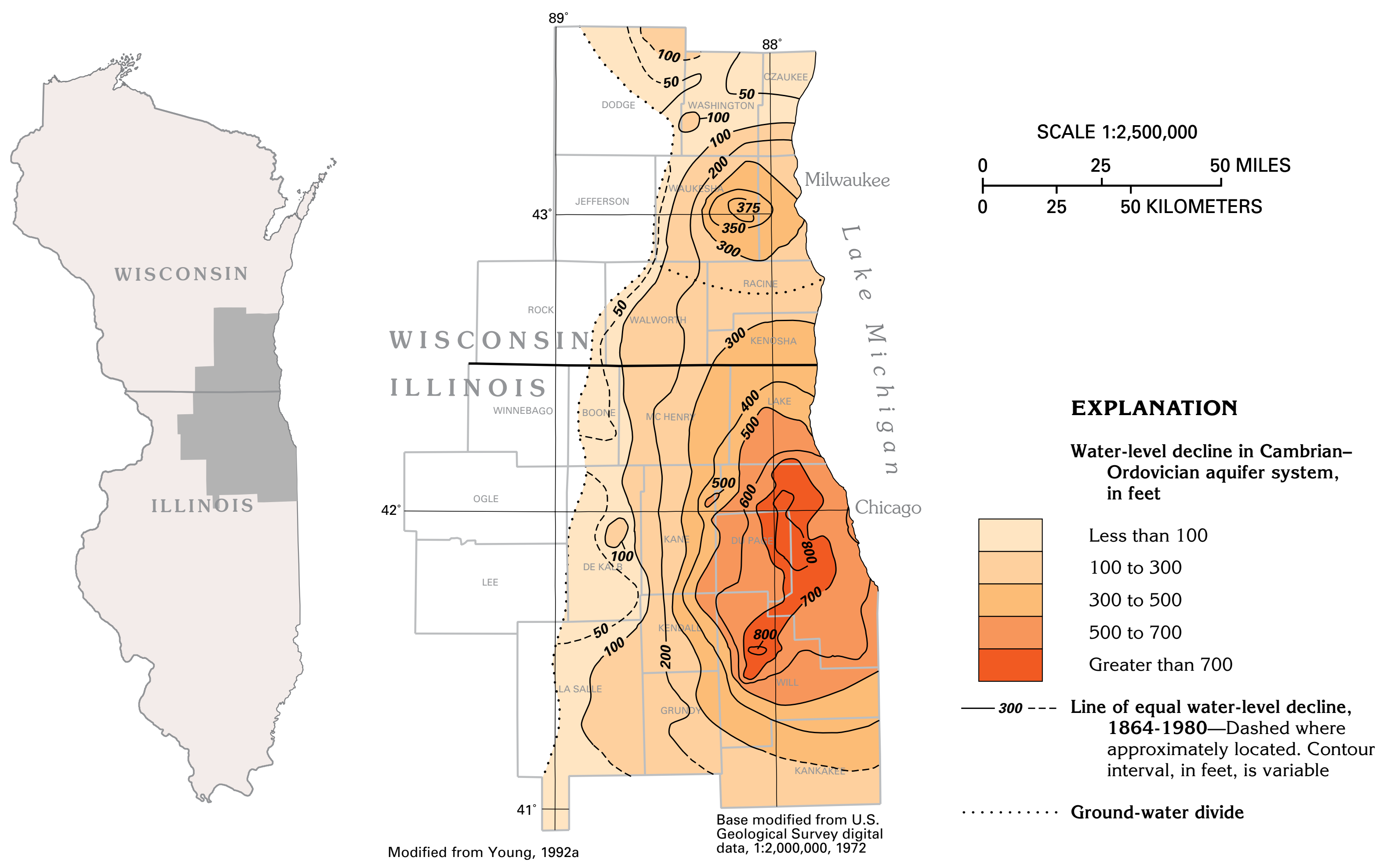


Figure 24. *Water levels in the Cambrian–Ordovician aquifer system declined more than 800 feet at Chicago as a result of large withdrawals from 1864 to 1980.*

SANDSTONE AQUIFERS— Continued

The ground-water flow system of the Cambrian–Ordovician aquifer system is summarized in **figure 25**. Water from precipitation moves downward through surficial deposits of glacial drift, shallower aquifers, and the Maquoketa confining unit into the St. Peter–Prairie du Chien–Jordan aquifer. Some of the water moves horizontally along short flow paths to local streams, such as the Little Cannon River, where it moves upward to discharge to the streams as base flow. Some water moves in a similar fashion along flow paths of intermediate length and discharges to larger streams, such as the Cannon River. Some of the water continues to percolate downward through successively deeper confining units into successively deeper aquifers. Water in these deeper aquifers moves laterally over long distances and eventually discharges to major rivers, such as the Mississippi River. A small part of the water moves down the regional hydraulic gradient, perpendicular to the plane of the section shown in **figure 25** and toward deeply buried parts of the aquifer system. This deep, regional flow discharges by upward leakage to shallower aquifers or is captured by pumping wells.

The chemical quality of the water in large parts of the aquifer system is suitable for most uses. The water is not highly mineralized in areas where the aquifers crop out or are buried to shallow depths, but mineralization generally increases as the water moves downgradient toward the structural basins. The distribution of dissolved-solids concentrations in the St. Peter–Prairie du Chien–Jordan aquifer (**fig. 26**) shows this increase. Where the aquifer is at or near the land surface in southeastern Minnesota, northeastern Iowa, southern Wisconsin, the Upper Peninsula of Michigan, and central Missouri, it contains water with dissolved-solids concentrations of less than 500 milligrams per liter (the limit recommended for drinking water by the U.S. Environmental Protection Agency) or less. Concentrations increase to more than 1,000 milligrams per liter in western and southern Iowa, north-central Illinois, and along the northwestern shore of Lake Michigan. Where the aquifer is deeply buried and ground-water movement is almost stagnant in parts of Missouri, concentrations are greater than 10,000 milligrams per liter. The lobe of water with low dissolved-solids concentrations that extends southward in central Iowa is thought to represent unflushed subglacial meltwater that moved into the aquifer during the Pleistocene Epoch from an area of extremely high hydraulic head created by the weight of the glacial ice. Dissolved solids in water from the Mount Simon aquifer show the same trends as those in water from the St. Peter–Prairie du Chien–Jordan aquifer.

Other layered sandstone aquifers that are exposed adjacent to domes and uplifts or that extend into large structural basins or both are the Colorado Plateaus aquifers, the Denver Basin aquifer system, the lower Tertiary aquifers, the Upper Cretaceous aquifers, the Lower Cretaceous aquifers, the Wyoming Tertiary aquifers, the Mississippian aquifer of Michigan, and the New York sandstone aquifers (**fig. 4**). The Rush Springs, Central Oklahoma, and Ada–Vamoosa aquifers of Oklahoma are small aquifers that contain water largely under unconfined conditions and generally yield small amounts of water. The Jacobsville aquifer on the Upper Peninsula of Michigan is also small, mostly unconfined, and yields little water; however, the glacial deposits that cover this aquifer store precipitation and release it slowly into the underlying sandstone. The Pennsylvanian aquifers that cover large parts of the east-central United States cap hills and plateaus, are poorly permeable, and yield water mostly from shallow fracture systems and interbedded, cleated coals. The early Mesozoic basin aquifers of the eastern part of the Nation occupy titled grabens or half-grabens, are commonly interbedded with fine-grained sediments and intruded by traprock, and generally yield only small amounts of water.

Figure 25. *Water in the stacked sandstone aquifers moves vertically downward, then horizontally toward major rivers, where it moves upward to discharge as base flow. Regional flow, not shown here, is perpendicular to the section and into deep, confined parts of the aquifers.*

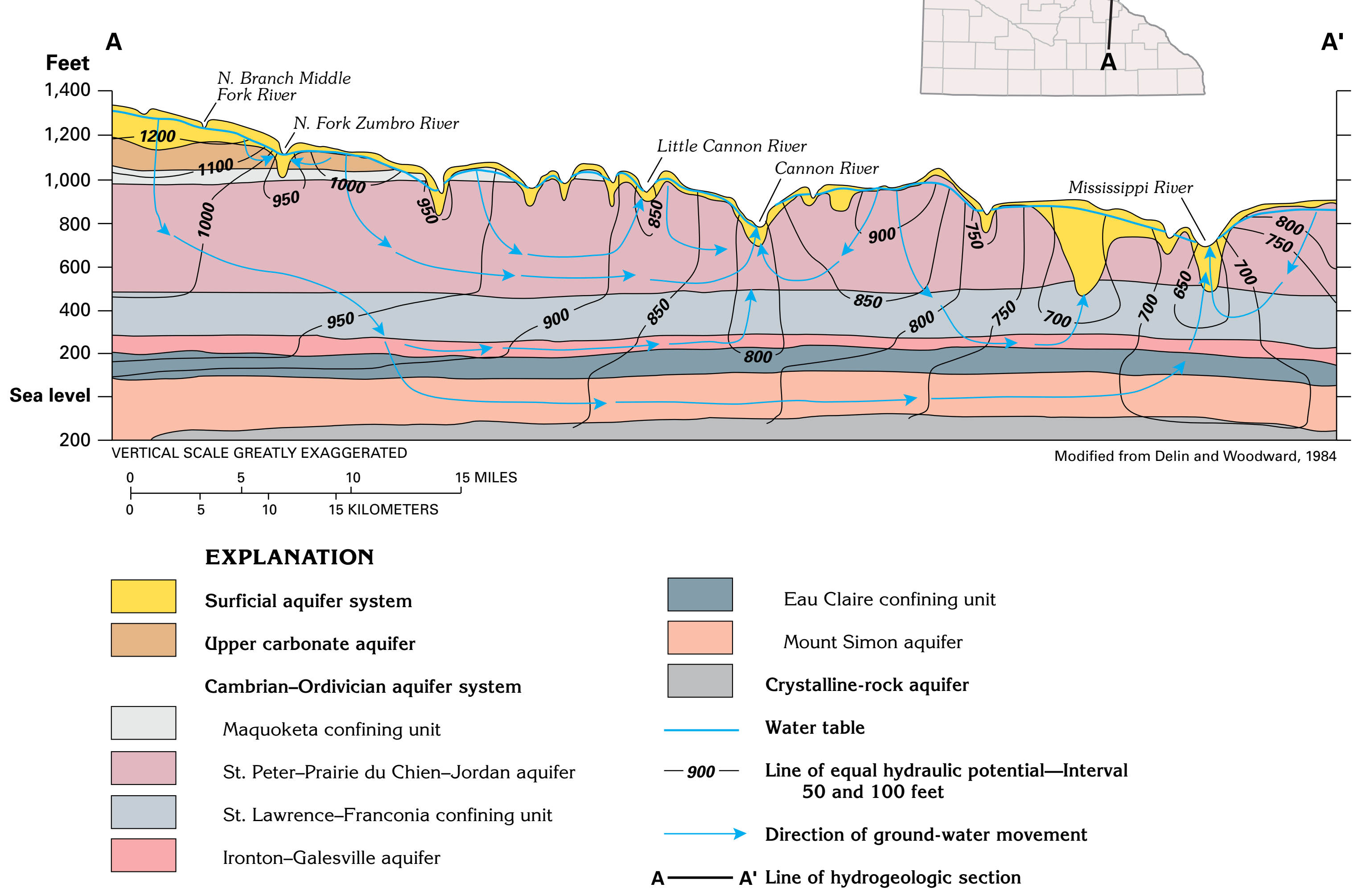
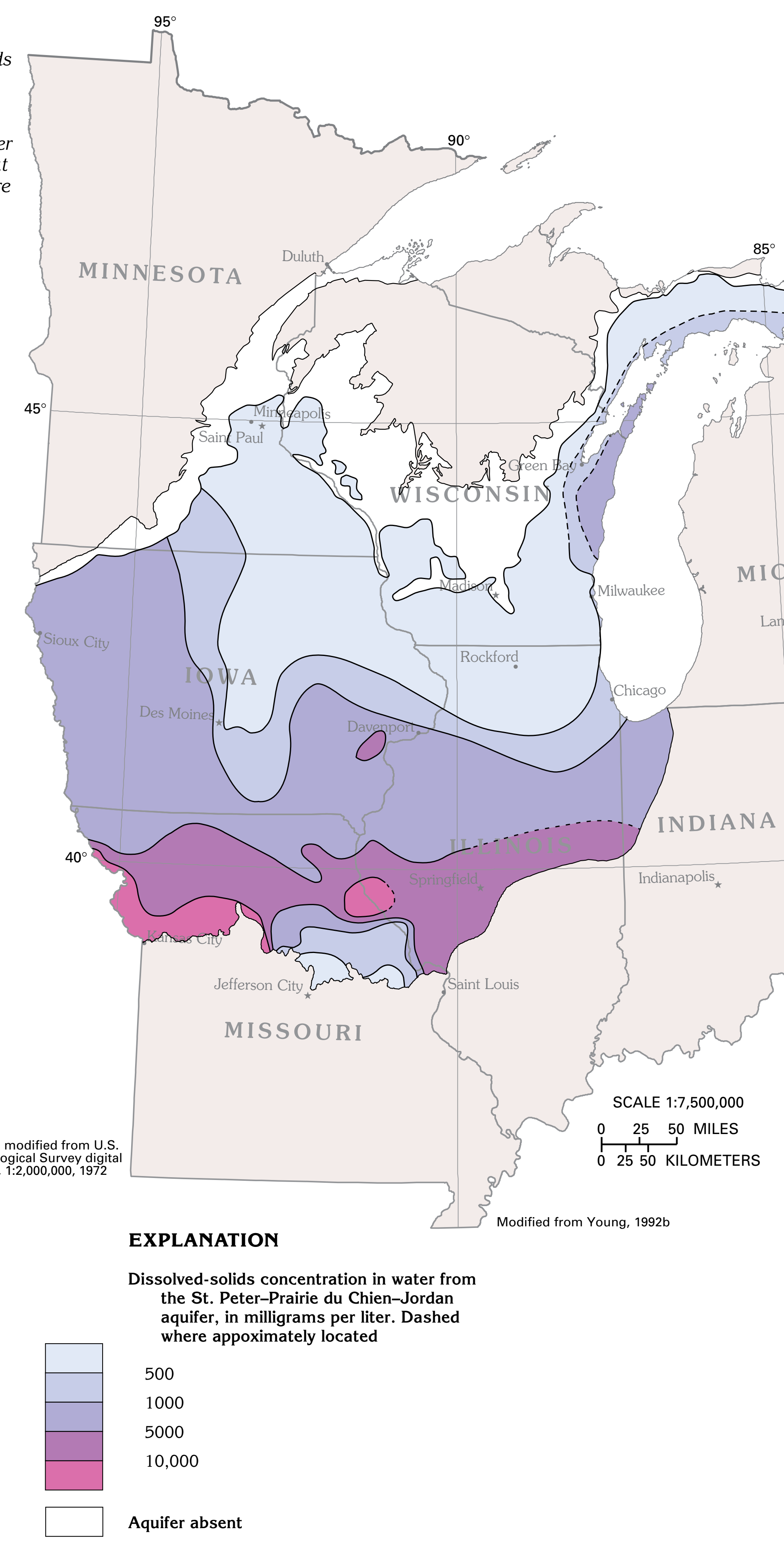


Figure 26. *Dissolved-solids concentrations in water from the St. Peter–Prairie du Chien–Jordan aquifer generally are less than 500 milligrams per liter where the aquifer crops out, but increase greatly downdip where the aquifer is deeply buried.*



CARBONATE-ROCK AQUIFERS

Aquifers in carbonate rocks are most prominent in the central and southeastern parts of the Nation, but also occur in small areas as far west as southeastern California and as far east as northeastern Maine and in Puerto Rico (**fig. 4**). The rocks that comprise these aquifers range in age from Precambrian to Miocene. Most of the carbonate-rock aquifers consist of limestone, but dolomite and marble locally are sources of water. The water-yielding properties of carbonate rocks are highly variable; some yield almost no water and are considered to be confining units, whereas others are among the most productive aquifers known.

Most carbonate rocks form from calcareous deposits that accumulate in marine environments ranging from tidal flats to reefs to deep ocean basins. The deposits are derived from calcareous algae or the skeletal remains of marine organisms that range from foraminifera to molluscs. Minor amounts of carbonate rocks are deposited in fresh to saline lakes, as spring deposits, geothermal deposits, or dripstone in caves. The original texture and porosity of carbonate deposits are highly variable because of the wide range of environments in which the deposits form. The primary porosity of the deposits can range from 1 to more than 50 percent. Compaction, cementation, and dolomitization are diagenetic processes which act on the carbonate deposits to change their porosity and permeability.

The principal post-depositional process that acts on carbonate rocks is dissolution. Carbonate rocks are readily dissolved to depths of about 300 feet below land surface where they crop out or are covered by a thin layer of material. Precipitation absorbs some carbon dioxide as it falls through the atmosphere, and even more from organic matter in the soil through which it percolates, thus forming weak carbonic acid. This acidic water partially dissolves carbonate rocks, initially by enlarging pre-existing openings such as pores between grains of limestone or joints and fractures in the rocks. These small solution openings become larger especially where a vigorous ground-water flow system moves the acidic water through the aquifer. Eventually, the openings join as networks of solution openings, some of which may be tens of feet in diameter and hundreds to thousands of feet in length. The end result of carbonate-rock dissolution is expressed at the land surface as karst topography, characterized by caves, sinkholes, and other types of solution openings, and by few surface streams. Where saturated, carbonate-rock aquifers with well-connected networks of solution openings yield large volumes of water to wells that penetrate the solution cavities, even though the undissolved rock between the large openings may be almost impermeable (**fig. 27**). Because water enters the carbonate-rock aquifers rapidly through large openings, any contaminants in the water can rapidly enter and spread through the aquifers.

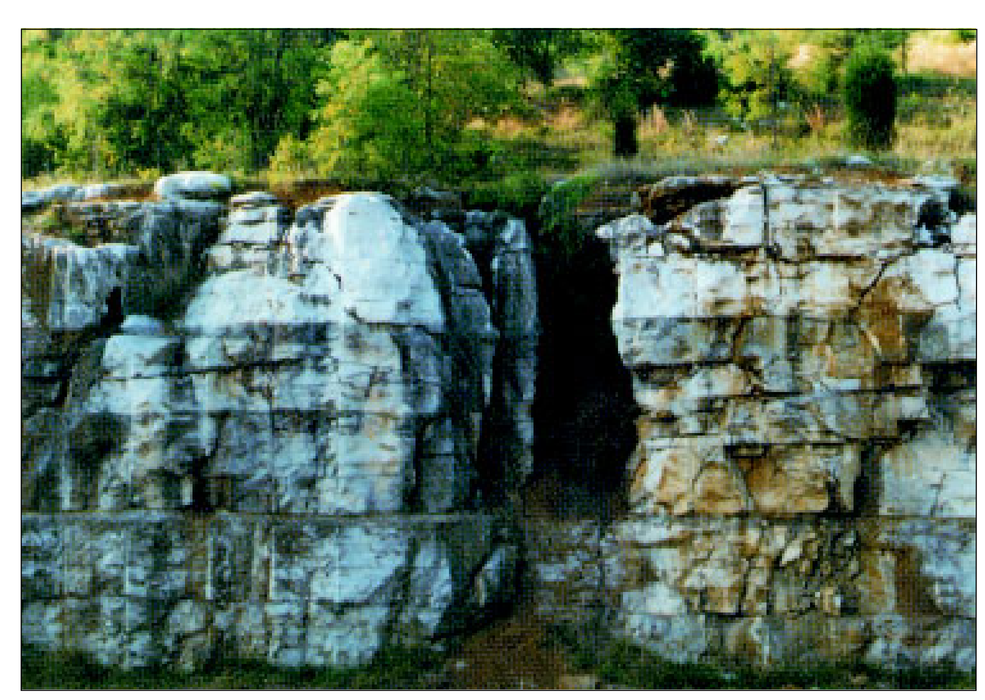


Figure 27. *Dissolution along joints and bedding planes in carbonate rocks forms extremely permeable conduits that conduct large volumes of water through the almost impermeable undissolved rock.*