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GEOLOGY OF CLAY DEPOSITS RED WING AREA, GOODHUE AND WABASHA COUNTIES, MINNESOTA

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GEOLOGY OF
CLAY DEPOSITS, RED WING AREA
GOODHUE AND WABASHA COUNTIES
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ABSTRACT

Clay deposits that have been used in the ceramic industry occur sporadically over an area of about 50 square miles in eastern Goodhue County, southeastern Minnesota. The deposits are in the Ostrander Member of the Cretaceous Windrow Formation and to a lesser extent in Pleistocene lake deposits. Currently they are being used in the manufacture of vitreous drain pipe and related products.

The Windrow Formation in the area overlies gently folded Cambrian and Ordovician strata. It consists of a lower Iron Hill Member, a ferruginous weathered residuum, and an upper Ostrander Member, a clastic unit. The Iron Hill Member was developed on a mature topographic surface; it formed through residual accumulation of limonite, clay, and chert, the relatively insoluble weathering products of the underlying carbonate rocks. The Ostrander Member formed as floodplain deposits, which were derived from a mixed Precambrian and Paleozoic source.

The clay deposits in the Ostrander Member are lenses or tabular bodies as much as a few feet thick and several tens of acres in areal extent that are intercalated with ferruginous sands. The only known deposit of Pleistocene age is laminated and is as much as 30 feet thick. It is interpreted to have been formed in a glacial lake.

INTRODUCTION

The clay deposits south of Red Wing, Goodhue County, Minnesota are among the best known and commercially valuable in the State and long have been used to sustain a ceramic industry in the area. Formerly, they provided raw materials for both the Red Wing Potteries and the sewer pipe plant at Red Wing. More recently the clays have been used exclusively in the manufacture of sewer pipe and related products.

Because of the economic importance of the clay deposits and their geologic significance, a field study of the clay-bearing area was made by the Minnesota Geological Survey in 1962. The region studied is bounded by the cities and villages of Red Wing, Lake City, Bear Valley, Zumbrota, and Vasa. The examination has indicated that clay deposits of commercial value are more widespread in the area than thought previously and that useable clays occur within strata of both Cretaceous and Pleistocene age. Reserves adequate for several years appear to be available. Mineralogic studies of the clays will be undertaken later.

PREVIOUS WORK

The first geologic description of the clays in the area of investigation is found in a report by Winchell (1888). Although Winchell lists clay occurrences as far south as Fair Point, 29 miles southwest of Red Wing, his geologic map indicates that extensive deposits of clay-bearing material are confined to a 13 square-mile area near Goodhue.

Sardeson (1898) studied the pits at Clay Bank (pl. 1) intensively and, in agreement with Lesquereux (1895), concluded that the sand and clay is of Cretaceous age. This age assignment was made originally by Lesquereux from five fossil leaves from the Clay Bank pits, only one of which was identified with any certainty; the specimens were neither described nor illustrated in the report. Sardeson believed that the clay and associated sand were picked up by a glacier, transported en mass, and deposited in the Clay Bank area. As evidence for such an origin, he cited the following: 1) the St. Peter Sandstone was exposed in the area during the Cretaceous but none of it is incorporated in the Cretaceous sand and clay, 2) muscovite is present in the sand surrounding the clay but there is no known local source of mica, and 3) the interlayered clay and sand layers are locally folded and dislocated. Sardeson did not consider any of the clay deposits reported by Winchell other than those at Clay Bank to be of Cretaceous age. Deposits similar to those found at Clay Bank, such as the Bellechester pits (pl. 1), were not known at this time. The singularity of the Clay Bank deposits gave further support to Sardeson's theory of en mass transport.

Later, in a summary of all the available information on the clay deposits of Minnesota, Grout (1919) devoted a large section of his report to the clays south of Red Wing. The data on the clays were mostly of an engineering nature. Additional clay pits near Bellechester had been opened by this time, the evidence from which weakened Sardeson's argument for glacial transport, but Grout did not refute the theory.

As part of a study of the Cretaceous rocks in Minnesota, Stauffer and Thiel (1941) concluded, in agreement with the earlier investigators, that the clay-bearing material south of Red Wing was Cretaceous in age. Their conclusion was based on the lithologic similarity of the sediments to known Cretaceous strata elsewhere in the State and on the earlier identification of the fossil leaves by Lesquereux. The strata were considered to be correlative with a part of the Dakota Formation.

In a regional study of related deposits of iron oxides, sand, grit, and clay in the Upper Mississippi Valley region, Andrews (1958) assigned the clay and associated strata in Goodhue County to the Windrow Formation, described earlier by Thwaites and Twenhofel (1921) from the Driftless Area of Wisconsin. He concluded that the formation is Cretaceous in age, but doubted that a more precise determination of the age within the Cretaceous is warranted. Andrews proposed that the older porous, concretionary, iron oxide layer at the base of the formation be called the Iron Hill Member. He concluded that this member formed from the concentration of iron oxides that were leached from the weathered products of Paleozoic carbonate bedrock. He designated the upper or clastic member of the Windrow Formation, which contains both sand and clay, the East Bluff Member. He interpreted the clastic deposits of the East Bluff Member to be fluvial sediments transported by streams of moderate velocity and the gray laminated clay, silt, and fine sand to have been deposited in fresh-water lakes or in the quiet water of a floodplain. In this report, Ostrander Member, previously defined by Stauffer and Thiel (1941), is retained for the upper clastic unit of the Cretaceous.

FIELD WORK AND ACKNOWLEDGMENTS

The field investigations for this study were made in the spring of 1962 over a period of 10 weeks. An area of about 50 square miles was mapped at a scale of 1:62,500 (pl. 1), and a larger area of about 400 square miles was mapped by reconnaissance methods. Concurrent with the field study, areas of potential economic significance for clay deposits were drilled. Many problems were discussed with R. E. Sloan, Department of Geology and Geophysics, University of Minnesota, R. L. Bleifuss, Mines Experiment Station, University of Minnesota, and J. E. Stone and P. K. Sims of the Geological Survey. Sims and F. M. Swain, Department of Geology and Geophysics, critically read the manuscript. The Red Wing Sewer Pipe Corporation cooperated during the study by making available their drill records and ceramic tests and by providing a truck-mounted auger to drill test holes.

GEOLOGY

The Red Wing area is underlain by gently dipping sedimentary rocks of Cambrian and Ordovician age that locally are overlain in an area of about 250 square miles in eastern Goodhue County and adjacent parts of Wabasha County by thinly bedded, poorly indurated sands and clays of Cretaceous age (pl. 1 and table 1). The Cretaceous strata, the dominant source of clay deposits in this area, lie disconformably on Paleozoic rocks, in which a mature topography apparently had developed. Unconsolidated deposits of Pleistocene age, not shown on the geologic map, locally overlie the Cretaceous and older rocks.

The Cretaceous sediments lie astride a breached, broad, asymmetric anticline, herein called the Red Wing-Rochester anticline, that extends northerly through the central part of the map area. The west limb of the anticline has a regional dip of about 10 feet per mile to the west, whereas the east limb dips eastward at about 100 feet per mile. Within the mapped area, the Cambrian Jordan Sandstone is exposed locally in the axial region of the anticline as a result of Pleistocene erosion. Prior to deposition of the Cretaceous sediments, the Middle Ordovician Platteville Limestone and St. Peter Sandstone and the upper part of the Early Ordovician Prairie du Chien Group were breached along the axis of the structure.

Table 1.--Generalized stratigraphic sequence exposed in the Red Wing area

	Maximum Thickness (in feet)
Cenozoic Era	
Quaternary System	
Pleistocene Series	47+
Unconformity	
Mesozoic Era	
Cretaceous System	
Windrow Formation	
Ostrander Member	50+
Iron Hill Member	19+
Unconformity	
Paleozoic Era	
Ordovician System	
Champlanian Series	
Platteville Formation	16
Glenwood Formation	4+
St. Peter Formation	135
Canadian Series	
Prairie du Chien Group	
Shakopee Dolomite	153
New Richmond Sandstone	8
Oneota Dolomite	105
Cambrian System	
Croixan Series	
Jordan Sandstone	102
St. Lawrence Formation	43
Franconia Formation	180

Paleozoic Rocks

The oldest rocks exposed in the area, the Franconia Formation, crop out in the following places: 1) at the base of the bluffs in the city of Red Wing, 2) in a road cut south of Highway 61, one mile west of town, 3) in a cut east of County Highway 53, half a mile south of Highway 61, 4) along a stream in sec. 1, T. 112 N., R. 14 W., south of Highway 61, and 5) at the base of the Hay Creek valley slope in NW1/4 NW1/4 sec. 13, T. 112 N., R. 15 W. In all exposures except 2) only the upper or Reno Member is exposed. Thiel (1944, p. 199) recorded 180 feet of Franconia in the Red Wing city water well at Barn Bluff.

The overlying St. Lawrence Formation, like the Franconia Formation, is limited in outcrop to exposures at the base of the bluffs along the Mississippi River and in the deeper tributary valleys in the northern part of the Red Wing area. The formation is as much as 43 feet thick at Barn Bluff, near Red Wing, and consists of interbedded dolomitic siltstones and silty dolomite.[1/] The best exposures south of Red Wing are on the valley slopes near Hay Creek in sec. 19, T. 112 N., R. 14 W., and in the valley of Wells Creek, in SE1/4 SW1/4 sec. 18, T. 112 N., R. 13 W.

The Jordan Sandstone is exposed more extensively. It crops out not only in the valleys and bluffs in the northern part of the area but also in the valleys to the east toward Lake City and along the streams near Bear Valley in the south, along the axis of the Red Wing-Rochester anticline. In the extreme northwestern part of the area the formation is exposed in the Cannon River Valley. The Jordan Sandstone is a clean, medium- to coarse-grained, generally cross-bedded sandstone. Commonly it is yellowish brown on weathered surfaces, and has crusts of iron oxide between the cross-bedded layers. Near Hay Creek, the sandstone in the upper 15 feet of the formation is so clean that it is easily mistaken for the younger St. Peter Sandstone; this part of the formation is mined for glass sand in sec. 26, T. 112 N., R. 15 W. The contact with the underlying St. Lawrence Formation is gradational and

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1/ McGannon, Donald E., Jr., 1960, A study of the St. Lawrence Formation in the Upper Mississippi Valley: Unpublished Ph.D. thesis, University of Minnesota, p. 286-288.

difficult to delineate. The contact with the overlying Prairie du Chien also is gradational; Crain[2] placed the contact at an intraformational conglomerate that lies about 15 feet above the base of the transition zone.

The Prairie du Chien Group, lowestmost Ordovician, is widespread at the surface and as a result has been deeply weathered. The group consists of three formations, from oldest to youngest, the Oneota Dolomite, the New Richmond Sandstone, and the Shakopee Dolomite. The Oneota Dolomite consists of a lower massive unit and an upper thinner-bedded unit. The lower massive unit, a maximum of 50 feet thick, is dominantly a medium- to fine-grained, thick-bedded dolomite that contains light gray chert nodules. Many exposures are porous and vuggy, with the vugs tending to be concentrated along certain stratigraphic layers. The vugs contain distinctive coatings of brown or amethystine drusy quartz. The upper unit is 30 to 40 feet thick and less massive than the lower unit; it contains a sand lens 13-16 feet below the top of the unit. This is the only sandy layer in the Oneota Dolomite except for the lower 10-15 feet of the formation, which is increasingly more arenaceous toward the base. The formation is reported[3] to be 105 feet thick in SW1/4 SW1/4 sec. 17, T. 113 N., R. 15 W.

The New Richmond Sandstone, the middle formation of the Prairie du Chien Group, is discontinuous within the mapped area, and was observed at only two localities: NW1/4 NW1/4 SE1/4 sec. 10, T. 112 N., R. 16 W., and SW1/4 SW1/4 sec. 14, T. 110 N., R. 15 W. At each locality two layers of cross-bedded sandstone, each 8 feet thick, occur between dolomite beds.

The upper unit of the Prairie du Chien Group, the Shakopee Dolomite, predominantly is a sandy, fine- to medium-grained, gray to buff dolomite that contains ubiquitous thin beds of very fine-grain, light tan argillaceous dolomite. Sandy and oölitic chert nodules are common throughout the unit, and Cryptozoon reefs cause local pseudo-folds. The Shakopee Formation is exposed mainly in the northwestern part of

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[2] Crain, William E., 1957, The areal geology of the Red Wing quadrangle: Unpublished M.S. thesis, University of Minnesota, p. 47.

[3] op. cit., p. 40.

the area, near Vasa, and in the extreme southwestern corner, near Zumbrota. It occurs also on the eastern border of the area, in R. 13 W. At Vasa, the Shakopee Dolomite is 153 feet thick.[4]

The St. Peter Sandstone contains a fairly uniform, clean, white, medium-grained quartz sand. The grains are generally well-rounded, frosted, and well sorted. The base is concealed in the area, but the upper contact is exposed in SE1/4 SE1/4 SW1/4 sec. 2, T. 111 N., R. 16 W. and at several places to the west, particularly between Vasa and Goodhue (pl. 1). Between Goodhue and the Zumbro River valley the formation is covered by glacial deposits. There are other large exposures of the formation on the steep faces of a large butte and several smaller buttes nine miles east of Goodhue, where the formation is overlain by a thin capping of Platteville Limestone. These buttes are the remnants of a former, much larger surface that extended many miles to the north and east. The sandstone exposed on the west side of the main butte has thin limonite crusts and the overlying Platteville Limestone is deeply weathered, with a surficial capping of iron-bearing clay. These limonite crusts, between 1 and 2 inches thick, are found sporadically throughout the area on exposed St. Peter Sandstone. They are interpreted to have been formed during a long interval of intense chemical weathering, possibly mainly in Cretaceous times, by the precipitation of iron salts from ground water. Crusts formed in a similar manner during the Pleistocene are on the average only 1/4 inch thick.

The Platteville Limestone, although more restricted in distribution, is exposed in the same general area as the St. Peter Sandstone--along the western border of the area and in the butte nine miles east of Goodhue. It forms thin cappings on the buttes and forms ledges along the valley walls in the border area.

Younger Ordovician rocks, the Decorah Shale and the Galena Formation, are exposed between Cannon Falls and Zumbrota, outside the area of plate 1.

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[4] op. cit., p. 45.

Cretaceous Strata

Distribution and Lithologic Character

Flat-lying, poorly indurated, heterogenous deposits of sand, clay, and, locally, a ferruginous regolith lie on the eroded and weathered rocks of the Prairie du Chien Group, St. Peter Sandstone, and Platteville Limestone in the central part of the area (pl. 1). The strata consist essentially of a lower ferruginous unit and an upper clastic unit, herein called respectively the Iron Hill Member and the Ostrander Member of the Windrow Formation. As no new information concerning their age was obtained during the mapping, the strata are here considered to be Cretaceous, following Stauffer and Thiel (1941) and earlier investigators.

The Cretaceous sediments lie on a mature topographic surface that was formed by post-Ordovician subaerial erosion. As a result of the erosion, the Ordovician rocks that underlie the mature surface in the area were greatly thinned. In the central part of the area (pl. 1), the base of the Cretaceous lies about 50 feet above the transition zone separating the Jordan Sandstone from the overlying Prairie du Chien Group; and it can be concluded by comparison with stratigraphic thicknesses in nearby areas that at least 400 feet of Ordovician rocks were removed. The Platteville Limestone and the St. Peter Sandstone were eroded entirely from most of the area, and significant amounts of the Prairie du Chien Group were removed.

Immediately overlying the erosion surface developed on the Prairie du Chien Group is a dolomite sand, composed almost entirely of small rhombohedrons of dolomite. The sand mantles the exposed surface of the dolomite, and appears to have been the first product formed from its breakdown. At the quarry in SE1/4 SE1/4 NW1/4 sec. 9, T. 111 N., R. 14 W. the sand is about half an inch thick and covers a surface pitted with small sink holes. At a road cut 2 1/2 miles away (NE1/4 SE1/4 sec. 2, T. 111 N., R. 14 W.), on the other hand, the dolomite sand is 30 feet thick, and surrounds partially weathered dolomite blocks.

Associated with the dolomite sand is a residuum composed of chert, drusy quartz, limonite concretions, and ferruginous clay. In most outcrops this material is homogenous and shows no consistent layering. Rarely, vague color changes are present, which indicate some selectivity in deposition. The residuum fills channels (pl. 2) and

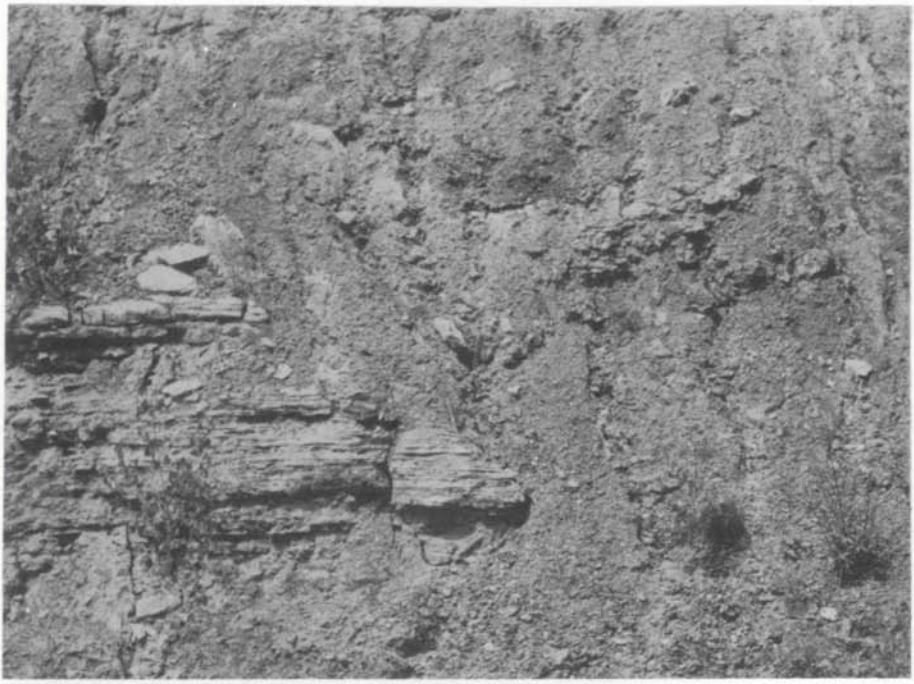

Plate 2.--Photograph showing ferruginous weathering residuum developed from Ordovician Oneota Dolomite. The residuum, which constitutes the Iron Hill Member of the Windrow Formation, largely fills a streamcut channel (right side of photograph). Scale is shown by hammer in center of photograph.

enlarged joints (pl. 3) in the Oneota Dolomite. The joints at the quarry shown in plate 3 strike east-west. The ferruginous residuum and the dolomite sand are included in the Iron Hill Member of the Windrow Formation.

The clastic Ostrander Member, which lies on the ferruginous residuum, consists primarily of sand and clay. The sand generally is stained bright orange as a result of a coating of limonite on the grains. The sand grains are composed of subrounded, medium- to coarse-grained quartz; in most outcrops less than 10 percent of the grains are

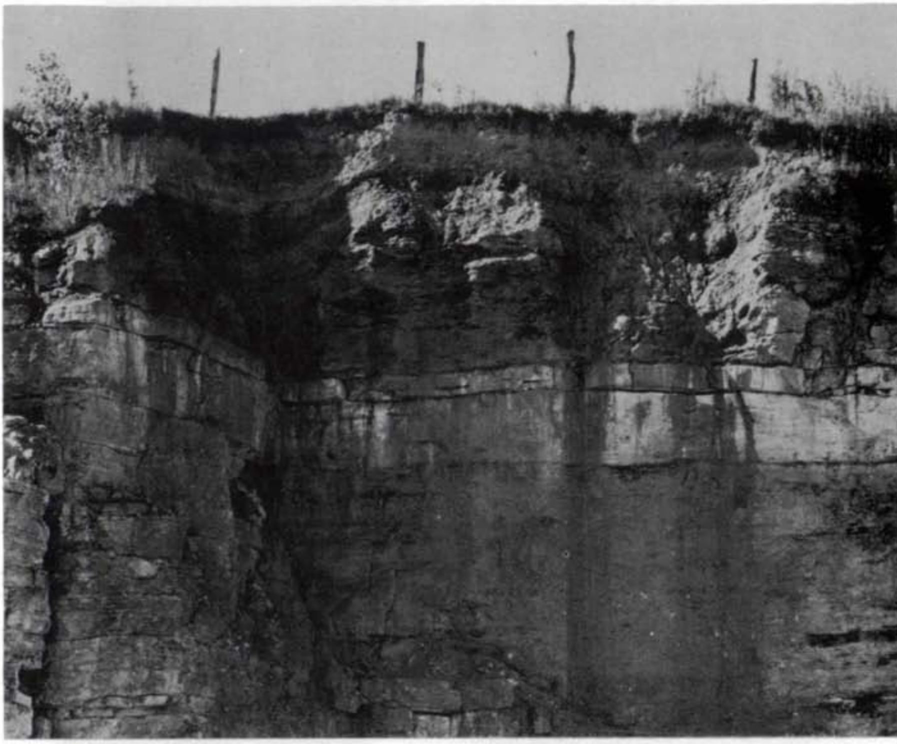

Plate 3. --Photograph showing weathered Oneota dolomite in quarry. Enlarged joints in the upper part of the formation are filled with a ferruginous weathering residuum. The fenceposts are about 4 feet high.

frosted. A mechanical analysis by Andrews (1958, p. 608) indicates that more than 70 percent of the channel sand found at the Thomforde pits has a size range between 0.25 mm and 0.5 mm. Lenses containing 50 percent or more of highly polished pebbles with sand are present in the central part of the exposed Cretaceous deposits, and are particularly evident in the Thomforde pit (loc. 3, pl. 1). Rarely, the pebble-sand layer is highly cemented by iron oxide and constitutes conglomerate.

Irregular bodies of grayish white clay occur within the Ostrander orange sand. Commonly, as at the Thomforde and Clay Bank pits, the clay is completely enclosed by the sand. At the Thomforde pit, the clay has a conspicuous layering in which clay laminae are separated by paper-thin layers of very fine white sand. Near the northern edge of the exposed clay pod the sand grains are stained yellowish brown by limonite deposited from water that penetrated the clay along the sand lenses. At the Thomforde pit there is transition zone 2 to 3 feet thick between the clay and the orange sand. At the Clay Bank pit small discontinuous lenses of gray clay occur in the orange sand without an intervening transition zone.

Dark brown sandstone is intercalated with the orange sand at several localities. At the Thomforde pit, the orange sand above the gray clay contains irregular layers of such a sand. The sand is irregularly bedded and, in contrast to the orange sand which merely is coated by hydrous iron oxide, is cemented by dark brown limonite. The quartz grains comprising the two types of sands are similar, but the dark brown sandstone contains 2 or 3 percent of white mica in the matrix. At Clay Bank a large body of similar sand, 4 feet by 8 feet in area, lies above the dominant clay-bearing orange sand, just below younger outwash deposits. It is jointed, and contains highly cemented ferruginous crusts 1/4 to 1/3 inches thick that cross one another and the bedding at various angles. Similar crusts are found in the Pleistocene material above the Cretaceous deposits, but these are subhorizontal and far more brittle to fracture than the crusts in the brown sand.

A final phase of the Ostrander Member, a very coarse red sand or grit, has a well developed inclined bedding. It is exposed only in SE1/4 NW1/4 sec. 29, T. 111 N., R. 14 W., and appears to lie at an altitude about 40 feet above clay that crops out 500 feet to the south. The grains in the sand are subrounded and consist of clear quartz (50%), pink quartz (30%), chert (15%), and dolomite (3%). As in the Clay Bank pits, hard ferruginous crusts as much as 3/4 inches thick traverse the sand at various angles. The rough bedding of the sand is interpreted to indicate that it was deposited by rapidly moving waters moving from east to west.

The altitude of the base of the Cretaceous strata in the area is about 1,000 feet. The contact of the Iron Hill Member of the Windrow Formation with the underlying Ordovician Oneota Dolomite is approximately at this altitude in NW1/4 NW1/4 NE1/4 sec. 5, T. 112 N., R. 14 W., NW1/4 NE1/4 sec. 36, T. 112 N., R. 15 W., and NW1/4 NW1/4 NE1/4 sec. 14 T. 110 N., R. 14 W. At places, as in SW1/4 NE1/4 SW1/4 sec. 5, T. 111 N., R. 13 W., porous zones and clay-filled cavities extend downward from the contact into the underlying dolomite.

Except for a clay deposit encountered by auger drilling in SW1/4 NW1/4 sec. 5, T. 112 N., R. 14 W., the clays in the Ostrander Member lie between altitudes of 1,115 feet (SW1/4 NW1/4 SE1/4 sec. 30, R. 112 N., R. 13 W.) and 1,160 feet (NE1/4 NW1/4 sec. 29, T. 111 N., R. 14 W.), an interval of 45 feet. The base of the clay intersected in the subsurface in sec. 5, T. 112 N., R. 14 W. is at an altitude of 1,035 feet. Aside from the clay deposit in sec. 5, the larger bodies of clay appear to lie on upland surfaces some distance from the thicker deposits of the Iron Hill Member. Apparently the clay was formed on benches between the deeper valleys that were the sites of deposition of the weathering residuum constituting the Iron Hill Member.

Origin

The residuum constituting the Iron Hill Member developed during a period of subaerial weathering that preceded deposition of the Ostrander Member. This interval could have extended back to the Ordovician, but regional data assembled by R. E. Sloan (personal communication, 1963) indicates that the weathering products now observed probably formed mainly in early Cretaceous time. Andrews (1958) similarily concluded that the Iron Hill Member is Cretaceous in age. The residuum appears to have formed from weathering of the underlying carbonate rocks, without appreciable addition of materials from outside the area. The chert, drusy quartz, and concretions in the residuum are identical to those in unaltered Oneota and Shakopee dolomite. Probably, adequate quantities of iron are present in the dolomites to account for the residual accumulations of this element. Stauffer and Thiel (1941) found from chemical analyses from other areas in southeastern Minnesota that four samples of Shakopee dolomite contained an average of 0.45 percent iron oxide and 10 samples of Oneota Dolomite contained an average of 1.39 percent iron oxide. If the carbonate rocks in this area contain similar quantities of iron, the weathering of 400 feet of strata easily could produce the thicknesses of residuum observed in the Iron Hill Member.

The sand, grit, pebbles, and clay of the Ostrander Member probably were derived from a terrane of mixed Precambrian and Paleozoic rocks, as proposed by Andrews (1958) for the clastic sediments of the Windrow Formation. The clastic materials contain a variety of grains that are foreign to the area, yet they virtually lack frosting, suggesting that they were carried in rivers without appreciable wind action. The absence of well rounded grains suggests a relatively short distance of transport. The coarseness of the grains eliminates both the St. Peter and the Jordan Sandstones as sources for the Ostrander Member. From the lack of locally-derived material, it can be inferred that the iron forming the coating on the sand grains also was derived from outside the area, but this is problematical. The environment of deposition suggested by the character of the deposits is a floodplain of a stream issuing from an acid igneous or metamorphic terrane that was undergoing chemical weathering. The clay-size fraction in the waters, probably derived mainly by weathering of feldspars, was deposited for the most part in local stagnant pools in the floodplain. The clay-size and sand- or gravel-size materials were interbedded by shifting of the position of stream channels and stagnant bodies of water, as well as by shifting of interfluvial areas.

Pleistocene Deposits

Three distinct types of Pleistocene material overlie the Mesozoic and Paleozoic bedrock. These are drift, which has been called the "old gray drift" or Kansan drift by Stauffer and Thiel (1941), loess, and outwash deposits.

The drift, which is the oldest material, is mottled grayish yellow and has a shale-like fissility at the surface and is a pebbly black clay where fresh. It occurs abundantly south and east of Bellechester and locally at a few other scattered localities. At a small exposure in a gully in SW1/4 SW1/4 SW1/4 sec. 19, T. 111 N., R. 14 W. gray drift lies on pebbles and cobbles consisting of ferruginous sandstone and limonite derived locally from the Cretaceous strata, dolomite derived from nearby Ordovician rocks, and foreign material derived from igneous and metamorphic terranes. The lower 6 feet of drift above the cobble layer is leached. A mile to the west of this exposure, the cobble layer contains many chert nodules as much as 12 inches in diameter. The surfaces of the nodules are very irregular, with horn-like protuberances, and are coated with siliceous material. Similar concretions have been reported by Crain[5/] in the Shakopee Dolomite in the bluffs behind Welch. Thicknesses of the drift generally are not known. The drift is reported (Mr. Herbert Stehr, oral communication, 1962), however, to be more than 200 feet thick in a well in NW1/4 NE1/4 sec. 1,

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[5/] op. cit., 1957

T. 111 N., R. 14 W. The clayey drift at this site overlies yellow sand (altitude of contact about 875 feet) that probably is the Jordan Sandstone If this is true, a channel filled with drift extends downward at least 200 feet below the surrounding land surface. An auger hole drilled during this investigation in NW1/4 NW1/4 NE1/4 sec. 1, T. 111 N., R. 14 W. penetrated more than 50 feet of clayey drift, confirming a substantial thickness of the gray drift in the area.

An extensive layer of loess, probably post-Iowan Peorian Loess, lies above the gray drift in the central part of the map area. The loess is unstratified calcareous brown silt. It is commonly found on the hill top and high-level surfaces between Red Wing and Bellechester and east of the village of Goodhue. A maximum thickness of 70 feet was observed in a road cut in sec. 17, T. 112 N., R. 14 W., near Hay Creek. No exposures of loess were observed south of the Thomforde clay pits (loc. 3, pl. 1), where 4 feet of loess immediately overlies Cretaceous sand. The sand and the loess are separated by a thin layer of pebbles and cobbles.

Outwash sands and gravels, the third type of Pleistocene material, occur mainly in the area west of State Highway 58. This material contains a high proportion of exogeneous pebbles and sand derived locally from the Cretaceous sediments. The only large extensive exposures in this area are west of the Clay Bank pits (loc. 1, pl. 1). A typical exposure, in SW1/4 SW1/4 sec. 6, T. 111 N., R. 15 W., consists of coarse gravel that overlies the St. Peter Sandstone. Similar coarse gravels are exposed east of Highway 58 in SW1/4 SW1/4 SE1/4 sec. 9, T. 111 N., R. 15 W., NW1/4 SE1/4 sec. 21, T. 110 N., R. 14 W., and NE1/4 NW1/4 sec. 21, T. 111 N., R. 14 W. The Pleistocene sand that caps all the older strata east of Highway 58 was derived mainly from the Cretaceous orange sand and accordingly is difficult to distinguish from it. The relationship is well shown in the Clay Bank pits, where Pleistocene outwash sand lies directly on Cretaceous sand. The lower 15 feet of the outwash represents a transition zone consisting of orange Cretaceous material, locally derived, and of buff sand derived some distance away. Some of the sand beds in the transition zone have crusts formed from iron-bearing ground waters that are similar to the crusts described in the Cretaceous sands.

The stratigraphic relations of the three types of Pleistocene deposits are not fully known. An auger hole in NW1/4 NW1/4 NE1/4 sec. 2, T. 110 N., R. 15 W., however, possibly penetrated material of all 3 types. Fifteen feet of silt, sand, and fine gravel, underlain by 32 feet of black pebbly drift, the fresh equivalent of the "old gray drift," was penetrated beneath the soil. The 8 feet of material immediately above the drift is composed of outwash sand and gravel; the sand and gravel, in turn, is overlain by 6 1/2 feet of yellow-brown silt. Although the silt is similar to the loess observed farther north, it is not necessarily its equivalent, for loess cannot be distinguished with certainty from water-deposited silt in samples obtained from an auger drill. Elsewhere in the area the three main types of Pleistocene materials are nearly mutually exclusive, except where a small amount of either outwash sand and gravel or loess rests on drift.

CLAY DEPOSITS

Clay deposits of two ages, both of which are satisfactory for ceramic uses, occur in the Red Wing area. The older deposits, from the Cretaceous Windrow Formation, have been used extensively in the past; a younger deposit of Pleistocene age also was being utilized in 1963.

The Cretaceous clay deposits, which have been the mainstay of the ceramic industry of the area since its beginning in the early 1870's, have been taken mainly from 3 pits in Goodhue County, the locations of which are shown on plate 1. The first pit to be opened, at Clay Bank (loc. 1, pl. 1), about 13 miles south of Red Wing, formerly supplied high-grade clay for the production of stoneware as well as clay for vitrified drain pipe and other products. Subsequently, pits were opened near Bellechester (locs. 4 and 5, pl. 1) and near the Thomforde farm (loc. 3, pl. 1).

The clay deposits in the Thomforde pits cover some 50 acres. A maximum of 6 feet of finely laminated, grayish-white silty clay is exposed (1962) near the bottom of one of the pits at the east end (pl. 4). The clay contains paper-thin laminae of iron-stained fine sand and thin crusts of limonite, and grades upward through a 2-foot interval into an overlying ferruginous sand. This is in sharp contrast with all observed other deposits in the area, where the contacts between the two materials are sharp. The sand is orange, 3 to 7 feet thick, and except for an irregular nearly horizontal thin layer of dark friable sandstone, which is more highly cemented by iron oxide, is uniform in color and grain size. A channel filled with sand is cut into the clay near the north end of the pits.

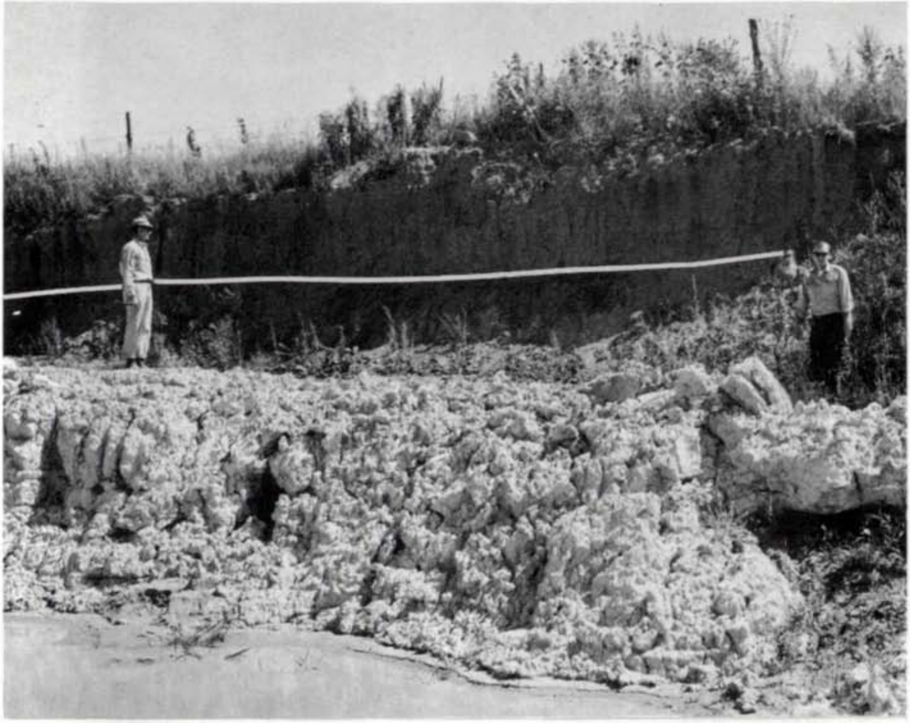

Plate 4.--Photograph showing part of the clay deposit in one of the Thomforde clay pits. The clay (white) is overlain by about 3 feet of Cretaceous orange sand (below marked contact), which in turn is mantled by loess (above contact).

A stratigraphic section measured at the center of the east end of the Thomforde pits, from youngest to oldest, follows:

	Thickness (in inches)
Soil	6
Loess	36
Rounded glacial pebbles and cobbles	3
Orange sand	2
Brown sandstone containing mica	6
Orange sand	6

Yellow-green clay	1
Orange sand	6
Orange sand and yellow clay	5
Yellow clay with some limonite fragments	8
Intercalated yellow and gray clay	6
Thin-bedded gray clay with thin laminae of white sand	60

An extension of the Thomforde pits to the east in 1963 has exposed a maximum of 8 feet of the thin-bedded gray clay at the bottom of the pit. Where visible, the clay-orange sand contact is sharp with a 1/4 to 1/2 inch layer of limonite between the orange sand and the clay. The orange sand is less uniform in color than in the older part of the pit and varies from orange to buff.

The Bellechester pits (sec. 33, T. 112 N., R. 14 W., pl. 1) have been abandoned for many years and the clay deposits could not be observed in 1962. However, Grout (1919, p. 170) described the clay as being one to 30 feet thick (average 10 feet) over an area of 40 acres. The clay removed was similar to that of the Clay Bank pits. It was capped by and underlain by ferruginous sand. Apparently the deposits were disturbed in a manner similar to the deposit at Clay Bank. A section at the Bellechester pits, as described by Grout (1919, p. 171), from youngest to oldest, follows:

	Thickness (in feet)
Drift	10
Limonite	1+
Clay	3
Red sand	1
Clay	5
Red sand	1
Clay	3
Limonite	1
Coarse sand	

Material in the waste dumps indicates that the Ostrander ferruginous pebble conglomerate was extensive in the pits. Clays exposed nearby, in a new pit approximately 100 feet northwest of the original pits and 2,000 feet to the west of Bellechester, contain numerous sand layers as much as 10 feet thick. The clay here is more variable and of poorer quality than that now exposed in the Thomforde pits.

The deposits at the Clay Bank pit, which cover some 90 acres in secs. 3 and 10, T. 112 N., R. 15 W., (pl. 1), no longer are exposed, but were described earlier (Sardeson, 1898, p. 679; Grout, 1919, p. 168-170). The geologic section, as described by Grout, from youngest to oldest, follows:

	Thickness (in feet)
Drift	4
Clay	3
Sand	1
Clay	1+
Sand	1
Clay	6
Sand	1
Clay	1
Sand	2
Clay	14
Sand	1
Clay	1
Sand	10+

In mining, it was necessary to sort the layers of sand from the clay; this was done by mining by hand and by washing. The exposed clay beds and intervening sand layers were crumpled and contorted, which led Sardeson (1898) to conclude that the deposit was transported _en mass_ by glacial ice from the original depositional area and redeposited at Clay Bank.

New pits in the Clay Bank area have served to clarify the relationships between the Cretaceous clay and sand and the overlying Pleistocene outwash material. A dark brown ferruginous sandstone identical to that found in the Thomforde pits, but more highly cemented, lies on an orange sand which contains small lenses of clay. The dark sandstone is thicker than that at the Thomforde pits, and is highly jointed. It seems probable that the jointing and the observed crumpling of the clays resulted from their being overridden by glacial ice.

Analyses of clay from the Ostrander Member in the Clay Bank pit are listed as follows:

Chemical analyses of clays from the Red Wing area
(Analyses by F. F. Grout, 1919, p. 170)

Constituent	1	2	3
Silica	69.92	69.26	64.98
Alumina	17.39	18.57	11.38
Iron Oxide	1.68	1.93	12.03
Magnesia	1.11	.62	2.51
Lime	.60	.45	.68
Soda	.07	.06	.00
Potash	2.25	2.41	1.93
Ignition	5.45	5.58	5.28
Moisture	1.10	1.10	1.08
Titanium Oxide	.63	.77	.71
Totals	100.20	100.75	100.58

1. Clay as shipped to the stoneware plant, ready for working
2. Washed clay; sampled at the plant
3. Refuse of washing; sampled at the plant

Elsewhere in the area, scattered deposits of clay occur as small isolated lenses in the Ostrander Member; the locations of these deposits are shown by outcrop symbols on plate 1. In each known occurrence the clay is grayish white or greenish white and is closely associated with orange sand. In several exposures, as in NE1/4 NE1/4 sec. 15, T. 112 N., R. 15 W., orange sand, clay, and ferruginous residual material are intimately mixed. Clearly, though, the clay and sand in each occurrence overlies the ferruginous residuum that is assigned to the Iron Hill Member.

A Pleistocene clay suitable for the production of ceramic products is exposed in the Hinsch pit (loc. 2, pl. 1), which was opened in 1962. The pit is in NW1/4 SW1/4 sec. 2, T. 111 N., R. 15 W., approximately 2,500 feet northeast of the Clay Bank pits. To judge from the drilling done before the pit was opened, the clay is as much as 30 feet thick and averages 12 feet. It is well laminated, sandy, and silty (pl. 5). The clay is overlain by 6 to 8 feet of outwash sand and one foot of soil and, to judge from the auger drilling, is underlain by a brown sand or

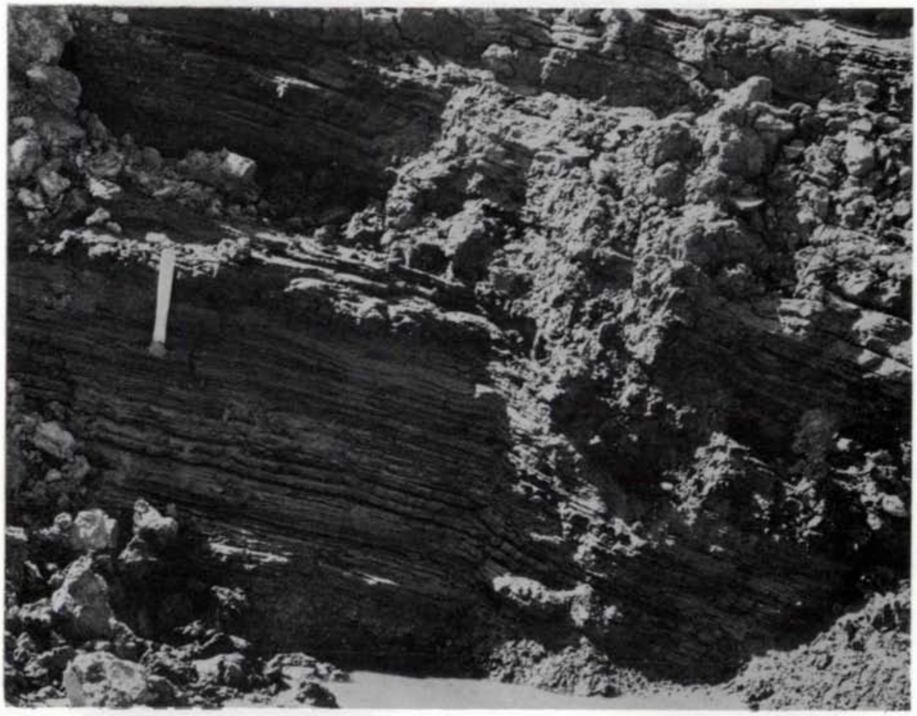

Plate 5.--Laminated clay exposed in the Hinsch clay pit. The laminae dip 15° NW. The clay is thought to have been deposited in a Pleistocene glacial lake.

possibly a well-indurated sediment. Within the small test pit the bedding in the clay is inclined 15° NW (pl. 5). Undoubtedly this material was essentially horizontal when deposited and subsequently became inclined either through differential compaction or mechanical deformation by ice. Beneath the 8-feet of exposed clay (pl. 5) is a homogeneous black pebbly material, which probably is the "old gray drift."

The clays within the Hinsch pit contain pebbles and cobbles of exogeneous mafic igneous or metamorphic rocks. The clay probably was deposited in a glacial lake, prior to deposition of outwash material. Although the deposit is at a lower altitude than the Cretaceous sands and clay in the Clay Bank area, it does not appear to contain detritus from this source.

FUTURE OF THE AREA

Clay deposits suitable for making ceramic products of the type now being manufactured in the tile plant at Red Wing occur locally throughout the area underlain by the Cretaceous Windrow Formation. Most deposits, however, are small and intimately interbedded with ferruginous sands, and exploratory drilling of areas judged to be favorable will be required to locate commercial deposits. All deposits probably occur above an altitude of 1,100 feet, and this can be a guide to selecting areas for drilling.

Pleistocene materials, which are more heterogeneous than the Cretaceous deposits, are less promising as future potential sources of clay, although other deposits similar to the Hinsch pit should be present. The gray drift, silt in former glacial valleys, and the loess of the area are unsatisfactory as raw materials, mainly because of a high lime content.

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