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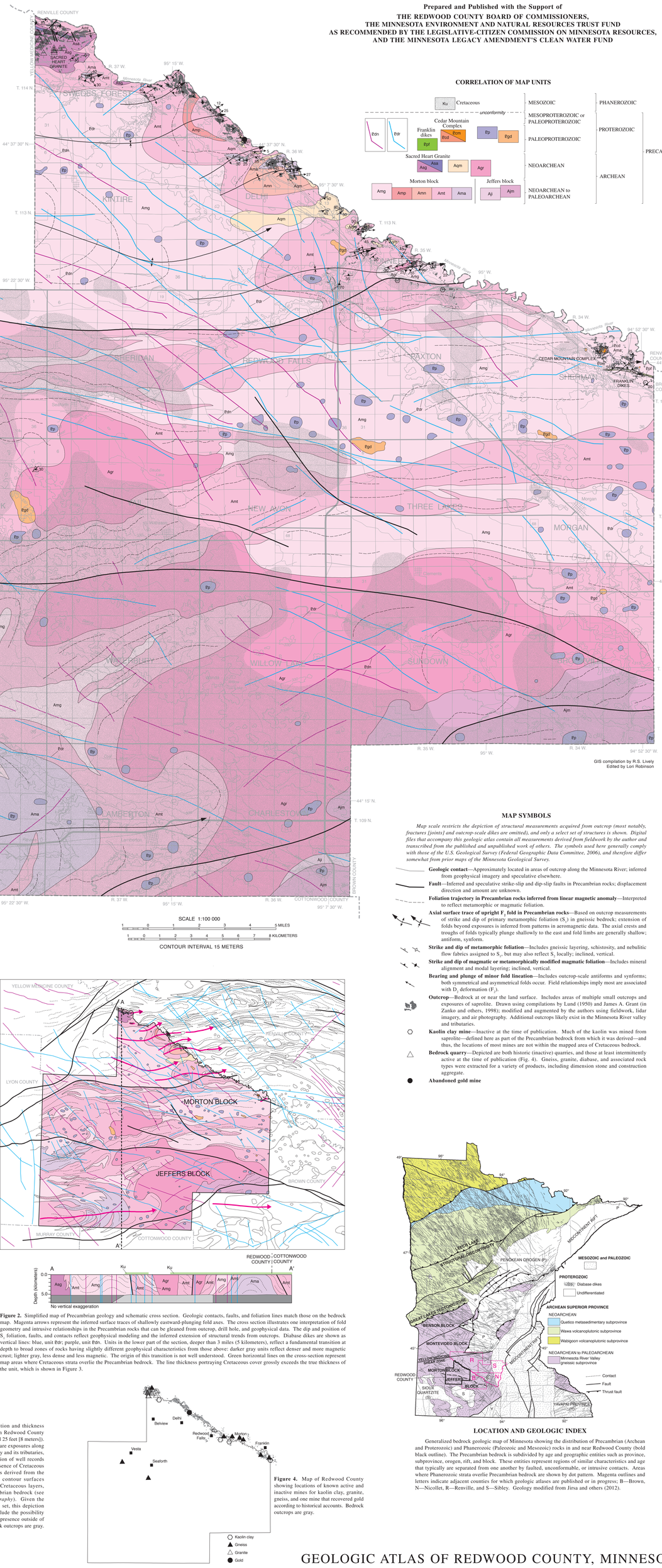
COUNTY ATLAS SERIES
ATLAS C-36, PART A
Redwood County
Plate 2—Bedrock Geology

BEDROCK GEOLOGY

By

Mark A. Jirsa, V.W. Chandler, and Dale R. Setterholm

2016



Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey

Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

SCALE 1:100 000

0 1 2 3 4 5 MILES

0 1 2 3 4 5 6 7 8 KILOMETERS

CONTOUR INTERVAL 15 METERS

GIS compilation by R.S. Lively
Edited by Lori Robinson

CORRELATION OF MAP UNITS

MAP SYMBOLS

Map scale restricts the depiction of structural measurements acquired from outcrop (most notably, fractures [jointe] and outcrop-scale dikes are omitted), and only a select set of structures is shown. Digital files that accompany this geologic atlas contain all measurements derived from fieldwork by the author and transcribed from the published and unpublished work of others. The symbols used here generally comply with those of the U.S. Geological Survey (Federal Geographic Data Committee, 2006), and therefore differ somewhat from prior maps of the Minnesota Geological Survey.

Geologic contact—Approximately located in areas of outcrop along the Minnesota River; inferred from geophysical imagery and speculative elsewhere.

Fault—Inferred and speculative strike-slip and dip-slip faults in Precambrian rocks; displacement direction and amount are unknown.

Foliation trajectory in Precambrian rocks inferred from linear magnetic anomaly—Interpreted to reflect metamorphic or magmatic foliation.

Axial surface trace of upright F_2 fold in Precambrian rocks—Based on outcrop measurements of strike and dip of primary metamorphic foliation (S_2) in geissic bedrock; extension of folds beyond exposures is inferred from patterns in aeromagnetic data. The axial crests and troughs of folds typically plunge shallowly to the east and fold limbs are generally shallow; antiform, synform.

Strike and dip of metamorphic foliation—Includes gneissic layering, schistosity, and nebulitic flow fabrics assigned to S_2, but may also reflect S_1 locally; inclined, vertical.

Strike and dip of magmatic or metamorphically modified magmatic foliation—Includes mineral alignment and modal layering; inclined, vertical.

Bearing and plunge of minor fold lineation—Includes outcrop-scale antiforms and synforms; both symmetrical and asymmetrical folds occur. Field relationships imply most are associated with D_2 deformation (F_2).

Outcrop—Bedrock at or near the land surface. Includes areas of multiple small outcrops and exposures of saprolite. Drawn using compilations by Lund (1950) and James A. Grant (in Zanko and others, 1998); modified and augmented by the authors using fieldwork, lidar imagery, and air photography. Additional outcrops likely exist in the Minnesota River valley and tributaries.

Kaolin clay mine—Inactive at the time of publication. Much of the kaolin was mined from saprolite—defined here as part of the Precambrian bedrock from which it was derived—and thus, the locations of most mines are not within the mapped area of Cretaceous bedrock.

Bedrock quarry—Depicted are both historic (inactive) quarries, and those at least intermittently active at the time of publication (Fig. 4). Gneiss, granite, diabase, and associated rock types were extracted for a variety of products, including dimension stone and construction aggregate.

Abandoned gold mine

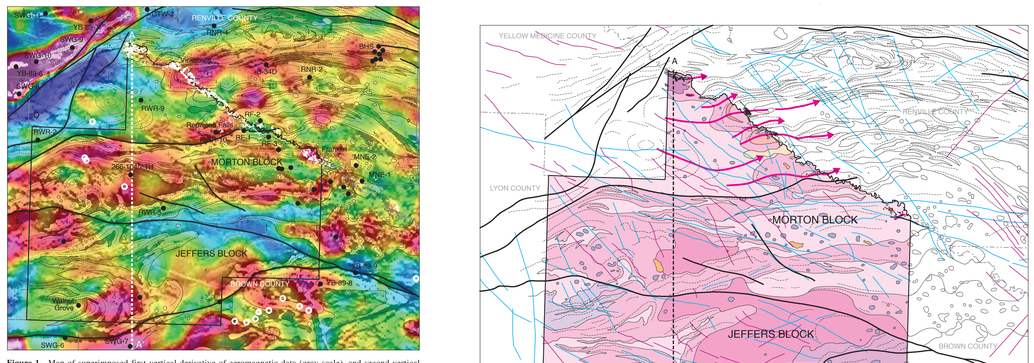


Figure 1. Map of superimposed first vertical derivative of aeromagnetic data (gray scale), and second vertical derivative of gravity anomaly data (color) in the Redwood County area. The aeromagnetic imagery reflects the amount of magnetite in the bedrock—light shades have larger magnetite content; dark shades, less. Variations in the gravity data reflect differences in the density or specific gravity of Precambrian bedrock types; the most dense, typically mafic rock; blues are less dense, typically granitic rock. Various simplified elements of Precambrian bedrock geology are shown in Redwood and adjacent Renville (Jirsa and others, 2013) and Brown (Boerboom and Steenberg, in press) Counties. The map depicts Archean and Proterozoic geologic contacts (thin black lines), faults (thick black lines), and foliation trajectories (dashed black lines). Foliation trajectories reflect patterns mapped S_2 foliation measurements made at outcrops. Control for the interpretation of Precambrian bedrock geology is shown, including drill holes that intersected bedrock (solid black circles), outcrops along the Minnesota River valley (white polygons), and small outcrops that lie outboard of the Minnesota River valley (white circles). The small outcrops in western Brown County lie within a thin veneer of Proterozoic Sioux Quartzite, and the outcrop in eastern Brown County exposes Cretaceous sedimentary strata—neither unit is portrayed separately on this image, largely because both are transparent to the geophysical techniques employed here. Drill holes for which sample materials (core or cuttings) are available are labeled with a drill hole number—see Plate 1 (*Data-Base Map*) for details. The location of geologic cross section A–A' depicted in Figure 2 is shown by a dashed white line.

Figure 2. Simplified map of Precambrian geology and schematic cross section. Geologic contacts, faults, and foliation lines match those on the bedrock map. Magenta arrows represent the inferred surface traces of shallowly eastward-plunging fold axes. The cross section illustrates one interpretation of fold geometry and intrusive relationships in the Precambrian rocks that can be gleaned from outcrop, drill hole, and geophysical data. The dip and position of S_2 foliation, faults, and contacts reflect geophysical modeling and the inferred extension of structural trends from outcrops. Diabase dikes are shown as vertical lines: blue, unit Edr; purple, unit Edn. Units in the lower part of the section, deeper than 3 miles (5 kilometers), reflect a fundamental transition at depth to broad zones of rocks having slightly different geophysical characteristics from those above: darker gray units reflect denser and more magnetic crust; lighter gray, less dense and less magnetic. The origin of this transition is not well understood. Green horizontal lines on the cross-section represent strata. Cretaceous strata overlie the Precambrian bedrock. The line thickness portraying Cretaceous cover grossly exceeds the true thickness of the unit, which is shown in Figure 3.

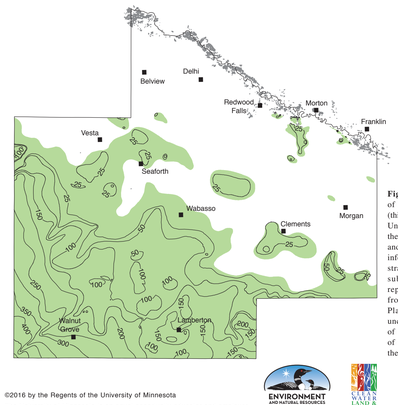


Figure 3. Map distribution and thickness of Cretaceous bedrock in Redwood County (thickness contour interval 25 feet [8 meters]). Unit outline is based on rare exposures along the Minnesota River valley and its tributaries, and on the distribution of well records inferred to report the presence of Cretaceous strata. Unit thickness is derived from the subtraction of gridded contour surfaces representing the top of Cretaceous strata from the top of Precambrian bedrock (see Plate 5, *Bedrock Topography*). Given the uncertainties of the data set, this depiction of the unit does not preclude the possibility of its absence within, or presence outside of the areas shown. Bedrock outcrops are gray.

Figure 4. Map of Redwood County showing locations of known active and inactive mines for kaolin clay, granite, gneiss, and one mine that recovered gold according to historical accounts. Bedrock outcrops are gray.

LOCATION AND GEOLOGIC INDEX

Generalized bedrock geologic map of Minnesota showing the distribution of Precambrian (Archean and Proterozoic) and Phanerozoic (Paleozoic and Mesozoic) rocks in and near Redwood County (bold black outline). The Precambrian bedrock is subdivided by age and geographic entities such as province, subprovince, orogen, rift, and block. These entities represent regions of similar characteristics and age that typically are separated from one another by faulted, unconformable, or intrusive contacts. Areas where Phanerozoic strata overlie Precambrian bedrock are shown by dot pattern. Magenta outlines and letters indicate adjacent counties for which geologic atlases are published or in progress; B—Brown, N—Nicollet, R—Renville, and S—Sibley. Geology modified from Jirsa and others (2012).

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Abandoned gold mine

INTRODUCTION

This map is an interpretation of bedrock geologic units exposed and covered by glacial sediment in Redwood County. This is one of several counties along the Minnesota River valley that have a long history of geologic study related to the antiquity of the bedrock, and commercial interest in quarrying, clay mining, and speculation about lignite and other resources. The interpretation presented here builds on previously published and unpublished geologic mapping, augmented with various types of drill hole data (see Plate 1, *Data-Base Map*), geophysical data, and fieldwork by the authors. It integrates many of the bedrock geologic units defined in adjacent counties including Renville (Jirsa and others, 2013) and Brown (Boerboom and Steenberg, in press); though some of the unit names differ slightly across county boundaries. The bedrock ranges in age from Paleoarchean (approximately 3,600 to 3,200 Ma, or million years old) to Late Cretaceous (approximately 90 Ma), and records a complex history involving multiple igneous, sedimentary, metamorphic, and tectonic events, as well as significant episodes of weathering and erosion. The geologic interpretation of Precambrian bedrock (rocks older than approximately 540 Ma) in most areas of the county is based on geophysical maps that show diffuse bands of varied geophysical expression. Where these geophysical patterns are intersected by drill holes, or cross areas of exposed bedrock in the Minnesota River valley and its tributaries, the outcrops typically show a complex mixture of rock types (Fig. 1). It is challenging to reconcile rock types at the map scale in the narrow exposure area with those in the remainder of the county where bedrock is buried. Measurements of magnetic susceptibility of various lithologic components within outcrops helped to assign specific rock types to the various aeromagnetic anomaly signatures. Nevertheless, parts of this interpretation that lie some distance from exposures and drill holes are uncertain. The distribution of Cretaceous bedrock is similarly uncertain, as it is based on scant exposures in valleys, and the extension of the exposed units to other parts of the county using drilling records that contain lithologic descriptions sufficiently detailed to allow differentiation.

GEOLOGIC SETTING

Archean and Proterozoic bedrock

Redwood County contains evidence of major geologic events in the crustal evolution of the North American continent during two time periods of the Precambrian—known as the Archean (4,000 to 2,500 Ma) and Proterozoic (2,500 to 540 Ma) Eons. The older of these events is the formation of gneisses during the Archean Eon in the Minnesota River Valley subprovince of the Superior Province (see Location and Geologic Index). Exposures along the Minnesota River valley have long been the subject of geologic investigations (for example Hall, 1899), and numerous geologic summaries exist (including Lund, 1956; Grant, 1972; Bauer and others, 2011; Southwick, 2014). The Minnesota River Valley subprovince is divided into largely fault-bounded blocks, each having distinctive attributes (Southwick and Chandler, 1996; Southwick, 2002). Redwood County straddles two of those blocks—the Morton block to the north, and the Jeffers block to the south (Fig. 2). Both are characterized by gneissic bedrock, but they differ somewhat in apparent composition of the gneisses contained therein. The Morton block contains tonalitic to granitic migmatitic orthogneiss (derived from an intrusive precursor or protolith) with amphibole-rich inclusions, and paragneiss having supracrustal (layered sedimentary and volcanic rock) protoliths. Judging from rare exposures and drill core in Brown County to the east and geophysical attributes, the Jeffers Block is similar, differing primarily by having somewhat greater gravity anomaly expression. The rocks in both blocks were metamorphosed to upper amphibolite facies, and intruded by granitic neosome that occurs as diffuse pods, lenses, and discrete bodies. The two blocks are separated by a large granitic intrusion and an unnamed fault that is not everywhere apparent on geophysical maps. The complexity and high metamorphic rank of the gneisses in both blocks indicate that they are uplifted and eroded remnants of moderately deep levels of the crust from 12 to 19 miles (20 to 30 kilometers) depth.

The complex intrusive, metamorphic, and deformation history of the gneisses and intrusions has been partially unraveled by high-precision U-Pb geochronologic study of samples collected in Redwood and adjacent counties. The oldest components of the gneissic bedrock range in age from 3,535 ± 4 Ma (Bickford and others, 2006) to 3,422 ± 1 Ma (Schmitz and others, 2006). Collectively, the ages from Bickford and others (2006) and Schmitz and others (2006) indicated that gneisses were formed in Paleoarchean time (3,600 to 3,200 Ma), were then partially melted, multiply intruded, deformed, and metamorphosed during Mesoarchean (3,200 to 2,800 Ma) and Neoarchean (2,800 to 2,500 Ma) time, and intruded by granitic magmas at about 2,600 Ma. The geochronologic data are consistent with the interpretation that the Minnesota River Valley subprovince represents one or more continental masses that were accreted to the evolving North American continent along the Great Lakes Tectonic Zone (see Index map)—a process that was largely complete by about 2,600 Ma.

Geologic mapping by the authors and structural analyses by Lund (1956), Grant (1972), and Bauer (1980) indicated that the gneissic bedrock underwent two major periods of regional deformation (designated D_1, D_2), and two later events that can be distinguished locally (Bauer, 1980). The D_1 event produced high-grade metamorphism, localized melting and melt dispersion, and gneissic foliation (S_1). The S_1 foliation and the limbs of associated fold structures (F_1) are nearly horizontal in many places. The D_2 event folded S_1 fabric into shallowly northeast-plunging antiforms and synforms (F_2 folds), and produced localized foliation (S_2) subparallel to fold axes and zones of semi-ductile shear. The D_2 deformation was the result of crustal shortening during the Neoarchean (approximately 2,680 Ma) Minnesotan Orogeny (Percival and others, 2006). The apparent complexity of map patterns is the combined result of open, shallowly plunging F_2 folds imposed on early-formed, subhorizontal S_1 metamorphic fabric, and the interdigitate nature of many of the Archean units.

The gneissic bedrock in both blocks is cut by a variety of intrusions, including granite, granodiorite, diorite, and quartz monzonite of likely Archean age (units Asg, Asa, Aqm, Agr); discretely bounded mafic to felsic intrusions (units Ep, Epm, Ecd, Egd) that are inferred to be Proterozoic in age; and diabasic dikes (units Edn, Edr, Epf) of Paleoproterozoic (approximately 2,500 to 1,600 Ma) and perhaps Mesoproterozoic (approximately 1,100 Ma) age.

Saprolite

A mantle of weathered rock known as saprolite covers most of the Precambrian bedrock surface in Redwood County. Saprolite is a residuum formed during long periods of extensive chemical weathering that converted some to nearly all of the minerals in the near-surface Precambrian bedrock into clay minerals. Chemical weathering is carried out by fluids generated at the land surface moving into the rock, typically along fractures. The process generally creates a relatively uniform gradient of decreased severity of weathering with depth; however, preferential fluid movement along fractures can also leave corestones of unweathered rock surrounded by planar zones of heavily weathered materials. Locally, this weathering process was so complete that the resulting kaolin-rich clays are suitable for ceramic, brick, and other uses (Zanko and others, 1998). Typically the uppermost parts of saprolite horizons are the most weathered, and original igneous and metamorphic fabrics are not discernible. In these zones, even the protolith (the original, pre-weathering rock type) cannot be established with certainty. In the deeper, less weathered horizons, original fabrics of protoliths are locally preserved, despite partial replacement of feldspar and other minerals by various clays. Based on scant drill hole data, saprolite varies in thickness from zero to several hundred feet. A detailed study of saprolite in the Redwood Falls area and other parts of Minnesota (Setterholm and Morey, 1995) indicated that saprolite can be considerably thicker, especially along steeply dipping fractures that presumably allowed deep penetration of groundwater. The timing of weathering that produced saprolite is unknown; however, this type of alteration typically requires prolonged tropical climatic conditions, which were common in the Cretaceous Period (approximately 145 to 65 Ma), but also occurred during other time periods prior to the Cretaceous. Saprolite is covered by and locally incorporated into overlying Cretaceous sedimentary strata (unit Ku), implying that at least some of the weathering occurred before or during the Cretaceous Period. Saprolite is not mapped as a separate unit here because: 1. It typically is gradational with underlying, less weathered bedrock; 2. It appears to be present nearly everywhere in the county, except along the Minnesota River valley and some tributary valleys, where it presumably was partially removed by erosion; and 3. Saprolite can