presumably dominant in the cratonic source area. He also noted that the absence of oversized pore spaces demonstrates that selective diagenetic leaching of plagioclase grains from the sandstone cannot account for the near absence of plagioclase. Furthermore, potassium feldspar and

Figure 3. Paleogeographic conditions in early Paleozoic time, when a shallow sea covered much of North America and quartz-rich sand was carried from the cratonic interior to a shoreline that at times occupied what is now the Minnesota, Wisconsin, Iowa and Illinois area. A-A’ refers to line of section for the stratigraphic cross section in Figure 4 and 5.

Chemically weathered Precambrian rock (Saprolite)
plagioclase have virtually the same resistance to mechanical abrasion, but differ greatly in resistance to chemical weathering. Runkel (1998) used Odom's (1975, 1978) evidence to suggest that chemical weathering in the cratonic interior (Fig. 3) probably preferentially dissolved plagioclase and similarly unstable minerals, creating a source area dominated mineralogically by quartz grains. Morey (1972) studied sub-Mt Simon weathering profiles, demonstrating that such selective leaching of grains did indeed occur prior to deposition of the Paleozoic quartzose sandstone layers.

Figure 4. Schematic model depicting nearshore to offshore depositional conditions at a moment in time during the early Paleozoic. The system was texturally graded, with the coarsest-grained, quartz-rich sand deposited in nearshore conditions of vigorous currents, and the finest grained material carried out to deeper, less energetic water. From Runkel (1998, 2007). A-A' shown in Figure 3.

The origin of the textural maturity of the quartz grains in these silica-rich layers remains somewhat more uncertain. Chemical weathering that produced the mineralogical maturity in the source area cannot account for the rounding and sphericity of the quartz grains. Experimental rounding of quartz grains in water (Kuenen, 1959) demonstrates that the maturity also could not been achieved solely by fluvial transport, even over distances of hundreds of miles, if the grains were derived directly from the igneous and metamorphic source rocks that dominate the cratonic interior today. Paleozoic quartzose sandstone does contain rare grains with abraded overgrowths that are reworked from older sandstone, which indicates that “recycling” of sand may at least partly account for the textural maturity, but the volumetric significance of such recycling is uncertain and a source of suitably large source of sedimentary rock has not been identified. Odom (1975, 1978) suggested that a long history of abrasion in marine conditions, e.g. transport in beach swash, could account for the textural (as well as mineralogical) maturity that he observed. Dott and others (1986) were the first to clearly identify the presence of substantial eolian deposits within some quartzose formations (the Wonewoc and St Peter Sandstones) and they suggested that wind abrasion, far more effective than abrasion in
water, could have been a major factor in creating the textural maturity of the sand. While each of the processes described above could have played a role they do not entirely account for what appears to be a record of virtually all fine-to coarse grained sand having arrived at the shoreline as texturally mature grains.

Figure 5. Restored cross-section highlighting the stratigraphic attributes of the upper Mt Simon, Wonewoc, and Jordan Sandstones from west-central Wisconsin to northwest Iowa. These sheet-like sandstones were deposited during long-distance migrations of the shoreline across this region. For example, the lower part of the Wonewoc was deposited during a fall in sea level and shoreline migration from west-central Wisconsin to northwest Iowa, followed by a rise in sea level and migration back to Wisconsin. FSL on the illustration refers to parts of a sandstone layer deposited during falling sea level, and RSL to rising sea level. From Runkel (2007). Line of cross section is shown in Figure 3.

The St Peter Sandstone (Fig. 1B), deposited about 450 million years ago, represents the youngest preserved record of widespread quartzose sand deposition in the region. Although shallow seas covered this region intermittently for another 100 million years, the sea floor deposits were mostly carbonate sediment and clay, covering the St Peter with layers that eventually became limestone, dolostone, and shale. Aside from a geologically brief incursion of the ocean about 90 million years ago, in the Cretaceous, the subsequent history of the Paleozoic bedrock, post deposition, is one of mostly exposure and erosion. As erosion occurred, an area of sagging known today as the “Hollandale Embayment” affected how the Paleozoic bedrock layers were sculpted (Fig. 6). The layers of bedrock in the upper part of the sedimentary pile, such as the St Peter Sandstone, are preserved mostly in the center of the sagging Hollandale embayment. These layers were removed by erosion along the upturned edges of the embayment. This produced a pattern where progressively lower (older) bedrock layers were exposed at the land surface towards the margins of the
embayment, such as along the edges of the Transcontinental Arch and Wisconsin Dome and Arch (Fig. 6). Erosion of Paleozoic bedrock was likely especially pronounced during glacial-related activity over the past approximately 2 million years, in particular by large volumes of glacial meltwater draining to the Mississippi River system. It was this fairly recent activity that likely produced much of the high relief topography on the Paleozoic bedrock present today, especially along the Mississippi River and its nearby tributaries.

Figure 6. Generalized maps and cross section illustrating the development of present-day distribution of the four silica sand-rich formations in parts of Wisconsin, Minnesota and Iowa where they are approximately within 50 feet of the land surface. (A) Subtle downwarping of the bedrock in the central Hollandale Embayment relative to its margins during erosion of Paleozoic bedrock led to a pattern with youngest (uppermost) layers preserved in the center, and progressively older layers preserved at the edges. (B, C) Continued erosion, especially by glacial meltwater, further sculpted the bedrock. Deposition associated with glacial activity also covered the bedrock to depths greater than 50 ft across large areas. Generalized from maps by Brown (1988), Mudrey et al. (1987), Jirsa et al. (2010), Witzke et al. (2010), and an unpublished silica sand resource map by A.C. Runkel posted on the Minnesota Geological Survey Website. See Figure 8 for similar map of part of southeastern Minnesota for example of the use of more detailed mapping that provides a more accurate depiction of the distribution of near-surface silica sand.
Many of the glacial advances and retreats also left behind unconsolidated sediment (various proportions of sand, gravel, and clay) that covers the Paleozoic bedrock of the midcontinent across the majority of its extent (Fig. 6). The distribution of where silica sand-rich layers are relatively close to the land surface, and thus potentially extractible, reflects both the pattern of preservation that occurred during their long history of erosion, as well as the pattern of subsequent burial by glacial-related processes. Substantially thick (several tens to hundreds of feet) glacial deposits are relatively widespread along the western margins of preserved Paleozoic bedrock, with the exception of local areas along the Minnesota River. To the east, close to the Mississippi River in Minnesota, northeast Iowa, and across a broad swath of southwestern Wisconsin, the cover of glacial-related unconsolidated sediment is minimal. In most places outside of buried valleys it is less than 50 ft thick.

An understudied aspect of the quartzose sandstone layers of this region is their history of cementation, which probably began soon after deposition and continues to today. Across most of their extent they are poorly cemented, so friable that collecting rock cores and drilling water wells in these layers is commonly hindered by sloughing sand. Most outcrops are surficially case-hardened, but even so most are so poorly cemented that the grains can be disaggregated by hand (E.g. note the graffiti in figure 2B). However, all four formations do have some cement in their quartzose sandstone, and locally they can be very tightly cemented along discrete intervals. Based on outcrop observations calcite appears to be the most common cement in these units. It commonly is present as isolated nodules, coalesced nodules (e.g. “grapestone”), and as laterally extensive, discrete beds typically less than 3 ft. thick. Some outcrops display preferential development of calcite cement along vertical joints. Pore-filling calcite in these units is typically considered a late-stage cement, likely precipitated out of relatively recent (geologically) groundwater. Thus it may be largely restricted in the subsurface to areas relatively close to outcrops or subcrops. Quartz overgrowths are in most areas known to be present on a relatively small percentage of quartz grains (e.g. Thomas, 1991). More pervasive quartz cement, which locally can tightly cement quartzose sandstone, has also been documented. Smith et al. (1993) noted that silcrete cement is present locally on and along the flanks of the Wisconsin Arch, beneath the unconformity that caps the Jordan Sandstone. Runkel et al. (2007) noted a similar silcrete cement in the northernmost exposed extent of the Jordan, along the St Croix River in Minnesota. Pervasive quartz cement is present very locally in the Wonewoc Sandstone as well, for example at Silver Mound in Jackson County Wisconsin. Pore-filling, iron-rich cements (e.g. hematite and goethite) are also common locally, and like the calcite cement, most commonly present along discrete beds. At least some might be attributed to precipitation as part of pedogenic processes in areas where the sandstone was in the past, or is now close to the land surface (e.g. Johnson and Swett, 1974).
SILICA SAND FORMATIONS AS A RESOURCE: ACCESSIBILITY AND TEXTURAL CHARACTERISTICS

Together, Minnesota and Wisconsin have expanded from what were likely fewer than 15 silica sand mining operations ten years ago, to perhaps over 100 active or “in-development” mines according to recent tallies (Fig. 1). The regional industry may soon have the capacity to provide nearly 50 million tons of processed silica sand each year according to some estimates (Wisconsin Center for Investigative Journalism). Even though silica sand-rich bedrock layers are potentially economically extractible across a large area of Wisconsin and Minnesota, and smaller parts of Iowa and Illinois, expansion of mining has not been uniform across the region. Instead, it has been most pronounced in west-central Wisconsin. Although regulatory, political and transportation issues have in part determined where mining has been preferentially expanded, there are also some important geologic factors. In particular, variability in the textural characteristics of the silica sand-rich formations, their depth of burial, and associated landscape characteristics appear to have collectively played a significant role in dictating where the expansion of mining has occurred. These factors also control to some extent the techniques used to mine at individual sites. Here we summarize these key geologic factors.

Textural Attributes

Grain size is an important factor in determining the value of a silica sand deposit. For example, the coarsest sand fraction commonly marketed from this region, 20-40 mesh sand, historically has had a relatively high value because of its demand for specific hydrofracturing procedures, and it’s relative scarcity in silica sand deposits elsewhere on the continent (Beckwith, 2011). Sand within the 40-100 mesh size has a lesser value, and even finer grain sizes are commonly treated as spoil.

Although the Mt Simon, Wonewoc, Jordan and St Peter Formations are all composed dominantly of fine-to-coarse-grained, quartzose sandstone, the relative proportions of grain sizes within this range are not the same in these units. Data synthesized from Ostrom (1971) and Thiel (1957) indicate that the most substantial difference among the four formations is the overall finer grain size of the St Peter Sandstone (Fig. 7). It has only a relatively small percentage of 20-40 mesh sand, and on average contains the highest proportion of sand finer than 100 mesh. As a result, the recent mining expansion, driven by demand for proppant, has in this region targeted the other three, coarser-grained formations. Among the remaining three formations, the Jordan Sandstone in extreme western Wisconsin and across most of southeastern Minnesota appears to most commonly contain the highest percentage of grains of the largest size (commonly about 40% 20-40 mesh), as well as having with the smallest proportion (<10%) of the least desirable >100 mesh fraction. Importantly, this characterization refers to the “Van Oser” or “quartzose facies” (Runkel, 1994b) of the Jordan only, which is generally the upper 30 to 80 feet of the formation (but see Runkel, 1994a, b for stratigraphic complexities) in Minnesota and
extreme western Wisconsin. The Wonewoc and Mt Simon Sandstones generally have a diminished coarser fraction compared to the quartzose facies of the Jordan, with the 20-40 fraction at about 20% in the tested Wonewoc, and 30% in the Mt Simon. These two formations also have a higher percentage than the Jordan of the least desirable grain size, with about 15% finer than 100 mesh.

![Histograms of grain size distribution for the Mt Simon, Wonewoc, Jordan and St Peter Sandstones in Minnesota and Wisconsin. Data from Ostrom 1971 (Wisconsin) and Theil (1959) (Minnesota).](image)

The averaged values for Minnesota (Theil, 1959) are based on analysis of individual five-foot channel samples, with the following number and location of samples: St Peter Sandstone, 24 samples from 5 exposures in 4 counties (2 in Dakota, one each in Goodhue, Olmsted, and Hennepin). All samples are from the upper 35 ft of the formation. Jordan Sandstone, 30 samples from 7 exposures in 7 counties (Goodhue, LeSueur, Scott, Nicollet, Wabasha, Chisago, Washington). All samples are from the upper 50 feet of the formation. Wonewoc Sandstone, 8 samples from two exposures in two counties (Winona, Houston). All samples are from the upper 30 ft of the formation.

The averaged values for Wisconsin (Ostrom, 1971) are based on analysis of individual five-foot channel samples (and at smaller spacings if there was a noticeable change in lithology), with the following number and location of samples: St. Peter Sandstone, 65 samples from 56 outcrops, in 13 counties (Crawford, Dane, Fond du Lac, Grant, Green, Green Lake, Iowa, Lafayette, Pierce, Rock, St. Croix, Vernon, and Winnebago). Jordan Sandstone 15 samples from 13 exposures, in 3 counties (Buffalo, Pierce, and Trempealeau). Wonewoc Sandstone, 124 samples from 109 exposures in 17 counties (Adams, Barron, Clark, Columbia, Dunn, Eau Claire, Iowa, Jackson, Juneau, La Crosse, Monroe, Pierce, Richland, Sauk, Trempealeau, Vernon and Waushara). Mt. Simon Sandstone 20 samples from 12 exposures, in 2 counties (Chippewa and Eau Claire). Because of complexities related to preferential truncation of the Jordan Sandstone beneath the Oneota Dolomite eastward from the Mississippi River, and intercalation of feldspathic beds within the Jordan (e.g. Runkel, 1994a), only those Jordan samples that could be confidently be attributed by the authors of this overview to the upper, quartzose facies of the Jordan were used in this synthesis.

**Geologic Conditions of Burial and Landscape Setting**

Because of the favorable textural characteristics of the Jordan Sandstone in Minnesota and extreme western Wisconsin, it has attracted considerable interest during the recent expansion of silica sand mining. Yet the number of active and proposed mines targeting the Jordan Sandstone appears to be far fewer in number than for other formations, especially
compared to the Wonewoc Sandstone. In addition to regulatory, political and transportation issues that may play a role in the more limited expansion of mining in the Jordan Sandstone, such as moratoriums enacted in a number of southeastern Minnesota counties, there are geologic and landscape issues that are also factors.

One such factor is simply proximity of a silica sand layer to the land surface, which determines how much unmarketable or low value material must be removed to extract the underlying silica sand. Figure 6 shows the Mt Simon, Wonewoc, Jordan, and St Peter, are shown in generalized fashion where they are present at or close (within 50 ft) to the land surface. The relatively great thickness of till, sand, and gravel on top of the Paleozoic bedrock across a wide expanse of the western part of their subcrop extent in Minnesota, limits access to the Jordan (as well as the other quartzose sandstone formations) in that area to only a relatively small number of mineable footprints along the Minnesota River. To the east, where the Jordan is commonly at or very near the land surface, different circumstances similarly limit easy access to mine the formation. Along the Mississippi River and its tributaries, the Jordan Sandstone most commonly outcrops and subcrops as relatively thin, winding areas that follow land surface contours (Fig. 8). A thick (commonly greater than 50 ft) layer of Oneota Dolomite caps the Jordan in these settings. As a result of these conditions high capacity, long-term mines extracting the Jordan Sandstone along the Mississippi River and its tributaries thus far appear to be limited to underground operations. At least two such mines are currently active, both located in bluffs along the Mississippi River in Wisconsin. Carbonate rock quarries where a substantial thickness of Oneota has already been removed have also been considered as potentially viable sites for mining Jordan Sandstone. The relatively thin remainder of the lower Oneota at these quarries would be removed, followed by extraction of the Jordan by routine open pit mining techniques. One such operation near Winona Minnesota has been intermittently active the past two years.

The three operations we will visit on this field trip are examples of geologic settings where expansion has been most pronounced, the Wonewoc Sandstone in west central Wisconsin. The Wonewoc in this area has a number of geologic features associated with it that have led to this expansion. It has a relatively high percentage of texturally and mineralogically mature sand in the coarser grain sizes, is at or near the land surface across a wide swath of western Wisconsin, locally has large (hundreds of acres) of individual footprints with thin cover, and commonly is in a landscape setting with less pronounced relief than nearer to the Mississippi River where the Oneota Dolomite caps the tops of bluffs.
Figure 8. Map and schematic landscape illustration showing relative accessibility of the Wonewoc, Jordan and St Peter Sandstones in a typical southeastern Minnesota geologic setting. The St Peter Sandstone commonly is present at or near the land surface with a relatively large footprint. In contrast the Jordan and Wonewoc are present at or near the land surface mostly as relatively thin, winding areas that follow land surface contours. This map is part of an unpublished map of silica sand resources for Minnesota, posted on the Minnesota Geological Survey website. Block illustration is modified from Mossler and Book (1984).

REFERENCES


Stop 1
Great Northern Sand, New Auburn, WI

Tour Guides:
Aaron Kent - Chief Geologist
Matt Thompson - Dry Plant Supervisor

Why Wisconsin sand:

• “Northern white sand” that is found principally in Wisconsin, Minnesota and Illinois is strongest, most spherical sand available in desired frac sizes.
• Wonewoc Formation – Friable, close to surface
• We want northern white sand to use both as substrate for our resin coating and to sell to our oil field customers.
• Markets such as Texas, Oklahoma, North Dakota, Western Canada, Wyoming and Pennsylvania are best addressed by building plants, along a desired rail system, in northern white sand areas.
• Having done the Atlas Resin Proppants plant in 2005, we are experienced in permitting, building and operating plants in western Wisconsin.
• High quality workforce

GNS project consists of:

• Quarry sand
• Truck the sand to washing/drying and screening facility on rail
• Wash and size the sand
• Dry and Screen the sand to required mesh distributions
• Rail sand in covered hopper cars to markets on Progressive Rail, including our resin coating facility in Shreveport, LA.

Crush Testing – Propstester Data
(this is preliminary core sample data and is not meant to be a representation of the final product)

Dovre Mine Site 7/24/11

20/40 - ISO Crush Analysis (% Fines) 4lb/ft² @ 5,000 psi 8.3
30/50 - ISO Crush Analysis (% Fines) 4lb/ft² @ 7,000 psi 9.5
40/70 - ISO Crush Analysis (% Fines) 4lb/ft² @ 8,000 psi 8.2
Processing Site
Density Separator
Density Separator

Principles of Operation

The CFS Density Separator is a hydraulic classification device consisting of an upper paralleled-walled section of square or rectangular cross-section, and a lower section consisting of one or more pyramidal discharge units. A rising current of water is established over the entire area of the upper unit by injection of a pre-determined flow through a series of nipple style spray pipes located at the junction of the upper and lower sections. These nipple spray pipes are installed to direct the flow of water straight down.

A mineral slurry continuously introduced into the upper unit through one or more feedwells is expanded into a teetered state by the rising water current. The particles are classified, with the coarser material reporting to the bottom of the teetered mass while the progressively finer material is distributed in the upper portion. Pulp level is maintained by a continuous overflow of the unit.

Interstitial water velocity and pulp-specific gravity progressively increase with depth from the top overflow weir to the bottom of the upper unit. An electronic, force-balance-pressure sensing device with transmitter is located in the wall of the upper unit, immediately above the rising-current water piping. The proportional output signal from the transmitter is coupled to electronic pneumatically operated discharge valve with positioner through a process controller or PLC.

For a pre-set upward current of water, the specific gravity of the mineral suspension at the level of the force-balance instrument is indicative of the average particle size of material above the instrument. When a specific gravity value is set in the controller, the automatic discharge valve will operate to maintain the set value, and thereby maintain an equilibrium condition of the teetered mineral suspension. With a preset upward current water flow and specific gravity, the teetered mineral suspension becomes, in fact, an operating part of the machine: "the sand is the machine."

Essential to the maintenance of the desired classification is a relatively constant-volume feed rate to the Density Separator, which is generally achieved in practice by feeding the unit with a constant-speed centrifugal pump operating with a constant suction head, or by conveyor with a metered feed. On the other hand, operation of the unit is not sensitive to the percentage of solids in the feed slurry, nor is it sensitive to changes in feed size gradation, up to a design maximum determined for the particular material to be classified.

The efficient operation of the Density Separator depends on the introduction of a constant rising current of water over the whole area of the tank. It is, therefore, essential that: 1) the water be supplied at a constant pressure and, 2) the water supplied is clean and free from trash that would plug the water distributing system.
To meet these criteria, each Density Separator is supplied with a modulating pressure reducing valve for installation in the users’ water supply system. The valve supplied would maintain a discharge pressure within acceptable limits regardless of fluctuations in inlet pressure.

It is essential that the operator install adequate inline strainers in the water supply piping to insure a clean water supply to the Density Separator. Non-return valves are supplied for installation in the water entries to the Density Separator manifold. These prevent reverse flow and entry of solids into the rising current piping.

Water flow meters is supplied with each Density Separator to measure rising current water and permit establishment of a pre-determined flowrate for a given classification. A flowmeter can also be supplied to monitor compensating water flow if this feature is required for operation.

**Community Involvement**

**Climbing to New Heights for New Auburn Schools**

After working hard to help the local community park, the New Auburn School District invited GNS to a higher challenge. The New Auburn Schools District Administrator, Brian Henning, asked if we had some individuals willing to help put together some climbing equipment. The employees of GNS, now experienced in this sort work, were eager to help out. Over 80 employee hours were put into a day’s work to get all the equipment ready for the younger ones. At the end of the day, Mr. Henning was very happy, commenting “Thank you very much for the assistance of your crew earlier in the week at our school. Your help with the playground assembly was one of the best examples of community partnerships working together to benefit kids that I have seen in several years. I look forward to partnering with you and Great Northern Sand to help kids again in the future!”

And we hope we can help again soon, Mr. Henning!
Great Northern Sand Donates Manpower for Playground
As training has progressed quicker than plan ahead of our plant startup, employees at Great Northern Sand took a day off from the busy days at the construction site to donate their time to help the town of New Auburn finish off some play equipment install at New Auburn Park. Great Northern Sand employees spent two days working to build safer transitions in and out of the play area, anchor and install equipment including new attractions, painting and general area cleanup. All the work was completed ahead of the upcoming New Auburn Jamboree Days at the end of July. GNS employees were extremely proud to be adding value to their local community that will stand for some time.

New Auburn Jamboree Days set for July 27th-29th
New Auburn Jamboree Days is an annual city festival organized by the New Auburn Park Committee. Every year the committee conducts the event to raise funds for playground equipment, pavilion upkeep, ball field maintenance, Christmas decorations and their annual Santa in the Park. Great Northern Sand is happy to lend support this year to further the capabilities of the committee to continue to provide these wonderful services to its community.
Planning is already underway for next year’s event. For more information about how you or your organization can help out with future events, please contact Dan North at (715) 237-2993.

GNS Supports the Cameron Blue Grass Festival
We have pledged our support for the 2012 Cameron Blue Grass Festival to be held July 20-22nd at the Pioneer Village Museum. All proceeds go to support the Pioneer Village Museum which is operated by the Barron County Historical Society. Monies will be used to cover expenses for the festival and hopefully some of their operating expenses beyond the festival. This year is the 7th annual festival and it has typically seen a range of attendance from 400 to 600 people for the weekend. Camping is being offered this year with hopes to see an increase in attendance.
**Scoot and Skedaddle for the Bloomer Food Pantry**
Great Northern Sand is proud to be a Platinum Sponsor for this year’s 5th Annual Scoot and Skedaddle Race to be held on Friday August 3rd, 2012. All proceeds from this year’s race will go to benefit the Bloomer Food Pantry which recently lost the space they have been renting for the last several years. The Bloomer Food Pantry provides food and clothing for those in need in addition to a weekend kid’s meal and school supplies programs. These much needed funds will go to help the Bloomer Food Pantry find a new appropriate facility and enable them to continue these much needed services within our local communities. Any person or organization wishing to help out this worthy cause or would like more details about this year’s race should contact Race Director Janessa Henning at 715-568-4699.

**Great Northern Sand sponsors Miles for Music**
Miles for Music is a 5K/10K/Childrens Walk through the City of Chetek on Saturday May 12th. Funds raised by this event will help to support the Chetek Weyerhaeuser High School Band Department. Individuals wishing to participate in the event can register on race day at the Chetek Weyerhaeuser High School at beginning at 7:30am. Organizations wishing to join Great Northern Sand in supporting our local youth may contact Tammy Craton at 715-237-3328.

**Support Needed for a New Fire Hall in New Auburn –**
Great Northern Sand has made an investment in our local support systems with a cash donation to provide prizes for the New Aurburn Fire Departments’ Summer Raffle. The Summer Raffle runs from Memorial Day to Labor Day and provides a chance for ticket holders to win a four wheeler, PC Notebook and other great prizes. All proceeds earned from the raffle will go toward the much needed new Fire Hall. Great Northern Sand is proud to support our local community in this manner and encourages other local organizations to do the same. Those who wish to lend their support may contact Assistant Chief Thomas Bischel at 715-642-0659.
Environmental Stewardship

Our Community

Great Northern Sand recognizes the importance of our state's public areas and therefore is working with the Wisconsin Department of Natural Resources to donate 24 acres of land to increase the accessibility and quality of habitat within the New Auburn Wildlife Area.

Our Groundwater

GNS has implemented a groundwater monitoring program that includes testing of private wells around our mine site and four monitoring wells within the mine site. In addition to water quality testing, private wells are evaluated by a licensed well driller for age, structure, and pump condition. The installation of monitoring wells at the mine site also enables us to track groundwater elevation so that our mining does not intersect, nor draw down the water table.
Our Wetlands

Wetland delineations are completed at our sites so that GNS can avoid and minimize wetland impacts as much as possible. Once the delineations are completed, representatives from the WDNR and the U.S. Army Corps of Engineers perform a site visit to concur with the delineated wetland boundaries. All wetland impacts at our sites are permitted through the WDNR and ACOE. Mitigation is performed based on suggestions from the ACOE.

Our Rivers and Streams

The WDNR requires that discharges of wastewater or storm water from nonmetallic mining operations to surface waters or groundwater directly or indirectly be permitted through the Wisconsin Pollutant Discharge Elimination System. GNS uses physical controls such as silt fences, seeding, and grading towards retention basins to prevent discharge off our sites. GNS also implements practices such as visual inspections of ditches and basins as well as employee training and awareness to prevent pollutant discharge.

Our Air

GNS acknowledges that there are valid concerns about air quality around any industrial processing site. To address these concerns and meet our own goals, GNS will be installing dust collection equipment for our process plant, an air monitor at our mine and will use effective management practices to limit particulate matter emissions. A third party working in conjunction with the WDNR will site the air monitor such that it captures an accurate representation of particle emissions. Effective site management practices include watering storage piles, keeping haul trucks on paved surfaces, and watering roads. These practices will decrease the amount of fugitive dust leaving the sites.

Our Public Infrastructure

It is also important to prevent mud from being tracked out onto public roads during operations. GNS uses tracking pads at its site entrances and exits to reduce build-up on its haul trucks. A water truck and sweeper are used to control dust and mud on public roads. GNS also has agreements in place with the Town and County of which we use the hwy systems to maintain suitable highway conditions.
Our Facilities & where our sand goes...

- 20-25 rail cars per day projected
- A portion of our sand production will feed our two line phenolic resin coating facility located in Shreveport, LA at the Port of Shreveport. The port is located on the UPRR and production and sand out of this facility is strategically placed to service the Haynesville Shale.
- The majority of our sand production will be shipped direct to customers in their cars to their specified locations. The hottest plays currently are South Texas, Oklahoma, Wyoming and the Marcellus out East.
- CRS Proppants / Great Northern Sand maintains a fleet of over 500 cars for to be used for resin shipments to transloads, sand transportation to Shreveport and sand transportation to transloads. CRS Proppants / Great Northern Sand currently operators three transload facilities outside of the Shreveport, LA production facility. These transloads are located in El Reno, OK, Gonzales, TX and Egbert, WY with additional facilities coming on line in Q4 for 2012 and in 2013.
Stop 2
EOG Resources, Chippewa Falls, WI

EOG Mining and Processing Operations, Colfax and Chippewa Falls, Wisconsin area

By Tony Runkel, Chief Geologist, Minnesota Geological Survey, St. Paul, MN

Part I: Mine Tour

Here we will tour a mine near Colfax, Wisconsin, and a processing plant in nearby Chippewa Falls. The mine is referred to as the “DS” mine, with silica sand extracted from the upper part of the Wonewoc Sandstone (See Figs 1 and 6 in the overview article of this guidebook for stratigraphic and regional geologic context). Unconsolidated sediment, and sandstone of the Tunnel City Group that rests on top of the Wonewoc is removed to access the quartzose sand. The buses will run the field trip participants through parts of the mining operation, with EOG representatives aboard each bus explaining the mining procedure and answering questions. Please refrain from taking photographs at this location.
Figure 1. Topographic map showing with dashed black line the approximate location of the EOG “DS” mining operation.
Figure 2. Map and cross section view showing operational plans for the EOG “DS” mine site. Both illustrations are from the Non-Metallic Mining Reclamation Plan, DS Mine, Town of Cooks Valley, Chippewa County, Wisconsin, Prepared for EOG Resources Inc. by Short Elliot Hendrickson (SEH) Inc. Report downloaded from Chippewa County website.
Part II: Processing Plant

The EOG Processing facility is located in Chippewa Falls, Wisconsin. The buses will transport the field trip participants through parts of the processing operation, with EOG representatives aboard each bus explaining the processing procedures and answering questions. Please refrain from taking photographs at this location.

Figure 3. This October 3, 2011 image was collected when the Chippewa Falls EOG processing facility was still under construction.

**Lunch in Irvin Park, Chippewa Falls.** During lunch the field trip participants will have an opportunity to view core and/or hand samples representative of the four silica sand-rich formations that are most commonly mined in this region: The Mt Simon, Wonewoc, Jordan and St Peter Sandstone. This will provide an opportunity to compare the four formations to one another, and discuss characteristics of each, such as grain size, that are relevant to their value as a resource.
Stop 3
Preferred Sands, Blair, WI

Tour Guides:
Matt Bendernagel, Manager of Geology, Preferred Sands, Philadelphia, PA
Todd Murchison, Northeast Regional Manager, Preferred Sands, Eau Claire, WI
Amanda Bauer, Office Manager, Preferred Sands, Blair, WI

Aerial Photography of the Blair Operation
**Wide Screen Design**
When handling higher capacities, the depth of the material passing over the screen increases. Increased bed depth diminishes the screener’s ability to stratify material, which is essential to effective screening. Expansion of the total screen area is key to increased screener capacity—but only if the area is increased properly. All screen area is not equally productive. Increased screen width expands capacity more effectively than increased screen length. MEGATEX screeners handle increased capacity and maintain screening accuracy by utilizing screen surfaces that are wider rather than longer. Using a two-bank, multi-level screen deck arrangement, MEGATEX screeners present 16’ to 50’ of width to the feed. This width serves to keep bed depths low so screening accuracy and efficiency are maintained at high capacities.

**Long-Stroke, Gyratory Motion**
The force level created by the long-stroke (up to 3”), low-frequency drive serves two important functions. First, the motion effectively spreads the material across the full width of the distribution panel. This achieves proportional feeding to each of the screen levels inside the machine and eliminates the need for multiple process feed points. Second, the long-stroke and low-frequency produce effective ball mesh cleaning to control blinding, providing long-term, uninterrupted operation. Screening units employing shorter strokes or higher frequency drives cannot match these two functions of MEGATEX screeners. Thus their screening effectiveness is poor, resulting in product loss or poor product quality.
Stop 4
Jordan Formation, Highway 93 road cut south of Arcadia

Stop Leaders
Kent M. Syverson, Dept. of Geology, University of Wisconsin-Eau Claire
Anthony C. Runkel, Minnesota Geological Survey
Bruce Brown, Wisconsin Geological and Natural History (retired)

LOCATION
Outcrop located south of Arcadia, 3.8 miles south of the intersection of Hwys. 95 and 93, approximately 175 ft north of the old Hwy 93 road path, road cuts are on both sides of Hwy 93. The Jordan Formation is at road level; the Oneota Formation is exposed in vertical cliffs above the Jordan Fm. NE1/4, Sec. 21, T. 20 N., R. 9 W., Trempealeau County (Tamarack 7.5' Quadrangle, Fig. 1).

SIGNIFICANCE
The Jordan Formation contains coarse-grained, well rounded quartz grains deposited in a shallow marine environment. As such, it is a highly sought-after unit for extracting 20/40-mesh quartz sand. Fairmount Minerals operates underground Jordan Formation mines in Maiden Rock and Bay City, WI, and is currently pursuing another underground mine in the Diamond Bluff area along the Mississippi River. Other small Jordan Formation mines are located in Buffalo and Trempealeau Counties.

DESCRIPTION
The road cuts south of Arcadia have long been recognized for their relatively complete exposure of Upper Cambrian stratigraphy. The road cuts have been described in detail by Ostrom (1987), and much of this stop description is borrowed from Ostrom. See Ostrom (1987) for more details.

The Norwalk Member is the basal member of the Jordan Formation. The Norwalk Member (located at a lower elevation than this field trip stop) is fine- to very fine-grained feldspathic sandstone (Ostrom, 1987; Runkel, 2000). For this reason, the Norwalk Member is not a frac sand target.

The Van Oser Member of the Jordan Formation overlies the Norwalk Formation (Fig. 2). At this stop, the Van Oser Member contains medium- to coarse-grained, well rounded quartz arenite near the level of the road (Fig. 3). The sandstone is thick-bedded and contains cross bedding and calcareous concretions (Fig. 4). In most areas the sandstone disaggregates easily. The Van Oser Member is approximately 45 ft thick in this area (Ostrom, 1987).

The sandstone fines upward toward the overlying dolomite of the Oneota Formation. Ostrom (1987) called this package of fining-upward sediment the Sunset Point Member of the Jordan Formation (Fig. 2). Based on an unconformity separating these sediments from
the Jordan Formation, Runkel (1994) considered these rocks part of the Coon Valley Member of the Oneota Formation. The sand in this zone not only becomes finer grained, but some white-colored beds are extremely well cemented by either silica or calcite (Fig. 5). These beds are extremely difficult to disaggregate. The sandstone is interbedded with thin layers of greenish siltstone and shale, and in some places the siltstone and shale are interclasts within sandy beds (Fig. 6).

The sandstone and siltstone/shale unit is overlain by the Oneota Dolomite of the Prairie du Chien Group. The tan dolomite is fractured, strong, and a cliff-former associated with the “bluffs” in the Mississippi River region. The dolomite has been quarried extensively for aggregate along the upland north of this stop (Fig. 1), and in places dissolution has enlarged fractures within the dolomite.

Figure 1. Location of Jordan Formation stop (red x) south of Arcadia and on the west side of State Highway 93. Oneota Dolomite was mined for aggregate. Yellow lines are UTM grid lines (NAD83, Zone 15). From Tamarack 7.5’ USGS quadrangle (2010), CI = 20 ft.
Figure 2. Stratigraphy of the Jordan Formation along State Hwy 93 south of Arcadia. The Van Oser Member is a good producer of 20/40 sand. The Sunset Point Member is no longer used in the literature, and Runkel (1994) considered this upper sediment package as part of the Coon Valley Member of the Oneota Formation. From Ostrom (1987).
Figure 3. Photomicrographs of the Jordan Formation sandstone at the Arcadia field stop. Well rounded quartz grains display quartz overgrowths that have been rounded (evidence for recycling of sand grains from older units) and authigenic potassium feldspar overgrowths. Sample contains little cement. Photograph from J. Brian Mahoney, Amy Rasmussen, and Rebecca Moore.
Figure 4. Calcareous concretions weathering out of Jordan Formation sandstone at the Arcadia field trip stop. Photograph by Bruce Brown.

Figure 5A. Resistant white beds of sand grains well cemented by silica (and in some cases calcite).
Figure 5B. Close-up of well cemented sandstone bed at the Arcadia field trip site. The rock typically breaks across grains, much like a quartzite. Such material could not be disaggregated in a silical sand processing facility. Photographs by Bruce Brown.

Figure 6. Interbedded fine- to medium-grained quartz arenite and greenish siltstone and shale beds. Shale beds are ripped up to produce intraclasts. White bed below handle of the hammer shows scouring at the base. Located just uphill from the Arcadia field trip stop (across the road from the Scenic Overlook parking area). Photo by J. Brian Mahoney.
INTERPRETATION AND DISCUSSION

Runkel (1994) interpreted the Jordan Formation as a marine regressive unit deposited during the latest part of the Cambrian Period. The lower Norwalk Member was deposited in low-energy marine environment located below the wave base except during storms. As sea level fell, water became increasingly energetic and the coarser-grained Van Oser Member was deposited within the intertidal zone. After a period of erosion, the Coon Valley Member of the Oneota Formation and the overlying dolomite were deposited above the Jordan Formation in the earliest part of the Ordovician Period.

The lower Norwalk Member is too fine-grained and feldspathic to be a good frac sand target. The Van Oser Member, however, is highly prized for its high yield of 20/40-mesh quartz sand.

Overburden is commonly an issue when seeking to mine the coarse-grained Van Oser. The Oneota Dolomite of the Prairie du Chien Group forms nearly vertical “bluffs” in southwestern Wisconsin. As such, the dolomite forms a thick, resistant cap more than 100 ft thick in many places. Removal of this thick overburden would be extremely expensive.

To avoid this problem, Fairmount Minerals operates underground Jordan Formation mines in Maiden Rock and Bay City, Pierce County, Wisconsin. The overlying dolomite is the cap rock for the mine, and sandstone pillars are used to support the roof of the mine.

Areas of surficial dolomite mining also present opportunities for mining the Jordan Formation. Dolomite in large quarries was commonly mined to the base of the valuable dolomite, and this removed much of the material above the Jordan Formation. Some companies are exploring active or abandoned dolomite quarries as possible surficial Jordan Formation mine sites.

REFERENCES CITED

