Wisconsin Geological
and Natural History Survey
DIVISION OF EXTENSION
UNIVERSITY OF WISCONSIN–MADISON

Supplemental report on elevation contours of the Precambrian surface of south-central Wisconsin

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Contents

Introduction

Precambrian elevation contour data and this accompanying report characterize the elevation of the top of Precambrian bedrock for part of south-central Wisconsin (fig. 1). Precambrian bedrock, sometimes called Precambrian basement, refers to the oldest (>542 million years) layers of solid rock. The Precambrian basement of southern Wisconsin is mostly buried beneath several tens to hundreds of feet of younger Paleozoic sedimentary rocks and Quaternary sediments (Smith, 1978a, b; Smith and others, 1978; Marshak and others, 2017). Within the map area, Precambrian rocks crop out in the Baraboo Hills (Columbia and Sauk Counties; Dalziel and Dott, 1970), the Waterloo area (Dodge and Jefferson Counties; Buell, 1892), and in small, geographically isolated exposures in the north-central part of the study area (Smith, 1978b). Between these geographically isolated outcrops, depth to Precambrian bedrock is known from water-well records, drill cuttings, and several drill cores, all with uneven spatial distribution (fig. 1). Regional geophysical surveys, including gravity and magnetic surveys (Daniels and Snyder, 2002; Snyder and others, 2004), provide additional information about the composition and structure of buried Precambrian rocks (e.g., Drenth and others, 2015, 2020; Ives and Mickus, 2019).

The purpose of this publication is to provide an updated map of the top Precambrian elevation surface for part of southern Wisconsin. This Precambrian elevation surface map is available as a geodatabase (dataset 1) that includes Precambrian elevation contours and faults, as well as the locations of Precambrian outcrops and wells that intersect the Precambrian surface at depth. Our objective is to provide a realistic Precambrian surface map based on geologic and geophysical data that can be incorporated into three-dimensional models of the region's subsurface geology or hydrogeology.

Geologic setting

Within the northern midcontinent of the United States, the Transcontinental Arch, Wisconsin dome, Wisconsin arch, and the Michigan Basin are regional Precambrian-basement topographic features. The Transcontinental Arch broadly trends northeast–southwest from east-central Minnesota into northwestern Iowa, extends southwest to west Texas and New Mexico (e.g., Carlson, 1999; Runkel and others, 2007), and is a composite feature that developed through reactivation of Precambrian structures (Carlson, 1999). The north–south-trending Wisconsin arch underlies the study area, and is similar to the Transcontinental Arch because it also likely developed through reactivation of Precambrian structures (Stewart, 2021). The Wisconsin dome is centered over north-central Wisconsin, and extends to the northern edge of the study area. The westernmost flank of the Michigan Basin abuts the eastern edge of the study area.

The Precambrian surface within the study area is composed of ca. 1.75 billion-year-old (Ga) post-Penokean granites, rhyolites, and diorites that are non-conformably overlain by quartzites, slates, and iron formation of the 1.71–1.47 Ga Baraboo interval (Dalziel and Dott, 1970; Smith, 1978a, b; Stewart and others, 2018; Holm and others, 2005; Medaris and others, 2021; E.K. Stewart and others, 2021). All of these rocks were folded into km-scale folds, metamorphosed,

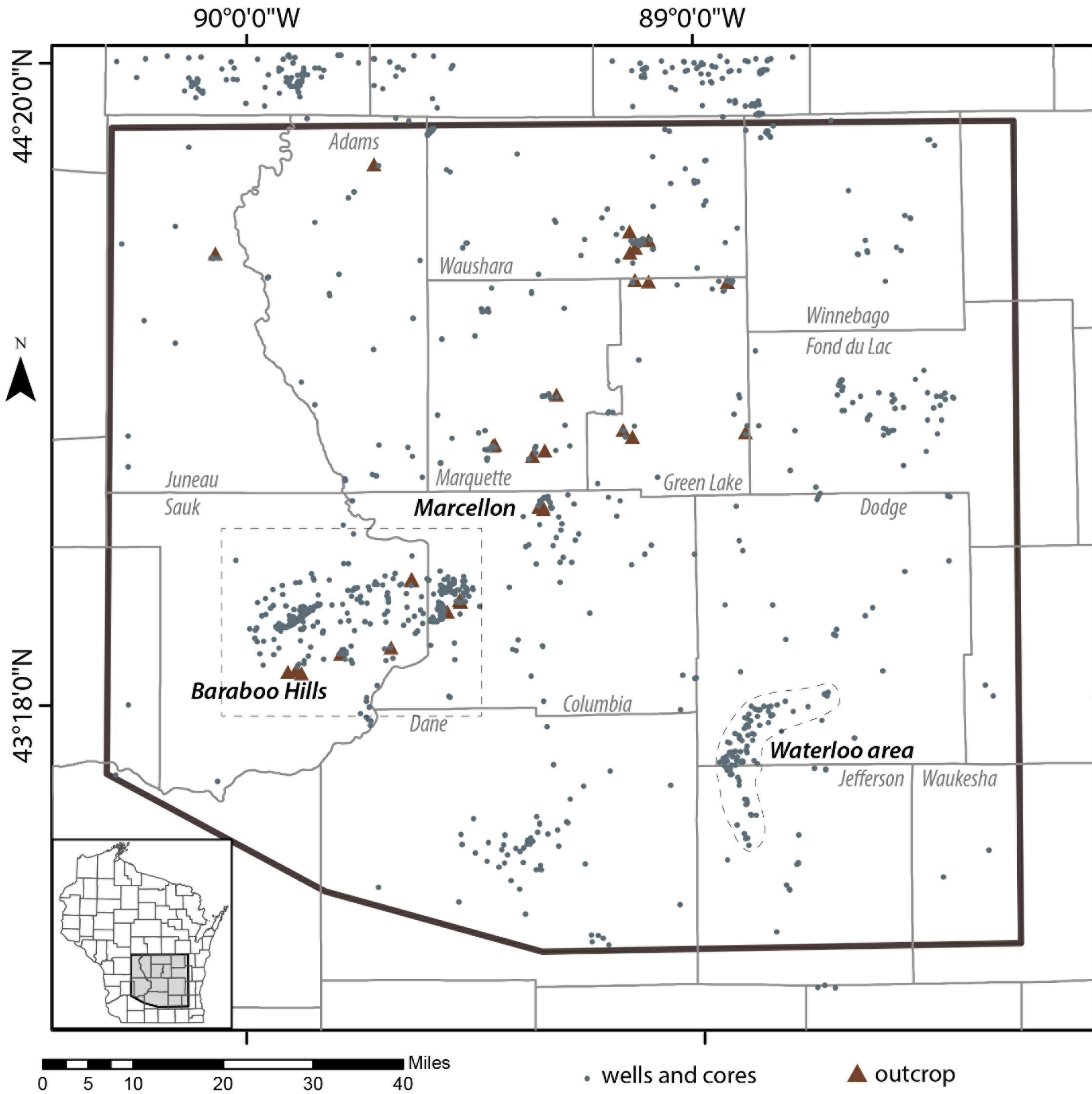

Figure 1. *Map showing distribution of wells that intersect Precambrian bedrock of any lithology, and Precambrian igneous and quartzite outcrops. The study area (thick gray line) is highlighted in gray on the inset map of Wisconsin (lower left). County boundaries are outlined in thin gray lines; county names labeled in gray, italic text. Igneous basement crops out in small, isolated locations represented as points at this scale. In contrast, most Precambrian quartzite is exposed more extensively in the Baraboo Hills and Waterloo areas except for the Necedah quartzite (Van Hise and Leith, 1911), which is found as an isolated exposure in Juneau County. The dashed box approximately locates the extent of quartzite outcrops in the Baraboo Hills. The dashed outline in the Waterloo area approximates the location of small quartzite outcrops and shallow subcrop (see Buell (1892) for more precise outcrop locations). The greater density of wells that intersect Precambrian basement north of the study area reflects relatively shallow Precambrian bedrock along the southern flank of the Wisconsin dome.*

and faulted, perhaps during the ca. 1.63 Ga Mazatzal orogenic event and/or at ca. 1.4 Ga related to emplacement of the Wolf River Batholith of the Eastern Granite-Rhyolite Province (Bickford and others, 2015; Medaris and others, 2021; E.K. Stewart and others, 2021). Baraboo interval metasediments are locally crosscut by dikes associated with the Wolf River Batholith (Kean, 1994). Mafic dikes or sills related to the ca. 1.1 Ga Midcontinent Rift may also crosscut the study area, although evidence for these is scarce (Smith, 1978a, b; Smith and others, 1978; Holm and others, 2020).

The metamorphosed, folded, and faulted Precambrian basement was eventually exhumed and exposed at the land surface sometime before deposition of the Middle Cambrian Parfreys Glen Formation conglomerate and correlative Elk Mound Group sandstone (Dalziel and Dott, 1970; Clayton and Attig, 1990; Stewart, 2021). The contact between Precambrian basement and overlying Cambrian through Ordovician sandstones and dolostones is known as the Great Unconformity, a continental-scale feature that indicates prolonged exposure, weathering, and erosion (e.g., Marshak and others, 2017). Weathering preferentially removed softer lithologies while harder rocks that were more resistant to erosion were preserved, often as topographic highs. Regional Precambrian folds and faults modified the elevation, attitude (strike and dip), and juxtaposition of Precambrian rock units with contrasting hardness; therefore, these structures also influence topography of the current Precambrian surface (e.g., see figure 5 of Stewart and others, 2018; cross-section A–A’ of Stewart, 2021). Minor reactivation of Precambrian faults before and during deposition of the overlying Paleozoic strata generated or accentuated local topography on the Precambrian surface (e.g., see cross-section A–A’ of Stewart, 2021).

Previous work

The present work builds upon previous interpretations of the Precambrian elevation surface by Smith (1978a) and Gotkowitz and others (2021). These works built on prior Precambrian surface contour maps by Thwaites (1931, 1940, 1957) and Dutton and Bradley (1970). Smith (1978a) published a page-sized (7.5 x 11 in.) figure of 100-foot elevation contours for Precambrian rocks in southern Wisconsin based on available wells and outcrops. As part of a groundwater model for Columbia County, Gotkowitz and others (2021) produced a GIS raster surface of the top of Precambrian bedrock by interpolating between Precambrian elevations recorded in wells. In addition to the work of Smith (1978a) and Gotkowitz and others (2021), Rasmussen (2021) interpreted the lithology, structure, and elevation of the Precambrian surface in southern Wisconsin using coupled aeromagnetic and gravity forward modeling. The digital Precambrian elevation contours and accompanying well and outcrop database presented herein are modified from Rasmussen (2021) to (1) more accurately portray Precambrian elevation in the Baraboo Hills area; (2) smooth the jagged appearance of hand-drawn contours throughout the study area; (3) show Precambrian structures that reactivated in the Paleozoic and revise contours near these interpreted structures; and (4) develop a consistent data format for digital contours, well, and outcrop records.

Methods

Precambrian elevation and lithology information from outcrops, well construction reports (WCRs), drill core, and geologic logs (i.e., interpretation of geologic contacts observed in well cuttings) were integrated with the Wisconsin aeromagnetic anomaly map (Daniels and Snyder, 2002; fig. 2) to create updated Precambrian surface elevation contours (fig. 3). The one-hundred-foot structure contour of the top of Precambrian basement was interpreted by hand throughout the study area.

Hand-contouring of Precambrian elevations was completed in ESRI ArcGIS after considering, and ultimately rejecting, computer-generated contours. First, outcrop and well information was compiled into a digital database. Computer gridding algorithms that incorporated only well and outcrop data suggested a qualitative correlation between trends of aeromagnetic anomalies and Precambrian elevation contours (Rasmussen, 2021), a correlation that is also supported by folds in igneous exposures that align with the trend of aeromagnetic anomalies (Smith, 1978a, b; Smith and others, 1978). Computer gridding algorithms that incorporated aeromagnetic anomalies as a guide surface were tested but rejected because there was no one-to-one relationship between the magnitude of aeromagnetic anomalies and Precambrian elevation, and the unevenness in well and outcrop density and distribution produced unrealistic contours. Geologically reasonable elevation contours were most efficiently drawn by hand by using the trends of aeromagnetic anomalies to guide the trend of Precambrian elevation contours in places with low well or outcrop density. Contours were then smoothed using a Bezier interpolation method in ArcGIS (Farin, 1997).

The interpreted Precambrian elevation surface was tested for reasonableness by comparing it to an unpublished statewide bedrock elevation surface, which is a raster surface with a 500-m grid size that represents the elevation of the top of bedrock, or solid rock. Within the south-central Wisconsin study area, the top of bedrock is usually composed of Paleozoic rock that overlies Precambrian basement. A top-of-Precambrian raster surface was generated from the Precambrian elevation contours, wells, and outcrops, then subtracted from the bedrock elevation raster to generate an isopach map with a 500-meter grid size that shows the thickness of Paleozoic bedrock above Precambrian basement. Areas that returned negative thicknesses were used to flag possible errors in the Precambrian elevation contours. Negative thicknesses reflect some combination of error in the Precambrian elevation surface and the bedrock elevation surface, and may be due to (1) human error; (2) topography on the Precambrian or bedrock surfaces that is finer than the 500-m grid size; (3) error in the computer interpolation; (4) inaccuracy in location or elevations in the well database; and/or (5) limited data. Negative thicknesses were calculated at locations in the Baraboo Hills, Waterloo area, and the northern part of the study area where Precambrian bedrock is close to land surface, and variation of the Precambrian elevation surface is at a finer scale than can be captured by available wells or outcrops. For these areas, the elevation of the top of Paleozoic bedrock recorded in WCRs was used to modify Precambrian elevation contours.

Uncertainty in the Precambrian elevation surface may be related to human error, data density, errors in well records (locations or depth to Precambrian recorded in wells), and topography on the Precambrian surface that is finer than the scale of the digital contours. The relatively large uncertainty across much of the study area is accounted for by the 100-foot contour interval. Uncertainty may be further assessed by data density: areas with sparse well or outcrop control (see fig. 1) are least certain. Finally, the relatively dense well and outcrop control in the Baraboo

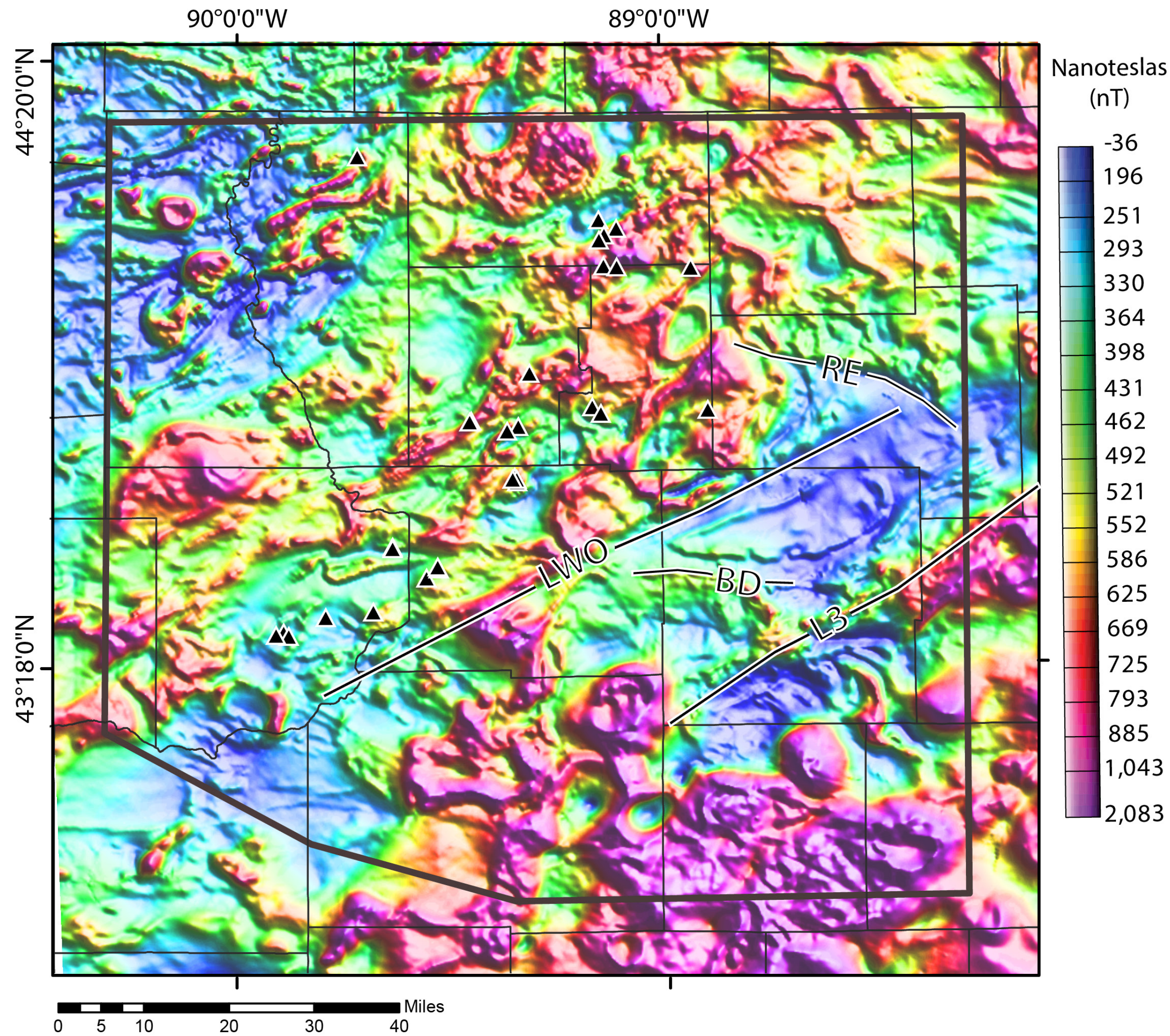

Figure 2. *Reduced-to-pole aeromagnetic anomaly map of the study area. Anomalies mentioned in the text are labeled, black lines. Several unlabeled northeast-trending anomalies subparallel to and north of the LWO anomaly tend to coincide with Precambrian igneous outcrops (triangles). BD: Beaver Dam anomaly; LWO: Lake Wisconsin-Oakfield anomaly, L3: linear anomaly 3; RE: Ripon-Empire anomaly. County outlines shown in black; refer to figure 1 for county names. Modified after Rasmussen (2021). Anomaly map courtesy of E. Anderson (USGS, unpub. data, 2018). See Daniels and Snyder (2002) and Stewart and others (2018) for a description of the aeromagnetic dataset and reduced-to-pole data manipulation.*

Hills indicates the Precambrian surface here is characterized by local, narrow valleys with >100 feet of relief that are cut into the sides of quartzite slopes. In many cases, these valleys are suggested by a single well point and too narrow to adequately characterize with the Precambrian elevation contours (dataset 1). It is possible that similar topography is present in other areas with less well and outcrop control.

Well data

Several compilations of geolocated wells that intersect Precambrian bedrock were available from the Wisconsin Geological and Natural History Survey (table 1). These data were evaluated, modified as necessary, and added to the dataset 1 geodatabase.

Table 1. Sources of Precambrian well and outcrop locations included in dataset 1

ORIGINAL DATA SOURCE	NUMBER OF RECORDS	REFERENCE
Wisconsin Department of Natural Resources digital well construction reports	485	Modified from: Wisconsin Department of Natural Resources (2020)
Wisconsin Geological and Natural History Survey (WGNHS) Geobase record	362	WGNHS unpublished database
Historic well records, Baraboo Hills	286	Stewart and others (2018)
Igneous outcrops	16	Dalziel and Dott (1970); Smith (1978b)

The well and outcrop records in table 1 were evaluated for accuracy and formatted for consistency. For each well, dataset 1 includes well location, land surface elevation, depth to Precambrian, and well name with either Wisconsin Geological and Natural History Survey (WGNHS) ID or Wisconsin Unique Well Number (WUWN). Depth to bedrock and bedrock elevation, Precambrian lithology, total well depth, and the date the well was completed are included if that information was available. Precambrian and bedrock elevation were calculated by subtracting depth to Precambrian or depth to bedrock from lidar-derived land surface elevation. Outlier Precambrian elevation values were checked against original WCRs and geologic logs. If the original well record did not record Precambrian bedrock, the outlier bedrock elevation record was removed and excluded from the interpretation of Precambrian elevation. If the original well record did record Precambrian bedrock, but the Precambrian elevation in the original record did not match the Precambrian elevation value in the database, the dataset value was adjusted to match the original record. In the Baraboo Hills area, there are several instances where two wells have overlapping location information, indicating one or both are mislocated. In cases where we were unable to verify more precise location information, we used land surface elevation and elevations of nearby wells to evaluate Precambrian elevation at these locations, and retained both wells in dataset 1.

Outcrops

Outcrop locations were digitized from geologic maps and reports including Dalziel and Dott (1970), Smith (1978a, b), Smith and others (1978), and Dutch and others (1995). Only the locations of isolated Precambrian outcrops are included in dataset 1 because these are small, distributed, and can be represented as points similar to the well data. In contrast, quartzite outcrops in the Baraboo Hills and Waterloo area are more continuous and cannot be represented as points, so are excluded from dataset 1. The reader is referred to geologic maps for polygon representations of quartzite outcrops in the Baraboo Hills (Dalziel and Dott, 1970; Clayton and Attig, 1990; Stewart and Stewart, 2020; E.D. Stewart and others, 2021; Stewart and Stewart, 2021) and near Waterloo (Buell, 1892). Bedrock elevation for outcrops and shallow subcrops of Baraboo Quartzite along the north and south ranges of the Baraboo Hills was interpreted by using land-surface elevation contours extracted from lidar as a guide. As a result, Precambrian elevation contours in these areas mimic land surface elevation and show more detail than areas with deeply buried Precambrian bedrock and sparse well control. Within the central valley of the Baraboo Hills, where Precambrian bedrock is deeply buried, Precambrian elevation was interpreted from water wells and historic mineral exploration drill records (Stewart and others, 2018). The extent of shallow subcrop associated with isolated outcrops not in the Baraboo Hills or Waterloo area was interpreted based on nearby wells, land surface geomorphology evident in lidar, and the trend of associated aeromagnetic anomalies.

Results

The top of Precambrian surface slopes gently away from the Wisconsin arch and dome, dipping to the east at ~0.5° and to the south at ~0.2° (fig. 3). Several areas of higher elevation, typically between 1400 feet to 700 feet above sea level, are superimposed on the regional dip, with adjacent Precambrian elevation lows decreasing from about 500 feet above sea level in the northwest to about 200 feet below sea level to the south.

Four faults are interpreted to offset the top Precambrian surface in Dodge and Fond du Lac Counties (fig. 3). Interpretation of these structures is based on recent bedrock mapping (Batten, 2018; Stewart, 2021) and the fact that significant aeromagnetic anomalies within the study area identified by Rasmussen (2021) coincide with breaks in the trend of Precambrian elevation contours (fig. 2). In Dodge County, the Lake Wisconsin-Oakfield (LWO) and Beaver Dam (BD) anomalies coincide with Paleozoic structures (Stewart, 2021). The South Flank fault of the Baraboo Hills (E.D. Stewart and others, 2021), together with the associated Paleozoic Denzer syncline (Clayton and Attig, 1990), are a similar structure that is not shown in this interpretation of Precambrian elevation contours because where present at land surface, erosion has smoothed any offset on the top Precambrian surface, and existing mapping and well data is insufficient to trace its subsurface extent south of the Baraboo Hills. Similar structures probably exist elsewhere within the study area but cannot be confidently identified with the available information. Below, results are organized by locations where Precambrian bedrock crops out at land surface or is present in the shallow subsurface.

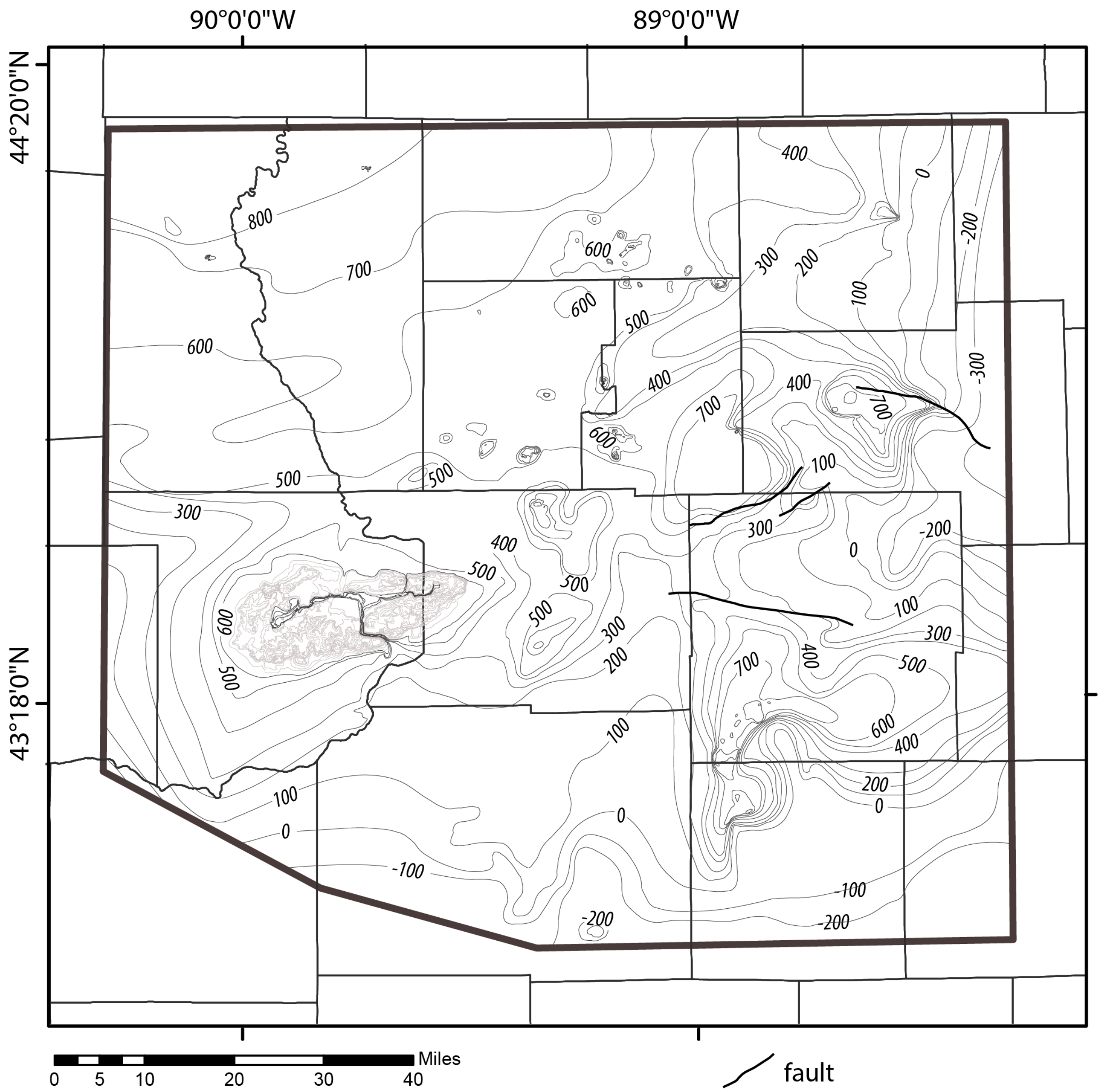

***Figure 3**. Elevation of the top of Precambrian bedrock surface given in feet relative to sea level; contour intervals = 100 ft. The Precambrian bedrock elevation of the Baraboo Hills (gray contours) is up to 1,400 ft above sea level (shown in detail in fig. 4). Counties are outlined in thinner black lines; see figure 1 for county names.*

Baraboo Hills

The north and south ranges of the Baraboo Hills represent the limbs of the east–west-trending, doubly plunging Baraboo syncline. The north and south ranges are underlain by Baraboo Quartzite, a durable rock that is resistant to erosion. Four narrow gorges cut into this quartzite: The Upper Narrows, Lower Narrows, and Narrows Creek of the north range, and the Devils Lake gorge of the south range (fig. 4). The Precambrian elevation surface indicates these gorges were part of a south-flowing, entrenched river that entered the Baraboo Hills at Narrows Creek and the Upper Narrows, and exited through the Devils Lake gorge. The Lower Narrows was a tributary that joined the main river near the city of Baraboo.

Waterloo area

The Waterloo area represents the western edge of an east–southeast-plunging syncline (Buell, 1892; Stewart, 2021). The Waterloo area is connected to Precambrian topographic highs in northern Dodge and Columbia Counties. A northwest-trending saddle extends from the northern side of the Waterloo syncline (Dodge County) northwest towards the rhyolite outcrops at Marcellon (figs. 1, 3). The saddle aligns spatially with the intersection of the BD aeromagnetic anomaly with the prominent northeast-trending LWO aeromagnetic anomaly (fig. 2; Rasmussen, 2021). The BD anomaly underlies the Beaver Dam anticline, a Paleozoic fold that likely developed along a reactivated Precambrian structure (Stewart, 2021). Rasmussen (2021) interpreted the LWO as a major structural zone that bounds distinct Precambrian terranes.

Sparse data constrain Precambrian topography in between the Baraboo Hills and the Waterloo area from southeast Columbia County to northeast Dodge County. The available well data indicate that the trend of Precambrian elevation contours in this area aligns with the northeast-trending LWO and L3 aeromagnetic anomalies (fig. 2; Rasmussen, 2021).

North-central study area

Isolated exposures of ca. 1.76 Ga granite and rhyolite are present in the north-central part of the study area and near the Baraboo Hills (fig. 1). Most outcrops are coincident with northeast-trending, linear aeromagnetic anomalies (fig. 2) that likely correspond to northeast-trending compositional bands and structures documented by Smith (1978a, b) and Smith and others (1978).

Fond du Lac County

Well data from central Fond du Lac County indicates quartzite and granitic rocks underlie a northwest–southeast to east–west-trending Precambrian topographic high with elevations between 300 feet to 500 feet above sea level. This Precambrian topographic ridge aligns with the Ripon-Empire aeromagnetic anomaly (RE; fig. 2), which intersects the LWO anomaly at a high angle (Rasmussen, 2021).

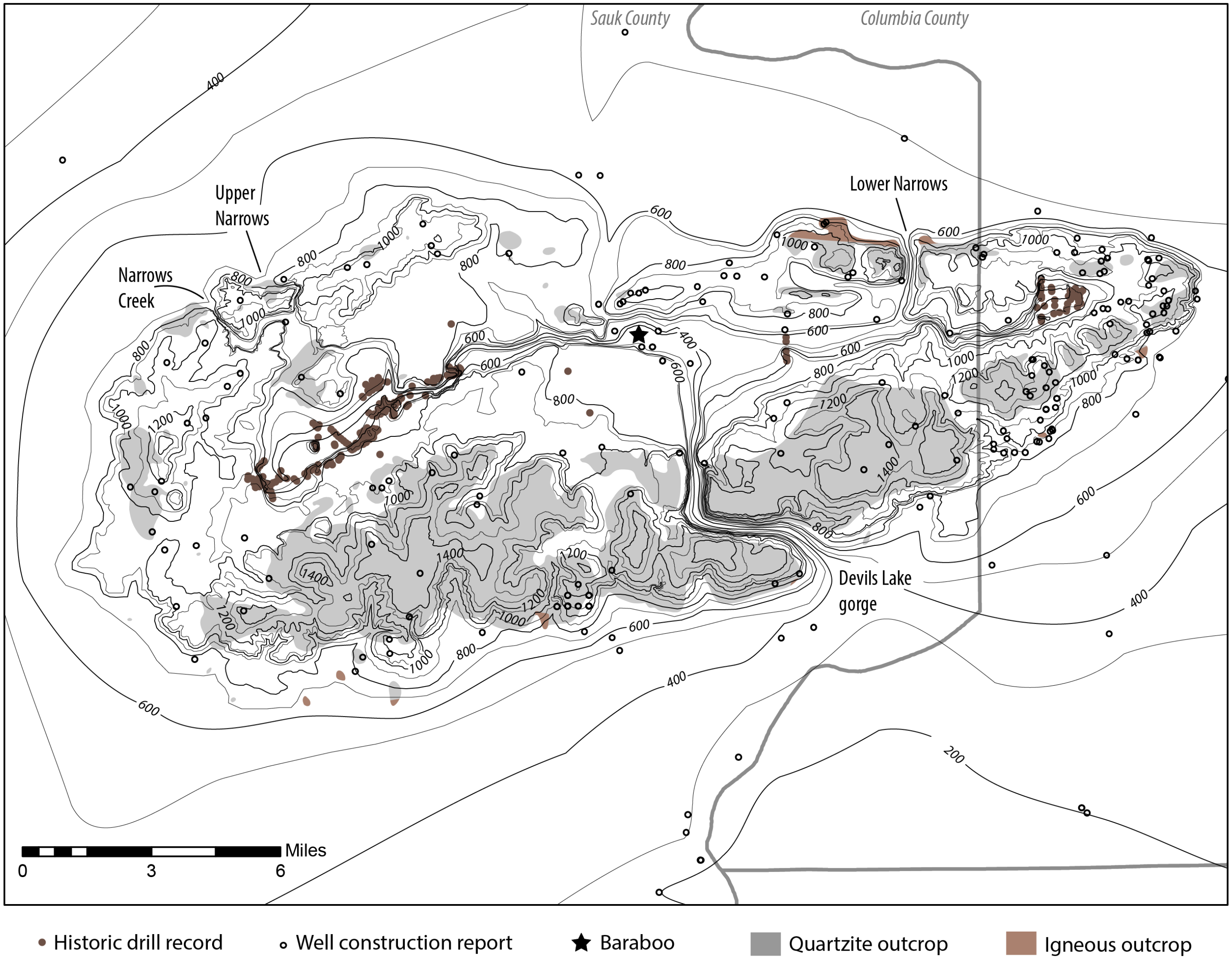

Figure 4. *Elevation of the top of Precambrian bedrock surface, Baraboo Hills. Contour interval = 100 ft. See dashed box in figure 1 for location of figure 4 within the context of the broader study area.*

Summary

The digital contour map provides an updated interpretation of the elevation of the top of Precambrian bedrock for part of south-central Wisconsin. It builds on previous work by incorporating recent well records and observations of aeromagnetic anomaly trends. Within the south-central Wisconsin study area, the top Precambrian surface slopes gently to the east and south, away from the Wisconsin arch and dome. Several areas of elevated Precambrian bedrock are superimposed on this regional dip, including the Baraboo Hills, Waterloo area, and igneous outcrops in the north-central part of the study area. The updated Precambrian elevation surface provides new detail on the entrenched bedrock valleys that were incised into the north and south ranges of the Baraboo Hills. It also documents a link between the distribution of Precambrian highs and Precambrian structures (e.g., Smith, 1978b; Stewart and others, 2018; Rasmussen, 2021; Stewart, 2021).

Data contents

The data and accompanying materials for this publication are available for download from the WGNHS Publication Catalog at: https://doi.org/10.48358/ojde4819.

Dataset 1: Elevation contours of the Precambrian surface of south-central Wisconsin
A file geodatabase (.gdb format) that includes Precambrian elevation contours, reactivated Precambrian faults, wells that intersect Precambrian rocks, historic drill records, and Precambrian outcrops.

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Peter Schoephoester assisted with data checks and compilation. This report was funded in part by the State of Wisconsin Groundwater Research and Monitoring Program through the University of Wisconsin Water Resources Institute under award number WR17R003, 2018, and the USGS National Cooperative Geologic Mapping Program under Statemap award number G19AS00006, 2019. The Wisconsin Geological and Natural History Survey provided additional support.

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