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Sedimentary Geology 184 (2006) 305 – 330
Sedimentary Geology
www.elsevier.com/locate/sedgeo

Evidence for hydraulic heterogeneity and anisotropy in the mostly carbonate Prairie du Chien Group, southeastern Minnesota, USA

Robert G. Tipping [a,*], Anthony C. Runkel [a], E. Calvin Alexander Jr.[b], Scott C. Alexander [b], Jeffery A. Green [c]

[a] *Minnesota Geological Survey, 2642 University Avenue, Saint Paul, MN 55114, United States*
[b] *University of Minnesota, Department of Geology and Geophysics, 310 Pillsbury Drive SE, Minneapolis, MN 55455, United States*
[c] *Minnesota Department of Natural Resources, Division of Waters, Rochester, 2300 Silver Creek Road, Rochester, MN 55906, United States*

Abstract

In southeastern Minnesota, Paleozoic bedrock aquifers have typically been represented in groundwater flow simulations as isotropic, porous media. To obtain a more accurate hydrogeologic characterization of the Ordovician Prairie du Chien Group, a new approach was tested, combining detailed geologic observations, particularly of secondary porosity, with hydraulic data. Lithologic observations of the depositional and erosional history of the carbonate-dominated bedrock unit constrained characterization of both primary (matrix) and secondary porosity from outcrops and core. Hydrostratigraphic data include outcrop and core observations along with core plug permeability tests. Hydrogeologic data include discrete interval aquifer tests, borehole geophysics, water chemistry and isotope data, and dye trace studies. Results indicate that the Prairie du Chien Group can be subdivided into the Shakopee aquifer at the top, consisting of interbedded dolostone, sandstone and shale, and the underlying Oneota confining unit consisting of thickly bedded dolostone. The boundary between these two hydrogeologic units does not correspond to lithostratigraphic boundaries, as commonly presumed. Groundwater flow in the Shakopee aquifer is primarily through secondary porosity features, most commonly solution-enlarged bedding planes and sub-horizontal and vertical fractures. Regional scale preferential development of cavernous porosity and permeability along specific stratigraphic intervals that correspond to paleokarst were also identified, along with a general depiction of the distribution of vertical and horizontal fractures. The combination of outcrop and core investigations, along with borehole geophysics, discrete interval aquifer tests, water chemistry and isotope data and dye trace studies show that the Prairie du Chien Group is best represented hydrogeologically as heterogeneous and anisotropic. Furthermore, heterogeneity and anisotropy within the Prairie du Chien Group is mappable at a regional scale (>15,000 km^2).

Keywords: Dolostone; Groundwater; Paleokarst; Prairie du Chien Group; Dual porosity; High-resolution flowmeter

1. Introduction

The Lower Ordovician Prairie du Chien Group, along with the underlying Cambrian Jordan Sandstone, is a primary source of groundwater in southeastern Minnesota and southwestern Wisconsin (Fig. 1). This part of Minnesota was largely unglaciated during the most recent Pleistocene Late Wisconsin glacial advance. As a result, bedrock is at depths of less than 15 m across most of the area, with overlying unconsolidated material consisting primarily of loess and weathered bedrock residuum. The combination of shallow-to-bedrock conditions and permeable bedrock make these

* Corresponding author. Fax: +1 612 627 4778.
E-mail address: tippi001@umn.edu (R.G. Tipping).

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doi:10.1016/j.sedgeo.2005.11.007

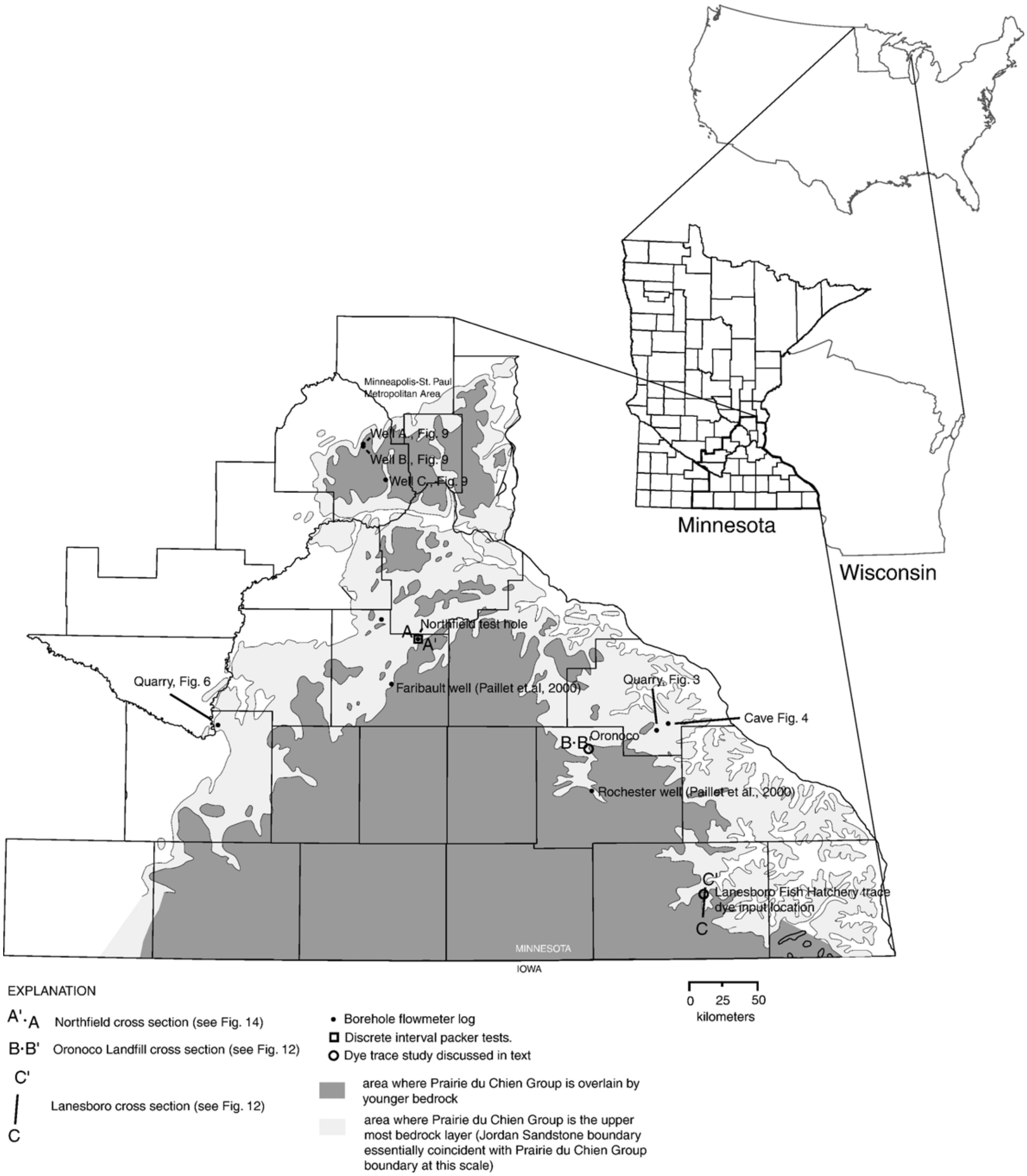

Fig. 1. Map showing extent of the Prairie du Chien Group, southeastern Minnesota. Areas where the Prairie du Chien Group is the uppermost bedrock layer is shown, as well as areas where it is overlain by younger bedrock. Locations are shown for boreholes, dye traces, quarries and other features discussed in the text.

aquifers highly productive, but also highly susceptible to contamination from activities at the land surface.

Paleozoic aquifers in southeastern Minnesota have typically been treated in groundwater flow models as equivalent porous media. Although models based on this assumption work well for estimates of aquifer yield, they have limited usefulness for predicting precise flow paths and groundwater velocities. The goal of this study was to test the hypothesis that the Prairie du Chien Group is best characterized as hydraulically heterogeneous and anisotropic. The hydrogeology of thick, carbonate-dominated units has proven quite difficult to characterize. Because the Paleozoic strata in this portion of the central mid-continent are relatively undeformed,