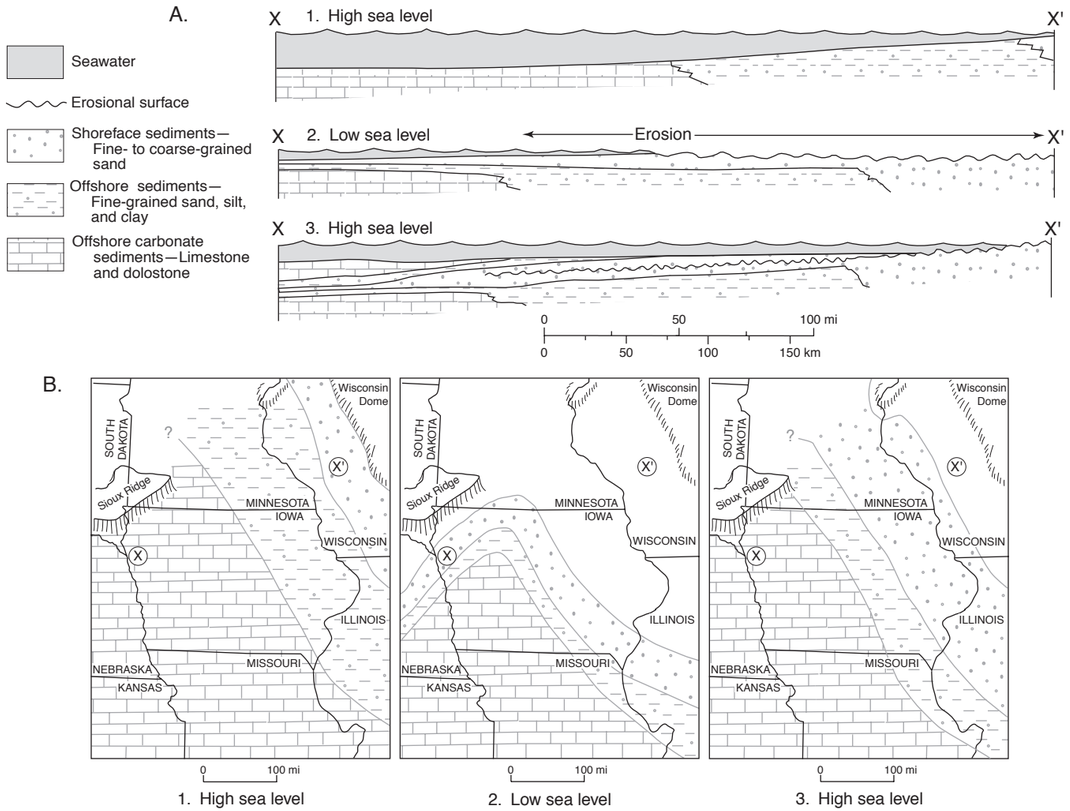

Figure 5. A. Profiles of shallow ocean conditions during the early Paleozoic Era that depict how a widespread layer of sediment is formed during changes in sea level. The layer of sand formed in this example eventually is lithified to become a sandstone bedrock formation (from Mossler, 2000). Location of cross section X–X' is shown on Figure 5B.
B. An aerial view of the sediments that accumulated in the shallow ocean that covered much of southeastern Minnesota and adjacent areas in the early Paleozoic Era. Compare to Figure 5A and note how changes in sea level result in a shifting of the kinds of sedimentary particles that are deposited (modified from Mossler, 2000).

Suggested Reading

Mossler, J.H., 2000, project manager, Contributions to the geology of Mower County, Minnesota: Minnesota Geological Survey Report of Investigations RI-50, 109 p.

———2008, Paleozoic stratigraphic nomenclature for Minnesota: Minnesota Geological Survey Report of Investigations RI-65, 76 p.

Runkel, A.C., 1996, The geology of Whitewater State Park: Minnesota Geological Survey Educational Series 9, 22 p.

Runkel, A.C., McKay, R.M., and Palmer, A.R., 1998, Origin of a classic cratonic sheet sandstone: Stratigraphy across the Sauk II–Sauk III boundary in the upper Mississippi valley: Geological Society of America Bulletin, v. 110, p. 188-210.

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Minnesota at a Glance

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Paleozoic History of Southeastern Minnesota—Ancient Tropical Seas

Imagine a sandy, tropical seashore extending across southern Minnesota—part of a vast, shallow sea that covers much of North America. The sandstone, shale, and limestone rock layers exposed across much of southeast Minnesota (Figs. 1 and 2) are a geologic record of such conditions that existed hundreds of millions of years ago, during the early Paleozoic Era.

Although many people are not aware of the geologic history of the Paleozoic bedrock in Minnesota, the rocks are familiar to anyone who has visited southeastern Minnesota. The bluffs along the St. Croix, Minnesota, and Mississippi Rivers, and their tributaries, are composed of layers of Paleozoic-aged rock such as the St. Peter Sandstone and the Prairie du Chien Group (Fig. 2). Paleozoic rocks lie beneath glacial sediments across much of southeast Minnesota, from as far north as Taylors Falls, southwest to Mankato (Fig. 1). They extend south into Iowa and east into Wisconsin.

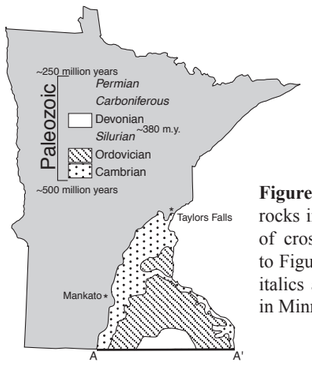

Figure 1. Distribution of Paleozoic rocks in southeast Minnesota. Line of cross section A–A' corresponds to Figure 2. Time periods shown in italics are not represented by rocks in Minnesota.

To understand the detailed history of the rock in southeastern Minnesota, you need only be familiar with the processes of deposition and erosion. These Paleozoic rock layers are sedimentary in origin. They are composed of particles of pre-existing rocks or minerals, or are precipitated by biological or chemical processes. Deposition is the accumulation of particles into layers, or beds. Small grains are dropped by wind or settle in water to form sandstone and shale. Elements, such as calcium, magnesium, carbon, and oxygen precipitate from seawater or are left as biological remains, such as shells, to form what we call calcareous, or carbonate sediments and later rocks—either calcium-rich limestone largely consisting of the mineral calcite, or more magnesium-rich dolostone largely consisting of the mineral dolomite—with much of the magnesium commonly added later by percolating water

Different rocks reflect the environmental conditions present at the time the original sediments were deposited. For example, where sand was scarce, carbonate minerals, chemically precipitated from seawater, and carbonate shells of marine organisms, accumulated to form limestone.

Weathering and erosion are the natural processes whereby water, wind, or ice breaks down rocks and soil and shapes the

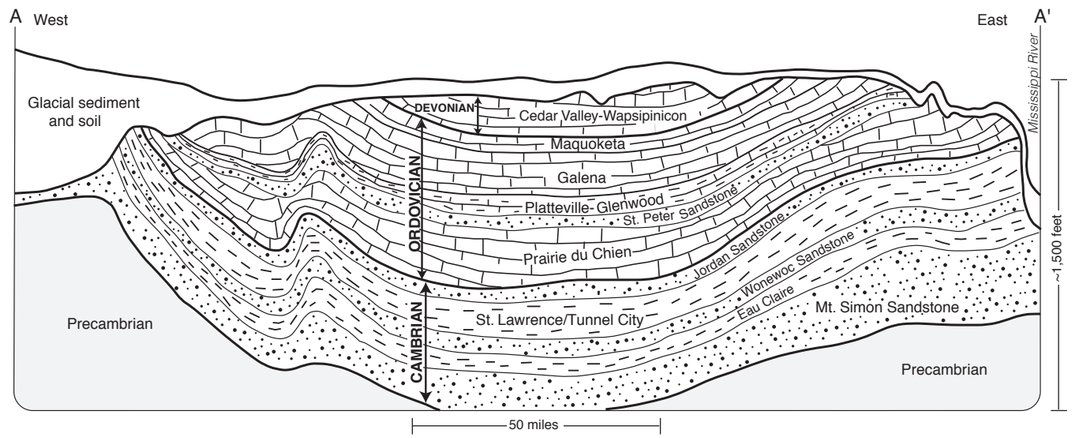

Figure 2. Cross section of bedrock from west to east across southeastern Minnesota. The bedrock consists of sedimentary rock layers composed of sandstone, shale, and carbonate rocks such as limestone. Location of cross section is shown on Figure 1.

land. Weathering can be chemical, such as when water dissolves limestone, or mechanical, such as when wind blows away the soil or glaciers scour the landscape.

DEPOSITION OF PALEOZOIC ROCKS

General Setting

In earliest Paleozoic time, North America was situated on the equator, and Minnesota was a low-lying, mostly flat area. Although the climate was probably tropical, land plants had not yet evolved so the land surface was barren except for some primitive algae and bacteria. Sea level began to rise much higher than it is today, and eventually most of North America was covered by the ocean. As a result, about 500 million years ago, southern Minnesota, Wisconsin, and Iowa became a shallow sea with islands in southwestern Minnesota, near Taylors Falls, and at Baraboo, Wisconsin (Fig. 3). The sea was bordered on the northeast side by higher ground called the Wisconsin Dome. Over the next 130 million years, sediments accumulated as more or less flat layers in this sea. These sediments were later buried and cemented, eventually forming layers of rock. Fossils contained in this rock record life that existed in this ancient sea. They are described in Minnesota at a Glance: Fossil Collecting in the Twin Cities Area.

If you examine the rock exposed in quarry walls, road cuts, or steep hillsides in southeastern Minnesota, you can see that it consists of more than one kind of rock—sandstone, shale, dolostone, and limestone (Fig. 2). The coarsest-grained sandstone layers are composed almost entirely of quartz grains, a mineral consisting of silica—similar in composition to window glass. Other layers are mostly limestone or dolostone—an altered limestone made up of calcium, magnesium, and carbon dioxide. Still other layers are mostly shale, or a mixture of fine-grained sand, shale, and carbonate rock. Geologists have assigned names to these individual rock layers. The names are from places where the rocks are, or were at one time, well exposed. For example, the Jordan Sandstone is named for the city of Jordan, Minnesota; and the St. Peter Sandstone, for the St. Peter (now Minnesota) River near Fort Snelling State Park.

The Paleozoic rock layers are more than 1,500 feet thick in some places, and were deposited over a span of 130 million years during the three geologic time periods known as the Cambrian, Ordovician, and Devonian (Figs. 1 and 2). The manner in which they were deposited varied through time, and is described in greater detail in two parts: 1) Late Cambrian to Late Ordovician time—when the rock layers were deposited as part of a texturally graded shelf; and 2) Devonian time—when the depositional environment was dominated by carbonate deposited in a wider variety of conditions.

Deposition on a Texturally Graded Shelf

To best envision what southeastern Minnesota may have looked like in the Cambrian and much of the Ordovician Periods, picture a sandy coast such as the Gulf of Mexico, but with a barren, mostly lifeless land surface. Sediments deposited in Minnesota at this time consisted mostly of sand, silt, and clay-sized particles that were carried by streams from the Wisconsin Dome to the shoreline. Shallow ocean currents subsequently sorted and

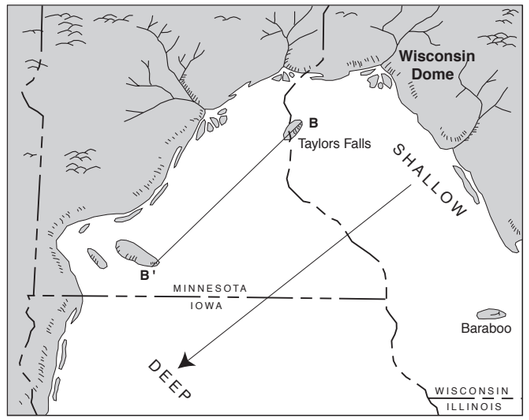

Figure 3. Paleogeographic map of southern Minnesota and adjacent states in early Paleozoic time, when a shallow sea covered much of North America. At times when the sea level was much higher than shown here, most of the state was covered with water. At other times, sea level was much lower and all of Minnesota was dry land. Line of cross section B–B' corresponds to Figure 4. Modified from Runkel (1996).

deposited these sediments forming a *texturally graded shelf* (Fig. 4). The coarsest-grained sand was laid down in a shallow marine environment known as the *shoreface*. The shoreface includes the beach and shallow water nearshore where oceanic waves and currents were relatively strong. At the same time, finer-grained sand, silt, and clay-sized particles carried seaward by storm currents were deposited in deeper water on the offshore shelf. In the deeper parts of the offshore shelf, hundreds of miles from the shoreface, silt and clay-sized particles and carbonate grains slowly settled out of suspension.

The different layers of Paleozoic rocks that stretch across southeastern Minnesota were formed when sea level, and therefore the depth of the ocean, changed through time (Fig. 5). Large changes in sea level led to drastic changes in the position of the sandy shoreface, moving it off of the Wisconsin Dome, and back and forth across southeastern Minnesota. Each time the shoreface passed across southeastern Minnesota, it left behind sandy deposits. The Mt. Simon Sandstone, the oldest Paleozoic Era formation, was deposited during the initial Cambrian Period flooding of Minnesota, during which the shoreface migrated northward when southeastern Minnesota was covered with water. The younger Wonewoc and Jordan Sandstones were deposited during subsequent major sea-level changes. When the sea level fell, the sandy shoreface retreated southward into Iowa, leaving behind a "trail" of quartz sand (Fig. 5). When the sea level rose again, the shoreface moved northward across Minnesota, also leaving behind a trail of sand. The last major shoreface sandstone accumulation is represented by the Ordovician-age St. Peter Sandstone. The St. Peter Sandstone was deposited during a slow rise in sea level that followed an extended period of low sea level and erosion across much of Minnesota.

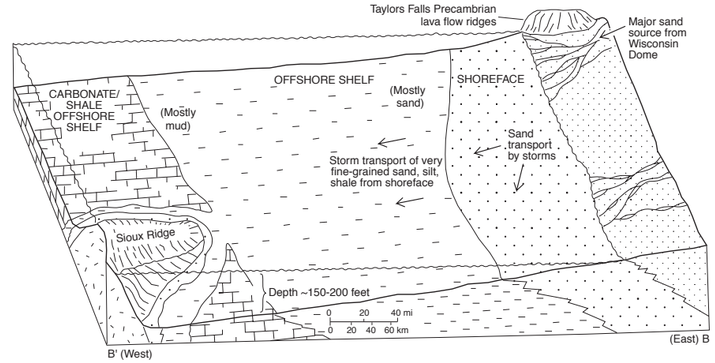

Figure 4. Conceptual model depicting the shallow ocean conditions, known as a *texturally graded shelf*, that existed during much of the early Paleozoic Era in southeast Minnesota. Sand, silt, and clay-sized particles were transported by rivers to the shoreline. Frequent storms sorted the sediment so that the coarsest-grained particles were deposited at the shoreface, where waves and currents were strong, and finer-grained particles were carried seaward, where they settled out in calmer, deeper water. Calcareous particles accumulated far from the shoreline. The different kinds of sedimentary particles eventually became sandstone, shale, and limestone. Modified from Runkel and others (1998).

When sea level was relatively high, the sandy shoreface was on higher ground to the northeast, outside of Minnesota (Fig. 5B). At these times, most of southeastern Minnesota was a large offshore shelf under relatively deep water where clay, silt, and fine-grained sand accumulated. Such offshore shelf deposits form the layers now called the Eau Claire Formation and the Tunnel City Group. Even higher sea level and deeper water led to offshore conditions where only silt, clay, and carbonate particles accumulated. The layers, called the St. Lawrence Formation, Glenwood Formation, and Decorah Shale (the lowest part of the Galena Group), are composed of variable proportions of shale, siltstone, and carbonate sediments deposited in such a setting. When the sea was at its highest levels, nearly all of Minnesota and surrounding areas were flooded, and carbonate deposition occurred in the deep water that covered southeastern Minnesota. Part of the lower Prairie du Chien Group, the Platteville Formation, and the remainder of the Galena Group, were deposited in such deep water. The upper part of the Prairie du Chien Group is an exception; it was deposited in shallow water shoals much like carbonate sediment accumulating in the Bahamas today. The Makoqueta Formation is the last deposit of the texturally graded shelf system. Afterward, sea level fell enough that the shoreline was mostly south of Minnesota for about 60 million years.

Deposition in Carbonate-Dominated Systems

The seas returned to Minnesota in the middle Devonian Period, about 370 million years ago. The shoreline remained at or near extreme south-central Minnesota, rarely, if ever, extending as far north as the Twin Cities area. The uppermost bedrock layers, the Cedar Valley and Wapsipinicon Groups, were laid down at this time (Figs. 1 and 2). Sand was largely absent, even in the shallowest water environments at this time, indicating that Minnesota may have been very low-lying, and perhaps much of its surface was covered with newly evolved vegetation, or by carbonate rock layers such as the Galena Group. Such conditions inhibited erosion across the Wisconsin Dome and nearly eliminated the supply of sand to the shoreline. As a result, deposition was dominated by calcareous sediments at all water depths. Communities of shelled organisms, such as corals, locally accumulated into tropical reefs.

POST-DEVONIAN HISTORY

There are no rocks in Minnesota representing the remainder of the Paleozoic Era and much of the early Mesozoic Era (350 to 100 million years ago [see Minnesota at a Glance: Geologic Time]). For most of this time, the region was above sea level, and the land surface was eroded by wind and water. The sea never became high enough for the shoreline to advance further north than Iowa. The sea returned to Minnesota for the last time about 100 million years ago during the Cretaceous Period, a time when dinosaurs roamed the Earth. Deposits laid down at this time are common beneath the surface of southwest Minnesota, but in southeast Minnesota, only thin, patchy remnants of Cretaceous strata are present.

EROSION OF PALEOZOIC ROCKS

Paleozoic Era rock formations are no longer the continuous layers they were when first deposited in the ocean. Instead, they have been eroded in places by relatively recent geologic activities, particularly during the Ice Age that began about two million years ago. At times, glaciers covered most of the state (see Minnesota at a Glance: Quaternary Glacial Geology). The Paleozoic bedrock of southeastern Minnesota was deeply eroded when large amounts of water from melting glaciers to the north caused the ancient Mississippi, St. Croix, and Minnesota Rivers and their tributaries to erode deeper into their valleys. Thus, the bluffs visible today along the major rivers in southeastern Minnesota are not mountains as early surveyors thought. Instead, they are more or less horizontal layers of Paleozoic rocks that have been carved by water over tens of thousands of years (Fig. 2). Relatively soft formations, such as the Jordan Sandstone, are easily eroded and commonly form the valley floors. Harder, more resistant rocks, such as the Oneota Dolomite and Platteville Formation, stand as cliffs along the valley walls.

If you visit the river bluffs in southeastern Minnesota, take note of the varied rock formations. Remember that these rocks record what the world was like hundreds of millions of years ago when a shallow tropical sea existed right here in Minnesota and across much of central North America.