DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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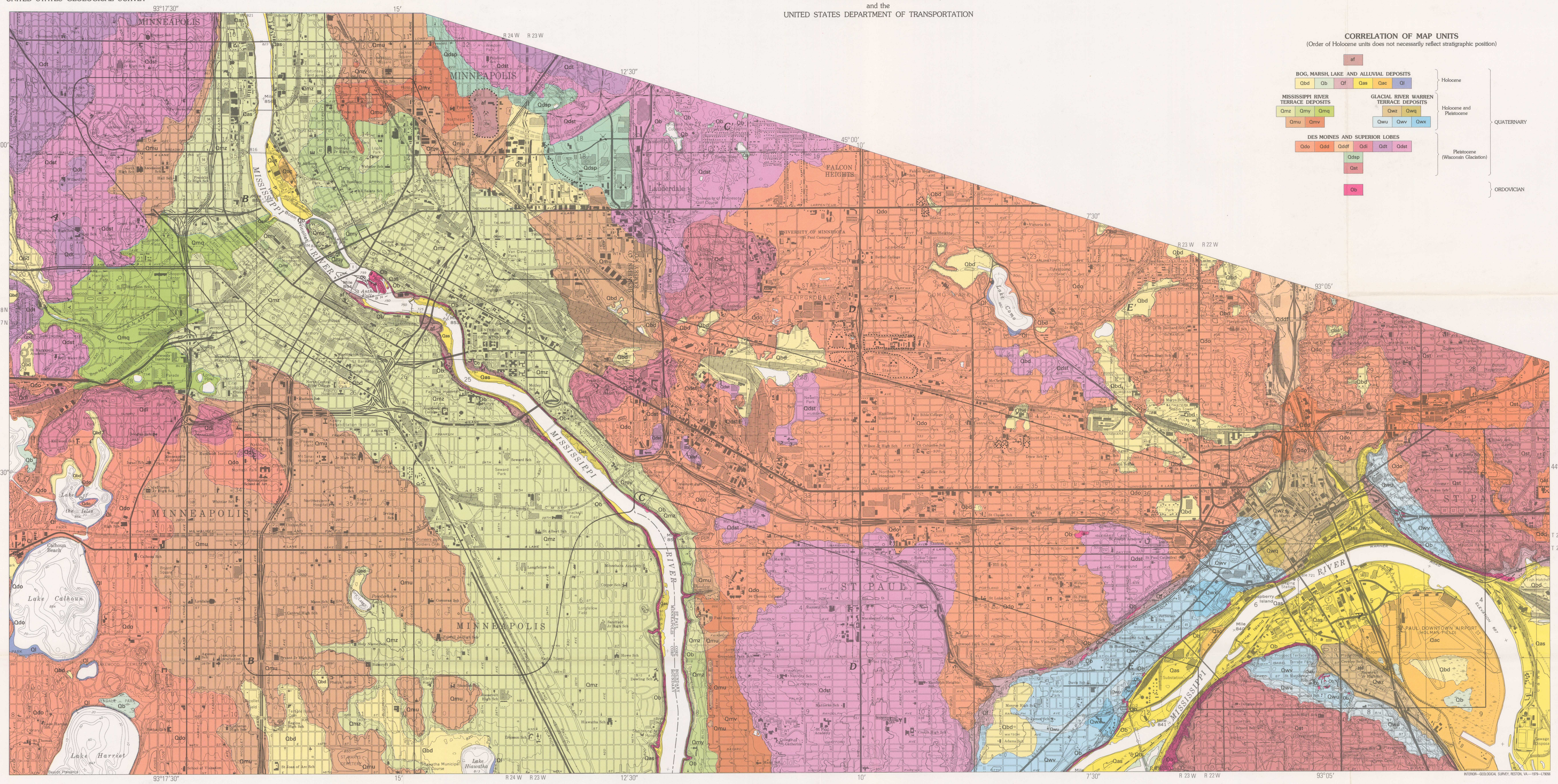
MINNESOTA GEOLOGICAL SURVEY,
and the
UNITED STATES DEPARTMENT OF TRANSPORTATION

M.F. Hoet

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–1157
PLATE 2



Base from U.S. Geological Survey, Minneapolis North, Minneapolis South, New Brighton, St. Paul East and St. Paul West 1:24,000, 1967. Photorevision as of 1972

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

CORRELATION OF MAP UNITS

(Order of Holocene units does not necessarily reflect stratigraphic position)

af
BOG, MARSH, LAKE AND ALLUVIAL DEPOSITS
Qbd
Qb
Qf
Qas
Qac
Ql
MISSISSIPPI RIVER TERRACE DEPOSITS
Qmz
Qmy
Qmq
Qmu
Qmv
GLACIAL RIVER WARREN TERRACE DEPOSITS
Qwz
Qwq
Qwu
Qwv
Qwx
DES MOINES AND SUPERIOR LOBES
Qdo
Qdd
Qddf
Qdi
Qdt
Qdst
Qdsp
Qst
Ob
Holocene
Holocene and Pleistocene
Pleistocene (Wisconsin Glaciation)
QUATERNARY
ORDOVICIAN

DESCRIPTION OF MAP UNITS

(Symbols in parentheses refer to principal soil textures in unit as described in Table 1)

af ARTIFICIAL FILL—Includes construction rubble and natural materials. Grades for most highways, railroads and bridges not shown

Qbd BOGS AND MARSHES, DRAINED AND FILLED—Artificial fill generally less than 10 feet thick; overlies organic deposits (Pt, OL, OH)

Qb BOGS AND MARSHES—Organic deposits (Pt, OL, OH) generally less than 10 feet thick

Qf COLLUVIUM AND SMALL ALLUVIAL FANS—Variable in texture; generally sandy clay, clay loam or silty sand (SC, CL, SM). Overlain by thick layer of artificial fill in some areas

Qas FLOOD PLAIN ALLUVIUM, SAND—Principally sand and gravelly sand (SP, minor SM) interstratified with clay and silty clay (CL, CL–CH, ML–CL)

Qac FLOOD PLAIN ALLUVIUM, CLAY—Principally silty clay and clay (CL, CL–CH); overlain by thick fill in developed areas

Ql LAKE BEACHES—Sand (SP, SP–SM)

MISSISSIPPI RIVER

LOWER TERRACE DEPOSITS

Qmz SAND—Sand, gravelly sand and silty sand (SP, SP–SM); may be overlain by a thin soil of variable composition (CL, CH–CL, or OL). Underlain by glacial till which crops out in ravines and banks along the Mississippi River. Bedrock more than 10 feet below land surface

Qmy SAND AND SILTY SAND—Sand (SP–SM, SP) and silty sand (SM), including some sandy till along river in northwestern St. Paul. Bedrock commonly less than 10 feet below land surface

Qmq FINE GRAINED FACIES—Fat clay and peat (CH, Pt), may exceed 50 feet in thickness in center of area. Includes some alluvium of Bassett Creek. Overlain in places by artificial fill commonly exceeding 10 feet in thickness

UPPER TERRACE DEPOSITS

Qmu SAND—Sand, gravelly sand and silty sand (SP, SP–SM, SM), may be overlain by a thin soil composed of clay loam or silt (CL, ML). Bedrock more than 10 feet below land surface

Qmv SAND AND SILTY SAND—Sand, silty sand and silt (SP, SM, ML). Includes some sandy till in area along river in western St. Paul. Bedrock commonly less than 10 feet below land surface

GLACIAL RIVER WARREN

LOWER TERRACE DEPOSITS

Qwz SAND AND SILTY SAND—Sand and silty sand (SP, SM); boulder zones (GM), stiff clays and clay loams (CL) and minor fat clays (CH) interbedded with sands. Bedrock more than 10 feet below surface

Qwq FINE GRAINED FACIES—Fat clay (CH); overlies boulder zones, sand and gravelly sand

UPPER TERRACE DEPOSITS

Qwu SAND AND SILTY SAND—Sand and silty sand (SP, SM). Bedrock more than 10 feet below land surface

Qwv VARIABLE SURFICIAL DEPOSITS—Artificial fill, organic deposits, silty sand, clay loams and clays (OL, SM, CL, CH). Bedrock commonly less than 10 feet below land surface

Qwx BOULDERS AND LIMESTONE BLOCKS—Numerous boulders and large limestone blocks; boulders, gravel and silty sand (GM–SM). Bedrock more than 10 feet below land surface

DES MOINES LOBE

OUTWASH

Qdo OUTWASH PLAIN DEPOSITS—Sand and silty sand (SP, SP–SM, SM); may be overlain by thin soil of variable composition (CL, SC, OL, CL–ML)

Qdd DRAINAGEWAY DEPOSITS—Sand (SP, SP–SM); substantial thickness of artificial fill (10 to 30 feet) overlies part of unit. Includes some alluvium of Phalen and Trout Creeks

Qddf DRAINAGEWAY DEPOSITS, FINE GRAINED FACIES—Silt, organic silt, peat and clay (ML–OL, Pt, CL). Substantial thickness of artificial fill where land has been developed

Qdi ICE CONTACT DEPOSITS—Sand and silty sand (SP, SP–SM, SM); cobbles and boulders commonly present

Qdt GLACIAL TILL—Gray clay loam, sandy clay and silty sand (CL, SC, SM) overlies gray till (CL, SC) complexly intermixed with sandy red-brown till (SM)

DES MOINES AND SUPERIOR LOBES

Qdst GLACIAL TILL—Complexly intermixed gray and red till; clay loam, sandy clay and silty sand (CL, SC, SM) containing sand lenses (SP)

Qdsp PROGLACIAL OUTWASH—Sand (SP, SW), cobbly in basal part; basal part is recessional outwash

SUPERIOR LOBE

Qst GLACIAL TILL—Red-brown silty sand, minor sandy clay and clay loam (SM, SC, CL) containing sand lenses (SP)

BEDROCK

Ob Exposures of Ordovician bedrock formations and areas with numerous discontinuous bedrock exposures; may be covered by thin mantle of colluvium or fill

Contact—Dashed where approximately located

Indefinite contact—Includes inferred, gradational, and indefinite contacts

Boundary of quarry or gravel pit

Isolated patches of buried peat (Pt) in developed areas—Lateral extent of peat uncertain

Quarry—Inoperative and filled with artificial fill

Gravel pit—Inoperative and generally filled with artificial fill

A —— A' Line of section—Sections shown on plate 5

SURFICIAL GEOLOGY

By John H. Mossler and Matt S. Walton
Minnesota Geological Survey

1979

INTRODUCTION

Plate 2 shows the surficial deposits that were formed by geologic processes during Quaternary time. Quaternary time comprises the Pleistocene Epoch ("Ice Age"), which began about 1.8 million years ago and ended about 10,000 years ago, and the Holocene Epoch ("Recent"), which extends from the end of the Pleistocene to the present. Quaternary sedimentary deposits, mainly of glacial origin, underlie most of the study area and influence almost all engineering and land-use activities. These deposits are typically 50 to 100 feet thick, but may be nearly 400 feet thick where they fill preglacial valleys. Shallow tunnels and entrys to deeper tunnels, as well as most foundations, generally encounter Quaternary materials. These materials commonly are masked or modified by man-made structures and surfaces or covered by agricultural soils and vegetation. In the Twin Cities area all Quaternary deposits are classified according to engineering practice as unconsolidated soils. On the map the Quaternary deposits are classified first by geologic age, and second by the nature of the depositional processes and environments in which they were deposited. This classification divides the deposits into map units representing bodies of material that were formed during a particular geologic episode under comparable processes and conditions of deposition. The engineering soil or assemblage of soils which characterizes each geologic unit of Quaternary age is given in the map explanation and shown on the geologic cross sections (plate 5).

SYNOPSIS OF QUATERNARY GEOLOGIC HISTORY

At the beginning of Quaternary time the Twin Cities area had greater topographic relief than at present. Relief was as much as 360 feet, and the topography was characterized by broad uplands and deeply incised valleys. The drainage pattern was comparable to the present drainage pattern farther south along the Mississippi River valley. An understanding of how this landscape evolved into the present terrain helps one to understand the complex relationships among bedrock formations, surficial deposits, and present topography and drainage, all of which influence the engineering geology of the area.

The Twin Cities area was overridden by ice during the Nebraskan, Kansan and Illinoian Glaciations, but evidence for these early glaciations was either destroyed by erosion during interglacial periods or buried about 15,000 to 10,000 years ago by deposits of the two final ice advances of Wisconsin Glaciation. The present topography is largely a product of these glacial processes during late Wisconsin Glaciation and subsequent erosion in the past 10,000 years. The fact that an older bedrock topography considerably different from the present surface is buried under glacial deposits, introduces many complexities in the subsurface geology of the area.

The older of the two glaciers during Wisconsin Glaciation (the Superior lobe) advanced southward from the Lake Superior basin and deposited till (**Qst**) and outwash (included in **Qdsp**) over much of the area. The unsorted and unstratified, ice-deposited till characteristically is red to reddish-brown sandy clay containing abundant pebbles, cobbles and boulders of volcanic rocks and red sandstone. The sandy till is exposed extensively on the east and south sides of St. Paul. The sorted and stratified outwash, deposited by glacial melt water and consisting of silt, sand, and gravel, appears in patches only in the subsurface, as shown on the cross sections (plate 5).

The final ice advance came into the Twin Cities area from the southwest because of deflection toward the east of a tongue of ice (the Grantsburg sublobe) from a large glacier (the Des Moines lobe) that moved southward down the Red River valley. Material carried by this glacier has a high clay and calcium carbonate content with pebbles and cobbles of shale and limestone. The material is typically gray in color, weathering to tan or buff. As it advanced, the Grantsburg sublobe discharged a sheet of outwash (included in **Qdsp**) before it. Till (**Qdt**) and more outwash (**Qdo, Qdi**) were deposited as it stagnated. The sublobe also incorporated a great deal of the older Superior lobe till (**Qst**) in its deposits, resulting in till of mixed composition (**Qdst**).

As the Pleistocene Ice Age ended, the Twin Cities area presented a chaotic scene. The preglacial drainage system had been obliterated, and a great quantity of meltwater from the retreating margin of the ice to the north sought outlets across the landscape of hills and ridges (moraines) and sandy plains (outwash plains). Blocks of stagnant ice remained, especially along major preglacial river valleys. A river known as Glacial River Warren, many times larger than the present Mississippi River, flowed through the present Minnesota River valley and then down the Mississippi River valley, carrying the sediment laden outflow from a great ice-dammed lake in the Red River valley called Glacial Lake Agassiz. The Mississippi River was just a tributary to this gigantic stream.

The story of the past 10,000 years (the Holocene Epoch) has been the integration of this chaotic pattern into the present drainage system and topography as glacial melt water receded and the present climatic regime became established. Retreating waterfalls on Glacial River Warren and the Mississippi River carved gorges from the vicinity of downtown St. Paul to downtown Minneapolis. Terraces and terrace deposits formed at several levels along River Warren (**Qwx, Qwv, Qwu, Qwq, Qwz**) and the Mississippi River (Qmv, Qmu, Qmg, Qmy, Qmz) during this time. River Warren disappeared when the ice that dammed the Red River valley melted and Glacial Lake Agassiz drained away to the north. The relatively small flow from local Minnesota sources was all that was left to form the present Minnesota River, and the Mississippi River became the major stream. Old melt water channels became filled with alluvium (**Qdd, Qddf**). The Mississippi and Minnesota Rivers laid down flood plain alluvium (**Qas, Qac**) in the broad valley left by River Warren, and stagnant ice masses melted, leaving lakes, ponds, and bogs (**Qb, Ql**) in the depressions the ice had occupied.

ENGINEERING GEOLOGY OF QUATERNARY DEPOSITS

Most of the Twin Cities area is underlain by more than one unconsolidated Quaternary geologic unit. These units are irregularly layered, intertongued, or discontinuous lenses in the subsurface. This complexity is portrayed along the lines of section shown on plate 5. For sites not close to a line of section, the map provides direct information for geologic materials at the land surface. The primary data base and other sources of geologic information should be examined for subsurface data relating to specific sites. Areas of bedrock exposures and of thinly covered bedrock are confined primarily to bluffs and terraces along the Mississippi River and denoted by map units **Ob, Qwv, Qmv,** and **Qmy**. These areas include important sections of the St. Paul and Minneapolis Central Business Districts (CBD) and a large section in northeast Minneapolis. Elsewhere, only deeper tunnels, major foundation structures, and water wells would encounter bedrock.

Available data on the physical properties that characterize the materials in each of the Quaternary geologic units are compiled in table 1. An evaluation of the behavior and suitability of these materials for various purposes is given in table 5.

TUNNELING IN QUATERNARY DEPOSITS

Any extensive system of tunnels in the Twin Cities will entail some construction in Quaternary materials, even if maximum advantage is taken of superior tunneling conditions in the underlying St. Peter Sandstone. At a minimum, access drifts and shafts will be necessary, and stations connected to underground building complexes are a logical development for a subway system. In some parts of the Twin Cities, shallow, soft-ground or cut-and-cover tunnels may be most economical.

Outwash deposits are the most widespread materials within 100 feet of the land surface in the eastern, or Ramsey County, part of the area (map units **Qdo** and, mainly in the subsurface, **Qdsp**). Terrace deposits are the most widespread in the western, or Hennepin County, part (map units **Qmu, Qmy,** and **Qmz**). All these deposits consist mainly of poorly to moderately graded silty to gravelly sands with sporadic lenses of silt, clay and gravel. Soils formed on these deposits are primarily free-draining, non-cohesive and granular, but the deposits tend to be fairly compact at depths of 20 feet or more. Terrace deposits are generally underlain by impervious materials such as till or Decorah Shale and contain water in varying amounts.

Though cut-and-cover methods are conventional for these materials, shielded, boom-excavator tunneling machines with continuous segmented lining systems have been highly successful in comparable ground. Because of the obvious environmental advantages of tunneling relative to surface construction, soft-ground tunneling systems should be carefully evaluated.

Ground water is likely to pose the most common difficulty to tunneling in the surficial deposits. Saturation of poorly graded gravelly sands can result in running ground. Dewatering, grouting, or freezing in advance of excavation may be required, depending on the relationship of tunnel grade to water table. Dewatering is likely to be quite feasible in general, because areas of high permeability in the Quaternary deposits are relatively small and localized. The water is unconfined, and is locally perched above the regional water table. However, if major dewatering is required close to structures, attention must be given to the possibility of ground subsidence. Site-specific investigation of the ground-water situation is advised for any proposed subsurface construction in surficial deposits, whether by conventional cut-and-cover or by soft-ground mole.

Other constraints to construction in the outwash and terrace deposits are local lenses of clay and organic-rich clayey and silty sediments. Buried inorganic clay deposits are likely to be very stiff; however, if water gains access during construction, they can become soft and sticky. The organic sediments tend to be soft and wet. Areas shown on the map as **Qmq** and **Qhb** are known boggy ground, but many former undrained boggy depressions have been reclaimed and are concealed by fill. Known buried bog deposits are shown as map unit **Qbd**, but similar deposits are likely to be present elsewhere. Where possible, these areas should be avoided. Many are shallow with impervious clay bottoms and could be readily tunneled under, whereas cut-and-cover would be difficult.

The tills (map units **Qst, Qdt** and **Qdst**) are the most wide-spread Quaternary deposits. In the subsurface, the tills tend to be compact, stiff and impervious. The Superior lobe till (**Qst**) is sandy and, in places, bouldery. The Des Moines lobe till (**Qdt**) is clay-rich and tends to contain smaller and fewer rock fragments and boulders. Intermixed till (**Qdst**) is intermediate in composition. In places the tills can be so stiff that excavation is difficult, but they have excellent stand-up characteristics. Except for occasional large boulders that require splitting or shooting, tills are likely to be excellent for machine tunneling. The tills contain scattered lenses of coarse sand, gravel, and stiff clay. The gravel lenses may yield a copious initial flow of water, though not necessarily sustained flow.

Other deposits of significant extent that near-surface underground construction may encounter are ice-contact deposits (**Qdi**). Ice-contact deposits are highly variable mixtures of silty to gravelly sands, frequently containing abundant coarse cobbles and possibly nests of boulders. Tunneling conditions in these deposits are similar to those in outwash but locally difficulties may be more severe.

To summarize: Shield tunneling is probably a feasible option in the large areas of the Twin Cities underlain by thick surficial deposits. Areas of high permeability occur locally in the Quaternary deposits. Dewatering may be required in places and generally should be feasible. Soft, organic silts and clays are present both in surface-bog areas and as scattered buried lenses. Stiff tills may be present locally and occasional boulders in till may require drilling and blasting.

TABLE 1.—*Engineering soil classification and test data for Quaternary geologic units*

Geologic Unit	Unified soil classification (ASTM)[1]	Standard penetration[2]	Dry density lbs/ft^3	Unconfined compressive strength, lbs/ft^2	Cohesion lbs/ft^2	Liquid limit	Plasticity index	Moisture as percent of dry wt.
Qhb, Qhbr	Pt,OL, OH	WH–B	15–40	<1000	100–250 1050^{e}	. .	. .	Often >90
Ql, Qf	. .	. .	. .	. .	. .	. .	. .	. .
Qas	SP; SP–SM	A–C<20' D–E>20'	. .	. .	. .	nonpl	nonpl	. .
Qac	CH–CL, CL	A–B	78–105 (23)	750–900 (16) 650^{e}–2020^{e}	325–550 (7)	27–65 (11)	13–37 (8)	30–44 (23)
Qmu and Qmz	SP, SM, SP–SM	B–C<10' C–E 10'–20' D–E>20'	. .	NA	NA	nonpl	nonpl	. .
Surface soils on Qmu + Qmz	CL CH ML	A–C B–C A–C	91–106 (4) 76–94 (3) 82–103 (4)	700–4700 (5) 2700–5500 (3) 1500 (1)	223–810 (4) . . 100–500 (11) 77^{e}–885^{e}	24–46 (4) 64–84 (2) 24–35 (3)	10–28 (4) 40–56 (2) 1–5 (3)	21–32 (4) 27–45 (3) 24–34 (4)
Qmq	CH, Pt	WH–C	49–82 (4)	1200–4700 (3)	280–2800 (78)[3] 207^{e}–3160^{e}	50–101 (6)	30–69 (6)	24–45 (39) 18^{e}–89^{e}
Qwu	SP, SM	A–C<12' D–E>12'	. .	. .	. .	. .	. .	. .
Qwz	SP, SM, GM w/boulders	A–C<12' D–E>12'	. .	. .	. .	nonpl-slpl	nonpl-slpl	. .
Qwq	CH	A	53–83 (7)	1500–2500 (2)	. .	57–107 (7)	30–72 (6)	41–81 (7)
Qdo, Qdd, Qdi	SP, SP–SM, SM	B–C<10' C–E 10'–20' D–E>20'	. .	NA	NA	nonpl	nonpl	. .
Surface soils on Qdo	CL ML	A–C A–C	81–110 (20) 85–108 (10)	1000–1200 (8) 900^{e}–2000^{e} 900–1500 (3)	. . . .	22–32 (21) 19^{e}–58^{e} 20–32 (6)	5–14 (19) 1^{e}–29^{e} 4–10 (6) nonpl^{e}	8–39 (21) 6–36 (10)
Qddf	ML–OL CL	WH–B A–C	49–54 (3) 93–95 (5) 108^{e}	. . . . . .	80–290 (50)[3] 1245^{e} 400–800 (9) 1050^{e}	nonpl-slpl 27 (1)	nonpl-slpl 7 (1)	70–85 (3) 26–29 (5) 17^{e}
Qdsp	SP, SM, SW	C–E	. .	NA	NA	nonpl	nonpl	. .
Qdt, Qdst	SC, CL, SM	B–D	109–132 (29) 96^{e}	2200–4900 (28)[3] 700^{e}–9500^{e}	1000 (15) 640^{e}–5300^{e}	17–29 (10)	6–12 (7)	11–24 (34) 3^{e}
Qst	SC, SM, CL	B–E	116–129 (7)	2300–5600 (5)[3]	1170–3200 (10) 6550^{e}	15–24	1–8	7.5–13 (14)
Qst? (only in subsurface)	SC, CL, SM	D–E	106–132 (18)	2100–6700 (6)[3]	. .	17–32 (5)	11–19 (3)	6–22 (18)

[1]Meaning of ASTM engineering soils group symbols
- GW Well-graded gravels and gravel-sand mixtures, little or no fines.
- GP Poorly graded gravels and gravel-sand mixtures,
- GM Silty gravels, gravel-sand-silt mixtures
- GC Clayey gravels, gravel-sand-clay mixtures
- SW Well-graded sands and gravelly sands, little or no fines
- SP Poorly graded sands and gravelly sands, little or no fines
- SM Silty sands, sand-silt mixtures
- SC Clayey sands, sand-clay mixtures
- ML Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
- CL Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
- OL Organic silts and organic silty clays of low plasticity
- MH Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
- CH Inorganic clays of high plasticity, fat clays
- OH Organic clays of medium to high plasticity
- Pt Peat, muck and other highly organic soils

[2]Standard penetration blows per foot, 140 pound hammer, 30-inch fall, 2-inch OD split spoon.
(WH weight of hammer)
- A WH–4
- B 5–8
- C 9–15
- D 16–30
- E over 30

[3]See histograms, figure 1.

- (23) Number of tests on which values are based
- ^{e} Denotes extreme minimum or maximum value outside of normal range given for test set.
- nonpl Not plastic
- slpl Slightly plastic
- NA Not applicable
- < Less than
- > Greater than

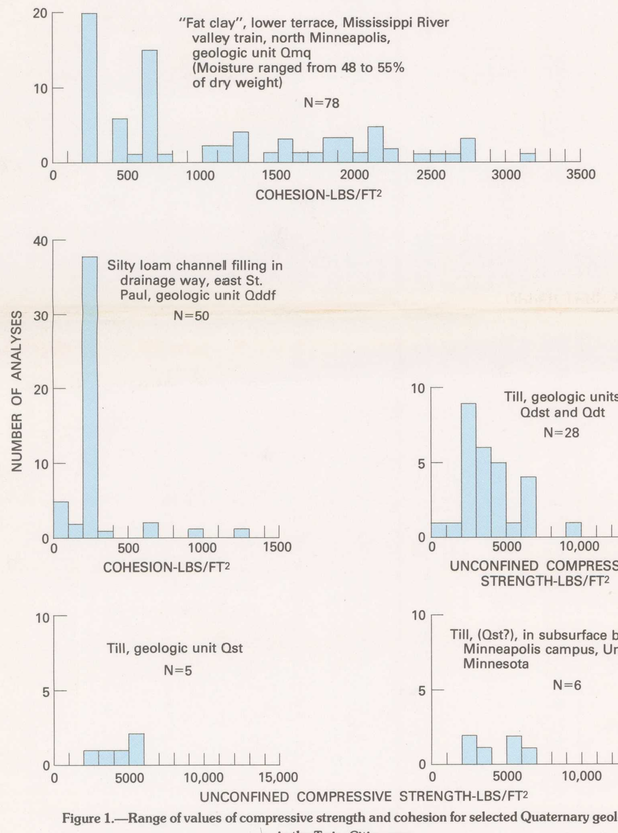


Figure 1.—Range of values of compressive strength and cohesion for selected Quaternary geologic units in the Twin Cities area.

GEOLOGIC AND HYDROLOGIC ASPECTS OF TUNNELING IN THE TWIN CITIES AREA, MINNESOTA