Understanding Groundwater Starts with the Rocks: Geologic Framework, Groundwater Occurrence and Irrigation Development in Nebraska

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Flat Water: A History of Nebraska and Its Water

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Cover: Whitetail Creek, Keith County, by Anne Burkholder. This painting illustrates the intimate connection between groundwater and surface water as groundwater seeps onto the floodplain and feeds into the creek. Courtesy of Donald F. McGinley.
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and Irrigation Development in Nebraska

Nebraska is blessed with abundant groundwater. This groundwater is found beneath much of the state, principally in the sediments and sedimentary rocks that blanket the ancient and largely crystalline rocks geologists call Precambrian (see block diagram of Nebraska's geology, p. 50). These younger deposits contain pieces of evidence such as fossils and sedimentary features that reveal the tremendous changes in the environment that have gone on over the last 570 million years, during which these deposits accumulated. **Change** is the name of the game in geologic history, just as it is in human history. Fundamental changes in geologic history across the Great Plains states, particularly during the last 66.5 million years (the Cenozoic Era), have had a dramatic role in and effect on the creation or destruction of the state’s water-bearing sediments and rocks.

From the Cambrian Period through the Cretaceous Period of geologic time (570-66.5 million years ago), Nebraska frequently was covered by a shallow inland sea or was a coastal plain where sediments were deposited by rivers and wind. The sediments deposited in the sea range from land-derived sands and muds laid down mostly near shore to lime muds that accumulated either farther offshore or nearshore but away from river mouths, where sands and muds entered the sea. Sediments deposited on the coastal plain when relative sea levels fell were river channel, floodplain and delta deposits, as well as wind-deposited dune sands and silt blankets. Stream and wind erosion periodically outstripped deposition, resulting in the removal of some of the previously accumulated sediments. Land plant cover on the coastal plain aided in developing ancient soils in the upper parts of the sediments there. Through time some of the sediments were hardened by compaction or by the introduction of natural cements that precipitated out as waters moved through these sediments. Other sediments remained relatively unaffected. Countless geology students have remembered this span of earth history generally by the adage, "the seas came in, the seas went out. . . ."

Some may react to the changes just sketched out and ask, "So what?" But the reader whose imagination is still intact can appreciate their enormity. If you have driven across Nebraska, you have a feel for how big the state is. Now imagine covering all of it with a sea perhaps hundreds of feet (continued on next page)

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**Block diagram of Nebraska geology showing distribution of strata (layers) of different geologic ages and major folds and faults (from The Groundwater Atlas of Nebraska, Conservation and Survey Division, IANR, UNL)**
deep. That sea extends from the Appalachians to the Rocky Mountains, or even from coast to coast, and from the Arctic Ocean to the Gulf of Mexico. Now drain off part or all of that sea and then bring it back again to cover parts or all of the former flooded area. Repeat that mental image time after time, and you begin to get a better appreciation of the fantastic things that were taking place across Nebraska. That’s change writ enormous! And if that’s not enough for you, then from time to time have a big meteorite strike the earth and imagine the damage it could do.

More than 30 years ago, Bob Dietz, a highly respected geologist, coined the term \textit{astroblemes} for the impact structures made from such a hit. There is a likely crater site about 67 million years old in west-central Iowa near the town of Manson. Rocks buried under the younger sediments beneath the farm fields there are intensely deformed. A piece of extraterrestrial rock perhaps several billion cubic feet in volume fell out of the sky and hit that spot, creating a huge deformed area of about 300 square miles and blasting up enormous volumes of rock debris into the atmosphere and sending out a shock wave of tremendous force in all directions. Everything standing would have leveled for hundreds of miles around the site and perhaps for years sunlight would have not been able to penetrate the debris cloud that appears to have surrounded the earth, according to geologists at the Iowa Geological Survey and the U.S. Geological Survey. The climatic effects of this and possibly other nearly simultaneous impacts in other areas of the world may have led to the extinctions of dinosaurs and many other life forms at the end of the Mesozoic Era (about 66.5 million years ago).

The seas really “went out” about 66.5 million years ago across most of what is now North America and have not returned to Nebraska or the rest of the Great Plains since. With the exception of a few scattered small sediment remnants of intermediate age, the geologic record in Nebraska is missing from 66.5 to about 38 million years ago. Starting at about 38 million years ago, volcanic eruptions from the Rocky Mountains west and south into Mexico produced vast clouds of volcanic ash that rained down on Nebraska periodically and produced most of the deposits known as the White River and Arikaree groups of rocks (see block diagram of geology). These eruptions became less common beginning about 17 million years ago. Then rivers transported proportionately more sediments eroded from Colorado’s and Wyoming’s Rocky Mountains. These sediments began to be deposited across Nebraska, forming the initial parts of the High Plains (Ogallala) Aquifer.

The High Plains Aquifer underlies most of Nebraska and parts of Colorado, Kansas, New Mexico, Oklahoma, Texas, South Dakota and Wyoming (see map of High Plains Aquifer). The U.S. Geological Survey has included all of the sediments and sedimentary rocks of the White River, Arikaree, Ogallala and most younger sediments beneath the area shown in the aquifer map. The thickest parts of the aquifer and the greatest quantities of water are in Nebraska. This water is generally most abundant in the Ogallala Group and younger Pliocene and Quaternary sediments beneath the Great Plains.

In Nebraska and adjacent areas, the Ogallala Group is composed mostly of mixtures of gravels, sands and silts in varying proportions deposited in complex valley fills. Time after time, rivers eroded valleys and filled them with sediments carried from the mountains to the west, then shifted their courses and began new cycles of cutting and filling. Now and again volcanoes to the west of Nebraska erupted and sent volcanic ash into the atmosphere that settled on the accumulating Ogallala deposits. These deposits were sometimes preserved. Preserved in them sometimes were fossils of ancient life. For example, at the Ashfall Fossil Beds State Historical Park in Antelope County, many ancient rhinoceroses and other animals were buried by ash. Sediments also accumulated in lakes as the sediment pile called the Ogallala accumulated and soils rich in calcium-carbonate formed on land surfaces. To the south, in west Texas, much of the Ogallala is wind-deposited sediments, indicating drier conditions in that area than in Nebraska.

Since the end of Ogallala deposition, riv-
ers continued to cut valleys across parts of Nebraska and to fill them with sediments. General pictures of the changes in river positions through time were worked up in 1990 by three colleagues at the Conservation and Survey Division, V.L. Souders, J.B. Swinehart and V.H. Dreeszen (see map of postulated evolution of Platte River and related drainages, p. 52). The oldest of these river systems crossed Nebraska at about the time that the oldest glacial ice sheets in North America reached eastern Nebraska (see Rolling Hills on topographic regions map, p. 53). Ice sheets also affected that area in the Illinoian glacial advance (see postulated drainages map). Imagine the effect that these river-blocking ice masses at least several hundreds of feet thick had on rivers flowing up to their edges, perhaps ponding those rivers, certainly changing their courses and causing them to deposit sediment upstream. The glacial ice and rivers issuing from the melting ice sheets caused enormous changes, particularly in eastern Nebraska. The former west-to-east drainage pattern was changed to a more north-to-south pattern that is still present. Ogallala and Pliocene-aged aquifers were mostly destroyed in the glaciated part of the state by glacial erosion, and many cubic miles of sediment were washed by glacial melt waters to the Gulf of Mexico. In place of these aquifers, thick deposits of impermeable or poorly permeable glacial till or boulder clays, with a few interbedded river silts, sands and gravels, were left behind.

Ice sheets only made it as far south and west as northeastern Kansas. Rivers to the south were not affected in the same ways as those in Nebraska. River deposits are not so thick and do not cover such a large area there.

Overlying the river sediments are wind-transported silts (loess) beneath the land surface on the Plains, Dissected Plains and parts of the Rolling Hills areas of the state (see topographic regions map). Sand covers the Ogallala and younger river deposits beneath the dunes of the Sand Hills areas. J.B. Swinehart has done extensive studies of the dunes and believes that the dunes we see today formed less than 10,000 years ago in several arid periods separated by wetter times.

Much of the loess and sand blanketing most of the state is less than 50,000 years old. The present river valleys are all very young geologically. River deposits buried directly beneath their floodplains are all probably less than 10,000 years old. During the last 10,000 years the river systems have eroded their valleys more than once and these each time have been filled in places with river-, lake- and wind-deposited sediments. These gravelly fills in ancient, buried valleys are good water-bearing sediments where they can be found. River system erosion across all of Nebraska during this time was responsible for dewatering some of the older parts of the High Plains Aquifer that formerly were saturated but were breached by that erosion.

To further complicate the geologic picture, the sediments and rocks of Nebraska have been folded and faulted in places (see block diagram of geology). Since the geologic bedrock map is such a small-scale map, many of these structures have been omitted. Most of these occur in the Panhandle and in eastern Nebraska. Some of this deformation has been so recent that even sediments as young as the Pliocene have been deformed; even younger deposits may have been too. These folds and faults are responsible for the position and development of at least some Nebraska river valleys and valley fills, and perhaps most of them.

The picture just painted is essentially without life and could lead you to see the Great Plains area as lifeless or as unaffected by events in other parts of the world. But neither of these things was true. The seas and lands teemed with life that migrated, died out locally or became extinct, or originated and expanded to occupy other areas after the environment changed there. These environmental changes were produced by changes in elevation of lands due to mountain uplift or land subsidence, by physical events resulting from volcanic eruptions or meteorite impacts, by changes in the amount of energy received from the sun and by changes in life forms and their impacts on the places where they lived. Life and the non-living earth have affected one another throughout the time that life has been present on the earth, and extraterrestrial forces have affected both as well. Even the formation of our aquifers and river systems here on the Plains were tied inextricably to the interplay of these forces.

**Irrigation and Aquifers**

For the most part, the Cambrian to Cretaceous sediments and sedimentary rocks beneath Nebraska are not important aquifers for one or more of the following reasons: they are often deeply buried and are overlain by better post-Cretaceous aquifers; their water is poorer in quality than that in overlying younger aquifers; or they do not yield any water to wells. The Cambrian to Pennsylvanian sandstones, limestones and dolomites have been used as water sources in parts of eastern Nebraska. The Dakota Sandstone of Cretaceous age is an important aquifer in parts of eastern Nebraska and is used in public, private, irrigation and industrial wells.

For obvious reasons, irrigation development in Nebraska is mostly in the areas underlain by the High Plains Aquifer (see map of registered irrigation wells; compare with postulated drainages map and topographic regions map) with the exception of the Sand Hills. If the soils in the latter area had been better suited to farming, this area would probably be more heavily developed than it is (that it is not suited is an accident of geologic history).

Many people believe that the regional aquifer in Nebraska (or anywhere) is some kind of vast underground lake. It is not; such an idea could not be further from the truth. In reality, most of our aquifers are uncremented sands and coarser grained river deposits. In these the groundwater is present in the spaces between adjacent grains called pores. The porosity formed at the time of sediment deposition and is thus called primary and intergranular (see diagram of types of porosity, p. 53). After the rocks have formed, secondary porosity occurs by fluids dissolving either crystals (intercrystalline porosity), fossil shells (moldic), or fine-grained lime muds (vug porosity) from limestone or dolomites or dissolving cements from sandstones, all of which create cavities. After the sediments have been deposited, larger scale openings (continued on next page)
are produced by fracturing or by solution. Recently, springs exiting from the tops of cylindrical conduits several feet in diameter and many tens of feet deep have been described along the Dismal River by geologists Ann Guhman and Darryll Pederson. These larger scale openings pass through unconsolidated sands and other sediments. Piping or development of narrow conduits through soils by erosion of the earth materials by percolating waters can also produce passages for water movement. If interconnected pores have diameters too small to allow water passage, the aquifer may contain water but is said to be not permeable.

Intergranular porosity occurs in some Cambrian to Permian sandstones, in some Cretaceous sandstones, in White River Group silts, sands and sands and gravels, in Arikaree Group sands and coarser deposits and through most of the Ogallala and younger sediments and sedimentary rocks. Intercrystalline, moldic and vug porosities occur in limestone and dolomites, while porosity due to dissolving cement may occur in sandstones of any age. Fracture porosity occurs mostly in White River Group and older rocks, large-solution cavities in parts of the Niobrara Chalk of Cretaceous Age, and conduits in the post-Ogallala sediments beneath the Sand Hills. Piping and fracturing occur in loess and in some parts of the weathered White River Group. Of all of these, the intergranular porosity mentioned above is the most important in Nebraska's principal aquifer, the High Plains Aquifer.

All of the aquifers, formed from rocks and sediments containing one or more of the porosity types described above, originated from fracturing or by solution. Recently, springs exiting from the tops of cylindrical conduits several feet in diameter and many tens of feet deep have been described along the Dismal River by geologists Ann Guhman and Darryll Pederson. These larger scale openings pass through unconsolidated sands and other sediments. Piping or development of narrow conduits through soils by erosion of the earth materials by percolating waters can also produce passages for water movement. If interconnected pores have diameters too small to allow water passage, the aquifer may contain water but is said to be not permeable.

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Types of porosity (pore space in black): a) primary porosity: small-scale intergranular; b) secondary porosity: small scale (< 1 in. in diameter): B1—intercrystalline; B2—moldic—fossil shells dissolved, rock matrix undissolved; B3—vug—parts of rock matrix dissolved; large scale (usually > 1 in. long or wide): B4—fracture; B5—conduit; B6—solution cavities (caverns); B7—piping in weathered sediments.
nated as a result of the interplay of forces and events carried out over lengthy periods of geologic time. A few seemingly minor changes in these events could have resulted in great changes in our aquifers and in the distribution and flows of our rivers.

—by R.F. Diffendal, Jr., CSD research geologist