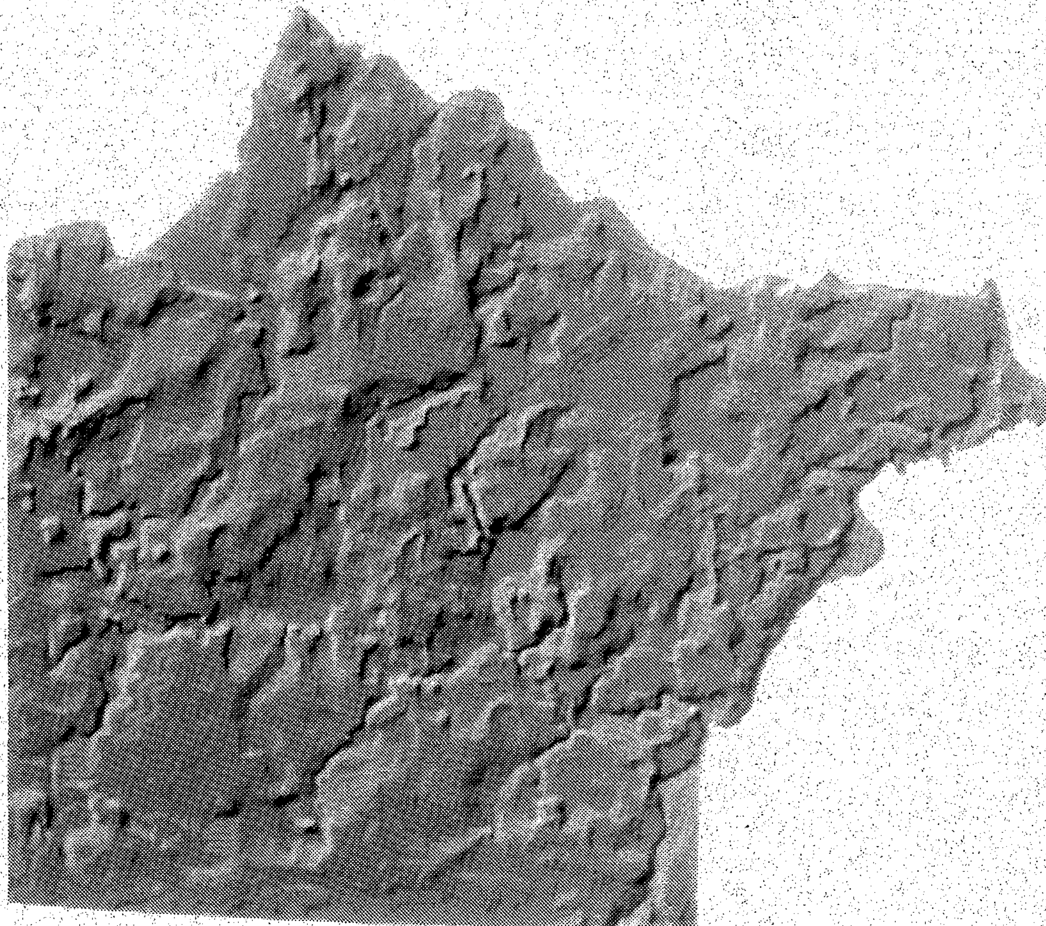
Aggregate Resources and Quaternary Geology



Wright County, Minnesota

1991

Report 294

Minnesota Department of Natural Resources
Division of Minerals

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Cover: Computer-generated shaded relief topographic map of Wright County produced using EPPL7. Data source: Minnesota Land Management Information Center MLMIS 100 data set.

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By

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William C. Brice, Director

CONTENTS

ILLUSTRATIONS

Aggregate Resources and Quaternary Geology of Wright County, Minnesota

By

J.D. Lehr

Abstract

Land-use conflicts involving aggregate mining and urban development are becoming increasingly more common as cities expand into adjacent rural areas. This inventory of potential aggregate resources in Wright County is intended to assist local planners in making land-use and zoning decisions regarding aggregate resources.

The distribution of potential aggregate resources in Wright County is presented on a 1:100,000-scale map. Aggregate resources were identified through study of aerial photographs, topographic maps and subsurface data, and by observation of surficial sediments in the field. The map was compiled and prepared using the cartographic tools available in geographic information systems.

Most of the potential aggregate resources in Wright County are located along the northwestern, northern and eastern boundaries of the county, as well as along the North Fork of the Crow River and in the area between Buffalo and Monticello. Aggregate in the southern one-third of the county is restricted to the valleys of Sucker Creek and the South Fork of the Crow River. In general, the higher quality aggregate with greater percentages of gravel is located in the northern and northeastern portions of the county.

The aggregate potential of individual geologic units varies both between units and within units. Therefore, conclusions on the suitability of a particular deposit for use as aggregate should be preceded by site-specific investigations.

Introduction

The purpose of this study is to identify and classify potential aggregate resources in Wright County, Minnesota. This aggregate resource inventory is presented on the map enclosed with this report. The following discussion is intended to supplement the map by presenting a summary of the regional geology, the methodology used in the study and additional detail about the aggregate potential of individual map units. Together, the map and report are intended to assist local planners in making land-use decisions regarding aggregate resources.

Land-use conflicts involving aggregate mining and urban development are becoming increasingly more common as cities expand into adjacent rural areas. One such land-use conflict arises when land underlain by a potential aggregate supply is built upon. In this situation, aggregate extraction is usually precluded since the value of the buildings exceeds the value of the aggregate. Other land-use conflicts arise when residential development occurs adjacent to land underlain by a potential aggregate source. In this case, it is often difficult to develop a gravel pit due to opposition by the adjacent homeowners.

Another land-use problem confronting government administrators, planners and engineers is depletion of aggregate resources within and adjacent to urban areas. Aggregate necessary to expand and maintain urban infrastructure, businesses and dwellings is currently transported from areas increasingly further away. The increased transportation distance adds significantly to the final cost of aggregate and all products constructed with aggregate. These increased costs are ultimately borne by the taxpayer and consumer.

Aggregate depletion and the incompatibility between aggregate mining and other land uses constitute a problem that the Minnesota Legislature addressed in 1984 by enacting Minnesota Statute 84.94 (Appendix A). This statute mandates that the Department of Natural Resources, in cooperation with the Minnesota Geological Survey, Minnesota Department of Transportation (MN/DOT) and State Planning Agency, conduct a program to identify and classify potential aggregate resources in Minnesota outside the seven-county metropolitan area. This statute further specifies that the program give priority to those areas of the state where urbanization or other factors may result in a loss of aggregate resources to development and that counties consider protection of aggregate resources in their land-use decisions.

Wright County (Fig. 1), which is the second county

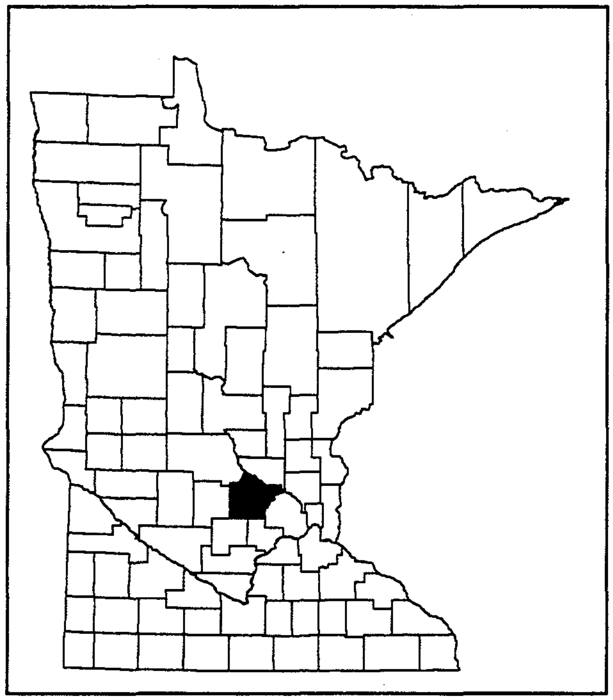

Figure 1. Location of Wright County, Minnesota

to be mapped under the DNR's aggregate mapping program, was chosen because its proximity to the westerly expanding metropolitan area has resulted in development on potential aggregate sources and depletion of other aggregate sources. Some of the aggregate depletion is the result of aggregate use in the Twin Cities metropolitan area, where many sources are already either depleted or built upon.

The identification of aggregate resources necessary for land-use planning is accomplished by geologic mapping. The dominant geologic processes that produced the modern landscapes of Minnesota, including Wright County, are associated with the advance and retreat of several continental glaciers. Study of modern glacial depositional environments coupled with study of the glacial history of a particular area, enables the geologist to predict the type of sediment present (e.g. aggregate) based upon the type of landform present (Eyles, 1983).

The following summary of the glacial history of

Minnesota provides the background necessary for discussion of the aggregate resources and Quaternary geology of Wright County.

General Glacial History of Wright County

Wright County was glaciated repeatedly during the past 2.5 million years. However, little is known about most of these early glacial advances in Wright County because their deposits have either been eroded or are deeply buried by younger sediments.

The sediments that comprise the contemporary landscape of Wright County were deposited by multiple glacial advances during the late Wisconsinan substage of the Pleistocene Epoch, approximately 35,000 to 10,000 years before present (Richmond and Fullerton, 1986).

The first late Wisconsinan glaciers advanced generally southwestward into Minnesota to the Alexandria moraine complex and covered all of Wright County (Clayton and Moran, 1982; Dyke and Prest, 1987). This glacier, referred to as the Wadena lobe (Wright, 1962), deposited a sandy till characterized by abundant carbonate clasts and the absence of shale.

Upon retreat of the Wadena lobe, the Superior lobe advanced southwestward from the lowlands of the Lake Superior basin into the Twin Cities lowland, covering most of Wright County (Fig. 2). The late Wisconsinan maximum of the Superior lobe is marked by the broad St. Croix moraine in the southeastern and eastern Twin Cities metropolitan area. Extending from the Scott-Dakota County line northwestward though Scott, Carver and Wright counties to central Stearns County, the St. Croix moraine is buried beneath younger sediment (Hobbs and Goebel, 1982). Diagnostic indicators of Superior lobe sediment are brown and red sandstone and volcanic rocks derived from the Lake Superior basin. Because the Superior lobe traversed primarily sandstone and crystalline bedrock, the texture of Superior lobe sediment in central Minnesota is generally sandy. The characteristic reddish-brown color of Superior lobe sediment is due to incorporation of the brown sandstone and interbedded red sandstone and shale.

As the Superior lobe retreated to the northeast, the Des Moines lobe advanced southward from the Red River valley into the Minnesota River valley, covering most of southern Minnesota (Fig. 3). Initially, debris-rich stagnant ice within the St. Croix moraine confined the Des Moines lobe to the lowlands flanking the Minnesota River valley. As stagnant ice within the St. Croix moraine melted, the Grantsburg sublobe of the Des Moines lobe advanced to the northeast, covering the area formerly occupied by the Superior lobe. The combined Des Moines lobe and Grantsburg sublobe covered all of Wright County (Fig. 3).

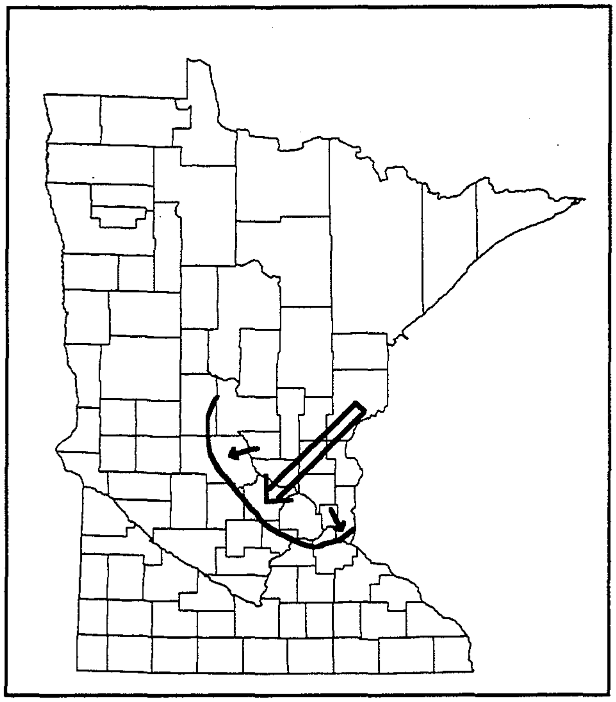

Figure 2. Maximum extent and generalized flow direction of the late Wisconsinan Superior lobe

The diagnostic indicator of Des Moines lobe sediment is a distinctive shale derived from eastern North Dakota and adjacent Manitoba. Des Moines lobe till is characteristically fine grained, reflecting the poorly consolidated sedimentary rocks and unconsolidated lake sediment which the glacier traversed. Unoxidized Des Moines lobe till is gray, reflecting the color of the incorporated shale and lake sediment. Where oxidized, Des Moines lobe till is olive-brown and yellowish brown.

As the Des Moines lobe retreated from central Minnesota, its meltwaters deposited outwash in river valleys that enter the Mississippi River drainage system (Fig. 4). Outwash from this recession occurs in

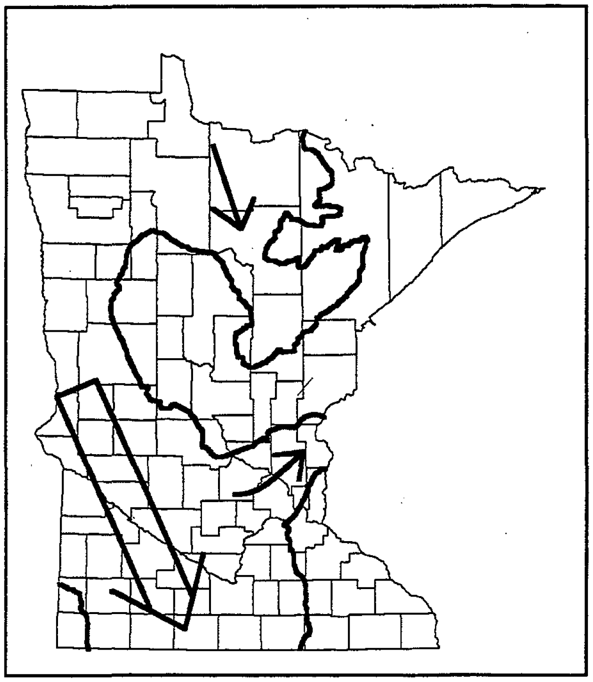

Figure 3. Maximum extent of the Des Moines lobe (adapted from Hobbs and Goebel, 1982)

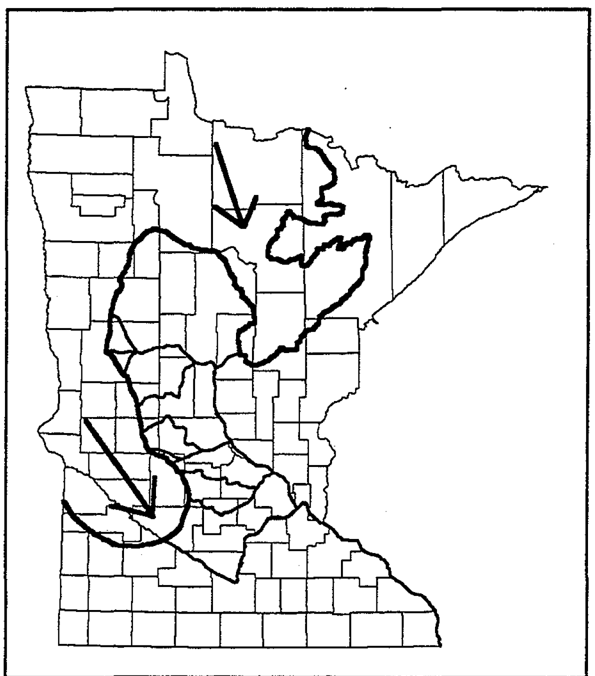

Figure 4. Retreat of the Des Moines lobe and paths of its meltwaters (adapted from Hobbs and Goebel, 1982)

Wright County along the valleys of the Mississippi River, the Clearwater River, the Crow River and its tributaries.

As the climate warmed and the Superior and Des Moines lobes retreated northward, they left behind large blocks of stagnant ice buried by debris. These buried blocks of stagnant ice melted slowly over thousands of years producing the hilly, lake-studded landscape of Wright County.

Physiography

The three rivers that form parts of the boundary of Wright County were major pathways for glacial meltwater. The Mississippi River flows from northwest to southeast along the northern boundary of the county. The Clearwater River flows from southwest to northeast along the northwestern boundary of the county and empties into the Mississippi River at Clearwater. The North Fork of the Crow River flows from west to east through the central part of the county joining the South Fork of the Crow River at Delano. From this point, the Crow River flows northeastward, forming most of the eastern boundary of the county, and joins the Mississippi River at Dayton. Lakes and ponds are common throughout the county, except for the area northeast of Pelican Lake.

The topography of Wright County is rolling to hilly. The lowest surface elevations are in the eastern part of the county along the Crow and Mississippi Rivers. From that point, the land surface generally rises to the west, with the highest elevations occurring in the vicinity of Lake Francis and Lake Sylvia and in the southwestern corner of the county. The county is transected by an east-west trending lowland occupied by the North Fork of the Crow River.

Nearly all of Wright County is characterized by morainal topography interspersed with narrow valley trains. The fairly level sandy areas immediately adjacent to the Mississippi River comprise the southern portion of the Anoka sandplain (Wright, 1972).

Methodology

The methodology used in this study to identify potential aggregate resources is presented to assist potential users in utilizing the map. Mapping methods and methods of map production are described below.

Mapping Methods

As mentioned previously, identification of aggregate resources is accomplished by geologic mapping. Mapping of glacigenic sediments and their constituent landforms through the study of aerial photographs and subsurface data enables inferences to be made about the potential aggregate resources within the various geologic units. The methodology used in mapping the Quaternary geology and aggregate resources of Wright County is presented below.

A preliminary Quaternary geologic map legend was developed after a review of the literature on the glacial geology of central Minnesota. The map units are based on the principle that glacial depositional environments, hence glacigenic sediments, can be mapped based upon their landform expression (Eyles, 1983). Because the glacigenic sediments in Wright County were deposited from distinct glacier lobes (the Des Moines and Superior lobes) that have predictable properties, the lobe from which the sediments were deposited is used as a framework for the legend. The units were chosen to provide detail within potential aggregate units. For example, the geologic units that consist primarily of sand and gravel are subdivided so their aggregate potential can be addressed separately. All surficial till is mapped as single unit, Des Moines lobe till, recognizing there are probably several textural varieties of Des Moines lobe till present.

All publicly available subsurface data were collected to supplement geologic inferences. These include: 1) 428 well logs from domestic water wells whose locations had been verified by the Minnesota Geological Survey; 2) MN/DOT gravel pit sheets which consist of shallow (10 to 40 feet deep) test-hole logs, sieve and quality test data; and 3) 57 MN/DOT bridge-boring logs. During the course of the study, 881 additional wells were located with the assistance of the Minnesota Geological Survey and the Wright County Soil and Water Conservation District. The subsurface data were then plotted onto U.S. Geological Survey 7.5 minute topographic maps that served as field maps. For each well location, an abbreviated interpretation of the upper portion of the driller's log was plotted.

To indicate those areas of the county where aggregate mining has occurred, locations of gravel pits were gathered from a variety of sources (Edwards, 1968; U.S.G.S. 15 minute map series; U.S.G.S. 30 x 60 minute map series, MN/DOT Wright County highway map, Wright County Highway Department files, and field observations by the author) and plotted on the field maps. Many of these pits were not verified in the field and in some cases they may represent pits other than sand and gravel pits, or gravel pits that are either depleted or have been reclaimed.

Mapping units were delineated on the 7.5 minute U.S. Geological Survey topographic maps using stereoscopic pairs of high altitude black and white aerial photographs (BIK 755-757; 345-350; 720-727 and 806-809; scale 1:90,000 and EKA 389-393; 442-446; 489-493; 541-545; and 588-592; scale 1:80,000). The delineations are based primarily on landforms, using the premise that certain glacigenic sediments are deposited as distinctive landforms (Eyles, 1983). These interpretations were supplemented by observations of drainage characteristics of the sediment as revealed by tonal contrasts on air photos, and to a lesser extent, the type of vegetation present. Solid lines are used where the delineation is quite certain. Dashed lines are used where the boundary is gradual, inferred or approximately located.

To supplement geological inferences, the physical properties of aggregate resources described on the MN/DOT pit-sheets were summarized and are presented in Appendix B. These data include sieve (gradation) data and quality data consisting of percent shale in the gravel fraction, percent shale in the sand fraction and the results of the Los Angeles Rattler (LAR) test. Sieve data show the percent gravel versus sand versus fine material present. *The gradation and quality of aggregate necessary for specific uses varies with the intended use.* The percent shale present in both the sand and gravel fractions is related to the durability of the aggregate. Shale readily disintegrates when used as aggregate, therefore lower shale percentages indicate higher quality aggregate. The LAR test is a direct measure of the durability of aggregate. The test consists of placing aggregate of a known gradation in a steel drum with steel balls. The drum is rotated for a specified period of time. At the end of this interval, the aggregate is re-sieved and the particles that are broken pass through the sieve. The LAR is reported as a percent loss with lower LAR values indicating higher quality aggregate.

Field work for this project, which was conducted during the summers of 1988 and 1989, consisted of observations of landform expression and surficial sediment as exposed in gravel pits, road cuts, natural exposures and excavations. Sediment from shallow hand-augered holes was described where exposures were lacking. Field notes were made at approximately 200 sites throughout the county describing representative sites for each of the major geologic units. The map legend was revised and expanded where necessary as field work progressed.

Upon completion of the field work, a field review of the county was conducted with representatives from other government agencies and universities to examine sites that were representative of the major geologic units, as well as some problematic exposures.

Map Production

After field work was completed, the maps and aerial photographs were reexamined in the office and unit boundaries were adjusted according to field observations. At this time, the soil survey maps were examined to corroborate interpretations not supported by field evidence and the maps were reviewed for completeness and continuity.

The geologic units were digitized and combined with base map data to enable integration of these data with other digital data, such as county land-use or zoning plans. The following information was digitized from the field maps by the Land Management Information Center (LMIC) of the State Planning Agency using ARC/INFO: Quaternary geology, county border, township lines, section lines, lakes, major streams, gravel pits and MN/DOT-identified aggregate sources. These data were then integrated with roads and minor stream data from U.S. Geological Survey Digital Line Graphs. The lake names, stream names and other annotations were taken from MN/DOT's Intergraph data.

Plots of the digitized data were produced at a scale of 1:24,000. These plots were proofread by overlaying them on the field maps and corrections were made, if necessary.

The digital information was delivered to the Wright County Planning and Zoning Office to be incorporated into their land-use plan and zoning plan. These data were also delivered to the Wright County Soil and Water Conservation district for use in their comprehensive water plan.

Results

The results of this study are portrayed on the map of Aggregate Resources and Quaternary Geology of Wright County, which is contained in the back pocket of this report. *This map is intended to be used as a tool for regional land-use planning. Site specific questions require additional data collection.* The summary of the aggregate resources of the county is presented below. A more detailed description of the geologic units and their aggregate potential follows later in this section.

The geologic units shown on the map were grouped into two categories reflecting their relative potential as sources of aggregate (Fig. 5). Those geologic units that were inferred to contain potentially significant aggregate resources were grouped into the *potential aggregate resources* unit and are depicted on the map with a dashed overlay pattern. The aggregate potential of this unit varies considerably between geologic units and even within geologic units. Areas with *identified resources* are shown on the map by symbols indicating gravel pits and MN/DOT-identified aggregate sources (Fig. 5). Those geologic units with little or no potential for aggregate resources are grouped into the *limited potential for aggregate resources* unit and appear on the map with no pattern.

Most of the potential aggregate resources in Wright County are located along the northwestern, northern and eastern boundaries of the county, as well as along the North Fork of the Crow River and in the vicinity of Buffalo (Fig. 5). Aggregate in the southern one-third of the county is restricted to the valleys of Sucker Creek and the South Fork of the Crow River. Within this unit, the texture and quality of the material varies considerably, but some general trends are apparent. The percent gravel in MN/DOT-identified aggregate sources is highest in the vicinity of the buried Superior lobe end moraines (Fig. 6) and is generally lowest along the Mississippi River (Fig. 7). Average LAR values are highest in the southwestern part of the county and are lower in the northern part of the county (Fig. 8). The average percent shale present in both the sand and gravel fractions is higher

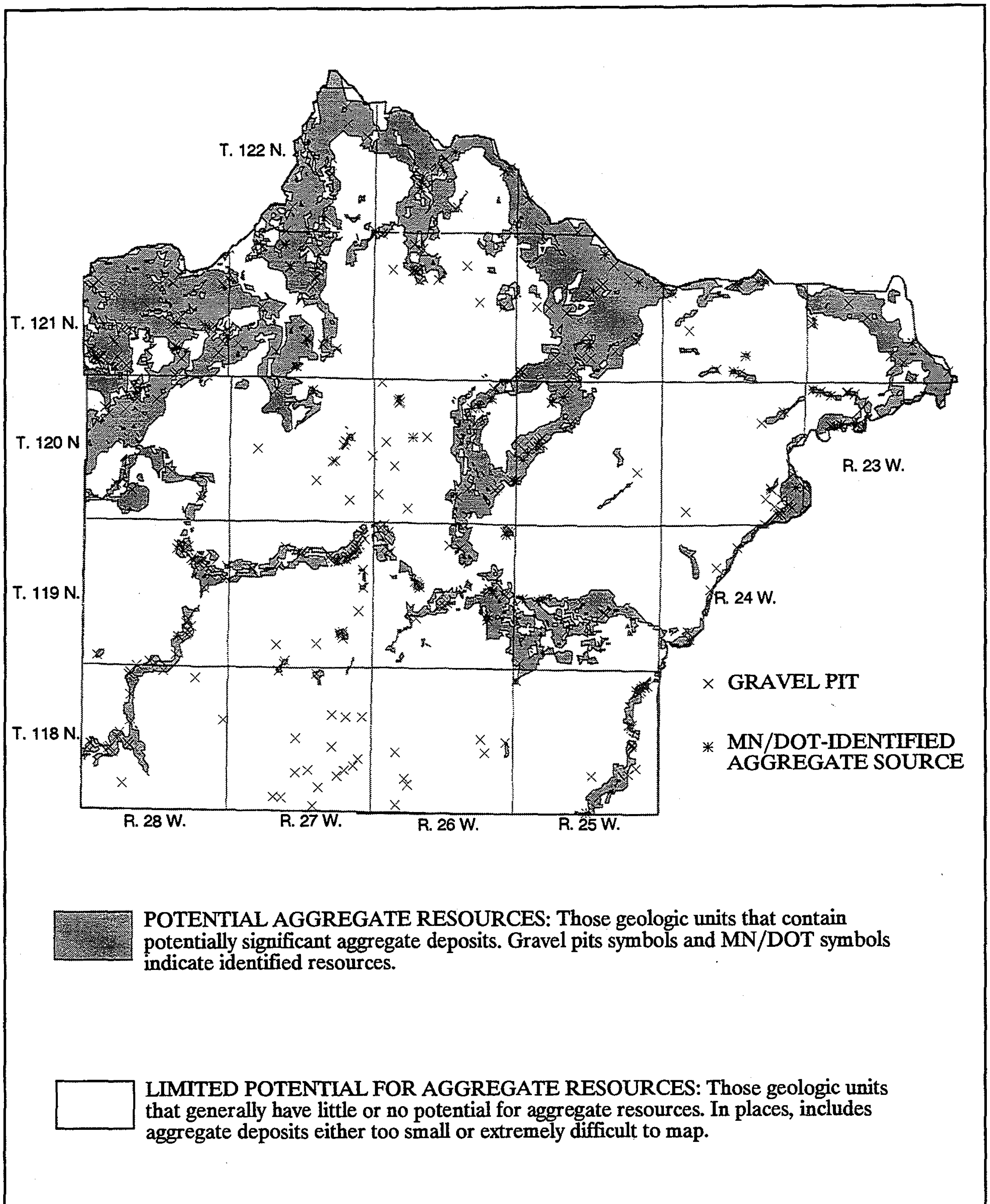

Figure 5. Aggregate resources of Wright County, Minnesota

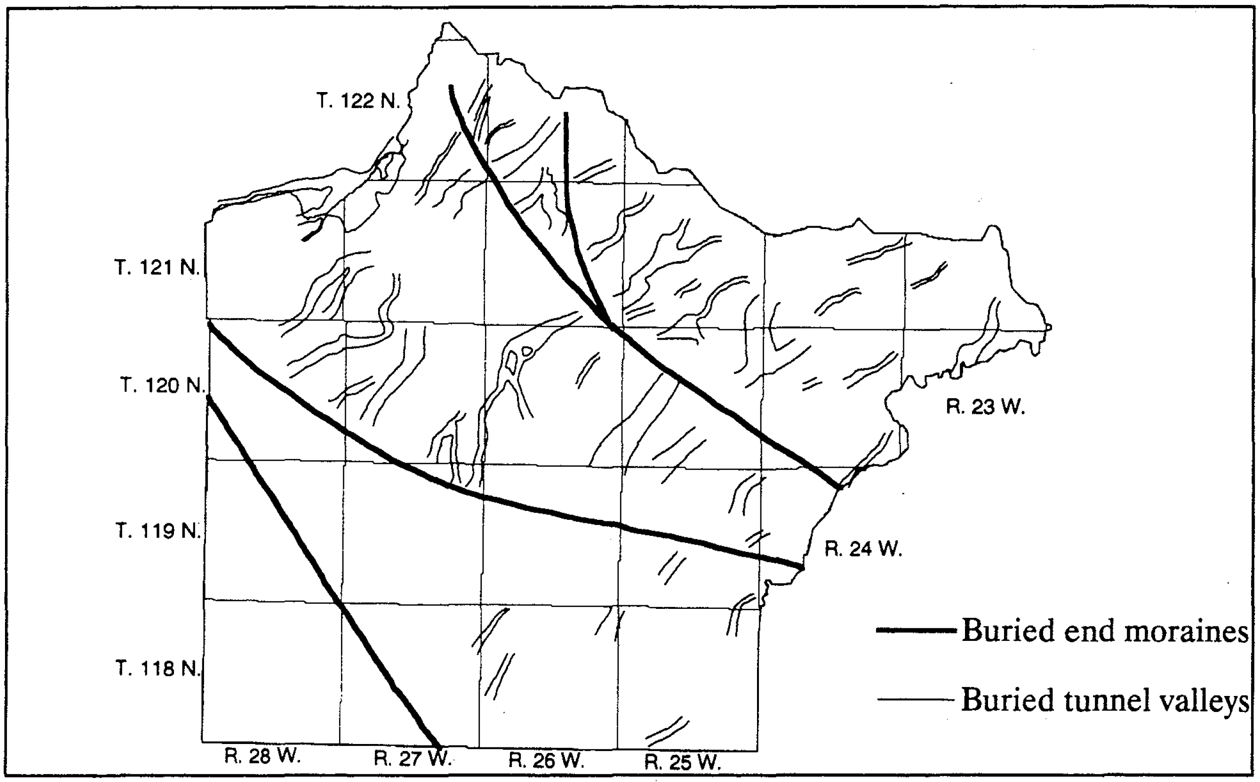

Figure 6. Approximate locations of buried Superior lobe end moraines and tunnel valleys

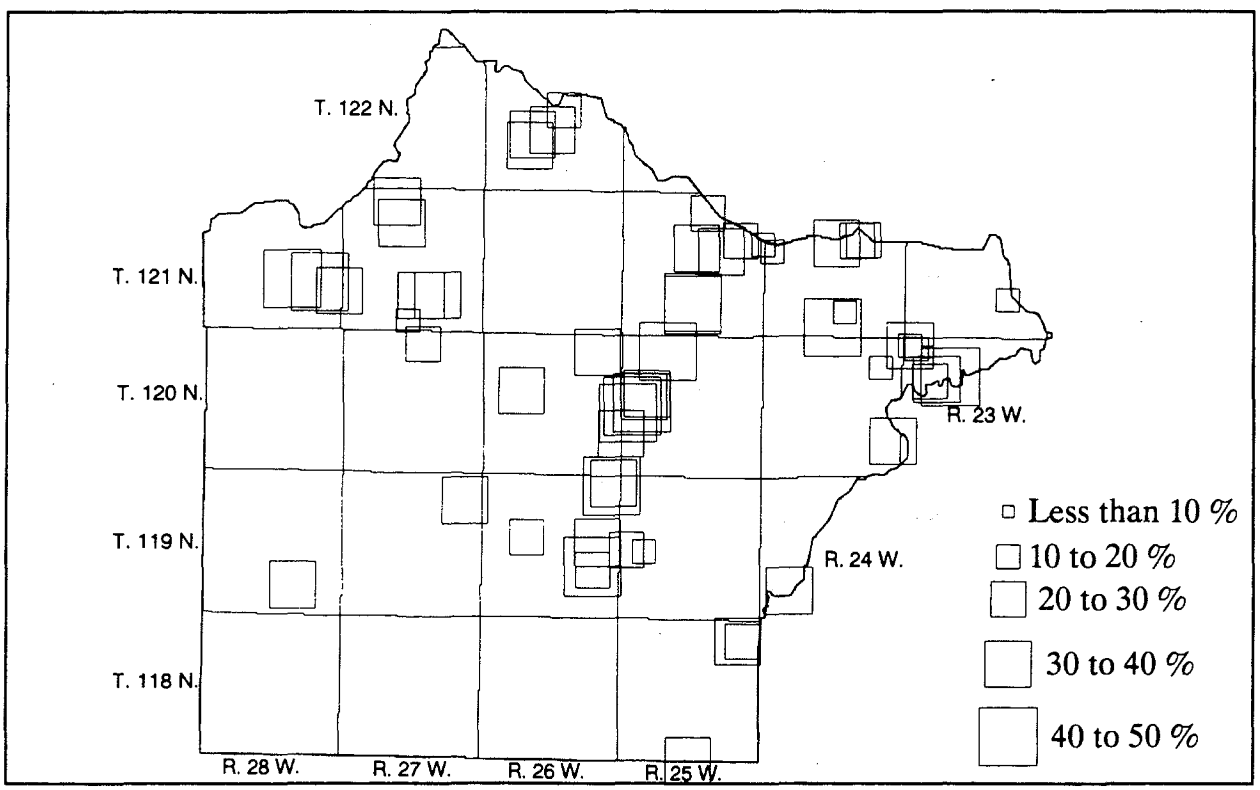

Figure 7. Average percent gravel (+ 4 mesh) for MN/DOT-identified aggregate sources

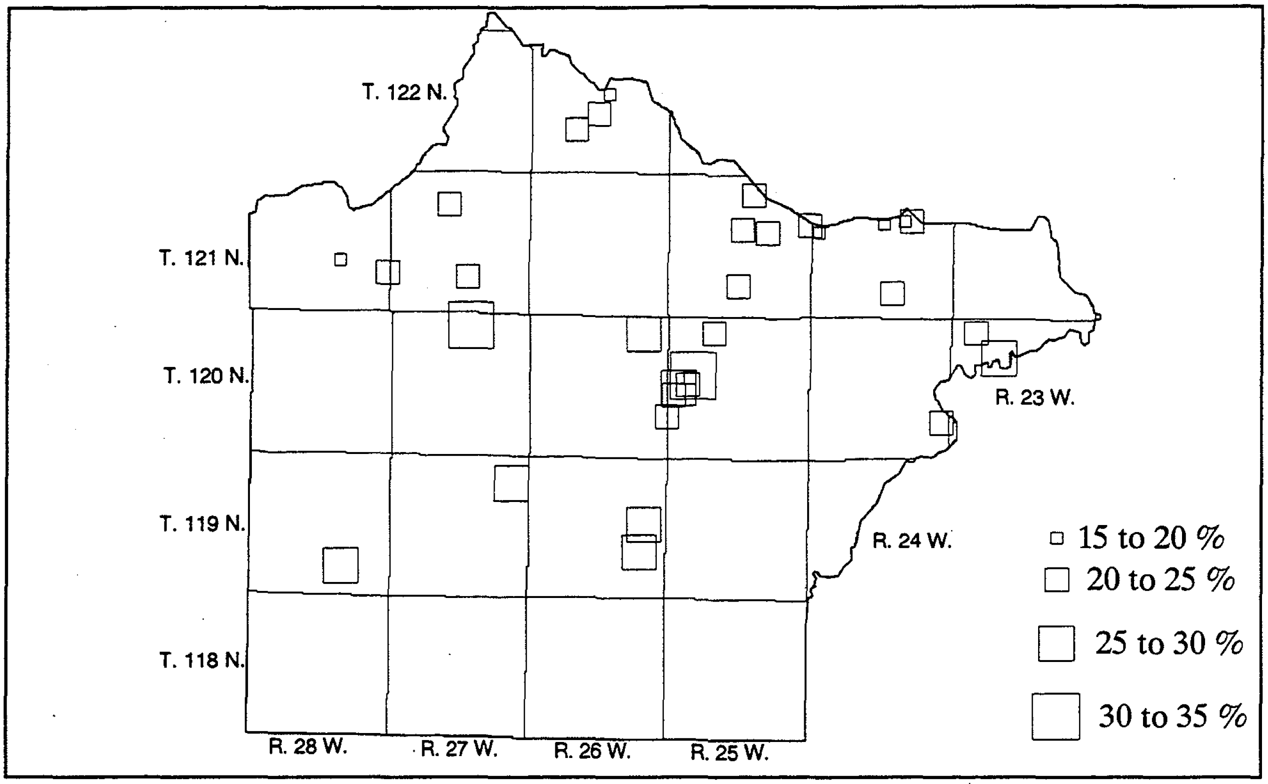

Figure 8. Average LAR values for MN/DOT-identified aggregate sources

in the southwestern half of the county and is lower in the northern and northwestern parts of the county (Figs. 9-10). All of the above-mentioned trends are due to progressive incorporation of Superior lobe end moraine sediment by the northeastwardly flowing Grantsburg sublobe and related meltwaters.

Within the *limited potential for aggregate resources* unit, there exists potential for scattered occurrences of aggregate. These inclusions are extremely difficult to map by traditional methods, but occur in a somewhat predictable pattern. The numerous gravel pits in T118N, R27-26W and T120N, R27-26W (Fig. 5). are related to the underlying Superior lobe end moraines. As the Grantsburg sublobe advanced over these sand- and gravel-rich end moraines, it incorporated a large amount of sand and gravel that was subsequently redeposited as isolated Des Moines lobe ice-contact deposits. Other occurrences of aggregate within the *limited potential* unit are found where the cover of Des Moines lobe till is thin, thereby making extraction of the high-quality aggregate from the underlying Superior lobe end moraines feasible. The gravel pits in SW¼, NW¼, sec. 32, T120N, R24W and SE¼, NE¼, sec. 7, T121N, R26W are good examples of this situation.

Table 1 presents a summary of the number of acres mapped per aggregate unit and per geologic

Table 1: Summary of acres per map unit

Potential Aggregate Resources	
Des Moines lobe ice-contact deposits	7,252
Des Moines lobe collapsed outwash	32,216
Des Moines lobe outwash	27,990
Des Moines lobe terrace outwash	10,827
Des Moines lobe upper terrace outwash	6,479
Des Moines lobe lower terrace outwash	2,925
Superior lobe ice contact sand and gravel	11,145
Total	98,834
Limited Potential for Aggregate Resources	
Organic deposits	41,293
Alluvium	5,389
Alluvium - fine facies	561
Alluvium - coarse facies	2,109
Des Moines lobe till & supraglacial sediment	274,121
Water	38,649
Total	362,122

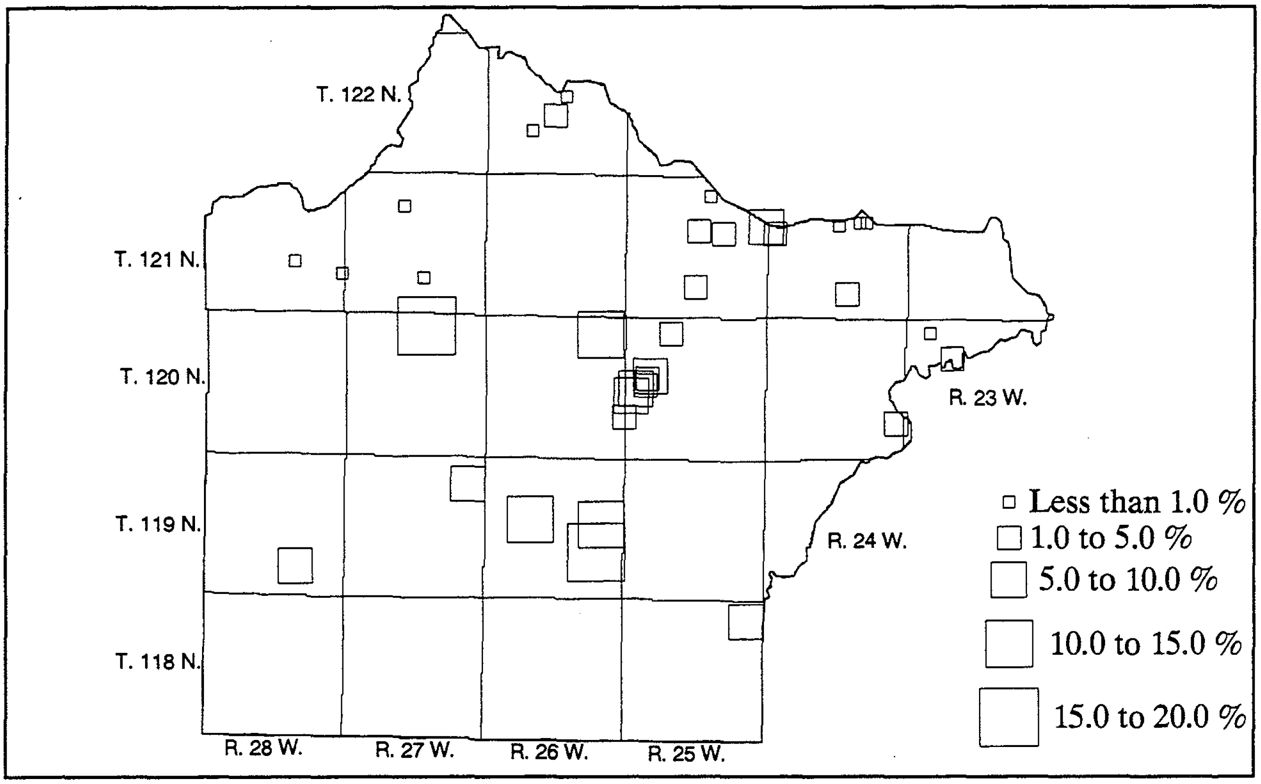

Figure 9. Average percent shale in the gravel (+4 mesh) fraction for MN/DOT-identified aggregate sources

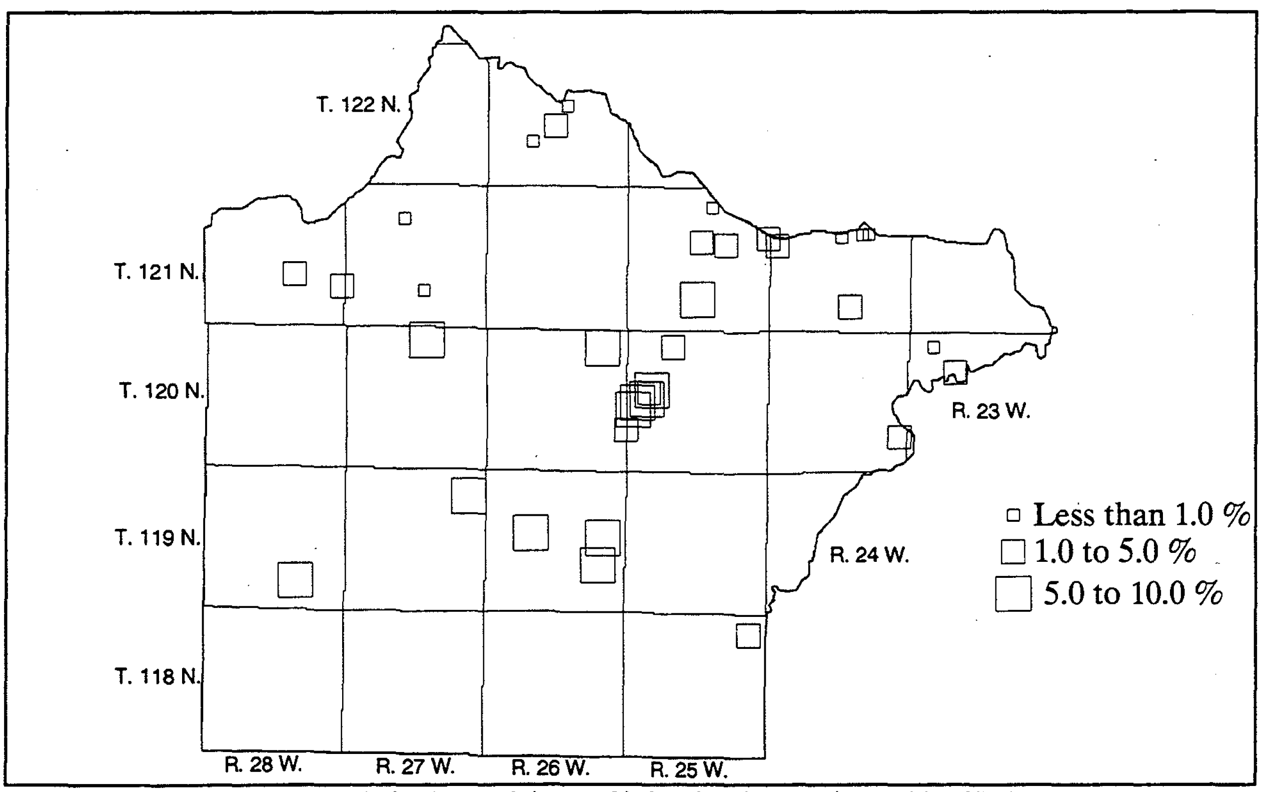

Figure 10. Average percent shale in the sand (-4 mesh) fraction for MN/DOT-identified aggregate sources

unit. Because the physical properties of aggregate vary both within and between individual units, the geology and aggregate resources of the individual geologic units will be discussed below.

Potential Aggregate Resources

Des Moines Lobe Ice-Contact Deposits: Des Moines lobe ice-contact deposits consist primarily of sand, gravel and silt ranging from sandy silt to sandy pebble- and cobble-gravel. These sediments are generally poorly to very-poorly sorted, but in places are moderately to well sorted. Boulders are common in this unit. The sand and gravel is commonly interbedded with till and sorted silt and clay. This unit ubiquitously displays horizontal and cross-bedding that is collapsed.

In general, the shale content of Des Moines lobe ice-contact deposits is highly variable. The highest percentages of shale are present in the southwestern part of the county and lower percentages in the northern half of the county. The percentage of rock-types common to the Lake Superior basin is higher in the northern part of the county. This lateral change in composition is due to progressive incorporation of sand and gravel from Superior lobe end moraines by the northeastwardly advancing Grantsburg sublobe.

Des Moines lobe ice-contact deposits occur as a variety of landforms. Typically they form irregular hummocks of variable size, but they also occur as eskers and kames.

The largest contiguous area mapped within this unit is the ice-contact complex southwest of Lake Sylvia near the western boundary of the county. This is a significant aggregate deposit because of the high percentage of gravel present, which consists primarily of durable Superior-lobe rock-types.

The remainder of Des Moines lobe ice-contact deposits in the county have highly variable potential for aggregate. The aggregate operations in these deposits are generally small, and there is only one MN/DOT-identified aggregate source within this unit.

A limiting factor for many Des Moines lobe ice-contact deposits is the high percentage of shale in the sediment. As mentioned previously, shale content is generally higher in the southern parts of the county and lower in the north. Exceptionally high amounts of shale are present in the ice-contact deposits in T120N, R27W. This area of abundant shale appears to extend into the collapsed outwash unit in the northern part of T120N, R27W. LAR values and percent shale from MN/DOT-identified aggregate source 86031 in this Des Moines lobe collapsed outwash (SW¼, NE¼, NE¼, sec. 3, T120N, R27W) (Appendix B) are some of the highest in the county. In contrast with this poor-quality aggregate, the LAR values and percent shale for MN/DOT-identified aggregate source 86060 in the northeastern part of the county (SW¼, SE¼ and SE¼, SW¼, sec. 27, T121N, R24W) are quite low (Appendix B).

Des Moines Lobe Collapsed Outwash: Des Moines lobe collapsed outwash consists primarily of interbedded sand and gravel that ranges from silty very-fine sand to sandy pebble-gravel, which is locally cobbly and bouldery. These deposits are generally poorly to very-poorly sorted. The sand and gravel is typically stratified or cross-bedded and exhibits collapsed bedding. It is locally interbedded with till and sorted silt and clay. Des Moines lobe collapsed outwash is broadly gradational with Des Moines lobe ice-contact deposits and Des Moines lobe outwash. It is distinguished by collapsed bedding and the presence of a somewhat continuous land surface that is extensively collapsed.

The aggregate resources of this unit have been extensively utilized in all parts of the county in which they occur. There are 20 MN/DOT-identified aggregate sources and several gravel pits within this unit.

The collapsed outwash plain that extends from Lake Sylvia northeastward towards Clearwater contains higher percentages of gravel in the vicinity of Lake John and Lake Sylvia and becomes sand-dominated towards the northeast. The large number of gravel pits in the southwestern portion of this outwash plain and the lack of gravel pits towards the north illustrate this trend.

The collapsed outwash plain that extends southward from Annandale towards Swartout Lake and Albion Lake appears to have different physical properties than the outwash plain to the north. The two MN/DOT-identified aggregate sources in this area (86048 and 86031) both have lower percent gravel than the outwash plain to the north. Quality data is available only for MN/DOT-identified aggregate source number 86031. The LAR value and percent shale for this pit are quite high, especially when compared with the remainder of data from Des Moines lobe collapsed outwash. The poor quality of the aggregate in this area may be related to the observed high shale content of the Des Moines lobe ice-contact deposits in T120N, R27W.

In summary, the collapsed outwash plain between Lake Sylvia and Bass Lake and Lake Sugar is a potentially significant source of aggregate. The aggregate potential of the area north of Bass Lake may be limited by low percentages of gravel. The aggregate potential of the area around Swartout Lake and Albion Lake may be limited by low percentage of gravel or by high percentage of shale.

Another occurrence of collapsed outwash is within the two collapsed valley trains north of Buffalo. The percent gravel in these valley trains generally decreases towards the northeast. LAR values and percent shale present are quite variable, depending on the amount of Superior lobe sediment incorporated by the Grantsburg sublobe and its meltwaters. In summary, the two collapsed valley trains north of Buffalo represent significant sources of aggregate but are being depleted in addition to being precluded from mining by urban development near Buffalo.

Des Moines Lobe Outwash: Des Moines lobe outwash consists of interbedded sand and gravel ranging from very-fine sand to sandy pebble-gravel, moderately to very-poorly sorted. The sand and gravel typically displays horizontal and cross-bedding that is locally collapsed. This unit is broadly gradational with Des Moines lobe collapsed outwash but is distinguished by the presence of fairly continuous low-gradient uncollapsed areas.

Des Moines lobe outwash forms outwash plains south of Monticello and south of Clearwater and also the valley trains along Silver Creek, Sucker Creek and the North Fork of the Crow River. Des Moines lobe outwash has been extensively utilized for aggregate in Wright County. There are several gravel pits and 18 MN/DOT-identified aggregate sources within this unit.

The outwash plain in the vicinity of Clearwater is an extension of the collapsed outwash plain to the south. The aggregate potential of this outwash plain is probably limited due to the low percentage of gravel present. There are no MN/DOT-identified aggregate sources in this outwash plain and only one small gravel pit was noted. In summary, this outwash plain may contain potentially significant aggregate resources, but the overall low percentage of gravel present will be limiting factor.

The valley train along Silver Creek (T121-122N, R26W) includes three MN/DOT-identified aggregate sources, each with low LAR values and low shale percentages (Appendix B). The high quality of aggregate present in this unit is due to extensive incorporation of underlying Superior lobe sediment by the Grantsburg sublobe and its meltwaters. In summary, the Silver Lake valley train, and adjacent ice-contact deposits, represents a significant future source of aggregate.

The outwash plain south of Monticello is an extension of the two collapsed valley trains north of Buffalo. Data from the eight MN/DOT-identified aggregate sources indicate a trend of decreasing gravel content from south to north. LAR values are consistently low while percentage shale varies considerably. The low LAR values are due to incorporation of durable rock-types from the buried Superior lobe end moraine immediately south of this outwash plain (Fig. 6). The coincidence of elevated shale values with lower LAR values is probably due to concentration of shale by flowing water. Some beds may be entirely free of shale while adjacent beds may contain substantial amounts of shale. In summary, the outwash plain south of Monticello represents a significant future source of aggregate. A limiting factor for certain uses is the variable percentage of gravel present.

The valley train along Sucker Creek (T118-119N, R28W) is one of the few sources of aggregate in southwestern Wright County. The highest percentage of gravel occurs in the southwestern portion of T118N, R28W and diminishes towards the north. Because the source of the meltwater of this valley train was the Des Moines lobe proper, and this area is beyond the maximum limit of the Superior lobe, the sediment of this valley train contains abundant shale and few Superior lobe rock-types. In summary, the outwash along Sucker Creek is an important source of aggregate in the southwestern part of Wright County. The aggregate resources of this unit appear to be under increasing pressure due to depletion and urban development near Cokato.

The valley train along the North Fork of the Crow River in the vicinity of Crawford Lake has been extensively utilized for aggregate. There are five MN/DOT-identified aggregate sources and several gravel pits present. The percentage of gravel present varies from 16 percent to 41 percent. LAR values and percentage shale are fairly consistent. These consistent quality data reflect the true Des Moines lobe source for these sediments. In summary, this valley train represents a potentially significant future source of aggregate in southeastern Wright County. Limiting factors for use of this outwash as aggregate are the variable amount of gravel present, fairly high LAR values and the high percentage of shale present.

Des Moines Lobe Terrace Outwash: Des Moines lobe terrace outwash consists of interbedded sand and gravel ranging from silty, very-fine sand to sandy pebble-gravel, moderately to poorly sorted. Bedding is typically stratified or cross-bedded, and in places is collapsed. This unit commonly contains abundant shale in the coarse sand and gravel fraction.

This unit forms terraces along the Crow River and its major tributaries, the North and South Forks. The upper surfaces of these terraces are commonly collapsed. In these hummocky terraces, the sand and gravel is typically interbedded with or overlain by Des Moines lobe till ranging from one to ten feet thick. This interbedded till was probably deposited by slumping of debris from adjacent ice-cored areas into meltwater streams in the river valley.

Des Moines lobe terrace deposits have been extensively utilized for sand and gravel aggregate in Wright County. In the west-central and eastern portions of the county, this unit is the principal source of aggregate. There are several gravel pits and 10 MN/DOT-identified aggregate sources present in this unit.

Because the source of this meltwater was the Des Moines lobe proper, the sand and gravel in the terraces along the Crow River contains abundant shale. The highest percentage of shale is present along the North and South Forks of the Crow River (Appendix B - Pit #'s 86069, 86075 and 86023) while the terraces along the Crow River have considerably less shale (Appendix B - Pit #'s 86081 and 86078).

The percentage of gravel present in the terraces along the Crow River and its tributaries is laterally quite variable (Appendix B). However, the percentage of gravel present in the Crow River terraces generally increases with depth. The reason for this pattern is that the lower portions of each terrace were deposited while the Des Moines lobe was fairly near to Wright County and the high-velocity meltwater streams contained more gravel. As the Des Moines lobe receded, the coarser sediment in the meltwater streams was deposited near the ice, and less gravel was transported to Wright County. This increase in percent gravel with depth is displayed in MN/DOT-identified aggregate source # 86081 near Hanover (Fig. 11).

In summary, Des Moines lobe terrace outwash represents a significant past and future source of aggregate for Wright County. Factors that could potentially limit its use for certain types of aggregate include excessive shale, especially in the western and southern parts of this unit, the local presence of interbedded till and supraglacial sediment, and the low percentage of gravel present at some locations.

Des Moines Lobe Upper Terrace Outwash: This unit consists of stratified sand and gravel ranging from very-fine sand to sandy pebble-gravel, moderately to poorly sorted and locally cross-bedded. This unit forms the upper terraces along the Mississippi River.

There are four MN/DOT-identified aggregate sources and a scattering of other gravel pits in this unit. This unit generally contains more gravel than the lower outwash terraces, because it was deposited while the Des Moines lobe and its high velocity meltwater streams were nearer to Wright County. The upper terrace outwash should also contain more gravel at depth for the above-mentioned reasons. The percentage shale present and LAR values for this unit are quite low.

In summary, this unit is a potentially important source of high quality aggregate, but it may be limited locally due to the relatively low percentage of gravel present.

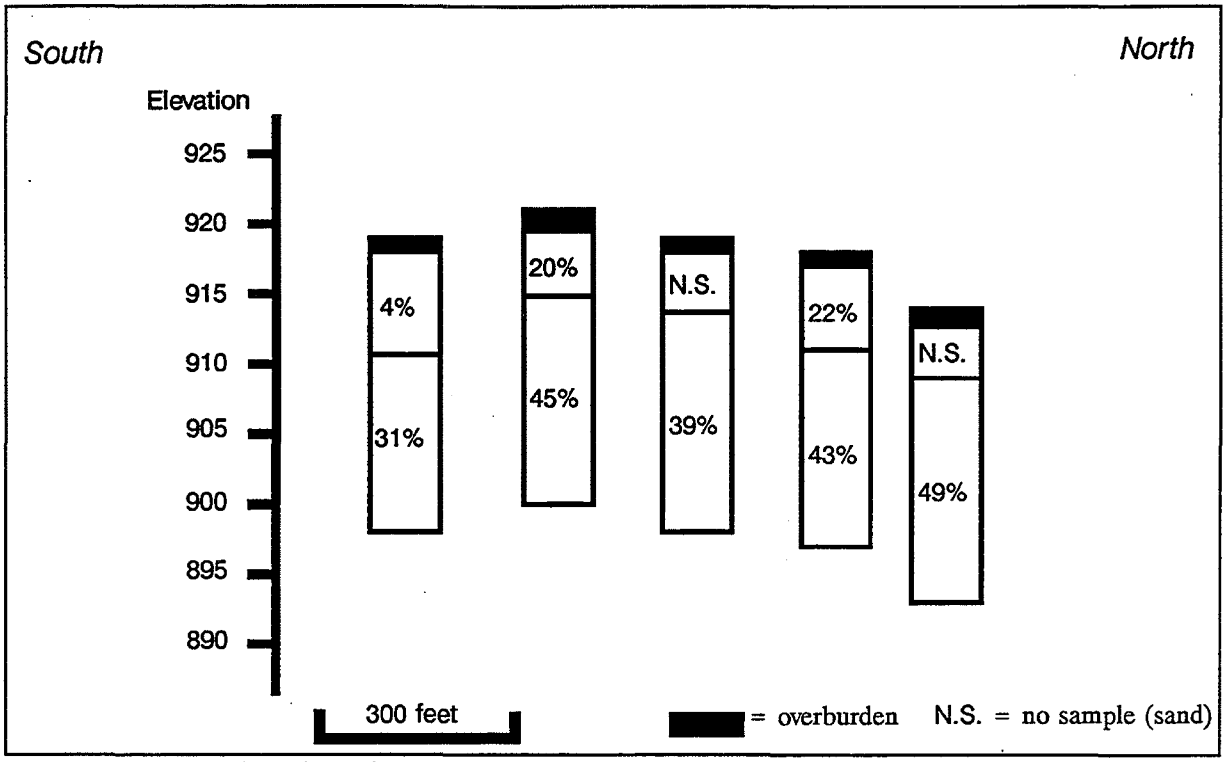

Figure 11. Cross-section of MN/DOT-identified aggregate source 86081 showing selected test holes. Values shown are percent gravel present in each interval sampled.

Des Moines Lobe Lower Terrace Outwash: This unit is stratified sand and gravel ranging from silty very-fine sand to sandy pebble-gravel, moderately to poorly sorted and locally cross-bedded. This unit forms the lower outwash terraces along the Mississippi River.

There is only one MN/DOT-identified aggregate source in this unit and a small number of gravel pits in the area between Otsego and Dayton. No quality data are available, but the percent shale and LAR values are probably quite similar to the upper outwash terraces. This unit has potential for aggregate, but a limiting factor is the low percentage of gravel present. This unit is less utilized for aggregate than the upper outwash terraces in Wright County.

Superior Lobe Ice-Contact Sand and Gravel: This unit consists of sand and gravel ranging from fine sand to sandy, cobbly, pebble-gravel, generally poorly to very-poorly sorted, but in places is moderately to well sorted. This unit commonly contains interbedded reddish-brown till. It is characterized by collapsed bedding and reddish-brown color. Superior lobe ice-contact sand and gravel occurs as kame complexes (T120N, R28W), esker complexes (T119-120N, R26W) and individual kames and eskers (T121N, R23-24W and T120N, R23-25W).

In several localities, the sand and gravel of this unit is overlain by Des Moines lobe till and supraglacial sediment ranging from three to greater than 10 feet thick. In most areas, logs from wells drilled in this unit indicate Des Moines lobe till and supraglacial sediment 10 to 35 feet thick overlying Superior lobe sand and gravel. In the large area of Superior lobe ice-contact sand and gravel mapped west of Buffalo, well logs indicate considerably thicker (up to 95 feet) cover of Des Moines lobe till. Superior lobe ice contact sand and gravel is mapped where overlain by a variable thickness of Des Moines lobe till because the landforms that these sediments comprise are clearly visible through the cover of Des Moines lobe till.

The aggregate potential of the kame complex south of Lake Sylvia and Lake Francis is not well understood. There are no MN/DOT-identified aggregate sources and only two gravel pits located in this kame complex. The northern one third of the kame complex appears to have the most potential, because the overburden appears to be thinnest here. The southern two thirds of the kame complex is covered by fairly thick Des Moines lobe till and supraglacial sediment.

The aggregate potential of the large buried Superior lobe kame south of the North Fork of the Crow River in T120N, R28W is probably quite similar to the kame complex immediately to the north. The upper portion of this kame has been reworked into a Des Moines lobe ice-contact deposit that contains abundant Superior-lobe rock-types.

The potential for aggregate resources in the large esker complex west of Buffalo is not well known. There are/were five gravel pits and no MN/DOT-identified aggregate sources located in this esker complex. Of all the areas mapped as Superior lobe ice-contact sand and gravel, this area seems to have the greatest variability of Des Moines lobe till cover. The only exposure in this esker complex that displays the stratigraphic relationships between the two units is in NE¼, NW¼, NW¼, SW¼, sec. 25, T120N, R26W.

The Superior lobe ice-contact sand and gravel located in the northeastern portion of the county has been utilized quite extensively for aggregate. There are four MN/DOT-identified aggregate sources and a few isolated gravel pits in this area. The percentage of gravel present in these deposits is highly variable, ranging from 9.3 percent to 32.0 percent. The LAR values and percentage shale present are quite low, as expected of Superior lobe sediment.

In summary, the aggregate potential of Superior lobe ice-contact sand and gravel is the most variable of all potential aggregate units mapped. This is due primarily to the variable cover of Des Moines lobe till present at many localities, thereby deterring development of the resource because of excessive overburden thickness. There are locally important sources of aggregate within this unit, but evaluation of these certainly requires site specific investigation.

Limited Potential for Aggregate Resources

This unit is comprised of organic deposits, alluvium, alluvium-fine facies, alluvium-coarse facies and Des Moines lobe till. In general, this unit has little or no potential for aggregate deposits, but there are potential sources of aggregate present locally.

Organic deposits located within or adjacent to a potential aggregate unit have potential where the overburden of organic deposits is thin. Another factor limiting the aggregate potential of areas underlain by organic deposits is the high water table usually present in these areas.

Alluvium, and alluvium-coarse facies have very limited potential for aggregate. The principal factor limiting the aggregate potential of these units is the low percentage of gravel present, in fact, at many localities, this unit is entirely sand.

Alluvium-fine facies has essentially no potential for aggregate due to the lack of gravel.

Des Moines lobe till and supraglacial sediment contains limited potential; however, locally significant sources of aggregate may be present. These deposits are extremely difficult to map, but occur in a somewhat predictable manner. The areas within this unit with the highest potential for aggregate are located in the vicinity of the buried Superior lobe end moraines (Fig. 6). These inclusions occur in two settings. The first setting is where Superior lobe end moraines containing abundant sand and gravel were eroded and subsequently deposited by the Des Moines lobe as isolated ice-contact deposits. The second setting is areas where the cover of Des Moines lobe till is thin enough to allow profitable extraction of Superior lobe ice-contact sand and gravel from the buried end moraines.

Summary

Identification of potential aggregate resources in Wright County was accomplished by mapping Quaternary geology. The geologic units which have potential for aggregate were then grouped into a single *potential aggregate resources* unit. This approach allows inferences to be made about the lateral and vertical variability of the potential aggregate resources present within individual geologic units.

The methodology used in mapping Quaternary geology consisted of stereoscopic examination of aerial photographs, study of large-scale topographic maps and review of subsurface data, including well logs and MN/DOT pit-sheet data. These interpretations were supplemented by observation of surficial sediments in the field. The map was prepared using the tools available in geographic information systems. The geologic units were digitized, integrated with base map data and printed on a 400 dot-per-inch plotter.

The aggregate resources in Wright County were deposited by the meltwaters of two separate glacial lobes, each contributing distinct physical properties to the resource. The Superior lobe advanced southwestwardly into Wright County, depositing gravel-rich sediment that yields generally high-quality aggregate. Following retreat of the Superior lobe, the Des Moines lobe advanced into southwestern Wright County from the northwest. The Grantsburg sublobe of the Des Moines lobe then advanced to the northeast, covering all of Wright County. These western lobes deposited sediment containing shale (a detrimental constituent of aggregate) over essentially all of the county.

The potential aggregate resources in Wright County are located primarily along the northwestern, northern and eastern boundaries of the county, as well as along the North Fork of the Crow River and in the area between Buffalo and Monticello. Aggregate in the southern one-third of the county is restricted to the valleys of Sucker Creek and the South Fork of the Crow River.

The texture and quality of aggregate within the *potential aggregate resource* unit varies throughout the county. The percent gravel in MN/DOT-identified aggregate sources is highest in the vicinity of the buried Superior lobe end moraines and is lowest along the Mississippi River. In general, higher quality aggregate (i.e. low percent shale and low LAR values) is present in the northern one-half to one-third of the county, reflecting the greater amount of Superior lobe sediment incorporated by the Grantsburg sublobe as it advanced over the buried Superior lobe end moraines.

Acknowledgements

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Appendix A: Minnesota Statutes, Section 84.94

84.94 AGGREGATE PLANNING AND PROTECTION.

Subdivision 1. **Purpose.** It is the purpose of this act to protect aggregate resources; to promote orderly and environmentally sound development; to spread the burden of development; and to introduce aggregate resource protection into local comprehensive planning and land use controls.

Subd. 2. **Definition.** For the purpose of this act, "municipality" means a home rule charter or statutory city, or a town.

Subd. 3. **Identification and classification.** The department of natural resources, with the cooperation of the state geological survey, departments of transportation, and energy, planning and development, outside of the metropolitan area as defined in section 473.121, shall conduct a program of identification and classification of potentially valuable publicly or privately owned aggregate lands located outside of urban or developed areas where aggregate mining is restricted, without consideration of their present land use. The program shall give priority to identification and classification in areas of the state where urbanization or other factors are or may be resulting in a loss of aggregate resources to development. Lands shall be classified as:

(1) identified resources, being those containing significant aggregate deposits;

(2) potential resources, being those containing potentially significant deposits and meriting further evaluation; or

(3) subeconomic resources, being those containing no significant deposits.

As lands are classified, the information on the classification shall be transmitted to each of the departments and agencies named in this subdivision, to the planning authority of the appropriate county and municipality, and to the appropriate county engineer. The county planning authority shall notify owners of land classified under this subdivision by publication in a newspaper of general circulation in the county or by mail.

Subd. 4. **Local action.** Each planning authority of a county or municipality receiving information pursuant to subdivision 3 shall consider the protection of identified and important aggregate resources in their land use decisions.

History: *1984 c 605 s 1*

Appendix B: Summary of MN/DOT Aggregate Data - Wright County

The following table of the physical properties of aggregate in Wright County is summarized from the data contained on MN-DOT's aggregate pit-sheets. These pit sheets are available from MN-DOT in St. Paul. The gradation data were calculated by averaging the weighted averages for all test holes on the sheet. These averages provide a crude measure of the amount of gravel versus fine material for a given area. The LAR values presented below are an average of all LAR tests for a given pit. In many cases, values from LAR tests using slightly different methods are averaged (see AASHTO T 96-83 for a discussion of the methods used in LAR A, LAR B and LAR C). These values are usually within a few percent for a given sample. They are presented in order to address general variations in quality.

GEOLOGIC UNIT[1]	PIT #[2]	LOCATION[3]	GRAVEL[4]	COARSE SAND[5]	FINES[6]	AVE LAR (% LOSS)	AVE % SHALE + 4 MESH	AVE % SHALE - 4 MESH
Di	86060	121-24-27CD & DC	19.3	40.0	40.7	20.1	1.5	1.3
	86043	120-26-17AC	31.4	45.4	23.2	-	-	-
	86025	119-26-01AC	37.1	46.6	16.3	-	-	-
	86024	119-26-01AC	42.5	45.4	12.1	-	-	-
Do	86068	122-26-15CA	29.3	39.1	31.6	19.6	0.4	0.5
	86015	122-26-21AD	37.1	39.5	23.4	21.2	1.7	1.3
	86022	122-26-29AA	35.0	44.6	20.4	21.4	0.4	0.7
	86057	121-25-13AA	12.9	50.4	36.7	22.5	7.8	4.7
	86062	121-25-14BC	30.6	45.1	24.3	23.0	2.2	2.3
	86072	121-25-15BB & BC	36.2	39.9	23.9	21.6	1.4	2.8
	86002	121-25-27BC & 28AD	43.5	38.2	18.3	-	-	-
	86004	121-25-27CB & 28DA	40.3	38.5	21.2	22.0	3.4	5.4
	86079	121-24-18BD	15.5	32.5	52.0	19.4	2.8	2.2
	86071	119-28-27DA	27.4	29.4	43.2	-	12.0	9.6
	86070	119-28-27DD	34.8	37.4	27.8	26.0	6.5	8.1
	86005	119-26-13CB & CC	33.1	39.4	27.5	26.5	11.9	6.0
	86006	119-26-23DD & DA	40.8	37.5	59.2	-	-	-
	86074	119-26-23DD	24.0	32.5	43.5	26.0	17.6	9.2
	86065	119-25-19BA	26.3	47.2	26.5	-	-	-
	86045	119-25-19AA & 20BB	16.2	41.2	42.6	-	-	-
Doc	86054	121-28-22DD	44.6	34.4	21.0	18.0	0.3	1.4
	86012	121-28-23DD & 24CC	49.5	36.9	13.6	-	-	-
	86082	121-28-25AA & AD	39.5	37.1	23.5	22.7	0.6	1.0
	86052	121-27-04BD & CA	37.5	45.2	17.3	-	-	-
	86053	121-27-09AC	34.9	47.5	17.6	21.9	0.4	0.3
	86030	121-27-26BC	31.8	33.8	34.4	-	-	-
	86049	121-27-27BD	35.8	37.2	27.0	23.5	0.4	0.3
	86048	121-27-33DA	11.6	29.8	58.6	-	-	-
	86031	120-27-03CA	28.5	44.2	27.3	30.1	16.6	5.3
	86042	120-26-02DA	30.5	30.7	38.8	25.7	12.4	8.0
	86066	120-26-25AA	31.4	38.8	29.8	24.7	2.3	2.0
	86073	120-25-05DA	40.1	32.1	27.8	23.2	3.5	3.7
	86032	120-25-18CD	45.1	32.4	22.5	27.4	6.5	5.6
	86027	120-25-18DA & AD	30.0	39.7	30.3	-	-	-
	86026	120-25-18DA & AD	31.5	39.6	28.9	18.5	2.8	4.6
	86028	120-25-18DA & AD	39.0	35.1	25.9	31.5	5.7	6.8
	86037	120-25-18DD	44.6	35.3	20.1	23.2	4.7	5.7
	86036	120-25-18DD	41.0	38.0	21.0	24.6	4.7	4.9
	86038	120-25-19B	42.4	33.4	24.2	-	-	-
	86039	120-25-19B	45.2	27.0	27.8	22.2	6.0	6.3
	86067	120-25-30BB	32.1	34.6	33.3	24.0	5.5	3.3

GEOLOGIC UNIT[1]	PIT #[2]	LOCATION[3]	GRAVEL[4]	COARSE SAND[5]	FINES[6]	AVE. LAR (% LOSS)	AVE % SHALE + 4 MESH	AVE. % SHALE - 4 MESH
Dot	86081	120-24-25AC	38.4	40.7	20.9	23.9	3.4	4.1
	86061	120-23-08CC	22.8	48.6	28.6	-	-	-
	86044	120-23-08CD	32.3	36.4	31.3	-	-	-
	86078	120-23-09CB	44.0	35.6	30.4	25.8	2.4	2.4
	86069	119-27-12BA & BB	37.8	38.3	23.9	25.9	8.5	9.3
	86075	119-26-16CB	28.1	44.8	27.1	-	13.7	6.4
	86010	119-24-29CA & CD	35.0	41.3	23.7	-	-	-
	86008	118-25-01CC	36.1	36.4	27.5	-	-	-
	86023	118-25-01CD	20.2	37.9	41.9	-	7.1	4.2
	86051	118-25-34CC	31.1	35.7	33.2	-	-	-
Dot-u	86029	121-25-03DC	29.2	47.0	23.8	22.8	0.2	0.2
	86059	121-24-10CC	39.2	27.9	32.9	17.4	0.2	0.4
	86064	121-24-10DD	25.7	33.4	40.9	18.3	0.2	0.2
	86063	121-24-11CC	29.5	49.9	20.6	22.4	0.4	0.2
Dot-l	86080	121-23-26BD	14.5	48.1	37.4	-	-	-
Si_m	86056	120-23-05CB	9.3	38.1	52.6	22.2	0.7	0.4
	86055	120-23-06AC	10.8	33.8	55.4	-	-	-
	86076	120-23-06BD	32.0	46.0	22.0	-	-	-
	86077	120-23-06BD	14.8	44.8	40.4	-	-	-

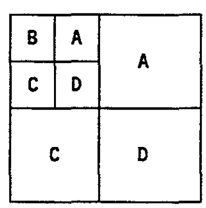
AVERAGES PER UNIT

Di	30.1	43.6	25.3	20.1	1.5	1.3
Do	30.2	39.5	32.6	22.6	5.7	4.4
Doc	36.5	36.3	26.2	24.1	4.8	3.9
Dot	32.6	39.6	28.8	25.2	7.0	5.3
Dot-u	30.9	39.6	29.6	20.2	0.2	0.2
Dot-l	14.5	48.1	37.4	-	-	-
Si_m	16.7	40.7	42.6	22.2	0.7	0.4

[1] Di = Des Moines lobe Ice-contact deposits, Do = Des Moines lobe outwash, Doc = Des Moines lobe collapsed outwash, Dot = Des Moines lobe terrace outwash, Dot-u = Des Moines lobe upper terrace outwash, Dot-l = Des Moines lobe lower terrace outwash, Si_m = Superior lobe ice-contact deposits mantled by Des Moines lobe till

[2] MN-DOT identification number

[3] First number refers to the township, the second number refers to the range, the third number refers to the section. The letters following the section number refer to the forty acre parcel within the section. A corresponds to the NE 1/4, B corrresponds to the NW 1/4, C corrsponds to the SW 1/4 and D corresponds to the SE 1/4.



[4] Percentage gravel - AASHTO definition (greater than 2.0 mm)

[5] Percentage coarse sand - AASHTO definition (.425 mm to 2.0 mm)

[6] Percentage fine sand, silt and clay - ASSHTO definition (less than .425 mm)

[7] Indicates no data available

Appendix C: Glossary [1]

alluvium A general term for clay, silt, sand, gravel, or similar unconsolidated material, deposited during comparatively recent geologic time by a stream or other body of running water.

calcareous Said of a substance that contains calcium carbonate.

carbonate A sediment formed by the organic or inorganic precipitation from solution of carbonates of calcium, magnesium, or iron; e.g. limestone and dolomite.

clast An individual constituent, grain, or fragment of a sediment or rock, produced by the disintegration of a larger rock mass.

collapsed A sediment or landform characterized by disruption of original bedding due to loss of underlying support caused by melting of underlying ice.

continental glacier A glacier of considerable thickness completely covering a large part of a continent or an area of at least 50,000 sq km, obscuring the relief of the underlying surface, such as the ice sheets covering Antarctica and Greenland.

cross-bedding An arrangement of strata inclined at an angle to the main stratification. Produced by the migration of ripples and dunes, caused by the action of currents.

debris The rocks, earth and other material lying on the surface, or incorporated in the body of a glacier, or pushed ahead of the glacier front.

diamicton A nongenetic term for a nonsorted or poorly sorted sediment that contains a wide range of particle sizes in a muddy matrix.

drift A general term applied to all rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.

esker A long, narrow, sinuous, steep-sided ridge composed of irregularly stratified sand and gravel that was deposited by a stream flowing between ice walls or in a ice tunnel of a stagnant or retreating glacier, and was left behind when the ice melted.

facies The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin; especially as differentiating the unit from adjacent or associated units.

glacigenic Said of processes, deposits and landforms directly or indirectly resulting from the presence of glacier ice and controlled by the activity of the ice and the variations in its melting.

Holocene The second epoch of the Quaternary period; 10,000 years before present to the present.

ice-contact deposits Stratified drift deposited in contact with melting glacier ice, such as an esker, a kame, a kame terrace.

kame A low mound, knob, hummock, or short irregular ridge, composed of stratified sand and gravel deposited by meltwater either at the glacier margin or within a low place or hole on the surface of the stagnant ice.

late Wisconsinan substage A subdivision of the Pleistocene epoch; 35,000 years before present to 10,000 years before present.

morainal topography An irregular landscape produced by deposition of drift and characterized by irregularly scattered hills and undrained depressions.

moraine A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacier ice, in a variety of topographic landforms that are independent of control by the surface on which the drift lies.

outwash Stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the end moraine or the margin of an active glacier. The coarser material is deposited nearer to the ice.

outwash plain A broad, gently sloping sheet of outwash deposited by meltwater streams flowing in front of or beyond a glacier, and formed by coalescing outwash fans.

Pleistocene The first epoch of the Quaternary period; 1.65 million years before present to 10,000 years before present.

Quaternary The second period of the Cenozoic era, 1.65 million years before present to the present. Comprised of the Pleistocene and Holocene epochs.

sandstone A medium-grained sedimentary rock composed of abundant rounded or angular fragments of sand size set in a fine matrix (silt or clay) and more or less firmly united by a cementing material (commonly silica, iron oxide or calcium carbonate); the consolidated equivalent of sand.

shale A fine-grained detrital sedimentary rock, formed by the consolidation of clay, silt or mud.

slump The sliding-down of a mass of soft, unconsolidated sediment shortly after its deposition on a slope.

sorted Said of an unconsolidated sediment or of a cemented detrital rock consisting of particles of essentially uniform size or of particles lying within the limits of a single grade.

stagnant ice (a) Ice that is not flowing forward and is not receiving material from an accumulation area. (b) Detached blocks of ice left behind by a retreating glacier, usually buried in moraine and melting very slowly without the production of large quantities of water.

supraglacial Carried upon, deposited from, or pertaining to the top surface of a glacier or ice sheet; said of meltwater streams, till, drift, etc.

terrace Any long, narrow, relatively level or gently inclined surface, generally less broad than a plain, bounded along one edge by a steeper descending slope and along the other by a steeper ascending slope. A terrace commonly occurs along the margin and above the level of a body of water, marking a former water level.

till A sediment that has been transported and subsequently deposited by or from glacier ice, with little or no sorting by water.

till plain An extensive area, with a flat to undulating surface, underlain by till with subordinate end moraines.

valley train A long, narrow body of outwash, deposited by meltwater streams beyond the margin of an active glacier and confined within the walls of a valley.

volcanic Pertaining to the activities, structures, or rock-types of a volcano.

[1] *Definitions modified from: Bates and Jackson, 1987; Richmond and Fullerton, 1986; Dreimanis, 1988; and Lundqvist, 1988.*

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