Depositional Trends of the Prairie du Chien Group (Lower Ordovician) along the Western Edge of the Twin Cities Basin, Minnesota: Possible Evidence of Syn-To-Post-Depositional Basin Formation

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1. ABSTRACT

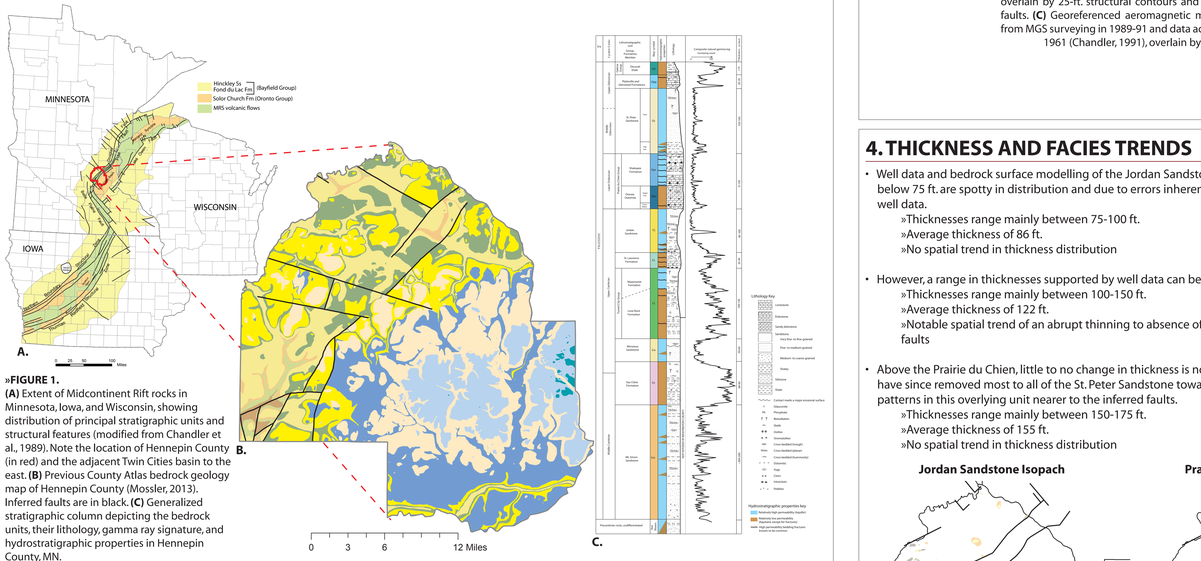
Preliminary mapping of Paleozoic bedrock in Hennepin County, MN, as part of a County Geologic Atlas program, reveals a possible connection between depositional trends in the Prairie du Chien Group (Lower Ordovician) and reactivated Mesoproterozoic Midcontinent Rift System (MRS) faults associated with the development of the Twin Cities basin. Structural elevation contours of the stratigraphic top of the Upper Cambrian Jordan and Wonewoc Sandstones disclose several NE-SW-trending faults in western Hennepin County. Aeromagnetic and gravity data show these Paleozoic faults directly overlie preexisting MRS faults. Structural maps also highlight a regional structural low, known as the Twin Cities basin (TCB), just east of these faults and centered near southeastern Hennepin County.

Facies of the Prairie du Chien change from the TCB center towards the MRS-fault-bounded western edge. A westward increase in sand content likely reflects progressively shallower water deposition in that direction. This trend parallels a westward thinning of the Prairie du Chien, from ~145 feet to absent, where the Middle Ordovician St. Peter Sandstone unconformably overlies the Jordan Sandstone. Drill cuttings indicate the unconformity is overlain by an apparent lag of variably thick, iron-cemented sandstone with possible Prairie du Chien intraclasts. This may indicate syn-to-post-depositional subaerial exposure and weathering of the Prairie du Chien prior to St. Peter deposition, signifying TCB development during the Early Ordovician.

Changes in thickness of the Prairie du Chien have also been noted in Washington County, MN, and into western Wisconsin overlying a preexisting MRS horst, suggesting syndepositional development. Previous studies proposed the TCB 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 depositional trends of the Prairie du Chien Group across Hennepin County may also be linked to these orogenic far-field stresses.

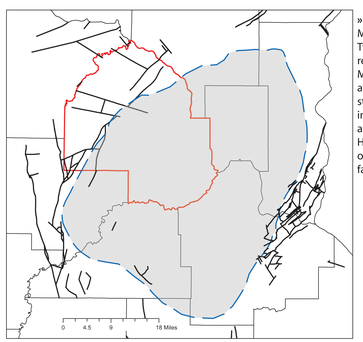
2. BACKGROUND

- The bedrock geology of Hennepin County is currently being mapped as part of an updated County Geologic Atlas, and is composed of sandstone, shale, and carbonate units deposited in shallow seas during the Cambrian and Ordovician Periods of the Paleozoic Era (about 500 to 450 mya) (Fig. 1B-C).
- The Paleozoic rocks lie atop a thick sequence of Mesoproterozic rocks of the Keweenawan Supergroup, which are associated with the Midcontinent Rift System that passes through western Hennepin County trending NE-SW, as inferred by geophysical imagery (Fig. 1A).



»FIGURE 1.
(A) Extent of Midcontinent Rift rocks in Minnesota, Iowa, and Wisconsin, showing distribution of principal stratigraphic units and structural features (modified from Chandler et al., 1989). Note the location of Hennepin County (in red) and the adjacent Twin Cities basin to the east. **(B)** Previous County Atlas bedrock geology map of Hennepin County (Mossler, 2013). Inferred faults are in black. **(C)** Generalized stratigraphic column depicting the bedrock units, their lithology, gamma ray signature, and hydrostratigraphic properties in Hennepin County, MN.

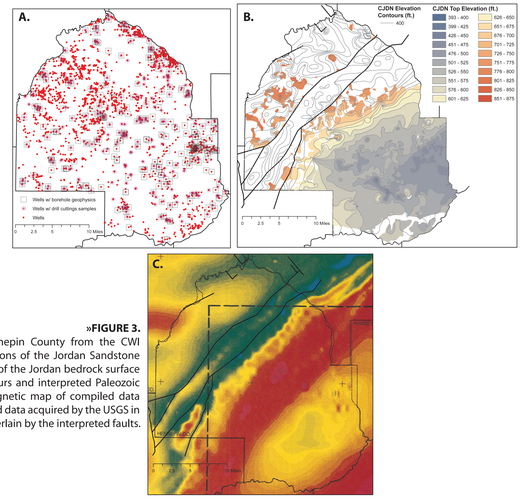
- Previous mapping in Hennepin County and adjacent counties has identified a regional, Paleozoic-aged structural low named the Twin Cities basin (or TCB) (Austin, 1972; Mossler, 1972; Olsen and Bloomgren, 1989; Mossler, 2013) (Fig. 2).
- The formation of the TCB is not well understood, but has long been attributed to isostatic and/or thermal adjustments accommodated by Midcontinent Rift System structures during Middle to at least Late Ordovician time (Austin, 1972; Mossler, 1972).
- Current mapping efforts for the updated County Atlas provide us with the opportunity to further investigate the depositional trends of the Paleozoic bedrock within the TCB, and how these might relate to the underlying Midcontinent Rift System.
- An array of different data sources were compiled for this study, and for the ongoing County Atlas mapping, including: nearly 29,500 water-well records from Minnesota's County Well Index (CWI), bedrock core, drill cutting samples, borehole geophysical logs, passive seismic soundings, geophysical imagery, and previously published geologic maps.



»FIGURE 2.
Mapped extent of the Twin Cities basin (shaded region) as interpreted by Mossler (2008) based on available well data, structural contours, inferred Paleozoic faults, and geophysical imagery. Hennepin County is outlined in red. Paleozoic faults are in black.

3. PALEOZOIC STRUCTURE

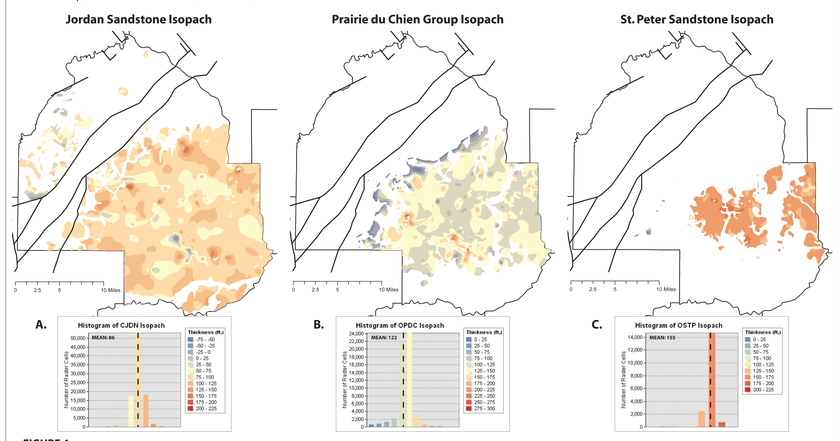
- Paleozoic faults were interpreted using elevation top values of the Upper Cambrian Jordan Sandstone and Wonewoc Sandstone, as these units provide the best spatial coverage and are well-recognized by drillers (Fig. 3A and 3B).
  - »Elevation values of the Wonewoc Sandstone are particularly useful in areas where the Jordan is absent.
- Interpretations were bolstered by existing aeromagnetic data, indicating that the majority of large-scale elevation changes denoted in our contouring are located directly above, and run parallel, to discontinuities in the geophysical imagery (Fig. 3C).
- It should be noted that the fault interpretations made here in our latest mapping efforts differ from those recognized in previous regional mapping (see faults in Figure 1B).



»FIGURE 3.
(A) Distribution of wells in Hennepin County from the CWI database that indicate top elevations of the Jordan Sandstone and Wonewoc Sandstone. **(B)** Top of the Jordan bedrock surface overlain by 25-ft. structural contours and interpreted Paleozoic faults. **(C)** Georeferenced aeromagnetic map of compiled data from MGS surveying in 1989-91 and data acquired by the USGS in 1961 (Chandler, 1991), overlain by the interpreted faults.

4. THICKNESS AND FACIES TRENDS

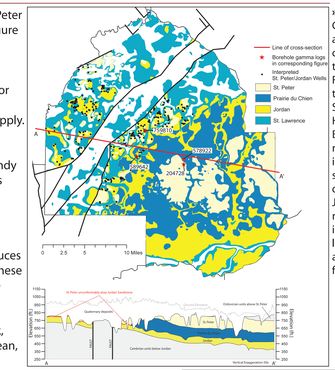
- Well data and bedrock surface modelling of the Jordan Sandstone indicate little to no fluctuation in total thickness (Fig. 4A). Many of the values reported below 75 ft. are spotty in distribution and due to errors inherent in the raster interpolation methods. These values DO NOT reflect actual thicknesses from well data.
  - »Thicknesses range mainly between 75-100 ft.
  - »Average thickness of 86 ft.
  - »No spatial trend in thickness distribution
- However, a range in thicknesses supported by well data can be seen in the Prairie du Chien isopach (Fig. 4B).
  - »Thicknesses range mainly between 100-150 ft.
  - »Average thickness of 122 ft.
  - »Notable spatial trend of an abrupt thinning to absence of Prairie du Chien as you move away from the TCB depocenter towards the inferred bounding faults
- Above the Prairie du Chien, little to no change in thickness is noted in the St. Peter Sandstone (Fig. 4C). It should be noted, however, that later glaciations have since removed most to all of the St. Peter Sandstone towards the outer boundary of the TCB. Therefore, we have no indication as to the thickness patterns in this overlying unit nearer to the inferred faults.
  - »Thicknesses range mainly between 150-175 ft.
  - »Average thickness of 155 ft.
  - »No spatial trend in thickness distribution



»FIGURE 4.
Isopach surfaces of the **(A)** Jordan Sandstone, **(B)** Prairie du Chien Group, and **(C)** St. Peter Sandstone in Hennepin County, accompanied each by a thickness histogram.

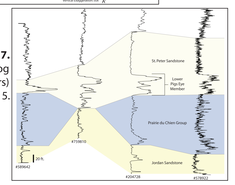
5. EVIDENCE FOR ST. PETER UNCONFORMABLY ATOP JORDAN

- Where the Prairie du Chien becomes absent, we interpret the overlying St. Peter Sandstone being deposited unconformably atop the Jordan Sandstone. Figure 5 highlights the wells (black dots) interpreted as such.
- Drillers' logs report sandstone and shale deposits that are either: (a) dramatically thicker than the well-studied Jordan Sandstone in the region, or (b) exist at elevations much higher than the interpreted top of the Jordan based on close proximity data and inferred fault offsets. Often times both apply.
- The basal member of the St. Peter Sandstone, the Pigs Eye Member, is composed of interbedded sandstone/siltstone and red/green shale and sandy shale (Fig. 6; Mossler, 2008). It is well-documented from drill cutting samples and borehole geophysical logs (Mossler, 2008).
  - »This lithology agrees with material descriptions of well logs that indicate St. Peter unconformably atop the Jordan.
- Furthermore, the shale and sandy shale of the basal Pigs Eye Member produces a repeatable and characteristic set of 'kicks' in the gamma ray logs (Fig. 7). These 'kicks' can be traced from well to well, and are also noted in wells where the Prairie du Chien is absent (also verified in drill cuttings).
- Drill cuttings through this interval indicate an apparent lag of variably thick, iron-cemented sandstone with possible Prairie du Chien intraclasts atop clean, white and yellow sandstone typical of the Jordan (Fig. 8).
  - »A deposit such as this lends further support to the idea of an unconformable surface.

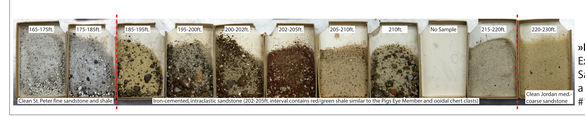


»FIGURE 5.
Geologic map and accompanying cross-section of the St. Lawrence Formation up to the St. Peter Sandstone in Hennepin County. Black dots represent wells interpreted to show St. Peter directly atop the Jordan. Note the red stars that indicate the location of wells in a corresponding figure.

»FIGURE 6.
Sandstone (top) and shale/sandy shale (bottom) in core of Pigs Eye Member of the St. Peter Sandstone. Stratigraphic top to the right. Core TCAAP 86-673, Ramsey County (Twin Cities), MN.



»FIGURE 7.
Borehole gamma log signatures of wells (red stars) in the corresponding Fig. 5.



»FIGURE 8.
Example drill cuttings set showing a clean St. Peter Sandstone, the iron-cemented, weathered interval, and a clean Jordan Sandstone. Cuttings from CWI well #122250, MGS cuttings #1962, Hennepin County.

6. DISCUSSION AND FUTURE WORK

- Previous geologic maps have also interpreted the St. Peter Sandstone directly overlying the Jordan Sandstone (Olsen and Bloomgren, 1989; Mossler, 2013); however, they failed to recognize any notable thickness trends in the Prairie du Chien. Their interpretations were mostly based on material descriptions similar to the Pigs Eye Member lithology.
- The abrupt thickness change in the Prairie du Chien and its absence and subsequent depostion of the St. Peter Sandstone directly atop the Jordan Sandstone, when combined with the spatial distribution of this evidence, begs the question as to whether or not these trends are linked to the reactivated Midcontinent Rift System faults associated with the Twin Cities basin development.
- Similar thickness trends are not apparent in the underlying Jordan Sandstone, indicating the Twin Cities basin likely formed syn-to-post Prairie du Chien Group deposition.
- Furthermore, the iron-cemented, intraclastic lag deposit may indicate that the Prairie du Chien Group was at one time subaerially-exposed and weathered, as opposed to purely a control on its depositional extent. This may explain the nature of the abrupt thickness change and absence noted here.
- Changes in thickness of the Prairie du Chien have also been noted in nearby Washington County, MN, and into western Wisconsin overlying a preexisting Midcontinent Rift System horst, suggesting syndepositional development (Steenberg and Retzler, 2015; Steenberg et al., 2015). Folding and truncation within the Prairie du Chien has also been documented in Wisconsin and Iowa by Ludvigson and McAdams (1980). They argued that the E-W trending folds were tectonic in origin.
- The trends in this study agree with previous proposals of the Twin Cities basin forming via isostatic and/or thermal adjustments accommodated by Midcontinent Rift System structures during Middle to at least Late Ordovician time (Austin, 1972; Mossler, 1972).
- 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 (Smith, 1993; Howell and van der Pluijm, 1990). The development of the Twin Cities basin and its affect on Prairie du Chien deposition may also be an early manifestation of these orogenic far-field stresses.

ACKNOWLEDGMENTS

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