



Wisconsin Geological
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DIVISION OF EXTENSION
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Depth-to-bedrock map of Dodge County, Wisconsin

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Introduction

The accompanying depth-to-bedrock map of Dodge County shows the thickness of unconsolidated sediments and soil that overlie solid bedrock. Across Dodge County, depth to bedrock ranges from 0 feet (ft), where bedrock is exposed at land surface, to over 250 ft within bedrock valleys. In much of the map area, depth to bedrock is related to the topography of the mostly buried bedrock surface, which reflects the variable resistance to weathering and erosion of different bedrock units. Harder carbonate and quartzite are more resistant to erosion and tend to form topographic highs covered by relatively thin deposits of unconsolidated material. In contrast, softer sandstone and shale are more easily eroded, tend to form slopes, and also tend to be dissected by preglacial drainages. Deposits of unconsolidated material are generally thickest in these areas, especially within preglacial drainage valleys. Bedrock units and topography are shown on the *Bedrock Geology of Dodge County, Wisconsin* map (Stewart, E.K., 2021). This map complements the recently completed depth-to-bedrock map of neighboring Fond du Lac County (Batten, 2018).

In Dodge County, bedrock depth is related to the underlying bedrock lithology. Bedrock is shallowest, commonly less than 50 ft below the surface, in areas where the uppermost bedrock unit is carbonate rock. In northwest and central Dodge County, dolostone of the Sinnipee Group is overlain by unconsolidated sediments commonly less than 20 ft thick, though locally it may be found at depths of up to 50 ft beneath glacial moraine and outwash deposits (Devaul and others, 1983; Stewart, E.K., 2021). In areas of south-central Dodge County underlain by Sinnipee Group dolostone, depth to bedrock is greater, typically between 20 to 50 ft, and locally may be up to 100 ft beneath glacial drumlins. Northeast Dodge County is underlain by Silurian undifferentiated dolostone, and bedrock depth in this area is commonly less than 20 ft. Locally, depth to bedrock increases to 50 ft or more within southeast-trending preglacial bedrock valleys and their tributaries. For example, one such valley is today occupied by the Theresa Marsh State Wildlife Area (plate 1); the locations of this and other tributaries to the ancestral Rock River are shown in Stewart (2021, fig. 1). The southeast trend of preglacial valleys that overlie Silurian bedrock parallels the strike of bedding, and they likely developed along small slopes in the buried bedrock surface that formed from erosion of softer interbeds within the Silurian dolostone. The subcrop extent of Silurian dolostone decreases to the southeast; in these areas Silurian dolostone is buried beneath 50 to 100 ft of unconsolidated sediment. Well data generally suggest that glacial drumlins that overlie carbonate rocks include bedrock cores.

Bedrock depth is greatest, typically between 50 to over 250 ft, in parts of Dodge County underlain by Cambrian sandstone and Ordovician shale. In northeastern Dodge County, an east-southeast-trending bedrock valley incises the Silurian-age dolostone and shale of the Maquoketa Group with at least 160 ft of relief, and bedrock depth locally exceeds 250 ft. To the southeast the uppermost bedrock is Maquoketa Group shale, and bedrock depth is generally 50 to 200 ft. Bedrock depth in areas underlain by the Maquoketa Group is poorly constrained because the contact between the shale and overlying Quaternary clay is difficult to pick from drill cuttings and well construction reports. Generally, well data suggest glacial drumlins that

overlie sandstone and shale bedrock lack a significant bedrock core, or potential bedrock cores are less defined and difficult to identify with well construction reports (WCRs).

The area of Horicon Marsh, in northeast Dodge County, is one exception to the observation that areas of greatest bedrock depths are underlain by sandstone or shale. Here, bedrock depth increases from about 50 ft along the western edge of the marsh, to as much as 200 ft where the gently eastward-dipping Sinnipee Group dolostone extends beneath the Maquoketa Group and Silurian undifferentiated at the Niagara Escarpment (Stewart, E.K., 2021). There is no well constraint for bedrock depths beneath Horicon Marsh, and the map pattern of depth to bedrock in this area reflects interpolation between poorly constrained bedrock elevation contours.

Map use

Depth-to-bedrock information can aid land-use decision making as well as inform scientific understanding of the geologic processes that produced Dodge County's modern landscape. Areas with bedrock depths shallower than 20 ft are of importance for land-use planning and to the construction stone industry, and they also are more susceptible to groundwater contamination. Most quarry operations for commercial stone and lime production are located in areas underlain by dolostone of the Ordovician Sinnipee Group or undifferentiated Silurian units in places where depth to bedrock is less than 20 ft.

Water wells drilled in areas of shallow dolostone bedrock are most susceptible to groundwater contamination. Where unconsolidated sediment and soil is thin, rain and runoff readily infiltrate into fractured dolostone. The extensive fracture network typical of dolostone bedrock allows rain and runoff to travel quickly from the land surface into the groundwater, carrying with it contaminants from septic-system effluent and land application of nutrients and pesticides. Shallow dolostone bedrock (<20 ft depth) underlies about 17 percent of Dodge County, including the more populated areas of Waupun, Randolph, Fox Lake, Beaver Dam, Juneau, Brownsville, and Lomira.

Methods for compiling the map

This depth-to-bedrock map is derived from an interpretation of the mostly buried bedrock topography. First, a bedrock elevation surface was interpreted. Bedrock elevation was subtracted from land-surface elevation derived from 5-foot resolution lidar to calculate depth to bedrock. Depth to bedrock was binned into increments of 0–20, >20–50, >50–100, >100–200, and >200–300 ft to reflect the uncertainty and scale of the map. A general explanation is provided below.

Step 1: Interpretation of bedrock topography

The bedrock-elevation surface was created by hand-contouring bedrock elevation at 20-foot intervals constrained by depth-to-bedrock information recorded in water-well drillers' WCRs, bedrock outcrops, bedrock quarries, drill core, soil survey data from the U.S. Department of Agriculture, and observations of land-surface topography.

- **WCRs.** The primary dataset used to interpret bedrock elevation and depth-to-bedrock was bedrock depth information recorded in WCRs. Bedrock depth records were evaluated for 3,213 wells selected from the full database (5,679 records). Records were eliminated if (a) they were available as paper records only, (b) their wells did not reach bedrock, or (c) information was incomplete. To improve location confidence, locations of 2,707 WCRs that reached bedrock were verified to the quarter section (570 m) or better (table 1). Wells that did not reach bedrock provided only minimum constraint on bedrock depths –124 of these wells were geolocated and are not shown on table 1.
- **Soil survey data.** Soils data from the U.S. Department of Agriculture were queried for soils that tend to develop on bedrock less than 3 feet below land surface and compared against well data. Bedrock-elevation contours were adjusted to match soils data where soils and well data were in agreement; soils data was excluded where well data indicated significantly greater depth to bedrock.
- **Surface topography.** Data from wells, outcrops, drill cores, quarries, and soil surveys suggest buried bedrock topography mimics surface topography, so bedrock elevation contours were interpreted to follow the trend of surface topographic contours.
- **Bedrock-elevation contours.** These contours were first smoothed and then interpolated to a 5-meter grid to create a raster surface of bedrock elevation.

Passive-seismic measurements of bedrock depth were collected, but ultimately did not prove useful due to their large uncertainty.

Table 1. Location confidence for WCRs that contain bedrock depth information (3,213 of 5,679 total WCRs in Dodge County)

| Location confidence | Number of wells |
|---|-----------------|
| Not locatable | 7 |
| Unverified | 483 |
| County | 3 |
| Quarter section, 570 m (1,870 ft) | 15 |
| Quarter-quarter section, 280 m (920 ft) | 104 |
| 230 m (750 ft) | 383 |
| 150 m (500 ft) | 276 |
| 100 m (330 ft) | 318 |
| 60 m (200 ft) | 816 |
| 30 m (100 ft) | 671 |
| 15 m (50 ft) | 129 |
| 10 m (30 ft) | 8 |
| Total wells | 3,213 |

Step 2: Interpretation of depth to bedrock

The depth-to-bedrock interpretation was calculated by subtracting the bedrock elevation surface from the land surface digital elevation model (DEM). The land surface DEM is derived from 5-ft resolution lidar and resolves significantly finer topographic variation than the bedrock elevation surface. Manipulation of the land surface DEM and bedrock elevation surface was necessary to account for the difference in resolution between these two surfaces and mitigate the impact of interpolation errors that result in projection of the bedrock elevation surface above land surface. First, the land surface DEM was uniformly depressed by 3 ft. The bedrock-elevation raster was then queried for areas where the bedrock elevation projected above the depressed land surface elevation. In those areas, the elevation value of the depressed land surface DEM was assigned to the bedrock elevation. Finally, the revised bedrock elevation surface was subtracted from Dodge County's 2017 5-ft land surface DEM. Values were then classified into five groups ranging from 0 ft to greater than 200 ft.

Assessing uncertainty in the interpretation method

The depth-to-bedrock surface was generated by subtracting an interpreted bedrock elevation surface from a DEM of land surface elevation. Therefore, most of the uncertainty in the depth-to-bedrock surface is related to uncertainty in the data and workflow used to interpret the bedrock elevation surface. Possible sources of error include human error recording or transcribing bedrock depth of WCRs; error in well locations; uneven data distribution; and

natural, localized variation in the bedrock surface across short (0.5 km-scale) lateral distances, as the map scale and data density is too coarse to capture this fine-scale variability. The process of drawing bedrock elevation contours and interpolating between those contours to make a surface contributes additional uncertainty to the interpretation. The 20-ft contour interval was considered an appropriate level of detail given the map scale; topographic variability of the bedrock surface; uneven distribution of the WCR, outcrop, quarry, drill core, and soils data; and time and budget constraints.

Hand-drawn contours were considered more accurate than computer-generated contours, which produce geologically unreasonable interpretations based on observations that the buried bedrock surface morphology mimics land surface morphology, especially in areas with unconsolidated sediment less than 50 ft thick. For example, computer-generated contours smooth over abrupt changes in slope of the bedrock surface that are common along the Niagara Escarpment (fig. 1).

The assumption of similar bedrock and land surface morphologies adds resolution to the bedrock-elevation interpretation that is otherwise unresolved based on the relatively coarse and uneven distribution of WCR, bedrock outcrop, quarry, drill core, and soil data alone. While this assumption yields bedrock elevation and derivative depth-to-bedrock surfaces that are consistent with the input data, the validity of the assumption varies across the map area depending on the underlying bedrock lithology and thickness of the unconsolidated sediments.

The following sections explore the relation between bedrock lithology and fit between the interpreted depth-to-bedrock surface and well data used to interpret that surface. Fit between bedrock depths recorded in all wells and the depth-to-bedrock surface is a first-order approximation of uncertainty in the depth-to-bedrock interpretation. A future, more rigorous study may build off the observations presented herein to constrain uncertainty in the bedrock depth interpretation and input data sets.

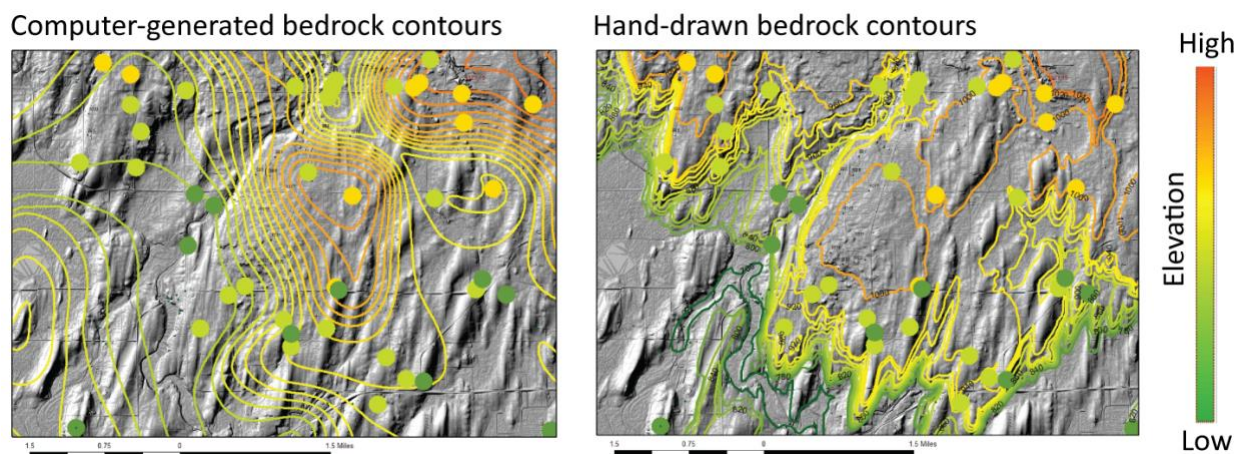


Figure 1. Comparison of computer-generated and hand-drawn elevation contours drawn over lidar. Points show well locations. Areas with abrupt changes in slope, such as along the Niagara Escarpment (shown here), were incorrectly smoothed by the computer model.

Evaluating data fit

The “fit” of the interpreted depth-to-bedrock surface to the WCR data was assessed by comparing the bedrock depths reported in WCRs to depths sampled from the interpreted surface at each well location. Fit was also evaluated by top bedrock unit, and figure 2 shows the fit of the interpretation to the well data plotted on the bedrock geology. Figure 2a shows wells with good fit—that is, the interpreted depth-to-bedrock surface is within 20 ft of the bedrock depth recorded in the WCR. Figure 2b shows wells with poor fit, where the difference between the interpreted depth to bedrock and the recorded depth to bedrock (from the WCR) is greater than 20 ft.

Graphs, including histograms (fig. 3) or box and whisker plots (fig. 4), provide another way to visualize the fit of the interpretation to the data. Figures 3 and 4 show the difference, by top bedrock unit, between bedrock depths recorded in WCRs and depths sampled from the interpreted depth-to-bedrock surface. For simplicity, the Ordovician Ancell and Prairie du Chien Groups were combined with the Cambrian sandstone units because these units tend to be more dissected by preglacial drainages and buried beneath deeper sedimentary cover. All Precambrian bedrock units were treated as a single unit. The difference (fit) represents the bedrock depth recorded in the WCR subtracted from the bedrock depth queried from the raster surface at the well location. A depth-to-bedrock raster surface that perfectly honors the data would have no difference between WCR data and bedrock depth values of the interpolated surface. The size of the difference (positive or negative) indicates the degree of uncertainty. As shown in figure 4 and table 2, the parts of Dodge County that are underlain by shale of the Maquoketa Group have the poorest fit between the interpreted and reported depths to bedrock.

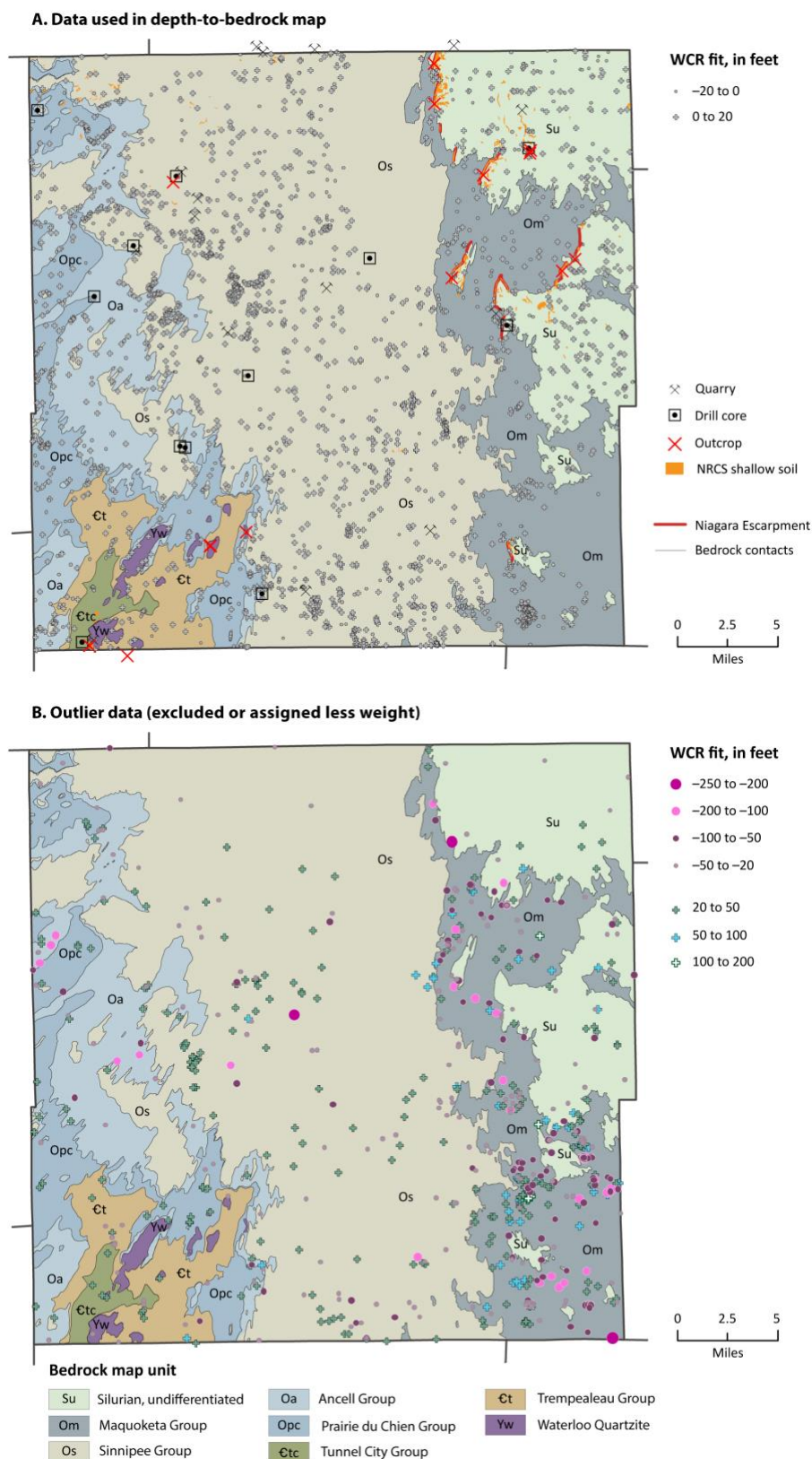
In addition to being influenced by which bedrock unit underlies an area, the fit may also depend on the quality of the well’s location information. For example, wells that were not geolocated to the quarter-quarter section (or better) may have poorer fit than comparable geolocated wells. Figure 5 shows the range of fit (shown on the vertical axis) for each location confidence category described in table 1. There is no clear correlation between confidence in well location and difference between WCR and interpreted bedrock depth values.

The fit of the interpretation to the well data shown in figures 2 through 5 gives the map user a qualitative idea of how uncertainty in the interpretation of bedrock depths varies across the map area and by geologic unit. The bedrock depths recorded in many wells were judged to be unreliable on a case-by-case basis based on considerations such as map scale, consistency with nearby wells, and geometry of the buried bedrock layers. For example, if four wells within a 0.5-mile radius record bedrock depths less than 16 ft and one well in that same area records a depth to bedrock of 256 ft, the 256-ft bedrock depth is considered an outlier and excluded from the interpretation. Similarly, many of the WCRs that overlie the Maquoketa Group shale report bedrock depths that vary by several tens of feet across distances of less than 1,000 ft. In these locations, the fit between the interpreted and recorded bedrock depths is poor (fig. 2b), and the WCRs were either excluded or used to loosely guide the trend bedrock elevation contours. Of the 3,213 total WCRs with bedrock depth information, 2,618 (81%) had a good fit (± 20 ft) with the interpreted depth-to-bedrock surface. The assessment is not a rigorous, quantitative investigation of uncertainty in the map or input data.

Figure 2. Maps showing spatial distribution of data relative to the top bedrock unit.

A. Distribution of WCRs with good fit (≤ 20 ft difference between interpreted and recorded depths) and other data used (quarries, cores, outcrops, and shallow soil data).

B. Distribution of WCRs with poor fit (> 20 ft difference between interpreted and recorded depths). Outlier data (B) was excluded or given less weight in the making of the map. Bedrock map units from Stewart, E.K. (2021).



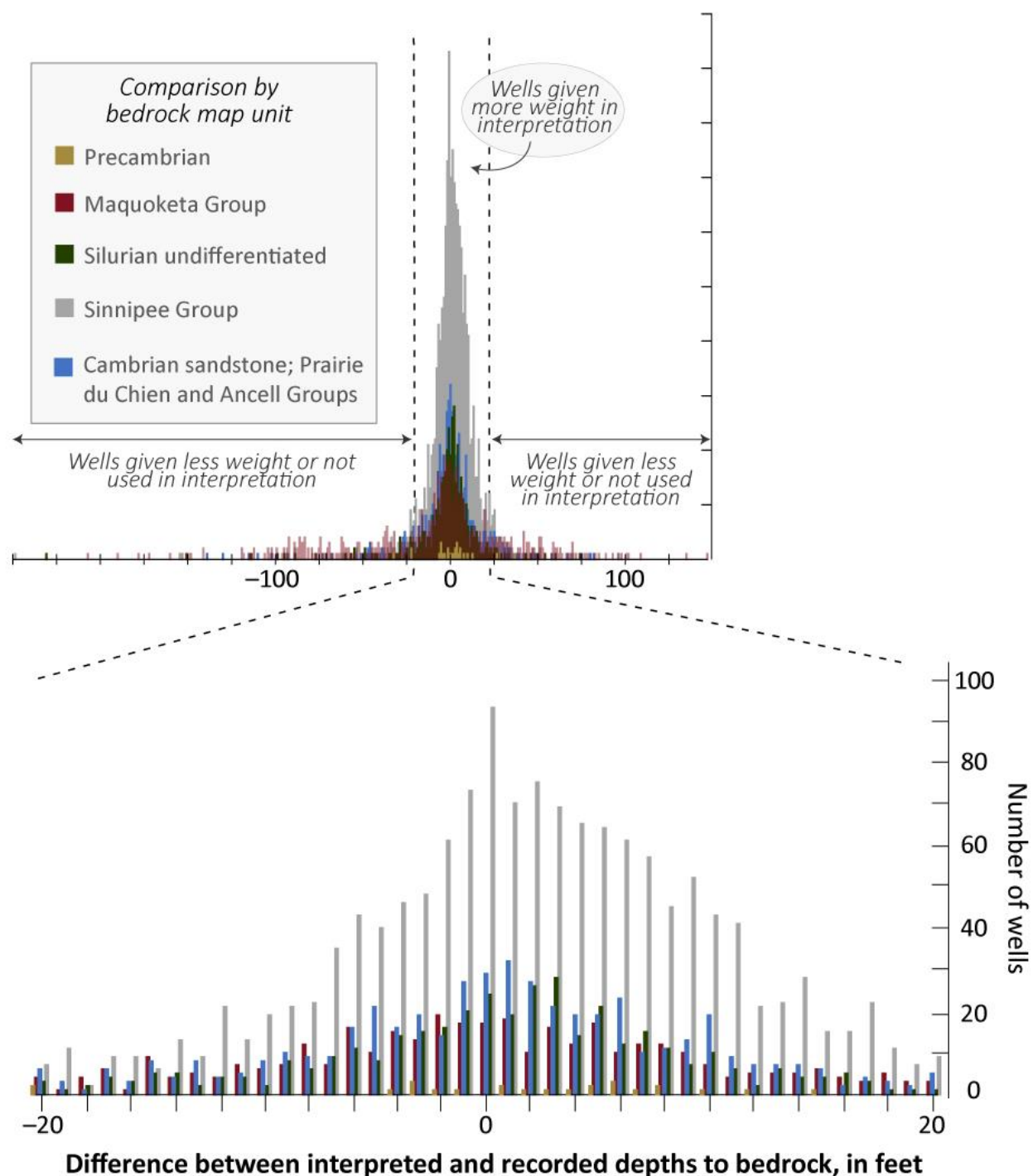


Figure 3. Histogram showing fit of WCR data to the interpreted depth-to-bedrock surface. Difference is calculated by subtracting the bedrock depth recorded in the WCR from the interpreted surface at each well location.

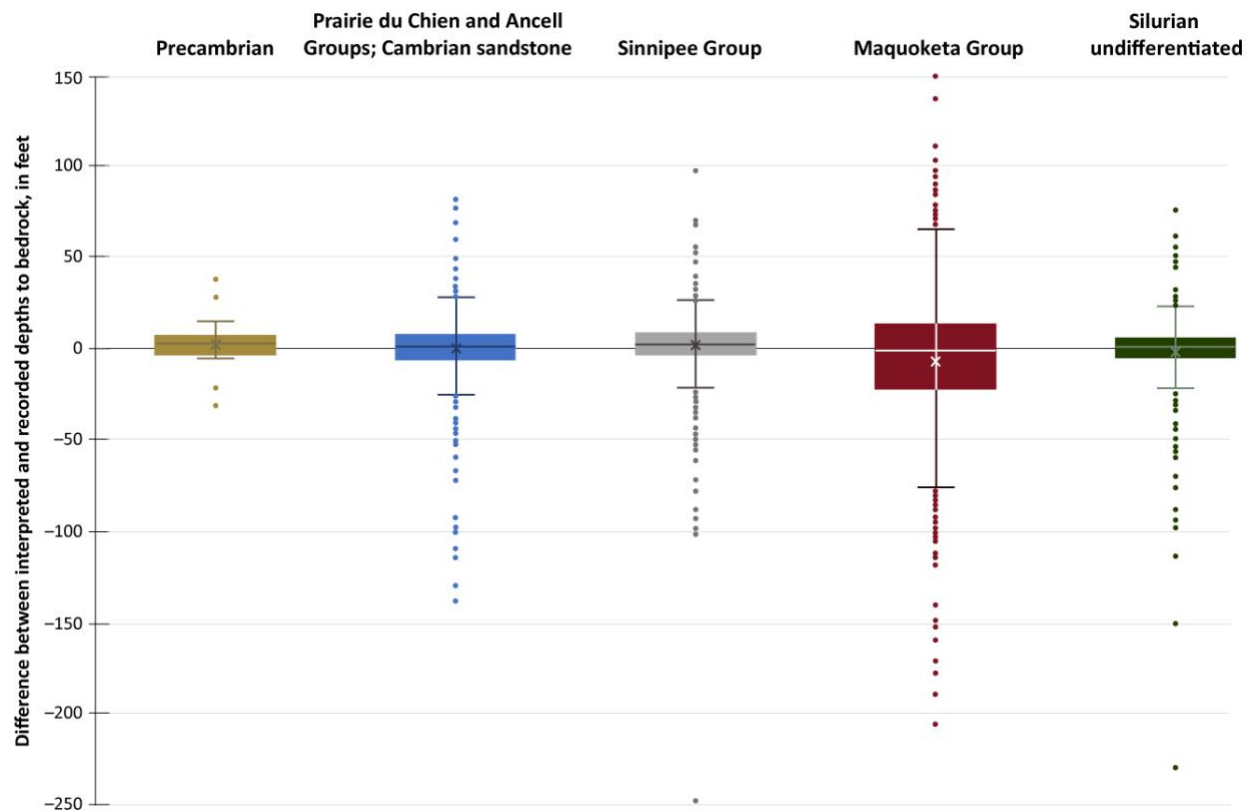


Figure 4. Box and whisker plot of the difference between bedrock depth recorded in WCRs and the interpreted depth-to-bedrock at the location of each well. Reading the data: The horizontal line within each box indicates the median; the boundaries of the box indicate the 25th and 75th percentiles; the “whiskers” (the horizontal lines above and below the box) extend to the largest or smallest value that falls within 1.5 times the interquartile range; and the dots show the distribution of outliers that fall outside of 1.5 times the interquartile range. The “x” within each box indicates the mean. Statistics used to create the graph are shown in table 2.

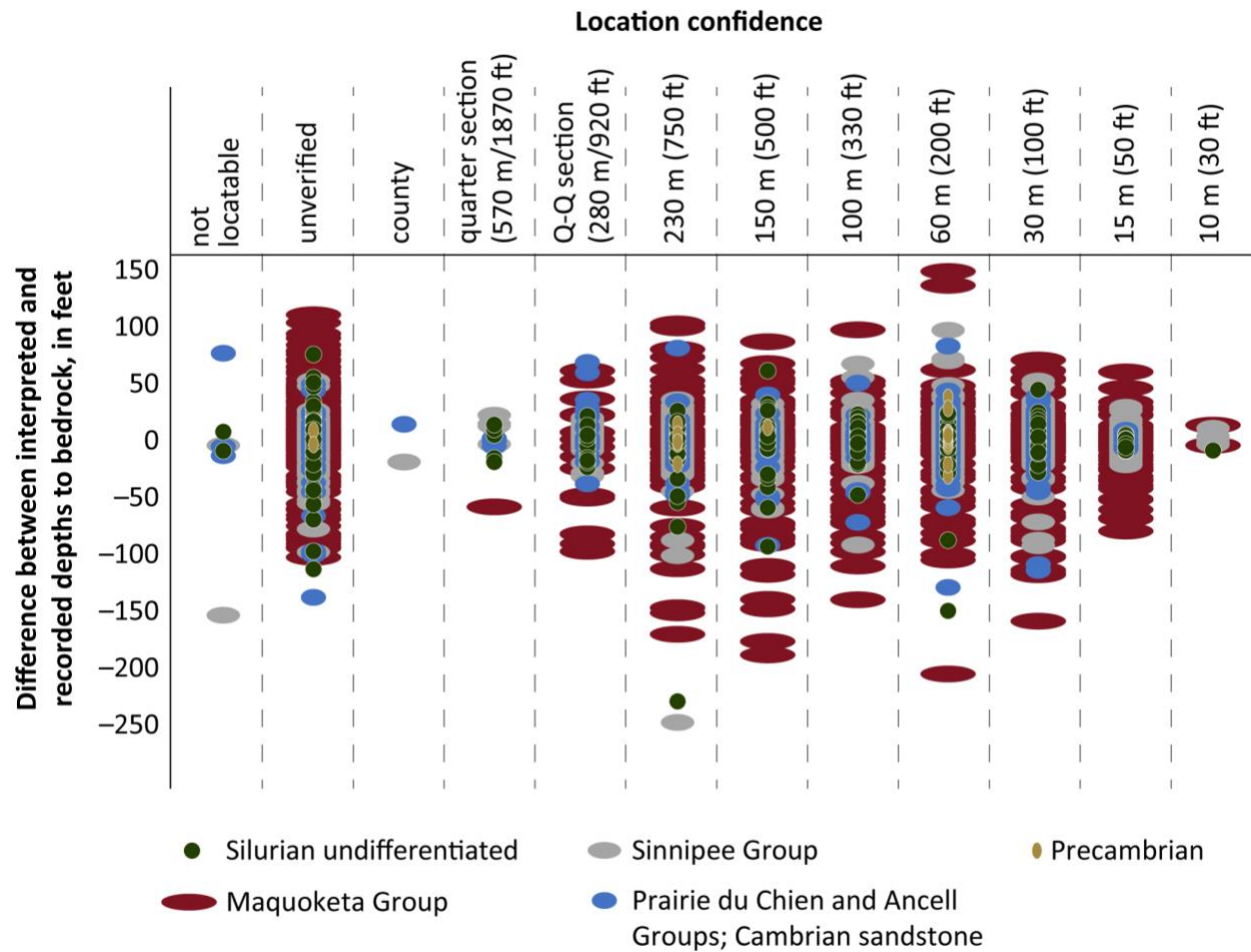


Figure 5. This plot shows the difference between the bedrock depths sampled from the interpreted depth-to-bedrock surface and the bedrock depth recorded in all WCRs broken down by location confidence and top bedrock unit. Refer to table 1 for number of wells within each location confidence category. There is no clear correlation between location confidence, difference value, or map unit. Abbreviation: Q-Q section = quarter-quarter section.

Table 2. Statistical differences between recorded and interpreted depth to bedrock, by map unit.

| Statistical categories | Difference between recorded and interpreted depth to bedrock, in feet | | | | |
|----------------------------------|---|---|----------------|-----------------|--------------------|
| | Precambrian undivided | Cambrian sandstone; Prairie du Chien, Ancell Groups | Sinnipee Group | Maquoketa Group | Silurian undivided |
| Mean | 2.49 | −0.19 | 1.86 | −7.24 | −1.58 |
| Standard error ¹ | 2.59 | 0.88 | 0.41 | 1.76 | 1.10 |
| Number of wells | 27 | 565 | 1,552 | 647 | 422 |
| Minimum | −30.76 | −137.59 | −247.73 | −205.27 | −229.32 |
| Q1 (25 th percentile) | −2.58 | −5.37 | −3.21 | −21.69 | −5.03 |
| Median | 3.03 | 1.21 | 2.48 | −0.72 | 1.25 |
| Q3 (75 th percentile) | 6.66 | 7.75 | 8.72 | 13.01 | 6.24 |
| Maximum | 38.20 | 83.34 | 97.36 | 148.85 | 75.96 |
| Interquartile range | 9.24 | 13.11 | 11.93 | 34.70 | 11.27 |
| 1.5*interquartile range | 13.86 | 19.67 | 17.89 | 52.05 | 16.91 |

¹ Standard error is calculated as standard deviation divided by the square root of the sample size. Differences are calculated by subtracting the bedrock depth recorded in each WCR from the bedrock depth value sampled from the raster at each well location.

More WCRs were discarded during the process of interpreting bedrock elevation contours within areas underlain by the Maquoketa Group than for other units. There is likely greater uncertainty in the interpreted bedrock elevation and depth-to-bedrock surfaces in map areas directly underlain by the Maquoketa Group. WCRs that penetrate the Maquoketa Group shale may unreliably differentiate that unit from overlying Quaternary clay. In this area the top bedrock unit indicated by WCRs is commonly the underlying Sinnipee Group dolostone, even where this unit is overlain by more than 100 ft of Maquoketa Group shale, as indicated by regional stratigraphic correlation to construct the bedrock geologic map and cross sections (Stewart, E.K., 2021). In addition, there may be greater variation in the topography of the Maquoketa Group shale that is unaccounted for in the interpreted surface.

Limitations of the map

This map provides a reasonable representation of depth to bedrock at the county scale based on best available data and geologic understanding of buried bedrock surfaces. Accuracy of the map depends on the distribution and accuracy of the input data. WCRs, the primary dataset, are unevenly distributed across the county, and the map is better constrained in areas with

greater well density. Few wells penetrate to bedrock in areas with greatest bedrock depths. In these areas, only a minimum bedrock depth can be interpreted. Well data does not exist for wetlands and lakes, so bedrock depths of these areas are poorly constrained. Closely spaced WCRs often show discrepancies of several tens of feet to recorded depth to bedrock, and the source of this uncertainty is unknown, but may include real variation in the bedrock surface that cannot be captured on a county-scale map, misidentification of bedrock surface, well mislocation, and errors recording or transcribing lithology of the drill cuttings. The preliminary assessment presented in this report of the fit between the bedrock depth interpretation and WCR data suggests that uncertainty is greatest in places where the Maquoketa Group is the top bedrock unit.

Depth-to-bedrock values shown on the map should not be considered as absolute values of depth to bedrock. While the map clearly shows trends in depth to bedrock, bedrock depths should be confirmed with appropriate methods, for example push probe, backhoe, or geoprobe, to address site-specific questions.

Acknowledgments

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