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Using large databases of groundwater chemistry in the northern Midwest USA: The effects of geologic and anthropogenic factors

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Abstract

Regional geochemical databases for the northern Midwest USA are being compiled to examine the various geogenic and anthropogenic factors that control the chemistry of groundwater. At the regional scale, variations are seen that are attributable to agricultural and urban effects, or to geologic factors. Examples of the former include enrichments of nitrate in groundwater, while examples of the latter mainly highlight geochemical differences between carbonate rocks and all other rock types in the region. This paper examines a few of these regional effects and the spatial scales at which they can be observed.

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1. Introduction

The Midwestern USA is host to numerous land uses, including dominantly agricultural, urban/suburban, and wild. The 11-state area (Kansas, Nebraska, South Dakota, Missouri, Iowa, Minnesota, Illinois, Wisconsin, Indiana, Michigan, and Ohio) includes urban centers of Chicago, Des Moines, Indianapolis, Columbus, Detroit, Milwaukee, Kansas City, Omaha, Minneapolis, Cleveland, and Wichita, which are among the 50 most populated cities in the USA. The area also includes extensive farmland (Fig. 1). Major crops include corn, wheat and other food crops, which use varying amounts of irrigation, fertilization, pesticides, or other amendments.

The climate in the region is largely humid-temperate[1], although west of about 98° longitude, the climate is drier

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and classified as semi-arid steppes. The northern portions of Minnesota, Wisconsin and Michigan comprise mixed coniferous-deciduous forests, grading southward into deciduous forests and forested prairies. Much of the study area lies within the drainage basins of the Mississippi River or its major tributaries- the Missouri and Ohio Rivers, although Michigan drains to the Great Lakes, as do parts of Ohio, Wisconsin and Minnesota.

1.1. Geologic Setting

The geology of the region primarily consists of gently dipping sediments from Cambrian to Quaternary age. The sediments include virtually all compositions. The area was heavily glaciated, especially in the north, and much of the surficial cover consists of tills and outwash from the last Glacial Maximum. Archean rocks of the Canadian Shield cover the northern parts of Minnesota. A broad area of limestone stretches from SE Minnesota and Iowa eastward through Illinois and Indiana to western Ohio. The lower peninsula of Michigan comprises a sedimentary basin with Devonian to Jurassic age rocks. The Midcontinent rift (MCR) is a broad arcuate feature that formed in the Precambrian[2,3] and traverses a number of the states in the study area (Fig. 1). The MCR is exposed at the surface in northern Minnesota, Wisconsin, and Michigan but is buried by progressively thicker sedimentary cover to the south. Some of this sedimentary cover was glacially transported from as far away as Minnesota or Canada.

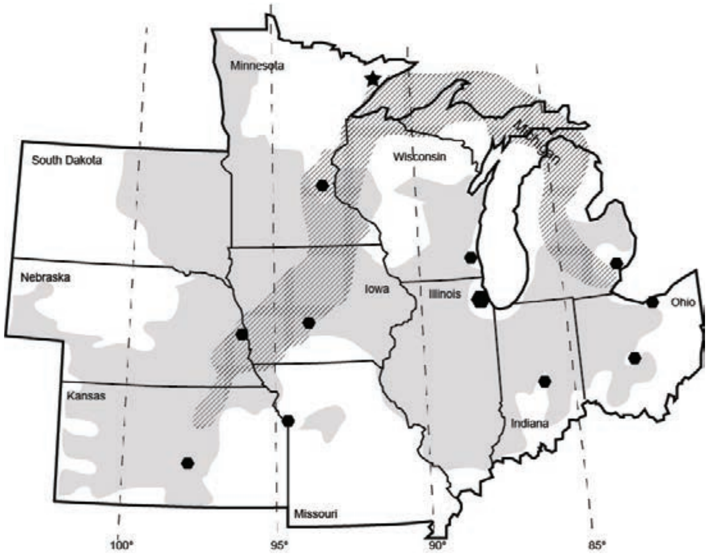

Fig. 1. Base map of study area showing major urban centers (hexagons) and agricultural land (shaded area). Agricultural information from U.S. Department of Agriculture[4]. The star denotes the location of Ni-Cu-PGE deposits in NE Minnesota. Hachured area is the approximate outline of the Midcontinent rift.

A variety of mineral deposit types occur within the study area, including taconite (Fe) deposits in NE Minnesota, sediment-hosted Cu deposits in northern Michigan, and volcanogenic massive sulfide deposits in the northern half of Wisconsin. Of particular interest to the current study are the Ni-Cu-PGE (platinum-group element) deposits that are hosted by the Duluth Complex of the MCR in NE Minnesota[5] (star in figure 1). During glaciation, some of these mineralized rocks may have been transported into the southern portion of the study area and could be a diffuse source of metals to present-day groundwater.

Objectives and Scope

A primary objective of this project is to determine whether Ni-Cu-PGE deposits associated with the MCR impart a distinct geochemical signature to groundwater or surface waters. To address this objective, the project is: (1) compiling regional geochemical databases from existing archives; (2) performing new focused field studies to more fully characterize the geochemistry and hydrology of groundwater in the vicinity of known mineral deposits; and (3) evaluating the types of local and regional effects that can be seen in the regional geochemical databases. By using the results of the new field studies near known deposits as a training set for interpreting the regional databases, we hope to be able to locate areas of interest for new deposits based on similar trends in groundwater chemistry. This paper focuses on the third part of the project.

The compilation of regional databases is an ongoing effort to collect available data, evaluate its quality, and incorporate the data into spatial and statistical analyses. For this paper, much of the data was derived from the U.S. Geological Survey's National Water Information System[6] (NWIS), although state-produced databases also were used to augment the NWIS data and to fill in gaps.

2. Results and Discussion

Groundwater is exploited throughout the Midwestern USA for agricultural, municipal, industrial, and domestic uses; groundwater wells are abundant and chemical analyses are available in many databases. For the 11-state area shown in Fig. 1, more than 97,000 analyses of groundwater were available in NWIS for samples collected after 1980. Both geogenic and anthropogenic effects can be seen in the distribution of various elements or element ratios. One of the challenges of resolving these effects derives from the widespread intense agricultural activity, and whether its effects on groundwater chemistry mask the geogenic signatures that we seek to identify. In a suite of samples we collected in 2015 in NE Minnesota (near the star in Fig. 1), the 80^{th} and 90^{th} percentile concentrations for Cu were 29 and 57 µg/L. Figure 2 shows the NWIS data for Cu, with these two concentration levels highlighted by larger symbols. As seen in the figure, Cu concentrations are regionally greater through much of Iowa, southern Minnesota, and western Kansas, all areas with intense agricultural activity, and the enriched Cu concentrations likely derive from the historic use of Cu compounds as fungicides, or from glacially transported material. Some enriched Cu concentrations also exist near urban areas and mining areas such as in SE Missouri. A map of nitrate (not shown) shows a similar distribution of enriched values that correspond to agricultural areas.

Geogenic effects can be seen in a variety of parameters, using chemical constituents that are not typically added as soil amendments in agricultural activities, and that are not common pollutants related to urban effects. For example, the ratio of Mg:Ca is expected to be greater in rocks where Mg is in a more leachable form, such as in limestones, dolostones, and mafic-ultramafic rocks. Figure 3 shows the distribution of these rock types overlain by the groundwater chemical data for Mg:Ca. Although the correlation is not perfect, there is a tendency for greater dissolved Mg:Ca ratios to occur in groundwater in these rock types. Other parameters, such as dissolved SiO_2, show strong spatial variations that likely are due to geologic/lithologic factors.

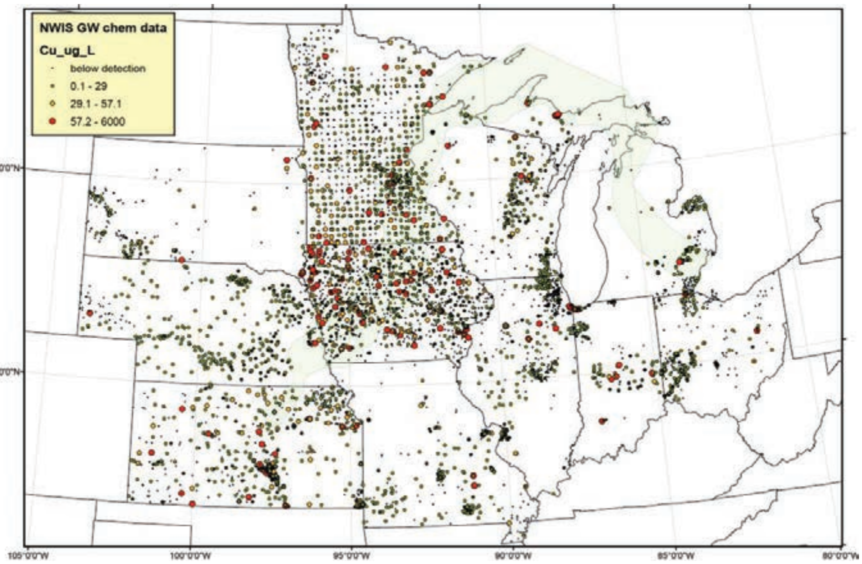

Fig. 2. Cu in groundwater, in µg/L. The MCR is shown as the green shaded area.

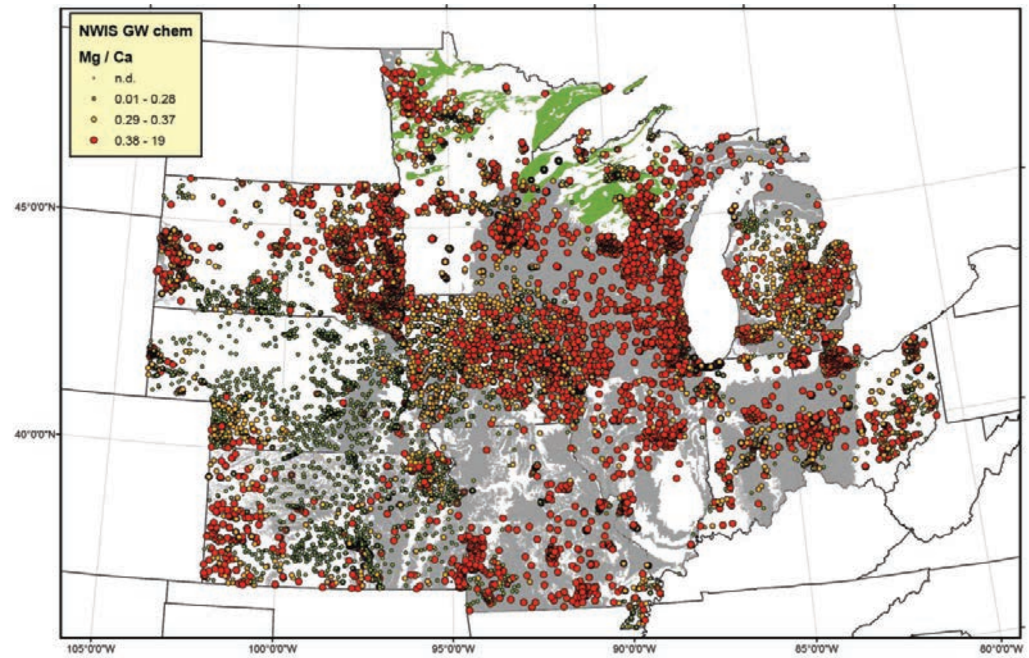

Figure 3. General lithologic map showing areas covered by limestone or dolostones in gray shading, and mafic-ultramafic rocks shown in green shading. Dots represent Mg:Ca ratios, shown as percentiles of the overall distribution. 'n.d.' means that either Mg or Ca was below detection.

3. Summary

With the increasing availability of large archival datasets, geochemists face the challenge of how to use and interpret these data. In this paper we provide an example from the northern Midwest USA that illustrates anthropogenic and geogenic effects on groundwater chemistry. An understanding of local and regional geology is particularly important, and the availability of geologic, lithologic, and land-use maps is critical.

Acknowledgements

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