Evidence for Early Ordovician reactivation of Mesoproterozoic rift structures within the Prairie du Chien Group: Washington County, Minnesota

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1. ABSTRACT

Recent mapping of Paleozoic bedrock in Washington County, MN, as part of the Minnesota Geological Survey County Geologic Atlas program, better constrains the timing and magnitude of reactivated Mesoproterozoic Midcontinent Rift System (MRS) faults, possibly as part of a regional-scale change in structural configurations that impacted Ordovician depositional patterns. Structure in the Paleozoic bedrock was mapped using the stratigraphic top of the Jordan Sandstone (Upper Cambrian). The structural top of the Jordan was constructed from drill hole and outcrop data. The most prominent feature is a structural high in southern Washington County accommodated along faults with displacements from 25 to 300 feet. Aeromagnetic and gravity data show that this feature directly overlies a thick sequence of uplifted MRS basalts known as the Hudson-Afton Horst. Digital elevation models and isopachs of Paleozoic units reveal significant thickness changes across the horst within the carbonate formations of the Early Ordovician Prairie du Chien Group, suggesting syndepositional reactivation of faults. The Prairie du Chien is much thinner atop the horst (<50 ft) relative to the grabens on either side (~150-250 ft). Much of the thinning is accounted for within the Shakopee Formation (upper Prairie du Chien), as it is nearly absent in areas atop the horst and thickens to over a hundred feet along either side. Folded and brecciated beds in outcrops of the Shakopee are another probable indicator of syndepositional reactivation. Reactivation of the Hudson-Afton Horst may be part of the same structural event triggering the earliest development of the nearby Twin Cities basin (TCB) to the west. The TCB has previously been suggested to have formed via isostatic and/or thermal adjustments accommodated by MRS structures during Middle to at least Late Ordovician time. Several other midcontinent basins and highs (i.e., Michigan Basin, Wisconsin Arch, Hollandale Embayment, etc.) were active roughly contemporaneously and possibly in response to far-field stresses generated during orogenic activity along present-day eastern North America. The reactivation of the horst structure and/or the development of the TCB may also be an early manifestation of these orogenic far-field stresses.

2. BACKGROUND

• The bedrock geology of Washington County is composed of widespread layers of sandstone, shale, and carbonate deposited in shallow seas during the Cambrian and Ordovician Periods of the Paleozoic Era, from about 500 to 450 million years ago (Fig. 1).

• The Paleozoic rocks lie on top of a thick sequence of Mesoproterozoic rocks of the Keweenawan Supergroup, associated with the Midcontinent Rift.

• An array of different data sources were used to produce the Washington County bedrock geologic map and associated products, including: nearly 14,000 water-well and scientific drilling records from Minnesota's County Well Index (CWI), outcrops, bedrock core, drill cutting samples, borehole geophysical logs, seismic soundings, geophysical imagery, and previously published geologic maps.

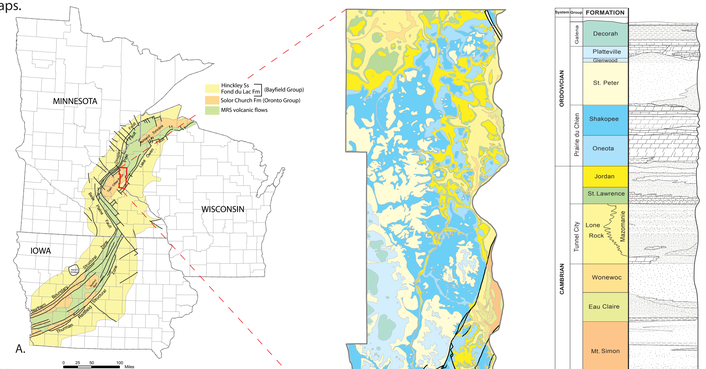


FIGURE 1.
A) Extent of Midcontinent Rift rocks in Minnesota, Iowa, and Wisconsin, showing distribution of principal stratigraphic units, and structural features (Chandler et al., 1989). B) Washington County bedrock geologic map showing the distribution of uppermost bedrock units and faults (Steenberg and Retzler, 2015). C) Generalized stratigraphic column depicting the bedrock units and their lithology in Washington County, MN.

3. PALEOZOIC STRUCTURE

• Structure of the Paleozoic bedrock was mapped using the stratigraphic top of the Jordan Sandstone at 25-foot (15 meter) intervals (Fig. 2A).

• The top of the Jordan Sandstone was selected to portray these structures because it is a well-recognized and distinct contact, has numerous control points including outcrops that expose the contact, and has water wells that penetrate it (Fig. 2B).

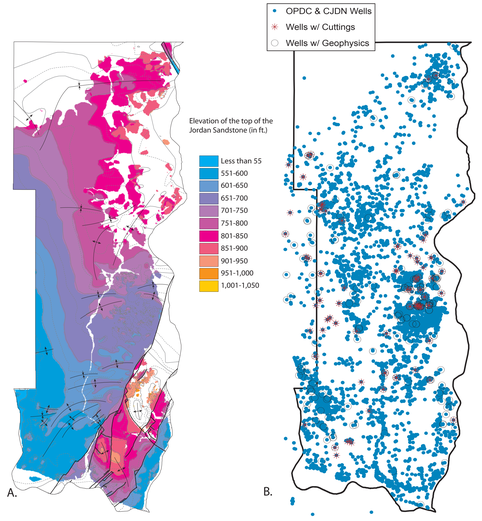


FIGURE 2.
A) Shaded elevation map of the stratigraphic top of the Jordan Sandstone and mapped faults (thick black lines), fold axes (thin black lines) and contour lines (light gray and dashed for 25 ft intervals). B) Map showing the data distribution for the construction of the Jordan Sandstone elevation map (OPDC- Ordovician Prairie du Chien Group; CJDN- Cambrian Jordan Sandstone).

• Several of the faults in Paleozoic strata are subparallel to faults in the underlying Mesoproterozoic Midcontinent Rift rocks, as inferred from geophysical imagery, and are therefore interpreted to represent reactivation of these older structures (Fig. 3).

• The aeromagnetic data show where a great thickness of magnetic Mesoproterozoic rift basalts (unit Mpv) have been brought near the surface in an inverted graben known as the Hudson–Afton Horst, bounded by thrust faults (Sims and Zeitz, 1967; Cannon et al., 2001).

• Paleozoic rocks overlying the Hudson–Afton Horst in Washington County are also uplifted relative to the rocks on either side, although the displacement is of a lesser magnitude than in the underlying Mesoproterozoic bedrock (see Figure 5).

• Overall, the Paleozoic bedrock units are slightly tilted (less than 1°) southwest towards the central Twin Cities metropolitan area, as part of the eastern margin of a shallow structural depression known as the Twin Cities basin.

• This general trend is interrupted by faults and folds in the northeastern and southeastern part of the county. Displacement along faults is on the order of 25 to 300 feet (8 to 91 meters).

FIGURE 3.
Faults (red lines) and folds (red dashed lines) that displace Paleozoic bedrock superimposed on the first vertical derivative aeromagnetic data (Chandler, 1991) and the underlying Mesoproterozoic rock units (Jirsa et al., 2012)
(HAH- Hudson-Afton Horst; CFF- Cottage Grove Fault; CGFZ- Cottage Grove Fault Zone; HF- Hastings Fault; HFZ- Hastings Fault Zone; FCG- Falls Creek Graben; Mss- Midcontinent Rift sandstones; Mpv- Powder Mill Volcanics; Mbv- North Branch Volcanics).

4. THICKNESS TRENDS

• The Jordan Sandstone ranges from about 80-100 feet thick throughout Washington County. It appears to thin to about 65-70 feet in the northernmost part of the county near Scandia (Fig. 4A).

• There is little to no change in the thickness of the Jordan Sandstone, nor in the underlying Paleozoic formations, across the southeastern faulted region of the Hudson-Afton Horst.

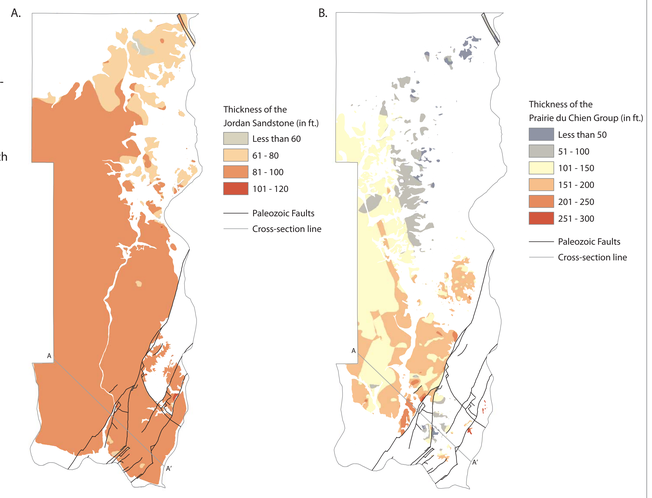
• In contrast, the thickness of the Prairie du Chien Group is more variable across Washington County, ranging from less than 50 to nearly 300 feet thick (Fig. 4B).

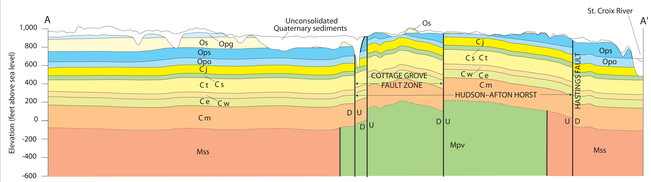
• Some thickness variation is expected because the boundary between the Prairie du Chien Group and the overlying St. Peter Sandstone is erosional; however, the variation documented in Washington County is unusually high.

• The thickness trends also correspond to the interpreted Paleozoic faults, suggesting syndepositional reactivation during Early to Middle Ordovician time.

• The Prairie du Chien is much thinner atop the horst (<50 ft) relative to the grabens on either side (~150-250 ft). Much of the thinning is accounted for within the Shakopee Formation (upper Prairie du Chien), as it is nearly absent in areas atop the horst and thickens to over a hundred feet along either side (see Figure 5). However, smaller scale thickness changes on the order of ~40-50 ft within the Oneota Dolomite have also been documented in cuttings sets and gamma logs across the structure.

FIGURE 4. »
A) Color shaded map indicating the thickness of the Jordan Sandstone where it lies beneath the Prairie du Chien Group.
B) Color shaded map indicating the thickness of the Prairie du Chien Group where it lies beneath the St. Peter Sandstone.





« FIGURE 5.
Cross-section across southern Washington County showing the bedrock units, their thicknesses and their displacement along the faults within the Hudson-Afton Horst (see Figure 4 for map view of transect).

5. DISCUSSION

• Extensive Prairie du Chien exposures near Washington County are rare and limited to quarries. However, some exposures show signs of bed-thickening and/or brecciation suggestive of syndepositional deformation not attributable to carbonate build-ups (Fig. 6).

• Folding and truncation within the Prairie du Chien has been previously documented in Wisconsin and Iowa by Ludvigson and McAdams (1980). Although, their folding is evident within the older Oneota Formation and not the Shakopee. They argued that the E-W trending pre-Shakopee folds were tectonic in origin.

• Reactivation of the Hudson-Afton Horst may be related to the structural event triggering the earliest development of the nearby Twin Cities basin (TCB) to the west, previously suggested to have formed via isostatic and/or thermal adjustments accommodated by MRS structures prior to or during deposition of the Prairie du Chien (Austin, 1972; Mossler, 1972).

• Several other midcontinent basins and highs (i.e., Michigan Basin, Wisconsin Arch, Hollandale Embayment, etc.) were active roughly contemporaneously (Fig. 7) and possibly in response to far-field stresses generated during orogenic activity along present-day eastern North America (Smith, 1993; Howell and van der Pluijm, 1990). The reactivation of the horst structure and/or the development of the TCB may also be an early manifestation of these orogenic far-field stresses.

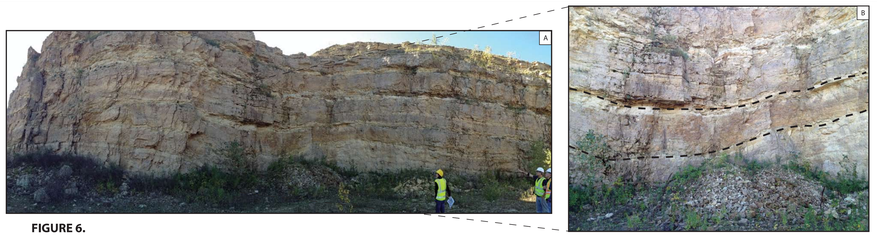
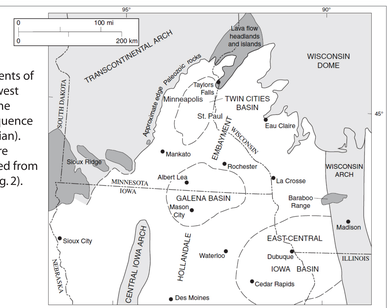


FIGURE 6.
Quarry exposure of the Prairie du Chien Group (Shakopee Formation) in southeast Washington County.
(A) Variable folding in alternating beds. (B) Close-up on a brecciated and relatively thickened bed (black dashed lines).

FIGURE 7. »
Structural elements of the Upper Midwest region during the Tippecanoe sequence (Upper Ordovician). Positive areas are shaded (modified from Mossler, 2008, fig. 2).



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