DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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MINNESOTA GEOLOGICAL SURVEY
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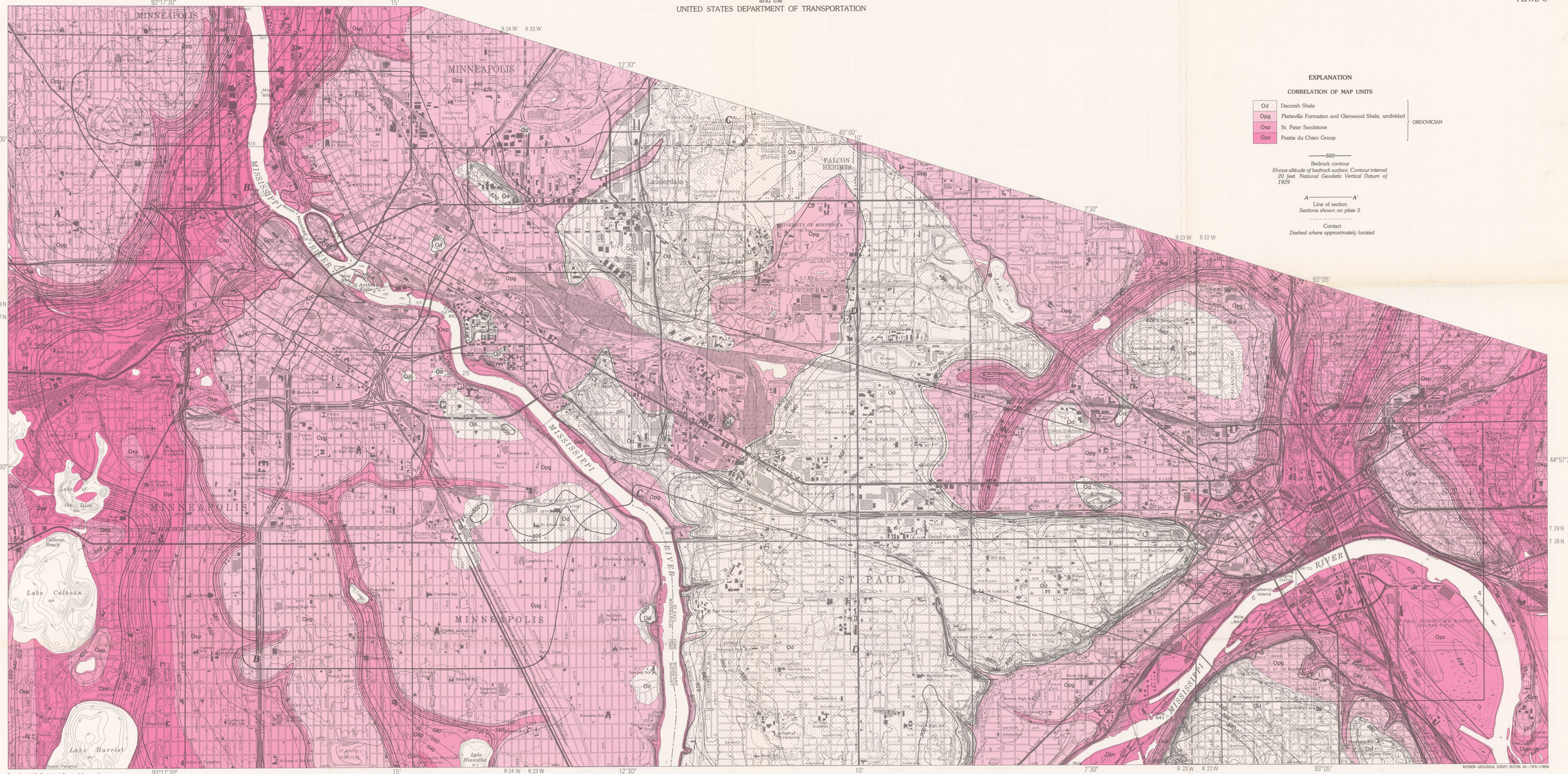
UNITED STATES DEPARTMENT OF TRANSPORTATION

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–1157
PLATE 3




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

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

## EXPLANATION

### CORRELATION OF MAP UNITS

| | | |
|---|---|---|
| Od | Decorah Shale | ORDOVICIAN |
| Opg | Platteville Formation and Glenwood Shale, undivided | ORDOVICIAN |
| Osp | St. Peter Sandstone | ORDOVICIAN |
| Opc | Prairie du Chien Group | ORDOVICIAN |

—560—
Bedrock contour
*Shows altitude of bedrock surface. Contour interval 20 feet. National Geodetic Vertical Datum of 1929*

A——A′
Line of section
*Sections shown on plate 5*

Contact
*Dashed where approximately located*

# BEDROCK GEOLOGY

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## BEDROCK GEOLOGIC MAP

Bedrock beneath surficial deposits in the Twin Cities area consists of well-stratified marine sedimentary rocks of Ordovician age (500 to 440 million years before present). Bedrock is exposed at the surface in bluffs and terraces along and near the Mississippi River and in a few other places (plate 2). The bedrock geologic map (plate 3) shows the bedrock formations and the surface topography that would be exposed if the younger, unconsolidated surficial deposits were removed.

### Bedrock Surface

The bedrock of the Twin Cities urban area is a sequency of almost horizontal sedimentary strata dissected by two very large, buried river valleys, their tributary valleys, and by the present Mississippi River valley. One major buried valley is just west of downtown Minneapolis; the other passes beneath the east side of downtown St. Paul.

### Bedrock Geology

Rocks of the Prairie du Chien Group (Opc) consist of thin- to thick-bedded dolomite, sandy dolomite, some interbedded quartzose sandstone, and some shale. They occur in the deeper parts of the buried valleys and beneath younger rocks on the uplands. Nearly the full thickness of this group, which is approximately 100 to 125 feet, is cut by the valley underlying the Minneapolis lake chain of Harriet, Calhoun, and Lake of the Isles.

Beneath the Prairie du Chien Group lies the Jordan Sandstone of Late Cambrian age, which does not crop out at the bedrock surface and is not shown on the map. This formation, 85 to 100 feet thick, together with the Prairie du Chien Group, constitutes an important bedrock aquifer in Minnesota. A major part of the ground water withdrawn in the Twin Cities comes from this aquifer. The presence of this aquifer and its water-yielding characteristics should be considered in planning underground work. In particular, the function of buried valleys as recharge or discharge channels for the aquifer should be considered.

The Prairie du Chien Group is overlain by St. Peter Sandstone (Osp). The contact between these two formations is irregular in places, indicating that beds in the upper part of the Prairie du Chien Group underwent some erosion before deposition of the St. Peter. At the base of the St. Peter Sandstone a few feet of shale interbedded with shaly to silty sandstone provide a confining bed for the underlying aquifer. Above these beds is almost 150 feet of light yellow to white, medium-grained to locally fine-grained, friable, massive sandstone composed predominantly of rounded to subrounded quartz grains. The most prominent bedrock outcrops in the Twin Cities area are the cliffs and bluffs of St. Peter Sandstone along the Mississippi River.

The St. Peter Sandstone is capped by 2 to 3 feet of shale, the Glenwood Shale which is overlain by the Platteville Formation, thin- to medium-bedded dolomitic limestone and dolomite about 30 feet thick. Because the Glenwood Shale is thin, it is combined with the Platteville Formation on the map (Opg). The Platteville Formation is the most resistant rock in the area. It forms a cap protecting cliffs of St. Peter Sandstone, underlies the terrace deposits along the Mississippi River, and is the resistant bed that forms St. Anthony Falls. This hard cap over the easily excavated St. Peter Sandstone provides an unusually favorable environment for bedrock tunneling and underground space utilization in much of the Twin Cities area.

The uppermost bedrock unit is the Decorah Shale (Od). It occurs as erosional remnants on the Platteville Formation, mainly in the western part of St. Paul, where as much as 80 feet of shale is present. The Decorah Shale is a greenish-gray, to olive-gray, fossiliferous shale interbedded with thin limestone layers. It ravels and decomposes rapidly on exposure to air and thus is exposed mainly in recent highway cuts and excavations.

Regionally the bedrock strata form a broad, downwarped, basin-like structure, the so-called Twin City basin, with structural relief of no more than a few feet per mile across most of the area, except near the buried valley west of downtown Minneapolis. East of the valley the contact between the St. Peter Sandstone and the Platteville–Glenwood unit rises 30 or 40 feet in about half a mile between downtown Minneapolis and the valley. West of the valley this contact is about 60 feet higher than its general altitude in downtown Minneapolis. The resultant structure is an abrupt monoclinal flexure down to the east. Apparently the hinge line lies within the buried valley. This structure is the only tectonic feature that can be delineated in the map area using the available data. Because of the presence of the Prairie du Chien–Jordan aquifer, as well as underlying aquifers in older formations, the Twin City basin is an important hydrologic structure that forms a major ground-water reservoir.

### Engineering Geology of Bedrock Formations

The engineering properties of bedrock formations are summarized in tables 2, 3, and 4. These test results are cited because they are available, but testing specifically for tunneling properties should be done. Because of the relatively simple "layer cake" configuration of the formations, there is a relatively high degree of predictability and continuity to the subsurface geology, except where bedrock is cut by the buried valleys of the pre-glacial drainage system. Available subsurface data are probably adequate to delineate the principal buried valleys in the area. There are not likely to be any undetected large valleys that cut more than a few feet into the St. Peter Sandstone, but there are doubtless numerous small gullies and gulches that have not yet been detected.

Buried valleys should be investigated carefully before any construction in them is contemplated. Available data indicate the valley fill is variable in composition. Some valleys are filled with high permeability gravel, cobbles and boulders, others with soft organic silt and clay, and still others with stiff, compact inorganic clay. Buried logs (trees) may be obstacles. These materials are described in the text for plate 2, Surficial Geology.

#### Prairie du Chien Group (Opc)

Except for the possible construction of a deep shaft for high-pressure gas storage or an inverted siphon under the Mississippi River, it is unlikely that the Prairie du Chien Group would be penetrated by any underground construction in the area. The formation lies below the altitude of the Mississippi River and, where not overlain by St. Peter Sandstone and younger beds, is buried under 150 feet to more than 300 feet of surficial deposits. (See plate 4, Thickness of Drift). Dolomitic beds in the group are fractured and broken, and sandstone beds tend to be weakly cemented and porous. Large amounts of water and artesian pressure can be expected. Openings would require casing or lining and support.

#### St. Peter Sandstone (Osp)

The St. Peter Sandstone provides an optimum environment for low-cost tunneling and underground-space development. Except for a few thin, discontinuous shaly beds in its lower half, it is an exceptionally massive, homogeneous sandstone with little or no discernible bedding. Though weakly cemented the rock is well compacted. Cohesion is provided mainly by a small percentage of clay binder. The rock has good confined compressive strength and low to moderate compressibility, but it is friable and easily disaggregated. Pieces can be broken by hand, and the formation is commonly excavated rapidly by a water jet, which reduces the rock to a sand slurry removable by pipeline and slurry pump.

Many miles of unsupported utility and drainage tunnels have been constructed in the St. Peter Sandstone. Unsupported caverns 30 feet or more in width, which were excavated 50 to 100 years ago when the St. Peter Sandstone was mined for foundry and glass sand, still remain open.

Failure takes place gradually in underground openings in the sandstone through grain-by-grain raveling and crumbling of exposed surfaces. This process is most rapid in zones of tensional stress in the crowns of openings. Over a period of time, the crowns of tunnels assume a "gothic arch" form or even a convexly curved "tented" profile. This process can be arrested by preventing skin decomposition. Research at the University of Minnesota (Nelson, 1977) has developed methods of arresting the skin decomposition by spraying. The rock is stabilized by impregnation with a chemical grout. Use of the technique makes the St. Peter Sandstone stable, and easily and rapidly excavatable by low-cost methods.

The principal problems with excavation in the sandstone relate to the occurrence of water, and to zones of diagenetic alteration in the clay binder. Both occur sporadically and are not predictable on the basis of existing information.

The St. Peter Sandstone generally has moderate permeability (coefficient of permeability 3.5 to 6.6 x $10^{-3}$ cm/sec), and because the rock is sparsely jointed, water enters excavations mostly by slow seepage. Difficulties arise where joints are encountered below the water table or where the formation has been disturbed by nearby operations. Once free flow begins in a joint or disturbed zone the rock erodes rapidly and must be protected.

In some places illite, which is the primary clay binder in the rock, has been altered to kaolinite. The illite tends to adhere to sand grains and bind them together, but the secondary kaolinite forms discrete crystalline grains in spaces between sand grains (W. E. Parham, written commun., 1975) and cohesion is greatly reduced. Where this process is well-advanced the rock becomes an almost incoherent, free-running sand. Such conditions cannot be predicted because the geologic factors that control the formation of kaolinite are not well-enough understood. Tunnelling operations should include stand-by preparation for rapid breast-boarding to deal with this phenomenon. Chemical grouting probably can be used as a control.

#### Platteville Formation and Glenwood Shale, undivided (Opg)

The opportunities for developing underground space in the St. Peter Sandstone are enhanced by the presence of the overlying Glenwood Shale and Platteville Formation, which forms a natural roof for excavations in the sandstone. Throughout most of the Twin Cities area the contact of the Platteville-Glenwood unit with the St. Peter Sandstone is at an altitude of 760 to 775 feet. Direct access to this zone is available all along the Mississippi River valley and in the lower terraces near the river. Elsewhere the contact is 100 to 250 feet below the surface, and the advantages of tunneling in the St. Peter Sandstone must be weighed against the problem of vertical access and the alternative of tunneling in glacial drift.

Excavation in the Platteville Formation requires drilling and blasting. Presplitting has been used to good effect to produce clean cuts with little or no overbreak. In the lower terraces along the Mississippi River, where the Platteville is at or near land surface, it is difficult and costly to excavate utility ditches. The rock has been used as a building stone, but it tends to spall and weather irregularly over long periods and is not regarded as a superior structural stone.

#### Decorah Shale (Od)

Where fresh, the Decorah Shale is firm and compact and probably rippable only with difficulty. Much of the exposed shale is weathered to varying degrees. As it weathers it becomes progressively softer, and finally disaggregates into a sticky clay. It is, in effect, transitional between rock and soil. The fresh shale should lend itself to rapid machine boring with a cutterhead but would probably be difficult to mine with a ripper tooth or hoe. Weathered to partly weathered shale can be treated as engineering soil. Continuous lining would be required to protect against raveling, even in fresh shale. Data are not available on the possible swelling characteristics of the Decorah Shale. Therefore, testing for this property should be conducted before excavation.

### TABLE 2.—*Engineering properties of Decorah and Glenwood Shales*

| | Core Recovery | Standard Penetration Test[1] | Density lbs/ft³ | Cohesion lbs/ft² | Compressive Strength lbs/in² | Torsion shear strength[2,3] |
|---|---|---|---|---|---|---|
| Decorah Shale | Variable in both weathered and unweathered shale. Ranges from 0 to 100 percent. | Weathered shale; disturbed or in place: up to 30± | Weathered shale: 91–119 (3) | Weathered or disturbed shale: 500 to 8000+ Generally less than 3500. | ..... | Shale: Saturated: $\phi$=9.5° c=440 lbs/ft² Moist: $\phi$=21.5° c=440 lbs/ft² |
| | | Disturbed or fractured, relatively unweathered shale: 30± to 70± | Unweathered shale: 108–122 (3) | Unweathered shale: 100 to 9000+ (100) | ..... | Bentonite zone approximately 5 feet above base of formation (shear zone): $\phi$=6° c=800 lbs/ft² (peak) c=400 lbs/ft² (residual) |
| | | Unweathered shale 75/0.7′ to 75/0.4′ | | | | |
| Glenwood Shale | Generally 90–100 percent in unweathered shale | Weathered shale: 20 to 100 | ..... | ..... | 33.5 to 40 (3) | |
| | | Unweathered shale: 100/0.8′ to 100/0.2′ | | | | |

[1]Standard penetration blows per foot, 140 pound hammer, 30 inch fall, 2 inch OD split spoon
[2]Schwantes, E. D., and Adolfson, R. A., 1969, Landslide stabilization with slit trench buttresses: 17th Annual Conference on Soil Mechanics and Foundation Engineering, University of Minnesota, pp 1–37.
[3]$\phi$=angle of shearing resistance.
c=cohesion value

### TABLE 3.—*Engineering properties of Platteville Formation and Prairie du Chien Group carbonate rocks*

| | Core Recovery | Standard Penetration Test | Density lbs/ft³ | Hardness Shore Schleroscope | Compressive Strength lbs/in² | Tensile Strength lbs/in² | Youngs Modulus (dynamic) lbs/in² |
|---|---|---|---|---|---|---|---|
| Platteville Formation | Generally 90 to 100 percent in unweathered rock. Variable recovery in weathered rock. | No penetration in unweathered rock. | 149 to 167[2] (21) | ..... | 8,500 to 26,800[2,3] (27) | 670 to 736[2] (3) | 5.34 x $10^6$ to [2] 6.75 x $10^6$ (3) |
| Praire du Chien Group | Generally 90 to 100 percent in unweathered rock. Variable recovery in weathered rock. | No penetration in unweathered rock. | 147 to 170[1,2] (34) | 37.0 to 55.9[1] 14.8e (7) | 4,460 to 11,800[1,2] 930 to 16,600 e (10) | 135 to 520[1,2] 80 to 937 e (10) | 3.82 x $10^6$ to [1,2] 6.59 x $10^6$ 9.41 x $10^6$ e (8) |

[1]USBM unpublished data.
[2]USBM RI 6702, 1965; USBM RI 6880, 1966.
[3]Minnesota Department of Transportation unpublished data.
(3) Number of tests on which values are based.
e Denotes extreme minimum or maximum value of a set of tests.

### TABLE 4.—*Engineering properties of St. Peter Sandstone*

Core Recovery: Generally none in upper part of formation; variable (0–100 percent) in lower part.

Standard Penetration Test[1]: Reworked sand derived from St. Peter Sandstone[2]—30 to 40 blows per foot to 75 blows per 0.7′; weathered sandstone[2]—75/0.7′ ± 75/0.3′ or 0.4′; fresh sandstone[2]—75/0.3′ to 75/0.0′.

Compressive Strength, lbs/in²: 670 to 2800[3,4] in harder zones; 100 to 300[4] in softer zones.

Modulus of Deformation, tons/ft²: 11,000 to 60,000[5] for 11 unconfined compression tests; 4000 to 15,000[5] for 8 triaxial compression tests; 1660 to 210,000[5] for 7 field pressure meter tests.

Angle of Internal Friction: Average 60°, ranging from 59° to 69°[5]; disturbed and recompacted sandstone 41°[5].

Density, lbs/ft³: Average field dry densities 126[3]; highly cemented samples 135[5]; excavated, disturbed and recompacted sandstone 112–115[5].

Porosity percent: 28.2 for 11 tests[7]; 29.8 for 6 tests[8]; 23–28[9].

[1]Standard penetration blows per foot, 140 pound hammer, 30 inch fall, 2 inch OD split spoon.
[2]Minnesota Highway Department, Working Document of November, 1971.
[3]Payne, C. M., 1967, Engineering Aspects of the St. Peter Sandstone in the Minneapolis-St. Paul area of Minnesota, M. S. Thesis, University of Arizona, 126 p.
[4]Nelson, C. R. and Yardley, D. H., 1976, Modification of engineering properties of St. Peter Sandstone (abs.): Institute on Lake Superior Geology, Proceedings 22nd Annual Conference, p. 43.
[5]Corps of Engineers, U.S. Army, 1958, St. Anthony Falls Upper Lock and Dam: Report UL–3, Corps of Engineers, St. Paul, Minnesota.
[6]Soil Exploration Company, 1970, Foundation recommendations proposed I.D.S., M.M.L.A.N.B. building, St. Paul, Minnesota #15099A, 21 p.
[7]Thiel, G. A., 1935, Sedimentary and petrographic analysis of the St. Peter Sandstone, Bull. Geol. Soc. Amer., v. 46, p. 559–614.
[8]Nelson, C. R. and Yardley, D. H., 1973, Final report on low cost tunneling for the Twin Cities area; Dept. of Mineral and Civil Engineering, University of Minnesota, 45 p.
[9]Minnesota Department of Transportation unpublished data.

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