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.

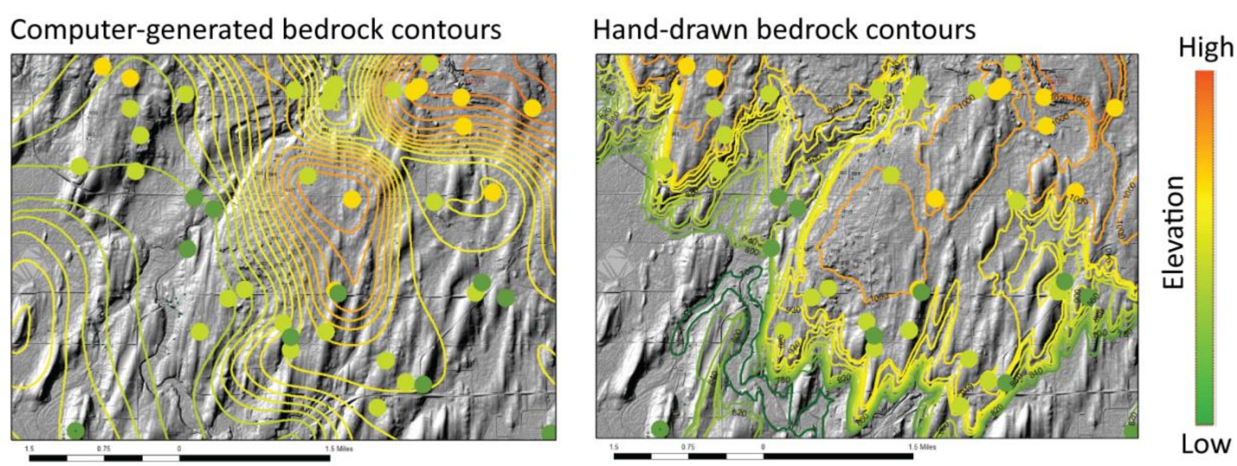

Figure 1. *Comparison of computer-generated and hand-drawn elevation contours drawn over lidar. Points show well locations. Areas with abrupt changes in slope, such as along the Niagara Escarpment (shown here), were incorrectly smoothed by the computer model.*

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.

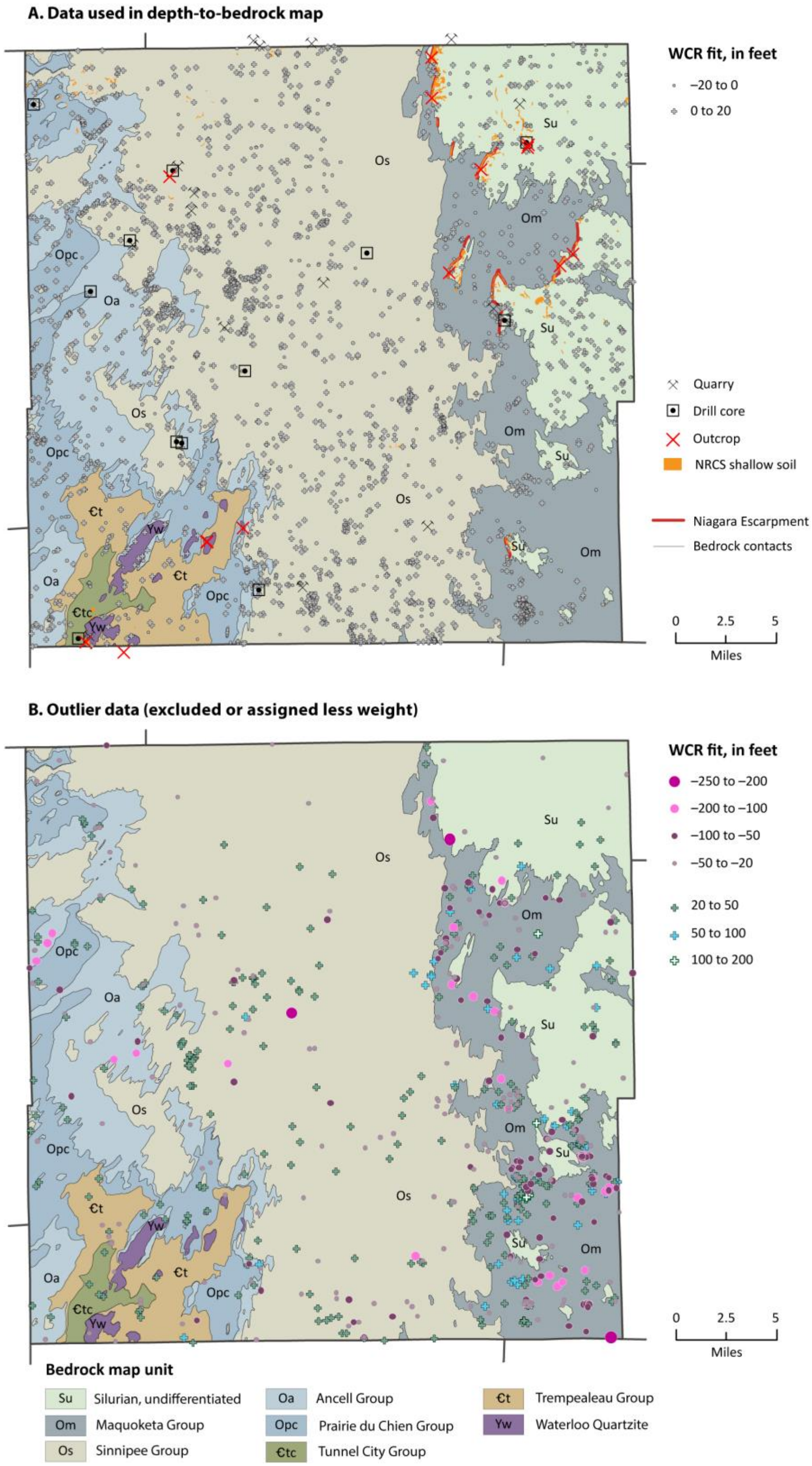

Figure 2. *Maps showing spatial distribution of data relative to the top bedrock unit.*
A. *Distribution of WCRs with good fit (≤20 ft difference between interpreted and recorded depths) and other data used (quarries, cores, outcrops, and shallow soil data).*
B. *Distribution of WCRs with poor fit (>20 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).*

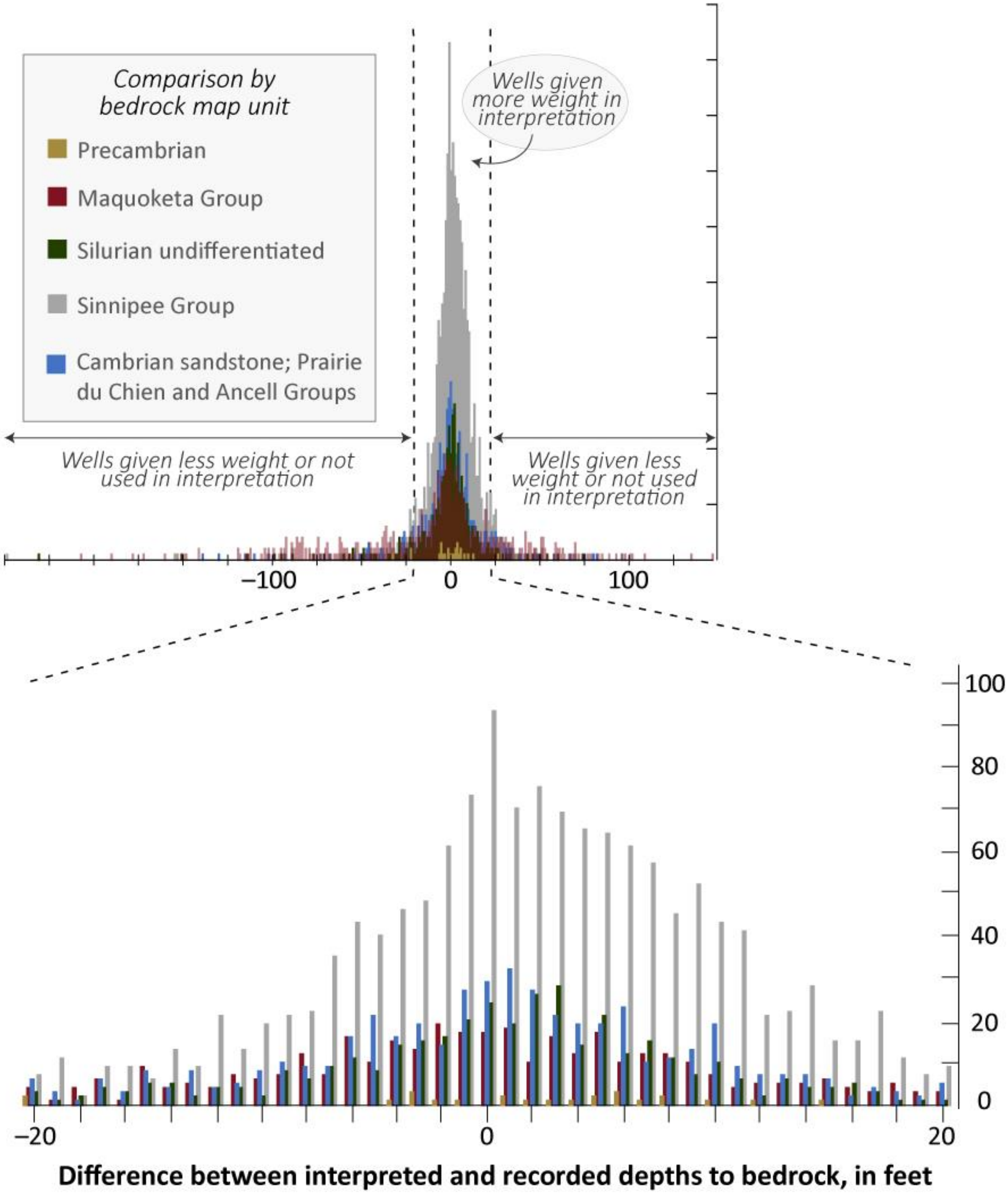

Figure 3. *Histogram showing fit of WCR data to the interpreted depth-to-bedrock surface. Difference is calculated by subtracting the bedrock depth recorded in the WCR from the interpreted surface at each well location.*

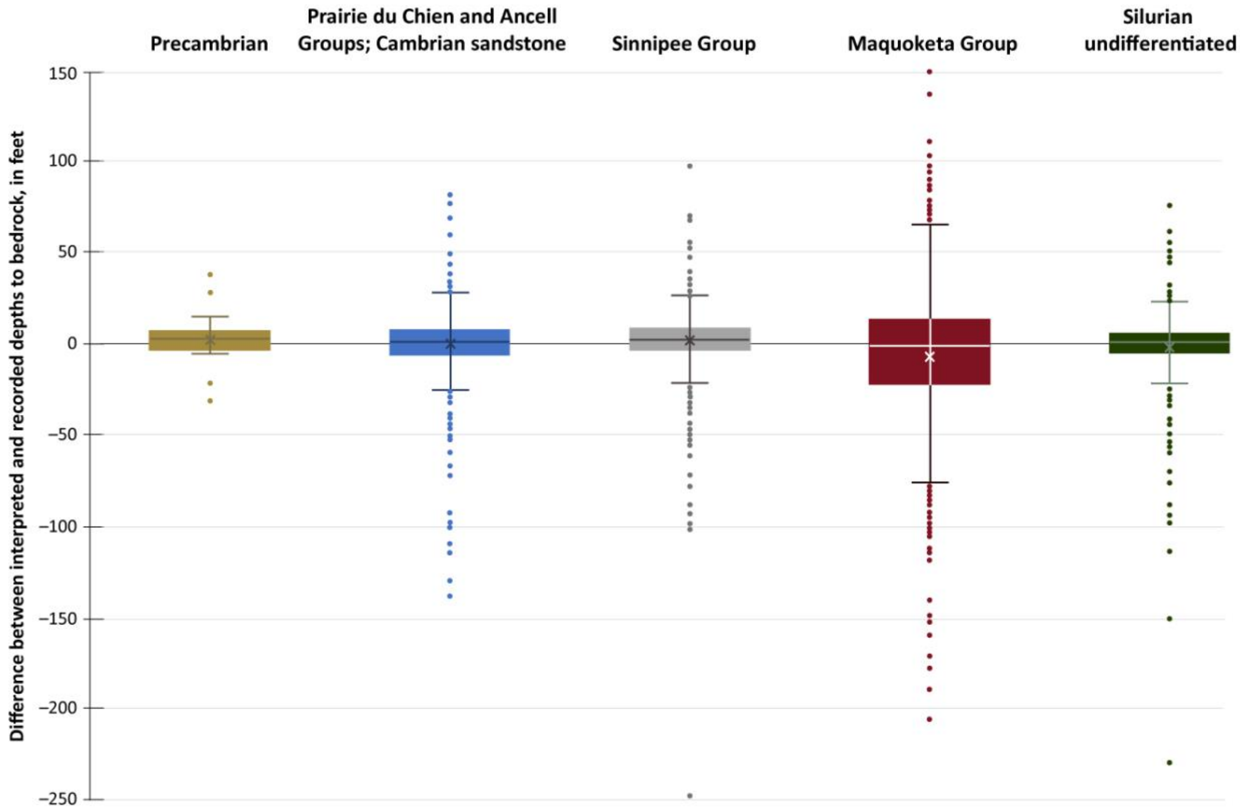

Figure 4. *Box and whisker plot of the difference between bedrock depth recorded in WCRs and the interpreted depth-to-bedrock at the location of each well. Reading the data: The horizontal line within each box indicates the median; the boundaries of the box indicate the 25th and 75th percentiles; the "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.*

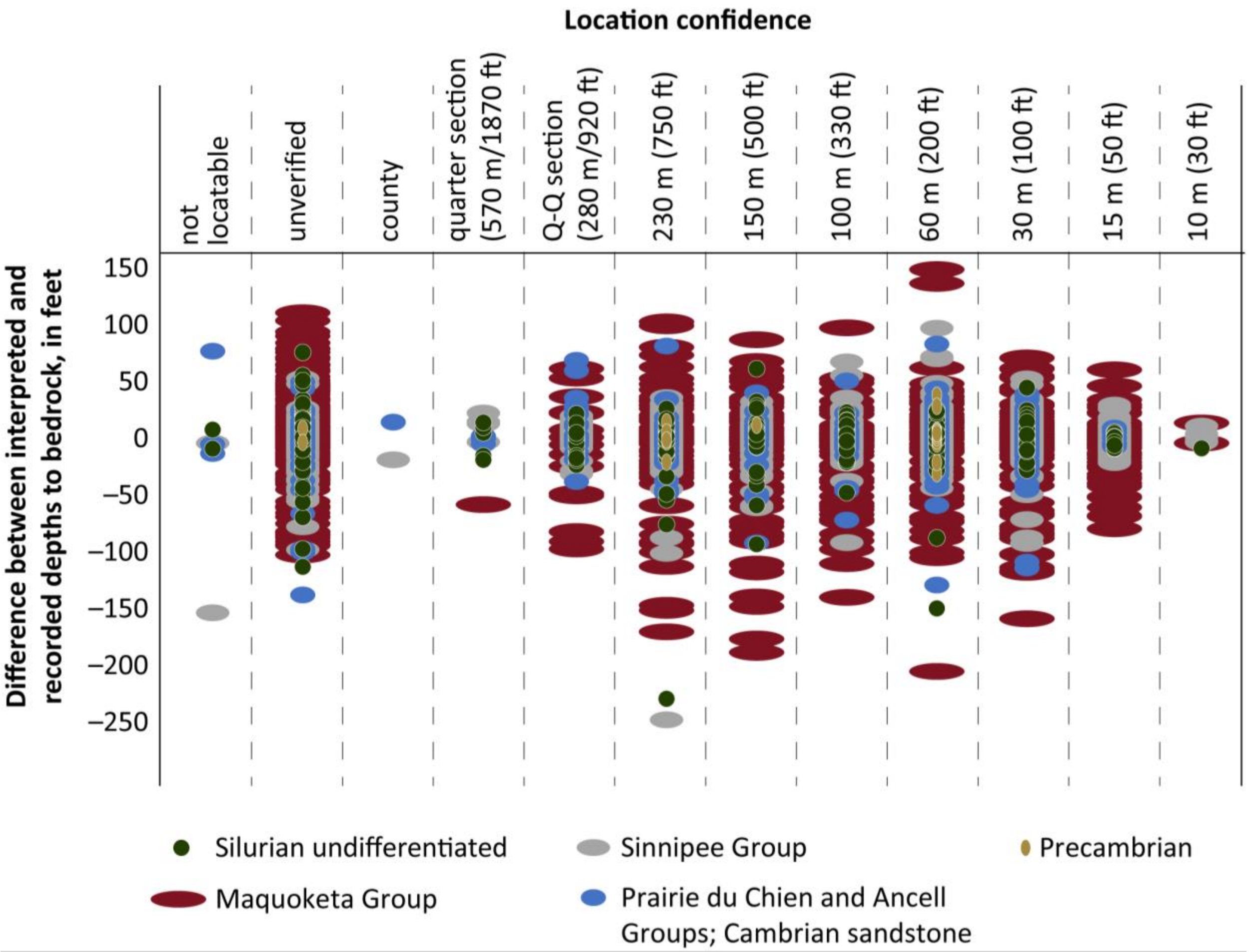

Figure 5. *This plot shows the difference between the bedrock depths sampled from the interpreted depth-to-bedrock surface and the bedrock depth recorded in all WCRs broken down by location confidence and top bedrock unit. Refer to table 1 for number of wells within each location confidence category. 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.

	Difference between recorded and interpreted depth to bedrock, in feet				
Statistical categories	**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 (25th percentile)	–2.58	–5.37	–3.21	–21.69	–5.03
Median	3.03	1.21	2.48	–0.72	1.25
Q3 (75th 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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