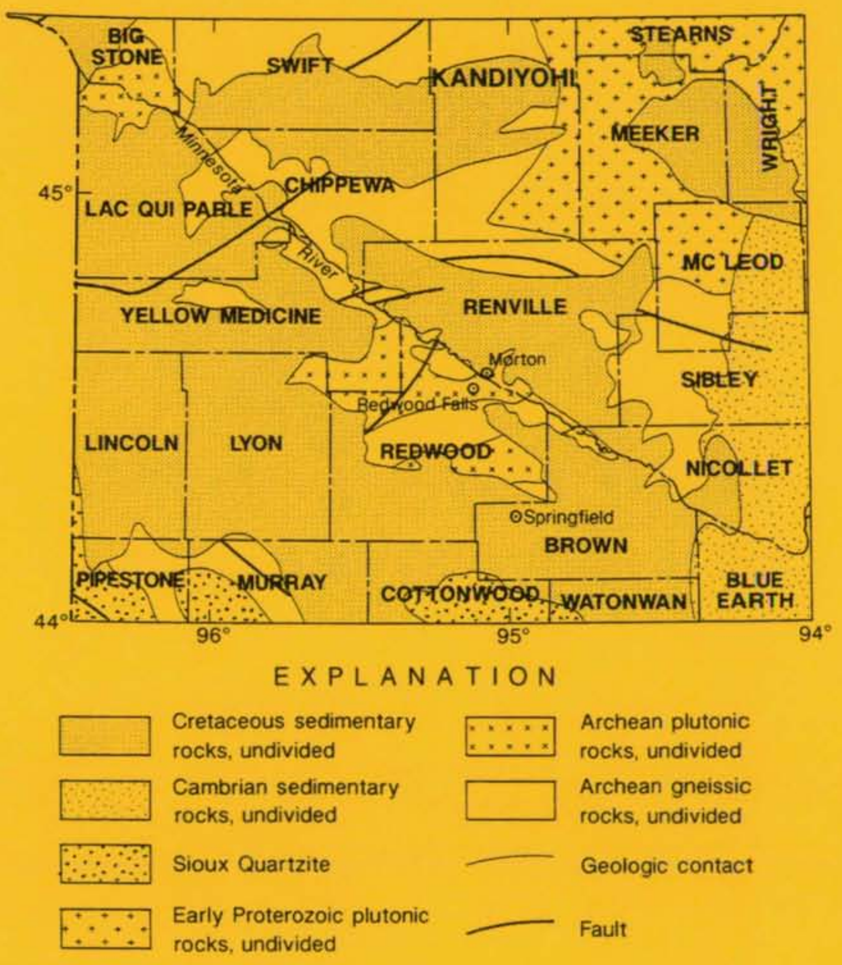
KAOLINITIC CLAYS OF THE MINNESOTA RIVER VALLEY AND SOUTHWESTERN MINNESOTA



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KAOLINITIC CLAYS OF THE MINNESOTA RIVER VALLEY AND SOUTHWESTERN MINNESOTA

Dale R. Setterholm
Minnesota Geological Survey
and
John J. Heine
Natural Resources Research Institute

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Introduction

A thick mantle of chemical weathering products covers crystalline bedrock of Archean and Proterozoic age in much of central and western Minnesota. The mantle has a vertical profile typically composed of progressively more weathered material upward from fresh bedrock to an erosion surface now covered either by strata of Late Cretaceous age or by glacial and postglacial deposits of Quaternary age. In a pioneering study of regional relationships, Parham (1970) showed that most upland areas underlain by crystalline bedrock in western Minnesota have weathering profiles averaging 30 m in thickness, though profiles as great as 60 m thick may be present locally. Weathered materials are considerably thinner on steep side slopes and absent in many places along valleys cut into the bedrock surface. Nonetheless, their widespread occurrence has created considerable commercial interest.

Much of our knowledge of the processes responsible for the origin of the weathering profile in southwestern Minnesota was established by S.S. Goldich in a 1936 University of Minnesota doctoral dissertation entitled "A study in rock weathering" (Goldich, 1938). Six samples of saprolite from the Redwood Falls–Morton vicinity in the Minnesota River Valley were compared chemically and mineralogically with fresh Archean gneiss, their probable parent material. Using these data, together with data from elsewhere, Goldich established an alteration sequence in which calcium-rich plagioclase was transformed to clay, followed by the dissolution of the potassium-rich feldspar and other mafic minerals. These observations are embodied in the so-called Goldich stability series, which in one form or another is taught to every beginning student in geology.

The precise age of the saprolith and rate at which it was produced remain unresolved. It is overlain in many places by stratified sedimentary rocks that are most probably Late Cretaceous (Cenomanian and younger) in age (Parham, 1970; Setterholm, 1990). Therefore the weathering is assumed to be an Early Cretaceous event (Parham, 1970).

A kaolinite-rich saprolite was first described from outcrops along the Minnesota River valley in southwestern Minnesota (Winchell, 1874). Interest in commercial development of kaolinite followed shortly thereafter and has occurred cyclically since (Upham, 1888; Hall, 1899; Hall and others, 1911; Grout and Soper, 1919; Bickford and Price, 1947; Parham, 1970; Setterholm and others, 1989). Much of that time, the only sustained commercial use of the deposits has been to produce material for bricks. More recently, clay from three localities along the Minnesota River Valley has been used for filler in cement. Of probably greater economic importance is the possible suitability of certain kaolin-rich components of the regolith in other industrial applications, such as high-technology ceramics and pharmaceuticals. These and other unconventional uses are currently being investigated by the state of Minnesota (Hauck and others, 1990, 1991). The use of these clays in the paper industry—for example, as high-grade paper coating—is also receiving considerable interest; several thousand acres of land have been leased in the current round of exploration.

Residual Weathering Deposits

The residual weathering deposits represent a gradational transition from fresh igneous or metamorphic rock to totally weathered residuum. This transition can be divided into four zones (Fig. 1). Just above the fresh rock is a zone of **slightly weathered rock** a few centimeters to a few tens of centimeters thick. This zone is characterized by alteration of the rock on fracture faces only, and no clay minerals. The next zone, **saprock,** is a fairly rigid product with appreciable clay content. The lower part of the saprock is characterized by hornblende partially altered to green clay (chlorite and smectite) and unaltered quartz, biotite, and potassium feldspar. In the upper part of the saprock zone nearly all the hornblende has been altered to chlorite and much of the green clay is a mixture of illite and kaolinite. Plagioclase has been replaced by a white clay consisting of kaolinite and illite, and biotite has been replaced by vermiculite. These alterations are mostly isovolumetric. Above the saprock lies **saprolite**, a less indurated product. At the base of this zone hornblende is completely dissolved, as is most of the plagioclase. In this lower part of the saprolite, textural attributes of the parent rock remain. Moving upward, biotite and potassium feldspar decrease and kaolinite increases in abundance. At the level where nearly all the biotite and potassium feldspar disappear, the parent rock textures are lost, non-isovolumetric processes can prevail, and kaolinite and minor quartz dominate the mineralogy. The highest zone in the weathering profile is a zone of **pisolitic, lateritic clay**. The pisolites are kaolinite-rich and commonly hollow or partly filled with pyrite. The groundmass is mostly kaolinite and halloysite with lesser quartz, gibbsite, and goethite.

The extent to which weathering has progressed at any point within the weathering profile can be characterized from whole-rock chemical analyses and the index of

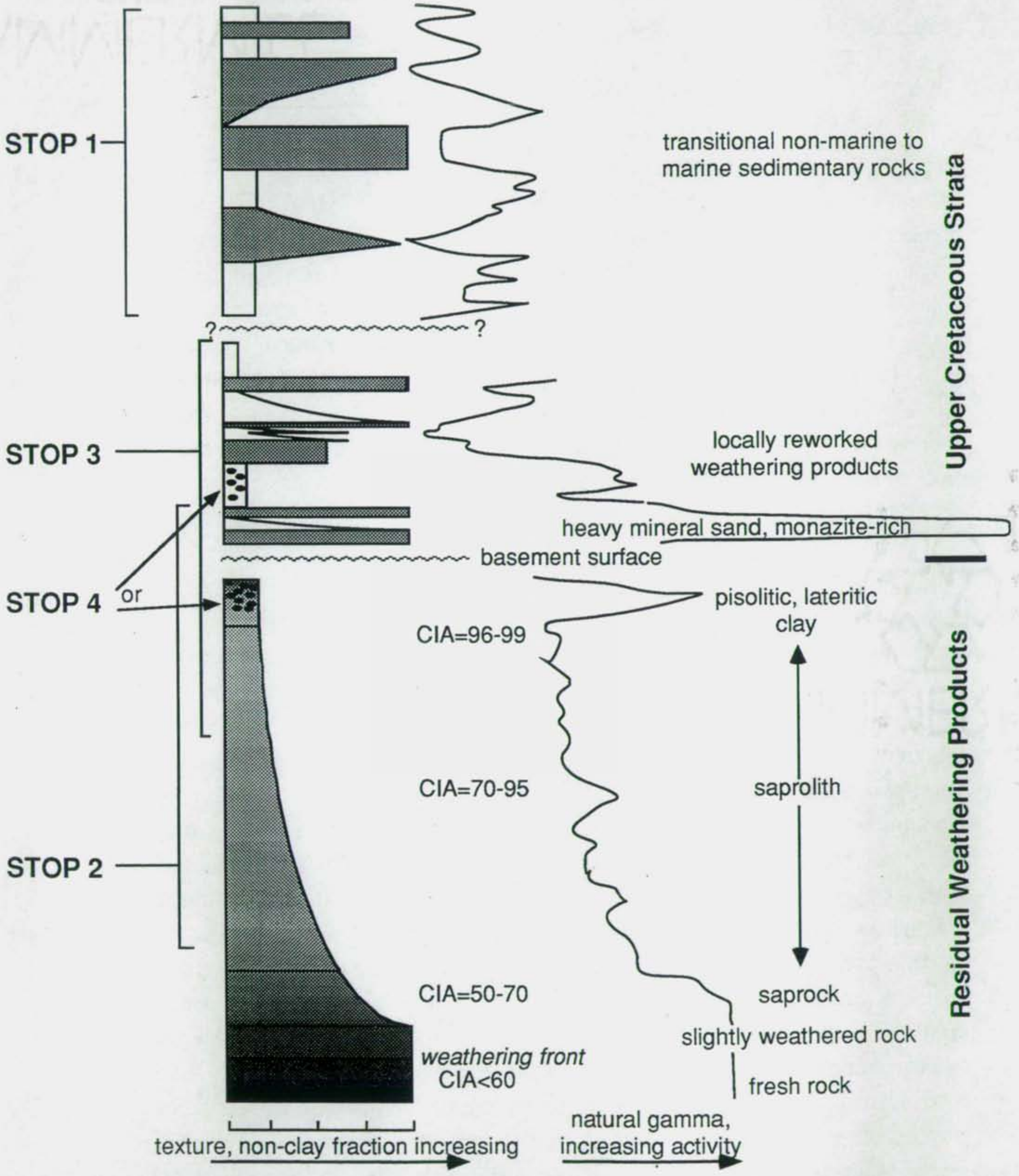


Figure 1. An idealized composite stratigraphic section showing the chemical, textural, and natural gamma characteristics of the stratigraphic units observed on this trip.

chemical alteration. This index (CIA) is calculated from the chemical data by using molecular proportions in the formula

$$CIA = [Al_2O_3 / (Al_2O_3 + CaO + Na_2O + K_2O)] \times 100$$

where CaO is the amount of CaO incorporated in the silicate fraction of the rock. Because feldspars are some of the most abundant minerals in the upper crust, the dominant process during chemical weathering involves the degradation of feldspars and the concomitant development of clay minerals. In that process, calcium, sodium, and potassium are generally removed from the weathered profile as kaolin deposits form. Thus, the ratio of alumina to the alkalis typically increases as weathering progresses. Unaltered granitoids typically have CIA values between 45 and 55, whereas kaolinite has a value very close to 100. Nesbitt and Young (1984, 1989) have shown that these chemical changes mimic those predicted from kinetic leaching data for alkalis and calcium from feldspars. The ternary diagrams in Figure 2 relate these chemical changes to the zones of weathering used in this paper.

Upper Cretaceous Sedimentary Rocks

The Upper Cretaceous rocks of southwestern Minnesota are the products of deposition in or adjacent to the Western Interior Seaway. The exposures we will examine on this trip represent fluvial and deltaic deposition (fresh to brackish water) before the seaway fully transgressed this area. These rocks are Late Cenomanian or older (>95 m.y.). The Upper Cretaceous sedimentary rocks immediately above the residual weathering products are characterized by white kaolinitic shale and quartz sandstone. At several locations pisolitic intervals similar to those occurring at the top of the weathering profile have also been observed within this sedimentary sequence. Erosion and transport of the residual materials have sorted them by grain size and thereby formed clay deposits of higher grade in some places. The angularity of the quartz grains suggests they have not been transported very far. In those places where more substantial thicknesses (>15 m) of Upper Cretaceous rocks have accumulated, kaolinite is less abundant, and illite and montmorillonite are more abundant higher in the section. This reflects the contribution of materials from the encroaching Western Interior Seaway and possibly from upland areas where chemical weathering products are not present (such as southeastern Minnesota). In this zone of transition between marine and non-marine environments, abrupt and frequent changes in the energy and chemistry of the

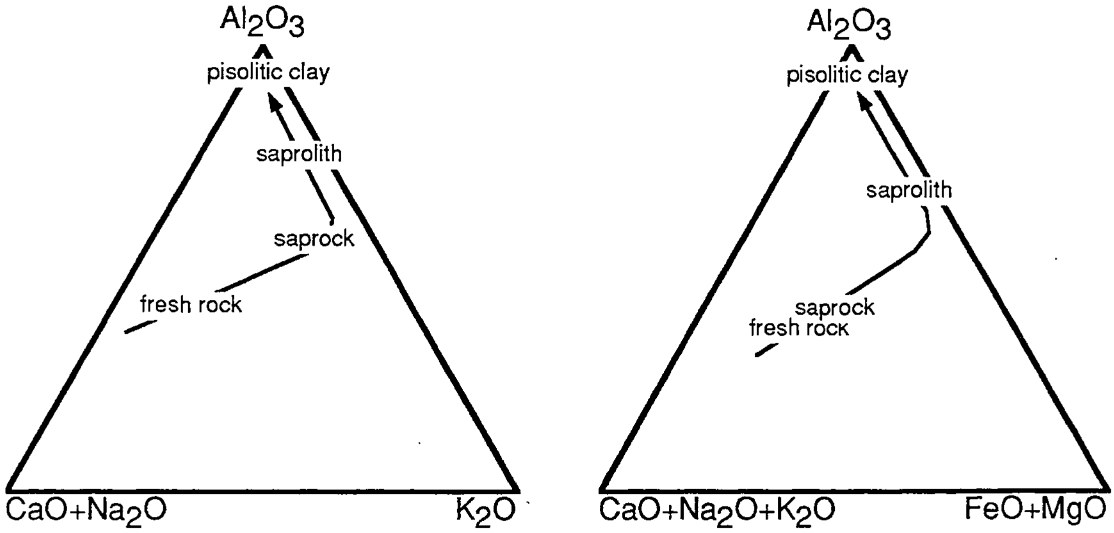


Figure 2. Chemical changes in a residual weathering profile. The difference in composition of *slightly weathered rock* from that of *fresh rock* cannot be distinguished on this plot.

depostional environment are represented in the rock record by relatively thin beds of widely varying grain size.

Stop Descriptions

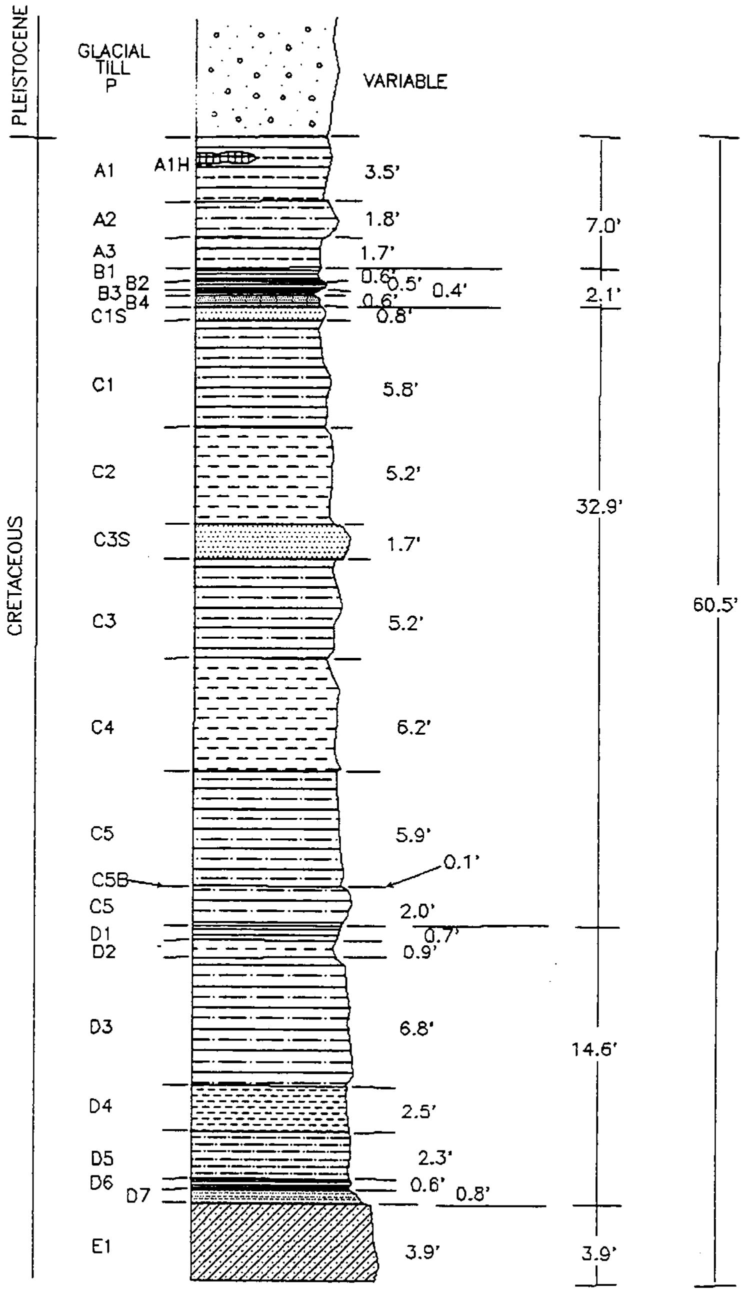
Stop 1. Springfield Clay Pit, Ochs Brick and Tile Company

This pit exposes 10 to 20 m (depending on the water level in the pit) of Upper Cretaceous mudrocks. Shale and mudstone are the dominant rock types; sandstone and lignite are less abundant (Fig. 3). The variety of grain sizes present and the abrupt and frequent changes in grain size within the sequence reflect the ever changing conditions associated with the marine to non-marine transition zone, and more specifically the changing flow rates and lobe switching in a fluvially dominated delta system. Channel, bar, interdistributary bay, and crevasse splay deposits are likely represented here. Kaolinite is the most abundant clay mineral; quartz, illite, chlorite, mixed-layer clays, and iron-oxides are also present. Fossil remains of a brackish-water fauna include sharks, bony fish, rays, reptiles, and leaf impressions.

The Ochs Brick and Tile Company has been mining in this vicinity for more than 100 years. The production plant in nearby Springfield uses material from this pit and another pit near Redwood Falls to produce residential and architectural brick in a variety of colors. The plant uses a tunnel kiln and produces approximately 30,000,000 bricks annually.

Stop 2. The Dahlberg Kaolin Mine, Nova Natural Resources Corporation

The Dahlberg Kaolin Mine exposes approximately 25 m of residual weathering products developed on Morton Gneiss. Most of the time the mine exposes the saprolite and pisolitic, lateritic clay zones of the weathering profile. The Morton Gneiss is a migmatitic hybrid rock consisting of older tonalitic to granodioritic gneisses and amphibolite rafts, and younger granitic gneisses. The oldest components are approximately 3,600 m.y. old, and the younger gneisses 3,000 m.y. old. The amphibolite rafts occur as pieces or clasts that range in size from small pods or schlieren to large angular blocks a kilometer across, and amphibolite also occurs as dikes. This internal inhomogeneity is reflected in



UNIT DESCRIPTIONS

PLEISTOCENE

GLACIAL TILL (P)-

CRETACEOUS

HARDPAN (A1H)-

BROWN SHALE (A1,A3)-

WHITE SILTY SHALE (A2)-

LIGNITE OR LIGNITIC BLACK SHALE (B1,D1,D6)-

BROWN LIGNITIC SANDSTONE (B2)-

GRAY UNDERCLAY (B3)-

SANDSTONE (B4,C1S,C3S,D7)-

INTERBEDDED SANDSTONE AND SHALE (D5)-

INTERBEDDED SILTSTONE AND SHALE (C1,C3,C5,D3)-

GRAY SHALE (C2,C4,D2,D4)-

BENTONITE (C5B)-

FORESET BEDS (E1)-

Figure 3. A graphic description of the lithologic units occurring in the Ochs Brick and Tile Company Springfield Mine, Brown County (from Hauck and others, 1990).

the weathering products as well. Within the more abundant white to light-greenish kaolinitic saprolite produced from the gneisses there are pods of green chlorite-rich clay which developed from the amphibolite rafts within the gneisses. Figure 4 is a graph showing the distribution of the major clay minerals in a core drilled south of the mine face. The data used here are normalized to show the relative proportions of these minerals only; minor amounts of quartz, feldspars, oxides, carbonates, and other clay-sized minerals are not represented. The minimum resolution of the data is approximately 15 percent. It can be seen that kaolinite forms at the expense of other clay minerals, that vermiculite is an intermediate product, and that chlorite is distributed as a function of the inhomogeneity in the parent rock composition and is related to the distribution of amphibolite within the gneiss. Some of the most interesting features of the mine to look for on your visit are: clay with remnant gneissic texture, loss of this texture near the top of the profile, the chloritic pods representing original amphibolite, and pisolitic (pedogenic) clays. Knobs of fresh Morton Gneiss can be seen in the Minnesota River valley north of the mine and polished slabs of the gneiss can be seen as facing on the liquor store in nearby Morton.

Stop 3. Morton Clay Pit, Ochs Brick and Tile Company

Mining in this pit generally exposes Upper Cretaceous shale and lesser sandstone and lignite. However, at times, all or part of an underlying weathering profile is exposed also. The Upper Cretaceous strata can be divided into a lower kaolinite-rich interval, and an upper organic-rich shale interval. Only the less sandy parts of the lower kaolinite-rich interval are mined for brick production. The kaolinitic interval was deposited in a fluvial environment that derived most of its sediment from the weathering profile developed on Morton Gneiss. This interval also is silty and sandy, and some beds have a pisolitic texture. The organic-rich section overlying the secondary kaolinite consists mainly of shale and lesser lignite beds. Figure 5 is a stratigraphic section measured in this pit several years ago.

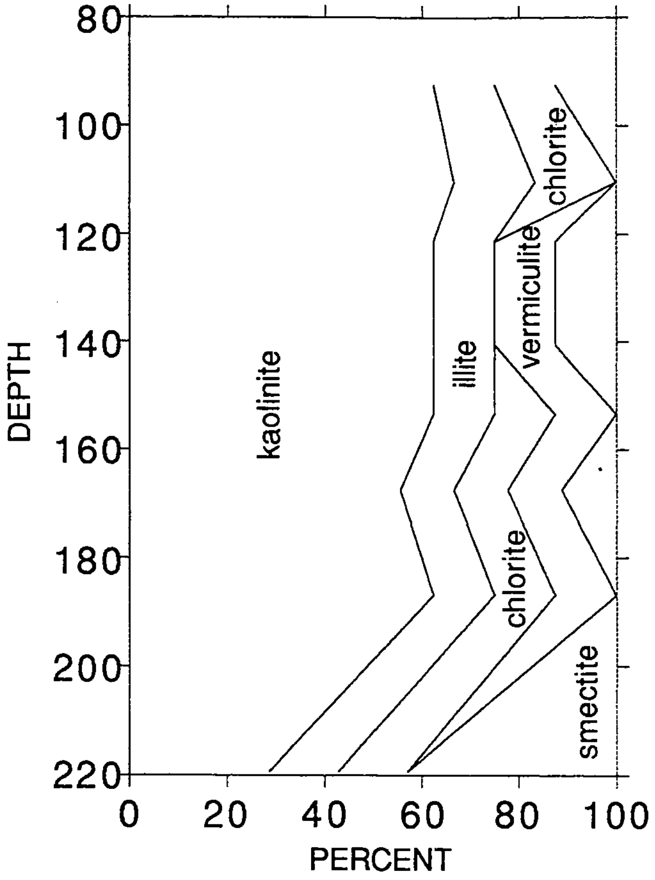


Figure 4. Distribution of the major clay minerals in a core drilled south of the Dahlberg Kaolin Mine, Redwood County (stop 2).

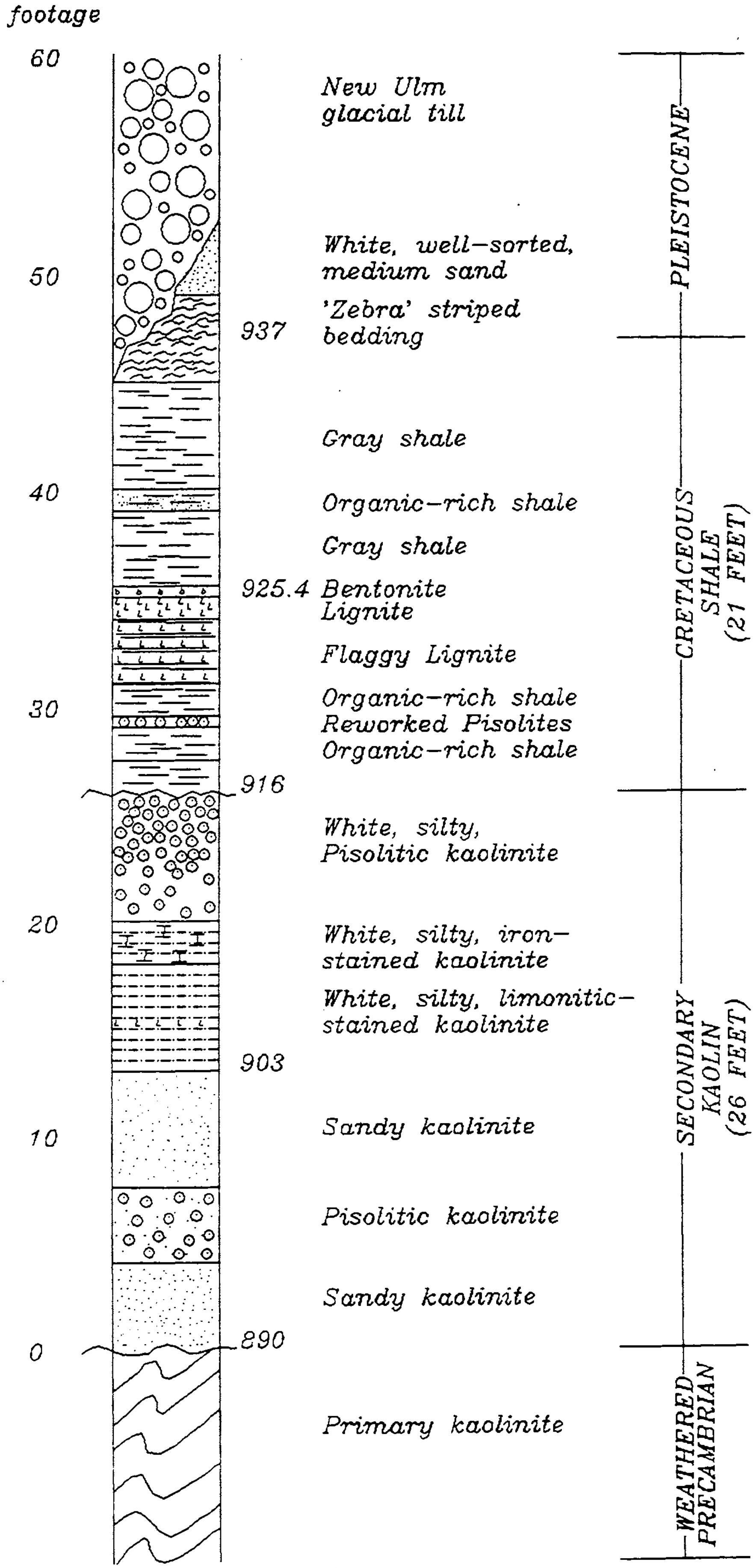


Figure 5. A graphic description of the lithologic units occurring in the Ochs Brick and Tile Company Morton Mine, Redwood County (from Hauck and Heine, 1991).

Stop 4. "Ferricrust" along unnumbered Renville Co. road (NE/SE/NW, sec. 4, T.112 N., R. 34 W.)

The hard, iron-stained, pisolitic clay exposed here lacks additional strata that would indicate if it is part of a weathering profile, or part of the Late Cretaceous sedimentary section. Parham (1970) states that kaolinite occurs both in the matrix and within the pisolites. The shell of the pisolites is iron-rich, and hematite, goethite, and possibly maghemite are present. Gibbsite is present within some pisolites and as a surface coating on others. Boehmite occurs less commonly within pisolites. This ferricrust has been taken as evidence that a tropical climate existed in Minnesota, either in the Late Cretaceous or preceding it.

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