Petrography and Stratigraphy of Glacial Drift, Mesabi-Vermilion Iron Range Area, Northeastern Minnesota

GEOLOGICAL SURVEY BULLETIN 1331-C

Prepared in cooperation with the Minnesota Department of Iron Range Resources and Rehabilitation

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By T. C. WINTER, R. D. COTTER, *and* H. L. YOUNG

CONTRIBUTIONS TO GENERAL GEOLOGY

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By T. C. WINTER, R. D. COTTER, and H. L. YOUNG

ABSTRACT

Glacial deposits in the Mesabi-Vermilion Iron Range area consist of four major till units and associated glaciofluvial sediments. Particle-size data and pebble, heavy-mineral, clay-mineral, and percentage-soluble content were used in addition to field description of color and texture to describe and correlate the drift units.

The lowermost till unit, basal till, occurs in only a small number of mines, but the mines are scattered across the entire Iron Range. The till is dark gray to dark greenish gray and brownish gray, sandy, silty, and calcareous. Pebbles are largely granitic and metamorphic rocks of local origin, but include limestone, dolomite, shale, basalt, felsite, agate, and gabbro. Clay-mineral content is largely illite. The age of the till is probably middle or early Wisconsin but could be pre-Wisconsin.

The middle till unit, bouldery till, is the thickest and most widespread of the four tills. It is gray, yellow, red, orange, or brown, sandy, silty, noncalcareous and contains abundant cobbles and boulders. Pebbles are largely granitic and metamorphic rocks of local origin, but also include gabbro, basalt, and felsite in minor amounts. Montmorillonite is the most common clay mineral. Colored bouldery till below gray bouldery till may be a separate subunit distinguished largely on particle-size differences, but the overall characteristics are similar to the other bouldery till. The till was deposited by the Rainy lobe, which has a minimum age of 14,000 to 16,000 years before present.

The uppermost, or surficial, tills were deposited contemporaneously by two minor sublobes of the Des Moines lobe about 12,000 years ago. Brown silty till occurs in the western and north-central part of the study area. It is light to medium brown, sandy, silty, and calcareous. Pebbles are largely granitic and metamorphic rocks of local origin, but include limestone, dolomite, shale, basalt, felsite, and gabbro. Clay-mineral content is largely mixed-layered montmorillonite and illite.

Red clayey till occurs in the south-central part of the area. It is red to reddish brown, clayey, silty, and calcareous. Pebbles are similar to those in the brown silty till, but contain less limestone than the brown till.

Glaciofluvial sediments are common between the various till units throughout the area, but are thickest near the east and near the west ends of the Iron Range.

INTRODUCTION

The Mesabi-Vermilion Iron Range area, as discussed in this report, covers about 4,400 square miles in northeastern Minnesota. A need for information on the ground-water resources of the region, particularly for municipal use and processing of iron ore, prompted the initiation of studies of the geology and ground-water resources. The effect on ground-water movement of large-scale mine dewatering is also of concern in some areas.

To evaluate the ground-water resources of an area, it is important to know the geometry of the geologic units and their internal characteristics such as grain size, fabric, and mineralogy. The purpose of this report is to describe the glacial drift in the Iron Range area and to establish the stratigraphic relationships of the various units recognized. The geologic maps needed to evaluate the ground-water resources are discussed by Winter (1972). The history of glaciation and ages of the various drift units are discussed by Winter (1971).

PREVIOUS INVESTIGATIONS

Most previous work on geology of the area has been on the iron-formations and associated Precambrian rocks. The most recent report on the basement rocks that covers a widespread area is by White (1954).

The most significant report on the glacial geology of the area is by Leverett (1932). Since that time Wright (1955, 1956) discussed certain aspects of the glacial geology of the area. The most recent general summary of the area is by Wright and Ruhe (1965). Reports on ground-water resources that have included discussions of glacial geology of various local areas in the Iron Range have been prepared by Cotter and Rogers (1961), for the Mountain Iron–Virginia area; Maclay (1966), for the Aurora area; Lindholm (1968), for the Hibbing area; and Oakes (1970), for the Grand Rapids area. Cotter, Young, Petri, and Prior (1965) reported primarily on the water resources, but included some discussion of the geology, in the vicinity of municipalities in the Mesabi–Vermilion Iron Range area. A map of the bedrock topography of the central and eastern Mesabi Range area was prepared by Oakes (1964). A preliminary map of the surficial geology of the Mesabi-Vermilion

Iron Range area was prepared by Cotter, Young, and Winter (1964).

NUMBERING SYSTEM

Location numbers in tables 1 and 2 are based on the U.S. Bureau of Land Management's system of subdivision of the public lands. Figure 1 illustrates the method of numbering. The number 57.18.8DDB identifies the first sample or measured section located in the NW¼SE¼SE¼ sec. 8, T. 57 N., R. 18 W. Where locations are not accurate to within 10 acres, they are identified by using only the first two letters.

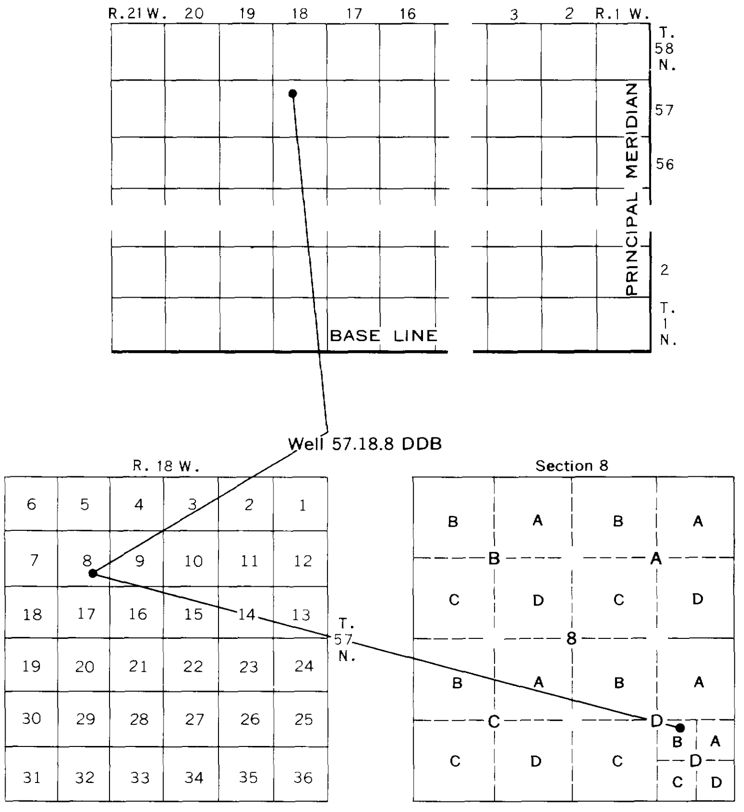

FIGURE 1.—Method of numbering samples and measured sections.

ACKNOWLEDGMENTS

We are grateful to the mining companies that permitted our examination and mapping of the glacial deposits in their mines. Data provided by mining companies, municipalities, and individuals also are appreciated.

REGIONAL GEOLOGIC RELATIONSHIPS

PHYSIOGRAPHY

The predominant physiographic feature in the study area is the Giants Range. The long, linear ridge, which consists largely of Precambrian granite, extends northeastward from near Grand Rapids to near the east edge of the area (fig. 2). The highest point of elevation along this ridge, more than 1,900 feet above mean sea level, is northeast of Aurora. The Giants Range is noticeably higher than the surrounding terrain, most of which is less than 1,500 feet above mean sea level (fig. 2).

The northeastern part of the area is a part of the Canadian Shield. This area has fairly rugged local topography characterized by many lakes interspersed among hills of Precambrian crystalline rocks.

Many long, linear, east-west trending glacial end moraines traverse the northeastern third of the area (pl. 1). Other areas of moraine occur in the western part of the area, but they do not exhibit striking linear trends.

A large area of drumlins occurs in the southeast near Toimi and a smaller group occurs between Hibbing and Keewatin. A few isolated drumlins occur south of Eveleth and near Buhl. All the drumlins have a northeast-southwest orientation.

Many eskers occur in the study area and especially within the areas of ice-contact deposits (pl. 1). Nearly all the eskers are oriented northeast, except in the northwest corner of the area, where a large number of eskers trend northwest.

Ice-contact deposits are abundant in the area immediately south of the Giants Range and in the western half of the area north of the Giants Range.

Several outwash plains of limited areal extent occur in the west-central part of the area. Smaller areas of outwash occur near Babbitt and south of the Giants Range between Biwabik and Gilbert.

Glacial lake basins constitute a fairly large percentage of the area. The Glacial Lake Upham basin extends northward into the south-central part almost to Biwabik. Glacial Lake Aitkin basin extends northwest through the southwest corner of the area near Grand Rapids. Glacial Lake Norwood basin occurs just north of the Giants Range in the eastern part. An unnamed and undefined glacial lake basin occurs in the north-central part of the area. This basin may have been an early, very high stage of Glacial Lake Agassiz. A small glacial lake basin occurs south of the Vermilion moraine in the Dunka River basin.

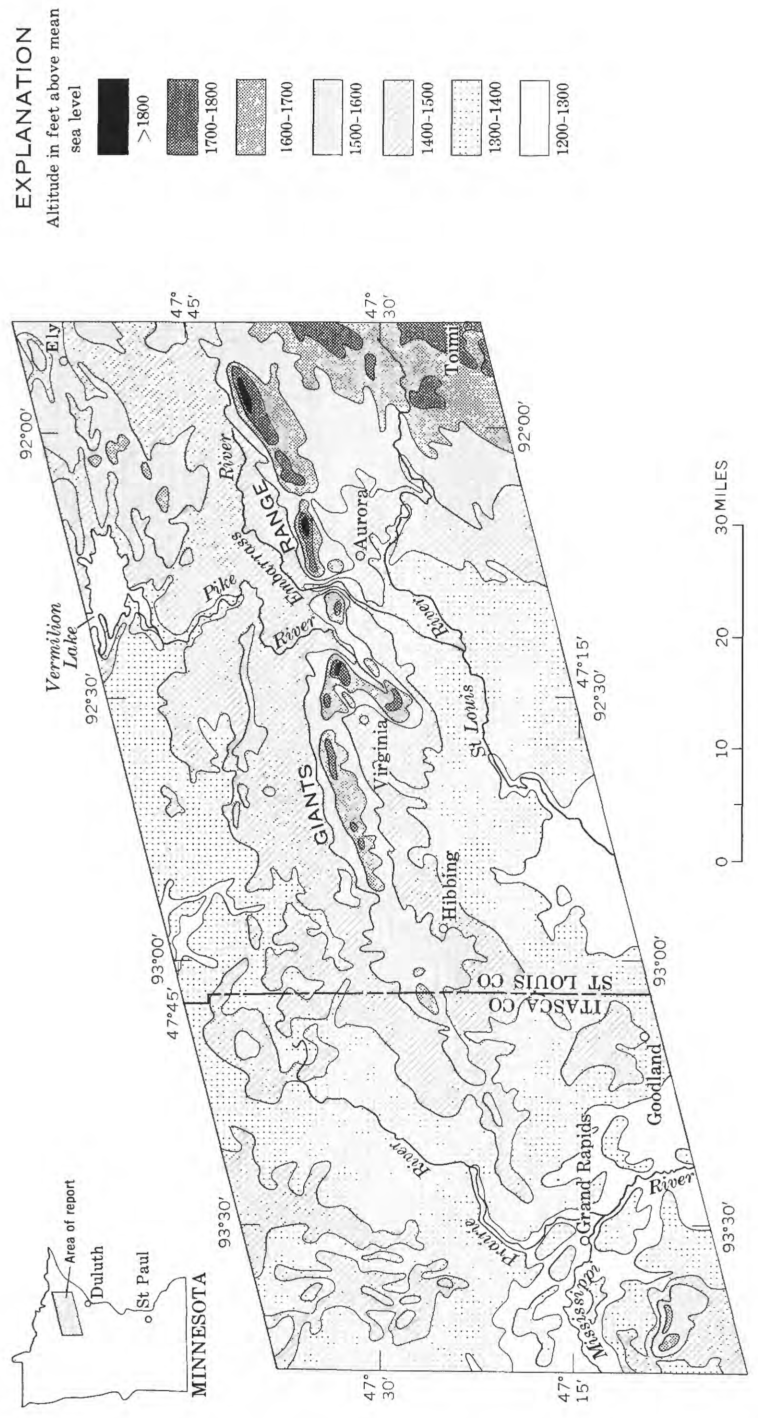

FIGURE 2.—Topographic map of report area.

SURFICIAL GEOLOGY

Surface deposits in the region are largely of glacial origin. Exposed bedrock includes Precambrian crystalline and metamorphic rocks along the Giants Range, in the northeastern part, and in isolated, local exposures in the north-central part of the area (pl. 1). Glacial deposits, largely silty sand and gravel, are thin and discontinuous in areas where the Precambrian rocks are at or near the surface.

The long, linear moraines in the northeastern part of the area consist largely of sand and gravel. The drumlins near Toimi and Hibbing, and probably those near Eveleth, consist of bouldery till. South of the Giants Range and east of a line between Goodland and Keewatin, red clayey till is exposed in a rimlike strip 4–12 miles wide at the margin of overlying sands and silts deposited in Glacial Lake Upham. The deposits of Glacial Lake Upham are generally well-sorted silt and very fine sand. Much of this glacial lake basin is covered by peatlands.

West of the red clayey till and north of the Giants Range eastward to Sand Lake, the surficial drift unit is brown silty till. This till is overlain at many places by glacial lake sands. The sand, silt, and clay deposits of Glacial Lake Aitkin occur southeast and northwest of Grand Rapids. The sand, silt, and clay in the north-central part of the region was deposited by an unnamed glacial lake. Sand deposited by Glacial Lake Norwood covers a fairly large area immediately north of the Giants Range in the eastern part of the area.

Extent, thickness, texture, and composition of glacial drift units generally vary considerably over short distances. However, certain characteristics of drift units often can be used to correlate the deposits over large areas, in spite of the local variations.

Open-pit mining in the Iron Range area has provided a rare opportunity for geologists to examine surface-to-bedrock exposures of glacial deposits along a zone about 75 miles long. The data for this report are largely from examination of the mine faces (selected sections are given in table 1) and a reconnaissance of roadcut exposures. This information, together with test hole data, has been used for reports on local ground-water resources, but a regional study of the glacial stratigraphy has never been attempted until now.

Although systematic geologic sampling and mapping was not a primary goal in the ground-water studies, samples were collected at three different times. In 1959 (prefix A, table 2), 37 samples were collected southwest of Mountain Iron and Virginia for determinations of particle-size distribution and permeability. Sixty-four samples were collected in 1961 (no prefix) for determinations of particle-size distribution, carbonate content, and pebble lithology. To provide supplemental data to that obtained previously, 35 samples were collected in 1968 (prefix C). Some of the 35 were analyzed for particle-size distribution, carbonate content, clay mineralogy, heavy minerals, pebble lithology, and pebble orientation (fabric).

TABLE 1.—*Selected geologic sections*

[All depths were measured except those for 58.15.5 BDD (Embarrass mine), 58.19.13 ABC (Wade mine), and 58.20.24 BDC (Forster mine), which were estimated]

Description	Depth (ft)
58.15.4 BBD (Hudson mine); land-surface elevation, 1,550 ft	
Silt, sandy, cobbly	0–2
Till(?), brown, sandy, gravelly, silty; contains abundant boulders, many of Biwabik Iron-Formation. Some zones stratified; apparently of fluvial origin. (Brown bouldery till?)	2–18
Till, medium-brown, sandy, silty, gravelly; contains many cobbles and boulders. (Brown bouldery till.)	18–33
Till, gray, silty, sandy, gravelly; contains many cobbles and boulders. (Gray bouldery till.)	33–46
Sand and gravel; contains many fragments of Biwabik Iron-Formation	46–53
Biwabik Iron-Formation	53+
58.15.5 BDD (Embarrass mine); land-surface elevation, 1,400 ft	
Till, red, clayey	0–20
Till, gray, silty, sandy, gravelly; contains many cobbles and boulders. (Gray bouldery till.)	20–60
Till, brown, silty, sandy, gravelly; contains many cobbles and boulders. (Brown bouldery till.)	60–90
Sand and gravel; thickens to about 50 ft in other parts of mine	90–100
Till, brown, silty, sandy, calcareous; contains pebbles of polished limestone	100–180
Sand and gravel	180–210
Sand, orange	210–250
Biwabik Iron-Formation	250+
58.16.3 BDC (Canton mine); land-surface elevation, 1,455 ft	
Till, brown (10*YR* 6/2 to 4/2), clayey; common rock types include granite, slate, and other metamorphic rocks	0–2
Till, reddish-brown, clayey, moderately calcareous; lithology similar to overlying till	2–32
Sand and gravel, largely medium sand to medium gravel; stained black and red	32–36
Sand, light-olive-gray (5*Y* 5/2), fine, well-sorted; contains thin beds of medium to coarse sand	36–47
Sand, light-olive-gray (5*Y* 5/2), medium, well-sorted	47–52
Silt, light-olive-gray (5*Y* 7/2 to 5/2)	52–53
Till, medium-brown (5*YR* 3/4 to 4/4), sandy, silty; contains many boulders and cobbles; rock types include granite, gabbro, felsite, basalt, and agates. (Brown bouldery till.)	53–86

TABLE 1.—*Selected geologic sections*—Continued

Description	Depth (ft)
58.16.9 DAB (Mary Ellen mine); land-surface elevation, 1,420 ft	
Peat, black	0–2
Till, brownish-gray, clayey; iron stain along joints (leached red clayey till?)	2–8
Sand, tan, fine to medium, well-sorted	8–10
Sand, light-gray, fine to medium, well-sorted, crossbedded	10–20
Silt, light-gray; contains thin beds of very fine sand	20–26
Sand, light-gray, very fine, stratified	26–48
Covered	48–67
Biwabik Iron-Formation	67+
58.17.24 DCB (Mariska mine); land-surface elevation, 1,445 ft	
Till, red, clayey	0–1
Sand and gravel, brown, silty; contains cobbles and boulders	1–17
Sand and gravel, bouldery and cobbly, stratified; much medium gravel; common rock types include granite, slate, iron-formation, and dark metasedimentary rocks	17–92
Biwabik Iron-Formation	92+
58.17.25 BBC (Pettit mine); land-surface elevation, 1,470 ft	
Till, reddish-brown, clayey, noncalcareous	0–16
Sand and gravel; bouldery near top; lower part is coarse sand to coarse gravel; granite is most common rock type, but also includes greenstone, iron-formation, slate, and other metasedimentary rocks	16–54
Till, brown (10*YR* 6/2), very sandy; lithology is similar to overlying sand and gravel. (Brown bouldery till.)	54–100
Sand; contains beds of sand and gravel, some crossbedding; rock types largely slate and other metasedimentary rocks; gravel contains gabbro and purplish and brown porphyritic and amygdaloidal fine-grained igneous rocks	100–137
Covered	137–187
Sand (could not examine in detail)	187–221
Biwabik Iron-Formation	221+
58.17.34 DCA (Genoa mine); land-surface elevation, 1,450 ft	
Sand, tan, medium to fine, silty, uniform (not stratified); wind-faceted pebbles at base but not a continuous horizon	0–2
Sand, tan, medium, well-sorted, stratified; contains a thin bed of red clay near bottom	2–8
Till, reddish-brown, clayey	8–11
Sand and gravel; gray, medium sand to coarse gravel; contains cobbles and boulders; red and black stain (iron and manganese precipitate) between 17 and 19 feet	11–23
Till, yellowish-brown (10*YR* 6/6 to 5*YR* 5/6), sandy, silty; contains iron-formation, granite, greenstone, schist, and slate rock fragments. (Brown bouldery till.)	23–29
Covered	29–44
Biwabik Iron-Formation	44+
58.17.16 CBA (Rouchleau mine); land-surface elevation, 1,555 ft	
Till, reddish-brown, clayey	0–10
Till, yellowish-brown (5*YR* 4/4 to 5*YR* 5/6); contains many iron-formation and granite rocks. (Brown bouldery till.)	10–17
Sand and gravel, bouldery; contains largely granite, slate, and other metamorphic rock types. Gabbro, felsite, and basalt are present in minor amounts	17–41
Till, yellowish-brown (10*YR* 4/2 to 10*YR* 5/4), sandy, silty; contains granite, greenstone, gabbro, felsite, basalt, iron-formation, slate, and other metamorphic rocks. Fine to medium sand from 81–85 ft. (Brown bouldery till.)	41–123
Biwabik Iron-Formation	123+

TABLE 1.—*Selected geologic sections*—Continued

Description	Depth (ft)
58.18.3 DDB (Wacootah mine); land-surface elevation, 1,500 ft	
Till, red, clayey	0–22
Till, brown, silty, sandy, very gravelly, cobbly and bouldery; contains many cobbles and boulders of iron-formation. (Brown bouldery till.)	22–36
Gravel, cobbly and bouldery; contains gabbro, felsite, basalt, and agate	36–40
Sand, brown, well-stratified; contains layers of medium to coarse gravel; iron-formation (very common), agates, felsite, and basalt common	40–46
Covered	46–70
Biwabik Iron-Formation	70+
58.19.13 ABC (Wade mine); land-surface elevation, 1,550 ft	
Till, red, clayey; contains concretions	0–4
Till, brown (10*YR* 6/2 to 10*YR* 7/4), sandy; contains many boulders of granite, slate, iron-formation, and metamorphic rocks. (Brown bouldery till.)	4–12
Till, gray (5*Y* 4/1 to 5*Y* 6/1), sandy; contains many boulders. (Gray bouldery till.)	12–34
Till, reddish-orange (about 5*YR* 4/4), sandy; contains many boulders. (Orange bouldery till.)	34–44
Till, greenish-gray (10*YR* 4/2 to 5*Y* 5/2), sandy, silty; contains slate, granite, porphyritic and amygdaloidal basalt, gabbro, agate, limestone, and dark metamorphic rocks	44–48
Covered	48–58
Biwabik Iron-Formation	58+
58.20.24 BDC (Forster mine); land-surface elevation, 1,520 ft	
Sand and gravel, poorly sorted; contains cobbles	0–5
Till, red, clayey	5–20
Till, grayish-brown, sandy, silty; contains many cobbles and boulders. (Brown bouldery till.)	20–50
Sand, tan to brown, fine, silty, well-stratified; fine to coarse sand in some layers	50–62
Sand, brown; contains gravel and silty and clayey layers	62–67
Sand, brick-red, medium to coarse, silty; contains poorly sorted gravel and cobbles	67–69
Till, brown (5*YR* 4/4), silty, noncalcareous, very hard; contains gravel and cobbles	69–72
Covered	72–82(?)
Biwabik Iron-Formation	82+(?)
58.20.23 CAD (Fraser mine); land-surface elevation, 1,500 ft	
Till, reddish-brown, clayey, noncalcareous	0–3
Till, light-gray (5*Y* 8/1), sandy; contains many cobbles and boulders of granite and lesser amounts of iron-formation, greenstone, graywacke, schist, and other dark metamorphic rocks. (Gray bouldery till.)	3–21
Sand, yellowish-tan, stratified	21–23
Till, yellowish-tan (5*YR* 4/4), silty, sandy; contains many cobbles and boulders, but fewer than the bouldery till above; rock types include granite, gabbro, porphyritic basalt, iron-formation, and dark metamorphic rocks. (Yellow bouldery till.)	23–49
Till, greenish-gray (5*Y* 5/2), sandy, silty, calcareous; contains numerous calcareous concretions; rock types include granite, iron-formation, dark metamorphic rocks, and a small amount of limestone	49–64
Till, dark-greenish-gray (5*Y* 4/2), silty, clayey, highly calcareous; no boulders; contains much limestone; also contains granite, slate, and basalt	64–82
Biwabik Iron-Formation	82+(?)

TABLE 1.—*Selected geologic sections*—Continued

Description	Depth (ft)
57.21.10 BBD (Mahoning mine); land-surface elevation, 1,570 ft	
Disturbed	0–2
Till, pink, sandy, very hard; contains many boulders. (Pink bouldery till.)	2–20
Sand and gravel, orange, well-stratified; coarse sand to cobbles	20–50
Biwabik Iron-Formation	50+
57.22.24 CAA (St. Paul mine); land-surface elevation, 1,510 ft	
Till, orange, sandy, silty; contains many cobbles and boulders. (Orange bouldery till.)	0–15
Sand and gravel, orange-brown, well stratified; medium to coarse sand, layers of coarse gravel to cobbles	15–42
Till, sandy, very calcareous; dark-gray (*N*4) in upper part, dark brown (10*YR* 4/2) in lower part; contains gravel and cobbles; rock types include granite and felsite	42–56
Biwabik Iron-Formation	56+(?)
57.22.26 ABB (Sargent mine); land-surface elevation, 1,490 ft	
Till, brown, silty and clayey	0–3
Till, pink, sandy (more clayey in upper part); contains many cobbles and boulders. (Pink bouldery till.)	3–12
Sand and gravel, yellow-orange, well-stratified; coarse sand to medium gravel; contains layers of silt, fine sand, and cobbles	12–35
Till, buff to brown, clayey; coarse fraction is largely fine to medium gravel	35–40
Till, dark-gray, very clayey; contains limestone pebbles	40–43
Till, red-brown, very clayey; much like the overlying gray till, but no limestone found. Contact between red-brown and overlying gray till is marked by very thin (½–1 in.) beds of sand (largely within the gray till); small blocks of each till are included in the other	43–65
Biwabik Iron-Formation	65+(?)
56.23.11 AAC (Patrick mine); land-surface elevation, 1,425 ft	
Till, brown, silty, clayey; blocky structure	0–3
Gravel, gray; abundant boulders and cobbles; small amount of sand, silt, and clay	3–5
Till, pink, sandy, silty; contains many cobbles and boulders. (Pink bouldery till.)	5–8
Sand and gravel, orange-brown, well-stratified; medium sand to medium gravel; lesser amounts of silt and cobbles; cross-bedding in some layers	8–23
Till, dark-gray, clayey, silty, sandy; only a few cobbles; contains silt and fine sand inclusions that appear to have been "scoured" into the upper part of the till	23–33
Covered	33–38
Biwabik Iron-Formation	38+
56.23.19 BBB (Arcturus mine); land-surface elevation, 1,390 ft	
Till, brown, silty, clayey, calcareous; calcareous concretions common	0–6
Sand and gravel, yellow-brown, well-sorted, stratified; medium sand to medium gravel; contains granite, dark metamorphic rocks, and considerable amounts of basalt and felsite. Boulders more common below 16 feet; silty and clayey below 30 feet	6–40
Till, brown, sandy, very hard; contains many boulders. (Brown bouldery till.)	40–42
Covered	42–60
Biwabik Iron-Formation	60+

TABLE 1.—*Selected geologic sections*—Continued

Description	Depth (ft)
56.24.24 BAA (Arcturus mine); land-surface elevation, 1,370 ft	
Overburden dump	0–5
Till, brown, silty; blocky structure; common rocks are granite, slate, and other dark metamorphic rocks	5–9
Sand, medium to coarse, well-sorted, thin-bedded	9–15
Sand and gravel, poorly sorted; medium sand to boulders	15–19
Till, yellow-brown, silty, sandy, bouldery; contains granite, iron-formation, greenstone, graywacke, slate, and other dark metamorphic rocks; discontinuous silt layer at 30 ft; top foot (19–20 ft) is red. (Brown bouldery till.)	19–48
Boulders; matrix is silty sand to gravel	48–63
Till, silty, sandy, clayey; brown (10*YR* 4/4) to 73 ft; dark gray (*N*+3) to 81 ft; limestone and shale not observed; many rocks are decomposed; noncalcareous except for zone at 75 ft	63–81
Biwabik Iron-Formation	81+
56.24.22 BBD (Holman mine); land-surface elevation, 1,340 ft	
Sand, tan, silty	0–1
Silt, greenish-gray, noncalcareous	1–3
Sand and gravel, tan, stratified; contains limestone	3–17
Till, gray (5*Y* 4/1), silty, clayey, highly calcareous; contains much limestone	17–24
Sand, reddish-brown, coarse to very coarse; predominant rock type is granite	24–33
Till, red, silty, sandy; contains many cobbles and boulders. (Red bouldery till.)	33–37
Covered	37–47
Biwabik Iron-Formation	47+
56.24.30 ADA (Canisteo mine); land-surface elevation, 1,410 ft	
Silt, gray; contains layers of gravel	0–3
Till, olive-brown, clayey, silty, calcareous; very gravelly and bouldery in upper 4 ft; limestone and shale abundant	3–14
Till(?), sandy, silty, bouldery. (Bouldery till?)	14–26
Sand and gravel, tan to gray and brown, stratified; crossbedded below 35 feet; contains stringers of bouldery till in bottom 1 ft	26–50
Till, yellow-brown, silty, very bouldery, slightly calcareous; stringers of this unit occur in underlying gray till in 2–3-ft mixed zone; platy structure. (Weathered part of underlying gray till?)	50–55
Till, dark-gray, very calcareous; much like overlying till	55–70
Cretaceous iron ore (reported), pebbly, reddish- and greenish-black; much hematitic silt	70+
56.25.35 CCC (West Hill mine); land-surface elevation, 1,380 ft	
Till, brown, silty; shale is abundant; one calcareous concretion found	0–5
Sand and gravel; contains many cobbles and boulders; most rocks are granite; much of the unit stands very steeply because of iron oxide cement	5–73
Covered	73–81
Till, greenish-gray (5*Y* 5/2), sandy, silty; contains many cobbles and boulders; rock types include granite, greenstone, graywacke, slate, quartzite, and iron-formation. (Gray bouldery till.)	81–108
Biwabik Iron-Formation	108+

TABLE 1.—*Selected geologic sections*—Continued

55.26.23 CCD (Tioga No. 2 mine); land-surface elevation, 1,380 ft	
Till, brown, sandy, silty	0–3
Silt, light-greenish-gray, clayey; mottled brown in parts	3–4
Sand, tan, silty, poorly stratified	4–6
Till, brown (10*YR* 5/4), sandy, bouldery; contains abundant granite, greenstone, slate, graywacke, and lesser amounts of basalt, felsite, quartzite, and iron-formation	6–13
Till, dark-gray (5*Y* 2/1 to 5*Y* 4/1), silty, sandy; highly calcareous except near upper contact; contains few boulders; coarse fraction is largely gravel; rock types include limestone, slate, chert, felsite, and basalt	13–97
Water	97+

TABLE 2.—*Types of analyses conducted on samples*

[Arranged by drift type and in east-to-west order within each sample group. Surficial till: query after description indicates questionable identification. Bouldery till: query before sample number indicates questionable stratigraphic position. Basal till: query after description indicates questionable identification or stratigraphic position]

Sample	Description	Location	Analyses: Particle size	Pebble lithology	Percentage of soluble material	Clay mineralogy	Heavy mineral content
Surficial till samples							
C–19	Red clayey till	56.15.30DDA (south of Aurora)		×			
C–21	do	57.15.26CBB (south of Aurora)		×			
5	do	58.15.12CCC (near Aurora)	×	×	×		
C–23	do	58.15.10DDC (near Aurora)		×			
36	do	58.16.10BAA (Mary Ellen mine)	×	×	×		
C–24	do	58.17.24BCD (near Mariska mine)		×	×	×	×
A–27	do	58.17.4BBD (near Virginia)	×				
A–28	do	58.17.17CAA (near Virginia)	×				
A–29	do	58.18.9ADB (near Mountain Iron)	×				
A–30	do	do	×				
A–31	do	do	×				
A–32	do	do	×				
A–33	do	do	×				
A–34	do	do	×				
A–35	do	58.18.10CAC (near Mountain Iron).	×				
C–25	do	5818.18.10CDD (near Mountain Iron).		×			
A–36	do	58.18.13BCB (near Virginia)	×				
A–37	do	58.18.32DAD (west of Eveleth)	×				
A–3	do	57.18.3DDA (southwest of Eveleth).	×				
A–4	do	57.18.12AAA (southwest of Eveleth).	×				
A–5	do	57.18.21BBA (southwest of Eveleth).	×				
A–6	do	57.18.23CCD (southwest of Eveleth).	×				
A–14	do	57.19.10DDD (southeast of Buhl)	×				
A–16	do	57.19.13DAD (southeast of Buhl)	×				
1	do	57.19.11CCC (southeast of Buhl)	×	×	×		
C–Z	do	58.19.13B (Wade mine)		×			
C–26	do	58.19.16ABD (northeast of Buhl)		×			

TABLE 2.—*Types of analyses conducted on samples*—Continued

Sample	Description	Location	Analyses: Particle size	Pebble lithology	Percentage of soluble material	Clay mineralogy	Heavy mineral content
	Surficial till samples—Continued						
C–22	Red clayey till	57.20.15ACD (east of Hibbing)		X			
C–20	---do	56.21.31AAA (south of Keewatin)	X	X	X	X	X
C–Y	---do	55.22.12DDA (south of Keewatin)		X			
7	---do(?)	54.21.7CCB (near Goodland)	X	X	X		
48	---do	55.22.12CB (north of Goodland)	X	X	X		
4	Brown silty till(?)	63.12.24ACB (near Winton)	X	X	X		
22	---do(?)	60.13.9BAB (near Babbitt)	X	X	X		
14	---do(?)	61.15.34CAA (near Embarrass)	X	X	X		
15	---do(?)	60.16.19DCB (near Big Rice Lake)	X	X	X		
9	---do	59.19.4ACB (north of Buhl)	X	X	X		
C–13	---do(?)	59.19.33ABB (north of Buhl)		X			
A–10	Gray clayey till	57.18.28ABB (southwest of Eveleth).	X				
A–12	---do	57.19.2BCD (southeast of Buhl)	X				
A–13	---do	57.19.10DCD (southeast of Buhl)	X				
A–15	---do	57.19.11CCC (southeast of Buhl)	X				
16	Brown silty till	57.19.11CCC (southeast of Buhl)	X	X	X		
C–15	---do	57.20.15ACD (east of Hibbing)		X			
C–X	---do	56.21.6BBC (south of Keewatin)		X			
2	---do(?)	54.21.7CCB (near Goodland)	X	X	X		
C–14	---do	54.22.8DDA (west of Goodland)	X	X	X	X	X
28	---do	56.24.22BBD (Holman mine)	X	X	X		
8	---do	56.24.32DBA (near Bovey)	X	X	X		
C–W	---do	55.24.19BBB (east of Grand Rapids).		X			
61	---do	56.25.35CCD (West Hill mine)	X	X	X		
C–V	---do	54.26.23C (near Pokegama Lake)		X			
29	---do	55.26.2ACA (near Cohasset)	X	X	X		
12	---do	55.27.11CBB (west of Cohasset)	X	X	X		
19	---do	58.27.24DAB (near Little Bowstring Lake).	X	X	X		
30	Black silty till	---do	X	X	X		
C–16	Dark-brown silty till	---do		X	X	X	X
C–17	Brown silty till	---do		X	X	X	X
C–18	Black silty till	---do		X	X	X	X
	Bouldery till samples						
11	Brown bouldery till	57.12.32AAB (near Toimi)		X	X	X	X
C–29	---do	58.15.4BBD (Hudson mine)	X	X	X		
44	Red bouldery till	58.18.25DDD (Leonidas mine)	X	X	X		
?20	Yellow sandy till	58.17.9DBD (Victoria mine)	X	X	X		
45	Tan bouldery till	58.19.13BAD (Wade mine)	X	X	X		
C–27	Brown bouldery till	55.21.4BAB (south of Hibbing)		X	X	X	X
?C–30	Orange bouldery till	57.22.24 (St. Paul mine)	X	X	X	X	X
?63	Brown bouldery till	55.26.23CCD (Tioga No. 2 mine)	X	X	X		
?C–28	Orange bouldery till	55.26.23CDC (Tioga No. 2 mine)	X	X	X	X	X
C–31	Gray(?) bouldery till	58.17.34D (Genoa mine)		X	X	X	X
18	Gray bouldery till	58.17.9DBD (Victoria mine)	X	X	X		
40	---do	58.19.13BAD (Wade mine)	X	X	X		
C–32	---do	58.19.13B (Wade mine)		X	X	X	X
51	---do	58.20.23CDA (Fraser mine)	X	X	X		
56	---do	58.20.34AAB (Duncan mine)	X	X	X		
57	Green-gray bouldery till	56.25.35CCD (West Hill mine)	X	X	X		
21	Brown bouldery till	58.15.4BCA (Hudson mine)	X	X	X		
?43	Brown sandy till	58 15.6DAB (Embarrass mine)	X	X	X		
?34	Brown bouldery till	58.16.3BDC (Canton mine)	X	X	X		
32	---do	58.17.9DBD (Victoria mine)	X	X	X		
38	Orange bouldery till	58.19.13BAD (Wade mine)	X	X	X		
C–33	---do	---do		X	X	X	X
49	Brown bouldery till	58.19.10CD (Seville mine)	X	X	X		
41	---do	58.20.23CBD (Fraser mine)	X	X	X		

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TABLE 2.—*Types of analyses conducted on samples*—Continued

Sample	Description	Location	Analyses: Particle size	Pebble lithology	Percentage of soluble material	Clay mineralogy	Heavy mineral content
	Basal till samples						
6	Olive-gray till	58.15.3CDB (St. James mine)	×	×	×		
26	Dark-brown silty till	58.15.6DAB (Embarrass mine)	×	×	×		
C–36	---do	58.15.5 (Embarrass mine)	×	×	×	×	×
13	Medium-brown silty till(?)	58.19.12BCD (Atkins mine)	×	×	×		
23	Dark-brownish-gray silty till	---do	×	×	×		
17	Medium-brown silty till	58.19.12BDC (Atkins mine)	×	×	×		
39	Greenish-gray sandy till	58.19.13BAD (Wade mine)	×	×	×		
C–37	---do	58.19.13B (Wade mine)	×	×	×	×	×
62	Dark-gray silty till(?)	58.20.25CAA (Elbern mine)	×	×	×		
31	Green-black till	58.20.25BDD (Elbern mine)	×	×	×		
37	Dark-olive-gray silty till	58.20.23CAD (Fraser mine)	×	×	×		
42	Greenish-gray sandy till	---do	×	×	×		
C–38	---do	---do	×	×	×	×	×
64	Dark-gray silty till(?)	58.20.34AAB (Duncan mine)	×	×	×		
54	Black till(?)	---do	×	×	×		
59	Dark-gray silty till	58.20.34AAA (Duncan mine)	×	×	×		
C–35	Dark-gray sandy till	57.22.24CA (St. Paul mine)	×	×	×	×	×
52	Dark-gray silty till	55.26.23CCD (Tioga No. 2 mine)	×	×	×		
55	---do	---do	×	×	×		
C–34	---do	55.26.23CDC (Tioga No. 2 mine)	×	×	×	×	×
	Miscellaneous samples						
35	Red-brown sandy till	57.12.33BAA (near Toimi)	×	×	×		
46	Silt	61.14.34ADC (west of Babbitt)	×	×	×		
33	Clay (till?)	62.15.29BAC (near Tower)	×	×	×		
53	Silt	60.17.23ABB (near Big Rice Lake)	×	×	×		
A–20	---do	58.16.3CBD (Canton mine)	×				
A–21	---do	---do	×				
A–22	---do	---do	×				
A–23	---do	---do	×				
A–24	---do	---do	×				
A–25	Sand	---do	×				
A–26	---do	---do	×				
47	---do (eolian?)	58.17.35BCC (near Sparta)	×	×	×		
C–41	Sand and gravel	58.17.17ACC (Rouchleau mine)	×		×	×	×
A–1	Sand	57.17.20DCD (south of Eveleth)	×				
A–2	---do	---do	×				
A–7	Silt	57.18.26ABB (southwest of Eveleth).	×				
A–8	---do	---do	×				
A–9	---do	---do	×				
A–11	---do	57.18.32BBB (southwest of Eveleth).	×				
A–17	---do	57.19.23ADA (southwest of Eveleth).	×				
A–18	---do	---do	×				
A–19	---do	---do	×				
60	Sand and gravel	58.20.34AAA (Duncan mine)	×	×	×		
C–40	Sand	57.22.24 (St. Paul mine)	×		×	×	×
50	Clay (brown silty till?)	56.24.22BBD (Holman mine)	×	×	×		
C–39	Sand	55.26.23CDC (Tioga No. 2 mine)	×		×	×	×
27	Clay (red clayey till?)	55.27.11CBB (west of Cohasset)	×	×	×		
24	Sand and gravel	135.34.18AAD (Wadena County)	×	×	×		
25	---do	134.35.29CCC (Wadena County)	×	×	×		
3	Sandy till	134.34.18AAD (Wadena County)	×	×	×		
58	---do	136.34.29BBB (Wadena County)	×	×	×		

This report is concerned largely with the analysis and interpretation of the sample data. Together with the field mapping, this information was used to establish a tentative glacial stratigraphic section for the Iron Range area in order to provide the background information needed for hydrologic studies.

LABORATORY ANALYSIS OF SAMPLES

A total of 134 samples were collected in the Iron Range area. Of this total, 112 were analyzed for particle-size distribution, 84 for percentage of soluble material (carbonate content), 94 for pebble lithology, 21 for clay-mineral content, and 21 for heavy-mineral content. The sampling locations are shown on plate 1, and pertinent data on the samples and analyses conducted on each are summarized in table 2.

PARTICLE-SIZE DISTRIBUTION

LABORATORY PROCEDURE

Sixty-four samples were processed in the St. Paul, Minn., office of the U.S. Geological Survey. The remaining 49 were processed by the U.S. Geological Survey in Denver, Colo. The procedure used in St. Paul was as follows: The original sample was divided into two parts; one part was subjected to the hydrometer method of analysis to determine the distribution of sizes less than 0.0625 millimeters, and the other part was sieved to determine the distribution of sizes greater than 0.0625 millimeters. Cumulative frequency curves for both subsamples were plotted on the same piece of graph paper. For most samples, the curve ends for each procedure were close enough to draw a continuous curve.

The procedure used at Denver differed somewhat. Only one sample was subjected to both techniques, first the hydrometer and then the sieving. After the hydrometer analysis the sample was washed through a 0.0625 millimeter sieve. The part retained on the sieve was dried and sieved, and the results were plotted as cumulative frequency curves.

The particle-size data are given in tables 3 and 4. Statistical summaries of the data, including mean, median, standard deviation, and skewness were calculated when data permitted (table 4). The calculations were based on the method described by Inman (1952) and discussed by Griffiths (1967).

TABLE 3.—*Particle-size distribution (in percent by weight)*
[Particle sizes in millimeters]

Sample	Clay (<0.004)	Silt (0.004–0.0625)	Sand					Gravel			
			Very fine (0.0625–0.125)	Fine (0.125–0.25)	Medium (0.25–0.5)	Coarse (0.5–1.0)	Very coarse (1–2)	Very fine (2–4)	Fine (4–8)	Medium (8–16)	Coarse (16–32)
A-1	6.7		42.1	39.9	9.3	1.5	0.5	---	---	---	---
A-2	7.8		46.2	38.3	6.7	.8	.2	---	---	---	---
A-3	50.9	29.9	4.4	5.0	4.8	2.3	.8	.8	1.1	---	---
A-4	39.8	24.1	7.5	6.0	4.2	1.4	2.0	3.3	4.7	7.0	---
A-5	46.5	30.9	7.1	7.3	5.1	1.6	.0	.6	.8	---	---
A-6	30.3	25.7	7.7	10.3	10.7	6.0	3.0	2.1	2.3	1.9	---
A-7	18.7	71.3	5.0	2.8	1.6	.4	.2	---	---	---	---
A-8	6.5	88.3	3.6	.8	.8	---	---	---	---	---	---
A-9	7.6	87.4	4.0	.6	.4	---	---	---	---	---	---
A-10	36.4	23.2	17.0	8.0	6.8	4.8	.8	1.6	1.4	---	---
A-11	16.5	65.1	2.8	6.6	5.2	3.2	.6	---	---	---	---
A-12	17.2	25.5	9.7	15.6	16.3	9.2	3.9	1.5	1.1	---	---
A-13	40.0	29.6	8.6	9.7	6.5	2.1	1.0	1.2	1.3	---	---
A-14	41.5	26.2	4.6	6.4	6.9	3.9	2.2	1.7	1.5	5.1	---
A-15	20.8	34.4	8.9	12.3	10.1	6.5	3.5	2.3	1.2	---	---
A-16	43.1	25.9	6.3	8.1	9.2	3.7	2.0	.9	.8	---	---
A-17	34.0	64.4	.6	1.0	---	---	---	---	---	---	---
A-18	24.0	73.2	1.4	1.4	---	---	---	---	---	---	---
A-19	33.8	65.6	.4	.2	---	---	---	---	---	---	---
A-20	18.8	72.6	6.2	2.4	---	---	---	---	---	---	---
A-21	8.2	91.0	.6	.2	---	---	---	---	---	---	---
A-22	10.0	88.0	2.0	---	---	---	---	---	---	---	---
A-23	14.9	83.3	1.8	---	---	---	---	---	---	---	---
A-24	39.0	57.4	3.2	.4	---	---	---	---	---	---	---
A-25	9.8	56.0	15.2	13.6	4.2	1.0	.2	---	---	---	---
A-26	9.7	51.9	18.6	14.0	4.4	1.2	.2	---	---	---	---
A-27	54.5	23.0	3.3	4.0	3.7	1.6	.9	1.6	.8	.0	6.6
A-28	29.0	16.3	3.8	5.4	5.6	6.4	6.4	12.0	6.9	8.2	---
A-29	63.0	25.9	2.4	2.5	3.4	1.0	1.0	.5	.3	---	---
A-30	60.2	27.6	2.4	2.7	2.2	1.7	1.0	.6	1.2	.4	---
A-31	56.6	26.0	2.2	2.0	2.2	1.3	.5	.7	.4	.0	7.9
A-32	63.5	24.5	4.4	2.7	.5	2.0	1.0	.7	.7	---	---
A-33	59.7	27.4	2.0	2.5	2.3	1.9	.8	.7	1.7	1.0	---
A-34	67.0	24.0	1.8	2.3	1.6	1.4	.8	.9	.2	---	---
A-35	50.5	28.2	4.5	5.8	4.6	1.7	1.2	.7	1.4	1.4	---
A-36	65.7	24.3	2.8	2.7	2.0	1.4	.2	.4	.5	---	---
A-37	44.5	26.5	5.1	6.7	5.3	3.9	2.7	1.6	1.3	2.4	---
C-14	21.4	23.0	6.9	12.2	14.1	11.3	4.0	3.5	1.2	2.4	---
C-20	32.0	37.2	7.2	7.5	6.5	4.1	2.2	1.4	.8	1.1	---
C-28	6.6	21.6	8.6	14.3	13.9	10.2	6.5	5.1	4.9	5.2	3.1
C-30	6.1	17.0	7.3	19.6	5.5	10.7	6.1	11.7	4.0	4.6	7.4
C-34	25.5	24.2	6.9	11.8	10.7	7.1	3.7	2.6	7.8	4.7	---
C-35	27.8	38.6	5.9	7.3	7.0	4.5	3.8	2.3	1.4	1.4	---
C-36	27.2	36.3	3.0	5.4	6.4	4.8	2.4	3.8	2.6	4.3	3.8
C-37	10.2	24.4	7.9	12.3	12.1	9.4	5.3	5.0	4.3	5.7	3.4
C-38	16.5	18.8	5.8	10.3	12.5	11.2	7.2	7.2	5.4	5.1	---
C-39	---	.3	4.2	26.8	33.7	23.5	7.6	1.6	1.0	1.3	---
C-40	14.9		1.4	7.3	26.1	19.5	10.0	7.4	4.6	4.0	4.8
C-41	1.8		5.3	15.6	26.0	30.5	12.6	3.4	1.8	1.3	1.7
1	62.8		3.4	5.0	5.4	3.7	1.9	1.2	3.5	3.1	---
2	32.0	18.3	7.5	12.3	12.7	7.7	3.8	2.3	.5	.3	---
3	12.8	13.4	6.4	15.3	22.7	12.7	6.1	4.1	4.8	.7	---
4	10.2	21.0	9.6	11.9	11.5	9.1	6.4	6.3	5.0	9.0	---
5	68.2	27.8	1.8	1.8	.2	---	---	---	---	---	---
6	13.5	16.8	5.6	9.1	9.2	6.3	4.6	3.3	2.0	29.5	---
7	18.5	28.0	9.7	18.3	17.5	10.0	3.9	2.1	1.1	1.3	---
8	22.7	20.8	8.3	13.8	14.1	8.4	3.8	2.5	2.0	3.0	---
9	27.6	27.2	4.9	6.4	6.4	4.7	3.1	1.4	1.2	17.2	---
11	4.0	20.7	12.5	14.9	13.2	10.7	7.9	4.9	5.7	4.3	---
12	38.0	28.4	7.8	9.9	6.0	2.9	2.2	1.5	1.4	2.0	---
13	4.5	18.5	8.6	11.6	11.7	9.8	8.3	6.3	10.4	9.6	---
14	22.6	33.8	9.5	6.8	5.4	3.6	3.0	3.6	4.4	7.4	---
15	12.0	57.3	10.8	6.0	5.7	3.1	.9	.9	.9	2.4	---
16	49.9		9.2	13.4	10.5	5.8	3.3	2.5	1.4	4.0	---
17	7.8	19.9	7.5	10.7	12.6	8.1	5.4	5.9	4.3	16.5	---
18	6.8	23.6	11.0	12.6	11.8	7.9	4.3	3.5	3.2	15.4	---
19	64.5	23.5	2.5	2.6	1.7	.8	.4	.5	.2	---	---
20	13.0	27.5	11.1	10.3	8.5	7.9	6.2	4.2	5.2	6.2	---
21	3.6	10.2	6.6	11.7	14.4	8.9	8.5	8.0	8.0	19.6	---

TABLE 3.—*Particle-size distribution (in percent by weight)*—Continued

Sample	Clay (<0.004)	Silt (0.004–0.0625)	Sand: Very fine (0.0625–0.125)	Sand: Fine (0.125–0.25)	Sand: Medium (0.25–0.5)	Sand: Coarse (0.5–1.0)	Sand: Very coarse (1–2)	Gravel: Very fine (2–4)	Gravel: Fine (4–8)	Gravel: Medium (8–16)	Gravel: Coarse (16–32)
22	14.5	26.5	7.6	10.9	11.7	10.6	6.1	3.8	2.6	4.0	---
23	8.3	14.2	4.3	6.3	7.5	7.0	4.8	5.6	6.8	34.7	---
24	8.4	13.1	7.7	19.0	24.3	13.2	4.9	3.9	2.4	3.2	---
25	3.7	2.3	.8	4.4	12.4	28.6	17.1	10.1	8.3	12.0	---
26	4.0	16.8	6.4	11.7	13.8	10.1	7.1	7.4	6.0	14.6	---
27	84.0	16.0	---	---	---	---	---	---	---	---	---
28	45.6	10.8	3.8	7.0	8.9	7.0	4.1	2.6	5.2	3.6	---
29	73.5	23.5	.6	.7	.7	.6	.2	.1	---	---	---
30	31.0	20.7	6.3	9.0	7.8	5.4	3.7	4.9	2.9	7.8	---
31	33.1	38.7	5.4	5.8	5.8	3.9	1.7	1.5	1.6	1.8	---
32	4.5	14.4	7.2	10.6	11.4	8.9	7.4	6.9	7.6	21.2	---
33	83.5	13.3	.3	.6	.5	.3	.3	.0	.1	---	---
34	2.0	12.4	7.8	13.3	14.3	9.5	7.6	6.3	7.0	19.0	---
35	8.7	15.9	9.1	11.8	12.3	11.5	10.9	8.9	7.1	2.0	---
36	57.7	23.2	4.2	3.9	3.6	2.4	1.6	1.1	.6	---	---
37	29.9	25.5	7.2	9.4	9.4	7.0	6.1	3.1	1.0	1.2	---
38	7.0	16.5	6.4	9.6	10.1	8.1	6.2	5.9	6.1	21.5	---
39	6.0	20.8	7.1	9.3	9.8	9.3	7.7	7.9	4.8	17.2	---
40	12.4	21.1	9.0	11.4	11.8	9.5	6.5	4.3	3.8	9.8	---
41	8.4	13.1	7.0	13.6	20.1	17.3	11.3	4.3	2.0	2.0	---
42	7.8	17.7	8.2	12.5	15.1	12.1	8.3	4.7	4.4	7.6	---
43	5.0	12.8	6.5	10.2	11.4	10.2	8.6	8.1	6.2	21.0	---
44	5.9	23.6	9.5	11.6	10.9	9.4	7.7	6.5	5.6	7.6	---
45	4.6	17.4	10.7	14.1	13.8	11.3	8.5	5.9	3.9	8.6	---
46	7.0	48.0	29.0	12.5	3.8	.9	.1	---	---	---	---
47	1.4	3.1	18.4	54.3	22.0	.9	.1	---	---	---	---
48	52.0	23.3	4.9	6.1	5.7	3.5	2.3	.9	1.0	.4	---
49	6.6	15.0	4.7	6.2	7.3	7.8	7.1	7.2	4.9	32.5	---
50	53.0	42.2	1.8	1.3	.7	.5	.4	.1	---	---	---
51	6.0	19.4	9.6	12.8	11.6	9.8	7.2	5.0	5.8	12.7	---
52	27.0	20.6	7.2	11.7	12.0	7.8	4.3	4.5	2.0	1.4	---
53	13.7	41.9	10.8	9.4	7.7	5.5	4.4	2.8	1.8	.5	---
54	26.0	29.2	3.1	5.5	12.0	11.5	5.2	1.8	.9	.4	---
55	25.6	28.0	6.8	9.2	8.7	6.8	4.1	3.2	1.6	2.8	---
56	5.5	14.9	7.3	11.5	14.6	13.0	8.9	4.7	2.7	16.3	---
57	9.8	13.8	9.5	17.3	19.6	12.7	5.7	3.9	2.3	3.4	---
58	8.9	15.9	8.6	19.8	22.2	11.5	4.7	2.4	3.0	.7	---
59	20.0	31.0	9.9	11.0	7.5	4.0	3.0	1.8	1.1	9.6	---
60	.1	1.3	.5	3.1	13.2	18.8	16.3	14.6	14.3	17.2	---
61	22.2	13.8	8.1	15.5	17.6	9.8	5.0	3.3	3.3	.8	---
62	18.4	65.1	3.9	2.1	2.3	2.0	1.2	.4	.3	.2	---
63	11.0	15.8	8.8	15.8	19.4	13.0	7.3	3.3	3.6	2.0	---
64	37.0	30.5	8.6	5.8	5.8	4.4	2.8	2.2	2.4	.4	---

TABLE 4.—*Particle-size percentiles and statistical summaries (in phi units)*

Sample	Percentiles (*P*), in phi (φ) units: 5	16	25	50	75	84	95	Mean (Mφ) $\frac{P_{16}+P_{84}}{2}$	Standard deviation (σφ) $\frac{P_{84}-P_{16}}{2}$	Skewness (αφ) $\frac{P_{16}+P_{84}-2P_{50}}{P_{84}+P_{16}}$
A–1	4.25	3.5	3.4	3.0	2.4	2.2	1.55	2.85	−0.65	0.23
A–2	----	3.45	3.3	3.05	2.7	2.4	---	2.92	−.52	.23
A–3	----	----	----	8.1	---	---	---	---	---	---
A–4	----	----	----	6.1	---	---	---	---	---	---
A–5	----	----	----	7.6	---	---	---	---	---	---
A–6	----	----	9.05	4.8	1.95	---	---	---	---	---
A–7	----	8.4	7.3	5.85	4.7	4.45	---	6.42	−1.97	−.29
A–8	8.5	6.95	6.5	5.6	4.95	4.75	3.95	5.85	−1.1	−.23
A–9	8.6	7.05	6.6	5.65	4.8	4.6	4.05	5.82	−1.22	−.13
A–10	----	----	----	6.05	---	---	---	---	---	---
A–11	----	8.05	7.4	6.4	5.25	3.1	---	5.57	−2.47	.33

TABLE 4.—*Particle-size percentiles and statistical summaries (in phi units)*—Continued

Sample	Percentiles (*P*), in phi (φ) units							Mean (Mφ)	Standard deviation (σφ)	Skewness (αφ)
	5	16	25	50	75	84	95	$\frac{P_{16}+P_{84}}{2}$	$\frac{P_{84}-P_{16}}{2}$	$\frac{P_{16}+P_{84}-2P_{50}}{P_{84}+P_{16}}$
A-12	---	8.3	6.1	3.2	1.65	1.0	---	4.65	−3.65	−0.39
A-13	---	---	---	6.35	---	---	---	---	---	---
A-14	---	---	---	6.8	---	---	---	---	---	---
A-15	---	9.05	7.15	4.5	2.1	1.25	---	5.15	−3.9	−.16
A-16	---	---	---	6.95	---	---	---	---	---	---
A-17	---	---	8.75	7.0	5.75	---	---	---	---	---
A-18	---	9.0	7.9	6.6	5.4	5.05	---	7.02	−1.97	−.21
A-19	---	---	8.7	6.9	5.65	---	---	---	---	---
A-20	9.25	8.2	7.7	6.6	5.3	4.65	3.5	6.42	−1.77	.10
A-21	---	7.3	6.85	5.9	5.2	4.9	---	6.1	−1.20	−.16
A-22	---	7.25	6.6	5.5	4.8	4.6	---	5.92	−1.32	−.31
A-23	---	7.8	7.1	5.9	5.0	4.7	---	6.25	−1.55	−.22
A-24	---	9.1	8.9	7.4	5.9	5.3	---	7.20	−1.90	.10
A-25	8.8	7.3	6.65	5.0	3.4	2.8	1.95	5.05	−2.25	−.02
A-26	8.7	7.3	6.6	4.65	3.3	2.8	1.9	5.05	−2.25	−.17
A-27	---	---	---	8.55	---	---	---	---	---	---
A-28	---	---	9.2	2.85	−1.15	---	---	---	---	---
A-20	---	---	---	8.9	---	---	---	---	---	---
A-30	---	---	---	8.8	---	---	---	---	---	---
A-31	---	---	---	8.85	---	---	---	---	---	---
A-32	---	---	---	9.25	---	---	---	---	---	---
A-33	---	---	---	8.85	---	---	---	---	---	---
A-34	---	---	---	---	---	---	---	---	---	---
A-35	---	---	---	8.1	---	---	---	---	---	---
A-36	---	---	---	---	---	---	---	---	---	---
A-37	---	---	---	7.2	---	---	---	---	---	---
C-14	---	9.2	7.3	3.1	1.2	.5	---	4.85	−4.35	−.40
C-29	---	---	8.95	5.95	3.2	---	---	---	---	---
C-28	9.1	5.6	4.3	2.1	.05	−1.6	−3.6	2.0	−3.6	.02
C-30	8.4	5.5	3.5	1.95	−1.4	−2.0	−4.35	1.75	−3.75	.05
C-34	---	---	8.0	3.85	1.35	---	---	---	---	---
C-35	---	---	8.55	6.85	2.55	---	---	---	---	---
C-36	---	---	8.25	6.65	1.5	---	---	---	---	---
C-37	---	6.85	5.4	2.35	.2	−1.5	---	2.67	−4.17	−.07
C-38	---	8.1	5.95	2.1	.0	−1.25	---	3.42	−4.67	−.28
C-39	2.95	2.4	2.2	1.5	.65	.25	−.6	1.32	−1.07	.16
C-40	---	3.2	1.9	1.0	−.55	−1.7	---	.75	−2.45	.10
C-41	3.3	2.35	1.95	1.0	.15	−.25	−2.0	1.05	−1.30	−.03
1	---	---	---	---	---	---	---	---	---	---
2	---	---	---	4.0	---	---	---	---	---	---
3	---	6.6	4.2	1.95	.8	---	---	3.3	−3.3	−.40
4	---	6.4	4.7	2.2	−.3	−1.7	---	2.35	−4.05	−.03
5	---	---	---	---	---	---	---	---	---	---
6	---	---	---	1.5	---	---	---	---	---	---
7	---	9.25	6.0	2.7	1.4	.8	---	5.02	−4.22	−.54
8	---	---	7.3	3.25	1.45	---	---	---	---	---
9	---	---	8.5	4.7	.5	---	---	---	---	---
11	7.7	5.1	4.0	2.2	.1	−1.0	−2.75	2.05	−3.05	.04
12	---	---	---	5.95	---	---	---	---	---	---
13	7.6	4.75	3.8	1.5	−1.2	−2.5	−3.6	1.12	−3.62	.10
14	---	9.15	7.6	4.6	1.6	−.85	---	4.15	−5.0	.09
15	---	7.4	6.45	4.7	3.6	2.55	---	4.97	−2.42	−.11
16	---	---	---	---	---	---	---	---	---	---
17	---	5.95	4.4	1.8	−1.3	−3.2	---	1.37	−4.57	.09
18	---	5.85	4.55	2.3	−.3	−2.8	---	1.52	−4.32	.18
19	---	---	---	---	---	---	---	---	---	---
20	---	7.1	5.65	3.1	.45	−1.0	---	3.05	−4.05	.01
21	---	3.6	2.6	.7	−2.4	−3.4	---	.10	−3.5	.17
22	---	7.6	6.1	3.05	.85	−.1	---	3.75	−3.85	−.18
23	---	---	---	−.4	---	---	---	---	---	---
24	---	5.0	3.5	1.95	.9	.2	---	2.6	−2.4	−.27
25	5.6	1.5	.9	.1	−1.5	−2.5	−3.85	−.5	−2.0	.30
26	7.5	4.7	3.5	1.4	−1.35	−2.75	−4.8	.97	−3.72	.11
27	---	---	---	---	---	---	---	---	---	---
28	---	---	---	5.8	---	---	---	---	---	---
29	---	---	---	---	---	---	---	---	---	---
30	---	---	---	4.25	---	---	---	---	---	---
31	---	---	---	5.85	---	---	---	---	---	---
32	---	4.5	3.2	.8	−2.5	−3.5	---	.5	---	---
33	---	---	---	---	---	---	---	---	---	---
34	---	3.8	2.8	1.05	−2.15	−3.4	---	.2	−3.6	.24

TABLE 4.—*Particle-size percentiles and statistical summaries (in phi units)*—Continued

Sample	Percentiles (P), in phi (ϕ) units: 5	16	25	50	75	84	95	Mean ($M\phi$) $\frac{P_{16}+P_{84}}{2}$	Standard deviation ($\sigma\phi$) $\frac{P_{84}-P_{16}}{2}$	Skewness ($\alpha\phi$) $\frac{P_{16}+P_{84}-2P_{50}}{P_{84}+P_{16}}$
35	10.0	5.6	4.0	1.6	−0.55	−1.45	−2.85	2.07	−3.52	−0.13
36	----	----	----	----	---	---	---	---	---	---
37	----	----	9.35	4.75	1.7	---	---	---	---	---
38	----	5.3	3.8	1.2	−2.35	−4.2	---	.55	−4.75	.14
39	----	5.5	4.2	1.35	−1.5	−3.5	---	1.0	−4.5	.08
40	----	7.0	5.2	2.3	---	−1.45	---	2.77	−4.22	−.11
41	----	5.0	3.5	1.6	.4	−.25	---	2.37	−2.62	−.30
42	9.1	5.5	4.1	2.15	---	−1.15	−3.55	2.17	−3.32	−.01
43	----	----	2.95	.65	−2.3	---	---	---	---	---
44	----	5.7	4.5	2.25	−.25	−1.4	---	2.15	−3.55	.03
45	7.75	4.8	3.7	1.9	−.2	−1.35	−4.2	1.72	−3.07	.06
46	8.9	6.55	5.7	4.25	3.3	2.95	2.0	4.75	−1.8	−.28
47	4.0	3.3	2.95	2.45	2.0	1.9	1.45	2.6	−.7	−.21
48	----	----	----	8.65	---	---	---	---	---	---
49	----	----	----	−.2	---	---	---	---	---	---
50	----	----	----	8.6	---	---	---	---	---	---
51	----	5.3	4.05	1.8	.75	−2.5	---	1.4	−3.9	−.10
52	----	----	8.55	3.7	1.45	---	---	---	---	---
53	----	7.6	6.55	4.45	2.3	1.1	---	4.35	−3.25	.03
54	----	----	8.1	5.0	1.4	---	---	---	---	---
55	----	----	8.1	4.35	1.75	--	---	---	---	---
56	----	4.75	3.4	1.3	−.8	3.2	---	.77	−3.97	.13
57	----	5.35	3.85	2.1	.8	.1	---	2.72	−2.62	−.24
58	10.0	5.65	4.0	2.2	1.15	.5	−2.05	3.07	−2.57	−.34
59	----	8.9	7.2	4.1	1.8	.25	---	4.57	−4.32	−.11
60	----	1.1	.7	−.75	−2.45	−3.1	---	−1.0	−2.1	.12
61	----	----	6.8	2.6	1.2	---	---	---	---	---
62	----	----	----	----	---	---	---	---	---	---
63	----	6.1	4.25	2.1	.7	---	---	3.05	−3.05	−.31
64	----	----	----	6.15	---	---	---	---	---	---

RESULTS OF ANALYSES

SURFICIAL TILL SAMPLES

Selected cumulative frequency curves for the red clayey till and brown silty till samples (pl. 2) show the extremely wide dispersion (poor sorting) of these fine-grained till units. The curves for samples from both till units are somewhat similar within each unit, but are dissimilar when compared with each other. Generally, curves for the red clayey till do not have an S shape and are very "open" on the fine-grained end, indicating a very large percentage of material finer than 1 micron (0.001 mm) in size. In contrast, curves for the brown silty till samples have a slight S shape and show a larger percentage of sand. This relationship can be seen more clearly on the trilinear diagram (pl. 2), which shows a clear separation of samples from the two till units. The diagram also shows that the field description of the brown silty till is a misnomer because sand and gravel is more abundant than silt. Comparison of curves in plate 2 indicates the red clayey till is slightly more clayey in the eastern than in the western part of the study area.

Some samples were collected which had questionable identification in the field and are shown by a question mark after the descriptive name (table 2). They were grouped with samples from the geologic unit they seemed most akin to.

The frequency curve for sample 7 (pl. 2) is considerably unlike the curves for the other red clayey till samples. It is the only red clayey till sample that has a questionable identification. This sample is from a location near Goodland where the red clayey till and brown silty till are intermixed and identification of either till is difficult. Sample 7 can be compared with sample 2 (pl. 2) which is a brown silty till of questionable identification (also collected near Goodland). Cumulative frequency curves for both samples are similar and are more characteristic of the brown silty till than the red clayey till.

A number of samples of questionable identification were grouped with the brown silty till samples (table 2). Most of these occur north of the Giants Range in the eastern part of the area. These samples were collected to determine the eastern extent of the brown silty till. East of the limit shown on plate 1 the till is very spotty, if the few exposures are, in fact, brown silty till. The data (tables 3, 4) for samples 4, 22, and 14 are very similar to those for the other brown silty till samples. The exception is sample 15. The data for this sample indicate that it is probably poorly sorted silt. Sample 29 also is anomalous and is probably clay rather than till.

Samples 19 and 30 are from an outcrop near Little Bowstring Lake that appears to contain three till units. A brown silty till and a darker brown silty till which have a very poorly defined contact overlie a black clayey till. It was believed that the black till perhaps correlated with the basal till (described later) that is found deep in a number of mines. The analysis of particle size indicates that the black till (sample 30) is similar to the basal till but that it is also similar to the brown silty till. Particle-size data for sample 19 are quite unlike those for the other brown silty till samples. There is no ready explanation for this unless the sample collected was not representative.

At a number of localities southwest of Eveleth and southeast of Buhl, lenses of gray clayey till occur within the red clayey till. Samples were collected from both types to determine if the gray till was a color variation of the red till or if it was brown silty till interbedded with red clayey till. Samples A–10, A–12, A–13, and A–15 are from the gray till, and samples A–14 and A–16 are from the red till (pl. 2). Samples A–12 and A–15 are much like other brown silty till samples, whereas samples A–10 and A–13 are more similar to, but not exactly like, the red clayey till samples. On the basis of particle-size data, the question of identification of the gray clayey till cannot be resolved.

Statistical summaries could not be calculated for most surficial till samples because of the "open ends" of the cumulative frequency curves. Those that could be summarized statistically are shown in table 4. The mean diameter is generally between 3.5 and 5.5 phi, and the standard deviation is very large. Most samples are negatively skewed.

BOULDERY TILL SAMPLES

Samples from bouldery till outcrops are grouped into three types in table 2: colored till above the gray till, gray bouldery till, and colored till below the gray till. The question marks before the sample number are to show uncertainty in stratigraphic position and not in identification. Selected cumulative frequency curves (pl. 2) are all very similar. There is a slight but consistent difference, however, in the curves for the samples of colored till below the gray till. Curves for these samples are slightly flatter in slope, indicating a higher gravel content than the curves for samples of the gray till and the colored bouldery till above the gray. This difference can be seen more clearly in the trilinear graphs (pl. 2) where all the sample data are plotted. The difference may be insignificant, but it suggests the possibility that the colored bouldery till below the gray is a separate unit from the two upper bouldery tills.

The statistical summaries of particle-size data (table 4) show a slightly coarser mean grain size for the colored till below the gray. Most samples of the bouldery till are positively skewed.

BASAL TILL SAMPLES

The dark-gray and greenish- and brownish-gray silty calcareous till that occurs deep in some mines is termed "basal till" in this report. It does not occur consistently in every mine across the range nor do the tills appear to be very similar (see table 1) ; thus, correlation is difficult. Samples of particularly questionable identification or stratigraphic position are shown with question marks (table 2). A few samples might be merely bedrock rubble that has an appearance of till. The basal tills are generally characterized by a silty to sandy matrix. Some cobbles and boulders occur in the tills but far fewer than in the bouldery tills. The particle-size data (tables 3, 4) for the basal till samples are similar and show a very wide dispersion. The data show a trend from coarser in the eastern part to finer in the central and western parts of the area. This relationship is shown on plate 2, which compares a sample from the east-central part of the area (curve 17) with a sample from the western part of the area (curve 55). This comparison shows clearly the similarity of shape but also the definite shift to finer grained till from east to west.

Particle-size data for sample 13, thought to be rubble, are similar to those for the other basal till samples. The data for samples 31 and 37 are somewhat unlike those for the other samples. The stratigraphic position of samples 31 and 37 is quite clear, and the differences may be due to sampling or the possibility that the samples are from a separate, additional till unit. Sample 62 is definitely unlike the other samples; its identification as till was questionable and is very likely silt.

MISCELLANEOUS SAMPLES

Many of the samples included in the following discussion are from deposits of fluvial and lacustrine origin. An exception is sample 35, which is of the red-brown sandy till that occurs in the extreme southeast corner of the area. The till is largely sand and has fairly wide dispersion. Samples 33, 53, 50, and 27 were collected because the deposits might be surficial till. The data (tables 3, 4) for all but sample 53 clearly are not similar to those of the surficial tills; thus, the deposits are very likely of fluvial or lacustrine origin.

Cumulative frequency curve A–9 shown on plate 2 is typical of samples from Glacial Lake St. Louis deposits. The curve of sample 47 is for an eolian sand deposit near Sparta. Many of the samples (tables 3, 4) are from the same locations and can be used to compare the variations within a unit. This is particularly true for samples of a silt deposit in the Canton mine (fig. 3).

Samples of till and sand and gravel from Wadena County were collected because of the belief that the basal tills in the report area might be correlative with till deposited by the Wadena lobe, a glacial ice lobe that deposited very prominent drumlins and moraines in central and north-central Minnesota. Results of particle-size analysis show very little similarity between the till from Wadena County and the basal tills in the Iron Range area (pl. 2).

The sand and gravel samples from the Iron Range area have a fairly narrow dispersion (well sorted) and consist largely of sand. A typical cumulative frequency curve for this type of deposit is shown on plate 2. Samples 60 and C–40 are from a sand and gravel unit that has a distinctive orange color and is probably continuous from the Duncan mine westward to the Swan Lake area.

PEBBLE LITHOLOGY

LABORATORY PROCEDURE

Pebbles of gravel size (2 mm and greater) were separated from the samples by washing the fines through a sieve. The pebbles were then identified, and a minimum of 50 pebbles was counted for

FIGURE 3.—Very well sorted silt deposit in Canton mine containing numerous calcareous concretions. Block of silt in center foreground is about 1 foot thick.

most samples (table 5). The totals were generally between 50 and 100 for the samples collected in 1968 (prefix C) and between 100

TABLE 5.—*Pebble-lithology data*

[Queries after sample numbers indicate questionable identification]

Sample	Granite	Gabbro	Felsite [1]	Basalt [1]	Limestone and dolomite [2]	Sandstone	Siltstone	Shale [2]	Slate	Schist	Gneiss	Chert	Taconite	Quartzite	Agate [1]	Graywacke	Greenstone	Dark plutonic rocks	Anorthosite	Amphibolite	Concretions	Unidentified	Total
Red clayey till																							
C–19	25	--	--	--	--	--	--	7	2	4	--	1	7	--	--	1	--	3	--	--	--	--	50
C–21	24	--	--	1	--	1	--	12	1	5	--	--	2	--	--	--	--	4	--	--	--	--	50
5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
C–23	27	2	--	--	--	--	--	6	4	1	--	--	6	1	--	--	--	4	--	--	--	--	51
36	30	2	--	1	2	--	--	--	9	--	--	--	2	3	--	7	3	--	--	--	--	--	59
C–24	14	--	1	--	--	--	--	7	9	11	--	1	8	1	--	--	1	--	--	--	--	--	53
C–25	26	1	--	--	--	--	--	5	6	2	--	--	4	1	--	--	--	5	--	--	--	--	50
1	40	3	1	--	1	--	--	7	30	2	--	--	16	6	--	6	1	--	--	--	--	--	113
C–Z	33	1	--	1	--	--	--	3	--	--	--	1	6	1	--	--	--	4	--	--	--	--	50
C–26	24	--	2	1	--	--	--	2	1	7	--	--	9	--	--	--	--	4	--	--	--	--	50
C–22	30	--	3	2	5	--	--	4	--	6	--	--	--	--	--	--	--	12	--	--	--	1	63
C–20	25	--	--	--	--	--	--	6	--	6	--	--	4	--	--	--	1	8	--	--	--	--	50
C–Y	26	--	1	--	--	--	--	7	--	3	--	6	--	--	--	--	--	7	--	--	--	--	50
7(?)	115	10	6	5	18	1	1	13	3	--	3	--	2	9	--	8	--	--	--	--	15	1	210
48	37	1	3	4	--	--	--	--	3	--	--	--	1	3	--	4	5	--	--	--	--	--	61
Brown silty till																							
4(?)	56	3	2	1	--	--	37	1	3	24	--	1	6	4	--	1	7	--	--	--	--	--	146
22(?)	124	8	--	1	--	2	--	--	--	--	--	--	1	12	--	7	--	--	--	--	--	--	155
14(?)	27	8	--	--	--	--	--	--	--	--	23	--	14	16	--	8	1	--	--	--	1	--	98
15(?)	33	3	--	--	--	--	--	--	1	9	1	--	36	5	--	2	1	--	--	--	--	--	90
9	83	7	1	2	--	1	--	--	2	2	1	--	1	2	--	6	4	--	--	--	--	--	112
C–13(?)	47	--	--	--	--	--	--	--	--	2	--	--	--	1	--	--	--	--	--	--	--	--	50
16	62	--	2	3	29	--	--	30	--	6	--	--	3	9	--	16	2	--	--	--	--	--	162
C–15	29	--	--	--	9	--	--	10	--	2	--	1	--	--	--	--	--	9	--	--	--	--	60
C–X	28	--	--	1	--	1	--	5	2	1	--	2	2	1	--	--	--	7	--	--	--	--	50
2(?)	59	--	--	--	--	--	--	85	4	1	--	1	1	5	--	3	--	--	--	--	--	--	159
C–14	28	--	2	1	2	1	--	1	1	2	--	1	2	--	--	--	--	9	--	--	--	--	50
28	88	9	3	6	4	--	--	--	1	--	--	--	5	6	--	8	--	--	--	--	--	--	130
8	85	2	--	--	20	--	--	7	2	3	1	--	3	9	--	10	1	--	--	--	2	--	145

C-W	38	--	1	--	--	--	--	--	--	6	--	--	--	--	--	--	--	5	--	--	--	--	50
61	76	3	--	3	--	1	--	147	--	2	--	1	4	6	--	9	2	--	--	--	--	--	254
C-V	31	--	--	2	--	--	--	--	--	8	--	2	--	1	--	--	--	12	--	--	--	--	56
29	3	--	--	--	--	--	--	--	--	--	--	--	5	1	--	1	--	--	--	--	--	--	10
12	51	3	1	3	27	--	--	--	1	--	--	--	2	2	--	1	2	--	--	--	--	--	93
19	7	1	--	--	17	--	--	--	--	1	--	--	--	--	--	2	3	--	--	--	--	--	31
30	17	1	--	1	12	--	--	89	--	--	--	--	--	5	--	--	1	--	--	--	--	--	126
C-16	9	--	--	--	4	1	--	37	--	1	--	--	--	5	--	--	1	--	--	--	--	--	58
C-17	21	--	--	--	--	20	--	2	--	1	--	1	1	--	--	--	--	1	--	--	--	--	47
C-18	4	--	--	--	8	--	--	36	--	--	--	--	--	--	--	--	--	4	--	--	--	--	52
Bouldery till																							
C-29	6	10	10	13	--	1	--	--	1	--	--	--	1	--	--	--	--	8	--	--	--	--	50
11	190	11	--	2	--	24	--	--	1	--	--	--	77	4	--	4	4	--	--	--	--	--	317
44	45	1	--	3	--	--	--	--	1	--	--	3	96	--	--	3	3	--	--	--	--	--	155
20	139	9	1	5	--	27	--	--	3	--	2	--	24	18	--	15	4	--	--	--	--	--	247
45	135	1	2	3	--	--	--	--	2	--	--	--	11	5	--	12	--	--	--	--	--	--	171
C-27	37	1	1	1	--	--	--	--	2	6	--	1	7	--	--	--	--	12	--	--	--	--	68
C-30	23	--	2	1	--	--	--	--	1	9	--	1	1	--	--	--	--	12	--	--	--	--	50
63	130	10	7	1	--	--	--	--	--	1	1	--	17	14	--	13	--	--	--	--	--	1	194
C-28	32	--	2	--	--	--	--	1	--	4	--	2	--	--	--	--	1	12	--	--	--	2	56
C-31 (?)	17	--	1	2	--	--	--	10	2	3	--	--	1	1	--	--	--	13	--	--	--	--	50
18	151	10	1	4	--	--	--	--	--	--	1	--	2	11	--	5	4	--	--	--	6	--	195
40	215	14	1	5	--	--	--	--	1	--	1	1	5	9	--	12	3	--	--	--	1	--	268
C-32	36	--	--	--	--	--	--	1	1	3	--	--	2	1	--	--	--	6	--	--	--	--	50
51	129	6	--	1	--	--	--	--	--	--	--	--	1	1	--	3	1	--	--	--	--	--	142
56	187	7	3	4	--	--	--	--	--	--	1	3	8	20	--	30	4	--	--	--	--	--	267
57	128	12	4	5	--	--	--	--	7	--	1	3	3	18	--	36	4	--	--	--	--	--	221
21	28	11	7	--	--	--	--	--	9	--	--	4	139	20	--	3	--	--	--	--	--	--	221
43	53	11	14	11	--	--	--	--	10	--	--	3	50	8	--	19	5	--	--	--	--	5	189
34	37	9	4	1	--	1	--	--	7	--	--	2	37	9	--	16	4	--	--	--	--	--	127
32	49	3	--	--	--	--	--	--	1	2	--	1	40	29	--	8	1	--	--	--	--	--	134
38	49	7	3	--	--	--	--	--	--	1	2	3	49	2	--	5	1	--	--	--	--	--	122
C-33	36	--	--	--	--	--	--	--	--	6	--	1	4	1	--	--	--	8	--	--	--	--	56
49	53	10	17	5	--	--	--	--	4	8	--	8	107	17	--	23	7	--	--	--	--	5	264
41	100	2	1	--	--	--	--	--	3	--	--	--	1	6	--	3	1	--	--	--	1	--	118
Basal till																							
6	80	4	1	1	--	--	9	--	1	1	1	--	5	3	--	1	2	--	--	--	--	--	109
26	29	5	10	4	--	--	--	--	--	--	--	--	71	8	--	4	1	--	--	--	--	--	132
C-36	27	2	1	1	--	1	--	2	1	9	--	4	2	--	--	--	--	4	--	--	--	--	54
13 (?)	119	7	4	5	--	--	2	--	6	--	1	1	72	15	2	7	3	--	--	--	--	--	244
23	42	11	7	9	4	--	--	--	17	--	--	1	18	10	--	5	--	--	--	--	--	--	124
17	49	12	12	9	7	--	--	--	5	2	2	5	24	11	1	11	--	--	--	--	6	--	155
39	98	30	21	--	--	--	--	--	5	--	--	5	21	7	--	16	1	--	--	--	--	2	204
C-37	25	--	1	5	--	--	--	4	--	9	--	1	1	--	--	--	--	5	1	1	--	--	53
62 (?)	36	1	2	1	--	--	--	--	--	--	--	--	1	1	--	2	--	--	--	--	4	1	49
31	33	2	2	--	3	--	--	--	--	--	--	--	24	9	--	2	1	--	--	--	13	--	89
37	92	7	2	--	18	--	--	--	7	1	--	2	3	3	--	9	2	--	--	--	--	--	146

TABLE 5.—*Pebble-lithology data*—Continued

Sample	Granite	Gabbro	Felsite[1]	Basalt[1]	Limestone and dolomite[2]	Sandstone	Siltstone	Shale[2]	Slate	Schist	Gneiss	Chert	Taconite	Quartzite	Agate[1]	Graywacke	Greenstone	Dark plutonic rocks	Anorthosite	Amphibolite	Concretions	Unidentified	Total
Basal till—Continued																							
42	76	7	--	--	--	--	--	--	4	--	--	2	2	7	--	15	--	--	--	--	10	2	125
C–38	36	--	--	1	2	--	--	--	--	5	--	1	2	1	--	--	--	6	--	--	--	--	54
64(?)	42	1	--	1	--	--	--	--	--	2	--	--	59	2	--	2	--	--	--	--	9	3	121
54(?)	94	3	3	2	--	--	--	--	--	--	--	2	2	3	--	7	--	--	--	--	--	--	116
59	47	5	4	--	22	--	--	--	1	--	--	2	3	4	--	7	1	--	--	--	6	3	105
C–35	28	1	--	1	8	--	--	2	--	6	--	--	1	--	--	--	--	3	--	--	--	--	50
52	53	8	9	2	31	3	--	--	4	--	--	3	7	5	--	12	5	--	--	--	--	3	145
55	68	12	12	2	18	--	--	1	5	--	1	5	8	12	--	20	2	--	--	--	22	--	188
C–34	16	4	6	--	7	1	--	1	1	6	--	--	3	1	--	1	--	3	--	--	--	--	50
Miscellaneous																							
35	33	13	14	3	--	--	--	--	2	--	--	--	52	4	--	4	3	--	--	--	--	2	130
46	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3
33	--	--	--	--	2	--	--	--	2	--	--	--	--	2	--	1	--	--	--	--	--	--	7
53	142	3	1	--	--	--	--	--	--	--	--	--	3	14	--	5	8	--	--	--	--	--	176
47	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
60	100	13	41	10	--	--	--	--	23	--	--	11	43	28	1	20	5	--	--	--	--	6	301
50	1	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	20	--	22
27	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	54	--	55
24	128	10	7	7	--	--	--	--	--	--	1	4	15	8	--	11	1	--	--	--	--	--	192
25	190	15	2	3	1	--	18	--	1	1	--	6	11	5	--	37	--	--	--	--	--	--	290
3	85	--	--	2	21	--	--	--	4	--	--	2	--	3	--	16	1	--	--	--	--	--	134
58	84	5	2	3	10	1	3	--	3	--	--	--	11	2	--	3	5	--	--	--	--	--	132

[1] Rock types that have been transported into the study area by ice moving from the Lake Superior basin.
[2] Rock types that have been transported into the study area by ice moving from a source to the northwest.

and 200 for the samples collected in 1961 (no prefix).

RESULTS OF ANALYSES

Nearly all the samples, regardless of glacial drift type, are characterized by high percentages of granite. Other rocks, such as schist, slate, chert, quartzite, graywacke, and taconite, are also very abundant. The types of rocks and numbers of each for the samples analyzed are shown in table 5.

Because glaciers incorporate rocks from the areas over which they pass, the type and abundance of rocks in glacial deposits are indicators of the path of the ice. The rocks listed above are very abundant in northeastern Minnesota (fig. 4) and were accumulated by the glaciers moving southward.

The samples also contain rocks that are not found in the immediate area such as limestone, dolomite, shale, gabbro, basalt, felsite, and agate. These rocks were transported into the area by glaciers and are helpful in determining the direction of movement of glaciers. In the study area, limestone, dolomite, and shale could have been derived only from rocks to the northwest in Canada, North Dakota, and the northwestern tip of Minnesota. Felsite, basalt, and agate could have been derived only from rocks in the Lake Superior basin. Gabbro is very common in the Lake Superior basin, but it could have been derived also by southwest moving glaciers from the uplands east of Ely. The relative abundance of rocks indicative of a source area to the northwest versus rocks indicative of a source area to the northeast by way of the Lake Superior basin is shown in table 5.

SURFICIAL TILL SAMPLES

Most samples of red clayey till and brown silty till contain pebbles that indicate both northeastern (Lake Superior) and northwestern source areas. The rows in table 5 are arranged in east-to-west order from top to bottom for each unit. There are no obvious trends in either group of samples, nor are there any great differences between the till units in presence or absence of indicator rocks. Several factors deserve special mention, however.

Of interest is that none of the samples of questionable brown silty till identity from the eastern part of the area contain northwest indicator rocks, whereas most samples of this till from other parts of the area do contain them. Among the northwest indicator rocks, shale predominates over carbonate rocks. The very large percentage of shale in several samples of brown silty till could be due to overrepresentation of this rock type. Commonly in outcrops

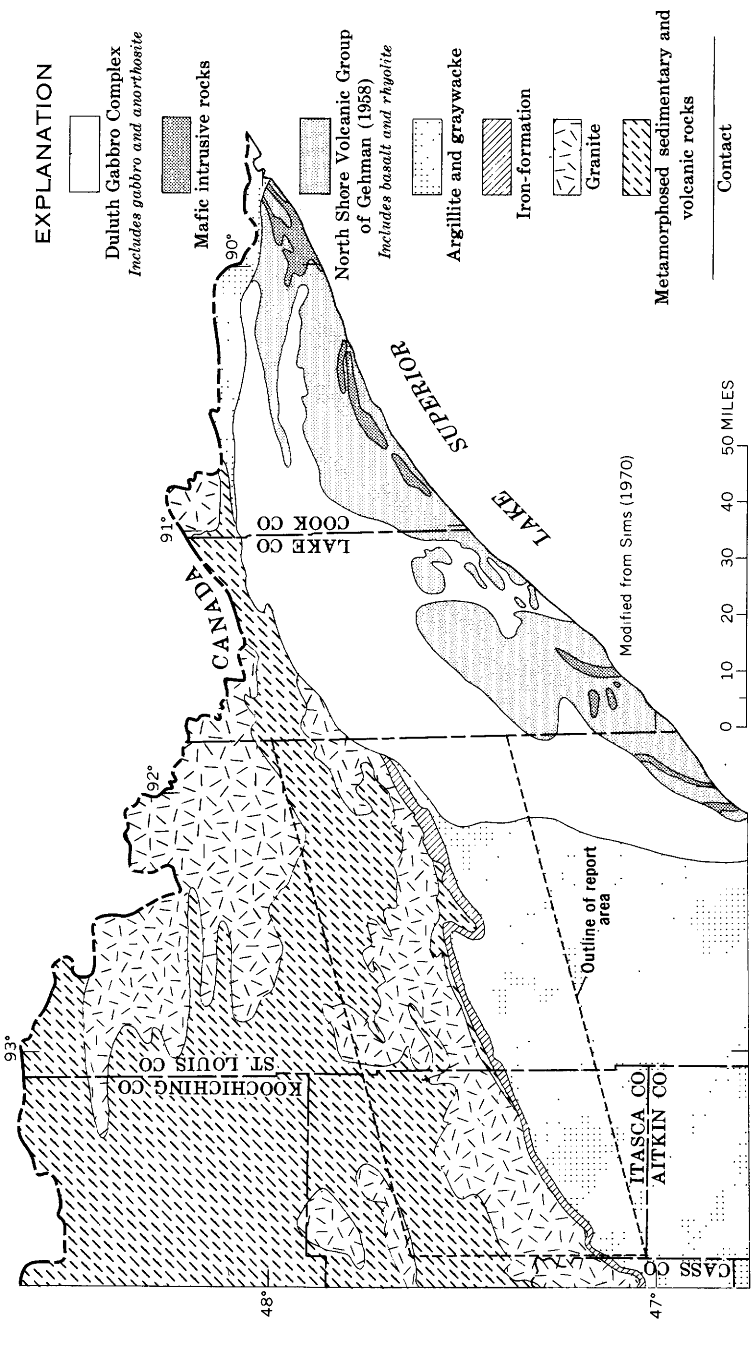

FIGURE 4.—Bedrock geology of northeastern Minnesota.

a very large number of shale fragments can be traced to the disintegration of a single fragment of shale of gravel or cobble size. Some of the variations in pebble-count results could be due to operator errors. Also, samples collected in different years were processed by different geologists. Nevertheless, where samples were collected from the same site, the pebble-count results were very similar. (See samples 19, 30, C–16, C–17, C–18, table 5.)

To evaluate the homogeneity of the surficial tills and to test whether pebble contents of till from a northwestern source versus till from northeastern sources are independent of the type of till in which they occur, a chi-square test was performed using pebble-count data. A contingency table was constructed in the following format using total numbers of stones counted.

	Northwest	*Other*	*Northeast*	*Total*
Red clayey till	105	811	52	968
Brown silty till	618	1,661	84	2,363
Total	723	2,472	136	3,331

Chi-square, calculated according to techniques described by Spiegel (1961) and Krumbein and Graybill (1965), was 96.25. Chi-square at the 0.05 level of confidence (1 chance in 20 of being wrong) and with 2 degrees of freedom, is 5.99. The hypothesis that northwest indicator rocks and northeast indicator rocks are independent of the type of till in which they are found must therefore be rejected. The large difference between the calculated chi-square and that obtained from the standard chi-square table may be due to one or all of the following factors:

1. The indicator rocks might actually be dependent on type of till. Northwest indicator rocks are 11 percent of the total in the red clayey till, but are 26 percent of the total in the brown silty till. Percentage of northeast indicator rocks are about the same in both tills.
2. The inclusion of all till samples, even those of questionable identity and those that have anomalous amounts of one type of rock, such as shale, might be responsible for the large chi-square value.
3. Sample collection may have been inadequate. Because of the apparent inhomogeneity of the numbers of indicator rocks in the samples, more samples might be necessary to make a definitive decision.

BOULDERY TILL SAMPLES

Samples of bouldery tills exhibit a striking dominance of northeast over northwest indicator rocks. The shale in the few samples collected might have been picked up locally by the glaciers. Opera-

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tor error is possible because all the samples with shale were counted by the same geologist.

BASAL TILL SAMPLES

Samples of the basal tills generally contain both northwest and northeast indicator rocks. Of the northwest indicators, carbonate rocks predominate. The percentage of northwest indicator rocks increases slightly from east to west.

MISCELLANEOUS SAMPLES

The sample of red sandy till from the southeast corner of the area has a fairly large percentage of northeast indicator rocks and none from the northwest. The most striking feature of the miscellaneous samples is the presence of gabbro and other northeast indicator rocks in the samples of Wadena lobe drift from Wadena County. On the basis of geomorphic and other evidence (Wright, 1962), the Wadena lobe almost certainly moved into Minnesota from the northwest; however, this question of direction of movement is beyond the scope of this report.

HEAVY-MINERAL CONTENT

LABORATORY PROCEDURE

Samples used for heavy-mineral analysis were washed through a 230-mesh sieve with distilled water. The material retained on the sieve was placed in a solution of bromoform of about 2.7 specific gravity (just dense enough to float a pure crystal of calcite). The minerals that sank in the bromoform were then placed on a slide, and a total of 300 grains were counted per sample.

RESULTS OF ANALYSES

The most common heavy minerals in all the samples are hornblende, limonite, and magnetite (table 6). Some differences can be noted between samples from the various general geologic units (surficial till, bouldery till, and basal till), but differences between samples within the various till units are not obvious.

The total percentage of heavy minerals is less (generally less than 1.5 percent) in the surficial till samples than in the other samples. Total percentage is greatest in the bouldery till samples (generally between 1.5 and 3.5 percent but as high as 7.1 percent) and the sand and gravel samples (between 2.5 and 10.0 percent). The basal till samples contain between 1.3 and 2.7 percent heavy minerals.

The surficial till samples generally contain more hornblende than the others. Two samples of brown silty till are the only ones containing dolomite. The bouldery till samples contain more augite and diopside than the other samples. The basal till samples gen-

TABLE 6.—*Heavy-mineral content of selected samples*

Sample (see table 2)	Augite	Diopside	Hypersthene	Hornblende	Actinolite	Apatite	Biotite	Chlorite	Dolomite	Epidote	Garnet	Hematite	Kyanite	Limonite	Magnetite	Pyrite	Rutile	Staurolite	Titanite	Tourmaline	Zoisite	Zircon	Unidentifiable	Percentage of heavy minerals in total sample
Surficial till:																								
C–24	7	<1	--	36	<1	1	1	--	--	--	1	6	<1	17	19	--	--	--	--	--	<1	--	10	0.8
C–20	5	--	4	14	--	<1	<1	--	--	--	2	8	--	21	20	--	--	--	--	--	--	--	25	1.2
C–14	5	--	4	26	--	1	--	--	--	--	<1	7	--	14	16	--	1	--	--	--	--	--	25	1.6
C–16	2	--	2	18	--	<1	--	--	--	--	2	2	<1	11	4	<1	--	--	--	--	--	--	57	.7
C–17	6	--	<1	31	--	2	1	--	18	--	2	--	--	2	6	--	--	--	--	--	<1	--	31	.3
C–18	7	--	1	22	--	1	--	--	9	--	4	1	<1	10	19	20	--	--	--	<1	--	--	5	.7
Bouldery till:																								
C–29	19	1	13	11	--	1	<1	--	--	3	<1	2	--	1	16	--	--	--	<1	--	--	--	32	7.1
C–27	13	<1	--	34	<1	<1	--	--	--	--	3	--	<1	12	21	4	--	--	--	--	--	--	11	2.5
C–30	13	--	5	18	<1	<1	<1	--	--	--	1	4	--	21	19	<1	--	<1	--	--	<1	--	16	1.8
C–28	10	<1	13	17	<1	<1	--	--	--	--	2	8	<1	7	24	--	<1	--	--	<1	<1	--	17	3.3
C–31	10	--	3	19	--	2	1	1	--	--	1	2	--	15	10	2	<1	--	--	--	--	--	33	3.2
C–32	12	<1	3	17	--	--	1	--	--	--	2	2	--	13	31	1	<1	--	--	--	--	--	17	1.6
C–33	12	--	3	18	--	<1	<1	--	--	--	3	2	<1	9	34	1	--	--	--	--	<1	--	17	2.7
Basal till:																								
C–36	<1	--	22	22	--	<1	<1	--	--	2	<1	6	--	28	19	--	--	--	--	--	<1	--	<1	1.5
C–37	5	--	2	24	<1	<1	--	--	--	<1	<1	6	--	21	35	--	--	--	--	<1	--	--	6	2.7
C–38	9	--	7	19	--	2	--	--	--	<1	2	8	--	20	22	--	--	<1	--	<1	--	<1	10	1.6
C–35	3	--	--	15	--	--	--	--	--	--	1	--	--	30	19	4	--	--	--	--	--	--	28	1.3
C–34	9	--	6	20	<1	<1	2	--	--	--	2	6	<1	17	18	1	<1	--	--	<1	<1	--	16	1.7
Miscellaneous:																								
C–41	--	--	<1	5	--	--	<1	--	--	--	--	13	--	55	18	--	--	--	--	<1	--	--	8	10.0
C–40	4	--	2	12	--	--	<1	--	--	<1	2	3	--	14	13	--	--	1	--	--	--	--	48	3.5
C–39	7	--	4	25	--	<1	--	--	--	--	3	8	--	21	8	<1	--	<1	--	--	--	--	23	2.5

erally contain slightly more limonite than the others. Samples of basal till from the eastern part of the area contain more epidote than the other samples.

CLAY MINERALOGY

LABORATORY PROCEDURE

Clay-mineral determinations were made by the differential thermal analysis (DTA) method at Denver, Colo.

RESULTS OF ANALYSES

Clay-mineral content in the samples analyzed is considerably different between the general till units, but fairly consistent within each general unit (table 7). Samples from both surficial till units are characterized by clays consisting of mixed-layered montmorillonite and illite. The bouldery till samples that contained enough clay for a determination generally contain montmorillonite. The clay fraction in samples from the basal tills consists largely of illite.

TABLE 7.—*Clay-mineral content of selected samples*

Sample (see table 2)	Clay mineralogy
Surficial till:	
C–24	Mixed-layered montmorillonite and illite.
C–20	Do.
C–14	Illite, some mixed layering with montmorillonite.
C–16	Mixed-layered montmorillonite and illite.
C–17	Do.
C–18	Do.
Bouldery till:	
C–29	Montmorillonite.
C–27	Illite, slight mixed layering with montmorillonite.
C–30	Montmorillonite.
C–28	(Not enough clay.)
C–31	Montmorillonite.
C–32	(Not enough clay.)
C–33	(Not enough clay.)
Basal till:	
C–36	Mixed-layered illite and montmorillonite.
C–37	Illite.
C–38	Illite.
C–35	Mixed-layered illite and montmorillonite.
C–34	Illite, slight mixed layering with montmorillonite.
Miscellaneous	
C–41	Illite.
C–40	(Not enough clay.)
C–39	(Not enough clay.)

PERCENTAGE OF SOLUBLE MATERIAL

LABORATORY PROCEDURE

The percentage of soluble material was determined on samples collected in 1961 (no prefix in sample number) by a simple acid treatment method. The samples were dried, weighed, placed in a solution of dilute hydrochloric acid, and heated. The insoluble residue was then dried and weighed. The percentage weight loss is the percentage of soluble material in the sample, assumed to be largely carbonate.

RESULTS OF ANALYSES

The percentage of soluble material is greatest in the surficial till and basal till samples (generally between 5 and 15 percent) and least in bouldery till samples (generally less than 8 percent). A general decrease from east to west in carbonate content in the red clayey till samples can be seen in table 8. The samples are arranged again in east to west order within each till unit. Percentage of soluble material in the brown silty till samples increases from east to west.

TABLE 8.—*Percentage of soluble material of selected samples*

Sample	Percentage	Sample	Percentage
Red clayey till		**Bouldery tills—Continued**	
5	15.9	32	6.5
36	12.6	38	5.8
1	10.9	49	6.2
7	10.9	41	4.4
48	9.8		
Brown silty till		**Basal tills**	
4	5.9	6	8.7
22	6.9	26	11.1
14	7.1	13	5.6
15	9.8	23	6.0
9	7.9	17	8.0
16	14.3	39	9.2
2	6.2	62	6.3
28	15.4	31	11.1
8	12.5	37	13.9
61	5.2	42	6.9
29	15.9	64	9.2
12	18.2	54	3.1
19	24.2	59	12.2
30	15.1	52	15.6
		55	12.5
Bouldery tills		**Miscellaneous**	
11	7.3	35	7.5
44	8.6	46	9.8
20	6.8	33	26.0
45	2.7	53	6.2
63	4.1	47	2.7
18	3.8	60	5.0
40	4.0	50	6.1
51	2.1	27	15.7
56	5.6	24	2.4
57	3.6	25	4.7
21	4.4	3	9.4
43	7.9	58	7.5
34	6.8		

The presence of soluble material in the bouldery till samples is rather surprising since these samples did not contain limestone pebbles and did not react to acid in the field. The soluble material in the bouldery till might be a carbonate precipitate that was deposited by leachate from the overlying calcareous surficial till. Some bicarbonate might be alteration products from igneous rocks.

DESCRIPTION OF GEOLOGIC UNITS AND REGIONAL STRATIGRAPHY

SURFICIAL TILLS

The red clayey till is characterized by a red or reddish-brown color and a clayey matrix (fig. 5*A*). Pebble content consists of a large percentage of granitic and metamorphic rocks. The till contains limestone, dolomite, and shale (rocks indicating a northwest source) and basalt, felsite, and gabbro (rocks indicating a northeast source, by way of the Lake Superior basin). The till contains a wide variety of heavy minerals, but hornblende, limonite, and magnetite predominate. The clay fraction consists largely of mixed-layered montmorillonite and illite. Percentage of soluble material is generally between 5 and 15 percent.

The brown silty till is characterized by a medium to light brown color and a sandy matrix (fig. 5*B*). Its pebble content is much like the red clayey till, but generally consists of slightly more limestone. Heavy-mineral content, clay-mineral content, and percentage of soluble material are similar to those of the red clayey till.

For many years the hypothesis was held that the red clayey till was deposited by ice moving out of the Lake Superior basin, and the brown silty till, by ice moving from the northwest (Wright, 1956). Subsequent work by Baker (1964) and Wright and Ruhe (1965) shows that the red clayey and brown silty tills are a single unit deposited by ice moving from the northwest. The red and clayey characteristics were derived from the incorporation of red lake clays into the till as the glacial lobe moved through the low-

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FIGURE 5.—Surficial till deposits. *A*, red clayey till near Mountain Iron exhibits rounded "ridges" when eroded, typical of clayey deposits. Notice the small number of cobbles. White card is about 2 feet high. *B*, brown silty till near Little Bowstring Lake is generally less clayey than the red till and the crests of the "ridges" are sharper, especially in the unweathered lower part of the outcrop. White card is about 2 feet high.

A

B

lands occupied by Glacial Lake Upham I. Although the data presented here do not prove either hypothesis conclusively, there is no reason to reject the more recent hypothesis. The more clayey composition of the red clayey till in the east than in the west also supports the more recent hypothesis because the ice that deposited this till would have crossed the central part of the preexisting lake basin and, therefore, could have picked up more of the lake clays. In this interpretation the presence of northeast indicator rocks in the till must be due to incorporation of older drift that had been brought in by glaciers from the northeast. The age of the surficial tills is about 12,000 years before present (Wright and others, 1969).

Samples 4, 22, 46, 14, 33, 15, and 53 were collected to help determine the most eastern extent of the brown silty till north of the Giants Range. Particle-size data suggest samples 4, 22, and 14 could be brown silty till. However, none of the samples contain pebbles indicating a northwest source except sample 33, which contained a total of only seven pebbles. Percentage of soluble material was lower in samples 4, 22, 14, 15, and 53 than in most brown silty till samples. In sample 33, percentage of soluble material was extremely high; heavy-mineral and clay-mineral contents were not determined for these seven samples. The data suggest that samples 4, 22, 14, and 53 are till and probably brown silty till, although the complete absence of limestone, dolomite, or shale lends some uncertainty to this conclusion. The brown silty till, therefore, extended east at least to Sand Lake (north of Virginia) and possibly as far east as Ely.

BOULDERY TILL

The bouldery till is characterized by large numbers of cobbles and boulders, largely of granite, in a sandy matrix (fig. 6). The till displays various shades of orange, red, brown, yellow, and gray. Pebble lithology is largely granite, but metamorphic rocks are also

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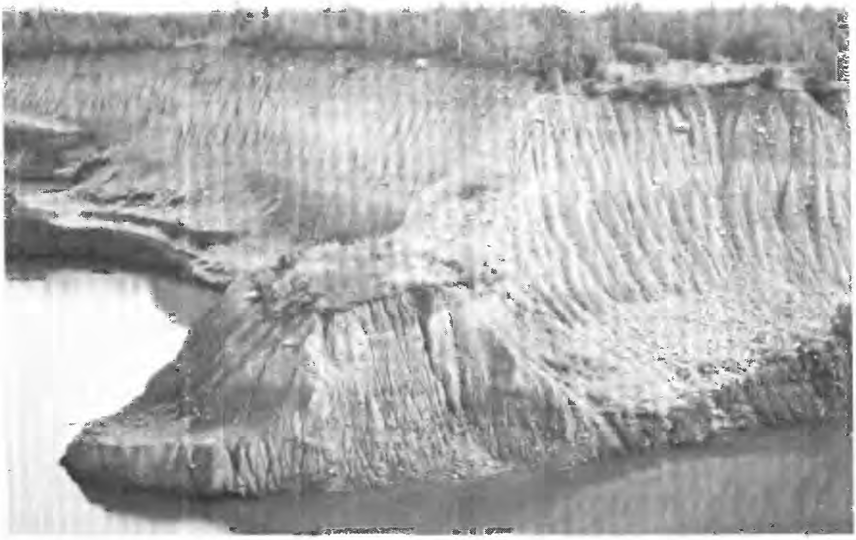
FIGURE 6.—Bouldery till in Wade mine. *A*, abundant cobbles and boulders occur in the bouldery till. The "cliff forming" character of the bouldery till is typical of this geologic unit. Thickness of the section from land surface to water is about 70 feet. *B*, a well-developed boulder pavement occurs at the top of the bouldery till. Thickness of the red clayey till, which overlies the boulder pavement, is about 10 feet in the center of the photograph.



A

B

abundant. Pebbles of gabbro, felsite, and basalt occur in nearly all samples. Pebbles of northwest origin are rare. Only three samples contain shale, and in two of these, shale constitutes about 2 percent of the total pebbles counted. Percentage of heavy minerals is higher in the bouldery till than in the other till units. Limonite, magnetite, and hornblende are common, and augite and diopside contents are higher in the bouldery till than in the other tills. Montmorillonite is the most common clay mineral in the bouldery till. Percentage of soluble material is lower (generally less than 8 percent) in the bouldery till than in the other tills.

The bouldery till samples showed very little variation among the samples for the parameters analyzed. Present data indicate that the bouldery tills are from a single glacial ice lobe. The till is probably a single unit, although the particle-size data show a clear separation in grain size between the gray till and colored tills above the gray from the colored bouldery till below the gray (pl. 2). The bouldery tills might be two separate units, but they are very closely related. If, in fact, they are individual units, they probably represent two separate pulses of the same general stade of glaciation.

The bouldery till was deposited by the Rainy lobe which advanced into the study area from the northeast across the Giants Range. It formed the Toimi drumlins and the bouldery-till drumlins near Hibbing and near Eveleth which all have a northeast orientation. Most of the present-day topography resulting from glaciation, except the morainal complex in the western part of the area, is the result of Rainy lobe deposits. Retreat of the Rainy lobe is dated at about 14,000 to 16,000 years ago, but the advance of the lobe could have begun much earlier, perhaps in middle Wisconsin time (Winter, 1971).

BASAL TILL

The basal till is characterized by dark colors of gray, greenish gray, and brownish gray. The matrix is calcareous and consists of sand and gravel but includes much silt and clay (fig. 7), especially in the central and western part of the study area. Cobbles and some boulders are also present. The till contains indicator rocks from both northeastern and northwestern sources, but the most common pebbles are granitic and metamorphic rocks of local origin. Heavy-mineral content is much like that of the other till units; magnetite, limonite, and hornblende predominate. The basal till in the eastern part of the area contains more epidote than the other till units. Illite is the predominant clay mineral in the basal till.

FIGURE 7.—Platy structure in the Embarrass mine is typical of the basal till.

Percentage of soluble material is generally between 5 and 15 percent.

The basal till was probably deposited by a single episode of glaciation. Several of the parameters analyzed show trends from east to west across the area that suggest the ice moved into the area from the west-northwest: The particle size grades from coarser to finer from east to west; limestone and dolomite content increases from east to west, and the highest percentages of northeast indicator rocks occur in the eastern part of the area; and the percentage of soluble material increases very slightly from east to west. The gradations in these parameters, plus the calcareousness of the till, would be expected normally in till deposited by ice moving from the west or northwest. As the ice lobe moved across the area from west to east, it incorporated more and more sand and gravel of local origin; thus the concentration of limestone and dolomite pebbles lessened as did the overall content of soluble material. The time of the glaciation that resulted in deposition of the basal till is probably middle or early Wisconsin, but it could be pre-Wisconsin.

SUMMARY

The generalized stratigraphic column for glacial till in the Iron Range area is shown in table 9. The till units are emphasized because they have a greater variety of diagnostic characteristics, are less variable, and are, therefore, easier to identify at any locality than sand and gravel units. Regional correlations of the glacial deposits are shown on plate 1. The section is greatly simplified to emphasize the regional extent of the major drift units. The great local variation is typical of glacial deposits.

TABLE 9.—*Stratigraphic column of glacial till*

Brown silty till	*Red clayey till*
Till, light- to medium-brown, sandy, silty, and calcareous. Pebbles are largely granitic and metamorphic rocks of local origin, but include limestone, dolomite, shale, basalt, felsite, and gabbro. Clay-mineral content is largely mixed-layered montmorillonite and illite.	Till, red to reddish brown, clayey, silty, and calcareous. Pebbles are similar to those in the brown silty till, but contain less limestone than the brown till.

Bouldery till

Till, gray, yellow, red, orange, or brown, sandy, silty; contains abundant cobbles and boulders and is noncalcareous. Pebbles are largely granitic and metamorphic rocks of local origin, but also include gabbro, basalt, and felsite in minor amounts. Montmorillonite is the most common clay mineral.

Colored bouldery till below gray bouldery till may be a separate subunit distinguished largely on particle-size differences, but the overall characteristics are similar to the other bouldery till.

Basal till

Till, dark-gray to dark-greenish-gray, and brownish-gray, sandy, silty, calcareous. Pebbles are largely granitic and metamorphic rocks of local origin, but include limestone, dolomite, shale, basalt, felsite, agate, and gabbro. Clay-mineral content is largely illite.

The bouldery till is the most continuous glacial geologic unit in the area. The surficial tills, although generally thin, are widespread and mantle the topographic features formed by the bedrock and (or) by earlier glaciations. Thick sections of widespread sand and gravel occur in various localities in the region, particularly between Gilbert and Aurora.

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