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GEOLOGIC MAPPING OF ALPENA COUNTY, MICHIGAN

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INTRODUCTION

The purpose of this project is to produce multiple geologic maps of the Devonian-Mississippian strata in Alpena County, Michigan with a focus on delineating the members of the Antrim Shale. The resulting maps will be useful for resource (aggregate and natural gas) and natural hazard (sinkholes) assessment. These refined Alpena bedrock maps provide the community with a better assessment of where natural resources are present and the susceptibility of natural hazards in the area for urban planning. Alpena historically has been a site of quarrying (limestone, shale) operations and hydrocarbon exploration from units including the Traverse Group. Carbonate-dominated intervals in the Traverse Group are susceptible to karsting and sinkholes are present in northern Alpena County. Understanding the risk of karsting assists in mitigating groundwater contamination from septic tanks and other sources of contamination.

GEOLOGIC SETTING

The Michigan Basin was a depocenter during the Devonian Period that is filled with a thick package of sediment. Alpena County is located in the northeastern Lower Peninsula of Michigan. This county is underlain predominantly by shale and limestone bedrock. The most recent geologic map of Alpena (Milstein, 1987 available on Geowebface, https://www.egle.state.mi.us/geowebface/) generalizes the Traverse Group as a single unit instead of identifying the ten formations mapped in the Alpena-area Traverse Group outcrop belt (Ehlers and Kesling, 1970). In addition, the Antrim and Ellsworth shales are mapped as a single unit as shown in Figure 1. Despite featuring similar lithologic characteristics, the deposition of Ellsworth occurs from the west whereas the rest of the

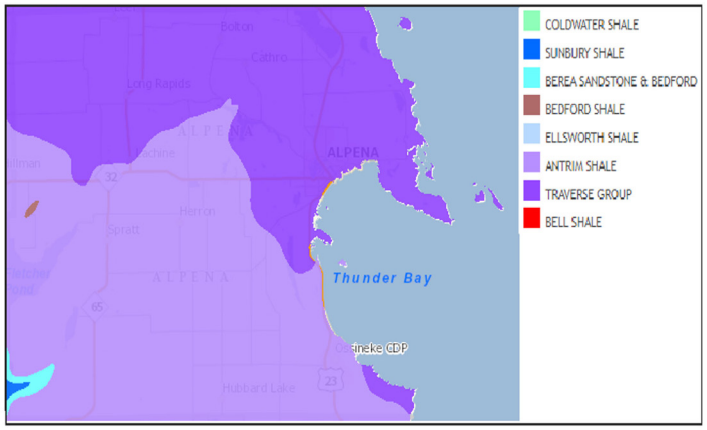

Figure 1. The Geowebface bedrock map (after Milstein, 1987) lumps the members of the Antrim and Ellsworth Formation as the Antrim Shale. Berea, Bedford, Coldwater (not shown on map) and Sunbury lithostratigraphic units only occur in the very southwesternmost portion of the county (a small outlier of Bedford also occurs in the western portion of the map area).

Mississippian and Devonian rocks were sourced from the east. Milstein (1987) also interpreted the younger Mississippian rocks to have limited exposures in far southwestern Alpena County. With recent driller's logs that are readily available for public use, a more detailed and accurate map can be produced. Exposed subsurface units that are featured in this county from youngest to oldest are Coldwater Shale, Sunbury Shale, Bedford-Berea formations, upper Antrim member, Ellsworth Formation, the Lachine, Paxton, and Norwood Members of the Antrim Shale, the "Squaw Bay Formation", and the Traverse Group.

The geography of the northern portion of Alpena County is blanketed by less than 50 feet thick of glacial drift, clays, gravels, and lake-shore deposits. The Wisconsin glaciation affected the fluctuation of land and lake elevations resulting in karsting of carbonates in the Traverse Group (Black, 1977) leading to possible sinkholes. Karst is a significant concern in this region of the state where homes have individual water wells and septic tank fields. In

addition, agricultural and industrial contamination may be readily moved through karst conduits.

The purpose of this research is to produce geologic maps of Alpena County by refining the contacts between bedrock units using the large volumes of well data that have become available since the Milstein (1987) map was compiled. It is important that the members of the Antrim Formation are subdivided further for clarity and gives better recognition of the distribution and scale of these members. The "Squaw Bay Formation" is undergoing efforts to rename and redescribe the unit due to 1) the name of the unit uses a derogatory term for Native American women, and 2) the unit has a long history of misuse in the subsurface (Fisher, 1969; Gutschick and Sandberg, 1991). The "Squaw Bay Formation" is sometimes lumped in with the Traverse Group and mapping its distribution will help with separating the interval from the underlying Traverse Group strata. A bedrock geologic map provides subsurface natural resource information that will be useful to regional planners, regulators, and other geologists. More specifically, it can be used for applications such as locating groundwater, oil and gas, and mineral resources.

METHODS

Oil/gas and water well logs were analyzed for formation tops and bedrock elevation in order to construct three maps using ArcGIS Pro: bedrock geologic, bedrock topography, and glacial drift thickness maps. The well distribution provided an interesting difficulty in constraining the geology of Alpena County. The southern half of the county has an extensive subsurface dataset from Antrim Shale gas wells which provided excellent constraints on bedrock elevations and formation tops. The northern half of the county by contrast has a paucity of oil and gas wells. Water wells provided constraints on the bedrock surface but the lack of detailed lithologic descriptions made interpreting the bedrock formations in this portion of the county challenging.

To better understand the units, a core from the Paxton Quarry (central Alpena County) was described and photographed in order to define the strata of the "Squaw Bay Formation", Antrim Shale, and Ellsworth Shale in the map area. After examining the core, subsurface datasets from the Michigan Geological Repository for Research and Education's archives were analyzed. The first dataset was composed of oil and gas drillers reports, documents prepared by the company drilling the well under state regulations. Drillers reports include information on the location of the well (surface location, surface elevation), the depth drilled to, and formation tops and lithologic information from units intercepted during drilling. An Excel spreadsheet was constructed from this dataset that included 1) the location of each well, 2) the surface elevation of the well, 3) the elevation of the bedrock surface, and 4) formation tops of each unit drilled through down to the Dundee Formation. In some cases, the drillers reports were validated using wireline logs.

Southern Alpena County has a significant distribution of oil and gas wells, but the rest of the county required using a second database, water well records from Michigan Wellogic. Water well drilling companies are also required by state regulations to submit drillers reports, unfortunately, these logs usually do not include information on stratigraphic units drilled through, but rather generalized descriptions of lithologic material encountered while drilling. A second Excel spreadsheet was generated from the water well reports that included the following information: 1) surface location of the well, 2) surface elevation of the well, 3) bedrock elevation,

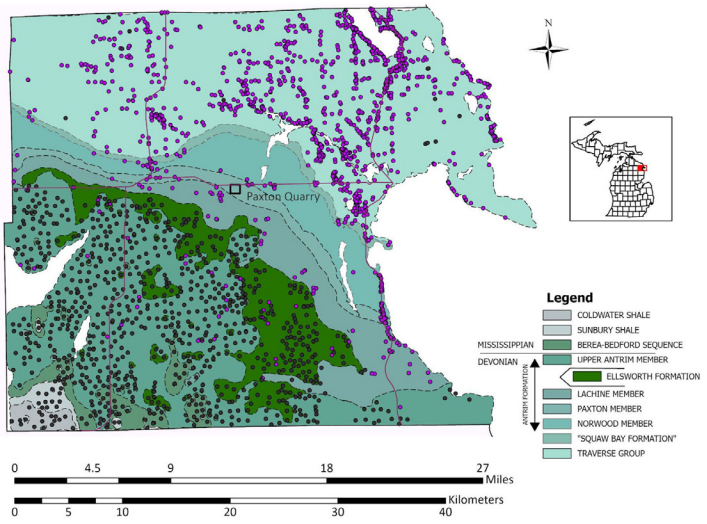

Figure 2. The current study's version of the bedrock map of Alpena County showing the subcrop pattern of the geologic map. A database of 886 oil and gas wells and 1361 water wells logs was used to create this map.

and 4) lithology of bedrock. Total of 886 oil and gas and 1361 water well logs from the database were imported into ArcGIS Pro. ArcGIS Pro was used to generate geologic maps. Wells were coded for the shallowest bedrock unit and mapped to show the distribution of these units (Fig. 2). ArcGIS Pro was used to draw polygons representing geologic units. The bedrock elevation map was drawn by contouring bedrock elevation data from the two well datasets (Fig. 3). Glacial drift thickness was calculated from the difference between the surface elevation and the bedrock surface in each well, followed by contouring these thicknesses across the county to generate a glacial drift thickness map (Fig. 4).

RESULTS

Lithologic Description

In the Paxton Quarry core, the upper Traverse Group is gray microcrystalline and fossiliferous limestone. In the subsurface, the Traverse Group consists of limestone, dolostone, argillaceous limestones, and calcareous shales (Ehlers and Kesling, 1970). Overlying the Traverse Group, the "Squaw Bay Formation" consists of fossiliferous gray shale with pyrite concretions in the Paxton Quarry Core. At the type locality (also in Alpena County), the "Squaw Bay Formation" consists of 1) *Zoophycos*-bearing, dolomitic limestones, and 2) Molluscan limestones (Gutschick and Sandberg, 1991). The oldest member of the Antrim Shale, the Norwood, is dark gray to black, laminated shale characterized by high gamma radiation emissions as shown in Figure 5. The Paxton Member is a light to gray laminated shale with pyrite inclusions and emitting lower gamma radiation. Above the Paxton Member, is the Lachine Member, which consists of gray-black laminated to bioturbated shale with a high gamma radiation signature. While Gutschick and Sandberg (1991) do not recognize the Ellsworth Formation in Alpena County, Currie (2016) has interpreted, from wireline log analysis, a thin interval of Ellsworth Formation between the Lachine and upper Antrim members of the Antrim Shale. The Ellsworth Formation is gray to green interbedded siltstone and shale. Returning to the fourth member of the Antrim Shale, the upper Antrim member consists of gray-black laminated shale.

No early Mississippian bedrock units are found in the Paxton Quarry Core and are cited from observations recorded on drillers reports. The Bedford-Berea composite stratigraphic unit is a moderate to gray compact sandstone-shale unit. The Sunbury Shale is a dark brown-black fissile and brittle shale. The youngest subsurface bedrock unit, the Coldwater Shale, is a gray micaceous and compact shale.

Geologic Maps

The bedrock geologic map produced in this study shows a structural pattern of the margin of a

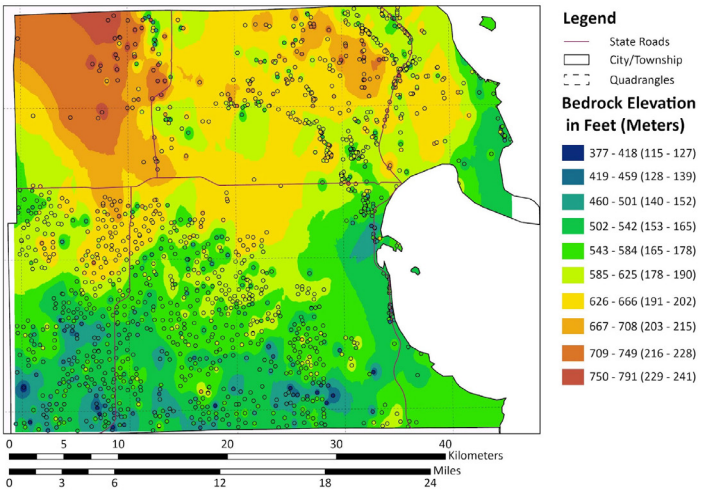

Figure 3. The bedrock surface map for Alpena County generated by this study. Note that bedrock elevations are higher in the northern part of the county and lower in Alpena County. Contour interval approximately 41 feet.

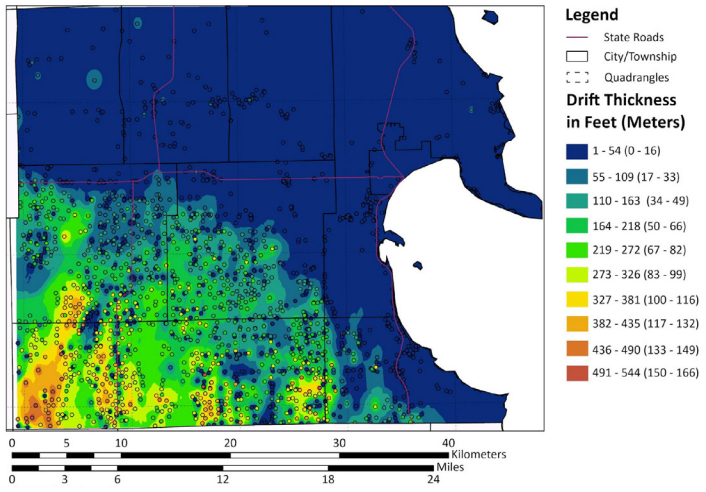

Figure 4. Drift thickness map was produced from oil/gas and water well logs where both the surface elevation and the depth to the bedrock surface were recorded. Note that the drift is thicker to the south and west in Alpena County. Contour interval approximately 54 feet.

depositional basin as shown in Figure 2. Stratigraphic units are younger to the southwest. The southern part of the county is dominated by the the upper Antrim member with significant subcrops of the Ellsworth Formation interfingered with the upper Antrim. The central portion of the county is underlain by the older members of the Antrim Shale (Norwood, Paxton, and Lachine Members) and the "Squaw Bay Formation" marking the transition to the older carbonates to the north and northeast. The northern portion of the county is mainly underlain by the undifferentiated Traverse Group.

The glacial drift thickness map indicates that glacial drift thickens towards the south. In northern Alpena County, the drift thickness above the Lachine Member, "Squaw Bay Formation", and Traverse Group ranges from 0 to 54 feet thick, which places glacial drift over carbonate rocks as shown in Figure 4. The Bedrock Elevation Map (Fig. 3) shows a different trend than the glacial drift thickness map - the bedrock elevation increases to the northwest. The topography of the bedrock elevation surface shows a mix of highs and lows in southeastern Alpena County suggesting the presence of glacially eroded valleys.

DISCUSSION

Geology

Bedrock units form arcuate belts from northwest to southeast in Alpena County and range from the Lower Mississippian units in the far southwest (Bedford-Berea, Sunbury, and Coldwater formations) to Devonian units across the majority of the county (Traverse Group, "Squaw Bay Formation", Antrim Shale, and Ellsworth Shale). The youngest unit is in the southwest and oldest unit in the northeast of Alpena County. This age distribution follows the regional dip of the Michigan Basin. The Traverse Group in northeastern Alpena County is characterized by interbedded carbonates and shales. The paucity of oil and gas wells (with detailed drillers logs) required using drillers reports from water wells. The observations from the water wells suggest a complex mosaic of shale and carbonates in northern Alpena County and the current study was unable to differentiate the ten formal formations in the

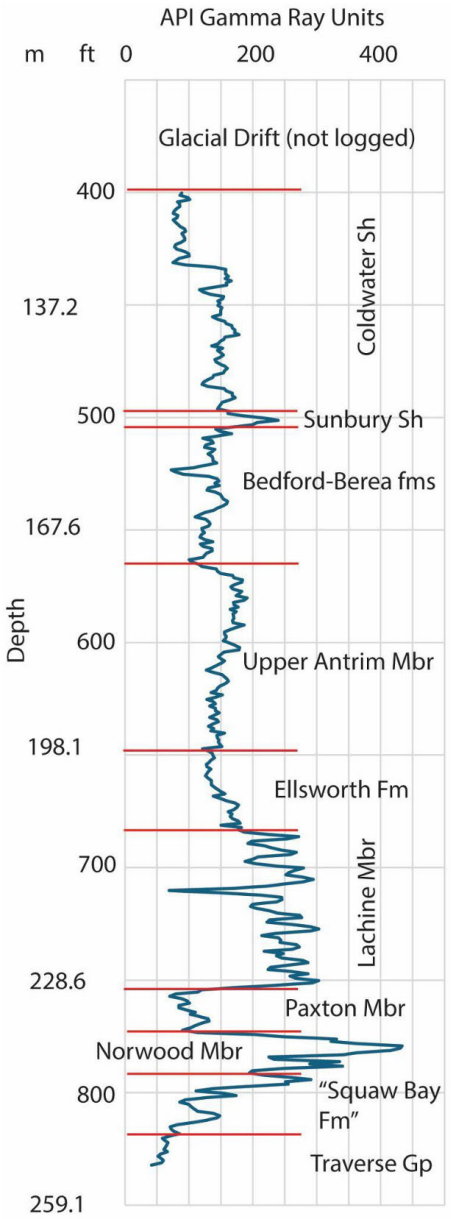

Figure 5. Gamma ray log from the Linn Operating Inc. Log Cabin Hunting Club #D2-24 well (Permit number 49295) in SW Alpena Co. The log shows the gamma ray signatures characteristic of each unit - note that the Norwood and Lachine Members of the Antrim Shale are characterized by high gamma radiation, while other units generally exhibit less gamma radiation. API – American Petroleum Institute, Fm – Formation, Fms – Formations, Gr – Group, Mbr – Member, Sh – Shale.

Traverse Group that had been mapped from outcrops; indeed, Ehlers and Kesling (1970 and references therein) lament the difficulty of correlation in the Traverse Group due to the lack of exposed contacts between formations in outcrops and the small size and scattered locations of available outcrops. As this study focused on subsurface data, no attempt was made to integrate the outcrop data from Black (1979) and Ehlers and Kesling (1970). The "Squaw

Bay Formation" was inferred to be present in the subsurface as a thin belt between the Traverse Group subcrop and the Norwood Member of the Antrim Shale. The "Squaw Bay Formation" does outcrop on the southern shore of Partridge Point on Birdsong Bay [Birdsong Bay is the revised name for "Squaw Bay" that is currently pending with the USGS] (Gutschick and Sandberg, 1991). The individual members of the Antrim Shale defined by Gutschick and Sandberg (1991) are geologically distinct and mappable across the county, suggesting that these units may be better treated as formal formations of an Antrim Group. The Ellsworth Formation outcrops in a belt between the Lachine Member of the Antrim Shale and the upper Antrim member of the Antrim Shale and further confirms the hypothesis of Currie (2016) for a thin Ellsworth Formation being present across the entire eastern Lower Peninsula in the subsurface. Drillers have identified the Bedford and Berea formations, the Sunbury Shale, and the Coldwater Shale in the southwesternmost portion of Alpena County. No attempt was made to subdivide the Bedford and Berea formations due to their gradational nature (Ells, 1979). Glacial incision during the Pleistocene has carved significant paleovalleys on this bedrock surface, with valleys trending NE-SW in Alpena County. Glacial drift thickens to the south and southwest in Alpena County.

Comparison to Published Maps

The updated geologic map is broadly similar to the Milstein (1987) bedrock map in Geowebface, while differing by providing more detail for the Antrim Shale and the Ellsworth Shale in central Alpena County. The high density of oil and gas wells in southern Alpena County allow for mapping of the members of the Antrim Formation. The only caveat is that where the Antrim Formation is less than 100 ft thick above hydrocarbon bearing zones, oil and gas wells were not drilled due to state regulations (W. Harrison, personal communication, 2024). This impacts the mapping of the boundaries of the Antrim members in the northern and eastern portions of their range where fewer wells were drilled.

The overall distribution of the Traverse Group is also similar to the Milstein (1987) bedrock map in Geowebface and like the previous map, we did not attempt to subdivide the Traverse Group into formations. While the density of water wells in northern Alpena County is also high, it was difficult to define the individual formations of the Traverse Group. Since the Traverse Group in this geographic region contains a range of lithologies including argillaceous limestone, shales, limestones, and dolostones, water well drillers did not identify specific units but instead described the lithologies at the bedrock surface. Factors such as this contribute to the uncertainty of the contact locations of the bedrock units for not only water well logs but oil/gas logs as well.

Natural Hazards

Portions of Alpena County underlain by the Traverse Group are prone to dissolution and collapse. The thinness of the drift over the Traverse Group allows infiltrating precipitation to widen fractures through dissolution (Holst and Foote, 1981) eventually leading to collapse and formation of sinkholes (Black, 1977). These sinkholes can be significant hazards during collapse events especially in the Thunder Bay area. Wells that are within sinkholes run the risk of water pollution as the karst act as conduits for contaminants and contamination of the aquifer from sewage is possible due to sinkholes. With the increasing pollution rate from active karst features, dangers of contamination from sewage may infiltrate residential areas affecting residents (Black, 1977).

CONCLUSIONS

Our maps broadly match the previously published map (Milstein, 1987) available on Geowebface, though this study demonstrates that the members of the Antrim Shale are readily mapped in Alpena County subsurface. The Ellsworth Formation is present as a thin unit between the Lachine Member and upper Antrim member of the Antrim Shale. The Traverse Group was mapped as undifferentiated Traverse as the quality of the water well records in northern Alpena County were too poor to divide the unit. In southwestern Alpena County, the area underlain by the Bedford and Berea formations, Sunbury Shale, and Coldwater Shale is mapped more precisely than in previous efforts. Karst is a significant hazard in

northeastern Alpena County where thin glacial drift overlies carbonates of the Traverse Group.

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