Wisconsin Geological
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DIVISION OF EXTENSION
UNIVERSITY OF WISCONSIN–MADISON

Supplemental report on the geologic map of the Castle Rock and Long Hollow 7.5-minute quadrangles, Grant County, Wisconsin

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Sources and Methods

Outcrop observations, groundwater well construction reports, and a digital-elevation model (DEM) derived from light detection and ranging (lidar) data were used to create the map plate and 3D raster sets. All datasets and rasters are available in the supplemental geographic information system (GIS) materials (dataset 1). Standard field methods using a Brunton compass and a global positioning system (GPS) were used to record orientation and location information at outcrops. Each well construction report included a lithologic log that was used to interpret subsurface geologic contacts. Well construction reports typically provide addresses (personally identifiable information has been removed) and locations accurate to the quarter-quarter section. Each well construction report was located to the correct land parcel before their lithologic logs were interpreted. Location confidence estimates are provided for each well construction report in the online supplemental files. Well construction reports were edited for accuracy, and only reports used in the interpretation are included in the supplemental materials. The map-unit contacts for Quaternary units and some bedrock units were delineated by interpreting a 5-ft lidar-derived DEM (Natural Resources Conservation Service personal commun., 2012).

The GIS files in dataset 1 contain 3D rasters of geologic unit contacts that were generated as a tool for individuals interested in using the map for applied geology studies that require 3D surfaces. The rasters were created by converting unit contacts that were drawn on the map as polylines in ArcMap (Esri, Redlands, California) to points, then deriving the elevation from the DEM for each point. These map elevations were then combined with the subsurface-unit contact elevations from well construction reports to create unit-contact rasters in ArcMap using its “Topo to Raster” tool.

Previous work in the area includes regional mapping by Strong (1876) at a scale of 1:200,000 (1 inch equals 3 miles) and Deal (1947), who mapped the Boscobel 15-minute quadrangle at a scale of 1:40,000. The Boscobel 15-minute quadrangle includes the Castle Rock 7.5-minute quadrangle but not the Long Hollow 7.5-minute quadrangle. None of these maps were completed at 1:24,000 scale or included 3D interpretations beyond their accompanying cross sections.

Structure

In southwestern Wisconsin, gentle folds in bedrock are associated with consistently oriented fracture sets; in some cases, the folds are cored by small faults (Heyl and others, 1959). While faults have complex relationships with permeability (Bense and others, 2013), fractures generally increase local permeability of a rock unit, often anisotropically. The orientation, heterogeneity, and density of fractures can also influence the flow paths of groundwater and contaminants (Bradbury and Muldoon, 1994). Folds and fractures in the Castle Rock and Long Hollow quadrangles are discussed below.

Folds

Cambrian and Early Ordovician rocks in the Castle Rock and Long Hollow quadrangles were deformed into a series of northwest-trending, gently folded anticlines and synclines with up to around 120 ft of structural relief (fig. 1A). Folds were interpreted from structure-contour maps (figs. 1A, 2A) generated from surface mapping and correlating lithologic logs in groundwater-well construction reports (figs. 1B, 2B).

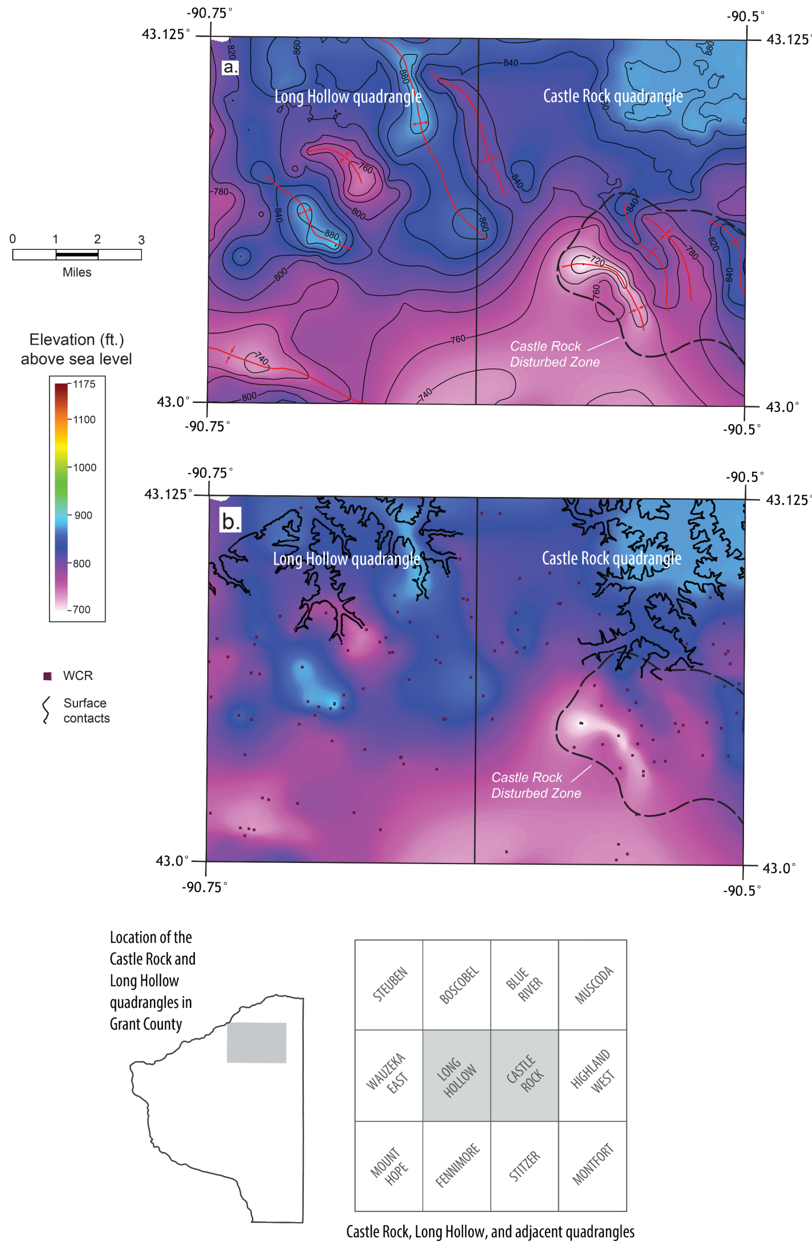

***Figure 1. A**, Structure-contour map for the base of the Prairie du Chien Group. Measurements are in feet above sea level; structure-contour interval is 20 ft. The color ramp is the same as for figure 2. Thin red lines show the interpreted folds and the dashed line outlines the Castle Rock Disturbed Zone. **B**, Sources used to construct the structure-contour map include surface mapping and 123 well construction reports.*

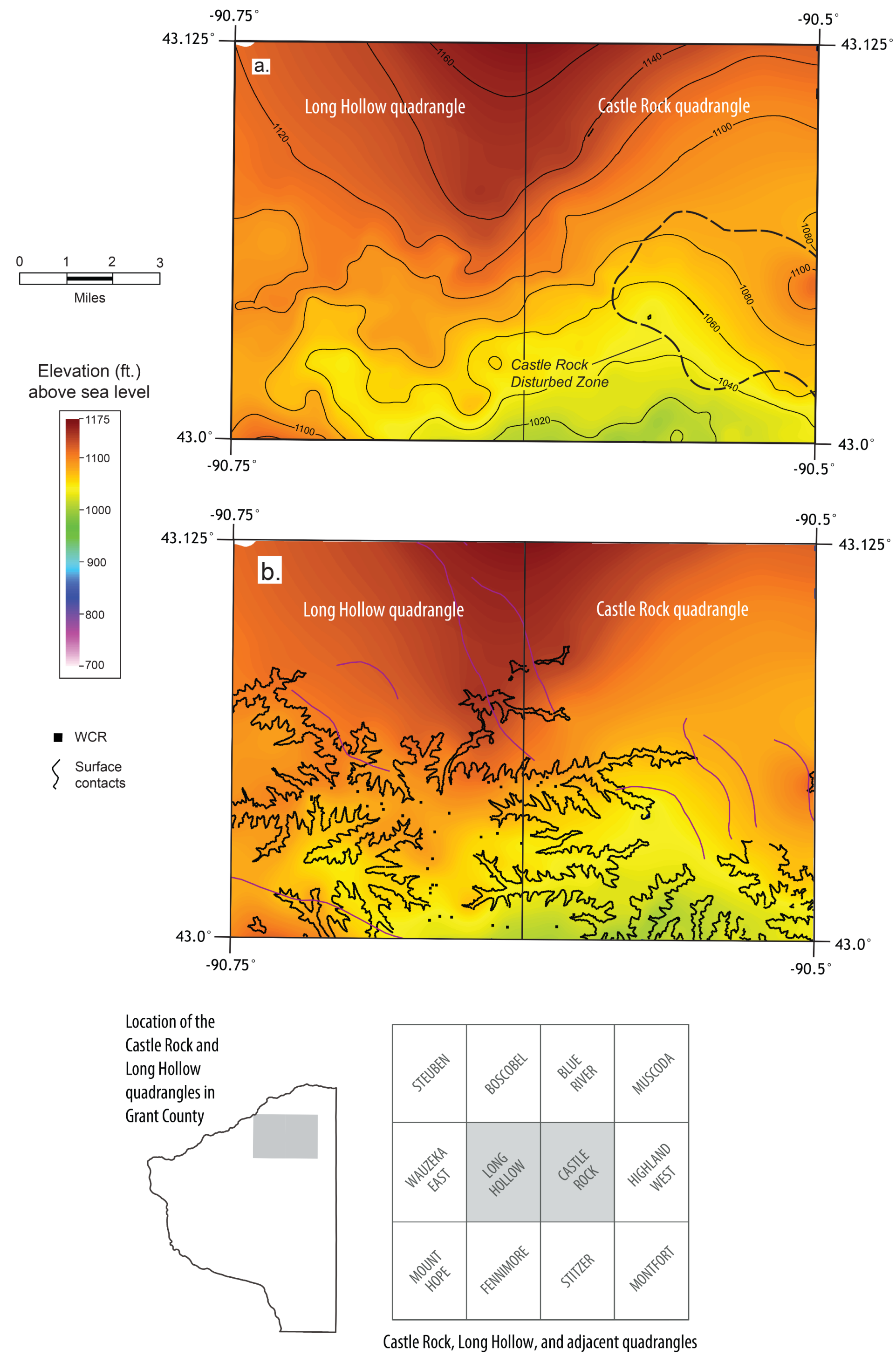

***Figure 2. A**, Structure-contour map for the base of the Platteville Formation. Measurements are in feet above sea level; structure-contour interval is 20 ft. The color ramp is the same as for figure 1. The dashed line outlines the Castle Rock Disturbed Zone. **B**, Sources used to construct the structure-contour map, including surface mapping and 44 well construction reports. Locations of interpreted folds (thin purple lines) from the base of the Prairie du Chien Group (see figure 1A) are shown for reference.*

Bedrock folding probably occurred in the Early or Middle Ordovician, but the exact timing is unclear. Ludvigson and McAdams (1980) interpreted a regional deformation event during deposition of the Early Ordovician Prairie du Chien Group. Locally, most deformation probably ended sometime in the Middle Ordovician because the base of the Platteville Formation shows little evidence of significant folding in the Castle Rock and Long Hollow quadrangles (fig. 2A). Many other studies have identified a similar Ordovician age for tectonic deformation in the region (Mossler, 2006; Steenberg and Retzler, 2016; Stewart and Stewart, 2020; Stewart, 2021). Immediately to the south in the Stitzer and Montfort quadrangles, however, the Platteville Formation is folded and faulted (Heyl and others, 1959; Carlson, 1961), indicating a later regional deformation event. Fracturing and deformation in the St. Peter Formation in the Castle Rock area (see below) and minor undulations in the basal Platteville surface (fig. 2A) suggest some amount of deformation may have postdated the Prairie du Chien in the map area, but the amount and timing of deformation is unclear.

Castle Rock Disturbed Zone

The Castle Rock Disturbed Zone is defined as the region in the southeastern portion of the Castle Rock quadrangle that contains several northwest-trending gentle anticlines and synclines with amplitudes of approximately 100 ft (fig. 1A) within the Prairie du Chien Group and underlying strata. Bedding dips up to 25 degrees within the Castle Rock Disturbed Zone. On an equal-area stereographic projection, the attitudes of poles to bedding planes produce a poorly defined great circle (fig. 3). Despite the scatter in the data, the cylindrical best fit to the pole data produces an inferred hinge plunging 5° degrees at N. 17° W. This inferred hinge orientation is similar to mapped fold axes in the area (fig. 1A), which suggests much of the tilting is related to tectonic activity rather than karstification, syndepositional seismicity with accompanying liquifaction, or subsidence, which have been noted elsewhere in the upper Midwest (for example, Dalziel and Dott, 1970).

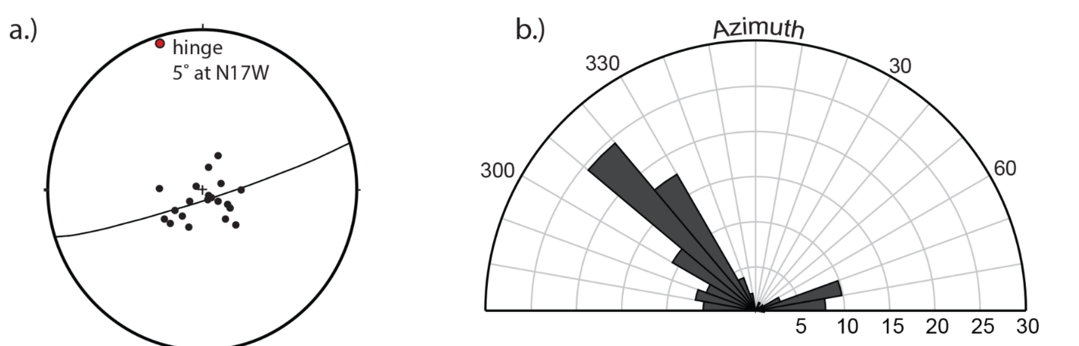

Figure 3. A, *Equal-area stereographic projection of poles to bedding and inferred hinge orientation from the Castle Rock Disturbed Zone (n = 20).* ***B****, Half-circle rose diagram showing number and orientation of dominantly vertical fractures in the St. Peter Formation at Castle Rock plotted in 10° bins. Rose diagrams are similar to histograms, except the bins are arranged according to fracture orientation in space. North is vertical and the east-to-west axis is horizontal (n = 103).*

Joints

The Castle Rock and Long Hollow quadrangles contain dominant northwest- and northeast-striking, vertical to subvertical joints (fig. 4). The joints plotted on figure 4 for all geologic units reflect the dominant joint orientation(s) recorded at outcrops across the two quadrangles. The northwest-striking joints roughly parallel the trend of mapped folds, and the northeast-striking joints are roughly perpendicular to folds. Detailed fracture measurements at individual outcrops show similar patterns. Fractures measured (n = 103) on a cliff face of the St. Peter Formation at Castle Rock in the Castle Rock Disturbed Zone show one dominant population of northwest-striking joints roughly parallel to local folds and a second subordinate population of northeast-striking joints roughly perpendicular to folds (fig. 3B). Several prior studies of the Middle Ordovician Galena Formation found similar relations between folds and fractures (Grant, 1906; Bain, 1906).

Joints striking parallel to fold axes are often interpreted to reflect stretching focused near folds, but stretching is unlikely to be the cause of fold-parallel joints in the map area. Joints accommodate stretching perpendicular to the plane of the joint, so joints striking parallel to folds are unusual because they indicate stretching in the same direction that the rock is being shortened to produce the fold. This type of stretching can occur because the maximum principal strain axis of the strain ellipse (representing the maximum stretching direction in the rock) can confusingly parallel the regional shortening direction on the convex (outer) portion of a fold (Ramsay, 1967). The maximum stretching direction parallels the regional shortening direction as a result of increasing curvature along the folded surface. Under the conditions found in the upper part of the Earth's crust, this strain is often accommodated by the development of vertical joints that strike parallel to fold axes. This relatively common but counterintuitive phenomenon is probably not the cause of northwest-striking joints in the map area because northwest-striking joints are not restricted to areas near mapped fold axes but are common everywhere (fig. 5). These relations suggests that the northwest-striking fractures did not form from folding and buckling, but instead are related to regional stresses.

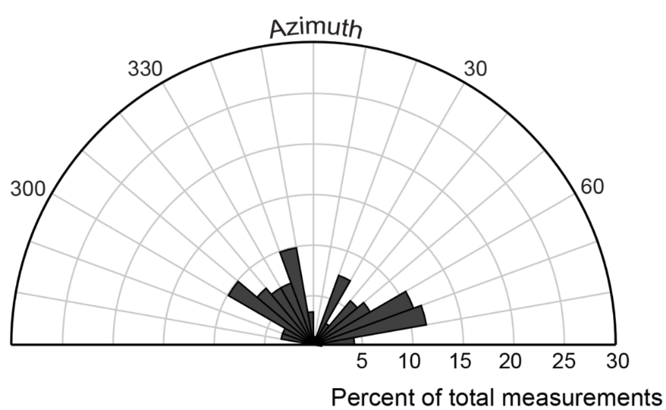

Figure 4. *Half-circle rose diagram showing dominant fracture orientation(s) at outcrops for steeply dipping fractures measured in all units across the map area (n = 123).*

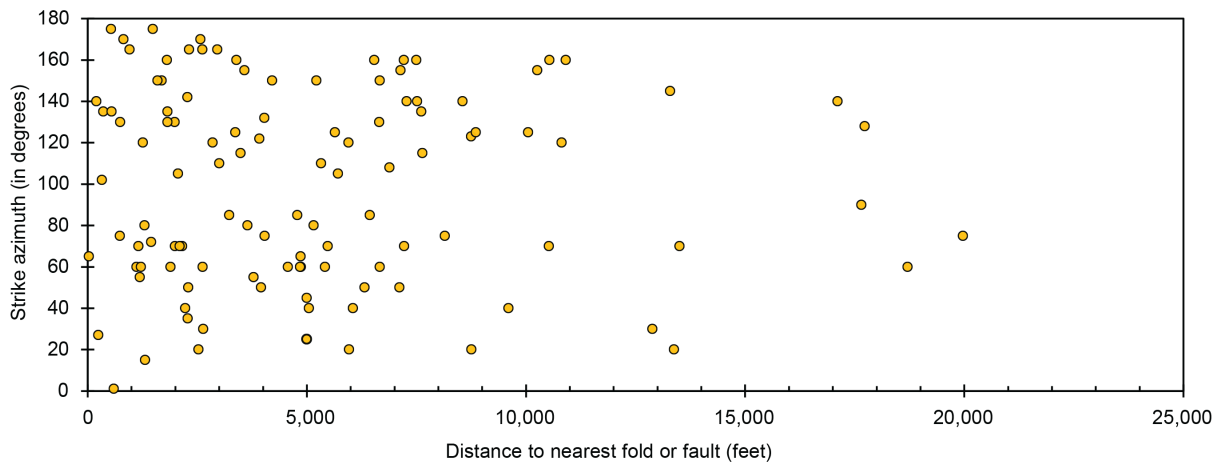

Figure 5. *Joint strike direction (azimuth) versus distance to nearest fold axis or fault. Values above 90° are in the northwestern quadrant of figure 4, and values below 90° are in the northeastern quadrant of figure 4. Northwest-striking fractures are not focused near folds but are pervasive across the map area.*

Fracture density, however, shows a weak relation to the distance to mapped fold axes (fig. 6). Fracture density was estimated in the St. Peter Formation and the Prairie du Chien Group by calculating the number of fractures intersected along a bedding-parallel transect normalized per foot. Within 1.25 miles of folds, fracture density is often heterogeneous. In these areas, relatively narrow (<1 ft wide) fracture networks display high fracture densities (>12 fractures per foot). These fracture networks cut through stratigraphic bed sets and are surrounded by wall rock that has a lower fracture density. In such cases, the high- and low-fracture-density areas were separately measured and plotted on figure 6.

Supplemental Material

This report is a supplement to the map "Geologic map of the Castle Rock and Long Hollow 7.5-minute quadrangles, Grant County, Wisconsin." This report, the map, and a supplemental GIS database (dataset 1) are available for download from the Wisconsin Geological and Natural History Survey Publication Catalog (https://doi.org/10.54915/qfnf9732).

Dataset 1: GIS data for the geologic map of the Castle Rock and Long Hollow 7.5-minute quadrangles, Grant County, Wisconsin

Includes one raster dataset each of the bases of the Prairie du Chien Group, Ancell Group, Platteville Group, Decorah Formation, and Galena Formation. Also includes vector layers for unit contacts, polygons of map units, field data, and well construction report locations and interpreted contact depths. Data are in file geodatabase (.gdb) format.

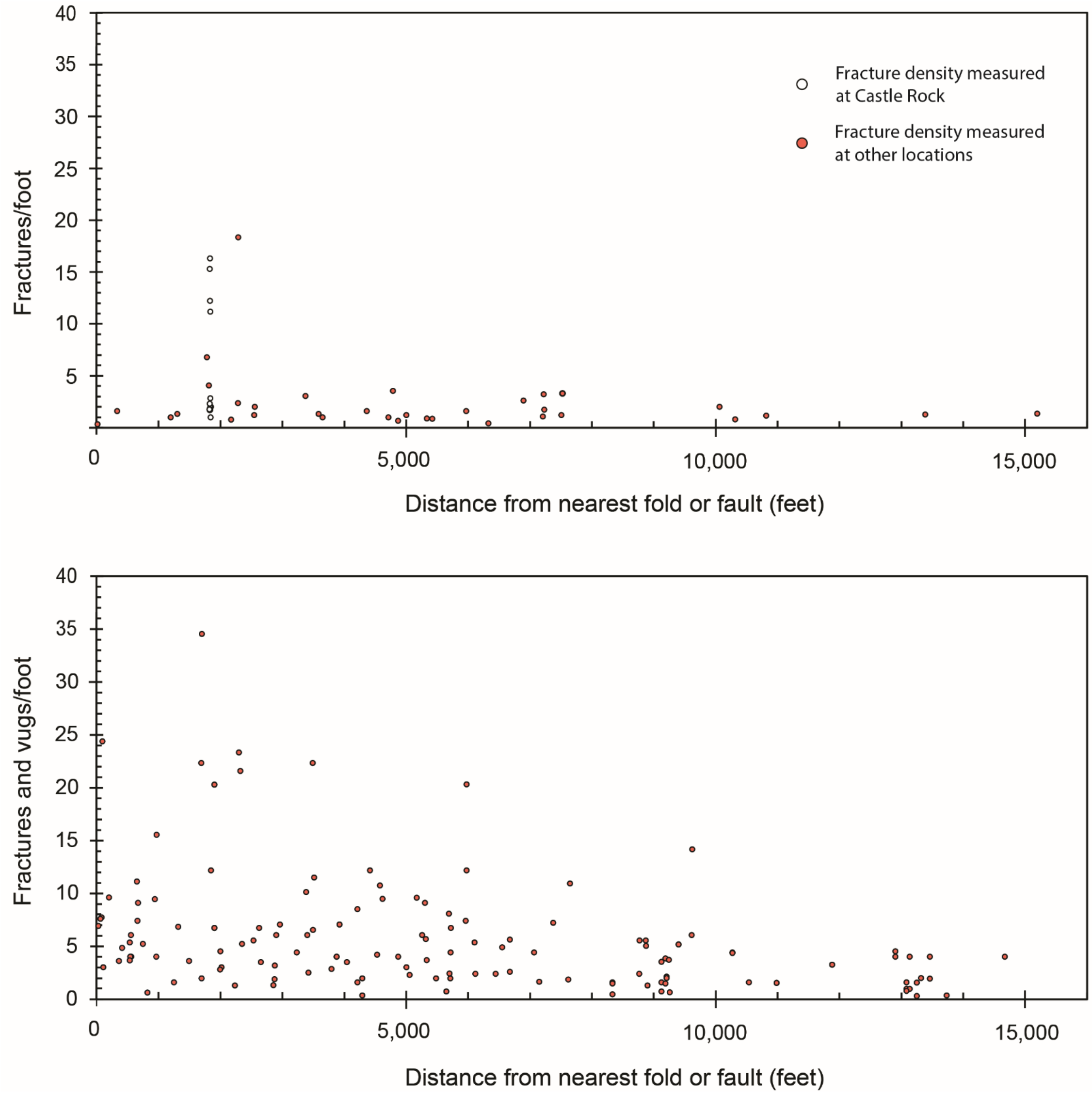

***Figure 6. A**, Fracture density measured in the St. Peter Formation versus distance to nearest fold axis or fault. **B**, Fracture and vug density (secondary porosity) measured in the Prairie du Chien Group versus distance to nearest fold axis or fault.*

References

Bain, H.F., 1906, Zinc and lead deposits of the upper Mississippi Valley: U.S. Geological Survey Bulletin 294, 148 p, https://doi.org/10.3133/b294.

Bense, V.F., Gleeson, T., Loveless, S.E., Bour, O., and Scibek, J., 2013, Fault zone hydrogeology: Earth-Science Reviews, v. 127, p. 171–192, https://doi.org/10.1016/j.earscirev.2013.09.008.

Bradbury, K.R., and Muldoon, M.A., 1994, Effects of fracture density and anisotropy on delineation of wellhead protection areas in fractured-rock aquifers: Journal of Applied Hydrogeology, v. 2, p. 17-23, https://doi.org/10.1007/s100400050034.

Carlson, J.E., 1961, Geology of the Montfort and Linden Quadrangles, Wisconsin, *in* Geology of parts of the Upper Mississippi Valley zinc-lead district: U.S. Geological Survey Bulletin 1123–B, p. 95–138, 2 pls., scale 1:24,000, https://doi.org/10.3133/b1123B.

Dalziel, I.W.D., and Dott, R.H., Jr., 1970, Geology of the Baraboo district, Wisconsin—A description and field guide incorporating structural analysis of the Precambrian rocks and sedimentologic studies of the Paleozoic strata: Wisconsin Geological and Natural History Survey Information Circular Number 14, 164 p., 6 pls., https://wgnhs.wisc.edu/catalog/publication/000264.

Deal, C.S., 1947, The areal geology and stratigraphy of the Boscobel quadrangle, Wisconsin: Madison, University of Wisconsin–Madison, unpublished M.S. thesis, 55 p.

Grant, U.S., 1906, Report on the lead and zinc deposits of Wisconsin, with an atlas of detailed maps: Wisconsin Geological and Natural History Survey Bulletin 14, 100 p., 26 pls., https://wgnhs.wisc.edu/catalog/publication/000014.

Heyl, A.V., Jr., Agnew, A.F., Lyons, E.J., Behre, C.H., Jr., and Flint, A.E., 1959, The geology of the Upper Mississippi Valley zinc-lead district: U.S. Geological Survey Professional Paper 309, 310 p., 24 pls., https://doi.org/10.3133/pp309.

Ludvigson, G.A., and McAdams, M.P., 1980, New evidence of Early Ordovician tectonism in the Upper Mississippi Valley: Iowa Geological Survey Technical Information Series 9, 29 p., http://publications.iowa.gov/id/eprint/26459.

Mossler, J.H., 2006, Bedrock Geology of the Prescott quadrangle, Washington and Dakota counties, Minnesota: Minnesota Geological Survey Miscellaneous Map Series M–167, scale 1:24,000, https://conservancy.umn.edu/handle/11299/58164.

Ramsay, J.G., 1967, Folding and fracturing of rocks: New York, McGraw-Hill, 568 p.

Steenberg, J.R., and Retzler, A.J., 2016, Bedrock geology, plate 2 *of* Geologic atlas of Washington County: Minnesota Geological Survey County Atlas Series C–39, Part A, scale 1:100,000, https://hdl.handle.net/11299/178852.

Stewart, E.D., and Stewart, E.K., 2020, Geologic map of the North Freedom 7.5-minute quadrangle, Sauk County, Wisconsin: Wisconsin Geological and Natural History Survey Map Series M–506, scale 1:24,000, https://wgnhs.wisc.edu/catalog/publication/000973/resource/m506.

Stewart, E.K., 2021, Bedrock geology of Dodge County, Wisconsin: Wisconsin Geological and Natural History Survey Map Series M–508, scale 1:100,000, https://wgnhs.wisc.edu/catalog/publication/000975/resource/m508.

Strong, M., 1876, Grant and parts of Lafayette, Iowa, Richland, and Crawford Counties, plate 16 *of* Atlas of the Geological Survey of Wisconsin: Madison, Wisconsin, scale 1:200,000, https://wgnhs.wisc.edu/catalog/publication/000214/resource/gatlasplate16.