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INVESTIGATION OF A GRANITE WASH AQUIFER IN GRANT COUNTY, SOUTH DAKOTA

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ABSTRACT

An aquifer referred to as "Granite Wash" has been identified in drilling logs and described in reports and was believed to underlie much of eastern Grant County, South Dakota. Additional work completed by the Geological Survey Program has shown that this aquifer does not exist as previously interpreted and instead is composed of two distinct stratigraphic intervals with differing origins and hydraulic characteristics. The two stratigraphic intervals are (1) a sand unit (informally named "granite wash") and (2) a regolith on the granite surface (Milbank Granite regolith).

The granite wash unit is a moderately sorted, fine- to coarse-grained sand with distinctive blueish grains. The regolith is composed of angular to euhedral quartz and feldspar grains in a kaolinitic clay matrix which has weathered in place and is found on top of the Milbank Granite. The following report describes the geology, stratigraphy, deposition, and aquifer characteristics of the granite wash sand unit.

INTRODUCTION

This investigation was conducted to gain more information about the ground-water source used for irrigation related to Water Right permit 7541-3. The irrigation well associated with permit 7541-3 is located in section 9, T. 119 N., R. 47 W. (pl. 1) and was completed in a "blue sand," the top of which was encountered at 168 feet below land surface and is approximately 20 feet thick. Upon well completion and development, a static water level was measured at approximately 63 feet below land surface.

A decision by the Water Management Board on the application for Water Right permit 7541-3 was initially deferred due to the lack of hydrologic and geologic data in the permit area and the uncertainty as to which aquifer the irrigation well was completed in. As part of the permit conditions, two observation wells were installed and an aquifer test was performed to help better understand the hydrologic and geologic setting. Observation well number 1 (Obs-1) was installed 207 feet to the west and observation well number 2 (Obs-2) was installed 1,416 feet to the south of the production (irrigation) well. The aquifer test was conducted for 3 days at a pumping rate of 700 gallons per minute. Water levels were measured during the test and continued to be measured for a period of 3.8 days after cessation of the pumping phase of the test. The water levels recovered to within 80 percent or greater of their pre-pumping levels during that time. From this information, it was determined the well could pump the requested 2 cubic feet per second without adversely impacting the aquifer (Water Rights Program, 2018a). The permit was then granted and the appropriated water related to Water Right permit 7541-3 was attributed to the "Granite Wash" aquifer (Water Rights Program, 2018a). The purpose of this investigation was to further define the areal extent, and hydrogeologic properties of the "blue sand" encountered in the drilling of the irrigation well for Water Right permit 7541-3.

Methods of Investigation

Fieldwork for this investigation was conducted over the summers of 2014 (6 weeks), 2016 (7 weeks), and 2017 (6 weeks). Over this period, 18 test holes were drilled (6 of which were completed as monitoring wells) and one 25-foot section of core was collected from the weathered Milbank Granite.

The geology of the area was examined by reviewing available literature and interpretation of lithologic logs and geophysical logs. Approximately 2,500 test-hole and well logs from Grant County were reviewed. Specifically, logs were evaluated in an attempt to distinguish the granite wash sand unit from the Milbank Granite regolith. Gilbertson (1990) was the primary reference used when evaluating quaternary sediments, while bedrock geology was evaluated with the aid of Tomhave and Schulz (2004), well logs from private wells (Water Rights Program, 2018b), Water Rights observation wells (Water Rights Program, 2018c), and Geological Survey Program test holes and wells (Geological Survey Program, 2018).

Cross sections were constructed to illustrate the subsurface stratigraphy (pl. 1). The logs selected for construction of the cross sections were chosen on the basis that they penetrated into the Cretaceous-age stratigraphy and often into the unweathered Precambrian-age Milbank Granite. Numerous shallower borings along the cross-section lines were not used because they only penetrated the quaternary-age sediments, and thus were not deep enough to be of use in illustrating the granite wash or granite regolith. In addition to shallow holes, some private well logs were not used along the cross-section lines due to lack of resolution in the data, for example, only describing units as clay or sand and not providing information on color, grain size, mineralogy, or angularity of the sand.

Water-level data are sparse for the Granite Wash aquifer and have only reliably been available since installation of production and monitoring wells associated with Water Right permit 7541-3 which was applied for in 2012. Water levels were measured for this project using a Geotech ET water level meter with an accuracy of 0.01 feet. Water levels were measured on October 10 and 11, 2017, and are presented in appendix A. In addition to water levels measured in this study, the Water Rights Program, Department of Environment and Natural Resources, has additional water-level data for wells M51-2014-11 (GT-2016B) and GT-2013A, which are completed in the Granite Wash aquifer, and well M51-2014-10 (GT-2016A) which is completed in the granite regolith. It was not possible to correlate the water-level data described by Hansen (1990) to a specific stratigraphic unit, and thus, those data could not reliably be attributed to the Granite Wash aquifer.

Water samples were collected from six wells on October 10 and 11, 2017. Of these six samples, four were collected from the Granite Wash aquifer and two were collected from the Milbank Granite regolith (app. A). Prior to sampling, 3 well volumes were purged and pH, conductivity, and temperature were measured to ensure that a representative sample was collected. Samples were analyzed at the South Dakota Public Health Laboratory.

BEDROCK GEOLOGY

Bedrock in this report refers to Precambrian and Cretaceous-age rocks which underlie Quaternary-age sediments. Bedrock units depicted on cross sections in plate 1 are briefly described below. Additionally, a brief description of the Dakota Sandstone is given to provide context for a discussion of a basal Cretaceous sand documented in Minnesota by Setterholm and others (1987).

There is an unnamed shale directly below the granite wash that was encountered in drill holes R20-2016-01, R20-2017-10, R20-2017-12, and in the irrigation well for Water Right permit 7541-3 (cross section D-D', pl. 1). The shale was also encountered in nearby drill holes GT-2013A, R20-2014-10, and R20-2017-14. No description is provided for this unit other than what appears in the logs for the drill holes.

Precambrian Deposits

Milbank Granite

The Milbank Granite has been assigned to an age of ~2.65 Ga based on U-Pb and Rb-Sr ages collected from similar granites in the Minnesota River Valley (Goldich and others, 1970). The Milbank Granite is a pink to dark-red, coarse-grained granite composed of orthoclase, quartz, and biotite (Tomhave and Schulz, 2004).

Milbank Granite Regolith

The regolith on the Milbank Granite formed while the unit was at or near land surface and continued forming until sufficiently buried by sediments. The regolith is white-gray and is composed of predominately kaolinite in the highly weathered upper zone and grades downward into equal parts quartz and feldspar grains. The regolith has been weathered in place and *has not been transported and redeposited*. Thickness varies widely in a seemingly non-uniform manner from 0 to 70 feet. The age of the regolith is only constrained by the age of the overlying sediment and therefore may not be Precambrian in age.

Cretaceous Deposits

During Cretaceous time, the Western Interior Seaway encroached into the center of the North American Continent and a succession of marine sediments was deposited. During this time period, eastern Grant County was proximal to the eastern margin of the seaway. Due to this proximity, the typical sequence of Cretaceous units may not be present. Additionally, units could manifest themselves as a different facies of their counterparts farther away from the margin (Witzke and others, 1983; Setterholm, 1994; Ludvigson and others, 1994).

Granite Wash

The sand of the granite wash is a blue to gray, fine to coarse sand that is angular to subangular in shape. The unit is comprised predominately of quartz with little to no feldspar or clays. Some hard silty fragments are found within the drill cuttings, but these fragments make up less than 10 percent of the total composition. Distribution of the unit in eastern Grant County is irregular and the thickness of the unit ranges from 3 to 32 feet.

Dakota Sandstone

The Dakota Sandstone is a light to reddish-brown, medium to coarse-grained quartz and minor feldspar sandstone which grades upward into a fine to medium-grained, quartz and minor feldspar sandstone. The formation contains a gray, silty, clay unit in the middle and interbeds of gray to dark-gray shale in the upper portion (Tomhave and Schulz, 2004). In southwestern Minnesota, a sandstone unit (lithologically similar to the granite wash) is described by Setterholm and others (1987) to resemble the Nishnabotna Member of the Dakota Sandstone. The comparison between the sandstone in Minnesota and the Nishnabotna member is based on lithologic similarities and relative stratigraphic position, thus it is not definitive evidence that the two are the same. Additionally, the Dakota Sandstone has not been directly identified in the lithologic logs in Grant County, but this may be due to the fact that borings do not penetrate deep enough in the central and western portions of the county.

Graneros Shale

The Graneros Shale is a dark-gray, noncalcareous, pyritic, poorly fossiliferous shale, with numerous sandstone layers at the base (Tomhave and Schulz, 2004). The unit has only been identified in 10 lithologic logs in Grant County and, when present, measures from 6 to 75 feet thick (Geological Survey Program, 2018).

Greenhorn Limestone

The Greenhorn Limestone is a gray shale, mudstone, marl, calcarenite, and shaly limestone grading upward into light-gray to tan, alternating marl and thin-bedded, fossiliferous limestone (Tomhave and Schulz, 2004). The Greenhorn Limestone in eastern Grant County, when present, measures from 1 to 45 feet thick (Geological Survey Program, 2018).

Carlile Shale

The Carlile Shale is typically the uppermost bedrock unit in eastern Grant County. The unit is a gray to dark-gray to black, silty to sandy shale with several zones of septarian, fossiliferous, carbonate concretions. Statewide, it contains up to three sandstone units in the upper portion of the formation and is a sandy calcareous marl at the base (Tomhave and Schulz, 2004). The unit can reach a thickness up to 330 feet, although it is significantly thinner in Grant County.

Four members of the Carlile Shale are present in South Dakota. Members of the Carlile Shale in northeastern South Dakota include (from stratigraphically lowest to highest) Fairport Chalk member, Blue Hill Shale member, Codell Sandstone member, and an unnamed shale member (Fahrenbach and others, 2010). Of these four members, only the Blue Hill Shale and the Fairport Chalk have been conclusively identified in Grant County. Again, the composition, thickness, and presence of these members vary due to their proximity to the margin of the Western Interior Seaway.

FAIRPORT CHALK MEMBER

The Fairport Chalk member is a calcareous shale and is often identified by its brown color and tan-white specs. When identified, it can range from 6 to 63 feet in thickness.

BLUE HILL SHALE MEMBER

The Blue Hill Shale member is identified by its gray color and non-calcareous nature, and ranges from 20 to 230 feet thick. This is typically the upper most bedrock unit in the vicinity of Water Right permit 7541-3.

CODELL SANDSTONE MEMBER

The Codell Sandstone is a coarse-grained facies deposited in the uppermost stratigraphic portions of the Carlile Shale. The unit typically signifies the maximum regression during the Greenhorn Cyclothem, which is lithologically represented by the Codell Sandstone's deposition in central South Dakota (Witzke and others, 1983). In western Minnesota, however, the Codell Sandstone likely reflects a coarse-grained facies of the Carlile Shale during a slowed transgression in the late stages of the Greenhorn Cyclothem. This is lithologically represented by onlap of the Codell Sandstone onto the Sioux Quartzite and Precambrian highlands in southwestern Minnesota (Witzke and others, 1983). The Codell Sandstone has been possibly identified in a small number of geophysical logs within Grant County, but has not been physically identified in drill cuttings.

QUATERNARY GEOLOGY

During Pleistocene time, a series of glacial advances and retreats eroded Cretaceous-age units and scoured the granite surface in some places (Gilbertson, 1990). In addition to erosion, a succession of till sheets and outwash bodies were deposited over Grant County. Outwash bodies were identified in cross sections (pl. 1), but individual till sheets were not separately identified in this investigation. A comprehensive discussion of the Quaternary sediments is beyond the scope of this report.

GRANITE WASH SAND UNIT

Previous Investigations

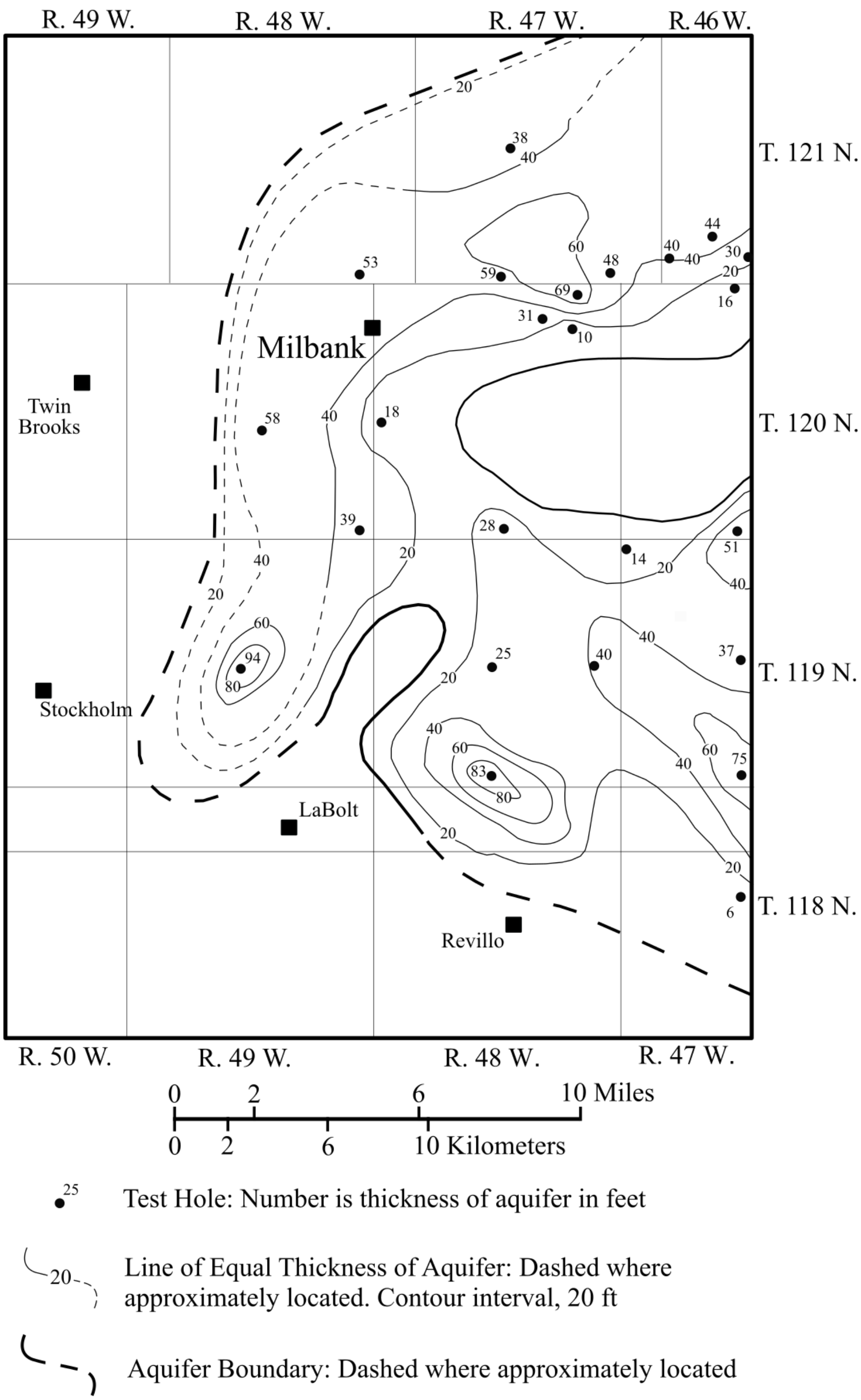
The term "granite wash" has been appearing in drill logs since the early 1980's (for example, SDGS well BSC-81-9), and has been described in publications by Hansen (1990, 1994). Hansen states the granite wash is an "uncemented, coarse, sub-angular to well-rounded, pink to blue to gray, quartzose and feldspathic sand, containing about 50 percent feldspar" and "the aquifer overlies the Milbank Granite in eastern Grant County" (fig. 1). Hansen did not place an exact age on this sand unit and only describes the sand under the heading of "Bedrock Aquifers." Hansen (1990, pp. 20, 37, 43) shows the granite wash to lie on the Milbank Granite surface and to occur just below the Carlile Shale and the Greenhorn Limestone (fig. 2). Hansen did not, however, recognize the regolith on the Milbank Granite surface as being distinct from the granite wash sand.

A study conducted by the Minnesota Geological Survey (Setterholm and others, 1987) identified a sandstone "composed of almost entirely fine- to coarse-grained quartz" at the base of the Cretaceous section in southwestern Minnesota. Their report divided the Cretaceous stratigraphy in southwestern Minnesota into units 1 through 6 with unit 1 being the oldest. The sands of unit 1 are overlain by a shale with silt lenses (unit 2) which is potentially equivalent to the Upper Dakota Sandstone and Graneros Shale. Units 3, 4, and 5 are correlative with the Greenhorn Limestone, the Fairport Chalk member of the Carlile Shale, and the Blue Hill Shale member of the Carlile Shale, respectively. Unit 6 was described as a shaly and silty interval which could not be clearly correlated.

Setterholm and others (1987) surmised that Unit 1 could be equivalent to the Dakota Sandstone (specifically the Nishnabotna member in northwestern Iowa) based on stratigraphic position and lithologic characteristics. The sand of the granite wash does match the lithologic characteristics of Unit 1, but it is difficult to confirm that the granite wash sand unit correlates with Unit 1 or the Dakota Sandstone due to the distance between the two units, lack of data, and the fact that no borings have intercepted the Dakota Sandstone in Grant County. However, this hypothesis cannot be ruled out and remains plausible. Unit 2 may be correlative to the Graneros Shale, in southwestern Minnesota, but the Graneros Shale has not been observed in direct contact with the granite wash within eastern Grant County. The descriptions of units 3, 4, and 5 from Setterholm and others (1987) more closely resemble the Cretaceous sediments found farther west in Grant and Codington Counties.

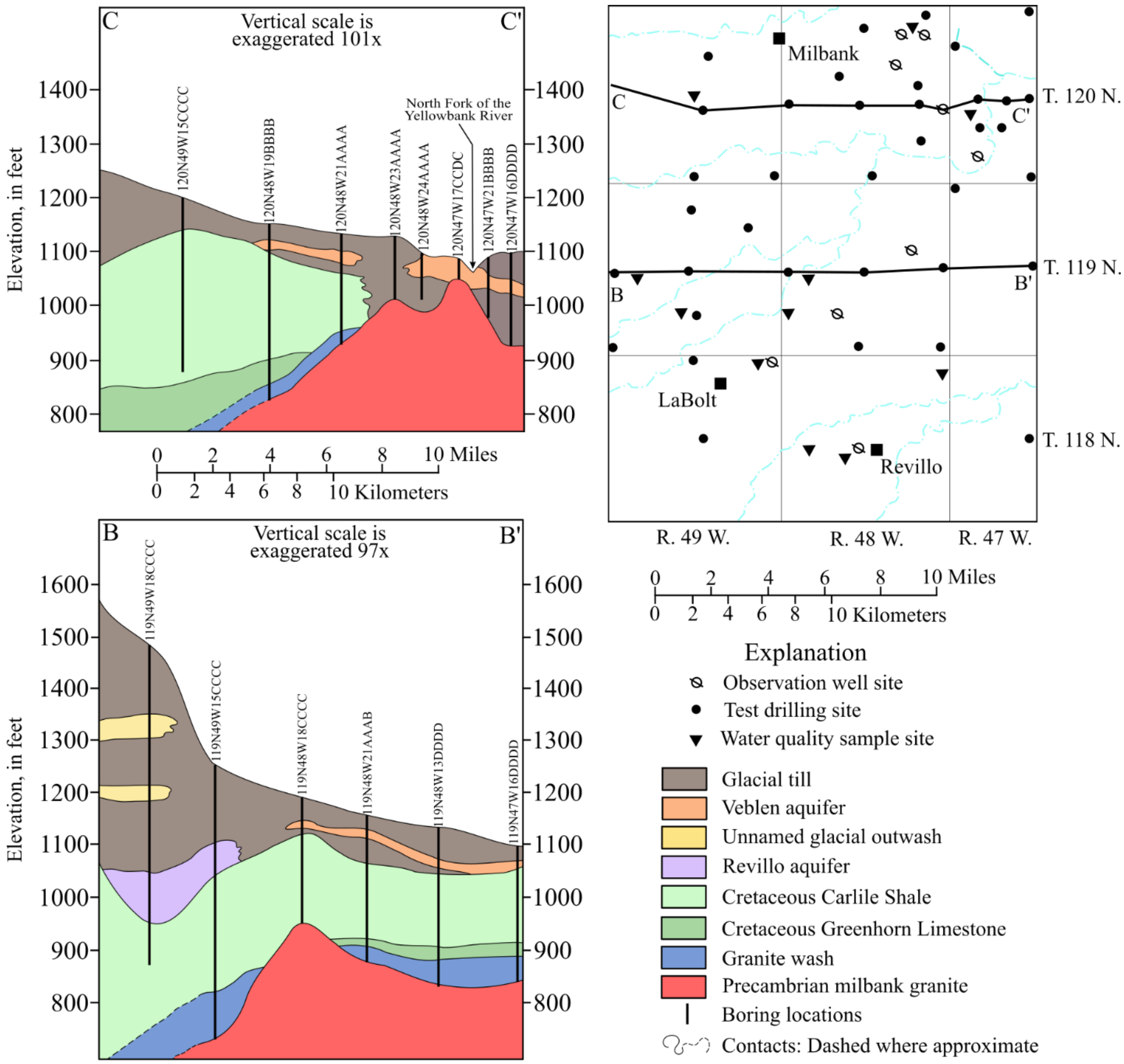
Differentiation of Granite Wash from Granite Regolith

Samples of the granite wash sand and regolith are shown on figures 3 and 4. While it is true the granite wash does often lie on the Milbank Granite surface, drilling and coring conducted for this study identifies that the granite wash sand also lies above, and potentially within, Cretaceous shales (test holes and wells R20-2017-10, R20-2017-12, R20-2017-14, M51-2014 10, and GT-2013A found in Geological Survey Program, 2018; irrigation well for Water Right permit 7541-3 found in Water Rights Program, 2018a).



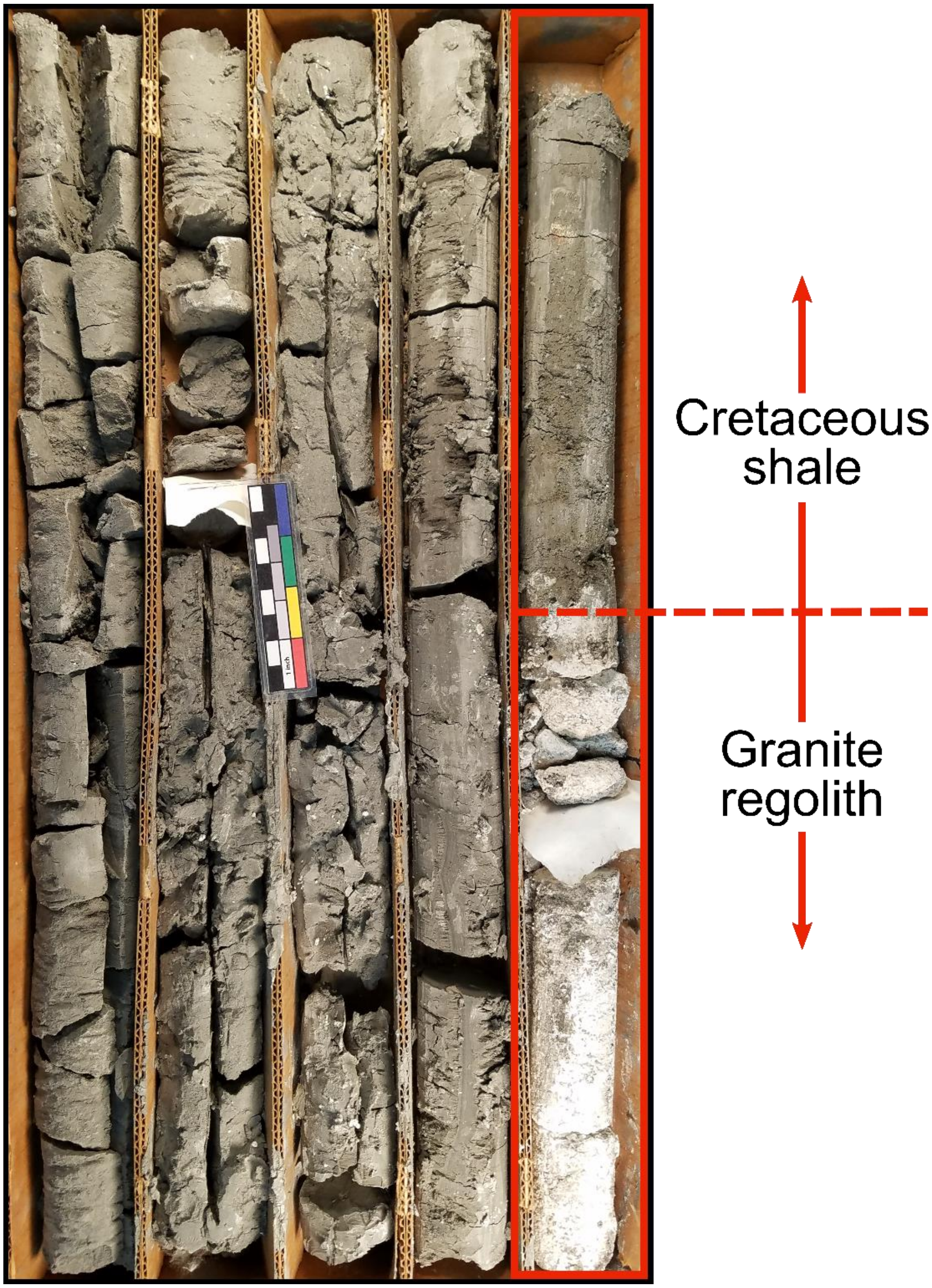
The map and explanation above were created using a portion of figure 23 in Hansen (1990). No new data or interpretations have been added.

Figure 1. Granite wash extent and thickness from Hansen (1990).



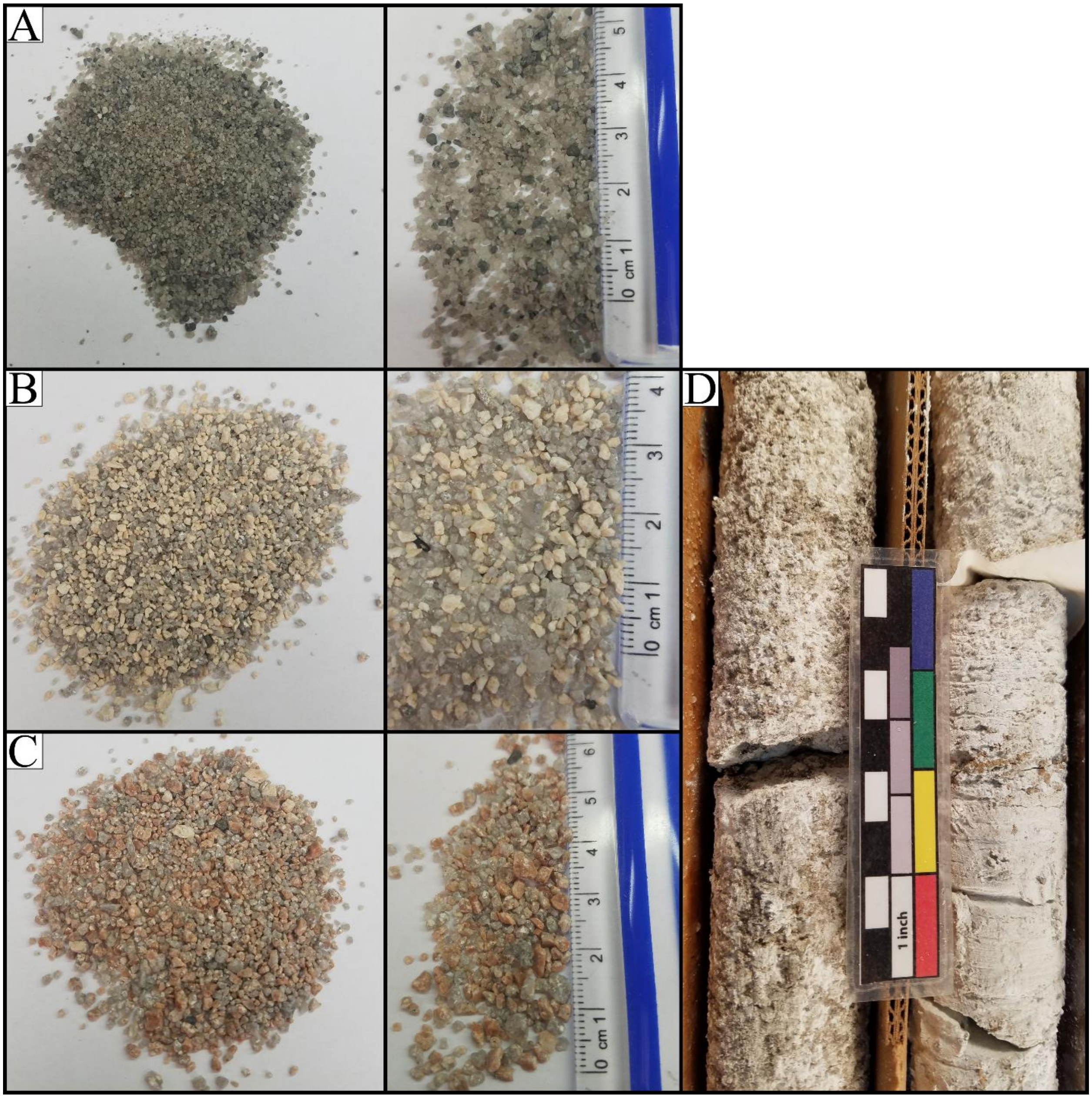
The cross sections and map above were created using portions of figures 2, 11, and 21 in Hansen (1990). Color has been added here for clarity but no new data or interpretations have been added.

Figure 2. Cross sections and location map from Hansen (1990).



The shale in the photo above is located stratigraphically below the granite wash aquifer.

Figure 3. Cretaceous shale overlying the Milbank Granite regolith in a core collected from test hole R20-2017-14.



Mud-rotary cuttings from the granite wash aquifer (A) and the Milbank Granite regolith (B & C).
The sand of the granite wash aquifer is void of feldspars (A).

Feldspars are abundant in the Milbank Granite regolith (B & C) and display a progressive decrease in weathering with depth.

Clays are present in the Milbank Granite regolith core (D) but are winnowed out during mud-rotary drilling and, thus, do not appear in the cuttings (B & C).

Figure 4. Photos of drill cuttings and core.

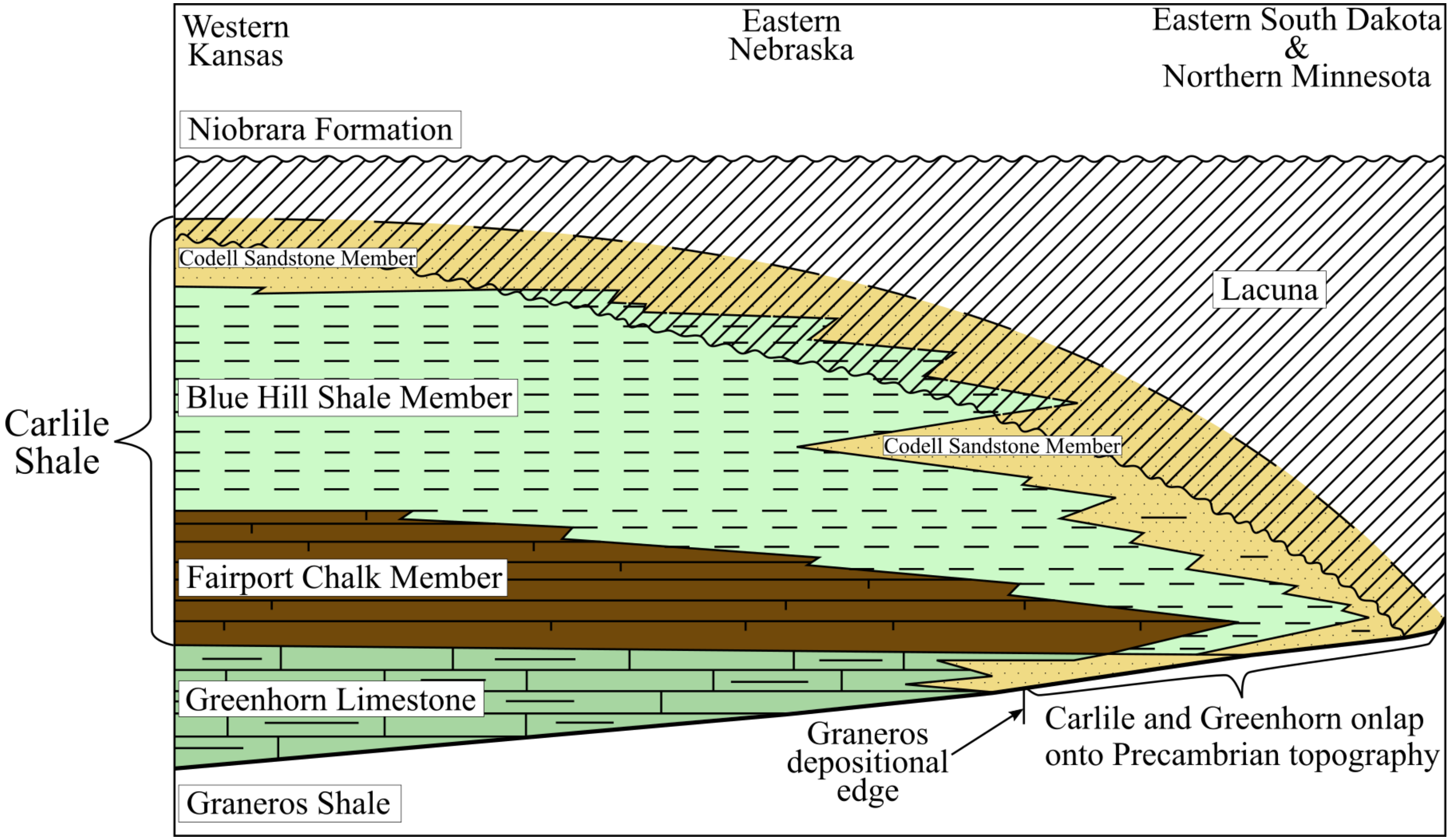
Stratigraphic Models for the Granite Wash Sand Unit

Historically, the stratigraphic age of the granite wash sand unit has been described in the context of the typical Cretaceous stratigraphy found farther west toward the center of the Western Interior Seaway. This lithostratigraphic approach makes it difficult to decipher the formations in eastern Grant County, especially when attempting to break units down into respective members that are observed farther away from the eastern seaway margin. The main problem with correlation is that the granite wash sand unit does not occur at the same stratigraphic position across the area. However, several logs from test holes in eastern Grant County identified member-specific stratigraphy as described below.

The Fairport Chalk member of the Carlile Shale is often described as a dark brown calcareous siltstone containing "tan specks," while the underlying Greenhorn Limestone is often described as a gray shale containing some zones of dark-brown calcareous shale. Distinguishing between the two is often aided by a geophysical log where the Fairport Chalk member of the Carlile Shale has a higher sustained gamma signature, while the Greenhorn Limestone has a generally lower, sporadic gamma signature. The sand of the granite wash is placed below the Fairport Chalk member of the Carlile Shale in test holes R2-85-29, R2-87-14, and CO-86-49 (Geological Survey Program, 2018) and below the Greenhorn Limestone (when present) in several logs from eastern Grant County in test holes CO-84-75, R2-87-14, and BSC-81-18 (Geological Survey Program, 2018). Most of the test-hole logs do not identify any members of the Carlile Shale and record the granite wash as simply occurring below the Carlile Shale. Using this lithostratigraphic model, it would indicate the sand of the granite wash was deposited prior to the deposition of the Greenhorn Limestone.

An alternative explanation for the stratigraphic position of the Granite Wash requires a shift from a lithostratigraphic paradigm to an allostratigraphic paradigm (fig. 5) such as is described by Holzheimer (1987), Kario (1987), and Setterholm and others (1987) for the Split Rock Creek Formation sediments deposited on and near the Sioux Quartzite Ridge in southeastern South Dakota. The Split Rock Creek Formation was deposited within embayments of the Sioux Quartzite Ridge during Cretaceous time (Holzheimer, 1987; Kario 1987). The typical Cretaceous strata is not necessarily present in these embayments, so lithologic divisions within the Split Rock Creek Formation are typically described using a numeric system with Unit 1 being the earliest unit deposited (Holzheimer, 1987; Kario 1987; Setterholm and others, 1987). In addition to a numeric labeling system, the Split Rock Creek Formation is traditionally described in an allocyclic nature, in reference to the four cyclothems during the Late Cretaceous. The Split Rock Creek Formation shows some variations in each embayment, but a sand dominated unit (Unit 1) is typically present at the base of the section. The topographic highs of granite in Grant County likely created a similar depositional environment (fig. 6), thus the Split Rock Creek Formation could serve as an analog for eastern Grant County.

Due to the proximity to the eastern margin of the Western Interior Seaway, the granite wash may represent a coarse-grained facies that crosses typical lithostratigraphic boundaries (i.e., a coarse-grained facies of the Greenhorn Limestone *and* the Carlile Shale; Witzke and others, 1983). This can explain the variability of the position of the granite wash in relation to the granite regolith



Modified from Witzke and others (1983)

Figure 5. Allostratigraphic model during the Greenhorn Cyclothem.

Figure 6. Conceptual model of an irregular shoreline with embayments in Grant County during Cretaceous time.
Photo credit: Per Pixel Petersson/imagebank.sweden.se

and other Cretaceous-age units. This paradigm can also explain the distribution of the granite wash over a variety of elevations along the bedrock surface.

Deposition of the Granite Wash Sand Unit

The granite wash sand unit occupies three linear trends within eastern Grant County. In southwestern Minnesota, Setterholm and others (1987) stated that the unit is likely fluvial in origin, occupying bedrock lows. However, the granite wash in eastern Grant County seems to represent fluvial processes introducing sediments into the basin and a redistribution of sediments into paleo-shorelines associated with the Western Interior Seaway. Plate 1 shows that the granite wash is deposited on moderate slopes, without any noticeable valley-fill deposition. Additionally, these linear trends occupy multiple elevation zones. The change in elevation of these linear trends likely reflects a rising sea level during the Greenhorn Cyclothem.

During the early stages of the Greenhorn Cyclothem, the southernmost linear trend of the granite wash (shoreline 1 on plate 1) was deposited first at the lowest elevations. After this period, sea level continued to rise resulting in a transgression and deposition of the central linear trend (shoreline 2 on plate 1). Intermediate elevations of the granite wash recorded in borings R2-85-29, R20-2017-15, M51-2014-10, M51-2014-11, and R20-2017-14 represent the transition between shorelines 1 and 2 and also likely represent areas receiving a plentiful sediment supply (pl. 1). The northernmost lineament (shoreline 3 on plate 1) occupies elevations slightly different than shoreline 2. It is difficult to interpret if shoreline 3 is a separate transgressive event from shoreline 2 or if it was deposited at a similar time, due to the limited amount of data and the disparity of thickness and elevation evident in test holes CO-86-09, BSC-81-9, and BSC-81-18 (pl. 1). Additionally, it is possible that Shoreline 3 is influenced by a separate, smaller, sediment source influencing the thickness and elevations of the granite wash recorded in these wells.

After the deposition of shoreline 3, sea level continued to rise and the coarse-grained facies transgressed eastward. This may be indicated by an increase of the top elevations of the granite wash in test holes CO-84-57, CO-84-74, CO-84-64, and CO-84-75 and the deposition of the Blue Hill Shale Member of the Carlile Shale over most of eastern Grant County.

GRANITE WASH AQUIFER

Extent and Thickness of the Granite Wash Aquifer

The interpretation of the extent of the Granite Wash aquifer has changed dramatically since Hansen (1990, 1994) last described it. Hansen (1994) states the Granite Wash aquifer covers an area of 190 square miles and ranges in thickness from 6 to 94 feet. However, Hansen's definition of the aquifer included the granite regolith. Results from the present study have caused a reduction in the interpreted area to approximately 18 to 21 square miles with a thickness ranging from 3 to 32 feet. The previously interpreted extent from Hansen (1990; fig. 1) included what is now considered to be Milbank Granite regolith as shown on plate 1. The un-transported granite regolith contains large amounts of clay, specifically kaolinite, and contains roughly equal parts quartz and feldspar. The discrepancy may be understood in the forward mud rotary drilling method that was used to explore the subsurface. As the regolith was encountered with the drill, the clay materials were preferentially removed and suspended in the drill fluid. The remaining portion of the cuttings showed a clean quartz and feldspar sand. These cuttings were often described as "granite wash" and considered to be part of an extensive aquifer when in fact this was in error (figs. 3 and 4). The regolith likely extends beyond the boundary displayed in plate 1, but the surface of the granite dips downward to the north, west, and south, the Pleistocene sediments thicken, and existing drill holes tend not to penetrate deep enough to encounter the granite surface. Thus, the boundary of the granite regolith portrayed on plate 1 records the farthest approximate extent as found in the lithologic logs.

The sand of the Granite Wash aquifer has been weathered from the Milbank Granite, transported, and redeposited. The granite wash has little to no clay or silt and is predominately composed of fine to coarse quartz grains. Distribution of the granite wash is irregular, following linear trends and probably represents numerous paleo shorelines. Setterholm and others (1987) state that the unit is thickest in depressions on the Precambrian surface and thinner on slopes bounding high-standing areas. This study found the unit is generally thicker in the east and thinner in the west, potentially due to higher sediment influx in the east. The approximate areal extent of the aquifer is shown on plate 1.

Aquifer Characteristics and Water Quality of the Granite Wash and Granite Regolith

The hydraulic conductivity of the Granite Wash aquifer is good, as demonstrated by the 700 gallons per minute pumped over 3 days and the recovery of water levels during the test conducted for Water Right Permit 7541-3 (Water Rights Program, 2018a). It is not possible to estimate the volume of water within the aquifer due to the variability in thickness and sparsity of data regarding aquifer extent. Additionally, the recharge rate to the confined aquifer is also unknown.

In terms of aquifer properties, the main issue with the Milbank Granite regolith is the hydraulic conductivity of the aquifer. Monitoring wells did recharge after pumping, but at a slow rate which is problematic for high volume usage. Fracture flow may play an important role in the viability of the granite regolith as an aquifer, but it is not possible with the available data to determine areas with a high probability of fractures or whether the kaolinite in the regolith will inhibit fracture formation.

Based on the information for two water samples from the Milbank Granite regolith and five samples from the granite wash (app. A), the quality of water in the regolith is inferior to the water quality of the granite wash. The number of samples on which this interpretation is based is very small but the difference in water quality is likely to be the same with a larger data set.

CONCLUSIONS

The granite wash sand unit is a separate stratigraphic interval from the weathered granite regolith. The granite wash sand unit is comprised almost entirely of coarse to fine quartz grains and contains little to no feldspar or clay fraction. The granite regolith contains abundant clays and increasing feldspar content with depth. Using this knowledge, the two units can be easily distinguished from one another.

Previous investigations in Minnesota have identified a quartz-rich sand unit at the base of the Cretaceous sediments. Though the Minnesota sand unit (unit 1 of Setterholm and others, 1987) and the granite wash sand unit share lithological similarities, they are unable to be conclusively correlated. Stratigraphic position, extent, and correlation of the granite wash sand unit in eastern Grant County are still not definitive, but three facts from this investigation provide valuable insight:

1. The granite wash sand unit was deposited on a Cretaceous shale and on the weathered granite regolith.
2. The granite wash has been identified stratigraphically below calcareous shales interpreted to be the Fairport Chalk member of the Carlile Shale and the Greenhorn Limestone (when the units are present).
3. The granite wash is seemingly deposited in a nearshore environment, with shorelines occupying multiple elevation zones.

From this information, it is unlikely that the granite wash is a Codell Sandstone equivalent, because it is often found at the base of the Blue Hill Shale member of the Carlile Shale and, in several instances, under calcareous shales mentioned above. The granite wash sand unit may still be correlated to the upper Dakota Sandstone, on the basis of its stratigraphic position and coarse-grained characteristics, but again there is a lack of evidence to conclusively make this claim.

Due to the proximity of the granite wash sand unit to the Western Interior Seaway's margin, a departure from a lithostratigraphic paradigm is likely necessary to understand its depositional history. The Cretaceous strata of eastern Grant County is better represented by an allocyclic model, with the granite wash sand unit reflecting a coarse-grained shoreline facies during the Greenhorn Cyclothem. As sea level rose, transgression occurred and the shoreline moved toward a higher elevation. Eventually, sea level exceeded the elevation of the granite high causing the deposition of coarse-grained sediments to transgress eastward into Minnesota.

Previously defined extents of the Granite Wash aquifer described in publications combined the two units of granite wash and granite regolith. Therefore, these earlier publications provide inaccurate information on the spatial distribution, thickness, and water-volume estimates for the Granite Wash aquifer.

The Granite Wash aquifer, when present, is a viable source of ground water in eastern Grant County. Water quality in the granite wash, while not exceptional, does also not rule out its use. The Milbank Granite regolith, though more prevalent in the region, is not a desirable aquifer due to low hydraulic conductivity within the unit and inferior water quality to that of the granite wash. Water-quality data are limited for both aquifers and were collected in a small area, due to the availability of wells. Water quality is likely variable in the region, thus extrapolation from this small data set is not advised.

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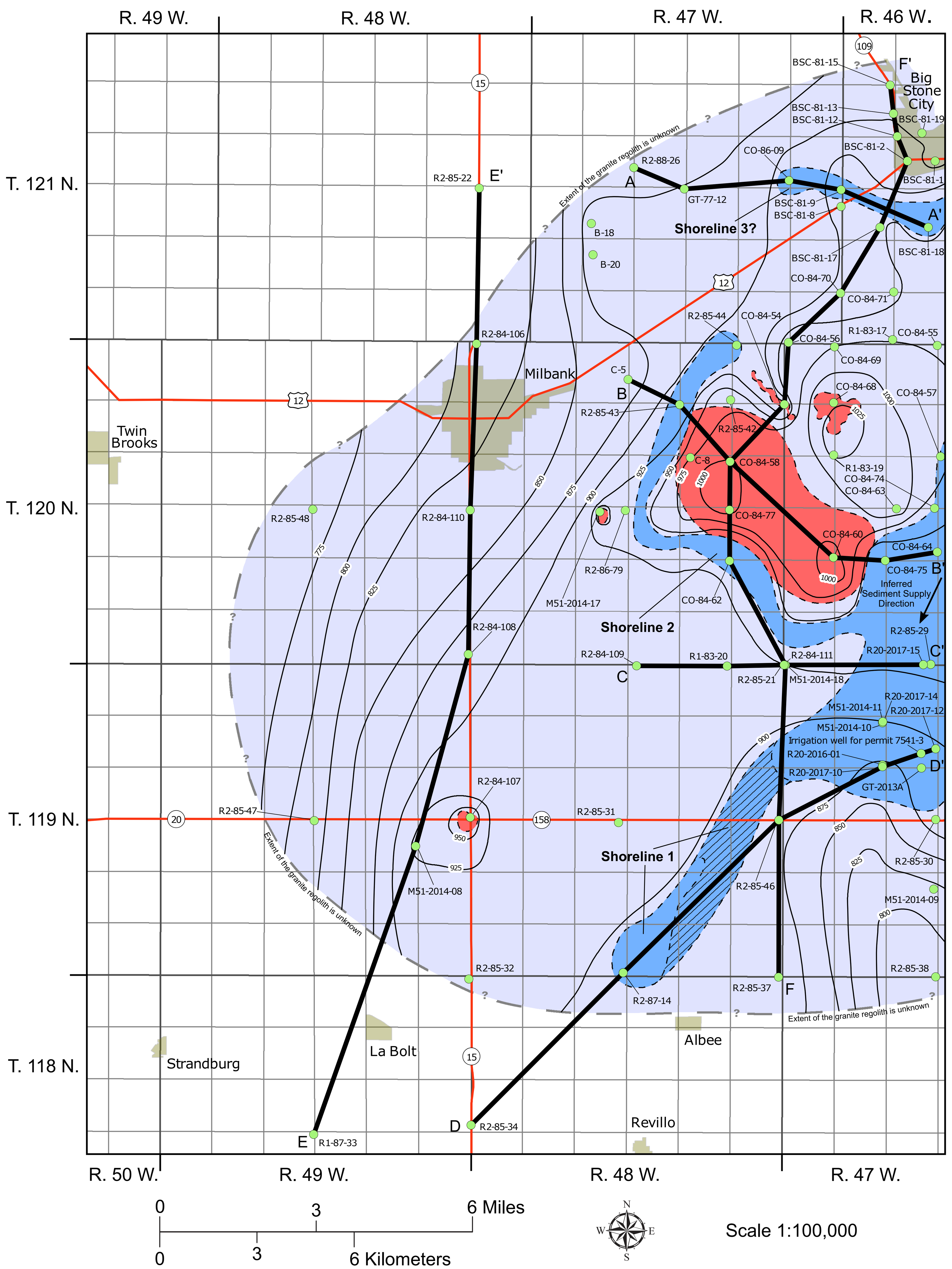
Appendix A. Water-quality data from the granite wash and the Milbank Granite regolith

Well	Sample number	Date sampled	Well depth below casing top (feet)	Depth to water from casing top (feet)	Constituent and concentration in milligrams per liter (mg/L)																Conductivity (µmho/cm)	pH
					Alkalinity-M	Alkalinity-P	Ammonia	Calcium	Chloride	Fluoride	Iron	Magnesium	Manganese	Nitrate + nitrite as nitrogen	Potassium	Sodium	Total dissolved solids	Sulfate	Bicarbonate	Carbonate		
Granite wash																						
GT-2013A	GWA-2017-002	10-10-2017	≈179	62.93	312	0	2.72	143	378	1.29	5.00	38.7	0.20	< 0.2	15.2	582	2,249	911	428	0	3,310	7.97
M51-2014-11	GWA-2017-004	10-11-2017	196	68.05	351	0	2.02	133	64	0.54	1.72	50.6	0.14	< 0.2	9.9	182	1,187	522	428	0	1,700	7.87
R20-2017-10	GWA-2017-003	10-11-2017	229.6	89.59	316	0	2.43	48.6	385	2.58	1.35	16.0	0.06	< 0.2	12.4	672	2,275	881	386	0	3,470	8.12
R20-2017-12	GWA-2017-001	10-10-2017	202.3	67.73	295	0	2.54	134	278	0.78	2.70	52.4	0.16	< 0.2	13.3	425	1,924	834	360	0	2,840	8.16
Production well[1]	---	3-1-2013	~ 188	~ 63?	---	---	1.98	80.48	254	---	0.80	26.42	0.06	<0.047[2]	11.97	416.04	1580.0	734	---	---	2,780	7.47
Milbank Granite regolith																						
M51-2014-08	GWA-2017-006	10-10-2017	360	17.32	318	5	2.63	50.4	725	3.78	0.60	18.2	0.28	< 0.2	17.0	1,042	3,435	1,270	376	6	5,120	8.49
M51-2014-10	GWA-2017-007	10-11-2017	273.8	63.44	240	0	3.03	138	520	1.60	3.98	50.4	0.24	< 0.2	18.2	674	2,753	1,130	293	0	3,970	8.37

[1] Information presented is presumed to be from the production well used in the aquifer test that was conducted for Water Right permit 7541-3.

[2] The laboratory report provided information for nitrate nitrogen, not nitrate + nitrite as nitrogen.



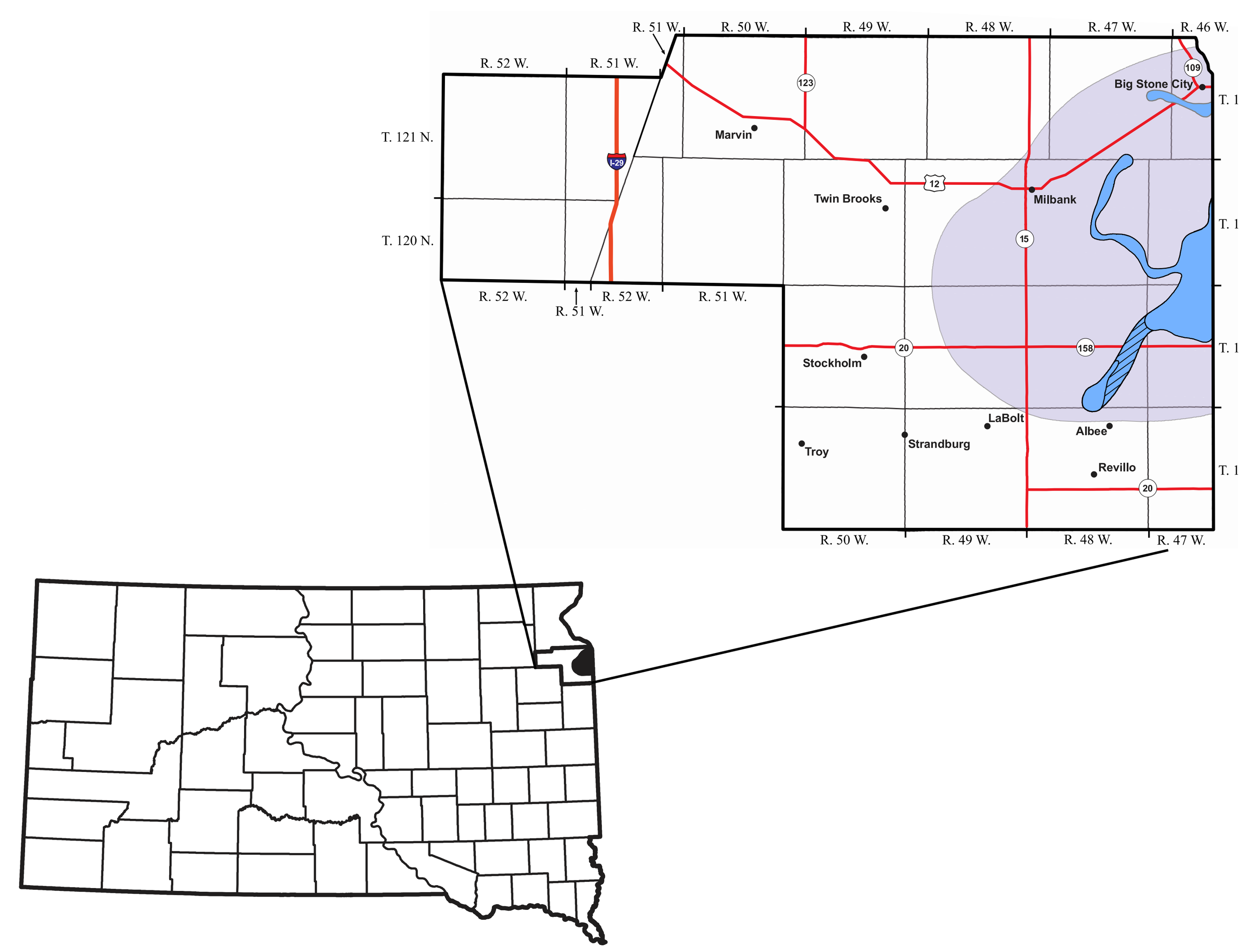


Plate 1. Extent of the granite wash and Milbank Granite regolith in eastern Grant County, South Dakota

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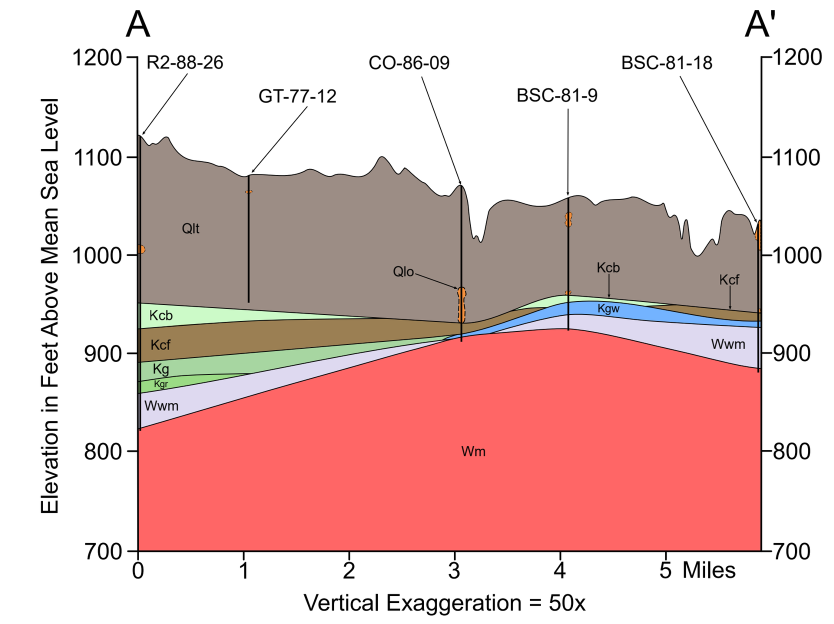
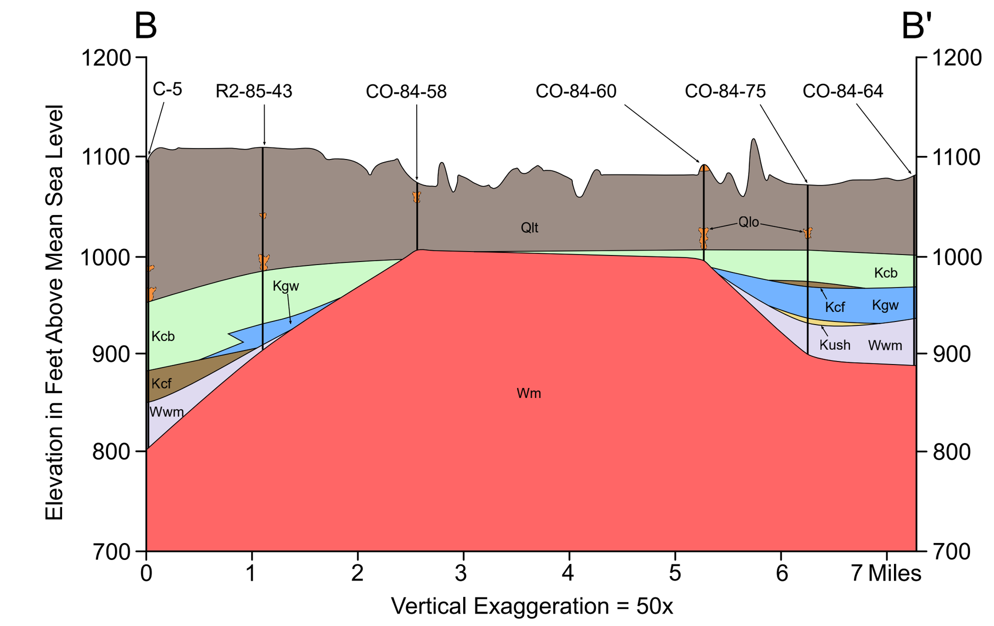
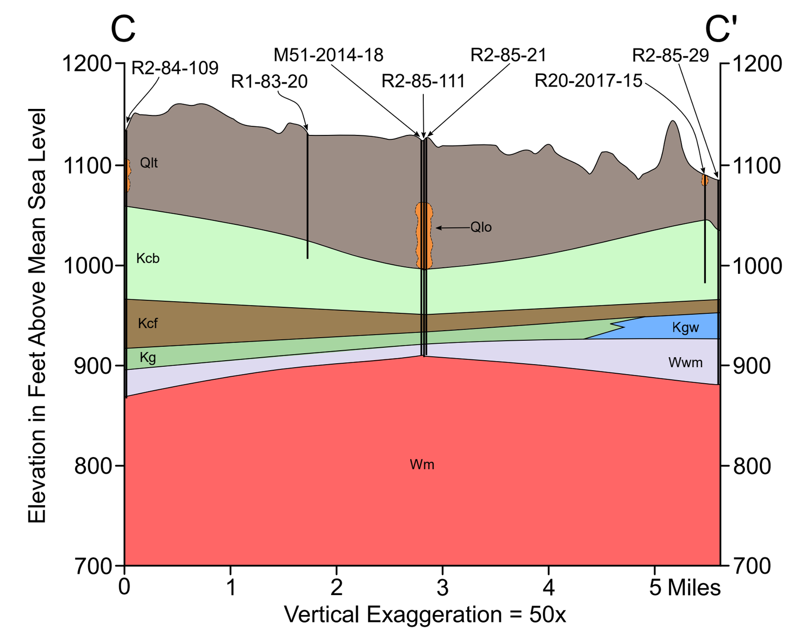
Division of Financial and Technical Assistance
Geological Survey Program

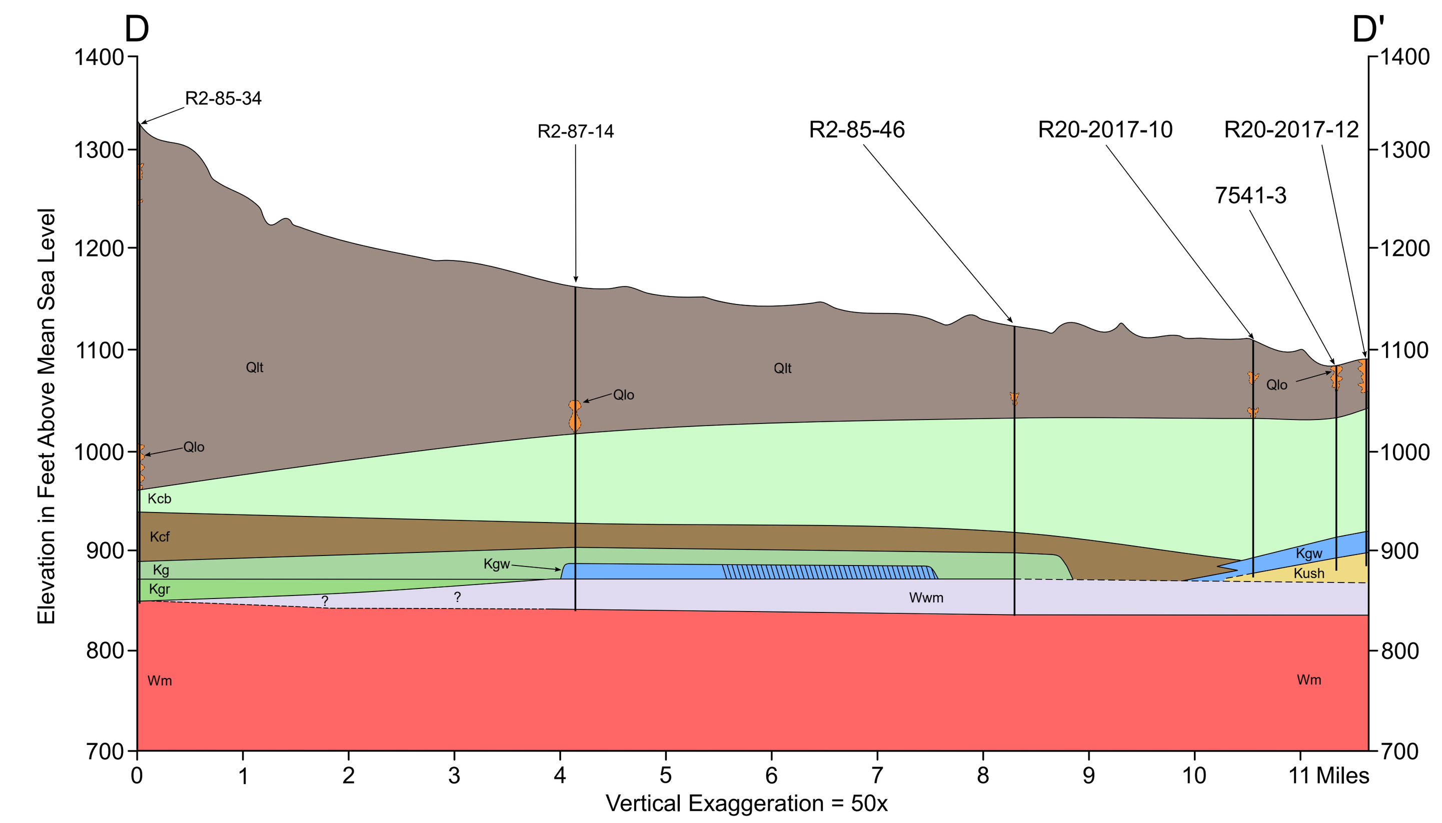
Open-File Report 96-UR

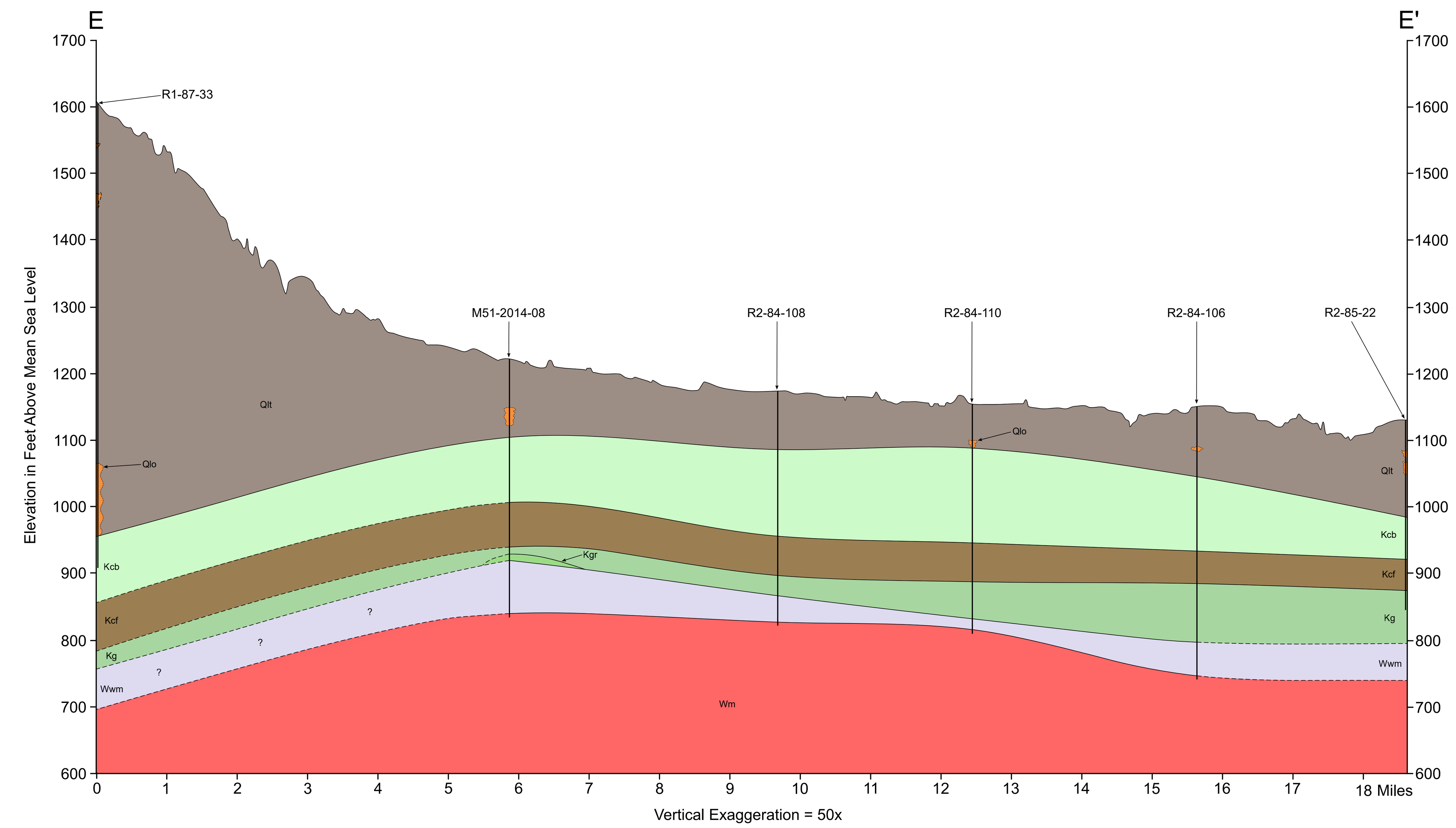
Nicholas J. Krohe

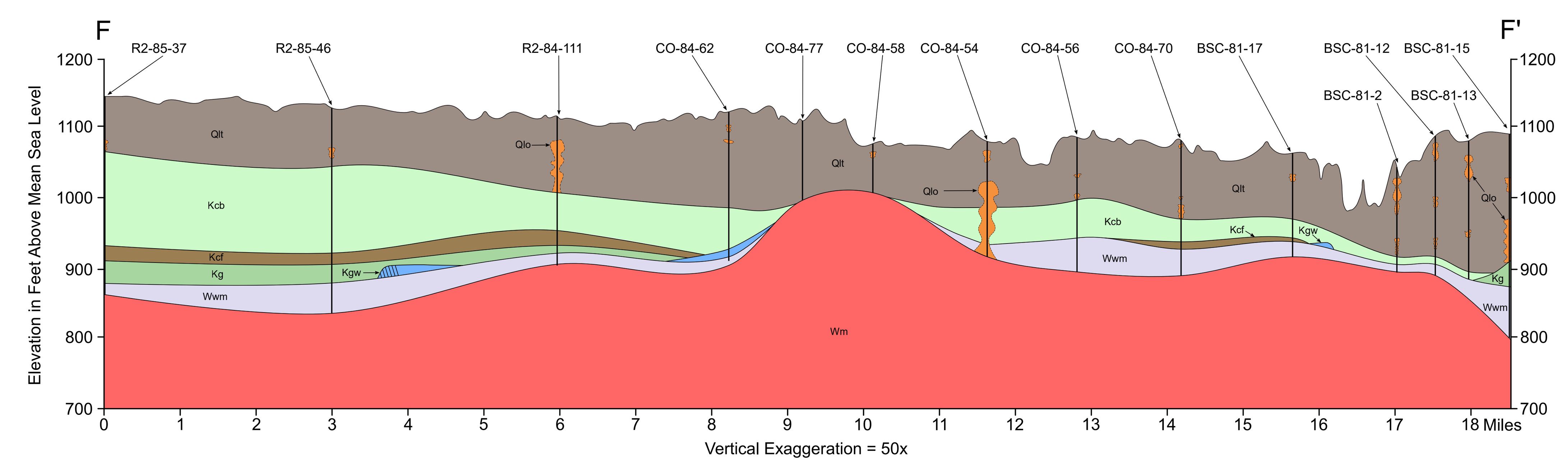












Description of Symbols and Shading on Map

- City limit
- Granite wash
- Granite wash (inferred)
- Granite regolith. Shaded area represents a region in which regolith is intercepted by borings. Beyond this area, the regolith is likely present, but is not intercepted by borings due to depth.
- Competent Milbank Granite
- R20-2017-12 — Test-hole or well with identifier.
- Line connectiong points of equal elevation on the Precambrian surface. Contour interval = 25 ft
- A — A' Line of cross section
- 12 Highway

Description of Units on Cross Sections

Qlo	**Outwash** - Heterogeneous sand and gravel with minor clay and silt of glaciofluvial origin.
Qlt	**Till** - Compact, silty, clay rich matrix with sand to boulder-sized clasts of glacial origin.
Kcb	**Blue Hill Shale Member of the Carlile Shale** - Dark-gray to black, silty to sandy shale with several zones of septarian, fossiliferous, carbonate concretions (Tomhave & Schulz, 2004).
Kcf	**Fairport Chalk Member of the Carlile Shale** - Dark-gray to dark-brown, siltstone, tan specks, calcareous.
Kg	**Greenhorn Limestone** - Gray shale, mudstone, marl, calcarenite, and shaly limestone grading upward into light-gray to tan, alternating marl and thin-bedded, fossiliferous limestone (Tomhave & Schulz, 2004).
Kgw	**Granite Wash** - Blue-gray to gray, sand, coarse to fine, subangular, well to moderately sorted. Hatched where inferred.
Kush	**Unamed Shale** - Dark-gray, noncalcareous, sticky, with minor amounts of very fine sand to silt.
Kgr	**Graneros Shale** - Dark-gray, shale, noncalcareous, pyritic, poorly fossiliferous, with numerous sandstone layers at the base (Tomhave & Schulz, 2004).
Wwm	**Granite Regolith** - White to gray, large amounts of kaolinitic clay, quartz and feldspar grains, angular, very coarse to fine.
Wm	**Milbank Granite** - Pink to dark-red, coarse-grained, composed of orthoclase, quartz, and biotite (Tomhave & Schulz, 2004).