Minnesota Department of Natural Resources
Division of Minerals
William C. Brice, Director

AGGREGATE RESOURCES
EASTERN CLAY COUNTY, MINNESOTA

J.D. LEHR

1997

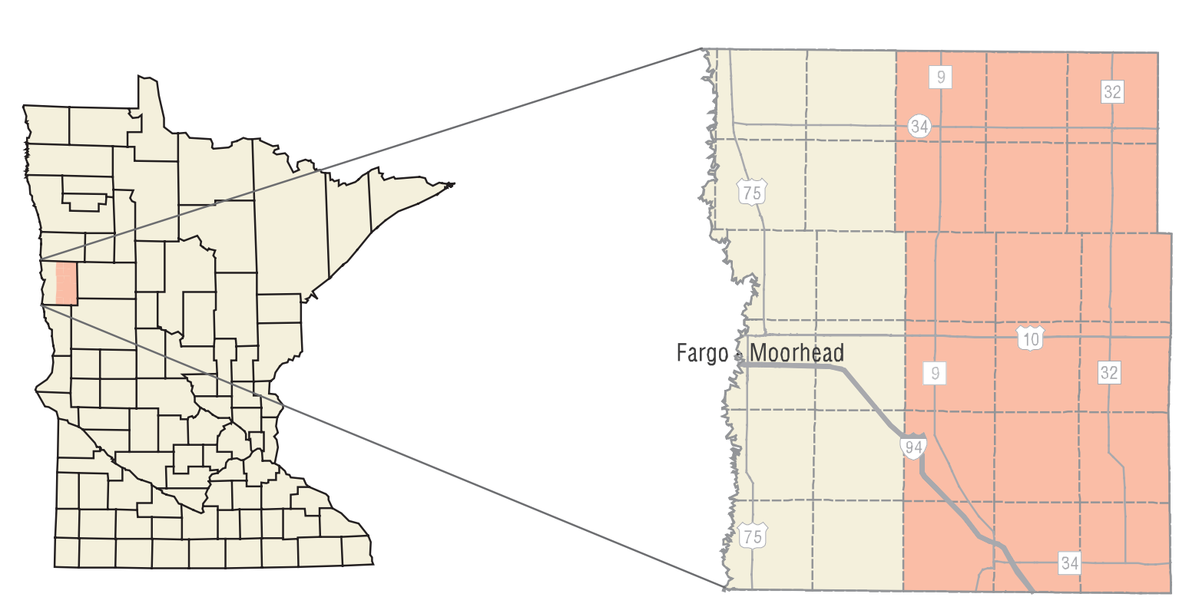
INTRODUCTION

The availability of aggregate sources near markets is critical to building and maintaining this country's infrastructure, and in controlling costs of construction projects, many of which are publicly funded. Aggregate consumption in the Fargo-Moorhead market, which includes all of Clay County, is approximately 12 to 13 tons per capita (Squires, 1996). Even though aggregate consumption is driven by our entire society, few people purchase raw aggregate products directly, and are therefore not well informed about the issues surrounding aggregate production.

Recent geologic processes have resulted in an uneven distribution of materials suitable for use as aggregate, as the situation in the Red River valley so readily demonstrates. The larger communities in the Red River valley lie in a region where aggregate sources are virtually absent, resulting in a situation where aggregate is commonly transported 25 to 40 miles, or more. The cost of transporting aggregate this distance adds significantly to the total cost of this essential resource. Therefore, there is an economic advantage to communities that have readily available local sources of aggregate for present needs, as well as future generation's needs.

Across the country, aggregate resource development is becoming increasingly more difficult due to conflict with other land uses, especially near expanding urban areas. Furthermore, other types of land use controls also result in conflicts with aggregate mining. Examples of land-use controls that restrict or prohibit aggregate resource development include parks, wetland protection, zoning regulations, cultural and historic resource sites, and other environmental issues, such as preservation of natural communities. With the above mentioned issues in mind, the 1984 Minnesota legislature passed a law (M.S. 84.94, Aggregate Planning and Protection) which mandates that the DNR, in cooperation with the state geological survey and state department of transportation, conduct a program to map potential aggregate resources, and provide this information to local governments to assist them in making land use decisions. This map was prepared to fulfil this obligation. The following paragraphs describe the methodology used in preparing the Aggregate Resource Potential Map of Eastern Clay County, Minnesota (Plate I), and provide supplementary information for users of this map. The audience is assumed to be local governmental officials and the aggregate industry. The location of the mapped area is shown in Figure 1.

Figure 1. Location of Eastern Clay County, Minnesota

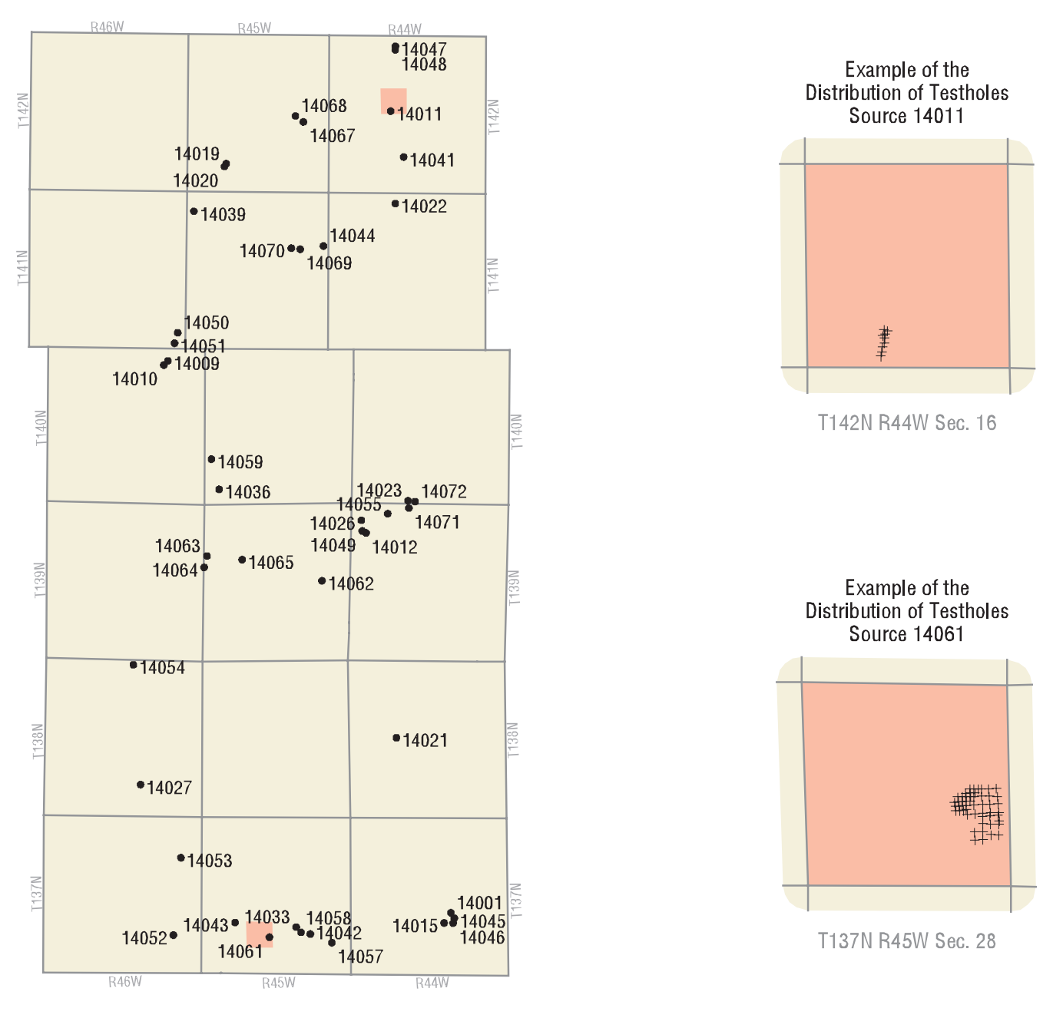


METHODOLOGY

This map was prepared using techniques that are widely used to prepare surficial geologic maps in areas affected by glaciation during the Ice Ages. Beginning with a general understanding of the distribution and types of sediments present in the region, a preliminary geologic map legend was formulated. Since the purpose of this map is to assess aggregate resource potential, most attention was given to those geologic units that may host aggregate deposits, and little time was spent studying geologic units that have limited potential as sources of aggregate.

Various sources of subsurface information and publicly available data on aggregate deposits were obtained and organized prior to the start of mapping. These data include the County Well Index (Minnesota Geological Survey, 1993) and data included on Mn/DOT gravel pit sheets. The County Well Index is a computer database containing well driller's logs of geologic materials encountered while drilling wells in addition to the field-verified location of each well. The well log information was used to substantiate geologic interpretations, especially the occurrence of buried deposits. The aggregate data received from Mn/DOT include test hole logs, sieve analyses and the results of quality tests performed on aggregate samples collected through auger drilling programs. The data presented on the pit sheets were summarized (Table 1) and used to characterize the physical properties of known aggregate deposits in Clay County (Fig. 2).

Figure 2. Locations of Mn/DOT Aggregate Sources Summarized in Table 1



Note: For any given aggregate source shown, there are between 3 and 139 testholes and 5 to 175 samples. There can be zero to multiple samples for any given testhole.

A commonly used approach to mapping glacial sediments is referred to as the landsystems approach (Eyles, 1983). This technique relies on the principle that depositional glacial landforms are composed of a predictable range of sediments, some with greater potential to contain aggregate deposits than others. Color infrared aerial photographs (NAPP, 1991, 1992) were examined stereoscopically for the 15 quadrangles (U.S. Geological Survey 7.5 minute series) in the eastern half of Clay County and landform genesis was interpreted. In addition to landform expression, tonal contrasts displayed on the aerial photographs reveal information about the drainage characteristics, hence sedimentary composition of near-surface sediments. These tonal contrasts are especially marked on infrared photography acquired in the early spring, as were the NAPP products. In addition to information inferred from depositional landforms and tonal contrasts, erosional landforms were mapped. Certain types of aggregate deposits in Clay County occur buried beneath younger, non-aggregate bearing sediments. Areas where post-depositional erosion has removed some of this younger sediment have higher potential to host aggregate deposits.

Of course, areas where aggregate mining is currently active, or has occurred historically, indicate a certain amount of future potential, a fact well known to local aggregate producers and landowners. For this reason, an inventory of past and "current" aggregate mining was assembled. During the mapping of geologic materials using aerial photographs, the locations of gravel pits were recorded. The aerial photographs used in this study were acquired, for the most part, in April and early May, 1991. A few of the frames available for the study area date from early spring, 1992. Gravel pits visible on these photos, and large enough to map, were delineated on 7.5 minute topographic maps and are shown on the map as polygons.

In addition to these gravel pits, three other classes of gravel pits are displayed on the map, small pits visible on the NAPP photos, pits shown on the published topographic maps, and pits that have opened since the early 1990's. Gravel pits that were visible on the aerial photographs, but were too small to map as polygons were mapped on 7.5 minute topographic maps as points. These points represent small gravel pits opened since the topographic maps were published. Most of the topographic maps used for this study date from 1965 and 1966 and were prepared from aerial photographs taken in 1963. A few quadrangles in the southern part of the county were prepared from aerial photographs taken in 1972 and 1977. Gravel pits mapped on the published 7.5 minute topographic maps which occur outside the gravel pits mapped as polygons were digitized and are grouped with the above mentioned pits for display on the map. Through the course of field work for this project (June - September, 1995), several gravel pits that have opened since 1991 were noted and are also shown on the map with point symbols. Some of these pits are now quite large.

Upon completion of a preliminary geologic map of the study area, approximately 20 days were spent in the field checking the preliminary map and describing the sediments encountered, primarily in gravel pits. The preliminary map was then revised where necessary, while examining aerial photographs for a second time.

Table 1. Summary of Mn/DOT Aggregate Source Information Presented on Pit Sheets

GEOLOGIC MAP UNIT	SOURCE NUMBER	N[1]	GRAVEL[2]	COARSE SAND[3]	FINES[4]	LAR A % LOSS	LAR B % LOSS	LAR C % LOSS	% SHALE +4 SIEVE[5]	% SHALE SAND[6]	% IRON OXIDES	OVER-BURDEN[7]
B-1	14047	17	29.3	37.4	33.2		26.7		0.2	0.8	0.2	1.1
B-1	14036	49	29.4	45.1	19.1							1.1
B-1	14027	77	32.1	34.0	31.5	22.1	23.8		0.0	0.0		1.6
B-1	14061	52	33.9	41.6	26.3				0.7	0.7	0.5	1.3
B-1	14052	33	34.5	39.7	26.4							1.4
B-1	14048	4	35.9	41.1	29.6				0.2	0.3	0.3	1
B-1	14011	9	42.1	33.4	24.5							1
AVERAGE[8]			**33.9**	**38.9**	**27.2**	**22.1**	**25.3**		**0.3**	**0.5**	**0.3**	**1.2**
B-3	14043	15	18.2	27.3	54.5							1.7
B-3	14053	25	28.3	33.7	40.0	23.6	24.3		0.4	0.6	0.3	1.2
AVERAGE			**23.3**	**30.5**	**47.3**	**23.6**	**24.3**		**0.4**	**0.6**	**0.3**	**1.4**
O-1	14071	47	30.4	27.5	42.1	27.4		23.5		2.4	1.0	2.8
O-1	14055	79	38.3	30.6	26.4	22.7	23.4		2.1	1.6	1.0	2.5
O-1	14072	26	39.0	26.4	34.6	27.8			2.4	2.6	1.2	2.2
O-1	14026	64	41.3	32.2	25.0		24.7	24.8	1.6	2.1	0.6	2.8
O-1	14023	12	42.8	29.3	32.4							1.4
O-1	14062	139	43.0	34.4	24.3	23.9	23.9		1.0	0.9	0.5	2.4
AVERAGE			**39.1**	**30.1**	**30.8**	**25.5**	**24.0**	**24.2**	**1.8**	**1.9**	**0.9**	**2.4**
O-3	14001	35	33.2	30.8	22.6	18.8	20.3		0.7	1.7	0.6	
O-3	14015	26	37.7	38.5	16.1							4.3
O-3	14046	6	45.4	36.1	30.7		27.5		0.7	2.4	0.2	2.6
O-3	14045	21	46.6	47.5	14.8		22.6		1.8	2.1	0.5	1.7
AVERAGE			**40.7**	**38.2**	**21.1**	**18.8**	**23.5**		**1.1**	**2.1**	**0.4**	**2.9**
I-1	14057	14	39.6	40.0	20.4							
I-2 in Till Unit	14012	3	13.9	40.4	45.7				3.1	0.0	0.2	9.7
I-2 in Till Unit	14021	33	31.2	28.8	18.3	22.8	23.5		2.2	3.8	0.8	5.8
I-2 in Till Unit	14049	3	33.3	30.6	17.1				1.0	1.7	0.1	14
I-2 in Tillw Unit	14058	16	52.3	35.1	31.6				2.2	6.4	1.0	1.8
I-2 in Tillw Unit	14042	9	52.9	29.4	39.4							0.8
AVERAGE			**36.7**	**32.9**	**30.4**	**22.8**	**23.5**		**2.1**	**3.0**	**0.5**	**6.4**
So	14069	24	28.3	26.9	14.2	23.7			0.0	0.1	0.1	2.3
So	14070	23	30.1	36.9	19.7	23.1			0.0	0.2	0.2	2.6
So	14068	30	36.6	23.3	40.1	24.5			0.1	0.2	0.1	3.9
So	14067	48	41.6	21.9	26.8	24.8			0.1	0.4	0.2	3.1
So	14050	14	42.0	34.2	37.4	21.1	21.5		0.1	0.1	0.0	1.3
So	14010	10	42.4	32.0	23.4	20.7			0.0	0.0	0.0	1.3
So	14039	16	43.4	28.9	19.1	19.9	21.9		0.0	0.1	0.2	1.2
So	14051	40	44.6	39.5	18.5	22.0	20.4		0.1	0.1	0.0	1.3
So	14059	42	46.9	35.2	23.2	22.8	23.0		0.1	0.3	0.3	1.6
So	14054	51	51.3	32.0	37.9	22.1	23.4		0.2	0.3	0.3	1.4
So	14009	22	52.0	41.7	15.9	25.0	23.4	25.2	0.0	0.0	0.1	1.3
So	14019	8	58.8	33.8	19.2						0.3	1.6
So	14020	3	59.4	27.4	13.2				0.1	0.0	0.0	1.7
AVERAGE			**44.4**	**31.8**	**23.7**	**22.7**	**22.3**	**25.2**	**0.1**	**0.2**	**0.1**	**1.9**
Atypical Deposits												
Buried Outwash	14064	50	17.5	42.9	39.6		24.9		2.1	1.4	0.4	2.7
Buried Outwash	14065	25	32.1	43.3	24.5		22.9		1.2	1.2	0.2	1.9
Buried Outwash	14063	33	28.2	41.1	30.7		25.4		2.6	1.7	0.6	2.5
Beach in Tillw	14022	12	4.6	29.0	66.4							1.6
Beach in Tillw	14041	40	39.3	34.4	26.2							1.5
Reworked So?	14044	8	37.5	46.4	16.1			22.3	2.0	1.0	0.1	1.4

Notes:
[1] Number of testholes within the aggregate source
[2] Average percent retained on #10 sieve (>2 mm)
[3] Average percent passing #10 sieve (2 mm) and retained on #40 sieve (0.425 mm)
[4] Average percent passing #40 sieve (<0.425 mm)
[5] Average percent shale in +4 sieve fraction
[6] Average percent shale in sand fraction
[7] Average overburden thickness in feet
[8] Simple mean of all samples from source. Number of samples ranges from 5 to 175.

DESCRIPTION OF AGGREGATE-BEARING SEDIMENTS

The geologic sediments that are utilized as aggregate sources in Clay County can be categorized into two general groups based on genesis. Those deposited by glacial meltwaters and others concentrated by shoreline processes in Glacial Lake Agassiz. Glacial meltwater deposits are further subdivided into **outwash** and **ice-contact stratified sediments**. Both types of meltwater deposits contain a wide range of sediment types, ranging from coarse gravel to silt. In general, ice-contact stratified sediments are more likely to be heterogeneous. In other words, these deposits more likely contain interbedded clay, silt and oversize materials. Conversely, outwash deposits are generally more uniform in composition. Both types of meltwater deposits occur at the surface and in buried positions in Clay County.

Lake Agassiz (Fig. 3) formed south of the retreating glacier that was present in the Red River Valley at the end of the Ice Age, resulting in deposition of thick silts and clays present in the western part of Clay County. The various levels of Lake Agassiz are recorded as beach ridges and wave-cut scarps in the eastern part of Clay County and adjacent areas. In places, waves and shoreline currents deposited sand and gravel in beach ridges, and in other places eroded preexisting sediments into scarps. The physical properties of the beach sediments are dependant upon the type of previously deposited sediments upon which the waves and currents were striking, and therefore have a variable composition. In general, beach deposits have a low percentage of coarse gravel and limited overburden.

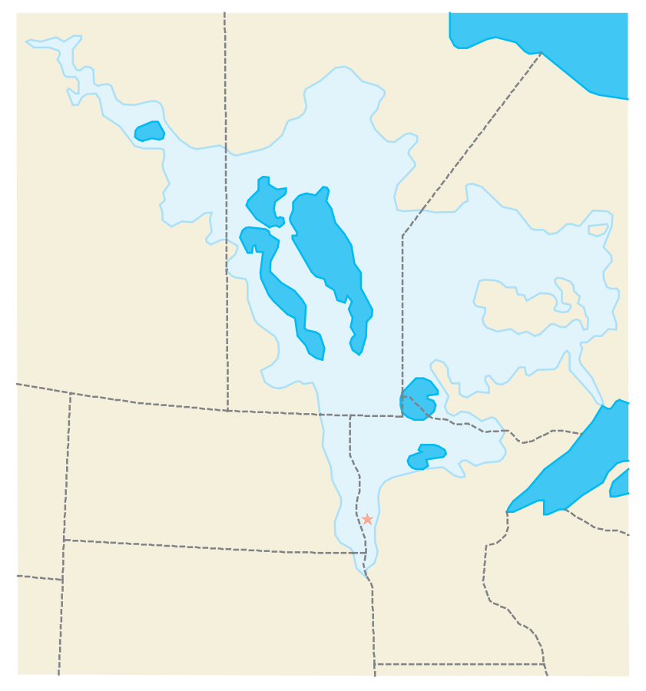


Figure 3. Location of Glacial Lake Agassiz

Another geologic factor contributing to the characteristics of aggregate deposits is the original source of the rock materials eroded by the glaciers. During the last Ice Age, western Minnesota was covered at different times by glaciers originating in areas to the northeast and in areas to the northwest. The glacial advances from the northeast occurred earlier. Northeastern-source sediments contain a suite of durable rocks derived from the Canadian Shield in northeastern Minnesota and adjacent Ontario in addition to appreciable amounts of carbonate rocks (limestone and dolomite). This factor is important to the aggregate producer, because the northeastern-source aggregate deposits yield products with low percentages of deleterious rock fragments. Aggregates with low percentages of deleterious rock fragments are required in the production of concrete products. Furthermore, these northeastern-source sediments locally contain abundant gravel-sized rock fragments, another desirable property of aggregate deposits.

The glaciers that advanced into the area from the northwest traversed parts of the Canadian Shield, in addition to soft sedimentary bedrock and unconsolidated fine-grained sediments. The northwestern-source deposits, therefore contain appreciable amounts of soft rock fragments, most notably siliceous shale, and also contain lower percentages of gravel-sized rock fragments relative to local northeastern-source deposits. Furthermore, the northwestern-source glacial advances have generally buried the northeastern-source sediments in Clay County. However, there are several northeastern-source aggregate deposits that are mined in the region and these generally occur in areas where post-depositional erosion, either by waves or streams, has removed some of the overburden.

CRITERIA USED TO INTERPRET AGGREGATE POTENTIAL

Aggregate potential is defined, for the purpose of this study, as follows: *an assessment of the relative probability that an aggregate deposit exists within a given area*. An attempt has been made to rank this potential as **high, moderate** and **slight**. This assessment does not imply that everywhere within a given unit there exist economic aggregate deposits. Furthermore, aggregate is used in a wide range of applications. Some of these applications require very specific types of materials, some of which simply can not be produced from certain deposits. This is a very important point, since not all aggregate is suitable for all end uses.

In an attempt to produce an aggregate potential map that is most useful to the non-geologist, while simultaneously providing a certain amount of detail, the geologic map units were grouped into four general categories based on the interpreted relative potential for these units to contain economic aggregate deposits. Obviously, historic and current aggregate production is also an indication of mineral potential and was considered. This assessment of aggregate potential considers only geologic factors. It does not include other factors important in developing an aggregate deposit, such as land ownership; land-use controls such as zoning; distance to potential markets; length of haul road construction; deposit development costs; or quantitative assessment of economic value. These factors are beyond the scope of this study.

The first step in assessing aggregate potential was to consider the geologic characteristics pertinent to aggregate deposit evaluation. These factors are: 1) the overall grain-size distribution of the sediments, or more specifically the percentage of gravel present; 2) the percentage of deleterious rock fragments present, primarily the percent shale present; 3) the general size of known and potential deposits; 4) general overburden thickness; 5) the probability of finding an economic deposit within a given unit; and 6) the presence of wetlands. The order in which these factors are listed is unrelated to their relative importance.

Within the Clay County area, deposits containing abundant gravel-sized material are generally more highly sought after than those deposits consisting of primarily sand. Furthermore, deposits containing both coarse (+ 4 mesh) and fine (4 to 10 mesh) gravel have more utility than those containing primarily fine gravel. The percentage of deleterious rock fragments present in aggregate is critical to producing certain products, especially concrete products. In the Clay County area, the most pervasive deleterious component is shale. Obviously, a larger deposit is more desirable than a smaller deposit. Utilization of larger deposits results in development of fewer gravel pits, but ones that are longer lived, thereby focusing gravel mining. Also, the cost of developing larger deposits is amortized over longer periods of time. Overburden thickness is often the critical factor in assessing the economic viability of an aggregate deposit. In general, more overburden can be economically removed from thicker deposits than from thinner ones. Of course, there is an upper limit to the amount of overburden that can be stripped from even the thickest potential deposits. The probability of finding a deposit within a given map unit is based on both the confidence of the map unit delineation (based in part on the distribution of supporting data and part on confidence of the geologic model) and the homogeneity of the geologic sediments. Proximity of wetlands to potential aggregate deposits is considered a geologic factor only because aggregate resource development within and near wetlands is more difficult from an engineering standpoint than situations where no wetlands are present. The specific regulatory factors (the Wetlands Conservation Act for example) associated with impacting wetlands are not considered.

The next step in the assessment of aggregate potential was to assign an arbitrary score to each geologic unit for each of the above mentioned geologic factors. While these scores are arbitrary, they reflect the relative ranking of the geologic map unit for each geologic factor considered important in aggregate deposit assessment. For some of the geologic factors, quantitative data exist to support this ranking process. For others, this ranking is based on geologic inference and qualitative field observations. The results of this scoring process are shown in Table 2 and the methodology is outlined below.

Percent Deleterious Rock Fragments [Shale on Table 2 and Figure4]: Scores range from 1 (higher percent deleterious) to 3 (lower percent deleterious) and are based on a combination of Mn/DOT data and qualitative field observations. Units with an average percent shale greater than 1% (Mn/DOT data) and where field observations showed shale to be common to abundant were assigned a score of 1. Units with an average percent shale between 0.5 and 1 % (Mn/DOT data) and where field observations showed small amounts of shale present were assigned a score of 2. Units with an average percent shale less than 0.5 % (Mn/DOT data) and where field observations showed either very small amounts of shale, or shale absent were assigned a score of 3.

Percent gravel [Gravel]: Scores range from 1 (lower percent gravel) to 3 (higher percent gravel) and are based primarily on Mn/DOT data. Units with an average low percentage of gravel (generally less than 30%) were assigned a score of 1. Units with an average high percentage of gravel (30 to 60%), where the gravel fraction is predominantly fine gravel (4 to 10 mesh) were assigned a score of 2. Units with an average high percentage of gravel (30 to 60%), containing abundant coarse gravel (+ 4 mesh) were assigned a score of 3.

Deposit Size [Deposit Size]: Scores range from 1 (smaller deposits) to 3 (larger deposits) and are based on field observations and geologic inference. Units with potential for and/or containing generally small deposits were assigned a score of 1. Units with potential for and/or containing medium sized deposits were assigned a score of 2. Units with potential for and/or containing large deposits were assigned a score of 3.

Overburden Thickness [Overburden Thickness]: Scores range from 1 (thicker overburden) to 3 (thinner overburden) and are based on Mn/DOT data, field observations and geologic inference. Units with a variable overburden thickness, which is locally excessive, were assigned a score of 1. Units with a few feet of overburden were assigned a score of 2. Units with minimal overburden were assigned a score of 3.

Probability [Probability]: Scores range from 1 (lower probability) to 3 (higher probability) and are based on the degree of current and historic aggregate resource development, confidence of map unit delineation, and availability of supporting subsurface data (primarily well log density). Prior to ranking the geologic map units, it was apparent that within the outwash units mapped (Type O), historic and existing gravel pits were somewhat clustered. Also, the distribution of available well logs was not uniform. Based upon this information, the outwash unit was subdivided into two units (O-1 and O-2), as was the collapsed outwash unit (O-3 and O-4). Units with a lower probability of containing economic aggregate deposits were assigned a score of 1. Units with an intermediate probability of containing economic aggregate deposits were assigned a score of 2. Units with a higher probability of containing economic aggregate deposits were assigned a score of 3.

In order to portray these scores in a form in which the various geologic map units may be compared, the results are presented on a stacked bar graph (Fig. 4). Graphing these five geologic factors aided in the grouping of the 10 geologic units into three aggregate potential categories, high potential, moderate potential, and slight potential. While Figure 4 appears complex, it is presented in order to provide the advanced user of this map a visual means of comparing the differences between the various potential deposit types within a single aggregate potential mapping unit.

Table 2. Scores of Aggregate Potential Economic Ranking Criteria for each Geologic Map Unit

Geologic Map Unit	Economic Ranking Criteria Type					
	Shale	Gravel	Deposit Size	Overburden	Probability	Cum. Score
B-1	2	2	1	3	3	11
B-2	2	1	1	3	2	9
B-3	1	1	2	1	1	6
O-1	1	3	2	2	3	11
O-2	1	1	1	2	2	7
O-3	1	3	3	2	3	12
O-4	1	3	3	2	2	11
I-1	1	3	1	2	2	9
I-2	1	3	1	1	1	7
So	3	3	3	1	1	11

AGGREGATE POTENTIAL RANKING CRITERIA

In the form
Criteria Type
Score[9] - Description

Shale
3 - Very small amounts or no shale (<0.5%)
2 - Small amounts of shale (0.5- 1.0%)
1 - Abundant shale (>1%)

Gravel
3 - High percentage of coarse gravel (30-60%)
2 - High percentage of fine gravel (30-60%)
1 - Low percentage of gravel (<30%)

Deposit Size
3 - Larger deposits
2 - Moderately sized deposits
1 - Smaller deposits

Overburden
3 - Minimal/thin overburden
2 - Moderate overburden thickness
1 - Thicker overburden

Probability
3 - Higher probability that the unit contains economic aggregate deposits
2 - Intermediate probability that the unit contains economic aggregate deposits
1 - Lower probability that the unit contains economic aggregate deposits

[9] where score of
3 = most desirable
1 = least desirable

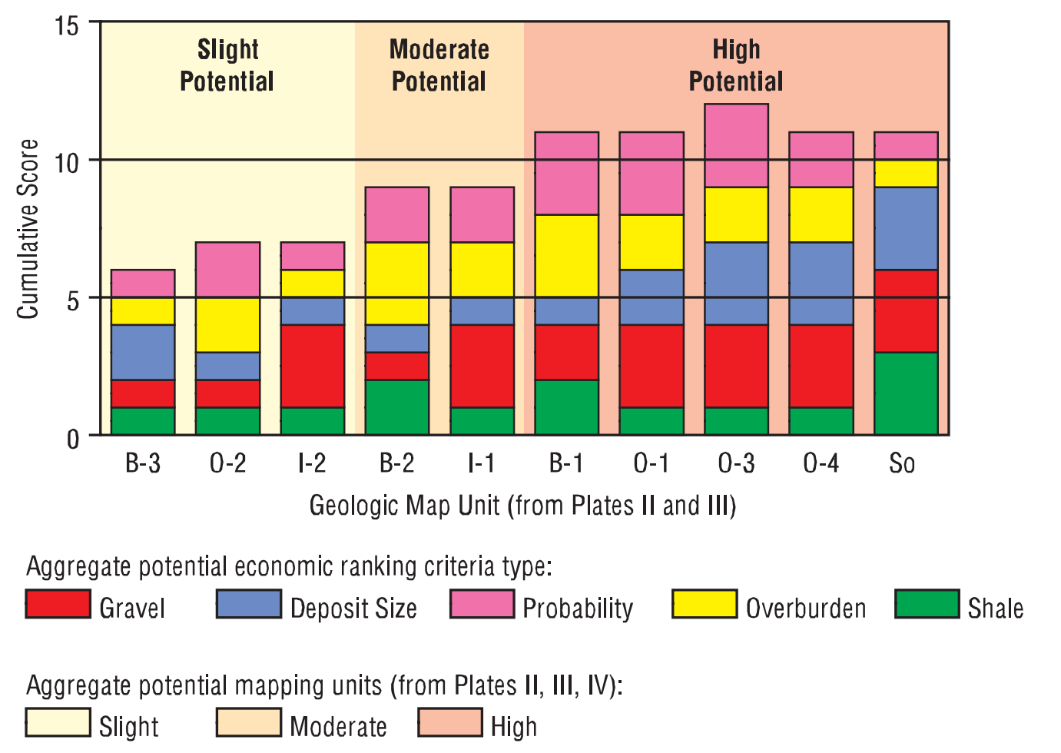
GEOLOGIC MAP UNITS

B-1 -- Major beach ridge
B-2 -- Minor beach ridge
B-3 -- Beach deposits not in ridges

O-1 -- Outwash (sand and gravel)
O-2 -- Outwash (sand)
O-3 and O-4 -- Collapsed outwash
So -- Subaqueous outwash of Northeastern Provenance

I-1 -- Ice-contact stratified deposits
I-2 -- Ice-contact stratified deposits, buried

Figure 4. Cumulative Scores of Aggregate Potential Economic Ranking Criteria for each Geologic Map Unit, Grouped by Aggregate Potential Map Unit



Those geologic units inferred to have limited potential for aggregate resource development were not scored and are shown separately on the map as limited potential. Examples of geologic map units within the study area that have limited potential for aggregate resources include silt deposited in Lake Agassiz, mapped in the far western part of the study area, and glacial till, some of which has been modified by stream processes and wave action, mapped in the eastern part of the study area.

Wetlands: Areas classified as wetlands on the National Wetlands Inventory (U.S. Fish and Wildlife Service, 1992) are displayed on the map in order to show areas where aggregate resource development may be hindered by saturated soil conditions. As mentioned above, no regulatory aspects of wetlands are implied, although they may exist. Determination of any conflict that may exist between wetland occurrence and aggregate mining usually requires site-specific wetland delineation.

ACKNOWLEDGMENTS

The landowners and aggregate producers in Clay County deserve thanks for allowing access to their properties during the course of this study. Without this access, the quality of the map would have been compromised. A great deal was also learned about the occurrence of aggregate and the local aggregate industry through discussions with landowners and aggregate producers. Special thanks (in no particular order) to Dan Ames (Ames Sand and Gravel and Ready Mix), Bruce Squires and Roy Sanders (CAMAS - Kost Division), Ray Zemple and Bob Bakkum (Northern Improvement Co.), Dave Asplin (Asplin Sand and Gravel), and Jack Cousins (Clay County Engineer). Mike Kamnikar and Geof George (Mn/DOT Aggregate Office) and the Minnesota Geological Survey are acknowledged for providing data that were so important to preparing this map. My supervisor, Dennis Martin served as a sounding board for many of the ideas presented on this map. Amy Griffin (DNR-Minerals) is acknowledged for her efforts in digitizing several of the included data layers. Finally, Renee Johnson (DNR-Minerals) deserves special credit for the computer and database aspects of this project as well as the map production.

REFERENCES

-- Eyles, N., 1983, Glacial geology: A landsystems approach, Glacial geology: An introduction for engineers and earth scientists, Pergamon Press, Oxford, p. 1-18.
-- Minnesota Geological Survey, 1993, County Well Index for Clay County, Minnesota, 1706 records.
-- Squires, Bruce, 1996, Presentation to the Lake Agassiz beach ridges steering committee, March 28, 1996.
-- U.S. Fish and Wildlife Service, 1992, National wetlands inventory of Minnesota, scale 1:24,000.

Plate II -- Aggregate Resources, North Half, Eastern Clay County, Minnesota, Map at a scale of 1:50,000.
Plate III -- Aggregate Resources, South Half, Eastern Clay County, Minnesota, Map at a scale of 1:50,000.
Plate IV -- Aggregate Resources, Eastern Clay County, Minnesota, Map at a scale of 1:100,000.