Educational Series- 5

Environmental Geology of the Twin Cities Metropolitan Area

Minnesota Geological Survey

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Minnesota Geological Survey
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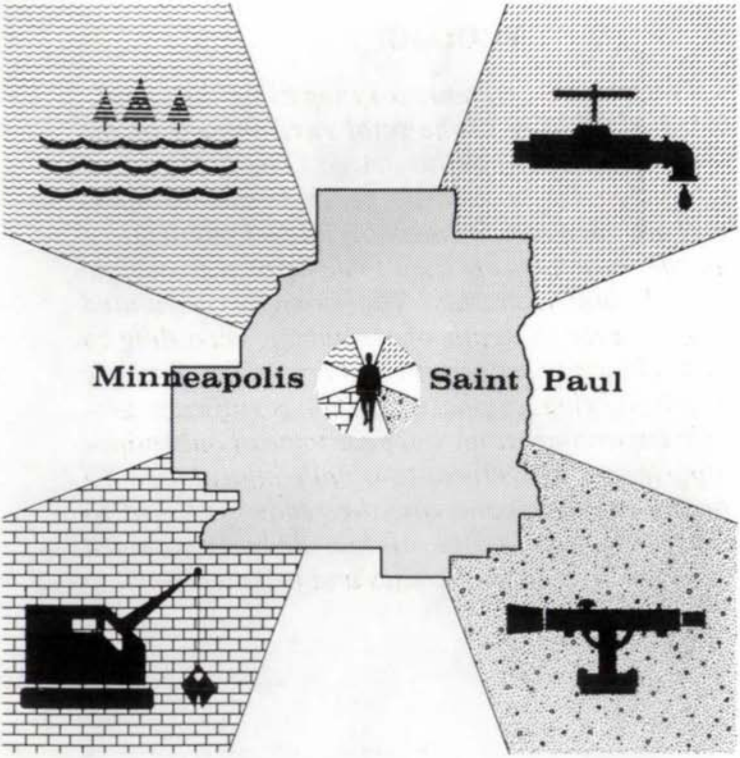
PROLOGUE

This booklet presents a synopsis of the significance of geology to the total environment of the Twin Cities Metropolitan Area. The background data given are necessarily generalized, but hopefully are adequate for meaningful communication. Specific examples are used to describe the geologic controls and restraints. The examples presented range widely in depth of treatment, according to their relation to each particular discussion. Because of this varying emphasis, certain significant geologic environments may appear to be of only minor importance. Therefore, to obtain information on special geologic concerns, the reader is urged to utilize the wide range of knowledge developed within many public agencies and private firms.



Illustrations by Ann Cross

Environmental Geology of the Twin Cities Metropolitan Area

R. K. Hogberg

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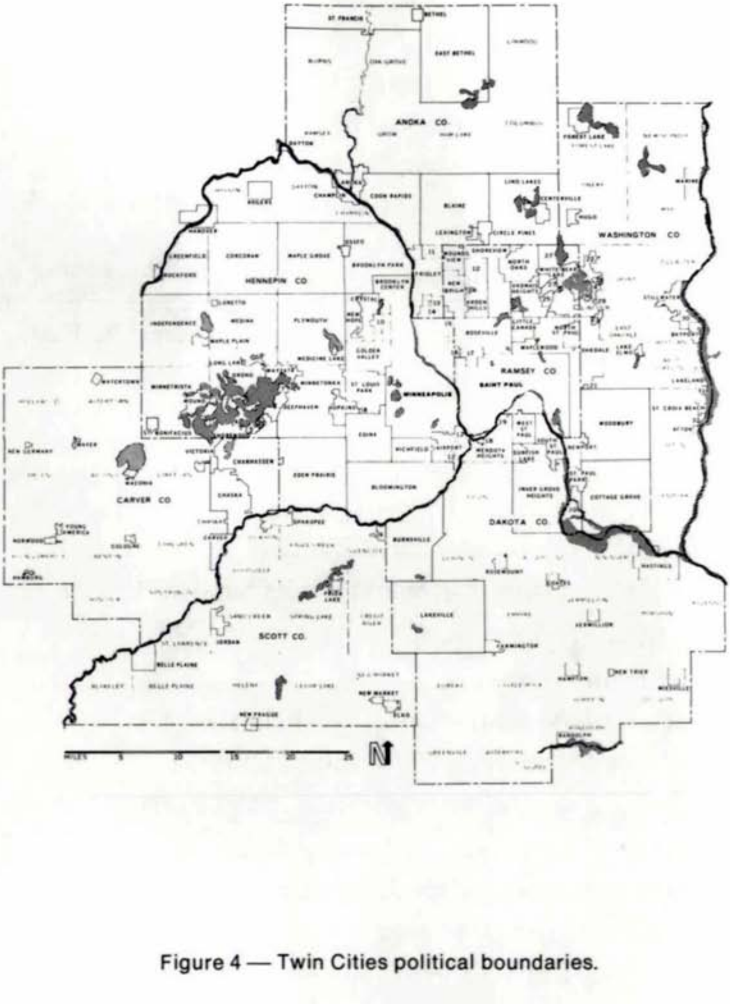

Figure 4 — Twin Cities political boundaries.

Environmental Geology of the Twin Cities Metropolitan Area

PERIODICALLY a staccato of crunching sounds emanated from the tongue-shaped *glacier** as it surged slowly forward overriding the lowland landscape. After a few thousand years the surges ceased, and the one-eighth mile high and 25- to 75-mile wide mass of dirty glacial ice began to melt. As the rate of melting increased, the glacier began to retreat, hesitantly, back toward its northern source. During its retreat, blocks of ice became separated from the main mass and settled into the sandy muds at the ice front and, after melting, formed lakes; many turbid, torrential streams carried the meltwaters and associated sediments out onto the barren *hummocky** terrane recently left by the melting glacier. These are some of the scenarios from the "ice age"—an age of ice, water, and mud—the last of the major geologic events that shaped a piece of the Earth's landscape that is now the Twin Cities Metropolitan Area.

It wasn't until the glacial ice had almost completely melted from the Twin Cities lowland—about 9,500 years ago—and until the soils had developed and grasses and trees were reestablished on the land surface, that the physical environment was again hospitable to man. Anthropologists tell us that the first people to view our State's post-glacial landscape probably were nomadic aborigines. They had traveled north to hunt the ice age animals in the lush, grassy plains irrigated by the meltwater streams. Hundreds of generations of the several tribes, in search of food, migrated across Minnesota during the tens of thousands of years of prehistoric time. The French fur traders, who reached Minnesota in the late 1600's, recorded in their journals the first accounts of two of the Indian tribes—the Sioux and the Dacotah.

In the approximately 300 years since the time of the early French fur traders, the Seven County Metropolitan Area, de-

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* Refer to Explanation of Terms, Appendix B., for this and other geologic terms.

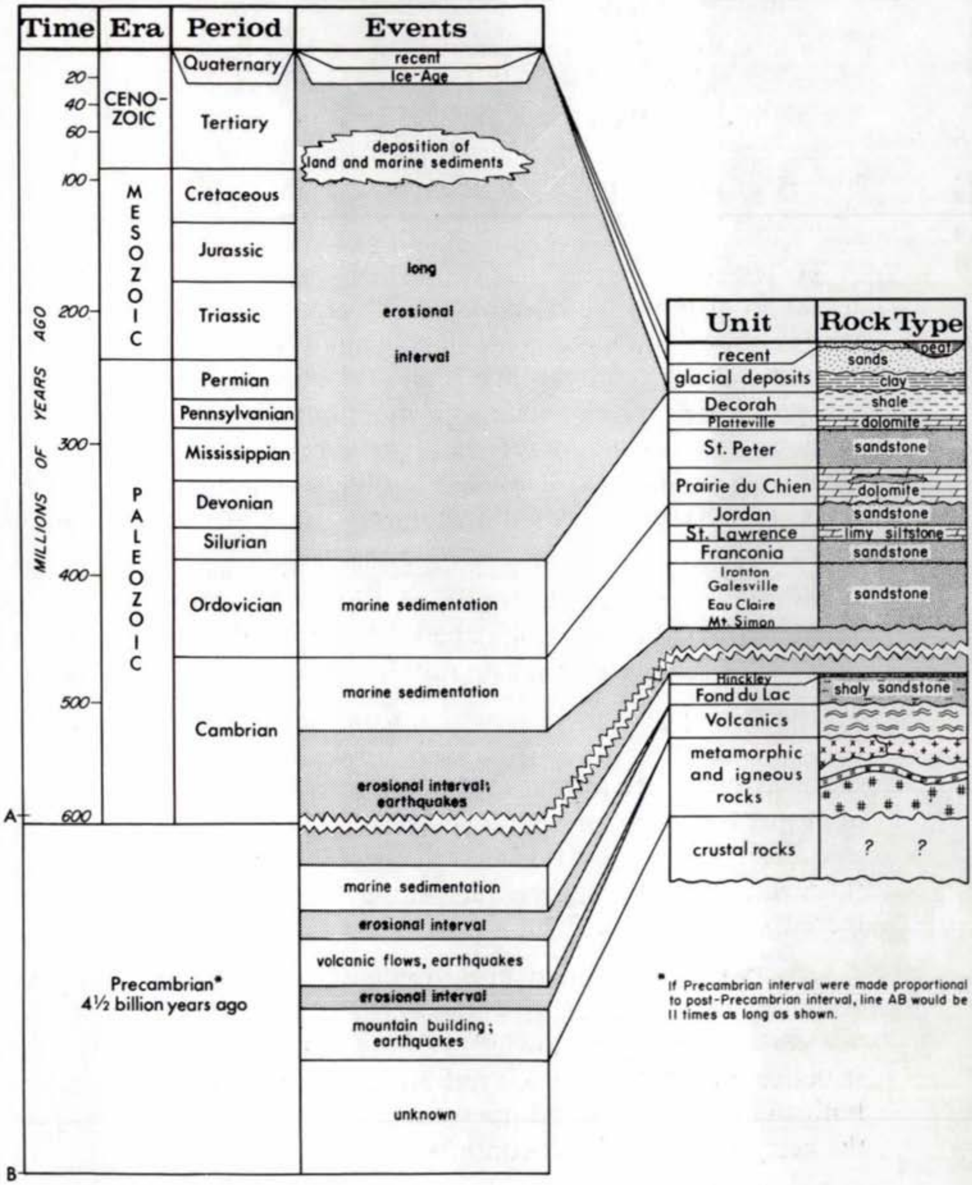
picted on the outside back cover, has been developed into an international commercial, industrial, educational and transportation center. Approximately half of Minnesota's 3.6 million people now live in the two core cities and the surrounding suburban communities. By the year 2,000, the population of the Metropolitan Area is predicted to reach 4 million.

In recent years there has been growing concern about deterioration of the overall living environment of the Twin Cities Metropolitan Area. Many private citizens and governmental groups are suggesting ways to alleviate this blight. However, few have recognized the substantial influence of geologic factors on the local environment. The overall interlocking, interdependent environmental system is literally built on a geologic framework.

This booklet seeks to describe the present status of knowledge of the physical controls and restraints of the environmental system excluding the climate. These physical elements include the type of soil available for raising food and fiber and the materials through which surface and ground waters flow and into which we dispose our wastes. Geologic factors also bear heavily on the nature of the materials in, on, and from which we construct our buildings and other engineering works. Natural physical hazards such as earthquakes, landslides, and floods are easily observed geologic events.

The mineral resources of the Twin Cities do not include economic deposits of gold, silver, or diamonds, nor is the landscape underlain by thick beds of coal or large pools of oil and gas. But beneath the hills, valleys, and lakes is an abundance of the rather mundane but important materials needed to support life and to build the needed facilities of the post-industrial age. Probably the most important of the Twin Cities' mineral resources is the plentiful supply of water. Also the rolling hills and gently sloping plains, the stream valleys, and the lake basins—the landscape—are important and unique natural resources, the base of our past, present, and future economic and cultural growth.

Geologic Time Chart and Column
Twin Cities Metropolitan Area



*If Precambrian interval were made proportional to post-Precambrian interval, line AB would be 11 times as long as shown.

Figure 5 — Geologic time chart and column, Twin Cities Metropolitan Area.

EARLY HISTORY OF THE LANDSCAPE

In this booklet the relationships of each of the environmental controls and restraints and each of the mineral resources are keyed to both their past and present geologic environments. Therefore, I will first present a brief basic account of the geologic history of the Metropolitan Area, so that the reader will have a firm basis upon which to build and to which we can refer later.

To begin, the parameters of geologic processes are vastly different from those we normally use. For example, thousands of years on man's time scale are approximately equivalent to a few seconds on the geologic time scale. Likewise, the magnitude of the geologic features—such as a mountain range—is measured on a very large scale, namely a planetary scale. Therefore, measurements of geologic features are almost imperceptible on the scales of time, distance, and size normally used by man.

The Metropolitan Area landscape is a result of about 4,500 million years of Earth history. This history is marked by a wide range of physical and chemical environments. Each environment reflected Minnesota's position relative to past dynamic events.

The "ice age," our introduction scenario, was the last page of the last chapter of the Earth history book. It should be the easiest of the geologic events to decipher because the record can be read at or just below the present land surface. As we search backward into Earth history, we find that the geologic events are more obscure and often missing; therefore, the older part of the record is increasingly more difficult to read.

Observations recorded in writings of explorers and missionaries, the most famous of whom was Father Hennepin, provide our earliest geologic knowledge of the state. The historic reconstruction that follows is a synthesis of work of geologists from both the University of Minnesota and industry, which began in the early 1800's and still continues.

Let us now briefly examine the known geologic framework, element by element, upon which the Twin Cities' landscape rests.

The Basement

The "basement," which is composed of very old Precambrian rocks, was formed during much more unsettled times, geologically speaking, than those we are experiencing today. At the present time the surface of these basement rocks lies from 700 to 5,000 feet below the land surface. It is composed mostly of dark gray volcanic rocks called *basalt*. The volcanic sequence formed during a long period of volcanic eruptions that took place from about 1,100 to 900 million years ago. The present record of this period is the several hundred lava flows that form an approximately 5½-mile thick, 30- to 50-mile wide, trough-shaped body which extends from Lake Superior to Kansas. Earthquakes probably occurred quite frequently during the early "chapters" or periodically through the Precambrian Era, especially during crustal adjustments accompanying the development of the mountain ranges north of the Twin Cities.

The Bedrock

During the last billion years of Earth history, Minnesota's landscape has been inundated by several inland seas. Each of the several seas invaded, and after some tens of millions of years, retreated from the State. When the seas withdrew, the sediments that had accumulated were left as layered sequences. After consolidation by the weight of subsequent rock materials, the sediments were transformed into several sedimentary rock units. The composite sequence of sedimentary rocks, or *bedrock,* beneath the Twin Cities attains a maximum thickness of about 3,500 feet. At the present time, the irregular top of the sedimentary rock units—the bedrock surface—lies at depths varying from 25 to 500 feet beneath the land surface.

Our bedrock "chapter" begins with Late Precambrian (Keweenawan) time. Sediments—mostly sands and silts—were carried by streams into and were deposited initially within local depressions on the eroded volcanic surface; somewhat later the sediments blanketed the remainder of the surface. One of the local depressions on this surface is the base of what is now called the Twin Cities Basin. The surface of this shallow, saucer-shaped depression is about one quarter of a mile beneath the land surface. It extends for about 50 miles along a line from Jordan to Forest Lake, and has a maximum width of about 30 miles along a line from Medicine Lake to Upper Grey Cloud Island of the Mississippi River. Its maximum *relief* is about 600 feet and slopes are very gentle, about 20 feet per mile, or less than 0.2 of a degree! The record of the Keweenawan sea within the Twin Cities Basin mostly consists of the 2,500-foot thick accumulation of impure *sandstones* and *shales* named the Fond du Lac Formation; the 150-foot thick Hinckley Sandstone, which also was deposited in the Keweenawan sea, caps the Fond du Lac sequence.

Earthquakes periodically reverberated through Minnesota during Late Cambrian and Early Ordovician time, or from about 600 to 450 million years ago. The tremors were caused by the breaking and continued adjustments in the basement and bedrock sequences. In the Twin Cities Area, these movements are recorded by several *faults.* A 40- to 60-mile wide block of the Earth's crust which extends from the southern Twin Cities into Wisconsin, was elevated along boundary faults. This "block" is one of a series of large blocks comprising the approximately 700-mile long midcontinental buried ridge. Upward movement along these boundary faults was as much as several hundred feet, but erosion had greatly reduced these positive features prior to early Paleozoic time.

In late Cambrian time, sediments derived from *erosion* of the older rocks again were carried by streams into inland seas. The sandy sediments accumulated mostly as beaches along sea shores; initially deposition was on the irregular surface of the Hinckley Sandstone. However, with time the sediments accumulated along the cliff-like edges of the "block," filling the low areas, and eventually the Twin Cities Area again received sediments.

The Cambrian succession is now a maximum of 700 feet thick. These sandy rocks are progressively richer in quartz and whiter upward in the succession, reflecting the abrasion and resorting of the rock materials many times over. Water, and less so winds, provided the energy to accomplish the cleaning and sorting. The resulting thick beds of white, well-rounded quartz sandstone are now interlayered with thin beds of shale and impure limestone in the Mt. Simon, Eau Claire, Galesville, Ironton, Franconia, St. Lawrence, and Jordan Formations (see fig. 5).

Another inland sea covered southeastern Minnesota in the Ordovician Period, from about 500 million to 440 million years ago. During Ordovician time, animal life was particularly abundant within the tropical, near-shore, reefal environments. Probably the reefs were similar to those now found in the Atlantic Ocean near the Florida coast. As the several animal species succumbed, their shells remained in place or were broken by the

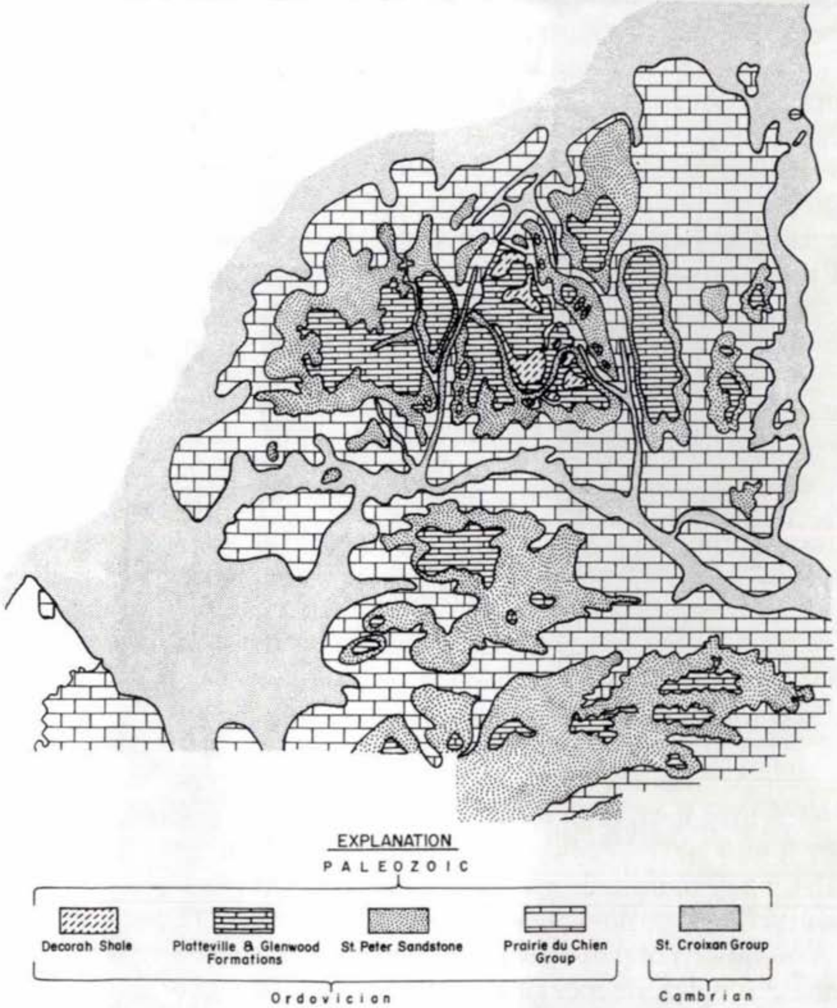


Figure 6 — Bedrock geologic map, Twin Cities Area.

waves and gradually accumulated layer by layer on the sea floor, forming some of the material in *limestone* beds. Intermittently—probably daily, seasonally, and during storms—the shell accumulations were flooded by sands and muds. During deposition of the St. Peter Sandstone, conditions were similar to those described for the deposition of the Cambrian sandstones. In Ordovician time sufficient sediments collected to form the 300- to 400-foot thick limestone, sandstone, and shale sequence of the Twin Cities Basin. These several rock units have been named the Prairie du Chien Group, and the St. Peter, Glenwood, Platteville, and Decorah Formations.

Rocks representing the next geologic period—the Silurian—have not been found in Minnesota.

After a *hiatus* of about 220 million years, and during the Devonian Period, extreme south-central Minnesota was again drowned by an inland sea and received fossil-rich debris. However, Devonian-age rocks are not present beneath the Twin Cities.

Tropical and Temperate Weathering

During the time interval from about 400 to 100 million years ago, the land surface of Minnesota was mostly above sea level and was subjected to erosion. The uplands were slowly reduced to a surface of low relief. In the latter part of this time interval, high temperatures combined with heavy precipitation resulted in the development of a 5- to 125-foot thick layer of punky, white, sandy clay called *regolith.* These deposits are now confined to the western part of Minnesota. No such regolith has been found beneath the Twin Cities.

About 100 million years ago, the last of the inland seas to cover Minnesota encroached from the west. The Metropolitan Area may have remained above the level of the Cretaceous sea, or it may have been drowned either by the shallow sea or one of the many marginal, dismal swamps. Unfortunately, these pages of the local geologic history book are missing. The scattered accumulations of patchy sands and clays in outstate areas constitute the geologic evidence of the Cretaceous-age events.

Minnesota's climate began to change about 90 million years ago, during the Tertiary Epoch. By late Tertiary time, the climate became more temperate and since that time the area has been subjected to less rigorous *weathering*.

In summation, most of the bedrock sequence of the Twin Cities Metropolitan Area was deposited within a saucer-shaped depression that was later modified by erosion. Individual rock units thin toward the rim of the basin, partly due to depositional thinning and partly due to erosion. The irregular bedrock surface beneath the blanket of *glacial drift* now consists of generally flat-lying uplands interrupted by a network of narrow, generally steep-walled, buried valleys. I will describe the development of the buried valleys next.

The Ice Age

During the last chapter of our Earth history book—the "ice age"—Minnesota was intermittently overridden by several glaciers. Each one carried loose bedrock and basement rock particles to the Twin Cities lowland and to other parts of southern Minnesota and beyond. When the ice melted, the rock materials were either distributed by meltwater streams—outwash—or settled out directly forming heterogeneous deposits—till.

After each of the glaciers had retreated from the landscape, there was a period of lush vegetative growth and animals inhabited the region. These relatively warm intervals are called interglacial periods.

Also valleys, now deeply buried, were developed during the ice age. Large volumes of meltwater flowing from the melting glaciers cut deep valleys into the unconsolidated materials as well as into the bedrock. The major buried valleys developed during the ice age, and probably during the preceding Tertiary Epoch as well, are depicted in Figure 7. These valleys are now filled with materials left by glacial ice, are from 50 to 500 feet deep and 1.4 to 2 miles wide, and extend along their lengths for tens of miles.

During the last of the several pulsations of ice advance, two separate ice lobes, which were 250 feet to 1 mile thick and 25 to 75 miles wide, overrode the landscape of the Metropolitan Area. The first lobe flowed from the northeast; its deposits are characterized by a pink sandy matrix containing many *granite* and sandstone *pebbles*. The second lobe, which closely followed and mostly covered the first, flowed from the northwest; its deposits

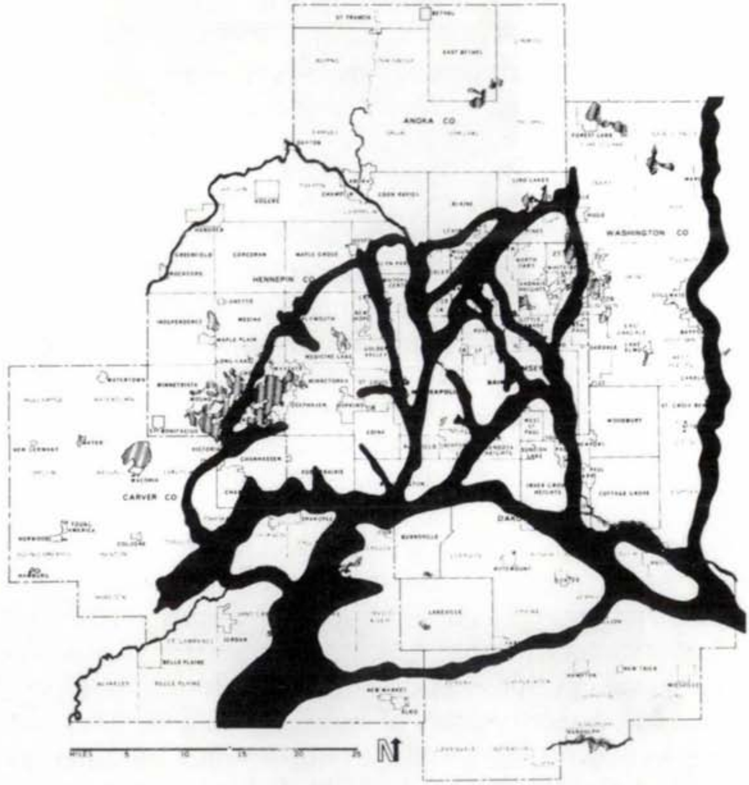


Figure 7 — Major bedrock valleys of Twin Cities Metropolitan Area.

are characterized by a matrix of tan silty-sand containing many limestone and shale pebbles.

The varied and pleasing forms of the present landscape emerged when the last of the glacial ice blocks melted. As the ice melted—over an interval of some thousands of years—the ice-supported glacial deposits slumped and slid into positions of gravity equilibrium. Also, glacial streams and lakes reworked and redeposited some of the surface materials.

Most of the Metropolitan Area lies within hilly *moraines* which form the eastern, western, and southern highlands. The moraines resulted from an accumulation of glacial materials at hesitation positions of the glaciers during their northward retreat. They are broadly hummocky in form, and are composed mostly of till, which is a heterogeneous mixture of pink to tan sand with lesser amounts of scattered clay- to boulder-sized particles.

Outwash plains were formed from the materials carried and deposited by the many glacial meltwater streams. They consist of a succession of overlapping *alluvial fans,* are broad and gently sloping in form, are distinctly layered, and are composed almost completely of light tan to light pinkish-tan sand. The outwash plains are designated the Anoka sand plain, Minneapolis-St. Paul outwash plain, and the Eastern outwash plain.

The *lake plains* confined to northern Ramsey County and Anoka County represent low-lying topography in which glacial meltwaters ponded and in which a veneer of layered sands and silts was deposited. The lake plains now have numerous *peat* bogs that developed within wind-deflated depressions that intersected the local *water table.*

In the 9,500 years since the last of the glaciers receded, surface streams—particularly the Minnesota, Mississippi, and St. Croix rivers—have removed some of the glacial drift and locally have cut down into the relatively hard bedrock. The present sequence and composition of the stream-deposited sediments is dependent upon the materials the streams encountered during their downcutting. Generally streams draining the Metropolitan Area have reworked their stream bed materials, forming the gravelly sands of the river terraces in the upper valley and the silty sand *alluvium* of the valley *flood plains.*

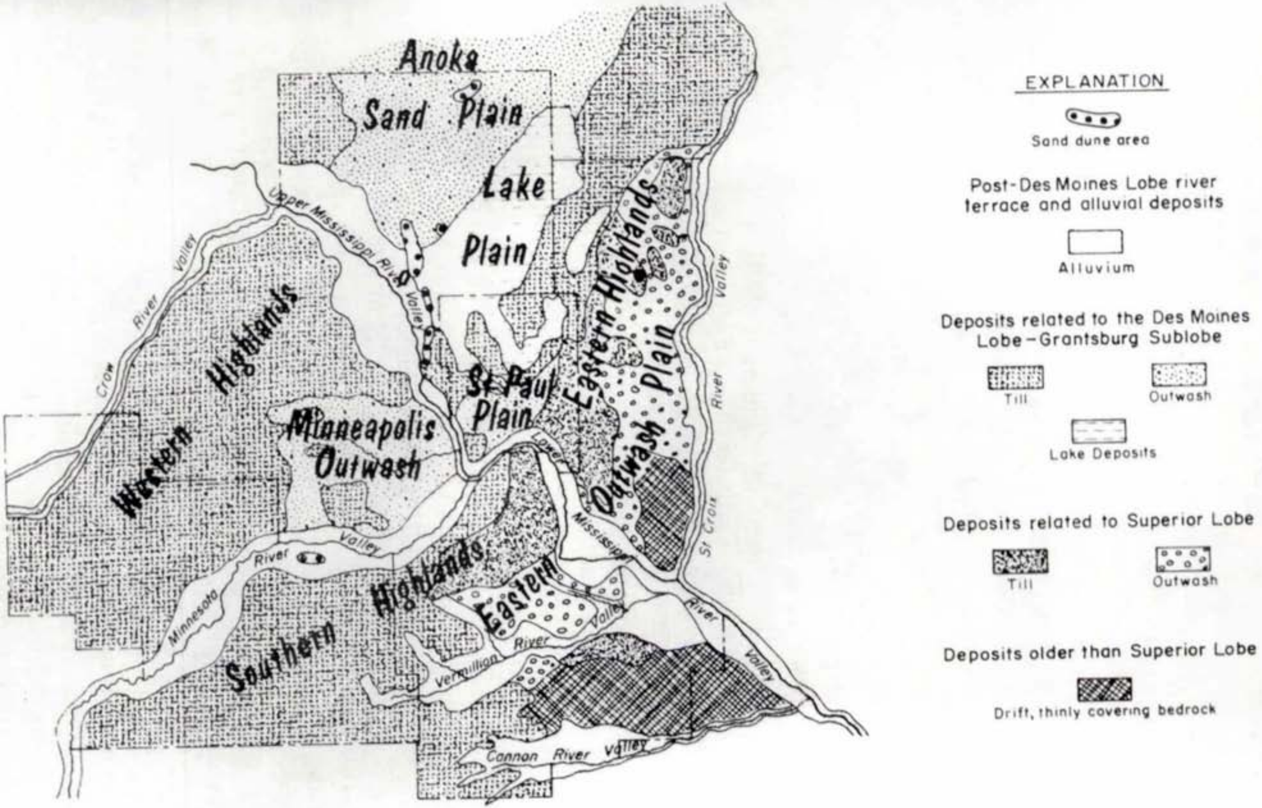


Figure 8 — Surficial geologic and geomorphic map, Twin Cities Area.

The foregoing has attempted to describe the highlights of the Twin Cities' geologic "history book." The earth materials can be readily seen in excavations for buildings, mineral resources, and highways. The record of the eons of Earth history is there to be observed, interpreted, and enjoyed.

THE LANDSCAPE AND MAN'S SETTLEMENT PATTERN

Ranges of hummocky morainal hills to the east, west, and south border the undulating outwash plains that slope gently toward the three major river valleys. An integrated drainage system consisting of hundreds of lakes and hundreds of miles of streams confluences with the Mississippi, the Minnesota, and the St. Croix rivers. These major topographic elements combine to form the Twin Cities landscape which, when viewed from its variety of natural settings, has been judged to be one of the most scenic of the United States' metropolitan areas.

The aboriginal tribes, the fur traders, the explorers, the missionaries, the military, and the early settlers were all strongly affected by the basic geologic resources of the Twin Cities landscape. Streams, lakes, and springs provided the life-sustaining supply of drinking water. Cobble- to boulder-sized rocks from the glacial drift were used for the making of axes, plows, hammers, knives, and other tools. Hearths, building foundations, and walls were built from glacial boulders and slabs of bedrock. The hard, yet brittle, agates collected from the northeastern-source glacial drift were chipped for use as arrow and spear points. Natural sandstone caves, with modification, provided convenient temperature-constant shelters.

Other elements of the geologic environment—in addition to water, shelter, and tools—have played a determining part in the settlement of the Metropolitan Area. Perhaps the major determinant has been the strategic position at the junction of three major drainage systems—the Mississippi, the Minnesota, and the St. Croix. The freeways of our earliest history were rivers; the Twin Cities were at the crossroads. At one of the major intersections, the *confluence* of the Minnesota and the Mississippi Rivers, a fur trading post was established that eventually became the town of Mendota. Later, the United States Army chose a promontory of the Platteville Formation at the same river junction as the site for Fort Snelling. It became a locus for settlement. Many new year-round residences, in addition to those in Mendota, were established near the Fort and along the banks of the two rivers.

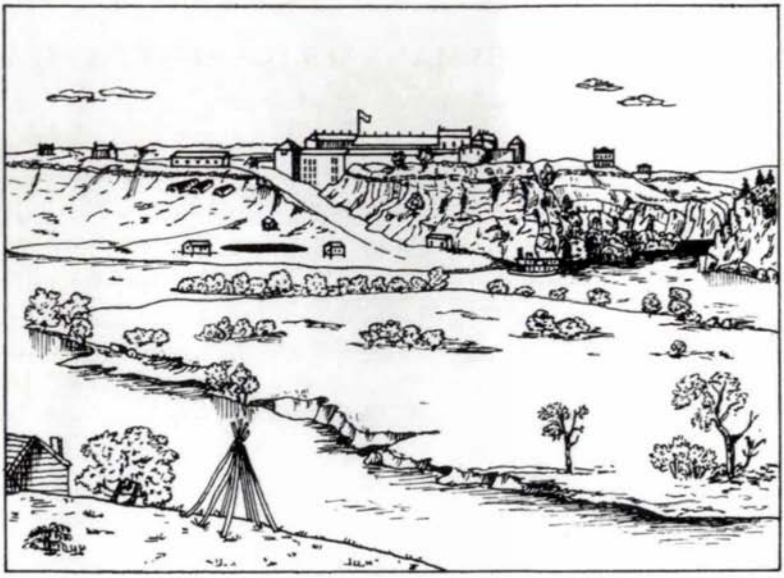


Figure 9 — Sketch of early settlement at Fort Snelling.

In 1821, because of the need for lumber in constructing the Fort, the Army built a sawmill eight miles up the Mississippi River and on the west side of the famous St. Anthony Falls. Two years later, the first flour mills were built and within the next several years firms began to utilize hydropower for furniture, wool, and machine manufacturing. River water was conveyed from the reservoirs of upper and lower dams via millrace conduits to the industrial facilities. The drop or "head" of the river waters was used to propel water wheels, which in turn powered a variety of machines. The outlet or tailrace "tunnels" were dug in the soft St. Peter Sandstone from the base of the falls to the riverbank industrial facilities. As the users increased, the number and length of the tailrace "tunnels" increased proportionately. Use of hydropower continued at a high rate until the late 1860's when a portion of the Eastman Tunnel—which was at that time nearly completed to Hennepin Island—collapsed. Large slabs of the Platteville Formation fell into the caved opening which was being rapidly eroded by the river. The nearby tailrace tunnels as well as the industrial sites were threatened. A disaster was averted by the construction of a temporary dam attached to the downstream end of Nicollet Island; a concrete dam spillway was completed in 1876. Thus, hydropower-dependent industries provided the impetus which led to the development of the village of St. Anthony and eventually to the "City of Lakes."

The early history of St. Paul also was tied to the Mississippi River. St. Paul began as a combined agricultural and "river town." Later the site for the State Capitol was selected about a mile north of the "River" and six miles from Fort Snelling. Thereafter St. Paul and the surrounding metropolitan area grew rapidly in population. The city soon became a focus for commerce and industry, as well as government, and developed into a railroad center in the late 1800's.

Early settlements in suburban communities of the Twin Cities were tied to the transportation of lumber and other timber products on the natural waterways. Minnesota's oldest non-military community, Marine-on-St. Croix, which was incorporated in 1838, began as a lumbermill town. The timber was floated down the St. Croix River from cutting areas upstream. In 1852, a dam and sawmill were constructed at Minnetonka Mills (Minnetonka) on a rapids of Minnehaha Creek. Logs cut from the nearshore areas of Lake Minnetonka were rafted to that mill. Later, a furniture factory and a flour mill were operated at the site. A flood destroyed the Minnetonka Mills dam in 1891. Shingle Creek, which flows through suburban Brooklyn Center and Brooklyn Park, received its name from the many shingle mills that were operated in the late 1880's along its banks near its junction with the Mississippi River.

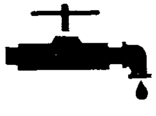
The preeminence of transportation on the Mississippi and its two major tributaries faded rapidly in the late 1800's with the advent of rail transportation. However, technological advances in diesel engines and the use of multiple barge groupings combined with navigational improvements have initiated a resurgence in river transportation. In the past two decades receiving terminals have been built on the Mississippi as well as on the Minnesota and St. Croix rivers. The volume of shipments has progressively increased; in 1969, shipments by water into and from the Minneapolis-St. Paul district totaled about seven million tons.

Residence and business buildings, during the early history of the Metropolitan Area, were constructed along and near the three major rivers and their tributaries. As the population grew and land transportation became more reliable, settlements moved away from the near-river sites onto the relatively flat outwash plains. Somewhat later, growth extended to the lands near the "chains of lakes" and in recent years to the more distant morainic hills.

Through the foresight of the early Twin Cities park commissioners, who recognized the value of purchasing stream-side and lake-shore lands, an overall park and parkway system was established during the late 1800's. The setting aside of this open space has added immeasurably to the quality-of-life in the Metropolitan Area. However, at this writing only a small part of the 310 miles of the lake shoreline, and only a few miles of the hundreds of miles of stream bank outside the core cities have been incorporated into a green-way system. Additional acreages of open spaces should be reserved now to meet the projected increase in leisure time of our expanding population.

The less obvious physical controls of our 3,000 square units of landscape, such as those affecting water supply, foundation conditions, and building materials are all intertwined with an area's environmental setting. These elements, which take on a greater importance as the population density increases and the urbanized area enlarges, are discussed next.

WATER, AN UNTAMED MINERAL RESOURCE



Let us now examine the Twin Cities' most important natural resource—its abundant surface and underground water. As population increases and the quality-of-life index rises, there is a greater demand for water and, therefore, a critical need to better understand the entire water resources system. This section provides a synopsis of the information that is known about the Twin Cities water resources and their relative quantity, quality, and storage locations.

Water, in our 20th century technological society, is the most vital of the ingredients in the resource mix. In fact, we in the United States now use about 155 gallons per person per day. Man cannot live without water; about 65 percent of our body is water. Water is necessary for all industries, businesses, and house-

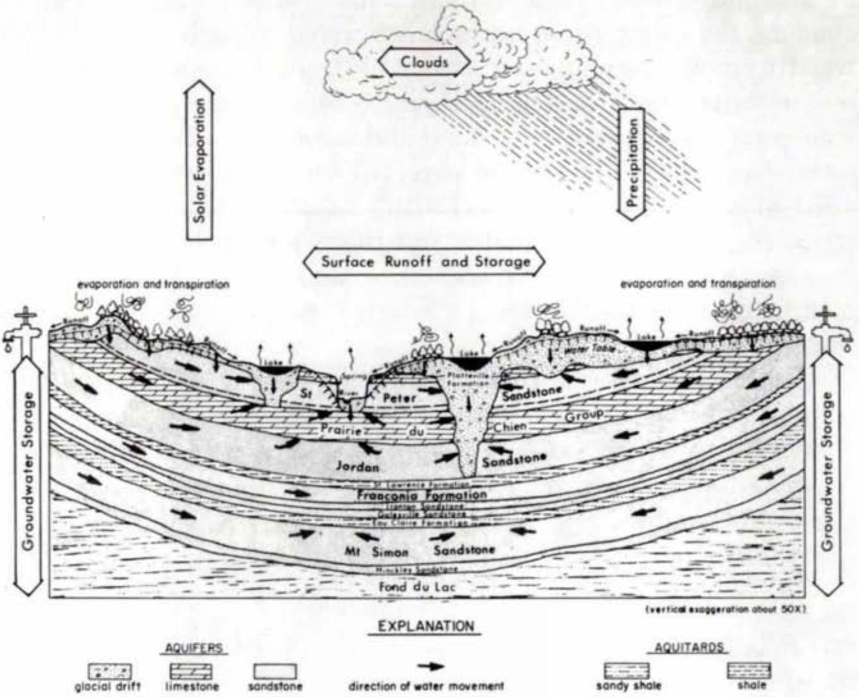


Figure 10 — Water cycle in Twin Cities Basin.

holds; it is used in manufacturing operations, to cool and cleanse our air, for producing electricity, for transporting various bulk resources and products, for cooking our foods, for disposing of some of our wastes, and for recreational activities such as sightseeing, boating, swimming, fishing, skating, skiing, and snowmobiling.

Water supplies, unlike most mineral resources, are replenishable. In this booklet water is considered a *feral* mineral, that is, an untamed mineral, one that is constantly moving through the natural environment. Not only are the water molecules moving constantly within their immediate environment—as waves and currents—but they also are changing with climatic conditions from one physical state of matter to another—from a gas (clouds) to a liquid (water) to a solid (ice and snow). These physical changes, whose energy is ultimately derived from the sun, enable water to move through a replenishable cycle or *water cycle.* The major parts of the water cycle are: (1) solar evaporation and transpiration at and near the land and water surfaces; (2) precipitation from clouds; and (3) storage, (a) within underground reservoirs after filtration into the Earth's near surface materials, or (b) surface runoff via streams and rivers with collection in surface water bodies—reservoirs, lakes, and oceans. The cycle is completed by returning to (1) solar evaporation and transpiration.

The description of Twin Cities water resources will be limited to the runoff and storage parts of the water cycle.

Surface Water

Surface water not only provides water supplies but also adds scenic recreational areas to the landscape. As previously described, the surface water system, which consists of an integrated network of streams and lakes, is mostly a legacy from recent geologic history—the "ice age."

The surface water system is closely interconnected with the underground or *groundwater* system. At some localities there is considerable augmentation of stream flow and replenishment of lakes by groundwater that is added during the wet seasons; conversely, water is lost to groundwater storage from both lakes and streams during dry periods. Lowering of lake levels and decreases in stream flow also occur when water wells are pumped heavily. Man short-circuits the water cycle in other ways. He regulates stream flow and maintains lake levels by control structures. A specific case of maintenance of lake levels within the Metropolitan Area is the use of 0.5 to 1.0 billion gallons of Mississippi River water each summer to maintain lake levels in the "chain of lakes" in Minneapolis.

Metropolitan lakes and streams have beds or basins and shores or banks of unconsolidated earth materials. An exception is at St. Anthony Falls, where the Mississippi River flows upon resistant bedrock of the Platteville Formation. The amount of leakage from or flow into the water body is dependent upon many factors. To gain a better understanding of our surface water, we will examine briefly the confining materials of the Twin City lakes and streams, as well as how they were formed, and how they change with time.

Lakes

Lake basins comprise about five percent of the surface area of the Seven Counties. Minnetonka and White Bear, the best known of the metropolitan lakes, as well as the other 702 lakes, occur almost exclusively within large basins left by the glaciers. As the ice melted, fine materials—clays and silts—accumulated in the bottoms of most depressions, forming a somewhat impermeable layer or "seal." The addition of groundwater and/or rain water and snow melt gradually filled the depressions.

Lakes are one of the most ephemeral of the physical features of Earth's landscape. With passing time, their basins fill with organic and inorganic materials, forming first a marsh, then an intermediate-stage bog, and ultimately a lowland. During the 9,500 years that have elapsed since the glaciers receded, grasses, plants, and trees have grown on the landscape adjacent to the lakes, and submergent and emergent vegetation as well as animal life has thrived within the lakes. Streams and winds have carried both organic and inorganic materials into the lakes, forming layers of alternating and/or mixed organic and inorganic materials.

In detail, the organic deposits within the lake basins consist of peat and *gyttja*. A mat of peat, which consists of partially decomposed plants—mostly mosses and/or reeds and sedges—generally borders the lakes of Minnesota. Gyttja consists of unoxidized dark brown to black mixed animal and plant remains which accumulate in the central part of some lake basins. The inorganic deposits generally consist of clay- to sand-sized mineral and rock particles and, in some lakes, significant amounts of a light gray substance called marl. In addition to containing large volumes of water, marl is composed mostly of calcium carbonate and lesser quantities of clay, silt, and sand.

The time period for a lake's metamorphosis to a marsh, to a bog, and eventually to a lowland area is dependent on many factors, the most important of which is rate of production of

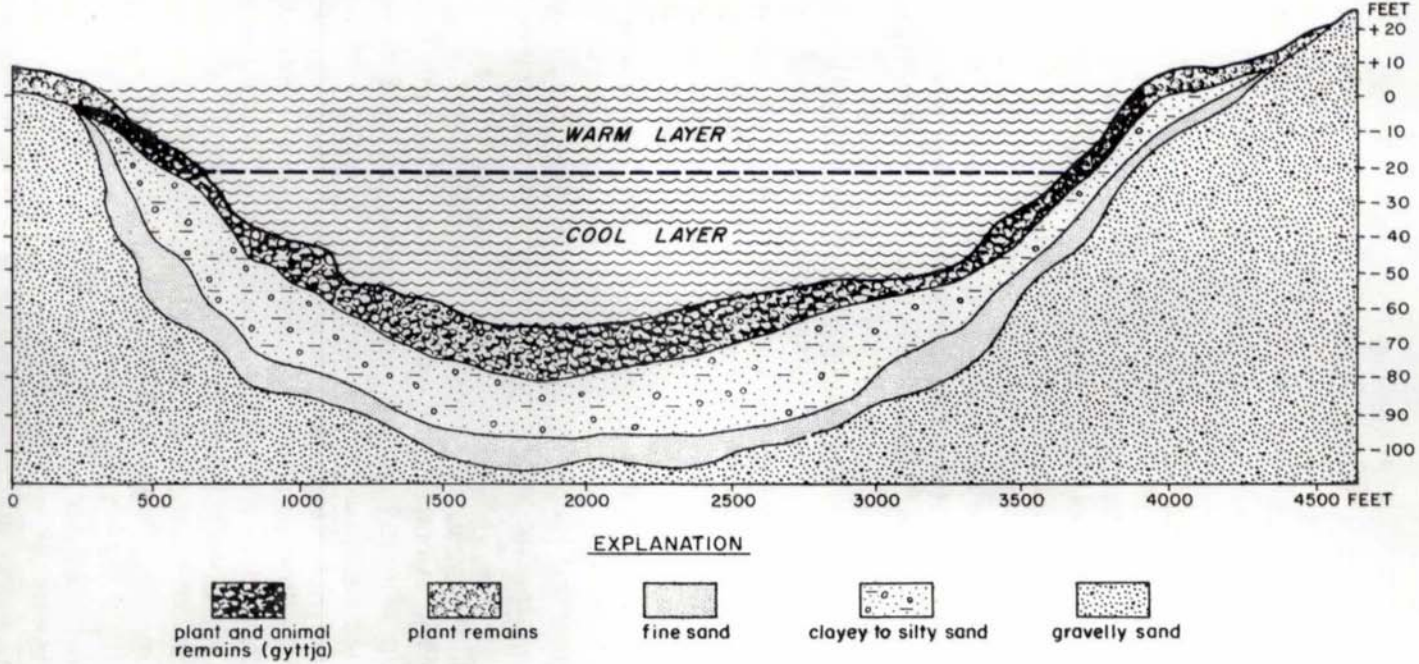


Figure 11 — Geologic section of typical Twin Cities lake.

organic materials. The filling or aging of a lake is greatly accelerated by man-generated pollution.

Probably the most unusual feature of the metropolitan lakes is the several "chains of lakes" in Minneapolis, St. Paul, and the adjoining northern suburbs. Each of the lake basins within the "chains" directly overlies a buried bedrock valley whose partially-filled depression trapped blocks of glacial ice. The subsequent history of these lakes was similar to that described above. The best known of the lake chains is in Golden Valley and Minneapolis and includes from north to south, Sweeney, Twin, Wirth, Birth Pond, Brownie, Cedar, Lake of the Isles, Calhoun, and Harriet lakes. Two prominent "lake chains" occur in St. Paul and its northern suburbs. One "chain" consists of Johanna, Josephine, and McCarron lakes. The other and longest of the Metropolitan Area "chains" includes Snail, Grass, Vadnais, Twin, Savage, Gervais, Kohlman, Keller, Round, and Phalen lakes.

To improve the aesthetic and recreational values of the aging or "dead lakes" in the core cities and suburban communities, many lakes are dredged and in some cases water is added to reestablish and maintain former water levels. In the restoration or development of lakes, the placement and construction of the basin should be guided by adequate knowledge of the water table, natural fill, and the confining materials.

Rivers, Streams, and Creeks

Creeks, streams, and rivers are the pipelines that convey rain and snowmelt to surface water storage reservoirs. Their courses are mostly through valleys, lakes, and other low-lying landscape features left by the glacial ice.

Streams, like the other elements of the water cycle, are constantly adjusting or attempting to reach that illusory state of equilibrium. Their rate of flow, channel form and position, *gradient,* sediment load, and water quality, change with the seasons and even hour by hour. For example, the upstream part of a stream is continually eroding headward, whereas the downstream part—where the gradients are generally lower—is commonly depositing sediment in its channel.

A customary way to pin down these stream networks is to describe their geographic position and map pattern. Streams drain the waters from a limited part of the landscape. When viewing streams from an aircraft, we see that each stream net-

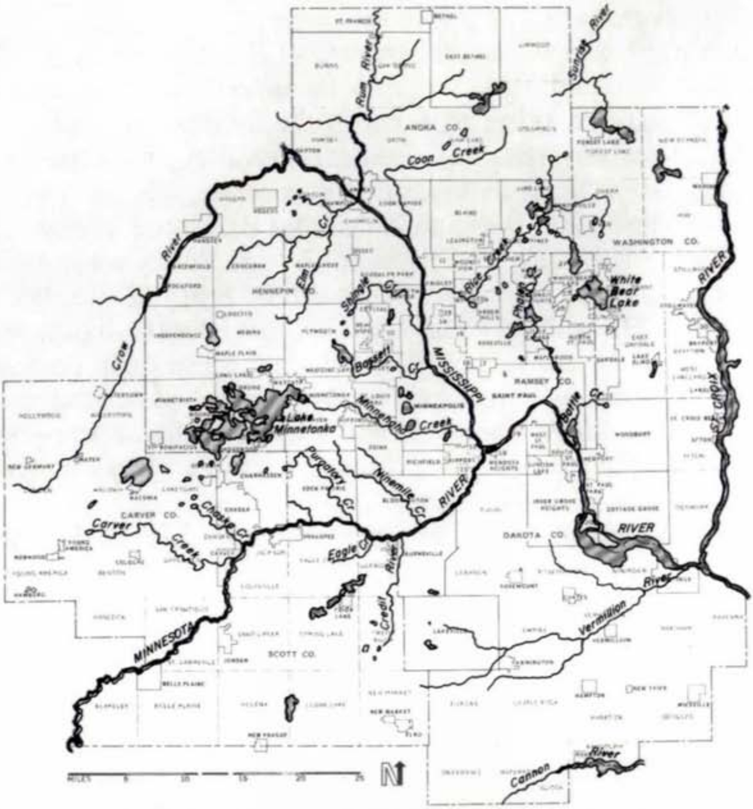


Figure 12 — Stream and lake drainage network, Twin Cities Area.

work is shaped quite similarly to the structural pattern of a deciduous tree—that is, its network consists of a main stem or trunk and several bifurcated branches, limbs, and twigs. An individual dendritic or tree-like drainage network constitutes a *watershed*.

Within the Metropolitan Area the drainage pattern consists of a trunk—the Mississippi River—two main limbs—the Minnesota and the St. Croix Rivers—several branches—Bassett, Battle, Canon, Carver, Chaska, Coon, Credit, Crow, Eagle, Elm, Minnehaha, Ninemile, Phalen, Purgatory, Rice, Riley, Rum, Shingle, Sunrise, and Vermillion Rivers—and hundreds of twigs tributary to each of the limbs and branches. Only the streams that may be categorized as branches or twigs have parts or all of their watersheds within the geographic limits of the Seven Counties. Such streams as the famous Minnehaha Creek, whose falls are described in detail later, can be easily traced from their sources to their confluences with limb and trunk drainages. In contrast to their branches, the main limb and trunk streams drain large watersheds, only small parts of which lie within the Twin Cities Area.

Figure 13 — St. Anthony Falls as drawn by Capt. S. Eastman, U.S. Army, in 1853.

The Mississippi River Valley. The mighty Mississippi, one of the longest rivers in the world, has a very small part of its watershed within the Metropolitan Area. In fact, from its source in Itasca Park in northern Minnesota to the Iowa border, the Upper Mississippi watershed drains about three-quarters of the land surface of Minnesota.

General G. K. Warren, who, about 100 years ago, wrote about the origin and history of St. Anthony Falls, describes very succinctly a part of the Mississippi River valley within parts of Minneapolis and St. Paul: ". . . The valley of the Mississippi below the junction, and the Minnesota above it, is wide and beautiful, and is continuous in direction and of nearly the same breadth, varying from about one to two miles. In marked contrast is the valley of the Mississippi above their junction, it being only about one quarter of a mile wide and nearly at right angles with the other. It is a mere gorge, whose bottom is almost completely filled by the river, and evidently has its origin in the water-fall now at St. Anthony . . ."

To add to General Warren's account, that part of the Mississippi from the "falls" upstream to Dayton is quite different from its "Twin Cities gorge." Above St. Anthony Falls the river has an average width of about 1,000 feet and flows within a channel whose sides and bottom are of sandy glacial materials. The channel must be periodically dredged to maintain a 9-foot channel for river traffic to the Soo Line Bridge, which is about 5 miles above the St. Anthony Falls Upper Lock.

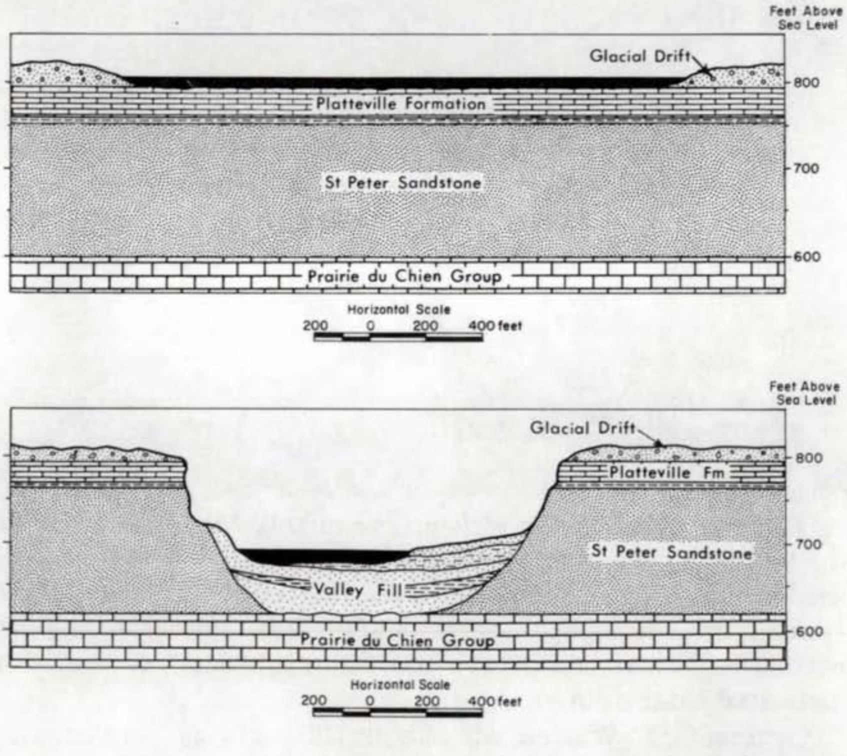


Figure 14 — Contrast of Mississippi River valley above and below St. Anthony Falls.

Downstream from downtown St. Paul to Lake Pepin, the Mississippi River alternately widens and narrows as a consequence of its previous history and the limits imposed by the geologic materials that bound it. River levels on this part of the

Mississippi are maintained by the Hastings Lock and Dam. Near St. Paul Downtown Airport (Holman Field) and Pig's Eye Lake, the valley widens from a normal 2,000 to 3,000 feet to as much as 10,000 feet. This widening of the valley is a result of buried bedrock valleys that underlie that part of the river valley. Downstream from Pig's Eye, the valley again narrows, but at Spring Lake—with Upper and Lower Grey Cloud Islands and their associated inlets—it widens to 5,000 to 7,000 feet. Several springs flow into Spring Lake from the glacial drift exposed in the valley walls.

Lake Pepin is the largest of the "lakes" in the Metropolitan segment of the Mississippi River valley. This lake is about 25 miles long and from 1 to 2½ miles wide. Its bedrock bottom—about 150 feet below the present river level—has been mostly filled by river-carried sediments. Lake Pepin became a natural lake soon after the outlet from famous glacial Lake Agassiz was shifted to the north. During the period of reduced flow, the Chippewa River, which enters the east side of Lake Pepin about two miles upstream from Wabasha, deposited a delta that dammed the local Mississippi River gorge. This delta is now seen as a 4- to 5-mile wide low-lying sandy plain, interrupted by many anastomosing river channels. The high and steep valley walls of Lake Pepin are mostly of Cambrian Jordan Sandstone with cliff faces of Prairie du Chien "limestone." Sandy glacial materials thinly cap the bedrock. The 667-foot level of the lake is maintained by Lock and Dam No. 4, which is situated about 10 miles downstream from Wabasha.

Retreat of St. Anthony Falls. As stated earlier, the shape, depth, and width of river valleys are dependent upon their histories and upon the earth materials in which they were and are now confined. To substantiate the foregoing statement, let me tell one of the most fascinating of geologic "short stories" about the Mississippi River.

In the rather recent geologic past, about 12,000 years ago, the ancestral Minnesota River was the master stream in the Twin Cities area. Its dominance resulted from its being the outlet stream for glacial Lake Agassiz which covered tens of thousands of square miles in northwestern Minnesota, northeastern North Dakota, and adjoining parts of the Canadian provinces of Saskatchewan, Manitoba, and Ontario. Near the eastern limit of what is now downtown St. Paul, the waters of the early Minnesota River cut down through the glacial drift and then flowed upon the uppermost resistant beds of the Platteville Formation. At a position near the present Lafayette Bridge, the stream intersected and eventually eroded a 300-foot deep channel in a drift-filled, buried valley. The river eventually intersected a bedrock wall and developed a waterfall approximately one-fourth mile wide. At the upstream side, the falls cut a concave notch into the very *friable* St. Peter Sandstone, thus eroding and undermining the lower several feet of the overlying Platteville Formation. With time, the "notch" moved progressively upstream as the falls removed the support from the limestone beds at the "lip" of the falls. Evidence of the retreat can even now be seen along the valley walls of the Mississippi River, particularly downstream from the Lexington Avenue (35E) Bridge to the Wabasha Street Bridge. Large tilted slabs of the Platteville are caught within the glacial drift; these slabs were displaced during the retreat of the falls but did not fall into the river valley. This undermining erosive process that literally dug the buried valleys still continues, and can be observed in the Minnehaha Creek waterfall and in the other "hanging" tributaries to the Mississippi River.

Thus, by a continuous process of erosion, the position of the falls has slowly migrated upstream, forming the Mississippi-Minnesota valley and the somewhat narrower "Twin Cities gorge." The rate of retreat was almost directly dependent on the erosive power of the river waters. The bedrock floor of the "Twin Cities gorge" which is eight miles long, decreases in average depth from 260 feet at the "Fort Snelling intersection" to about 100 feet at the Lake Street Bridge and to about 75 feet immediately below St. Anthony Falls. These depths are the result of the combined erosion by St. Anthony Falls and subsequent downcutting into the St. Peter Sandstone by the high flow volume of the ancestral Mississippi River.

Because of the subsequent deposition of river sediments and slump of the bedrock walls, the Twin Cities gorge is only 75 to 150 feet deep. The channel fill reaches a maximum thickness of about 120 feet near Fort Snelling.

How long did it take the falls to migrate from the Lafayette Bridge to the present position?

First of all, *radiocarbon dates* of Lake Agassiz bottom sediments indicate that its southward drainage, via the early Minnesota River, began about 12,000 years ago and ended about 9,200 years ago. Further, we can hypothesize that St. Anthony Falls began when the Mississippi River was left "hanging" as the main falls continued to retreat upstream within the Minnesota River Valley. Concurrently the flow of the ancestral Mississippi had also been increased by the addition of large volumes of glacial meltwater from east-central Minnesota. At that time, the eastern Great Lakes were covered by ice, and consequently drainage was via the Mississippi River system. Thus, the falls retreated from the Lafayette Bridge locality in two stages; the rate of retreat in any one section probably varied considerably. However, in taking into account the overall history, a retreatal rate of about 6.2 feet per year is plausible.

The Minnesota River Valley. Streams carrying meltwater from the retreating glaciers also controlled the pattern and position of the Minnesota River Valley. That part of the valley's history downstream from Fort Snelling has already been described.

The most striking feature of the Minnesota River Valley, from Chaska downstream to Fort Snelling, is its anomalous channel width—200 to 300 feet—as compared to its valley width—5,000 to 20,000 feet. This disparity is a consequence of the migration of the river channel, while it was an outlet stream for Lake Agassiz, down the bedrock shoulders of a very deep bedrock valley. The present 700-foot flood plain was formed soon after Lake Agassiz uncovered a lower outlet now known as the Red River of the North. As a consequence of the lessened flow, sediments accumulated, filling most of the former river channel. Also, its relatively low gradient has caused the river to *meander.* As a consequence of the low gradient, the river has developed two types of lakes: (1) *oxbow* and (2) saucer. Oxbow lakes, the smaller of the two types, occupy meander loops that were abandoned when steeper-gradient channels were opened. The saucer lakes form during floods when sediments are deposited in the form of *natural levees,* which impound the flood waters. For the most part, both types of lakes now are nearly completely filled with organic and inorganic materials. Some of the "lakes" are actually quagmires that during dry periods are too shallow to traverse with a boat but too marshy to safely walk upon.

Despite the relatively low normal flow of the Minnesota River,

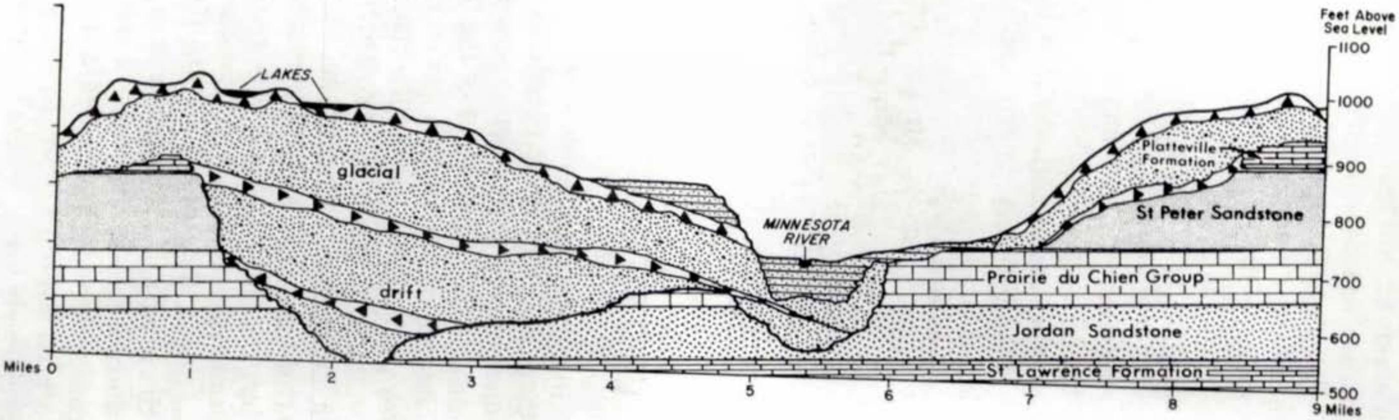


Figure 15 — Geologic section across Minnesota River Valley.

a nine-foot channel is maintained from Fort Snelling to a commercial facility about 3 miles downstream from the Highway 101 bridge in Shakopee. In recent years, facilities related to river transportation—barge terminals and industrial and commercial buildings—have been constructed on the river banks. The total bulk shipments to and from Minnesota River terminals is now second only to the Port of St. Paul, within the Minneapolis-St. Paul district. Also, commercial, industrial, apartments and single family structures have been built within the broad, relatively flat flood plain.

In addition to its use for industrial and commercial enterprises and housing, a part of the flood plain is being developed into a park. Fort Snelling State Park will ultimately occupy the 1- to 1½-mile wide valley from the Minnesota-Mississippi confluence, including Pike Island, to a property line approximately three miles upstream. It will be bounded both legally and topographically by valley walls held up by the resistant Platteville Formation and capped by a thin cover of glacial sands. The park will include several saucer and oxbow lakes, much marshland with developed nature trails and riding trails, wildlife sanctuaries, and several historic sites, including an abandoned sandstone quarry.

The St. Croix River Valley. The scenic St. Croix River Valley is a favorite "playground" of Twin Citians. The watershed of the St. Croix River consists of a main limb—the Namekagon—which flows southwestward from the Wisconsin lakelands, and a major Minnesota limb, the Kettle River, which drains an area of peat bogs and morainal hills southwest of Duluth. The St. Croix River was also an outlet for several large glacial lakes during the latter stages of the "ice age."

I will begin the description of the St. Croix River Valley at Interstate Park, located in Chisago County, about 45 miles north of the core cities.

Turbulent meltwater flow during thousands of years carved the scenic, approximately 1½-mile long St. Croix *Dalles.* At this locality, the glacial and post-glacial rivers have cut down through about 150 feet of material, about 85 to 125 feet of which is Precambrian volcanic rocks consisting mostly of a dark gray basalt. The top of each lava flow can be distinguished by its spongelike character, which resulted from a concentration of gases before the rock's solidification sometime between 1,100 and 900 million years ago. A continuation of similar Precambrian volcanic rocks is found about 3,500 feet beneath the land surface of the Twin Cities!

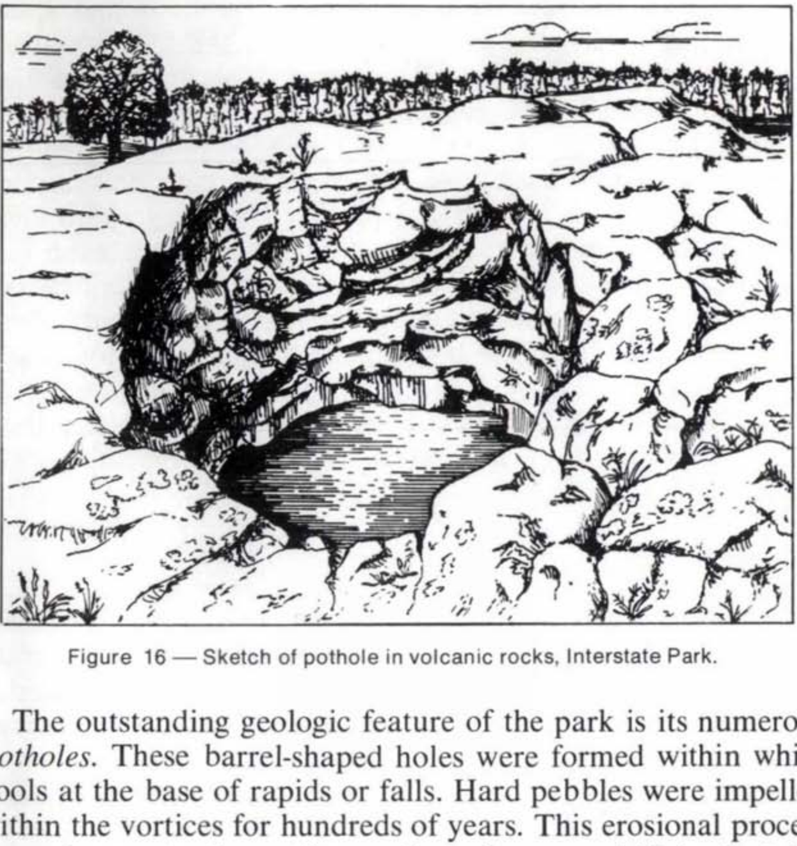


Figure 16 — Sketch of pothole in volcanic rocks, Interstate Park.

The outstanding geologic feature of the park is its numerous *potholes.* These barrel-shaped holes were formed within whirlpools at the base of rapids or falls. Hard pebbles were impelled within the vortices for hundreds of years. This erosional process is analogous to the cutting action of a core drill in that the trapped "rock cutters," impelled at the periphery of the vortex, slowly chipped downward into the basalt. The potholes range in diameter from 1½ to 15 feet and their greatest known depth is 60 feet. The depth and size of each of the potholes depended upon the length of life of its whirlpool, its location with regard to maximum flow, and the hardness of the rock "cutters." In addition to pothole erosion, natural fractures, roughly perpendicular to the surface of the volcanic flows, aided the river in its "digging" of the Dalles.

From the Dalles downstream to Stillwater, the St. Croix River flows within a picturesque 500- to 1,500-foot wide valley bounded by 150- to 300-foot high walls of the relatively soft and easily-eroded sandstones and shales of Keweenawan and early Paleozoic ages. Short and steep intermittent streams have cut V-shaped notches into the valley walls, exposing the bedrock sequence. The bedrock surface is mostly capped by a thin layer of pinkish-tan glacial sands.

The St. Croix changes from a river to a lake in the stretch from Stillwater to its junction with the Mississippi River at Prescott, Wisconsin. Lock and Dam No. 3, located about 5 miles upstream from Red Wing, maintains the 675-foot "pool" level. The south limit of the 2,000-foot to 1-mile wide Lake St. Croix is dammed by a ridge of sandy sediments called Point Douglass. These sediments were deposited by the "main-stem" Mississippi River. "Benches," at elevations about 25, 100, and 200 feet above the present lake surface level, slope very gently downstream and parallel to the shorelines of the St. Croix. These terraces, which are partially eroded, indicate the former position of river channels occupied by the ancestral St. Croix River during its late glacial and early post-glacial history.

Natural Springs

Let us now turn to one of the "connectors" where we can see the direct contribution of groundwater to surface water flow. Groundwater flows out from the glacial and bedrock materials as natural springs at several well-known localities and many other outlets within the Seven Counties. The outlet conduit is generally along a fracture within a layer of consolidated and unconsolidated rock materials that are confined below, and in some cases also above, by impervious materials.

The most famous of the springs, Glenwood-Inglewood, was located just south of Theodore Wirth Park in Minneapolis, within the valley of Basset Creek. Other historic springs are the Highland Springs, near the southwestern corner of Randolph Avenue and Lexington Parkway in St. Paul, and Boiling Springs, about 3 miles southwest of Savage in the Minnesota River Valley. Because of pollution from the land surface, the waters of Highland Springs now are drained directly into a storm sewer. Numerous other springs carry groundwater to the walls of the three major river valleys and lesser quantities to their tributaries. Sandstone caves, most notably Fountain and Carvers in St. Paul, had natural springs that were used by the aborigines, explorers, and early settlers of the Metropolitan Area.

With modern techniques in engineering and the health sciences, water can now be transported for considerable distances to points of use. Today, springs are used as a source of valuable data on the location and quality of the groundwater resources and much less as sources of high-purity water.

Groundwater

Next we will examine the underground or groundwater part of the water cycle. About 60 percent of our present Metropolitan water supply is from groundwater aquifers—natural reservoirs that yield water to wells. In addition to its abundance, groundwater generally is of better quality than surface water. To a certain extent, we have a choice of *water quality* in that different combinations of water quality, such as temperature, hardness, and iron content, can be obtained from each of the Twin Cities' aquifers. The economic cost of drilling and completing the wells and pumping the water, of course, limits the choices.

Groundwater in the Twin Cities Area is much cooler than surface water because it attempts to equilibrate to the temperature of the rock materials in which it is contained. The rock temperatures in turn reflect the approximate mean annual ground-surface temperature. In the Metropolitan Area, groundwater temperatures range from about 50 to 55° Fahrenheit in the upper 100 to 450 feet. Below that level, water temperatures follow the normal thermal gradient of the earth's crust, and increase about 1 ° F. for each 100 feet of depth.

To reach the storage reservoirs, precipitation percolates downward through the thin soil layer into the unconsolidated glacial drift and/or bedrock to the water table. The water table is the upper undulating plane-like surface of the *saturated zone.* In the saturated zone, the pores of the earth materials are completely filled with water. The lower limit of the saturated zone can be several thousands of feet below the earth's surface, within a high pressure environment where there are few or no open pores for fluid storage.

In the Twin Cities, groundwater is temporarily stored within both the near-surface "blanket" of unconsolidated glacial materials and in the upper 1,000 feet of the sedimentary bedrock.

Groundwater fills all the available openings below the water table. However only certain *aquifers* within the drift or bedrock sequence yield satisfactory amounts of water to wells. The confining layers or *aquitards* contain abundant quantities of clay- and silt-sized materials. Although they may contain a considerable volume of water, little water flows through these layers because they lack interpore connections or *permeability*.

Glacial Drift Aquifers

Within the Metropolitan Area, the glacial drift ranges in thickness from 5 to 500 feet. The drift consists dominantly of sands with lesser amounts of intermixed clay, silt, pebbles, cobbles, and boulders. The various types of glacial deposits are generally layered, and each layer varies in thickness and extent and in the nature and arrangement of its constituent materials. The water-yielding reservoirs or aquifers of the glacial drift are sand units that vary widely in shape and size. Much of the water for single-family housing units on the outer ring of suburbs is withdrawn from shallow glacial drift wells, that is, wells generally less than 125 feet deep.

Probably the most important and essentially untapped glacial aquifers are those confined within the deeply buried bedrock valleys. Preliminary data indicate that high-volume groundwater flows are available from the porous glacial drift within the several bedrock valleys.

Bedrock Aquifers

Three major and three minor aquifers occur within the bedrock of the Twin Cities Basin. The principal bedrock aquifer is the approximately 200-foot thick Prairie du Chien-Jordan. The lower part, or Jordan Sandstone, is a 90-foot thick, even-grained sandstone. The upper part, the Prairie du Chien Group, which is composed dominantly of "limestone," yields the aquifer's highest flow volumes. The Prairie du Chien-Jordan aquifer is confined by the Decorah Shale above and the St. Lawrence Formation below.

The second most important and deepest aquifer of the basin is the Mt. Simon-Hinckley. It yields a softer and generally higher-quality water from the sandstone beds than does the Prairie du Chien-Jordan. It is bounded above and below by shaly sandstone aquitards.

The third major aquifer, the St. Peter Sandstone, lies below the Glenwood Formation. This aquifer is partly exposed in the valley walls of the major river valleys, and lies at shallow depths below the Twin Cities. Because of its near-surface position, water from the aquifer is locally unsafe for human ingestion.

The three minor sandstone aquifers of the Twin Cities Basin, from top to bottom are, the Decorah-Platteville, the Reno Member of the Franconia Formation, and the Ironton and Galesville formations. All three yield low to moderate quantities of water to wells and are of medium to high water quality.

Metropolitan Water Supply

Most of our Metropolitan Area water reserves are within the groundwater aquifers; however, nearly all the water supply of the core cities is withdrawn from rivers and lakes. The total water supply of Minneapolis and most of the water for St. Paul is taken from the Mississippi River at Fridley. St. Paul supplements the Mississippi River source with water stored within the Centerville chain of lakes. Parts or all of the suburban communities purchase water from their nearest core city. All other municipal systems use groundwater, the overwhelming majority of which is pumped from the deep bedrock aquifers. The remainder of the Twin Cities water supply is pumped from private glacial drift wells; minor quantities of water are pumped from private bedrock wells.

Conclusions

Man has altered, to a considerable extent, the surface drainage and the *recharge* to the groundwater aquifers in the Seven Counties. He has done this by the construction of thousands of acres of buildings, streets, parking lots, and by the building of water-control structures. In so doing, he has created an imbalance in the formerly well-balanced surface drainage system and has altered the "plumbing" of the recharge to the groundwater aquifers. He also adds his wastes, sometimes as raw sewage, to the stream and lake network. It is no wonder that there is a deterioration in the quality of the surface waters.

Soluble and insoluble wastes have also polluted parts of the drift and bedrock aquifers. Dire predictions have been made about the deterioration of our groundwater reserves; however, no thorough analysis of the system has been carried out. Because all the elements of the water cycle are interrelated, both ground and surface waters must be considered. Until we adequately determine the parameters of the local water cycle, we cannot manage this abundant resource wisely.

MINERAL RESOURCES

To know where to search for mineral resources we must know how and where concentrations have formed and what has happened to them since they formed. Information from mineral extraction operations and geologic and engineering studies indicate that the Twin Cities Metropolitan Area has had favorable environments for the concentration of the common industrial minerals of sand, gravel, limestone, clay, peat, and marl.

For our discussion, the industrial mineral resources are divided arbitrarily into the construction materials and other industrial mineral commodities. The abundant construction materials may be grouped into three categories—aggregate and dimension stone, sand, and clay.

Construction Materials

Aggregate and Dimension Stone

Aggregates include rock materials that are comparatively strong and low in dollar-value and that are used in construction projects to add strength, take up space, and cut material costs. Aggregates are customarily subdivided into two groups, "natural" and "crushed stone" aggregates.

The Metropolitan Area has an abundance of natural aggregates, better known as sand and gravel. The sand and gravel bodies are directly related to glacial and post-glacial events in the region. They can be found, therefore, by using geologic clues present at the land surface to reconstruct the favorable geologic environments of the recent past. Alluvial fans of glacial meltwater streams and post-glacial river *terraces* are the most favorable sites for concentration of natural aggregates. Most of the gravel-rich bodies occur at localities where meltwater streams flowed from the ice sheets during the various *stillstands* of the glaciers. The size and shape of the natural aggregate bodies is related to the duration of flow; the particle size is directly dependent upon the viscosity and velocity of the particular meltwater stream. The river terrace gravelly sands consist of the materials of former primary deposits that have been carried and redeposited by late glacial and post-glacial rivers.

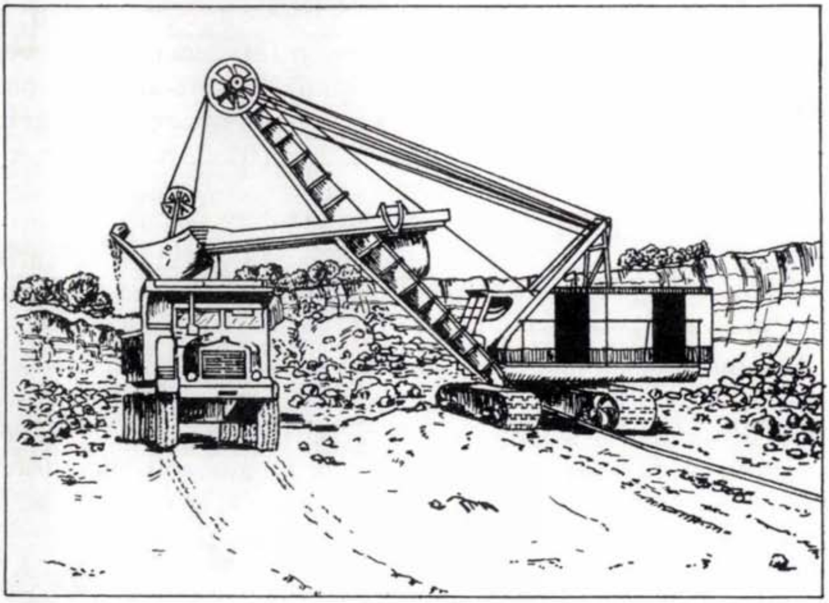


Figure 17 — Sketch of operations at a Twin Cities rock quarry.

The quality of crushed stone, the second category of aggregates, varies with the physical properties of the particular bedrock unit. The Twin Cities quarries are located within the confines of the major river valleys where the glacial drift has been mostly removed. All the crushed rock aggregates produced within the Seven Counties are from the Prairie du Chien Group because of its availability and its good physical and chemical properties. The stone is crushed to the desired sizes in plants in or near the quarries.

Most of the natural and crushed aggregate is used in the construction of highways and other engineering projects. Lesser amounts are used for other building purposes. About 90 percent, by weight, of the bituminous concrete for surface coatings of streets and highways, about 90 percent by weight of concrete construction blocks, and about 75 percent by weight of construction concrete consists of aggregate. Approximately 400 to 600 tons of aggregate are used in the paving of each block of residential street. Commonly, 50 to 100 tons of aggregates are consumed in the construction of an average-sized house.

Natural and crushed-rock aggregates are characterized by a high bulk and a low intrinsic value. Therefore, they are transportation-sensitive. In fact, most of the cost of the aggregates to the customer in urban areas results from transportation charges. Short-sighted land use restrictions have closed many gravel pits and eliminated the use of known aggregate reserves within the middle and outer suburbs. As a result, more and more of the aggregate needs are met by crushed rock. Because of the greater consumption of the more costly crushed rock and/or greater transportation distances from more distant natural aggregate deposits, overall aggregate costs to the consumer will continue to rise. To alleviate this problem, strong guidelines should be spelled out for the Metropolitan Area for the sequential use of the pits and quarries from primary extraction through the restoration phases.

Dimension stone, another category of construction materials,

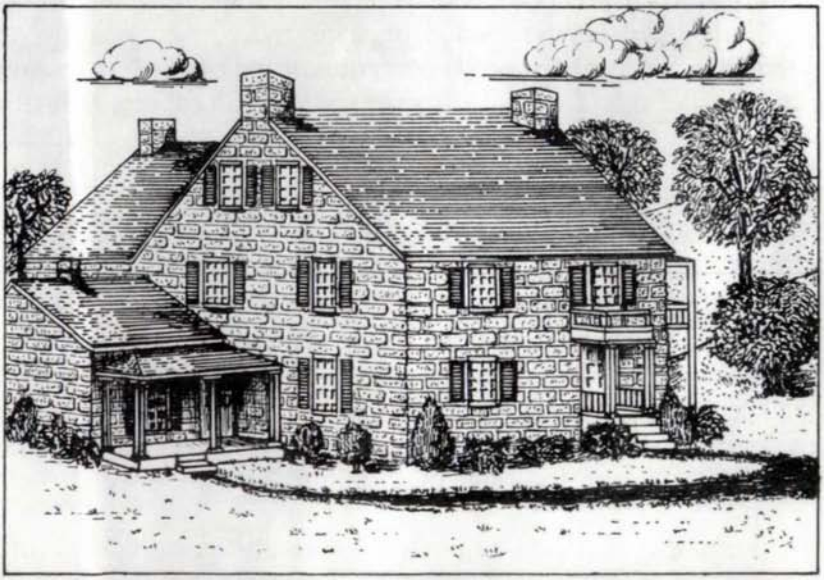


Figure 18 — Sketch of Sibley House in Mendota.

is quarried in blocks suitable for facings, foundations, trim for buildings, and other construction uses. Early building and basement walls, such as those of the famous Sibley House in Mendota, many early churches, flour mills, railroad bridges, and other "dry wall" constructions were of blocks from the Platteville Formation. However, this limestone unit has proved unsatisfactory for retaining walls, sidewalks, or steps because it splits into thin laminae and gradually is reduced to rubble. This disintegration occurs when the rock is subjected to the cyclic freezing and thawing of water. There has been no significant use of the more resistant Prairie du Chien Group within the Metropolitan Area except as large blocks to protect river-bank facilities.

Sand

The very light tan to white quartz sand mined from exposures of the Jordan and St. Peter Sandstones is used for construction sand, oil-reservoir fracturing sand, engine sand, foundry sand, glass sand, and abrasive particles for sand blasting. The sand grains have been recycled many times during millions of years of geologic time. By cycle I mean the process whereby a sand grain incorporated into a rock is freed by erosion, is redeposited, and eventually is reincorporated into a younger sedimentary rock. In this process only the most resistant minerals (quartz) remain. In contrast with the recycled sandstone, the glacial sands may only have been recycled once or twice. Accordingly, the glacial sands have a 10 or 20 percent content of the less resistant minerals and therefore are less suitable for high-quality industrial uses.

Clay

When we mention *clay,* most people think of the common molding clay—a product composed mostly of clay minerals with an oil added to keep the material plastic. Actually clay means two things: (1) clay-sized particles, that is, particles less than 0.00004 of an inch in diameter, and (2) clay minerals. Clay-sized particles can be composed of a wide variety of minerals that have a variety of shapes. In contrast, most clay minerals have a platy or *mica*-like form, and their mineral particles are mostly of clay size.

Common items such as bricks, sewer-tile, pottery, and other ceramic products are made mostly from certain types or mixtures of types of clay minerals. Water is added to the clays to develop plasticity, and the material is shaped, dried, and fired in a kiln to produce the desired ceramic product.

A modern-day use of clay-rich materials is in the production of light-weight aggregate, which is used in concrete structural units to reduce bearing loads. The clayey materials are heated to about 2,200° Fahrenheit in a kiln, until they become viscous. The vesicles formed by the entrapped gases cause the development of a porous, clinker-like aggregate.

The clay resources of the Twin Cities are of two types; the ancient sea muds that now comprise the shales of the Decorah Formation, and certain glacial materials. Bricks are made from the Decorah Shale, which is quarried in Mendota Heights. Impure glacial clay- and silt-rich sands, from a pit in Plymouth, are bloated to produce light-weight aggregate.

Other Industrial Mineral Commodities

Peaty Materials

Peat is partly decomposed and disintegrated plant matter derived mostly from mosses, reeds, and sedges. Gyttja—non-decomposed mixed plant and organic materials—normally underlies the near-surface peat deposits within "dead lakes" or "peat" bogs. Such bogs are most abundant in central and northern Anoka County, especially in a 50 square mile area in the northeastern part, where the peaty materials average 7 to 9 feet in thickness and are as much as 40 feet thick. Peat- and gyttja-rich sequences have nearly completely filled the shallow lake basins of the Minnesota River flood plain. Similar organic-rich fill underlies many low-lying areas within the Metropolitan Area. The primary use of the peaty materials is in improving soil structure and for "black dirt."

Marl

Accumulations of marl, of very limited economic potential, occur in the beds of some of the lakes in the northwestern part of the Seven Counties. Marl is composed dominantly of calcium carbonate ("lime"), with variable quantities of clay, silt, sand, and large quantities of interstitial water. Although there is no current economic use, the marls have been used in the past as soil sweeteners.

Soil

In the north-central United States the soil cover has developed since the last of the glacial ice lobes melted. The verdant green cover of grasses, shrubs, and trees that now grows within the soil of the Metropolitan Area hides what would otherwise be a rather drab tan, hummocky, glacial terrane.

For this booklet, soil is considered to be an intimate mixture of organic and inorganic materials that has developed at the land surface. The thickness and types of soil vary according to parent materials, biologic history, slope, and other past and present environmental conditions. For example, a poorly-drained, thick, organic-rich soil develops marginal to a bog. In contrast, a well-drained, very thin, low-organic-content soil develops at the crest of a sand dune.

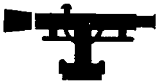
In 1964, crops valued at about $72 million were produced from soil of the Metropolitan Area peripheral to the urban fringe.

Man's use of the upper parts of the glacial drift, commonly called "soils," as a foundation for his engineering works is described in the next part of the booklet.

OTHER IMPORTANT GEOLOGIC ENVIRONMENTS

As stated previously, it is difficult for a casual observer to delineate the many important geologic controls and restraints. Also, some of the environments that are well known have complex and economically important implications on man's use of the landscape.

Engineering Geology



Construction activities are strongly affected by geologic controls and restraints. Unfortunately the hazards—losses incurred by the collapse of a building, a tunnel cave-in, or a landslide that resulted in a loss of lives as well as considerable property damage—associated with this phase of engineering practice are publicized the most.

Foundation Conditions

Large areas in the Seven Counties have fair to good sites for constructing buildings. However, siting conditions vary widely from place to place, and can change rapidly over very short distances. Inasmuch as the foundation conditions are directly dependent upon the underlying earth materials—the glacial drift and/or the bedrock—the design of any project should include, as a budget item, the cost of obtaining adequate knowledge of these materials.

The foundation conditions within the glacial drift vary with respect to the nature, thickness, and geographic extent of the several types of deposits. In addition to knowing these factors, the relief of the land surface, and the ground and surface waters must also be considered in planning construction of buildings and other structures.

The large areas of outwash plains in the Metropolitan Area provide good building sites; however, even low-load bearing foundations have failed within the more troublesome morainal hill terrane. In this terrane, groundwater can lubricate the clay-rich materials and cause soil creep on steep slopes. Small displacements have occurred in such sites, and structures have sustained major damage.

Perhaps the most common foundation problem in the Twin Cities Area is caused by peaty materials. Although most commonly found in former lake basins, peaty materials also occur within less easily-recognized, partially filled, glacial stream channels. In areas known to contain peat, a network of wooden or steel piles generally is driven into the peaty sequence to support the foundations. However, there is no assurance of the long-term maintenance of foundation levels, because one or several of the piles may sink relative to the others. One reason for such differential settling may be man's disturbance of water table levels. When an area of peaty materials is drained, the release of interstitial water eventually causes the local land and the structures founded in them to sink differentially. But on the other hand, when water is added to the peaty materials, there can be a relative rising of the local land surface with attendant problems such as basement leakage and foundation "floating."

Two other foundation problems occur within certain parts of the Metropolitan Area—subsidence and high water table levels. *Sink holes* or subsidence areas overlie small caves developed adjacent to the walls of the Mississippi River along West River Road at 36th, 43rd, and 44th streets in Minneapolis. However the overall subsidence problem is not great in the Seven Counties, because of the thick glacial drift cover and relatively thin section

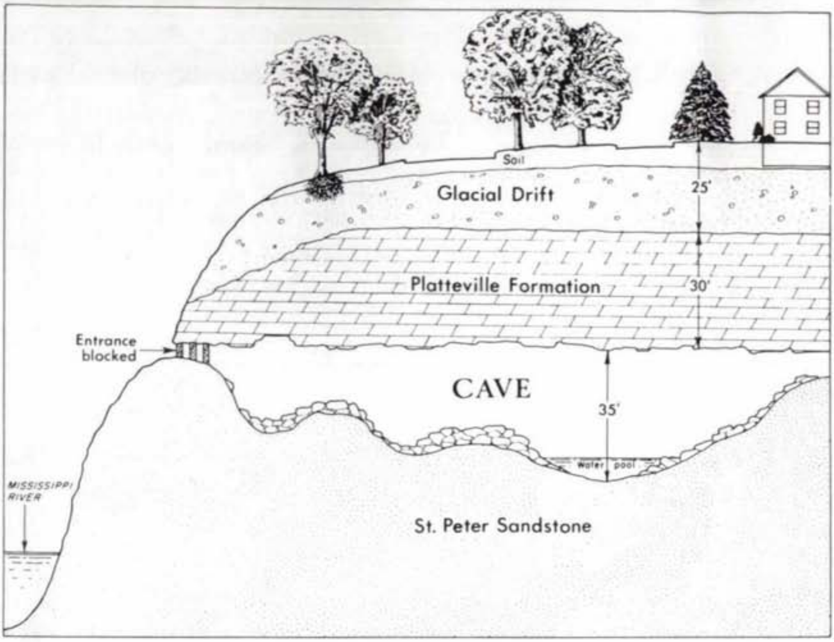


Figure 19 — Geologic section through a typical Twin Cities sandstone cave.

of soluble "limestone." In contrast, the problems caused by high water table levels can be acute. As stated previously, changes in water table levels in peaty areas cause problems in the maintenance of foundation levels. Also, a considerable amount of foundation damage can be caused by the flow of groundwater streams, particularly if they are under hydrostatic head.

High-load bearing structures for buildings in downtown districts and other engineering works such as bridges are generally founded on bedrock. Within the downtown business districts, most of the buildings have substructures anchored in either the Platteville or the St. Peter, both of which can provide good foundation support. Funds are normally budgeted for investigations of the foundation conditions in the high-load bearing structures to insure against possible large financial losses.

Significant engineering structures have been built within the sandstone walls of the Mississippi River gorge within the core cities. In St. Paul, several buildings have their foundations in the nearly vertical walls of St. Peter Sandstone. The 65- to 85-foot high and 300-foot long retaining wall adjacent to the Lock and Dam No. 1—just below Ford Bridge—prevents the slumping of the sandstone valley wall. The upper and lower locks at St. Anthony Falls are secured within the St. Peter Sandstone; parts are within the Platteville Formation.

Tunnels

Good tunneling conditions occur below the downtown areas of the Twin Cities. The friable St. Peter Sandstone provides easy excavation and the overlying, resistant Platteville Formation provides the necessary structural support. About 40 miles of tunnel openings have been driven beneath the core cities for use as storm and sanitary sewers and to house utility cables and pipes. The tunnels range in diameter from about 8 to 14 feet. Where tunnels have intersected buried, drift-filled bedrock valleys or have encountered broken zones, some difficulties have been encountered in tunnel construction. Both these problems can result in flooding and roof falls.

Figure 20 — Sketch of a tunnel in St. Peter Sandstone.

The generally favorable tunneling conditions in the Metropolitan Area provide economically feasible possibilities for subsurface developments such as transportation, housing, communication systems, parking facilities, commercial centers, and underground storage. The geologic sequence beneath the core cities also is favorable for an advanced design concept modelled somewhat after that of Montreal, Canada: that is, a two-level use of the earth's materials—a lower underground "weatherproof" system, and an above ground "weather harmonized" system.

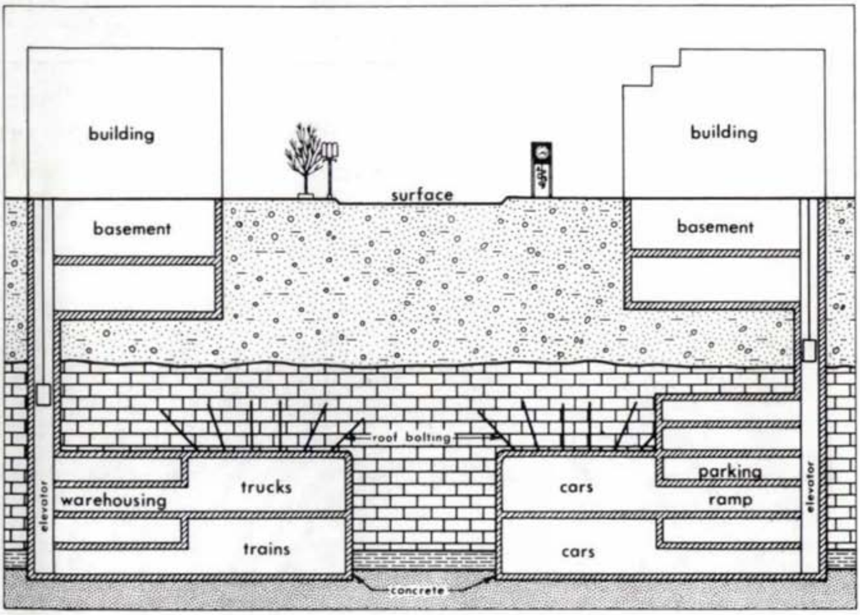


Figure 21 — Vertical section through a "downtown" of Twin Cities.

Geologic Hazards

Geologic hazards, classified as natural and man-caused, are not a major problem in the Twin Cities Area, but can cause rapid and destructive damage to man-made structures. Natural hazards include floods, some landslides or slope failures, and nearly all earthquakes. Man-caused hazards are generally confined to slope failures and displacement or fracturing of the ground surface in filled sites. Natural hazards as well as man-caused hazards can be prevented or at least ameliorated.

Landslides. Probably the most susceptible sites for landslides within the Twin Cities Metropolitan Area are along the relatively steep north valley wall of the Minnesota River. The wall is com-

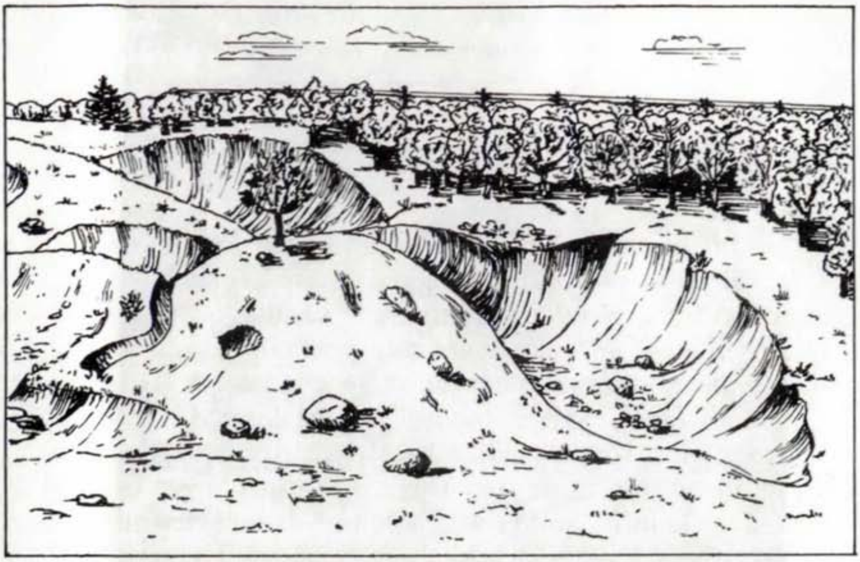


Figure 22 — Sketch of an area of landslides near Chaska.

posed of unstable, unconsolidated sands with some interlayered "sliding" planes composed of layers of clay- and silt-rich materials. The slope failures that have occurred to date have caused little damage. However, as the sandy valley banks continue to be modified by man's activities, landslides will become more common and will probably cause more damage.

Floods. Flooding of man-made structures along the Minnesota and Mississippi rivers is in part a natural and in part a man-caused physical hazard. Damage by spring floods occurs because the flood plain—the area of the river channel during high volume flow—is used for industrial buildings, houses, engineering works, and even an airport. Flood damage within the Metropolitan Area has been alleviated by constructing levees and dikes; however, even with continued building of flood control structures, flood damages will continue to rise because of the increasing development on the flood plain.

Earthquakes. Although Minnesota lies well within the stable part of North America, it has experienced nine confirmed low intensity earthquakes in the past 100 years. Six earthquakes were centered within the State. The *epicenters*—locations in the Earth's crust directly above where the rocks broke—were within an area ranging from 50 to 150 miles northwest of the Twin Cities. However the low-intensity tremors have caused only minimal damage in outstate areas, such as cracking of floors and plastered walls and the shaking loose of bricks from chimneys.

Waste Disposal

One of the major problems besetting all metropolitan areas is the disposal of solid and liquid wastes. The interaction of wastes with the physical environment results in the pollution of streams, lakes, and air. Currently, sanitary landfills are considered the most economical and satisfactory method of disposing of solid wastes. A sanitary landfill may be defined as a depression or trench into which solid wastes are disposed. Sites must be above the water table and surface streams must be directed around the landfill. Solid waste is densely compacted and covered each day by at least 6 inches of unconsolidated materials.

Only two of the 60 landfills now (1970) operating within the Metropolitan Area may be classified as sanitary landfills. Disposal of solid wastes is currently accomplished by filling low topographic areas. Landfills such as Pig's Eye in St. Paul, and others in the Minnesota River Valley, are situated on river flood plains. Most of the others, in the uplands, are bottomed within various types of glacial drift.

Geologic data are necessary to determine the long-term effects on our environment from the dumping of trash, rubbish, putrescible refuse, and other discarded materials on or into earth materials. Because landfills not only receive solid but also liquid wastes, such as noxious chemicals, the receiving pit should not be below the water table and should have little or no exchange with the surface waters or groundwaters. Clay- and silt-rich glacial deposits and bedrock shales are the best local materials for near-surface waste disposal because of their low permeability.

In other parts of the United States, especially in the oil-producing states, liquids and gases are disposed of or stored in subsurface strata. Liquid wastes, like solid wastes, have a wide variety of concentrations and potentially harmful environmental effects. To safely dispose liquid wastes into the bedrock of the Twin Cities Basin, we must have a thorough assessment of the groundwater circulation system and its interaction with the geologic framework.

RECREATIONAL AND AESTHETIC RESOURCES

As urban sprawl engulfs more and more of the land area within the Seven Counties, greater and greater amounts of the natural environment are radically changed, and as a consequence, increasingly less open space is available for recreation and enjoyment of nature. Scholars who study human psychology tell us that one of the basic human needs—to identify and commune with the natural environment—is starved in heavily populated areas. The beauty of a waterfall, the open expanse of a rippling lake, and the coolness and silence of a subterranean cave are some of the available geologic recreational and aesthetic sites within the Twin Cities Metropolitan Area.

Minnehaha Falls

Minnehaha Park, the Twin Cities' best known park, whose falls (see front cover) have been made famous by Henry Wadsworth Longfellow in his "Song of Hiawatha"—

> "Where the Falls of Minnehaha
> Flash and gleam among the oak-trees,
> Laugh and leap into the valley."

is but one of the sites for recreational and aesthetic enjoyment.

In addition to its falls, Minnehaha Creek creates a streamside recreational environment as it descends some 230 feet in the 20 miles from Lake Minnetonka to the Mississippi River. From its source—the overflow from a timber spillway at Gray's Bay—it forms a canoeable stream that twists and turns through a marshy lowland within the hummocky morainal hills of Minnetonka, Hopkins, and St. Louis Park. During its flow through Edina and Minneapolis, the creek has developed a flood plain and continues to cut its meandering channel into the sands of the Minneapolis-St. Paul outwash plain. Astraddle its flood plain, in Minneapolis, is a sinewy "parkway system" with green-ways and many stone-arched bridges. In its eastern part, Minnehaha Creek serves as an overflow outlet for Lakes Harriet and Nokomis and intermixes with the waters of Lake Hiawatha. Upon leaving Lake Hiawatha, it meanders through southeastern Minneapolis for about a mile before entering Minnehaha Park, pauses briefly in the Longfellow Gardens pool, and then plunges over the falls into the "lower glen."

Minnehaha Falls, similar to its other hanging valley sisters along the Twin Cities gorge, has had a history analogous to that previously described for St. Anthony Falls. Its history differs somewhat in that most of its present valley was formed by a split flow of the Mississippi River during the interval from 2,000 to 5,000 years ago. At that time, the Mississippi flowed in two channels on either side of the highland area that is now the site of the Minnesota Veteran's Home. The greater volume of flow in the eastern channel caused its more rapid lowering, and eventually it captured the flow from the western channel.

Minnehaha Creek was left hanging a few hundred years prior to abandonment of the west channel, when the "west channel

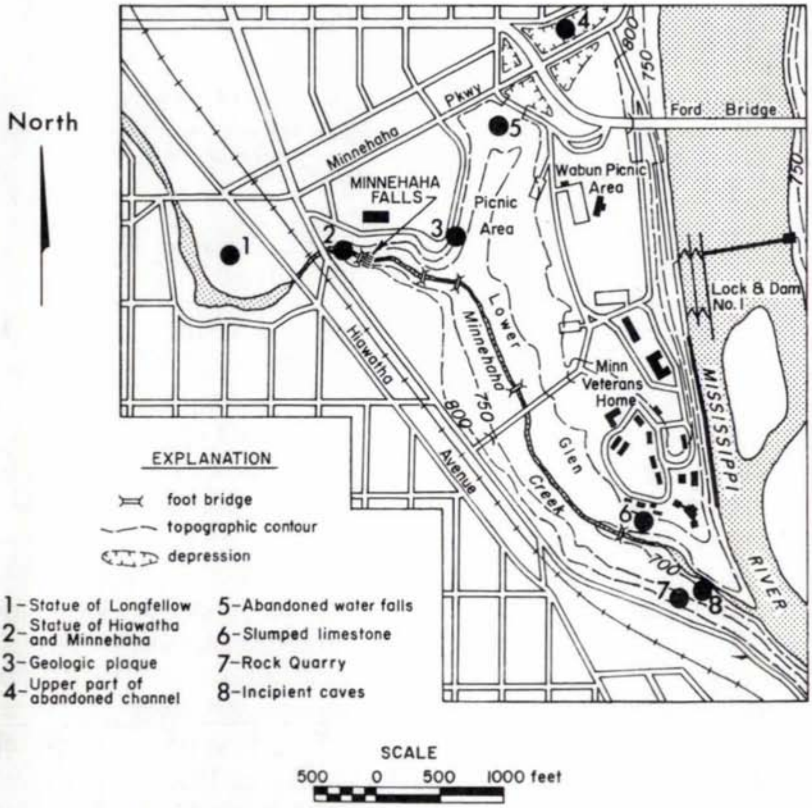


Figure 23 — Map of Minnehaha Park and vicinity (modified from U.S. Geological Survey St. Paul West Quadrangle).

falls" retreated beyond its entrance. Then Minnehaha Falls began to retreat upstream, but at a much slower rate than had the west channel falls because of its much smaller flow volume.

The bends in the narrow "Minnehaha gorge," which extends about 300 feet upstream from the abandoned "west channel," developed during the retreat of Minnehaha Falls. The stream course is a legacy of vertical, northeasterly- and northwesterly-trending rock breaks that controlled the stream channel as it eroded through the resistant beds of the Platteville Formation. The channel maintains the same "pattern" as the creek continues to erode down into the soft underlying St. Peter Sandstone.

When the pirating of the west channel occurred, Minnehaha Creek flowed as an anomalously small stream within a part of the wide west channel gorge. Because of the lessened stream flow, glacial materials, sand from the St. Peter Sandstone, and slabs of Platteville "limestone" slumped into the gorge. During the last few thousand years, Minnehaha Creek has managed to cut down through some of the "fill" and now flows upon the floor of the 65- to 125-foot deep, and 300- to 500-foot wide gorge. This part of Minnehaha's stream bed is nearly flat—slopes are about 50 feet in ¾ of a mile or about 0.6 of a degree toward the Mississippi River. As a consequence of the low gradient, Minnehaha Creek decelerates rapidly after entering the west channel gorge and meanders upon a sandy flood plain.

The slow, almost imperceptible erosion that has caused the retreat of the falls still continues. The present form of the rock layers supporting the falls is that of a concave amphitheater in plan view, and is that of a cantilever-shaped overhang in vertical section. Stream channel erosion loosens and removes the limestone slabs at the Platteville's upper surface. Retreat of the lower concave notch is by: (1) erosion of the underlying sandstone; and (2) the prying apart of the rock blocks within the natural separations and fractures by alternating cycles of freezing and thawing of the falls' mist. These two erosive processes combine to progressively remove support from the Platteville beds at the falls' lip, causing the loosened blocks to drop into the plunge pool.

Today, Minnehaha Falls normally fills only about ⅛ of the 150-foot wide amphitheater and the creek waters fall about 50 feet onto a jumbled pavement of broken Platteville "limestone" slabs that partially cover the St. Peter Sandstone.

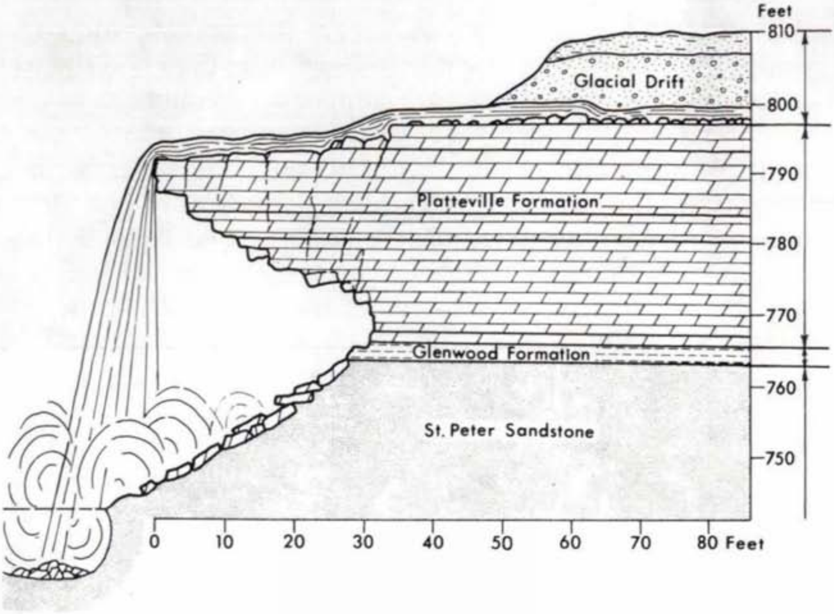


Figure 24 — Geologic section through Minnehaha Falls.

In the last one hundred years, urbanization of the Minnehaha Creek watershed has probably slowed the retreat of Minnehaha Falls. The lessened stream flow, except during the spring season, has been caused by surface water diversions and reduction of normal runoff by evaporation from the thousands of acres of roofs, sidewalks, roads, and other works of man.

When you visit Minnehaha Falls and its environs, many of the interesting physical features of its geologic history can be easily found and observed. The stream channel just above the falls is lined with large boulders of granite and basalt that were carried there by the several ice age glaciers; the statue of Minnehaha and Hiawatha is on an island of these boulders. Also, a part of the rock wall in the falls vicinity is built of the glacially transported boulders. The exposed stream banks above creek levels are composed mostly of clay- and silt-rich sandy glacial drift.

More rocks and rock materials can be seen in the lower glen. At the northwestern corner of the picnic and playground area—at the head of the west channel gorge—is a "dry" version of Minnehaha Falls. The several beds of the Platteville and their individual rock type and resistance to erosion can be observed. The Platteville beds are also exposed in a 10- to 15-foot high rock face of an abandoned quarry located at the top of the southeastern stairway. A few of the lower "limestone" beds were quarried by the Minneapolis Park Board for use in bridges and for fences, retaining walls, and other construction.

Figure 25 — Sketch of north wall of lower glen.

In the upper two-thirds of the lower glen the pathways are on tan, silty glacial sand containing a few pebbles and some boulders; pathways in the part near the Minnehaha Creek-Mississippi River confluence are on light tan to white sand that has fallen from the sandstone valley walls. On the valley slopes are numerous slumped, slabby blocks of the Platteville Formation. The several springs that issue intermittently from the valley walls are the direct flow from the groundwater aquifers. Near the eastern limit of the park, and in the sandstone wall on the south side of the creek, are several interesting, closely spaced, half-moon shaped cavities. These cavities are probably incipient caves. However, groundwater flow, which normally developed these cavities, was not sufficiently strong for a sufficiently long period of time to develop any large man-sized caves.

Sand Dunes

It is perhaps hard to believe that our present northern continental climate could give rise to sand dunes. Nevertheless, conditions were right in early post-glacial time, before vegetative cover was reestablished, to form a significant number of dunes in three geographic areas within the Seven Counties. The major areas of sand dune accumulation are near Anoka and near Shakopee. Small areas of low-relief dunes occur in Bloomington.

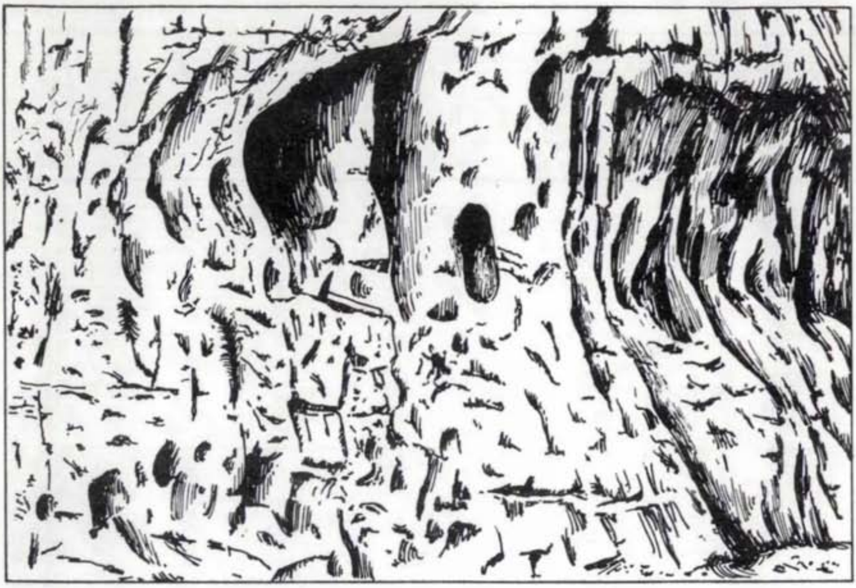


Figure 26 — Sketch of incipient sandstone cave.

The Anoka sand plain has several areas of abundant dunes, which comprise about 6 percent of the total of 350 square miles underlain by outwash plain and lake deposits. The sands were deposited originally by glacial meltwater streams and formed a very broad, gently sloping outwash plain. Some sands were redistributed by late glacial and post-glacial rivers and lakes. The dune materials are sand, dominantly 0.02 to 0.004 inches in diameter, and commonly contain irregularly distributed lens-shaped bodies of silt. In local areas, sands rich in pebble- to cobble-sized particles are mined for natural aggregate.

The largest dune field in the Anoka sand plain is located within parts of the communities of Blaine and Coon Rapids. In this field, the dunes lie between elevations of 900 and 930 feet above sea level, reach 20 feet in height, and are from 200 feet to a mile in length. Compound dune complexes are aligned north-

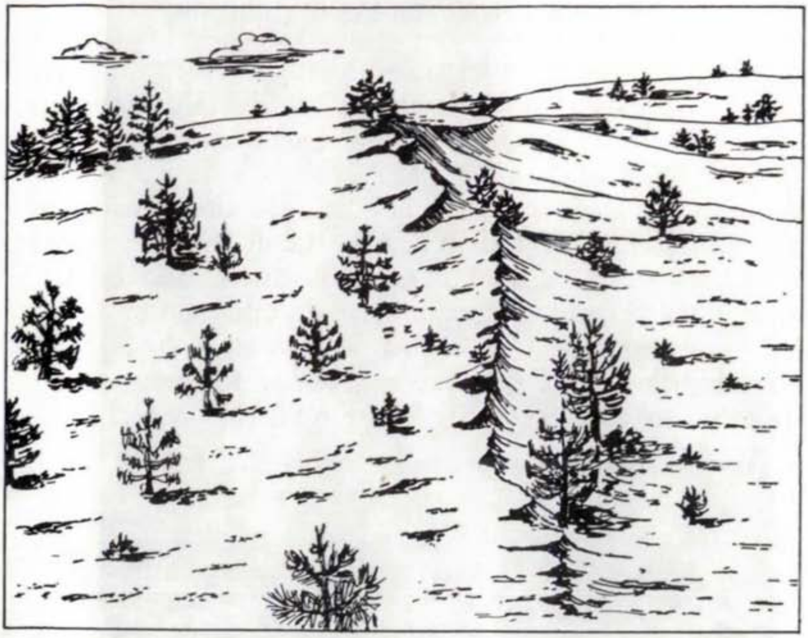


Figure 27 — Sketch of sand dune area.

south and reach about a square mile in size. Between and within the dune complexes are deflated areas that are lowlands, lakes, marshes, or bogs depending mostly upon the position of the local water table. The areas of bog make excellent sites for truck gardening, but are rather poor sites upon which to construct buildings or other structures. The Carlos Avery Wildlife Management Area is located northeast of the Blaine-Coon Rapids dune field. It is in the northeastern corner of Anoka County, within low-lying lake and marsh topography of the Anoka sand plain.

A second, somewhat smaller area of sand dunes occurs about two miles east of Shakopee, in Eagle Creek Township and within the "Shakopee Prairie." The area of dune concentration is oval in shape; its axis extends about 3 miles northwest-southeast, and is about 0.5 miles wide. The dunes are 5 to 15 feet high and 200 to 300 feet wide, reach 1,000 feet in length, and occur at elevations between 735 and 750 feet above sea level. Small lake basins and marshes have formed where the silty sand materials have been eroded by winds down to the Prairie du Chien bedrock surface.

Mineral, Rock, and Fossil Collecting

Collecting minerals, rocks, and fossils has become a hobby that now appeals to an estimated 10 million Americans. The following geologic background is intended to aid local collectors.

Nearly every child in the Twin Cities has started a rock collection. He generally collects pebble-sized or larger materials derived from the glacial drift near his home. For the most part, the samples are of the hard, durable basement rocks I described earlier in the booklet as Precambrian granites and basalts. Sedimentary limestones, from either the local bedrock or from materials transported by glaciers from as far away as central Manitoba, are also frequently found in his rock collection.

Figure 28 — Sketch of Lake Superior agates.

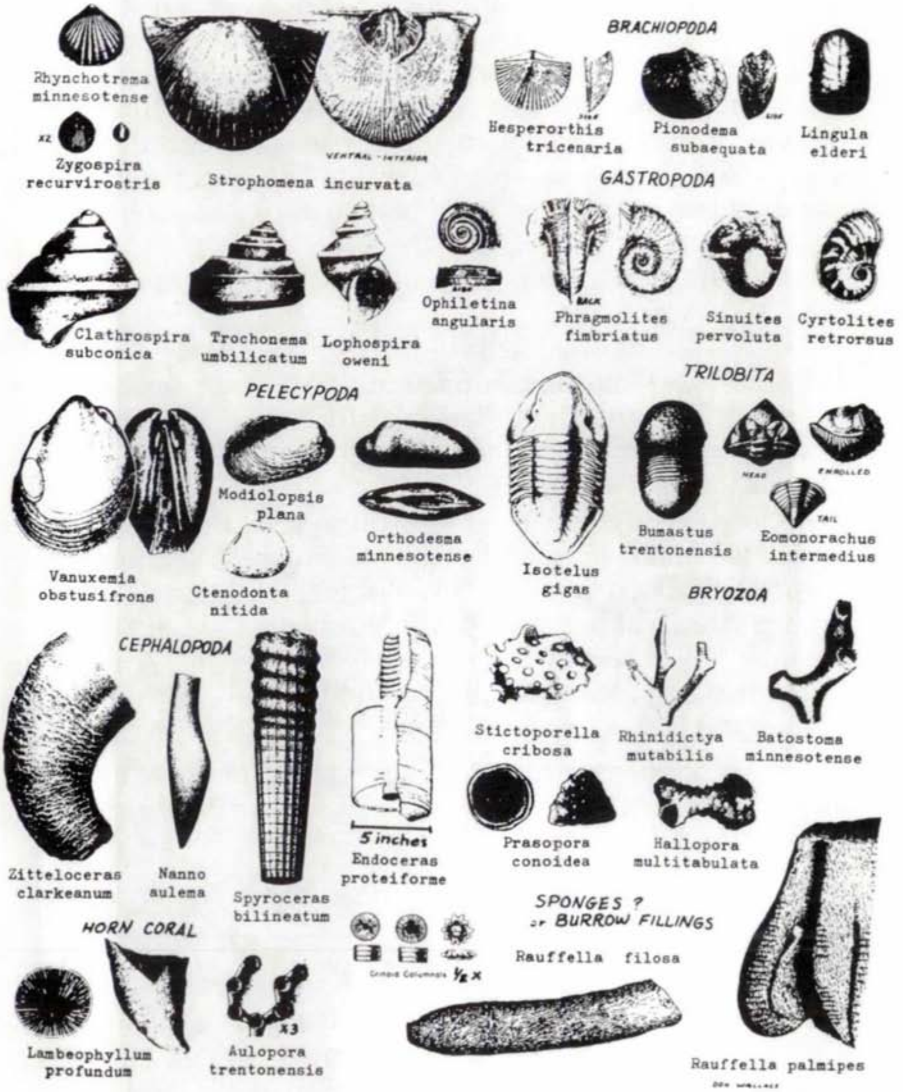


Figure 29 — Sketch of Ordovician fossils, Twin Cities Area.

As the hobbyist becomes more perceptive, he attempts to find agates in gravel pits and in road cuts. In contrast to a rock which is an aggregate of one or more common minerals, an agate is composed of a single mineral species. The Lake Superior agate, Minnesota's state rock, is found in pink sandy glacial drift as dull reddish-brown, slightly waxy, pitted and rounded particles that retain the imprint of the cavity in which they were formed. The broken or sawed face of this highly-sought mineral generally consists of alternating red- and white-tinted, concentric wavy bands; it may also be patchy in pattern or of a solid color. More detailed data on agates and the other important Minnesota minerals are given in the "Guide to Mineral Collecting in Minnesota" (See Appendix C).

Fossils are most abundant in outcrops of the Ordovician Decorah and Platteville Formations; also, some fossils can be collected from the Cambrian sandstones and from the "limestone" blocks of the glacial drift. The Decorah Shale contains abundant fossils within the Twin Cities Area; the most accessible collecting locality is at the Twin Cities Brick Company clay pit within the south valley wall of the Mississippi River, just west of Lilydale. The best known fossil-collecting localities of the Metropolitan Area within the Platteville Formation are in St. Paul at Shadow Falls, west of the intersection of Summit Avenue and East Mississippi River Road, and Hidden Falls Park, just south of the Ford Motor Company Plant.

For those interested in more information on fossil collecting I refer you to "Guide to Fossil Collecting in Minnesota" (See Appendix C).

Caves

Numerous small sandstone caves occur at shallow depths beneath the Twin Cities. The caves are nearly all confined to positions adjacent to the bedrock walls of the major stream valleys. The caves were developed by hydraulic forces generated by the sudden changes in water table levels that closely followed the local retreat of waterfalls. Several natural caves occur in the walls of the Mississippi gorge, particularly along West River Road in Minneapolis. Sandstone caves in St. Paul—Carvers and

Fountain—and those in and near Stillwater—Stillwater and Boom Hollow—have had romantic histories of human use. Nearly all of the caves have been enlarged by man. Some past and current uses of the caves are for general storage, for aging of beer, for mushroom culture, and even for nightclubs.

"Guide to the Caves of Minnesota" (See Appendix C) gives a more detailed account of Minnesota's caves.

Other Sites of Interest

Appendix A gives the location of other sites of geologic interest that are described by plaques. In addition, local and often only temporarily-exposed sites offer an opportunity to observe first hand the geology of your immediate environs.

ENVIRONMENTAL PLANNING

One of the greater challenges to our post-industrial society is to modify, build, and manage our private and public institutions in such a manner that we can live in harmony with our natural environment. We in the Twin Cities Metropolitan Area have only to observe the poor livability indices of the east and west coast megalopolises to see what could happen here. In recent years, many individuals and organizations have expressed concern about the deterioration in the "quality of life" in the Twin Cities. It is important that we alleviate the major problems and reverse this trend.

To tackle the physical problems of the local environment, such as pollution and unwise land-use, we need to reexamine our relationship to the landscape and its material resources. The base of the natural environment is the geologic environment. In fact, the subsurface geologic framework provides a third dimension to the physical environment.

Background geologic knowledge is necessary before we can adequately plan, test, and develop systems to insure the maximum beneficial use of the natural resources. We must realize that mineral resources are finite in quantity and fixed in position. Geologic materials are also important controllers or restrainers on water supply, building sites, tunnel construction, slope stability, waste disposal, and on the aesthetic resources—our lakes, streams, hills and valleys—the critically needed open spaces. When the basic physical information has been gathered and synthesized, and alternatives have been weighed, we can then, hopefully, practice wise sequential use of our landscape's resources.

Figure 30 — Sketch of a typical geologic plaque.

APPENDIX A

Plaques on The Geology of The Twin Cities Metropolitan Area

The several plaques listed below describe local geologic environments within the Twin Cities Metropolitan Area. Nine of the eleven plaques have been erected by the Geological Society of Minnesota with the cooperation, according to the particular site, of the Minnesota Highway Department and/or city park boards, and the Minnesota Historical Society. The Minnesota Historical Society has cooperated with the Minnesota Highway Department on the Christmas Lake plaque and with the City of St. Paul on the Fountain Cave plaque.

Title	
Battle Creek Park	Plaque within retaining wall south of creek and 25 feet east of Park headquarters building.
Christmas Lake and Lake Minnetonka	At access road and on west side of roadside park south of and about 1.5 miles east on Highway 7 from Excelsior.
Dakota County Region	In south-central part of Hastings roadside park, about 0.25 miles west from the intersection of Highways 55 and 61.
Fountain Cave	About 1.4 miles northeast on Shepard Road from Lexington Avenue Bridge, in a roadside pullout that overlooks Mississippi River Valley.
Indian Mounds Park	In south-central part of Indian Mounds Park; overlooks Mississippi River Valley.

Lake Harriet Region	In picnic area northwest of lake; approximately 100 feet west of intersection of shoreline road with road to Lake Calhoun.
Lake Pepin	Overlook on Highway 61 about 1.6 miles northwest of Reeds Landing; a view of the south end of Lake Pepin.
Minnehaha Falls	Plaque within wall at southwest corner of main parking lot; overlooks the falls.
Stillwater Region	Roadside park on Highway 95, about one mile north of the intersection of Highways 95 and 96; view of the St. Croix valley.
Taylors Falls Region	Roadside lookout on Highway 8 about 0.75 miles southwest from Interstate Bridge; overlooks St. Croix Dalles.

APPENDIX B

Explanation of Terms

Alluvial fan—an accumulation of sediments deposited by a stream at a position where there has been a major lessening of flow velocity.

Alluvium—stream-deposited sediment.

Aquifer—a natural water-bearing reservoir composed of porous rock or glacial materials.

Aquitard—a layer of consolidated or unconsolidated rocks that retards the normal flow of water.

Basalt—a fine-grained, dark gray, igneous rock that has been crystallized from a molten state.

Bedrock—the composite sequence of sedimentary rocks below the blanket of glacial drift.

Clay—either clay-sized particles—particles less than 0.00004 of an inch in diameter—and/or clay minerals—the platy, mica-like minerals generally of clay size.

Cobble—generally rounded rock particle varying from about 2.5 to 10.0 inches in diameter.

Confluence—the geographic point at which two streams meet.

Dalles—a French word meaning a narrow rock-bound river channel.

Epicenter—the point on the Earth's surface directly above the focus of an earthquake.

Erosion—the process whereby rock material is loosened or dissolved and removed from any part of the Earth's surface.

Fault—a break in the continuity of a rock body, where there has been displacement of the two sides relative to a plane parallel to the break.

Feral—untamed, wild, and savage.

Flood plain—that part of a river valley, adjacent to the river channel, built from river-borne sediments; is covered by the river waters during flood stage.

Friable—easily crumbled.

Glacial drift—the composite "blanket" of glacially-deposited rock materials.

Glacier—the moving part of an ice sheet.

Gradient—the grade or downward slope of a stream.

Granite—a light-colored, massive, crystallized rock formed from magmas that were intruded and also cooled within the Earth's crust.

Groundwater—that part of the Earth's water lying below the water table.

Gyttja—a black mud of non-decomposed materials derived from plant and animal matter; found at the bottom of lakes and swamps.

Hiatus—a time gap in the rock sequence.

Hummocky—a field of hillocks of low relief characteristic of the land surface left by a glacier.

Lake plain—a nearly flat, very shallow depression in which fine inorganic and organic materials have accumulated.

Limestone—a bedded, sedimentary rock composed mostly of calcium carbonate; the consolidated equivalent of limy mud, calcareous sand, or shell fragments.

Meander—one of a series of loop-like bends in the course of a low gradient stream that shifts laterally with time.

Mica—a six-sided light gray to black mineral that splits in thin, wafer-like sheets.

Moraine—rock materials that have settled directly from glacial ice; form positive hilly, topographic features.

Natural levee—an alluvial ridge of fine sediments deposited by a stream during floods.

Outwash plain—a composite of overlapping alluvial fans deposited by meltwater (glacial) streams.

Oxbow lake—a U-shaped channel loop of a meandered stream that was abandoned when a steeper gradient channel was opened.

Peat—the dark-brown material resulting from the partial decomposition of mosses, sedges, grass, trees, and other plants that grow in moist lowlands.

Pebble—generally rounded rock particle varying from 0.2 to 1.5 inches in diameter.

Permeability—capacity for transmitting fluids.

Pothole—a barrel-shaped hole that has been worn in solid rock by the cutting action of resistant rocks impelled in a circular path by a whirlpool of water.

Radiocarbon dating—a method of determining the age of relatively young organic and carbonate materials (50,000 years) by measuring the amount of the isotope C-14 remaining.

Recharge—processes by which surface water is added to groundwater reservoirs.

Regolith—mineral and rock materials that have been weathered or altered in place.

Relief—the difference between the high and low points of a land surface.

Sandstone—a bedded sedimentary rock composed dominantly of sand grains, mostly quartz, that is cemented by a variety of minerals.

Saturated zone—rocks or rock materials the pores of which are filled with fluids.

Shale—a laminated to blocky sedimentary rock composed dominantly of clay-sized particles and clay minerals.

Sink holes—a funnel-to cup-shaped collapse feature that results from local dissolution of limestone bedrock.

Stillstand—to remain stationary with respect to sea level or the Earth's center.

Terrace—a nearly level plain marking the position of a former river channel complex; generally narrow in comparison to its length.

Water cycle—the complete sun-powered cycle whereby water passes from atmospheric water vapor to precipitation, to surface or groundwater, and returns to atmospheric water vapor by means of evaporation and transpiration.

Water quality—the chemical, physical and bacterial characteristics of water that determine its usefulness for municipal, commercial, industrial, agricultural, domestic, and recreational purposes.

Watershed—the total geographic area drained by a stream or network of streams.

Water table—the upper surface of the Earth's materials wholly saturated with water.

Weathering—the decay and disintegration of rocks at or near the Earth's surface, caused by the chemical and physical elements of the weather.

APPENDIX C

Further Reading

Ahlquist, Gerald, editor, 1961, *Geologic plaques in Minnesota:* St. Cloud State College, 31 p. (Gives the general location, inscription and background of geologic localities and regions. Available only at libraries.)

Beiser, Arthur, and eds. of Life, 1963, *The Earth;* Life Nature Library: Time Inc., New York, N.Y., 192 p. (A well-illustrated volume on the history and development of planet Earth. Available from Time Inc.)

Fearing, Jerry, 1964, *The story of Minnesota:* Northwest Publications Inc., St. Paul, Minn. (A compilation of colored comic strips on the history of Minnesota. Available from Pioneer Press.)

Hogberg, R. K., and T. N. Bayer, 1967, *Guide to the caves of Minnesota:* Minn. Geol. Survey Ed. Series E.S.-4, 61 p. (Tells the where, how, and when of the caves of Minnesota. Available from Minnesota Geological Survey. See inside back cover.)

Hogberg, R. K., R. E. Sloan, and Sarah Tufford, 1967, *Guide to fossil collecting in Minnesota:* Minn. Geol. Survey Ed. Series E.S.-1 (revised), 40 p. (Provides background information and guidance for the beginning and experienced fossil collector. Available from Minnesota Geological Survey. See inside back cover.)

Leopold, L. B., K. S. Davis, and eds. of Life, 1966, *Water:* Life Science Library: Time Inc., New York, N.Y. 200 p. (A well-illustrated volume describing the subject in relevant detail. Available from Time Inc.)

Payne, C. M., 1965, *Bedrock geologic map of Minneapolis, St. Paul and vicinity:* Minnesota Geol. Survey, Misc. Map Series, M-1. (1-inch to 2,000-foot scale colored map showing the composition and relief of the bedrock surface. Available from Minnesota Geological Survey.)

Rapp, G. R. Jr., and D. T. Wallace, 1966, *Guide to mineral collecting in Minnesota:* Minn. Geol. Survey Ed. Series E.S.-2, 42 p. (A booklet designed for both the beginning and the experienced collector, to aid in the search for gemstones and other minerals of the state. Available from Minnesota Geological Survey. See inside back cover.)

Schwartz, G. M., 1936, *The geology of the Minneapolis-St. Paul metropolitan area:* Minn. Geol. Survey Bull. 27, 267 p.(A basic account of the geology of the Twin Cities metropolitan area. Available only at libraries.)

Schwartz, G. M., and G. A. Thiel, 1963, *Minnesota's rocks and waters, a geological story:* Minn. Geol. Survey Bull. 37, 366 p. (A summary of the state's geology written for the nongeologist. Available from Minnesota Geological Survey. See inside back cover.)

Sloan, R. E., and G. S. Austin, 1966, *Geologic map of Minnesota, St. Paul sheet (Bedrock Geology):* Minn. Geol. Survey. (Four miles to the inch scale colored map of the bedrock geology of southeastern Minnesota; includes approximately the south half of the Twin Cities. Available from Minnesota Geological Survey.)

Winchell, N. H., 1911, *The aborigines of Minnesota:* Minn. Historical Society, The Pioneer Co., St. Paul, 761 p. (Volume on the early Indian peoples. Available only at libraries.)

Winchell, N. H., 1888, *The geology of Hennepin County; (in) the geology of Minnesota:* The Geol. and Natural History Survey of Minn.: v. 2 of the Final Report, 693 p. (Includes the classic summary work on the reconstruction of historical accounts to estimate the retreat of St. Anthony Falls of the Mississippi River. Available only at libraries.)

Educational Series *

			Price
ES-1	1967.	Guide to Fossil Collecting in Minnesota (revised Edition)	$0.50
ES-2	1966.	Guide to Mineral Collecting in Minnesota	0.50
ES-3	1966.	Geologic Sketch of the Tower-Soudan State Park	0.50
ES-4	1967.	Guide to Caves of Minnesota	0.50
ES-5	1971.	Environmental Geology of Twin Cities Metropolitan Area	0.50

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* Order from Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota 55108

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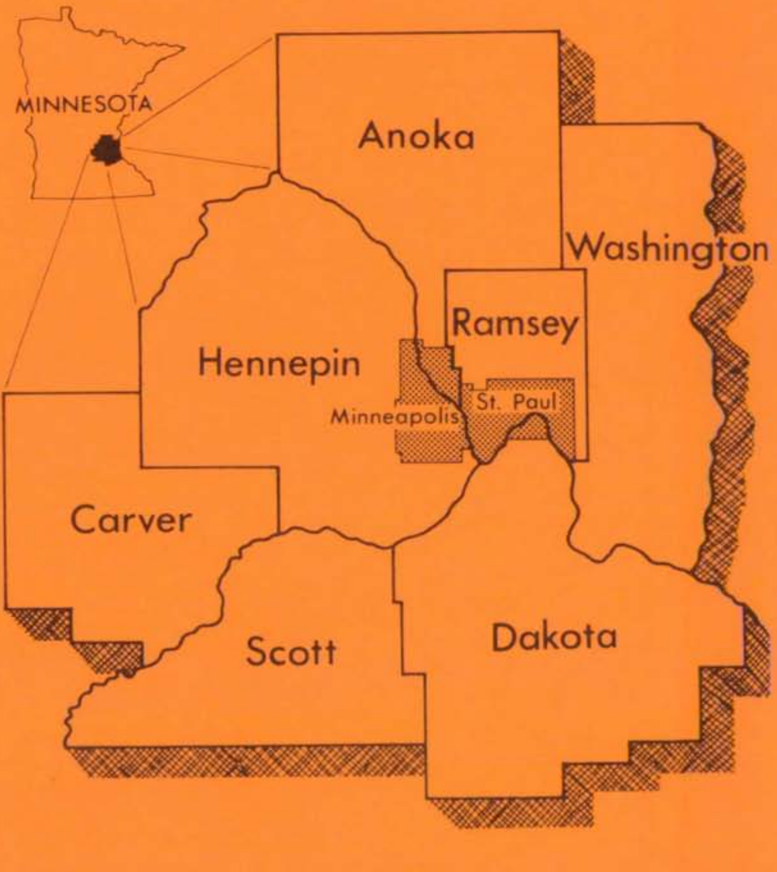

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