FINAL REPORT: ANALYSIS AND RECOMMENDATIONS FOR THE CAMP SEA GULL ROCK WALL

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INTRODUCTION

Hayes Township, located in Charlevoix County, is developing a park at the site of the former Camp Sea-Gull along the north shore of Lake Charlevoix (Figure 1). Park development includes the construction of a new road entrance, road system, parking lot, fishing pier, rain gardens, and boat ramp. The park slopes from the Boyne City Road dropping approximately 100 feet from the Boyne City Road at an elevation of approximately 680 ft (MSL) to the water edge at 581 ft (MSL). Construction of the parking lot adjacent to the lake required excavation of the slope. During excavation, however, shale was encountered, which resulted in a shale rock wall with a height ranging from three feet to a maximum height of eight feet towards the middle of the parking lot. The shale is highly fractured, resulting in rock breakage and rockfall along the wall's face. Concerns were raised regarding the stability of the rock wall.

Mr. James (Jim) Maleweitz of Performance Engineering in Charlevoix, MI requested that I assess the stability of the shale wall and to provide recommendations on the wall's long-term stability. The purpose of this report is to provide my evaluation and recommendations.

SUMMARY

The rock located at Sea Gull Park is part of the Antrim Shale, which is noted for its oil & gas production in Northern Michigan. The shale has two sets of joints, both with near vertical to sub-vertical jointing striking N-NE and NW. The jointing observed at the Sea Gull Park is consistent with the jointing in the Antrim Shale across the northern portion of the lower peninsula. The upper portion of the slope is composed of glacial overburden soils, consisting of sands and gravel. Below the glacial overburden is the Paxton Shale, Norwood Limestone/Shale, and the Jorden River Limestone, which are all part of the lower Antrim Formation. The shale wall is composed of the Norwood Shale ranging in height between three feet to eight feet in the middle of the parking lot. The Paxton Shale and glacial overburden above the wall slope at an angle ranging from 30 to 45°. The Norwood Shale, which is horizontally bedded, breaks easily along its bedding planes or laminations due to past weathering. Although the Norwood Shale is significantly jointed with horizontal laminations, the joints and bedding laminations are favorably orientated in regards to the stability of the shale wall.

Point load strength and durability tests were conducted to provide input to the stability analysis. A limit equilibrium slope stability analysis was conducted using the following strength parameters: (1) likely, (2) conservative, and (3) weathered shale. The factor of safety for these three cases is 3.2, 1.9, and 1.2, indicating the shale wall is stable. While some shale fragments will break off from the wall, forming a small

debris or talus pile along the slope, this process will take many years to develop and will not affect with the stability of the rock wall.

Based on the durability tests, the shale is resistance to weathering. The shale, however, is thinly laminated, and near-surface shale is weaker along these laminations. Since the shale formation is primarily horizontal, the weathering of the interface strength of the lamination is not a factor in the long-term stability of the wall. Further, the Paxton and Norwood formations are exposed along the Lake Michigan shoreline near the community of Norwood. At this location, the Paxton and Norwood formations forms, steep, near vertical cliffs with significant vegetation established on this cliff. Given the storm and wave action that this cliff experiencing facing north-northwest to Lake Michigan along with the biodegradation that is caused by tree and vegetation roots suggests that the Paxton and Norwood shales can maintain their stability over time. Overall, the shale wall at Camp Sea Gull is stable and will not require additional reinforcement.

Figure 1 Location of Sea Gull Park in Charlevoix County, Michigan.

SITE INSPECTION

Two site inspections were conducted on Tuesday, May 2, and Monday, May 13, 2019. Individuals present at the Tuesday, May 2 meeting, was Jim Malewitz and Brad Muma of Performance Engineering and Mike McCain of MDC construction. The Tuesday, May 13 meeting Jim Malewitz was present. During these meetings, the general layout of the site and the shale rock wall inspected. Further, observations and fracture measurements were made on both the Norwood and Paxton rock fragments. Rock samples were obtained for mechanical testing. General discussions concerning the stability of the wall and possible remediation methods were discussed.

GEOLOGIC FRAMEWORK

General Geology

The topography surrounding Lake Charlevoix consists of rolling hills that have been formed by glacial action resulting in lacustrine, moraine and drumlin soil deposits. A drumlin field is located to the northeast of Camp Sea Gull. The Lake Charlevoix Watershed Management Plan (2012) indicates that the soils are lacustrine sands and gravels with good to medium permeability.

The bedrock geology of the Lake Charlevoix area is part of the Michigan Basin, a 500 hundred million old sedimentary basin composed of limestones, sandstones, evaporites, and shales. Figure 1illustrates a cross-section of the Michigan Basin geology with the rock units in the Lake Charlevoix area being Middle and Upper Devonian in age. The two primary rock units in the Lake Charlevoix are the Traverse Group, consisting mostly of limestone and some shales and the younger Antrim Shale, noted for its oil and gas production. In 1974, the detailed geology of Charlevoix and Emmet Counties was conducted by Kesling, Seagall, and Sorensen from the University of Michigan's Museum of Paleontology. They identified the black shale at Camp Sea Gull as the Norwood Shale. A map from Kesling's report illustrating the geologic formations in western Charlevoix County is provided in Figure 3 and indicates the approximate location of the Norwood Shale. The original location called a "type location" for the Norwood Shale was located north of Norwood MI, just west of Charlevoix, which was conducted by Rominger (1876) who was the Michigan State Geologist. However, an expedition in 1926 failed to locate this outcrop along Lake Michigan. Instead, they inspected the black shale in a quarry at Kamp Kairphree[1], which was later renamed Camp Sea Gull. Rominger (1876) also notes inspecting an outcrop along Lake Pine (now Lake Charlevoix) in which Kesling believed was also at Camp Sea Gull on Lake Charlevoix. Evidence of a quarry at Camp Sea Gull, however, was not observed in my site inspections. It is possible that the area on the southeast side of the camp, where several cabins are located, might have been a small quarry at one time. Later, in 1973, Kesling et al., located a small outcrop along the Lake Michigan shoreline south of Norwood, which according to Kesling's report is the possible "Type Location." A photo of this site from the Kesling Report is shown in Figure 4. It is probable that this site is located south of Norwood along Lake Shore Drive where a small stream flows through a culvert under the road. Figure 5 is a photo of the site showing the exposed Norwood Shale. This site is on private property. Both Figure 4 and Figure 5 illustrate the Norwood Shale forms a steep bluff along Lake Michigan. Talus (broken) material from the shale can be seen in Figure 5(b).

Gutschick and Sandberg (1991), investigated the Upper Devonian-Lower Mississippian interval using conodont biofacies to reestablished the stratigraphy of the Antrim Shale. They investigated the Antrim Shale south of Norwood, MI along Lake Michigan where it forms 12 to 15 feet cliffs along the beach strand line. Their work divided the Antrim Shale into the following four members from the base to the top as the Norwood, Paxton, Lachine and upper members. The Paxton and Norwood Members can be seen in Figure 2 overlying the Squaw Bay Limestone in the Paxton Quarry located just west of Alpina, MI. In the Charlevoix area, the Squaw Bay Limestone is identified as the Jordan River Formation. At Camp Sea Gull, the Antrim Formation is lying conformably over the Jordan River Formation limestone. The Jordan River Limestone can be seen along the shoreline at Camp Sea Gull and immediately below the boat ramp and parking lot.

At Camp Sea Gull, both the Norwood and Paxton Members are present, as shown in Figure 6. The Norwood Shale is described as a black paper-shale. Geologists have interpreted this shale as being deposited in an oxygen-stratified basin with a fluctuating pycnocline, i.e., a layer in an ocean or another body of water in which water density increases rapidly with depth, producing thin laminations in the shale (Dellapenna, 1991). The thin shale laminations can be seen in Figure 7. The Norwood Shale in the Lake Charlevoix area is estimated to be between 10 and 15 feet in thickness. Structurally, the Norwood Shale is relatively flat at Camp Sea Gull but dips to the east, according to Kesling et al., (1974). Kesling et al. indicates that the shale

[1] Kamp Kairphree was a summer camp for young women started and operated by George and Louise Swain. George Swain was the University of Michigan's first official photographer. The camp was originally opened in Bell, MI and operated from1922-1926. The camp was then relocated to Lake Charlevoix. A photo of the camp's entrance is shown in Appendix A.

is on the western flank of the Camp Sea Gull Syncline, causing it to dip to the east, which results in the shale wall dipping away for the present shale wall. The Camp Sea Gull Syncline and other folded structures in the Charlevoix area can be seen in Figure 3. Kesling et al., further imply that these folds, especially the Oster Bay Anticline, are responsible for the formation of Lake Charlevoix.

The Paxton Member is a light gray, argillaceous limestone interbedded with dark and light gray calcareous shale. According to Budai et al. (2002), the carbonate layers within the Paxton are dolomitic limestone. The thickness of the Paxton Member varies between 20 And 70 feet. Photo of the Paxton Shale at Camp Sea Gull is shown in Figure 6 and Figure 8. It is likely that the slope above the Norwood Shale wall is composed of the Paxton Member with a glacial soil cover given that the Paxton member is generally between 20 and 70 feet in thickness, although glacial erosion might have eliminated a portion of this rock layer.

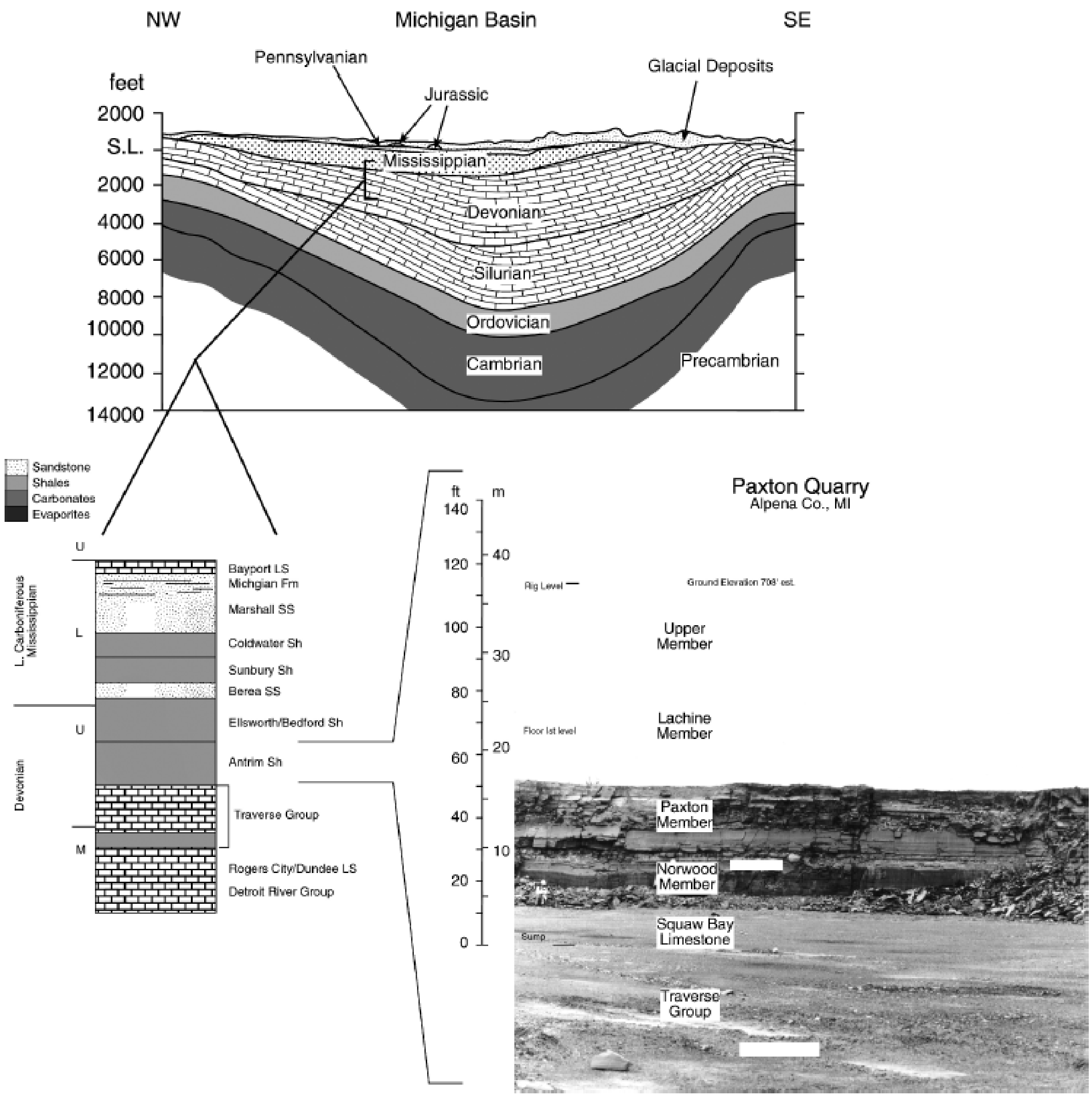


Figure 2 Cross-section of the Michigan Basin and the Upper Devonian stratigraphy in the Northern Lower Peninsula (Budai et al., 2002).

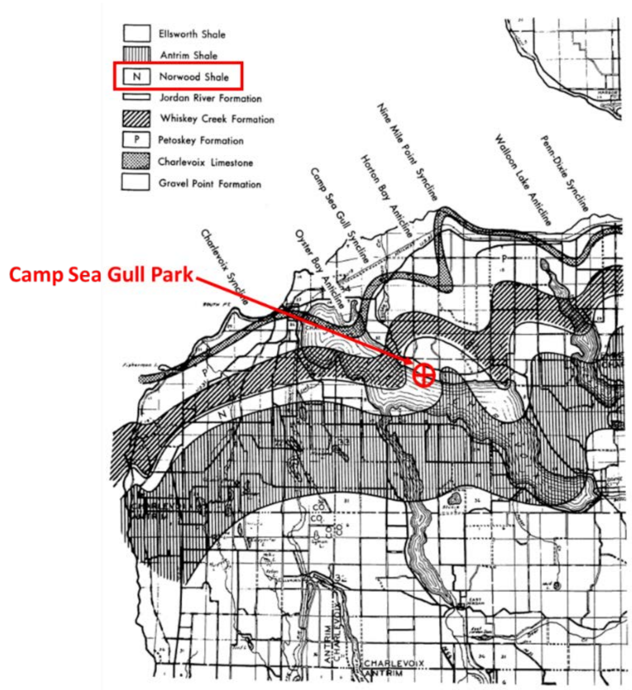
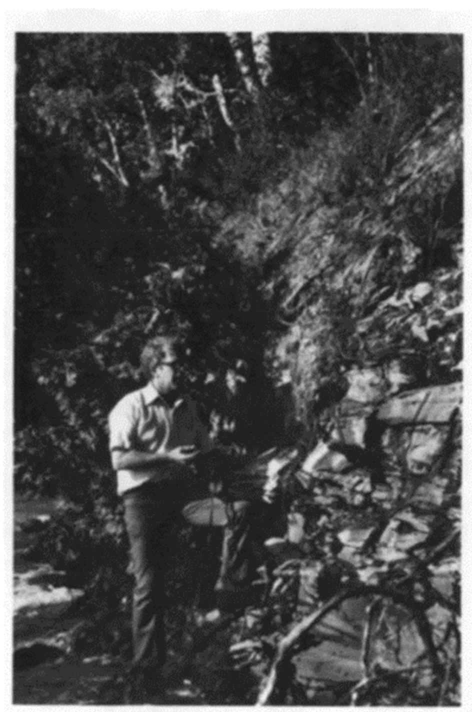


Figure 3 Stratigraphy of western Charlevoix County, Michigan from the Kesling et al., Report 1974 indicating that the shale at Camp Sea Gull is the Norwood Shale.



TEXT-FIG. 66 -- Antrim Shale near type locality, about 1 mile south of Norwood. Sorensen stands on one of the narrow strips of beach available at high-water level. Photo by Kesling, 29 Sep 1973.

Figure 4 The "Norwood Type" Location located south of Norwood, MI from the Kesling et al., 1974 report.

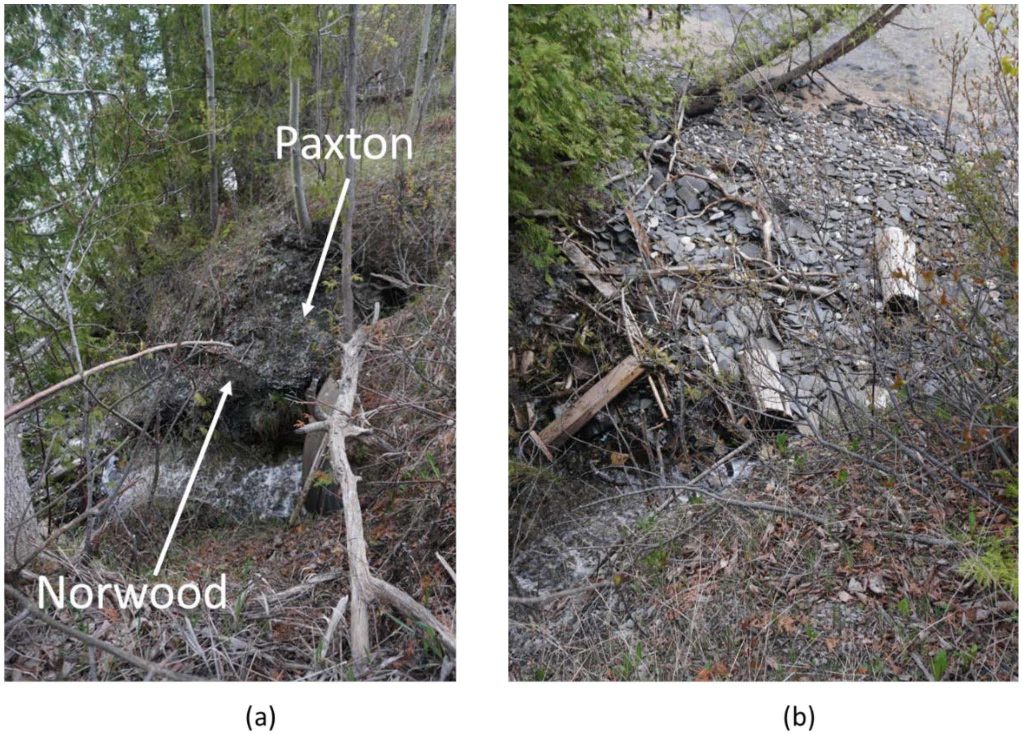


Figure 5 May 2019 photo of the Norwood Shale along Lakeshore Drive south of Norwood, MI.

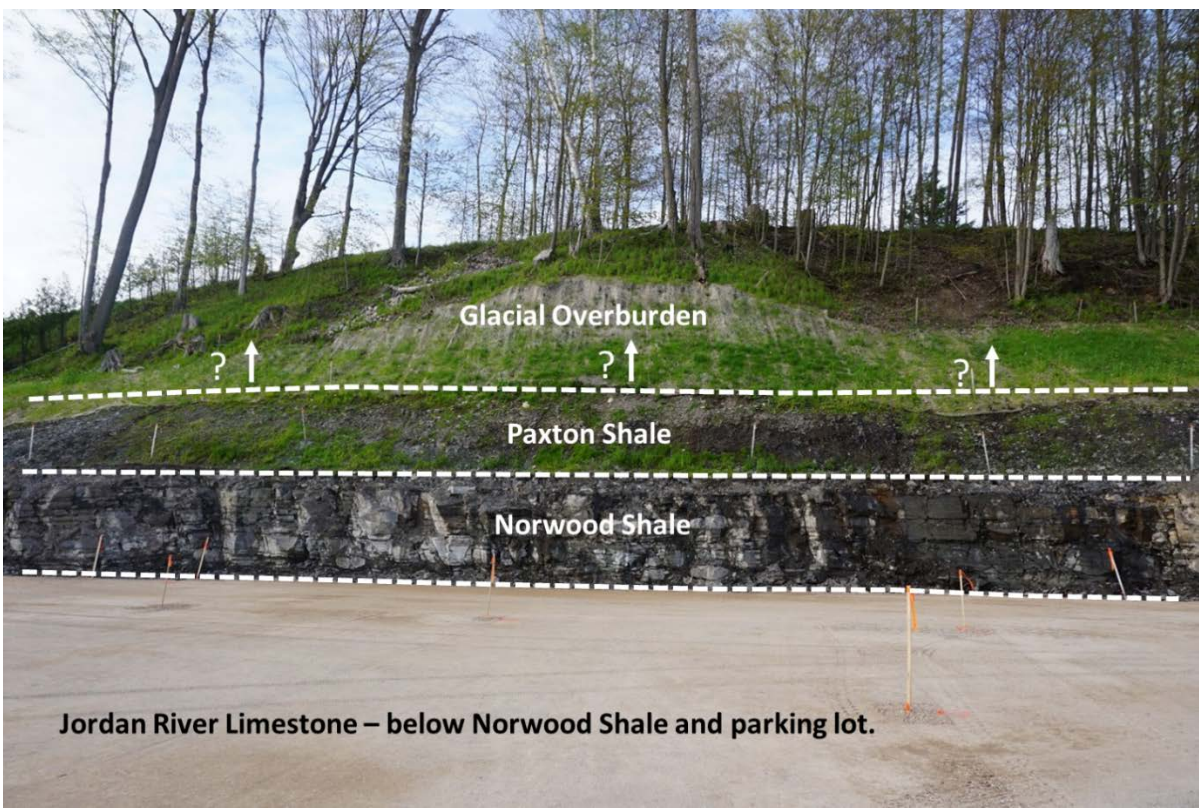


Figure 6 Glacial overburden and rock layers at Camp Sea Gull.

Figure 7 Norwood shale thin laminations.

(a)

(B)

Figure 8 Paxton Member: (a) slope cut to a 1:1 slope and (b) dolomitic limestone shale.

Groundwater Table

The groundwater level at Camp Sea Gull is controlled by Lake Charlevoix with groundwater recharge coming from the upland's region to the northeast. The water level of Lake Charlevoix is, in turn, controlled by Lake Michigan due to the direct hydrologic connection via Round Lake and the Pine River. The current water elevation of Lake Michigan and Lake Charlevoix is approximately 581 feet (MSL). The long-term average for Lake Michigan is 578.4 feet (MSL). Thus, the groundwater table below the shale wall.

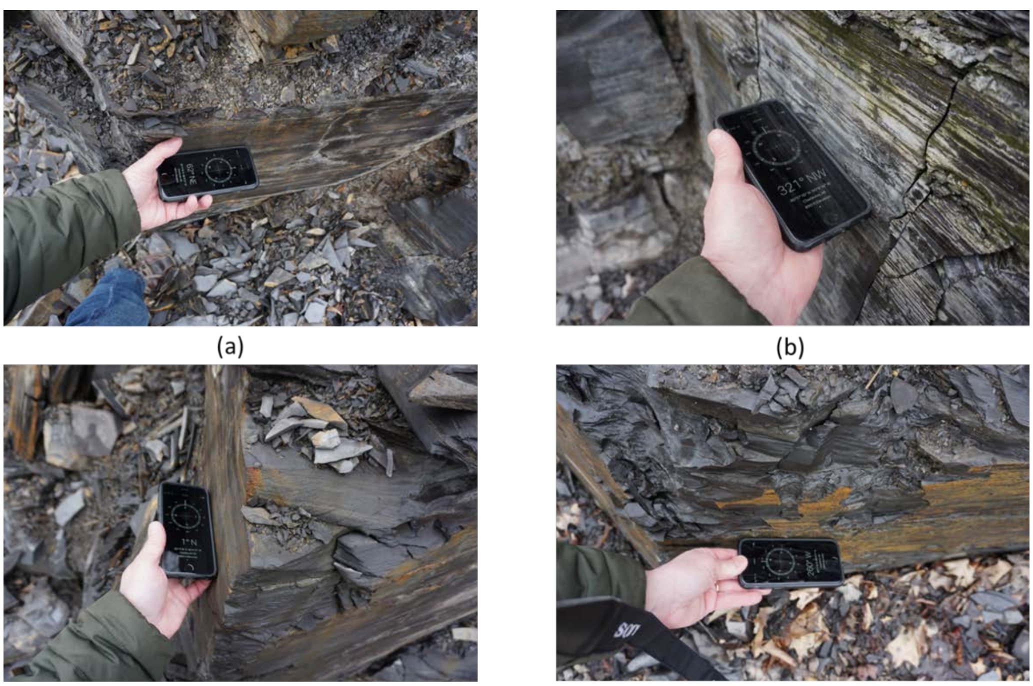
Fracture Geometry

The black shale members of the Upper Devonian Antrim Shale are a significant source and reservoir for gas in northern Michigan. Consequently, there have been several studies documenting the orientation and characteristics of the natural fractures in the Antrim Shale. Ryder (1996) has provided a review of these studies. According to Ryder, the Antrim Shale has two sets of dominant joint sets and two subordinate, and that the joints maintain consistent orientation across the northern portion of the Lower Peninsula. Table 1 summarizes the joint information. Approximately 95% of the joints have vertical or sub-vertical dips (Holst and Foote, 1981).

Table 1 Norwood joints, orientations, spacing, and aperture (Ryder, 1996).

Joint Set	Average Orientation	Dominant/ Subdominant	Spacing (m)	Aperture (mm)
NE-SW	052°	Dominant	0.4 (±0.02)	0.3 to 8 mm
NW-SE	314°	Dominant	0.9 (±0.3)	0.3 to 8 mm
N-S	002°	Subdominant	-	-
E-W	272°	Subdominant	-	-

Similar joints sets were observed in the Norwood Shale at the Camp Seagull Park. Figure 9 shows the orientation measurements taken on May 2. It can be observed that the orientations of the joints are relatively close to the Antrim Shale average joint orientations reported by Ryder (1996). Further, the dips of the joints are relatively vertical. There was one joint observed, however, with an N-S orientation with a sub-vertical dip of about 60°. This joint is shown in Figure 10.



(a) (b) (c) (d)

Figure 9 Joint orientations measured at Camp Sea Gull: (a) NE-SW at 062° vs 052° (formation average), (b) NW-SE 321° vs 314°, (c) N-S 002° vs 001°, and (d) E-W 260° vs 272°.

Figure 10 N-S joint with a 60° dip to the east.

Geologic Significance

Based on the geological literature for the Norwood Shale, there are only three locations that have been available to view and inspect the Norwood and Paxton members. The first site, where it was first identified, was on a small outcrop along Lake Michigan north of Norwood, MI. Geologist, however, were unable to locate this outcrop and instead found an outcrop along a road south of Norwood, MI along Lake Michigan. The other site was Camp Sea Gull. The third exposure was at the Paxton Quarry located a few miles west of Alpena, MI. The information in Figure 2 was taken at the Paxton Quarry. The Norwood Shale can be seen in the photo at the bottom of the quarry's high wall overlying the Squaw Bay Limestone. The Paxton quarry, however, was abandoned and filled with spoil materials and allowed to fill water and is no longer available for inspection. It should also be noted that the Norwood Shale in the Paxton Quarry remained stable at the base of an approximate 80-foot-high wall indicating its unweathered strength and ability to remain stable at a vertical slope.

In discussions with John A. Yellich, the Director of Michigan Geological Survey at Western Michigan University and Dr. William B. Harrison, III Professor Emeritus and Director, Michigan Basin Core Research Laboratory also at Western Michigan University, they expressed an opinion that if at all possible this exposure should be preserved. According to Dr. Harrison,

> *I think this is too important an exposure to be destroyed or covered up…. This exposure in the park is one of the very few available to be viewed by the public or studied by scientists. The Antrim Shale is a significant formation that has played a key role in Michigan's natural resources history. In the mid-1980s, Michigan's oil and gas industry began drilling wells to capture natural gas from the Antrim Shale, first in Otsego County, then spreading across most of the northern Lower Peninsula. Over 12,000 wells have been drilled and have produced over 3.7 Trillion cubic feet of clean-burning natural gas for Michigan citizens….. Preservation of this exposure of some rocks which are very relevant to Michigan's geological and energy history is important. I think it would also be of interest to the public to have some signage at this exposure explaining the importance of these rock layers.*

STABILITY ASSESSMENT

The stability assessment of the Norwood Shale rock wall is based on the following field observations:

1. The Norwood Shale is significantly jointed with two sets of near vertical to sub-vertical joints. The joint sets appear to be consistent with the general jointing in the Antrim Shale.
2. The Norwood Shale is relatively horizontally bedded but dipping to the east and therefore has a favorable orientation for slope stability.
3. The shale, however, is highly laminated and can easily break along the horizontal bedding planes when weathered. The resulting rock fragments are plate-like and appear not to be stable after breakage. No degradation of the delaminated shale was observed in the field.
4. The glacial overburden slope above the shale is relatively steep, with some portions at a 45° slope. These sections appear to be stable with vegetation likely helping in the slope's stability. It is possible that the slope is composed of the Paxton Member with overlying glacial soil.
5. While shale breakage and toppling were observed along the shale wall, the overall slope stability is stable; the wall was constructed in the fall of 2018 and going through one winter and spring cycle.

Rock Property Testing and Assumptions

Broken samples of the Norwood Shale were obtained and tested for strength and durability for input to the stability analysis. The point load test was used to provide an approximate strength of the shale while the slake durability and jar slake tests were conducted to assess the shales durability. No in situ samples were obtained to assess the strength of the shale

Point Load Tests

Point loads tests were conducted on the broken shale samples from the front of the shale wall. Tests were conducted parallel to the bedding, as shown in Figure 11. Due to the plate-like nature of the shale fragments, however, the diameter to width ratio just met the ASTM standard for point load testing in which most of the samples were at 0.3 or somewhat less. Attempts to fragment the samples resulted in additional delamination. Therefore, two effective diameters, D_e, were used in the analysis. One D_e based on an irregular shape and a second the distance between the load points.

To convert the $I_{s,50}$ to a uniaxial compressive strength (UCS), a conversion value of 16 was used. In general, the conversion value for sedimentary rock ranges from 16 to 24, thus the lower value was used to represent weathered shale. The UCS values are provided in Table 3.

Figure 11 Point load test and test samples.

Table 2 Point load tests results.

	Sample	W1 (mm)	W2 (mm)	W (mm)	D (mm)	D/W	(De)^2 (mm^2)	(De)^2 (in^2)	De (in)	Reading (Gauge) pressure (psi)	Load (lbs)	Is	Irregular, Is50		D (in)	(D)^2 (in^2)	Is	Straight, De, Is50
	1	52.68	44.84	48.76	16.45	0.337	1021.786	1.583768	1.258479	41	50.84	32.1	26.2		0.65	0.42	121.21	73.50
	2	30.02	27.55	28.79	9.8	0.340	359.3541	0.556999	0.746324	26	32.24	57.9	37.4		0.39	0.15	216.58	104.02
	3	40.23	33.66	36.95	11.64	0.315	547.8214	0.849123	0.921479	23.8	29.512	34.8	24.7		0.46	0.21	140.53	72.93
	4	37.87	28.47	33.17	13.5	0.407	570.4395	0.884181	0.940309	33.7	41.788	47.3	33.9		0.53	0.28	147.93	82.07
Norwood	5	34.71	30.6	32.66	11.61	0.356	482.9612	0.74859	0.865211	24.4	30.256	40.4	27.9		0.46	0.21	144.82	75.07
	6	41.28	38.61	39.95	11.44	0.286394	582.1284	0.902299	0.949894	29	35.96	39.9	28.7		0.45	0.20	177.27	91.28
	7	24.52	22.84	23.68	10.21	0.431166	307.9908	0.477386	0.690931	19.4	24.056	50.4	31.5		0.40	0.16	148.88	72.84
	8	35.29	33.78	34.54	10.88	0.315043	478.6507	0.741909	0.861341	32.8	40.672	54.8	37.8		0.43	0.18	221.67	111.60
	9	30.13	34.06	32.10	9.83	0.306278	401.903	0.62295	0.789272	18.1	22.444	36.0	23.9		0.39	0.15	149.85	72.07
	10	29.3	24.11	26.71	9.1	0.34076	309.5739	0.47984	0.692704	27.2	33.728	70.3	43.9		0.36	0.13	262.77	122.07
											Average Is50		**31.6**			**Average Is50**		**87.74**
	11	33.8	32.53	33.17	10.47	0.315694	442.3408	0.685628	0.828027	20.8	25.792	37.6	25.5		0.41	0.17	151.80	75.11
	12	34.09	33.71	33.90	10.18	0.300295	439.6204	0.681412	0.825477	30.8	38.192	56.0	37.9		0.40	0.16	237.76	116.17
	13	35.61	28.55	32.08	10.21	0.318267	417.2443	0.646729	0.804194	16	19.84	30.7	20.5		0.40	0.16	122.79	60.07
	14	31.26	27.5	29.38	10.23	0.348196	382.8757	0.593457	0.770362	36.8	45.632	76.9	50.4		0.40	0.16	281.31	137.75
Paxton	15	35.73	27.14	31.44	13.09	0.416415	524.1836	0.812485	0.901379	15	18.6	22.9	16.1		0.52	0.27	70.03	38.32
	16	28.86	27.82	28.34	9.52	0.335921	343.6902	0.53272	0.729877	15.2	18.848	35.4	22.6		0.37	0.14	134.17	63.61
	17	31.49	30.21	30.85	9.9	0.320908	389.0637	0.603049	0.776562	16	19.84	32.9	21.6		0.39	0.15	130.60	63.01
	18	26.94	25.41	26.18	10.23	0.390831	341.1086	0.528718	0.72713	18	22.32	42.2	27.0		0.40	0.16	137.60	67.38
	19	35.11	29.52	32.32	10.98	0.33978	451.9983	0.700597	0.837017	24.2	30.008	42.8	29.1		0.43	0.19	160.58	81.18
	20	32.42	30.22	31.32	9.85	0.314496	392.9962	0.609144	0.780477	14.8	18.352	30.1	19.9		0.39	0.15	122.03	58.75
											average Is50		**27.1**			**average Is50**		**76.13**

Durability Tests

A key element for the stability of a shale wall is the shale's durability. To determine the durability of both the Norwood and Paxton rock samples, the Slake Durability and the Jar Slake Test were conducted. Figure 12 shows the test samples.

The durability test results are shown in Table 3 and Table 4. The results indicate that both the Paxton and Norwood Shale are highly resistant to degradation with a slake durability index above 98% and no change in the Jar Slake Test.

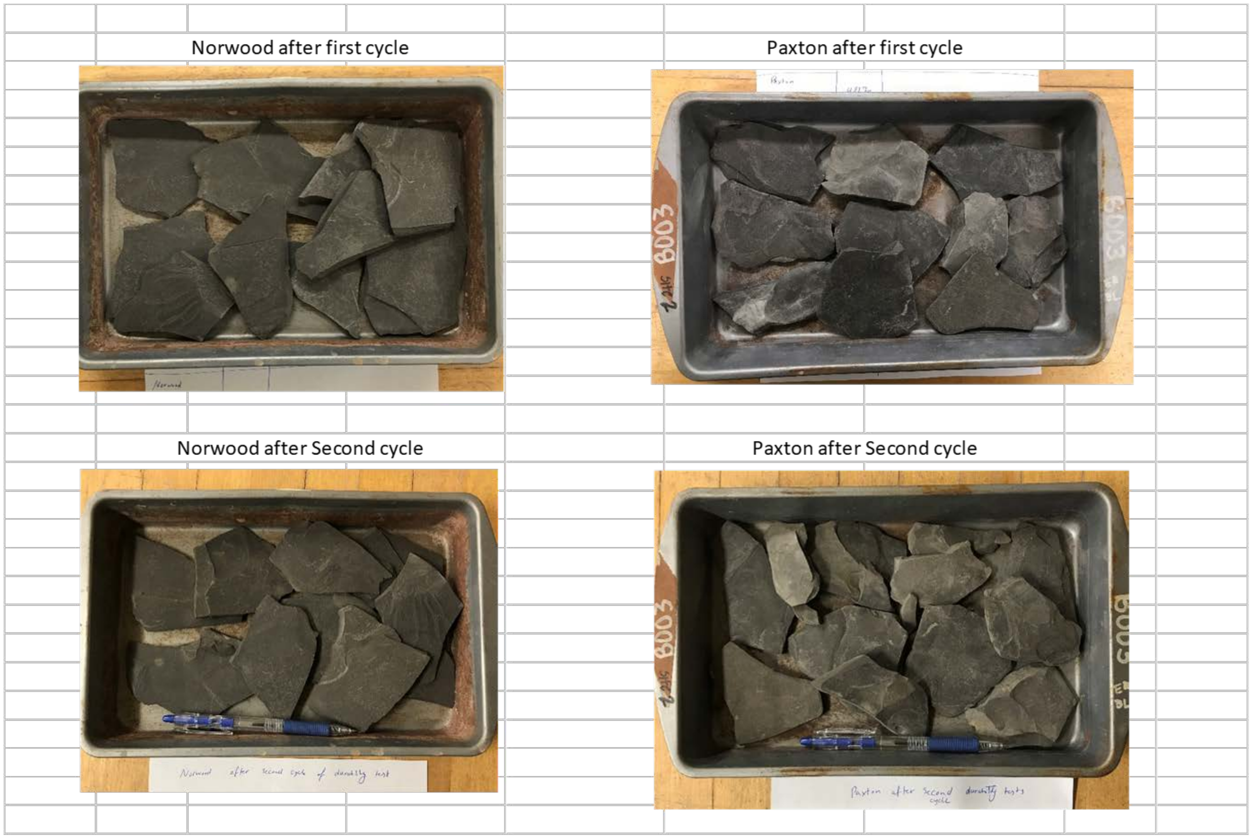


Figure 12 Slake durability tests samples.

Table 3 Slake durability test results.

	Slake Durability Tests				
Sample	Total Dry Weight Before Cycle 1 (g)	Total Dry Weight after Cycle 1 (g)	Total Dry Weight after Cycle 2 (g)	Slake duribility index Id1	Slake duribility index Id2
Paxton	481.7	478.1	476.8	99.25	98.98
Norwood	452	451.5	451.3	99.89	99.85

Table 4 Jar slake test results.

Jar Slake Tests		
Sample	Jar Slake Index Ij	Behavior
Paxton	6	No Change
Norwood	6	No Change

Radioactivity

During oil and gas exploration, the Antrim Shale is identified using a gamma radiation probe. Black shales are known to have some level of radioactivity and thus are identified using gamma probes. In the 1950s, the Antrim Shale was investigated as a potential source for uranium (Swanson, 1961). While some black shale had some levels of uranium, the Antrim Shale did not. Nonetheless, the radioactivity was measured using a scintillation counter to determine if the Norwood Shale wall emitted any radioactivity. No radioactivity was measured.

Global stability of the Norwood Shale Wall

The overall stability (or global stability) of the wall was investigated using a standard limit equilibrium analysis program from Rocscience called Slide version 8.015. To conduct this analysis, the slope was assigned the following four units from top to bottom: (1) glacial overburden, (2) Paxton Sghale-Limestone, (3) Norwood Shale, and (4) the Jorden River Limestone as shown in Figure 13 and Figure 14.

The upper portion of the slope is composed of glacial sand. The slope is at a fairly steep angle ranging from 30 to 45°. It is likely that the glacial sand is at its angle of repose and where the vegetation is assisting in the slope's stability. The slope stability analysis used a Mohr-Coulomb failure criterion for the glacial sand.

The Paxton shale, Norwood Shale and the Jordan River Limestone are modeled as "rock" using the Hoek-brown failure criteria. The rock parameters are provided in Table 5. The Jordan River Limestone is immediately below the Norwood Shake. Three cases were conducted assuming the following strength parameters (1) likely, (2) low and (3) weathered soil and rock. Since this unit does not affect the stability of the slope, the value remained the same for the three cases investigated.

The shale face, as can be seen, is highly jointed with breakage of the exposed shale. This breakage is common for a shale face until it comes into equilibrium with the environment. Generally, a rocky talus slope will form in front of the wall. The rock behind the wall, however, will remain under stress maintaining the strength of the rock. According to the durability tests, the shale is highly resistant to degradation. Therefore, the rock behind the face should retain it *in situ* strength, thus assuming "likely" strength parameters. If weathering does occur behind the face than the strength parameters have been lowered to a "conservative" value. Assuming the entire slope becomes weathered, the strength values were lowered to a "weathered" state.

Table 5 Rock strength parameters and safety factors.

Rock Unit	Likely	Conservative	Weathered
Paxton Shale			
Unit Weight, γ, pcf	165	160	150
UCS, psf	400,000	175,400	62,400
GSI	40	30	20
m_i	7	5	4
Norwood Shale			
Unit Weight, γ, pcf	165	160	150
UCS, psf	500,000	202,000	72,000
GSI	40	30	20
m_i	8	6	5
Limestone			
Unit Weight, γ, pcf	170	170	170
UCS, psf	1,500,000	1,500,000	1,500,000
GSI	70	70	70
m_i	10	10	10

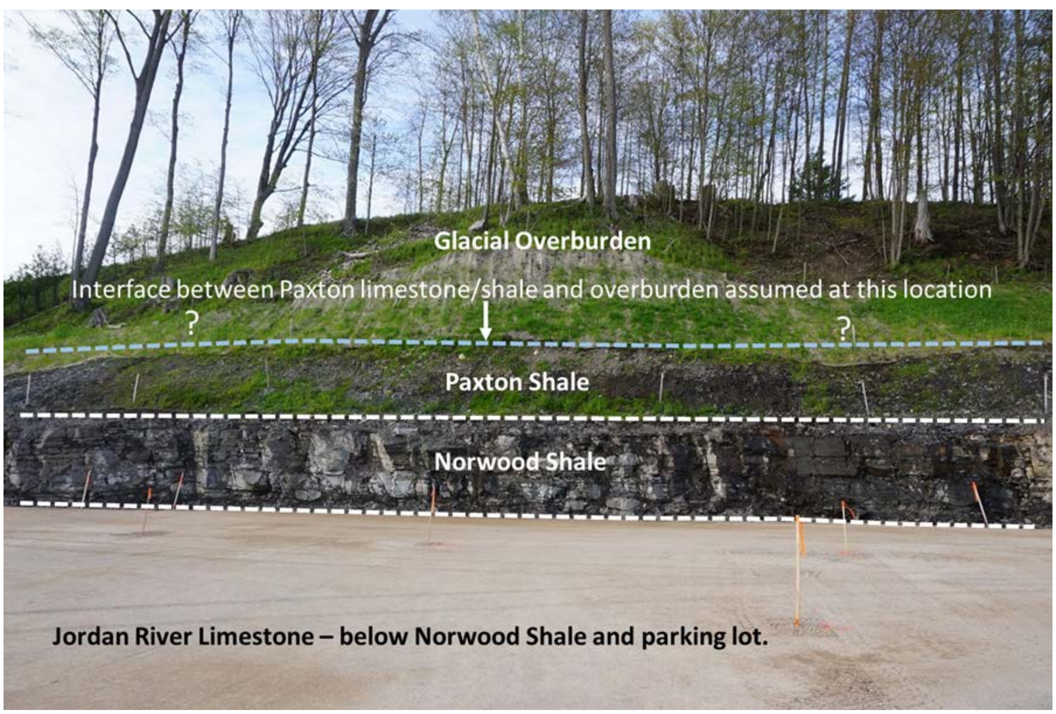


Figure 13 Soil and rock delineation of the Camp Sea Gull Slope.

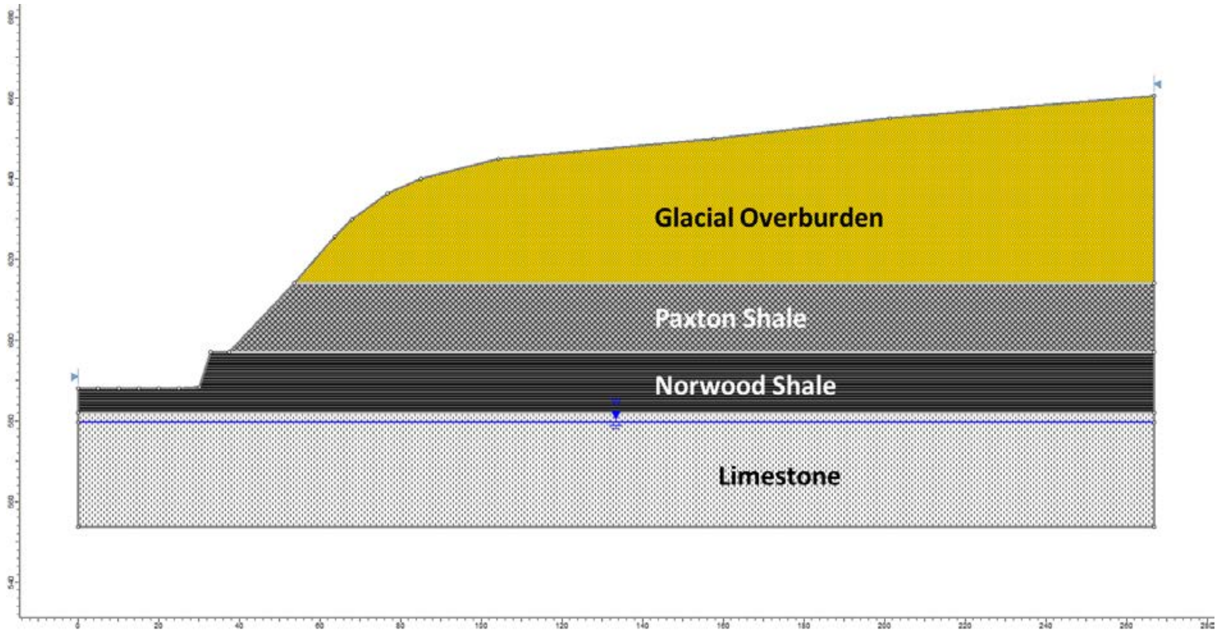
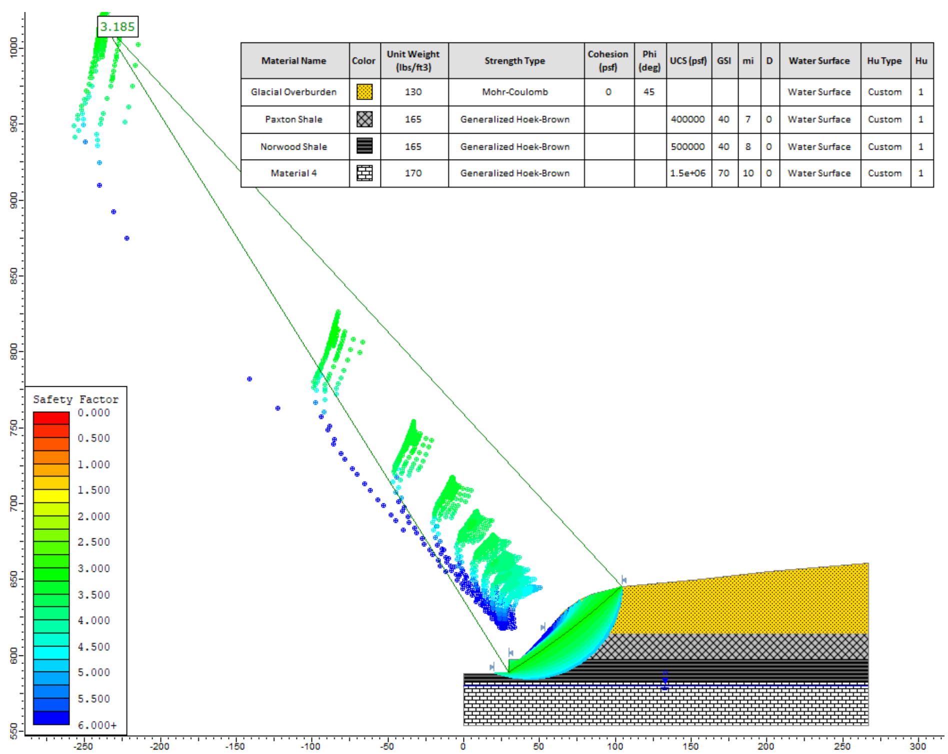


Figure 14 Model used to assess the stability of the Camp Sea Gull slope.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	UCS (psf)	GSI	mi	D	Water Surface	Hu Type	Hu
Glacial Overburden		130	Mohr-Coulomb	0	45					Water Surface	Custom	1
Paxton Shale		165	Generalized Hoek-Brown			400000	40	7	0	Water Surface	Custom	1
Norwood Shale		165	Generalized Hoek-Brown			500000	40	8	0	Water Surface	Custom	1
Material 4		170	Generalized Hoek-Brown			1.5e+06	70	10	0	Water Surface	Custom	1

Figure 15 Slope stability analysis for the "likely" strength assumptions.

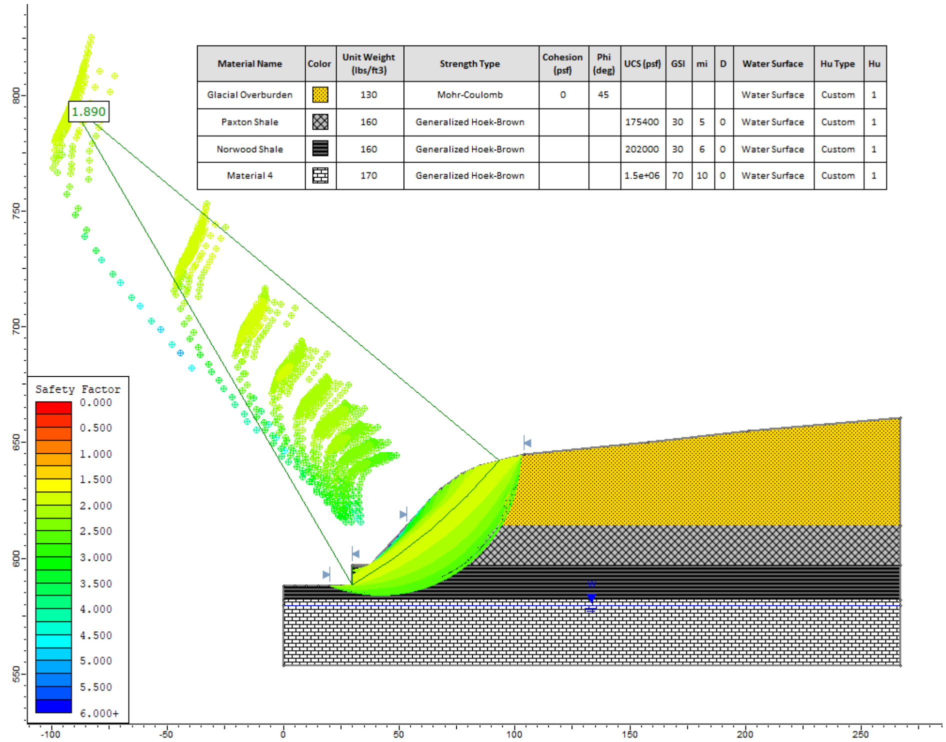


Figure 16 Slope stability analysis for "conservative" strength assumptions.

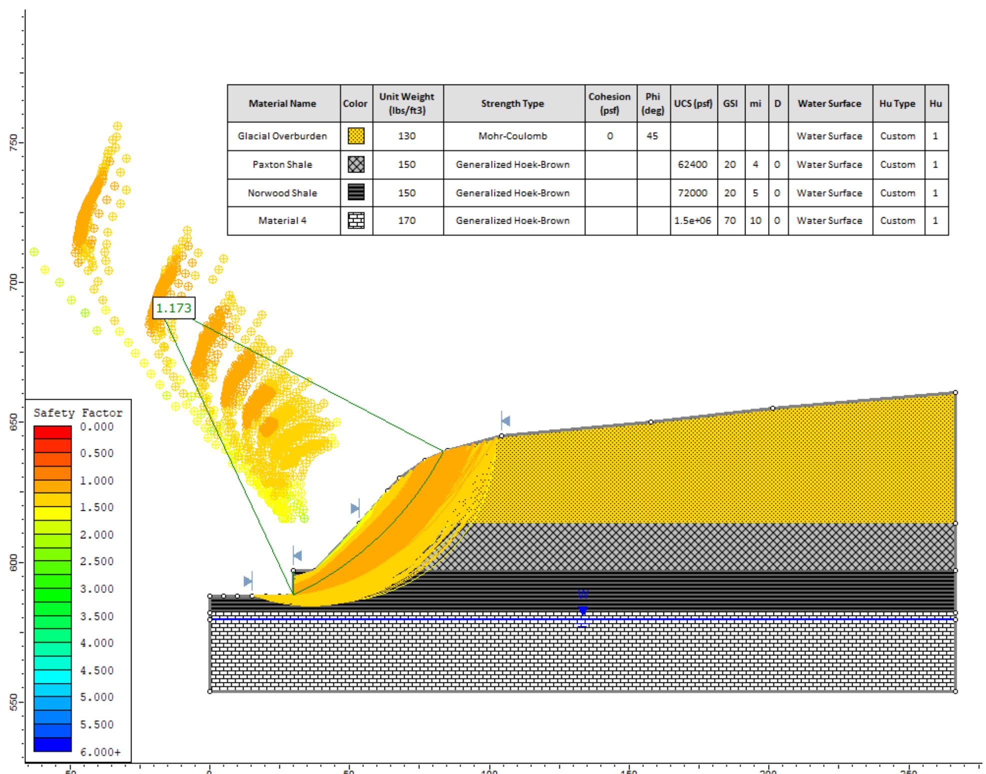


Figure 17 Slope Stability Analysis for "weathered" strength assumptions.

An assessment of the rock units indicates that there are no planes of weakness that can affect that stability of the wall negatively. Thus, a standard limit equilibrium stability analysis was conducted assuming a circular failure surface. The results of the slope stability analysis are provided in Table 6, while the three analysis are shown in Figure 15, Figure 16, and Figure 17.

Based on this analysis, the shale wall is stable and will not need reinforcement. As seen with Norwood Shale at the Paxton Quarry and along the Lake Michigan shoreline, a near vertical wall will remain stable over time.

Table 6 Stability analysis results.

Assumed Strength	Factor of Safety (FS)
Likely	3.2
Conservative	1.9
Weathered	1.2

Long term stability of the shale rock wall

Due to the construction of the shale wall, debris formed along the wall, as shown in Figure 7 due to the shale's thin laminations (bedding planes) and jointing. Figure 18 shows the shale wall after the wall had been scaled and the debris removed. Over time, a small amount of talus, will again form along the wall as the wall adapts to its new environment, the breakage will mostly cease. The rock durability tests indicate that the shale is resistant to degradation and therefore the talus slope will be stable over time.

Perry and Andrews (1982) investigated slope failures, and shale slopes, mostly at coal mines with mine spoils ranging in age from 2 to 10 years. While significant slope failures occurred with shales with high rates of weathering, for shale slope without degradation, such as the Norwood Shale, they found that:

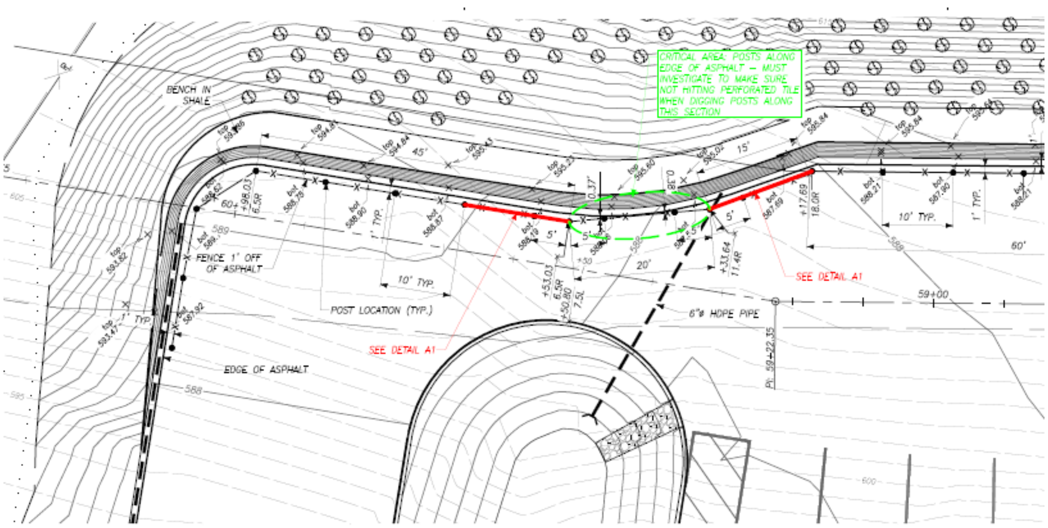
> "*little or no stability problems were found where slab or block slaking dominated [degradation to thick, blocky fragments]. Where chip slaking was dominant [degradation to thin, flat segments], the mass appeared to be relatively stable. The chips form an interlocking matrix which is resistant to bulk movement. When slaking to inherent grain size [degradation to fine-grained particles] was found to be the primary mode, stability problems were observed, as evidenced by slips, slides, and similar features.*

Thus, since the broken shale forming a small talus slope overtime will consist of weather resistant shale, the long-term stability of the shale wall will be acceptable. As noted above, the long-term stability of the shale wall can also be observed along Lake Michigan just to the south of Norwood, MI where the Antrim Shale forms near vertical cliffs12 to 15 feet high along the beach strand line. Considering that this cliff experience significant weather effects from Lake Michigan would suggest that the long-term stability of the Norwood Shale wall at Camp Sea Gulls will likewise be stable over time.

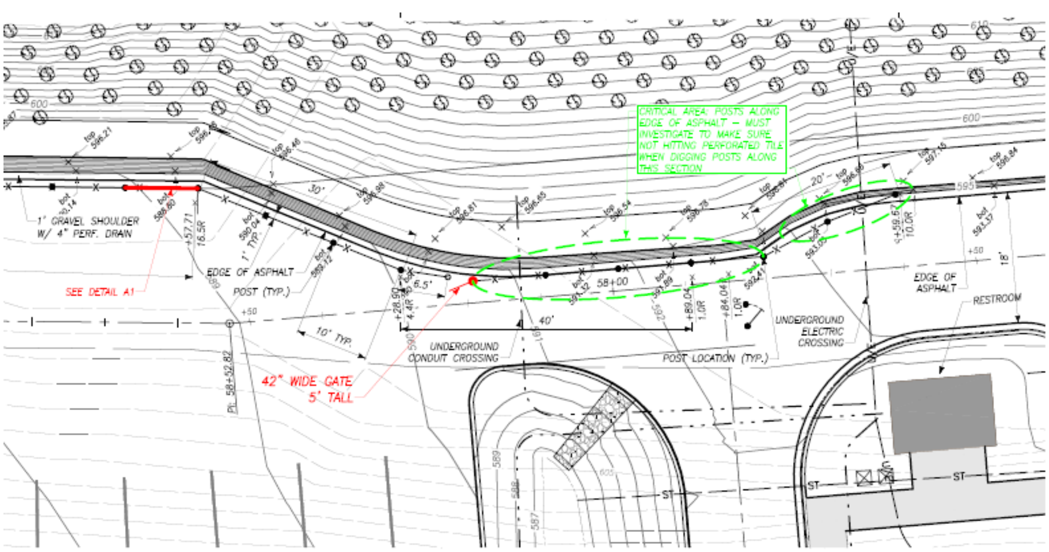
Figure 18 Photo of shale wall taken on June 10, 2019 after scaling and removing the loose debris.

RECOMMENDATIONS

Due to the jointing and lamination of the shale, the exposed wall will have some breakage over time, which will result in a small talus slope (broken rock) forming along the wall. To protect the public from falling rock due to breakage and possible toppling failures of loose sections of the wall, I am recommending that a fence be placed in front of the shale wall. A five-foot high fence will be adequate. The distance between the fence and the rock wall can be variable but should be within five feet of the wall. Access locations should be provided to allow inspection of the shale wall. Figure 19 provides a proposed fence location, which should be adequate.



(a)



(b)

Figure 19 Proposed fence for the shale wall at Sea Gull Park with (a) the northwest section and (b) the northeast section.

CONCLUSIONS

Based on the information and analysis provided in this report, the following conclusions are provided:

1. The shale wall at Camp Sea Gull is part of the Norwood and Paxton members of the Antrim Formation, a well-known oil & gas formation in the Michigan Basin.
2. During the geological investigations of the geology of the Michigan Basin, the shale outcrop at Camp Sea Gull, then known as Kamp Kairphree, was one of the locations in which the Norwood and Paxton Shales were investigated by geologists in the nineteenth and twentieth centuries.
3. The Norwood and Paxton member formed cliffs along Lake Michigan south of Norwood, Michigan, the rock exposure is limited to a small location below a drainage culvert and is on private properties.
4. The Norwood/Paxton cliff along Lake Michigan is steep and covered with vegetation indicating that the rock unit has been stable over the long-term.
5. Camp Sea Gull is the only public area in which the Norwood/Paxton shales can be seen and studied.
6. Point load strength tests on the broken shale from the face of the wall indicate that the strength of the shale is relatively low but has high resistance to weathering and degrading.
7. A limit equilibrium stability analysis indicates that the shale wall is stable and should remain stable over the long term and will not require additional reinforcement.
8. A fence is recommended to be placed in front of the shale wall to prevent the public from accessing the wall.

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