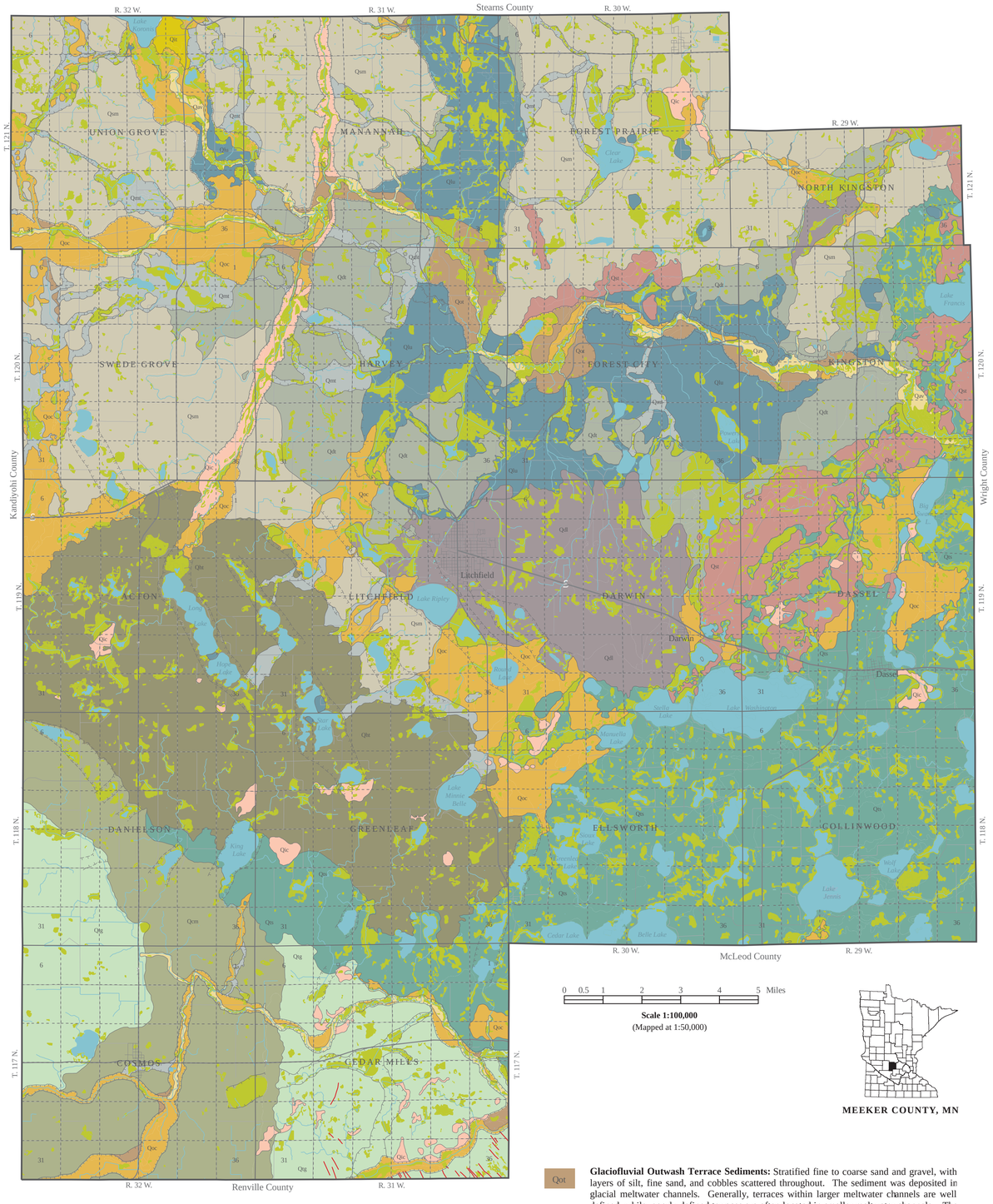
Minnesota Department of Natural Resources
Division of Lands and Minerals
William C. Brice, Director



MEEKER COUNTY, MN

GEOMORPHOLOGY OF MEEKER COUNTY

Landform Sediment Association

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Department of Natural Resources
Division of Lands and Minerals

GEOLOGIC HISTORY: The purpose of this plate is to relate the spatial distribution of aggregate resources to the geology of Meeker County. The presence of aggregate resources depends on the geologic events and processes that create landforms. Landforms can be the result of many geologic events over a long span of time and may be comprised of multiple sedimentary units. For that reason, the methodology for aggregate mapping involves interpreting the sequence of geologic events that created the present-day landforms of Meeker County. Geomorphology is a branch of geology that interprets the characteristics and evolution of landforms. The information gathered by observing landform allows for associated sediments to be interpreted, described, and delineated for the purposes of aggregate resources mapping. Therefore, the primary goals of this geomorphic plate are to: (1) show the distribution of landforms within Meeker County, and (2) to describe the sediment associations within those landforms.

Geological units exposed within Meeker County consist of glacial and modern sediments. During the Pleistocene (1.8 million to ~10,000 years ago), large continental glaciers advanced across Minnesota. Continental ice sheets originating in Canada formed ice lobes that slowly moved southward into Minnesota. As the glacial lobes advanced, they picked up (eroded) sediments consisting of bedrock and other surface materials. These sediments were transported and deposited by various processes related to glacial advance and retreat. The sediment exposed at the surface of landforms within Meeker County came from two different glacial sources. The older sediment was transported by glacial ice flowing through the Lake Superior basin that picked up indicator rocks like basalts and gabbros. Glaciers from the northwest flowed from the Winnipeg area and picked up indicator rocks such as limestone and shale.

Multiple glacial advances and retreats created the landforms observed in central Minnesota. As the glaciers advanced they deposited unsorted sediment (called till) composed of clay, silt, sand, gravel and boulders to form ground moraines, end moraines, and hummocky moraines. Although most of the county is covered in till from the latest glacial advance, most of the topography is related to earlier glacial advances and retreats creating a complex geologic history in the area. Glacial meltwater sorted sediment, carrying away silts and clays, and depositing coarser sand and gravel sediment (termed outwash) in landforms such as channels and plains. These channels were occasionally dammed by stagnating ice to create glacial lakes where the underlying material is covered by fine sand, silt, and clays. After all of the glacial activity ceased and the ice melted, modern day sediments such as flood plains, alluvial fans, and alluvial terraces began to form. These Holocene (10,000 years ago to Present) sediments continue to be deposited today as a result of recent geological processes.

MAPPING METHODOLOGY AND DATA SOURCES: Identifying the distribution of aggregate resources is largely determined by understanding the surficial geology and the geologic history of an area. The geologic history is the story, or sequence of events, of when and how the aggregate and other sediments were deposited. By understanding this story, we can identify the landforms most likely to contain aggregate resources. Traditional geologic mapping techniques were integrated with GIS (Geographic Information Systems) to interpret the geologic history and identify the distribution of aggregate resources for Meeker County. This was accomplished in several phases: 1) preliminary information gathering, 2) compiling, interpreting, and summarizing data, 3) field checking the data, and 4) producing the final maps and data sets.

The first step was to conduct a literature and data search to obtain a basic understanding of the geology in the area and to compile a list of existing data. Some of the data used are aerial photographs, topographic maps, digital elevation models, shaded relief, subsurface data, gravel pit and quarry data, surficial and bedrock geology, wetlands, lakes, streams, vegetation, soils, land-use, as wells as several datasets of background information, including roads, railroads, township - range - section boundaries, and others.

Subsurface data used for this study included the County Well Index (CWI) database and the Minnesota Department of Transportation's (MN/DOT) files. The CWI is an online database maintained by the Minnesota Geological Survey (MGS, 2003) that contains basic information for over 300,000 wells drilled throughout Minnesota. As of 2003, when the CWI data were obtained, approximately 731 of these wells were located in Meeker County. Almost all of the wells (695) contained geological descriptions that were found to be useful for the study. The MN/DOT Aggregate Source Information System (ASIS) digital files consist of aggregate quality and textural (i.e., sieve or particle size) data, and where pit sheets were available, shallow test hole logs, and a diagram of test hole locations (the associated data were summarized in a database). The subsurface information was used to look for buried sand and gravel deposits, determine the depth to bedrock, and identify the type of bedrock encountered.

Once all of this information was digital, a computer program by ESRI called ArcView©, was used to help interpret, compile, and summarize the data. Compiled information was then incorporated into the development of a working geologic history for Meeker County. Color infrared and black-and-white aerial photographs were then used in conjunction with geological modeling to delineate geological landforms and aggregate resources. Stereoscopic pairs of color infrared aerial photographs (NAPP, 9"x 9" at 1:40,000 scale, April 1991 and 1992) were used along with reconnaissance-level, high-altitude, black-and-white photographs (1:80,000 scale) Aerial photographs (DOQs) were also available digitally and used within ArcView© (1:12,000 scale, 1991).

Aerial photographic interpretation was completed with a glacial mapping technique known as the landsystems approach. This technique relies on the principle that depositional glacial landforms are composed of a predictable range of sediments, some consisting of sorted sand and gravel and others consisting of silts, clays, or unsorted materials. In addition to the landsystems approach, several other general characteristics helped determine the nature of the material, such as tonal contrasts, texture, context, shape, size, trend, association, and patterns. These characteristics help determine the properties of the surface materials (e.g., certain vegetation grows on well drained soils, such as sand and gravel, which on an aerial photograph have a distinctive texture, tone, pattern).

The landform recognition approach (part of the landsystems approach) was also used when interpreting the topography within Meeker County; glacial landforms have distinct and unique shapes and patterns that can be observed in their topographic expression. Topographic maps (USGS 1:24,000), digital elevation models, and shaded relief maps were all used to help delineate the sand and gravel bearing features. The topographic expression of a feature can also be observed by looking at the distribution of lakes and wetlands. For example, a string of lakes and/or wetlands may be the signature of a glacial outwash channel or collapsed channel, which may host sand or gravel deposits. Several aggregate bearing features (outwash channels, collapsed outwash, alluvial fans, and terraces) were located using this technique.

Aerial photographs, subsurface data, location and distribution of existing pits, topographic expressions, and soils were all compiled and the inferred geologic and aggregate resource contacts were digitized on-screen, using ArcView© software, generally with a digital version of the USGS 7.5 minute topographic maps (1:24,000) or the aerial photography (DOQs at 1:12,000) used as a backdrop. The mapping units were then ready to be field checked.

Fieldwork consisted of driving every accessible road in the county looking for outcrops and exposures of geological sediments, as well as drilling test holes where needed. Sediments exposed in road cuts, stream exposures, excavations such as basements, judicial ditches, construction projects, trenches (cable, pipe, tiling), and even animal holes offered several places where the surficial materials, and glacial stratigraphy were observed. A total of 885 observation sites were logged in Meeker County. Some of the already mined aggregate resources were exposed at 214 gravel pits found in the county. These locations supplied additional quality data and good stratigraphic cross-sections to help interpret the modes of deposition. Test holes were also drilled, with the permission of the landowner, where additional data was needed to confirm the presence of sand and gravel.

After completing the fieldwork, a very detailed interpretation of the aerial photographs was done to finalize the geologic map units, incorporate the field data, and classify the potential aggregate resources (further defined on Plate A). The overall result is that the aggregate resources are mapped at a scale of 1:50,000 (Plate A).

MODERN SEDIMENTS, WATER, AND WETLANDS: Includes features where recent geological processes related to erosion, transportation, and depositions of sediments have been occurring. Map units are Holocene (10,000 years ago until Present) in age and include lakes, streams, wetlands, floodplains, fans, and terraces.

Water: Open water including lakes, rivers, and streams.

Wetlands - Organic Sediments: Partially decomposed plant material, silt, and clay found in or around shallow lakes, marshes, and peat lands. Wetlands occur throughout the county and overlay other mapped units.

Qav — **Alluvial Sediments:** Silt, fine sand, coarse sand, gravel, and organics. Sediment is deposited in subhorizontal layers, generally moderately to well sorted, and is interpreted to be alluvial overbank, terrace, and stream bottom deposits. Within this unit, coarser sediment is typically found in abandoned and modern channels, point bars, and river bars. Alluvial sediments exist throughout the county in valleys, or in low-lying areas where drainage occurs as channelized flow.

GLACIAL SEDIMENTS: Includes all material (clay, silt, sand, gravel, cobbles, and boulders) transported by glaciers and deposited directly from the glacier, from the stagnant ice as the glacier melted, or by meltwater associated with the glacier. Glacial sediment, which covers all of Meeker County, is associated with two glacial events: an earlier advance from a northeastern sourced lobe call the Superior Lobe and a later advance from a northwestern sourced lobe called the Des Moines Lobe. The glacial sediment ranges in age from 25,000 to 8,000 years before present.

Qlu — **Glaciolacustrine Sediments:** Silt, clay, and fine sand deposited in massive layers or thinly interbedded laminae. Sediment is deposited in ponded glacial meltwater that form glacial lakes. Some sediment is observed in pre-existing meltwater valleys mantling till and thick outwash sediments. Other glaciolacustrine sediments formed in lakes partially or entirely bounded by ice. Thickest accumulations of sediment are associated with the presence of stagnant ice (east of Meeker County) that dammed glacial meltwater and prevented drainage into the Mississippi River valley. Glacial lake boundaries range from steeply walled and well defined to partially eroded and poorly defined contacts. Within the landform, discontinuous channels and drainage features were observed.

Qdl — **Deltaic/Glaciolacustrine Sediments:** Silt, fine to coarse sand, and gravel. Sediment is bedded horizontally (topsets) and at a slope (foresets). The landform is the result of former meltwater streams flowing and depositing sediment into ponded water. Coarse grained sediment is observed near the point of meltwater discharge; finer grained sediment is observed distally and grade into glaciolacustrine sediment. Steep slopes on the eastern edge of the large delta suggest stagnant ice partially bound the lake margin.

Qdt — **Lake Modified Till Sediments:** Thin, discontinuous layers of sands, silts, and clays mantling unsorted till sediments (unsorted clay, silt, sand, gravel, cobbles, and boulders). The sediment is interpreted to be till that has been modified by wave action of water. Thicker accumulations of lake sediment are found in the small depressions between till hummocks. This unit is interpreted to have formed by the ponding of glacial meltwater over existing till sediments and is associated with deltaic/lacustrine se diments.

Qoc — **Glaciofluvial Outwash Sediments:** Stratified silt, coarse to fine sand, and gravel with layers of cobbles; deposited in cross-bedded to sub-horizontal layers. Sediment is deposited in meandering streams within broad, poorly defined channels and wi thin narrow, well-defined, outwash channels. Where deposited proximal to glacial ice (observed in the east and west central part of the county), the landform may contain coarse sediment, may be interstratified with till, and may grade into ice contact sed iments. The sediment is associated with meltwater of the Des Moines Lobe and contains rock lithologies, such as shale, carbonates, and iron oxides.

Qot — **Glaciofluvial Outwash Terrace Sediments:** Stratified fine to coarse sand and gravel, with layers of silt, fine sand, and cobbles scattered throughout. The sediment was deposited in glacial meltwater channels. Generally, terraces within larger meltwater channels are well defined, while, poorly defined terraces are often located in smaller meltwater channels. The sediment is associated with meltwater of the Des Moines Lobe and contains rock lithologies, such as shale, soft carbonates, and iron oxides.

Qmt — **Outwash Modified Till Sediments:** Thin, discontinuous layers of fine to coarse sand and gravel, with occasional layers of silt, fine sand, and cobbles. The sediment mantles scoured, unsorted till sediments (unsorted clay, silt, sand, gravel, cobbles, and boulders, which may have produced a pebble/cobble lag at the contact). The sediment is interpreted to be till that has been modified by glacial meltwater in or near outwash channels.

Qic — **Ice Contact Sediments:** Stratified silt, fine sand, coarse sand, and gravel, with an occasional mantle of glacial till. Associated with the Des Moines lobe, ice contact sediments are deposited in contact with glacial ice. Resulting landforms include long, narrow, sinuous ridges of stratified sand and gravel and steeply walled hills and mounds. Some ice contact features are associated with outwash channels partially bounded by ice; therefore, these sediments may grade into outwash sediments.

Qtg — **Till - Ground Moraine Sediments:** Mostly unsorted and unstratified clay, silt, sand, gravel, cobbles, and boulders. The sediment is clay-rich and occasionally contains lenses and pockets of sorted silts, sands, and gravels on top of and within the mapping unit. Till sediment was deposited directly by and underneath the glacier, and subsequently has been slightly reworked by ponded glacial meltwater behind and in front of the higher relief of end moraines. The random melting of ice and deposition of material produced a relatively flat to gently rolling, hummocky topography that is characteristic of ground moraine. Associated with these sediments are sub-parallel, linear ridges of till located in the southeast corner of the county.

Qcm — **Till - Cosmos End Moraine Sediments:** Mostly unsorted and unstratified clay, silt, sand, gravel, cobbles, and boulders. The sediment occasionally contains lenses and pockets of sorted silts, sands, and gravels on top of and within the mapping unit. This till sediment was deposited into a large, arcuate landform that marks a relatively long-standing ice margin deposited by a small tongue of the Des Moines Lobe. Meltwater was briefly ponded between morainic ridges.

Qts — **Till - Stagnant Ice Moraine Sediments:** Till sediment (unsorted and unstratified clay, silt, sand, gravel, cobbles, with occasional boulders) with pockets of sorted and stratified silt, sand, gravel, and cobbles. This till sediment was deposited beneath glacial ice, within glacial ice, and on top of glacial ice and has been subsequently modified by gravity and meltwater. Stagnation ice moraine sediments are interpreted to be the result of Des Moines Lobe ice overriding and stagnating on top of stagnant ice of the Superior Lobe. Therefore, the rolling topography is mostly related to Superior Lobe sediments buried by Des Moines Lobe till and sorted sediments.

Qsm — **Till - Sandy Ground Moraine Sediments:** Mostly unsorted and unstratified clay, silt, sand, gravel, cobbles and boulders. The sediment grades sandier to the north and occasionally contains lenses and pockets of sorted silts, sands, and gravels on top of and within the mapping unit. This till sediment was deposited by active and stagnating ice. To the northeast, the sediment varies in thickness from less than 2 feet to greater than 30 feet. Consequently, Superior Lobe sediments are discontinuously exposed at the surface. The random melting of ice and deposition of material produced a relatively flat to gently rolling, hummocky topography that is characteristic of ground moraines.

Qht — **Till - Hummocky Moraine Sediments:** Mostly unsorted and unstratified clay, silt, sand, gravel, cobbles and boulders. The sediment occasionally contains lenses and pockets of sorted silts, sands, and gravels on top of and within the mapping unit. This till sediment was deposited directly by and underneath the glacier; and was not s ubsequently re-worked by glaciofluvial meltwater. The random melting of ice and deposition of material produced rolling and hummocky topography that is characteristic of ground moraine. These sediments cover a larger morainic feature called the Alexandria moraine.

Qit — **Interlobate Complex Sediments:** Unsorted and unstratified clay, silt, sand, gravel, cobbles and boulders intricately mixed with sorted silt, sands, and gravels. This till/outwash complex was deposited between two glacial lobes originating from the northeast (Des Moines Lobe). Sediment deposition is associated with both glacial and glaciofluvial processes that create a complex of till and outwash.

Qst — **Till (Des Moines Lobe) over Ice Contact Sediments (Superior Lobe):** Unsorted and unstratified clay, silt, sand, gravel, cobbles and boulders (associated with the Des Moines Lobe) over stratified medium to coarse sand, gravel with occasional layers of silt, cobbles, and small boulders (associated with the Superior Lobe). The sands and gravels are interpreted to be outwash deposited in between and within stagnant ice. Till from the Des Moines Lobe caps the outwash with varying thickness (2 to 30+ feet).

GEOLOGIC CONTACTS AND LANDFORMS

Geologic Contact: Approximate boundary between geologic landforms.

Channel Scarp: A linear break in elevation delineating a well-defined edge of a channel.

Inferred Channel Scarp: Obscured linear break in elevation delineating a poorly defined edge of a channel that has been buried or eroded by later geologic events.

Collapsed Channel: Interpreted as a channel formed beneath glacial ice that has been subsequently collapsed and filled in by glacial sediment.

Till Ridges: Sub-parallel, linear ridges composed mostly of glacial till.

GENERAL REFERENCE

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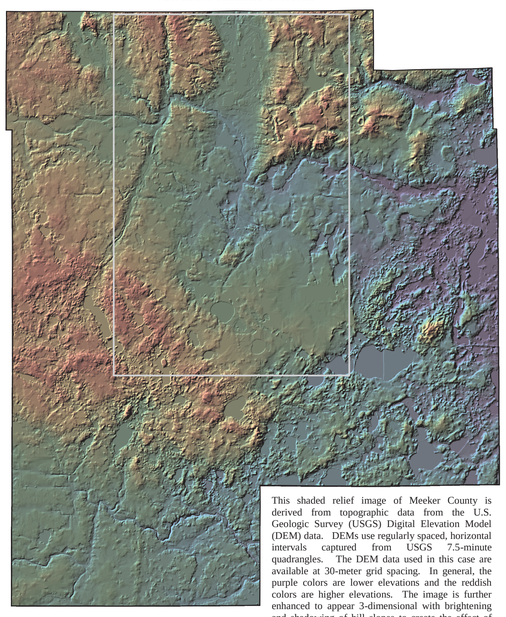
Civil Townships and Municipal Boundaries from MN/DOT Basemap 2001 - Civiltwp and Muni, Minnesota Department of Transportation, BaseMap Development Group, Surveying and Mapping Section.

Cartography by Kevin Hanson, Heather Arends, and Renee Johnson. GIS database design by Renee Johnson with database assistance by Kristen Lee. Field and drilling assistance by Ricco Riihiluoma, Doug Rosnau, Pat Geiselman, and Mike Ellett.

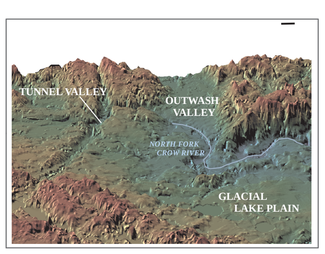
SHADED RELIEF IMAGE



This shaded relief image of Meeker County is derived from topographic data from the U.S. Geologic Survey (USGS) Digital Elevation Model (DEM) data. DEMs use regularly spaced, horizontal intervals captured from USGS 7.5-minute quadrangles. The DEM data used in this case are available at 30-meter grid spacing. In general, the purple colors are lower elevations and the reddish colors are higher elevations. The image is further enhanced to appear 3-dimensional with brightening and shadowing of hill slopes to create the effect of sunlight.

THREE DIMENSIONAL VIEWSHED

The rectangle within the shaded relief image (above) outlines the extent of the three dimensional viewshed (vertical exaggeration of 15 times applied to the actual elevation). This viewshed looks to the north and features a large outwash valley, a narrow tunnel valley, and a flat glacial lake plain. Flowing or stagnant water forms these landforms depositing sediment like gravel, sand, silt, and clays. Observing, delineating, and classifying these landforms are important steps in determining the aggregate potential of a county.



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Mineral Diversification projects are determined by a committee composed of Governor-appointed members from the public and private sectors.

Products of this project include a CD/ROM of maps, data, and metadata in a digital format and the following plates:
Plate A, Report 364 Aggregate Resources **Plate B, Report 364, Geomorphology**