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LOCATION

From the intersection of (Olmsted) Co. Hwy 2 and U.S. 52 (Main Street) in Chatfield, MN drive south-southeast on U.S. 52 for approximately 3.5 miles (5.6 km) and turn west on 320th Street (gravel road) just before passing over the Root River. You will see a 3.6-4.6 meter (12-15 ft) high dolostone cliffs on either side of U.S. 52 just before the turn (figs. 1 and 2).

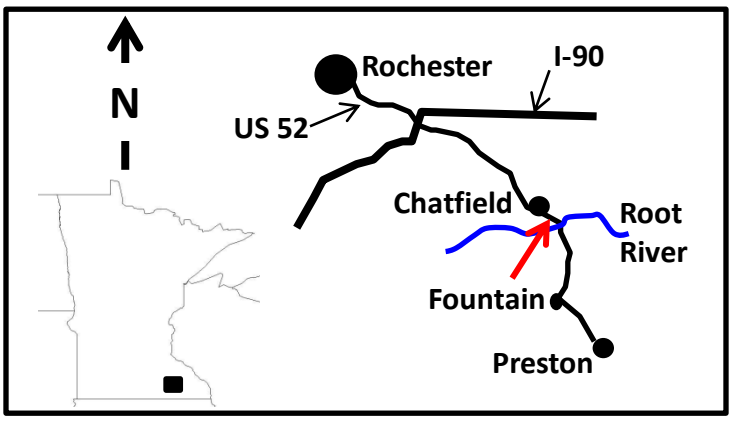

Figure 1. Map showing outcrop locality. Red arrow points to the approximate location of the outcrop

SIGNIFICANCE OF SITE

The Shakopee Formation crops out in road cuts, quarries, and river valleys throughout southeastern Minnesota, southwestern Wisconsin, and northeastern Iowa. In places where exposures of the Willow River Member of the Shakopee Formation occur there are excellent exposures of large, domal algal stromatolites (fig. 3).

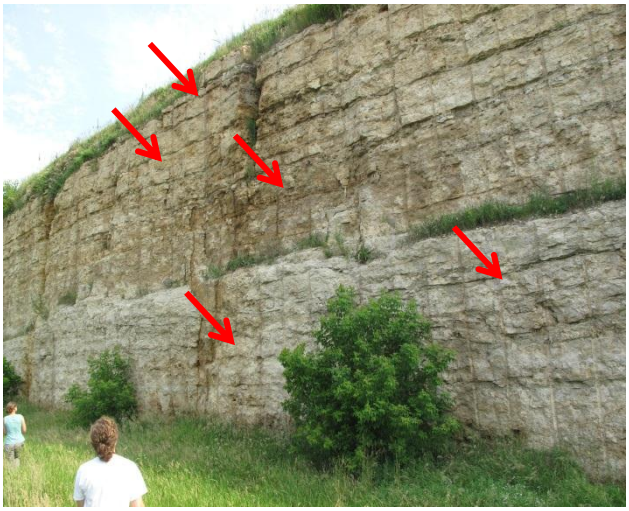

Figure 3. Exposure of the Willow River Member in a large road cut along the north side of U.S. Hwy 61 just west of Red Wing, MN. Red arrows point to the stromatolitic horizons.

Figure 2. Google Earth imagery (dtd 3 July 2011) showing location of stromatolites in dolostone outcrops of the upper Willow River Member of the Shakopee Formation. Due to the roughly north-south and east-west trends of the stromatolite horizons, it is possible to get a sense of the 3-dimensional structure of the environment of these stromatolites.

The Shakopee Formation and General Stratigraphy

The Shakopee Formation was first described by Winchell (1874) for exposures of limestones and dolostones, which crop out along the Minnesota River to the southwest of St. Paul near Shakopee, Minnesota (fig. 4). These strata were part of those described by Owen (1840) as the 'lower magnesian limestone' lying between the 'upper sands' of the St. Peter Sandstone and the 'lower sandstone' of the Jordan Sandstone. Bain (1906) subdivided Winchell's Shakopee Limestone into the lower Oneota Dolomite, the middle New Richmond Sandstone, and the upper Shakopee Dolomite and placed all three formations within the Prairie du Chien Group for the sequence of dolostone, quartz-rich dolostone and quartz sandstone that occur above the Jordan Sandstone and below the St. Peter Sandstone in the upper Mississippi River valley. Davis (1966a) revised Bain's stratigraphy and subdivided the Prairie du Chien Group into the Oneota Formation (lower) and Shakopee Formation (upper) and further

subdivided the Shakopee Formation into the lower New Richmond Sandstone Member and upper Willow River Member.

The lower New Richmond Sandstone Member of the Shakopee Formation was recognized as a quartz sandstone and quartz-rich dolostone. The upper boundary is marked at a thin zone of interbedded, gray-green mudstone (at most localities). The upper Willow River Dolomite Member of the Skakopee Formation was recognized as a dolostone and quartz-rich dolostone and containing abundant, well-developed algal stromatolites. Other than stromatolites, fossils are rare, but when found include inarticulate brachiopods, gastropods, orthocerid nautiloids, and crinoid stems. The Willow River Member of the Shakopee Formation is unconformably overlain by the distinctive St. Peter Sandstone.

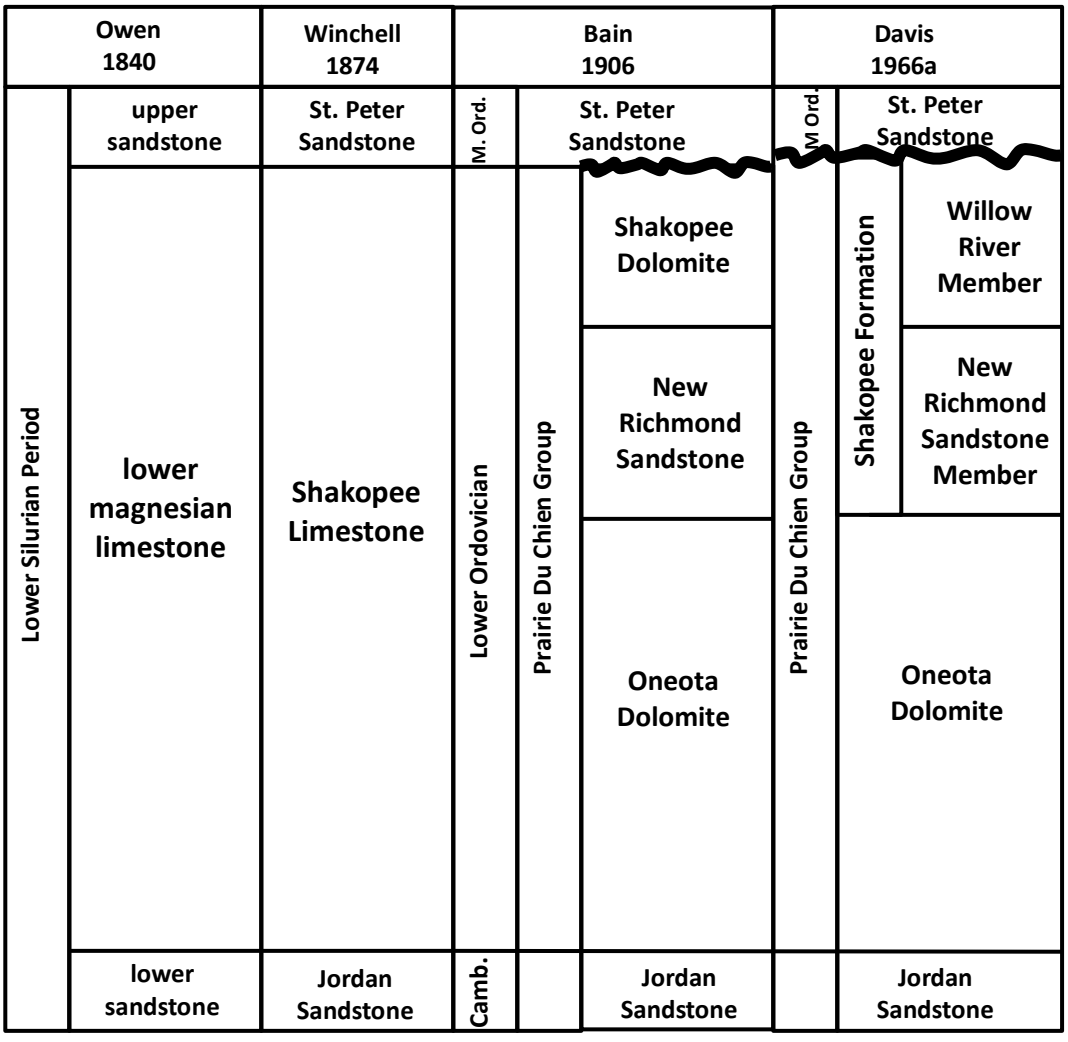

Figure 4. Lower Ordovician nomenclature for strata exposed in southeastern Minnesota, southwestern Wisconsin, and northeastern Iowa. Figure adapted from Davis (1966a).

Stromatolites

The term stromatolite was first used by Kalkowski (1908, p. 68) to describe 'laminated structures of problematical origin'. Later, stromatolites were recognized as laminated structures of both organic and inorganic origins. Logan *et al.* (1964, p. 69) suggested the term 'stromatolite' be preceded by an adjective to define specific types of stromatolites, e.g. algal stromatolite, foraminiferal stromatolite, inorganic stromatolite. In keeping with Logan *et al.* (1964) suggestion, the stromatolites Shakopee Formation are algal stromatolites. They formed through the trapping of fine carbonate and siliceous sediment by cyanobacteria, which created a finely laminated structure. Using the terminology of Logan *et al.* (1964) there are three stages of stromatolite development: (1) formation of descrete cryptozoon structures, with an upward growth expansion of algal laminae, (2) development of algal mats linking two or more cryptozoon structures to form a laterally-linked hemispheroid (L-L-H), and (3) in-filling of void space between cryptozoon structures (fig. 5). Through cryptozoon structures of Stage 1 (fig. 5) can be observed in the Shakopee Formation, Stage 2 and 3 are the more common forms (fig. 6).

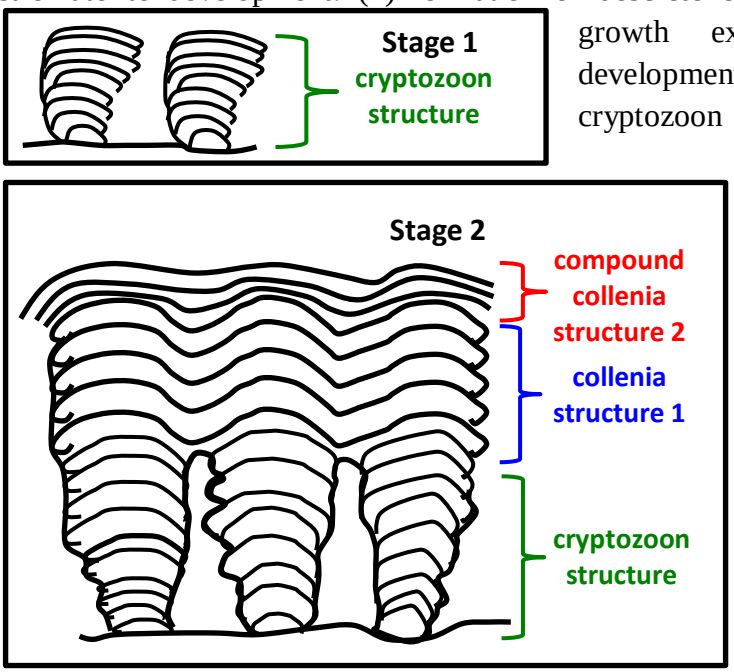

Figure 5. Stages 1 and 2 of stromatolite development as described by Logan *et al.* (1964). Adapted from Logan *et al.* (1964, p. 72, fig. 1).

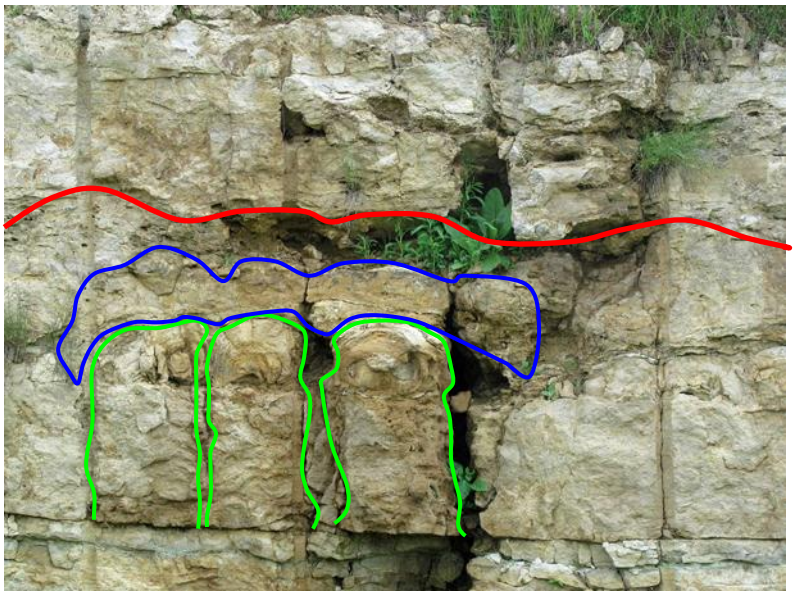

Figure 6. Individual cryptozoon structures are outlined in green; the collenia structure 1 is outlined in blue; and the upper surface of the compound collenia structure 2 is outlined in red.

Outcrop

The outcrop at the intersection of U.S. 52 and 320th Street just north of the Root River provides an opportunity for a 3-dimensional view of an algal stromatolite reef. Multiple algal stromatolite horizons exist in both the east-west and the north-south trending outcrops. The easiest horizon to correlate between the two outcrops has been outline in red in figures 7.

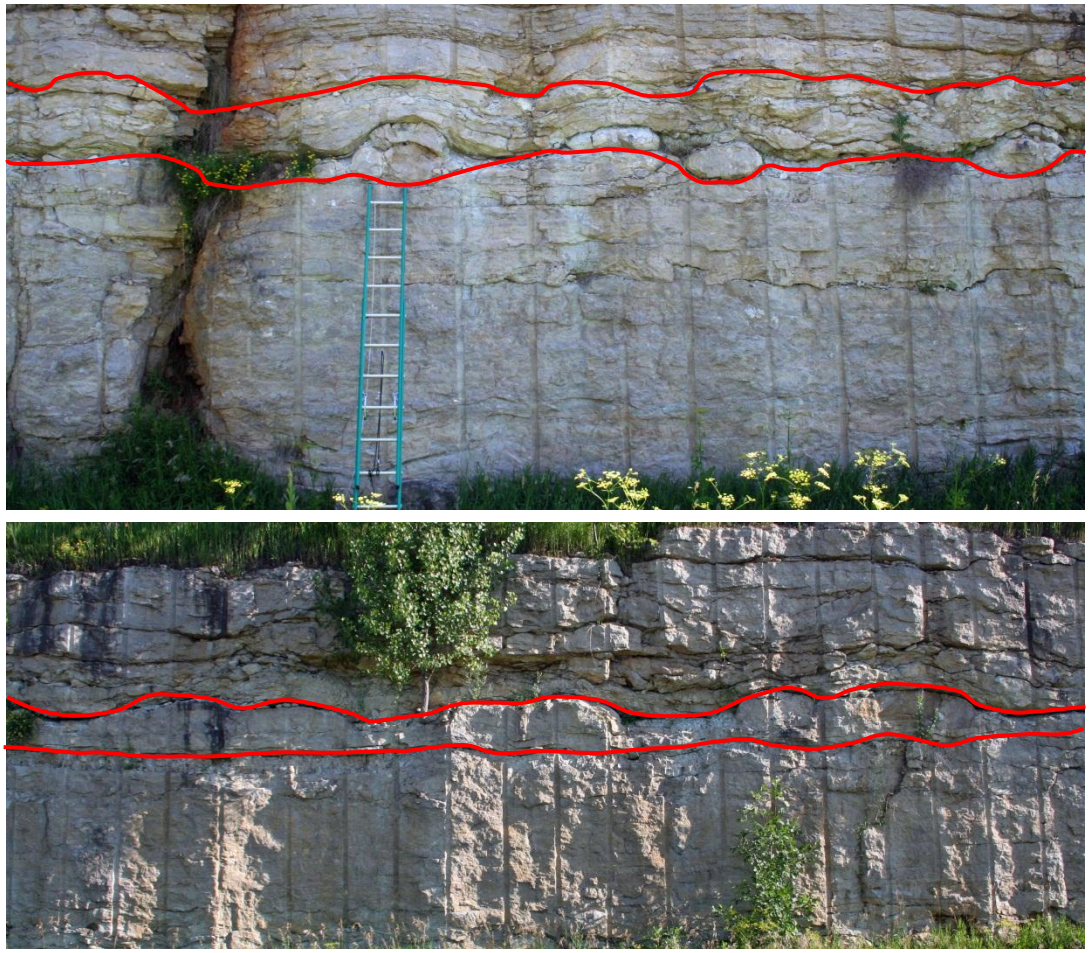

Figure 7. Upper photo is a view to the east along a portion of the north-south trending outcrop (parallel to the U.S. 52). Several algal stromatolite horizons can be observed. The horizon outlined in red is easily correlated with the algal stromatolite in the lower photo along the east-west trending outcrop (parallel to the Root River). **Note** the plant with yellow-colored flowers at the base of the outcrop. This is wild parsnip *(Pastinaca sativa),* which is common in the southeastern Minnesota and contact with the skin should be avoided as a severe and long-lasting rash and skin discoloration can develop.

The carbonate rock in the Willow River Member has been extensively dolomitized, and, unfortunately, algal laminations are indiscernible in thin section. Algal laminations are discernible in cut hand samples, but are more easily recognized on weathered surfaces. Laminations range from 1 to several millimeters. Algal mounds are 0.5 to 1.2 meters in height and can be upwards to 2 meters in diameter (fig. 8). The upper surface of the algal stromatolites,

where observable are typically pustular (fig. 9), which arise from gas bubbles trapped below cohesive microbial mats and can form in emergent and submergent conditions (Schieber, *et al.*, 2004; Schieber, *et al.*, 2007).

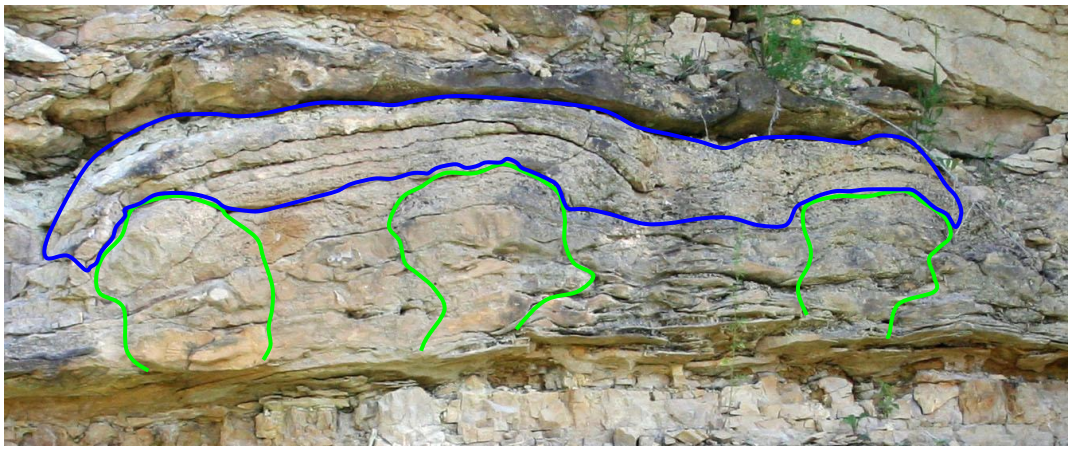

Figure 8. An algal stromatolite in stage 3 development of Logan *et al*. (1964). This algal stromatolite is exposed at the west end of the east-west trending outcrop. The individual cryptozoon structures have been outlined in green, and the collenia structure 1 has been outlined in blue. Individual laminae are extremely difficult to discern in the cryptozoon structures, however micro- and mega-laminae are easily observed in the collenia structure.

Figure 9. Pustular surface often observed on the upper surfaces of Willow River Member algal stromatolites . Pustules range in diameter from 3-6 cm (1-2.5 in) and 1-2.5 cm (.5-1.0 in) in height.

Carbonates of the Willow River Member of the Shakopee were deposited in a warm, intertidal to shallow subtidal waters of the Hollandale Embayment (Davis, 1966b; Austin, 1971). The scarcity of fossils, the presence of salt hoppers as observed by Davis (1966b) and the presence of asymmetrical ripples and mudcracks, suggests a restricted, hypersaline environment. Ripples and mudcracks are readily observable on bedding planes between algal stromatolites in an outcrop approximately 1.8 km (1.1 mi) north along U.S. 52.

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