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Applied geology in the Beulah-Hazen area, Mercer County, west-central North Dakota

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APPLIED GEOLOGY IN THE BEULAH-HAZEN AREA, MERCER COUNTY, WEST-CENTRAL NORTH DAKOTA

by

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This Thesis submitted by Gary N. Meyer in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Title Applied Geology in the Beulah-Hazen Area, Mercer County, West-Central North Dakota

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Funds for the project were provided by REAP, the Regional Environmental Assessment Program of the State of North Dakota. REAP was created by the state legislature to provide a comprehensive and coordinated environmental information service for the state. It is concerned with data aquisition, assessment and forecasting, and monitoring changes in the environment arising from resource development activities.

I would also like to extend my thanks to the many members of the NDGS staff who assisted in the preparation of this thesis.

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ABSTRACT

Increased lignite development around the small towns of Beulah and Hazen, North Dakota, will cause rapid growth and necessitate the development of new subdivisions and expansion of present sewage disposal facilities. A detailed geologic study of a 90-square mile area surrounding the two towns was undertaken to provide information valuable to those concerned with proper management of this growth. A surface and near-surface materials map was prepared at a scale of 1:24,000 showing relative depths and thicknesses of a maximum of three earth materials to a depth of 9 m. Eleven units were mapped at the surface, and six units in the subsurface. Four cross-sections, and four interpretive land-use maps at a scale of 1:63,000 were also compiled, including a hazard map and three suitability maps for sanitary landfills, septic tank systems, and general construction. A map showing buried valleys, diversion trenches, and meltwater channels was also compiled at a scale of 1:63,000.

The Sentinel Butte Formation (Paleocene) is the only preglacial unit at the surface or within the near-surface. The late Cenozoic Charging Eagle Formation is possibly present in a few places. The Napoleon "till" of the Coleharbor Formation (Pleistocene) is probably the only pebble-loam exposed at the surface. Older pebble-loam beds are apparently present in many buried valleys. Postglacial sediments are within the Oahe Formation.

Evidence from limited exposures indicates deposition of the Sentinel

Butte Formation in a predominantly fluvial environment by low sinuosity streams. Several of these streams may have been braided as is the modern Brahmaputra in the Bengal Basin.

A possible late Wisconsinan age for the Napoleon drift is suggested from evidence associated with the Krem moraine. Buried valleys north and northeast of Beulah, and the Renner trench were recognized by drilling and sags in the topography. At least three fills reveal multi-stage origins for diversion trenches. The second fill is believed to have been laid down in an ice-dammed lake. The third fill was deposited as a wall-to-wall fill between Beulah and Hazen, and within a newly cut, ice marginal valley east of Hazen.

Flooding, mine sinkhole subsidence, slump and sliding, and drifting sand are existing or potential hazards. Flooding is the most serious as other hazards are removed from present population centers. Regional climate is favorable for leachate containment in sanitary landfills, but many areas are inadequate due to steep slopes, high permeability, or potential flooding. The proper location of septic tank systems is governed chiefly by permeability and depth to the water table. Many good sites are available, provided areas prone to flooding and areas of steep slopes are avoided, and proper design and spacing of the septic system is employed. The best site for a new sewage lagoon for Beulah is to the east on the Knife River floodplain, but special engineering precautions will be required to prevent water pollution. The present site of the sewage lagoon northeast of Hazen is the most suitable. Most favorable construction sites are to the north of both Beulah and Hazen. Further development on the floodplain would be ill-advised due to occasional flooding.

PURPOSE

Due to increased lignite development and the concomitant construction of new coal gasification and electric generation plants in the area, the towns of Beulah and Hazen are expected to expand at a rapid rate. New subdivisions are already appearing, and at the time of this report both towns have or are seeking to increase and improve their school systems, water supplies, and sewage disposal facilities. Future projections for expansion vary from two to ten fold (United States Department of Agriculture, 1977). The primary purpose of this study is to provide geologic data that can be useful in aiding both state and municipal authorities, as well as individual landowners, in further planning for the expansion and development that will accompany the influx of workers and their families into the area. A secondary purpose of this study is to obtain a fuller understanding of the geologic history of the Beulah-Hazen area in particular, and the surrounding region in general.

Rapid expansion of population and industry will increase the competition for available land. This will require more stringent controls and regulations (1) to prevent financial losses resulting from uncontrolled building in areas with unstable conditions or subject to periodic flooding; (2) to insure proper disposal of increasing amounts and varieties of waste products; and (3) to avoid destruction and degradation of certain aesthetic features of the landscape (Hackett and McComas, 1969). Long term and careful planning can largely avert potential conflicts. Decisions arrived at in land-use planning reflect the amount and scope of information available. Geologic information in this report, combined with other pertinent information, should aid considerably the decision maker.

PREVIOUS WORK

The first detailed geologic investigation including the Beulah-Hazen area was accomplished by Benson (1952). With the existing data at hand, Benson prepared an exhaustive study of the Tertiary and Pleistocene stratigraphy and of the mineral resources in the area. Carlson (1973) prepared a report of the geology of Mercer and Oliver Counties that included subsurface information. The present study stemmed from that of Groenewold and others (1979), which includes a detailed examination of the lignite stratigraphy, and the hydrogeology and hydrogeochemistry of the Knife River Basin area, based on extensive subsurface information.

Environmental geology studies in North Dakota include that of Deal (1972) and Arndt and Moran (1974) at the county level and Groenewold (1971) at a more detailed level. Applied geologic studies in Illinois, where somewhat similar earth materials are found, include those of Gross (1970), Bergstrom, Piskin, and Follmer (1976), and others.

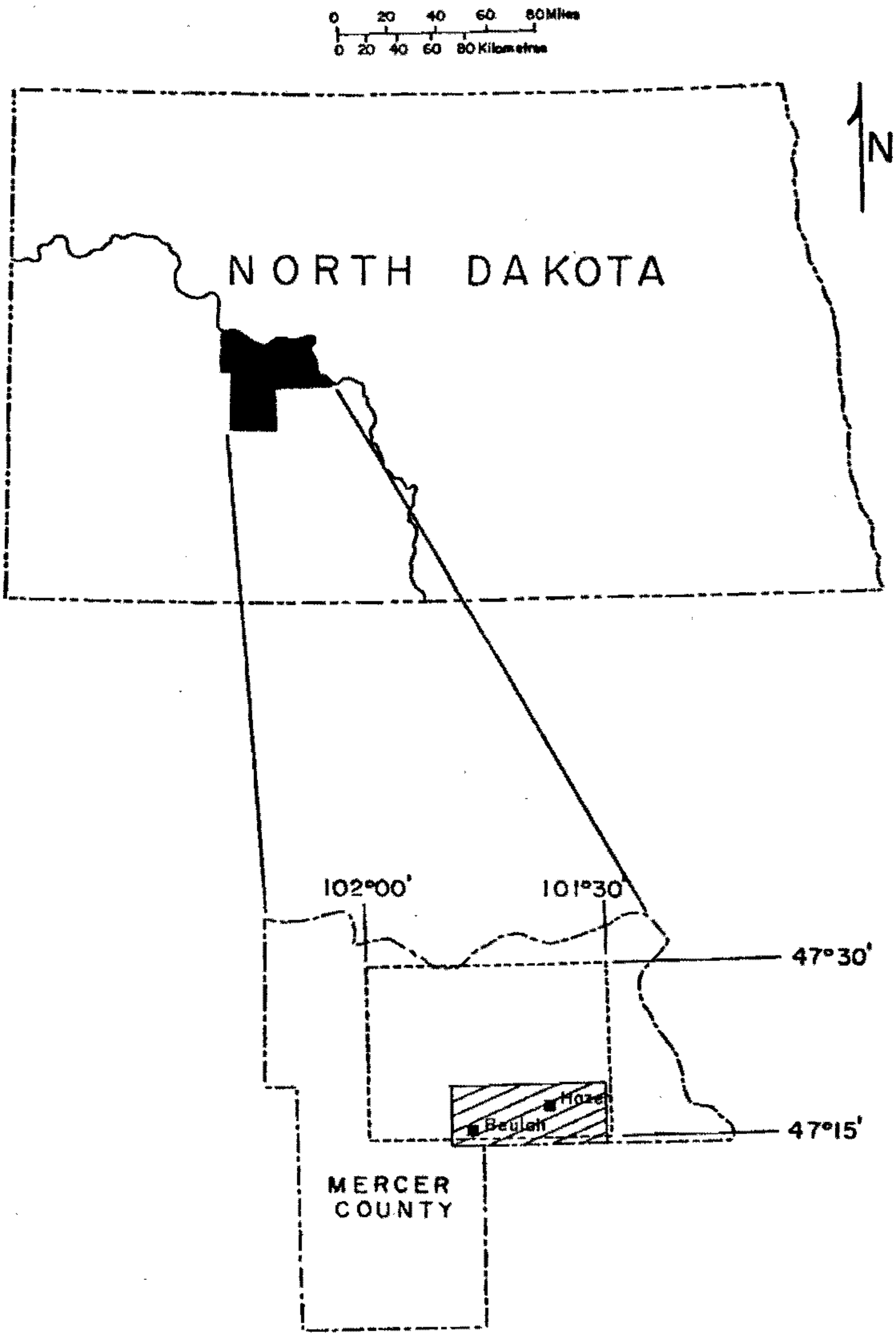
DESCRIPTION OF STUDY AREA

The Beulah-Hazen area lies south and west of the Missouri River (fig. 1); physiographically it is within the Glaciated Missouri Plateau Section of the Great Plains Province (Carlson, 1973). The climate is continental, with extremes of both hot and cold, but in general it is cool and semi-arid, with an average annual precipitation of about 16 inches (Croft, 1973). The region is characterized by mixed prairie vegetation, with native grasses covering most of the uncultivated uplands and slopes (Benson, 1952). Wooded areas occur only along stream bottoms and on steep gully sides. Benson (1952) listed common types and gave a detailed discussion of vegetation in the Knife River Valley.

The 1970 populations of Beulah and Hazen were 1344 and 1240 (U.S. Bureau of the Census, 1970). Both towns are probably over 2000 at present, and continue to grow. The economy of the area is based on agriculture, and strip mining of lignite for production of electric power. Agricultural products include small grains, beef and hay.

Both Hazen and Beulah lie predominantly within the floodplain of the Knife River, which flows from the southwest corner to the northeast corner of the study area in a preglacial bedrock valley (pl. 6). The Knife joins the Missouri River at the town of Stanton, about 18 km east of Hazen. Tributaries to the Knife River within the study area include Otter, Brady,

Fig. 1. -- Study area (diagonally ruled) in south-central Mercer County, North Dakota. The larger area outlined within the county was mapped by Groenewold and others (1979).


0 20 40 60 80 Miles
0 20 40 60 80 Kilometres
N
NORTH DAKOTA
102°00'
101°30'
47°30'
47°15'
Hazen
Beulah
MERCER
COUNTY

and Kinneman Creeks from the south, Spring Creek from the west, and Antelope and Coal Creeks from the north.

The north half of the study area is dominated by the Hazen and Zap branches of the Beulah trench (pl. 6), large valleys containing only small streams, and in places, no streams at all. These trenches are believed to have carried water diverted from the ancestral Missouri by glaciers during the Pleistocene. Both the Knife River Valley and the trenches have relatively flat floors and are underlain by nearly 100 m of fill.

The study area in general is characterized by glacially-modified bedrock topography. Erosion has prevailed, however, since the last ice retreat, especially along the sides of the diversion trenches and larger stream valleys. Their slopes are often steep and retain only vestiges of glacial drift, thin patches of pebble-loam or a scattering of boulders. On the more gently sloping uplands glacial drift seldom exceeds 5 m, except in buried valleys where thicknesses reach 20 m or more. Scoria occurs throughout much of the area as resistant rims or caprock where lignite has burned and baked the overlying sediment.

The south side of the Knife River Valley from Beulah to the Missouri River is bordered by a terrace that widens to the east and southeast of Hazen to over 5 km. Here, sand has been reworked by the prevailing northwest winds into what are now, for the most part, stabilized dunes. Dunes to the west of Kinneman Creek are locally more than 15 m high.

METHODS

The detailed geologic study of the Beulah-Hazen area involved mapping the near-surface as well as the surficial materials of a 90-square mile, rectangular area surrounding the two towns (fig. 1). Four cross-sections, two east-west and two north-south (pls. 2, 3, 4, and 5), and four land-use suitability maps (figs. 12, 15, 16, and 17) were constructed. The surface and near-surface materials map (pl. 1) was constructed at a scale of 1:24,000, the largest scale thought practical for showing the available geologic information.

Upon completion of the surface and near-surface materials map and cross-sections, the material units were evaluated in terms of their engineering properties. The results were used in preparation of various land-use maps including a hazard map and three suitability maps for sanitary landfill, septic tank system, and general construction. The suitability maps were compiled at a scale of 1:63,000 (about 1 mile to the inch). An interpretative geologic map showing buried valleys, diversion trenches, and meltwater channels (pl. 6) was also prepared at a scale of 1:63,000. The maps should not be enlarged to a scale greater than that in which they were compiled or a false sense of accuracy will result.

Field work was done during the summers of 1976 and 1977, being completed in early June, 1977. Initially, the surficial geology was mapped using soil maps compiled by the soil conservation service and aerial photographs at a scale of 1:20,000. Soil units were combined into geologically meaningful units and mapped on 7.5 minute topographic quadrangles that had contour intervals of 10 or 20 feet. Contacts were then checked in the field by traveling all roads and trails and examining all good exposures, stream cuts, railroad cuts, road cuts, and many mine sinkholes. Geologic maps by Benson (1952), at a scale of 1:63,000, and Carlson (1973), at a scale of 1:126,000, were also helpful.

Mapping of the near-surface materials was accomplished by extensive drilling utilizing the North Dakota Geological Survey's truck-mounted, 8-inch diameter, continuous-flight, power auger (fig. 2). Continuous samples were collected for further examination. Representative samples from 5-foot (1.5 m) intervals were then collected in "zip-loc" plastic bags, labeled, and placed in a larger plastic garbage bag for storage. Logged descriptions of 167 boreholes are given in Appendix A. Additional subsurface data was obtained from Croft (1970); from lignite evaluation rotary drilling under the supervision of the U.S. Geological Survey during the years 1975-76, and rotary drilling by REAP in 1976, published in Groenewold and others (1979); and from unpublished records of the North Dakota Geological Survey. Auger drilling in this study was done at half-mile (0.8 km) intervals where necessary and feasible. In those areas where topography was rugged, adequate exposures were available and extensive drilling was generally unnecessary. Subsurface information is less extensive in a few locations where permission to drill was not granted by the landowner.

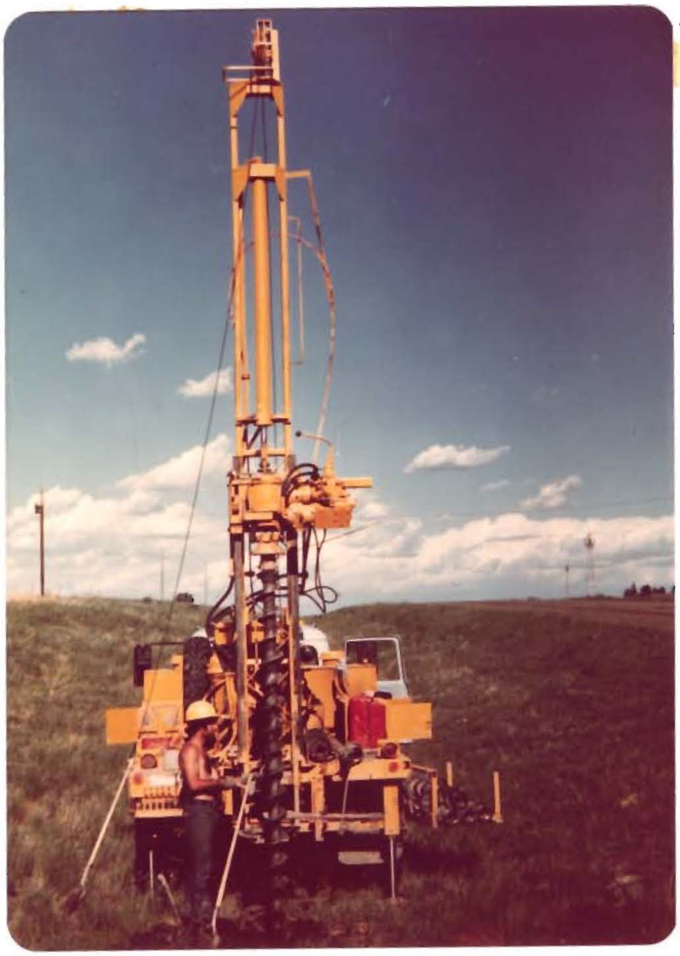


Fig. 2. -- North Dakota Geological Survey's auger truck used during the study.

An attempt was made in preparing the surface and near-surface materials map to represent lithology to a depth of 9 m (30 feet). This arbitrary depth was arrived at partly by considering the effective depth capacity for auger drilling. Although good samples were obtained from several relatively dry holes to a depth of 22.5 m (75 feet), often upon intersecting the water table samples would become increasingly disturbed and difficult to place in proper sequence. This proved particularly true in drilling done on the floodplains of the Knife River and Spring Creek. Also 9 m seemed to be an appropriate depth for most engineering concerns in the area. Many holes 15 m (50 feet) or more in depth were drilled in the uplands to give a better understanding of the lateral variations in lithologies of the bedrock and geological history of the region.

Surface and Near-Surface Earth Materials Map

The surface and near-surface earth materials map (pl. 1) is designed to show a maximum of three earth material units and their relative depths and thicknesses to a depth of 9 m (30 feet). Each unit was assigned a letter designation. The thickness of the surficial unit in metres is indicated by the number 2, 3, or 9, which follows the first letter designation, the surficial unit, and represents a maximum thickness of 2, 3, or 9 m.

Symbol	Explanation
A	Minimum of 9 m of unit A.
A_{3B}	Maximum of 3 m of unit A overlying unit B.

A_{9B} Maximum of 9 m of unit A overlying unit B.

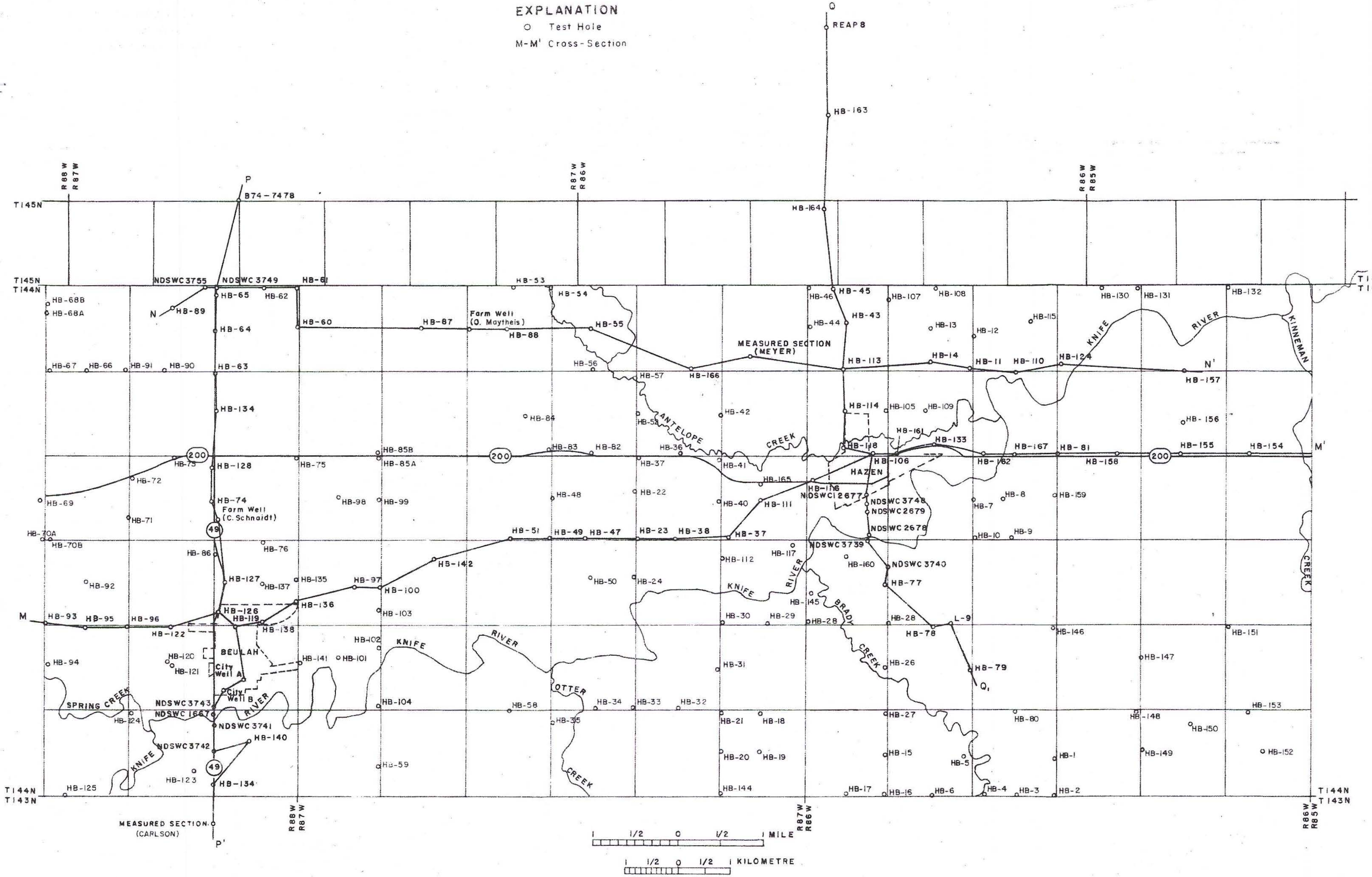
A_{3BC} Maximum of 3 m of unit A overlying unit B; unit C at a maximum depth of 9 m.

A_{9BC} Maximum of 9 m of unit A overlying unit B; unit C at a maximum depth of 9 m.

In cases where four or more materials occurred within 9 m of the surface, those considered more important, typically the thicker units, were chosen for representation. Units less than 0.5 m in thickness were not mapped. Some generalization was necessary. For these reasons, data from nearby boreholes (fig. 3) should be consulted in conjunction with the materials map. Contacts shown by a solid line should be given an error factor of $\pm$30 m or about 100 feet, and those shown by a dashed line should be given an error factor of $\pm$60 m or 200 feet.

Similar surface and near-surface earth materials maps have been compiled in Illinois by members of the Illinois State Geological Survey (Gross, 1970; Bergstrom, Piskin, and Follmer, 1976; and others). Their practice has been to assign a lithostratigraphic unit letters or numbers and place one symbol over another as the units occur in the field. Although more than three units are sometimes represented, information is only given to a depth of 20 feet (6 m). Also, except for loess thickness in Bergstrom, Piskin, and Follmer (1976), no attempt was made to represent relative thicknesses of different units within the 20 feet.

Fig. 3. -- Location of the testholes drilled in this study with the location of the cross sections (pls. 2, 3, 4, and 5). All descriptions of auger testholes (HB series) are included in Appendix A. Carlson's measured section is in Carlson (1973), and NDSWC testhole and farm well descriptions are in Croft (1970). The remaining testhole descriptions and measured section are in Appendix B.


EXPLANATION
Test Hole
M-M' Cross-Section
REAP 8
HB-163
R88W R87W
R87W R86W
R86W R85W
T145N
T144N
T143N
P
874-7478
HB-164
NDSWC 3755
NDSWC 3749
HB-61
HB-53
HB-54
HB-45
HB-46
HB-107
HB-108
HB-130
HB-131
HB-132
HB-68B
HB-68A
HB-65
HB-62
N
HB-89
HB-43
HB-44
HB-13
HB-12
HB-115
HB-64
HB-60
HB-87
Farm Well
(O. Maytheis)
HB-88
HB-55
MEASURED SECTION
(MEYER)
HB-113
HB-14
HB-11
HB-110
HB-124
KNIFE
RIVER
N'
HB-157
KINNEMAN
HB-67
HB-66
HB-91
HB-90
HB-63
HB-56
HB-57
HB-166
HB-134
HB-84
HB-53
HB-42
ANTELOPE
CREEK
HB-114
HB-105
HB-109
HB-156
HB-161
HB-133
200
HB-73
HB-128
HB-75
HB-85B
HB-85A
HB-83
HB-82
HB-36
HB-37
HB-41
HB-118
HB-106
HAZEN
HB-167
HB-81
HB-155
HB-154
M'
HB-162
HB-158
HB-72
HB-165
HB-116
NDSWC 12677
HB-69
HB-74
Farm Well
(C. Schnoidt)
HB-98
HB-99
HB-48
HB-22
HB-40
HB-111
NDSWC 3748
NDSWC 2679
HB-7
HB-8
HB-159
HB-71
49
HB-70A
HB-70B
HB-51
HB-49
HB-47
HB-23
HB-38
HB-37
NDSWC 2678
HB-10
HB-9
HB-86
HB-76
HB-117
NDSWC 3739
HB-112
HB-160
NDSWC 3740
HB-142
HB-92
HB-127
HB-137
HB-135
HB-97
HB-100
HB-50
HB-24
KNIFE
RIVER
HB-77
CREEK
HB-145
BRADY
M
HB-93
HB-95
HB-96
HB-122
HB-126
HB-119
HB-136
HB-138
HB-103
HB-30
HB-29
HB-28
HB-28
HB-78
L-9
HB-146
HB-151
HB-102
KNIFE
RIVER
HB-94
HB-120
HB-121
BEULAH
City Well A
HB-141
HB-101
HB-31
CREEK
HB-26
HB-79
HB-147
Q'
City Well B
SPRING CREEK
NDSWC 3743
NDSWC 1667
HB-124
RIVER
HB-104
OTTER
HB-58
HB-34
HB-33
HB-32
HB-35
HB-21
HB-18
HB-27
HB-80
HB-148
HB-150
HB-153
NDSWC 3741
HB-140
NDSWC 3742
KNIFE
HB-123
HB-59
HB-20
HB-19
HB-15
HB-5
HB-1
HB-149
HB-152
HB-125
HB-134
CREEK
HB-144
HB-17
HB-16
HB-6
HB-4
HB-3
HB-2
MEASURED SECTION
(CARLSON)
P'
1 1/2 0 1/2 1 MILE
1 1/2 0 1/2 1 KILOMETRE

Mapping Units

The lithologic, lithostratigraphic, morphogenetic, and lithogenetic descriptions of each map unit are given below.

Unit A

Unit A consists of organic to highly organic, brown and dark grey, silty clay and clay. It was deposited, for the most part, in ephermeral ponds and oxbow lake basins. Unit A was mapped only at the surface, generally within floodplains, and in a few areas in gully bottoms on residual uplands. In the subsurface, silty clay and clay was included in unit B. Unit A is within the Oahe Formation of late Quaternary age.

Unit B

Unit B consists of sandy silt and clay, often organic near the surface, with lenses of fine silty sand and clay, which, occasionally, may be very organic. This unit contains occasional pebbles and pebble-rich lenses, generally of lignite, scoria, and fragments of iron concretions. It generally occurs on gentle to moderate slopes.

Unit B is comprised of both alluvium and colluvium at the surface, and occurs over much of the floodplains and within gully bottoms and in swales on uplands. In the subsurface, it includes material in buried valleys beneath or within pebble-loam. Unit B, therefore, is found within both the Coleharbor and Oahe Formations, and may range from pre-Pleistocene to Holocene in age.

Unit C

Unit C consists of well-sorted, unbedded, slightly sandy and clayey silt. It was mapped only at the surface, with an estimated maximum thickness of 2 m. Unit C is an eolian deposit (loess) occurring as a thin veneer on gentle to moderate slopes over much of the uplands. It overlies a variety of materials, often having been reworked and mixed with the sediment below. Unit C is within the Oahe Formation of late Quaternary age. The different members of the Oahe, as defined by Clayton, Moran, and Bickley (1976), were not formally recognized, although at least two are undoubtedly present.

Unit D

Unit D consists of very well-sorted, poorly consolidated, largely very fine to medium-grained sand. The unit is eolian in origin. It was mapped only at the surface, but reaches thicknesses of over 9 m in dunes to the southeast of Hazen. Towards the uplands it becomes generally more silty, finer grained, and thinner. Unit D is the dominant surficial material over much of the area south of the Knife River, but is generally less than 3 m thick outside the dune areas. The unit also occurs locally on the Knife River floodplain where scroll bars have been reworked by the wind, and commonly grades into unit E both vertically and laterally. This unit is included in the Oahe Formation of late Quaternary age in this study.

Unit E

Unit E consists of well-sorted, fine to coarse-grained sand and silty sand, with lenses of clay and of gravel. This unit is a fluvial deposit, and is found on gentle to moderately steep slopes. Unit E is quite extensive in the Beulah-Hazen area, but is often covered on the floodplains and lower terraces by unit B, and on the higher terraces by unit D, which is derived from unit E. It is the predominant unit in the near-surface of the Knife River floodplain and in the terraces south of the river. This unit is also the dominant constituent of the fill in glacial diversion trenches.

Unit E is found on the uplands at the surface, for the most part, as reworked bedrock sand, and in the subsurface beneath or within pebble-loam. It is included in both the Coleharbor and Oahe Formations, and is probably pre-Pleistocene to Holocene in age.

Unit F

Unit F consists of silty, sandy, pebbly, bouldery clay (pebble-loam) with gravel, sand, silt, and clay lenses. It is olive brown to grey brown, iron-stained, and locally contains abundant lignite fragments. This unit is a glacial deposit and is found draped over bedrock on much of the uplands. Slopes range from gentle on the broad uplands south of Hazen, to moderate to very steep on the uplands in the rest of the study area.

Unit F is generally 2-6 m thick over bedrock, except in buried valleys and glacial meltwater trenches where it is typically more than 9 m thick and often overlies units B and E. In places, the upper metre of unit F resembles unit B, but becomes more clayey and more consolidated below. Unit F is commonly underlain by a metre or more of reworked bedrock, both sand and clay. Unit F is included in the Coleharbor Formation of Pleistocene age.

Unit G

Unit G consists of moderately poor to poorly sorted, silty sand and gravel. The unit is cobbly in many places, and occurs on gentle to steep slopes. Unit G is a glacio-fluvial deposit laid down in outwash plains, terraces, and kames by meltwater. Sand and gravel in the subsurface occurs as lenses in pebble-loam (Unit F) and as fill in the glacial diversion trenches and the Knife River Valley. Gravel on upper terraces is patchy and less than 2 m thick. On the lower terraces bordering the diversion trenches and the river valley, sand and gravel deposits reach thicknesses of 5 m or more. The gravel is mostly of rather poor quality, as gravel from deposits near the Missouri River must be brought in for use as concrete aggregate. An asphalt mixing operation has been set up about 5 km north of Beulah, using deposits from a gravel terrace in the Beulah trench, Unit G is a facies of the Coleharbor Formation of Pleistocene age.

Unit H

Unit H consists of coarse-grained silt to very fine-grained sand. It is generally very well sorted and is interbedded with silty clay and fine silty sand, with carbonaceous layers and occasional lenses of detrital lignite and scoria fragments. It is characterized by gentle to moderate slopes, and is often covered with pebble-loam, sand or gravel. Unit H is interpreted to be predominantly a lacustrine deposit laid down in the standing or very slowly flowing waters of an ice-dammed lake (Benson, 1952, p. 128). The unit occurs only on the flanks or within the fill of diversion trenches and in the Knife River Valley. The unit is exposed in the Zap branch of the Beulah trench north of Beulah, and is also present in the Hazen branch. Unit H is in the subsurface near Beulah and in the northern part of the broad terrace to the east of Hazen, as well as in the deeper valley fills. Unit H is a facies of the Coleharbor Formation and is Pleistocene in age.

Unit I

Unit I is scoria (porcelanite), material composed of baked clay and sand of unit J, and baked pebble-loam of unit F. It is a common unit in the uplands north and northeast of Beulah and west of Hazen, and typically occurs on steep to very steep slopes of gullies. Scoria is also found on gentle to moderate slopes where it is overlain by about a metre of loamy sediment. In such settings, it is differentiated on the map by the symbol I_1. All signigicant scoria deposits in the study area resulted from the burning of the thick Beulah-Zap lignite bed within unit J, and thus always overlie unit J. Scoria is a source for road subbase and surfacing of roads with low traffic load. Scoria ranges in age from at least the Oligocene to Holocene, and is a constituent of several formations.

Unit J

Unit J consists predominantly of partially consolidated and consolidated sand, silt, and clay. This unit was differentiated in surface exposures into a fine-grained subunit (Jf) and a coarse-grained subunit (Jc). It was considered as a single combined unit in the subsurface (J). The subunits tend to interbed and grade into each other. For this reason it was not possible to differentiate them in the subsurface.

Subunit Jf consists of partially consolidated silt, silty clay, and clay with lignite and carbonaceous beds and minor limestone and iron concretions. The subunit is interpreted to include fluvial (crevasse-splay, natural levee, and overbank), paludal, and lacustrine sediment.

Subunit Jc consists of sandstone and partially consolidated sand, silty sand, and sandy silt. The sand is very fine to medium-grained. This subunit also contains lignite and carbonaceous beds, and iron concretions. It is interpreted to be mainly fluvial sediment (natural levee, crevasse-splay, channel fill, and point bar), with paludal material.

All other units overlie Unit J to a greater or lesser extent throughout the area. Widespread exposures of Unit J occur in the western half of the study area. It is also exposed to the north of Hazen, predominantly in the more rugged areas along gully sides and steep divides. Subunits Jf and Jc are facies within the Sentinel Butte Formation of Paleocene age.

STRATIGRAPHY

The Beulah-Hazen area is on the east side of the Williston Basin, an intracratonic, broad, structural downwarp extending under most of western North Dakota and parts of eastern Montana, southeastern Saskatchewan, and northwestern South Dakota. The deepest point of the basin is approximately in the area of the Killdeer Mountains in Dunn County, about 80 km northwest of the study area (Groenewold and others, 1979). The Williston Basin contains sedimentary rocks of every geologic period from the Cambrian through the Quaternary.

Pre-Tertiary Sediments

The Williston Basin was active in controlling sedimentation from the Middle Ordovician through the end of the Permian, but had little effect on sedimentation during the Mesozoic (Carlson and Anderson, 1966). The combined Paleozoic and Mesozoic section beneath the Beulah-Hazen area should exceed 10,000 feet (3000 m) of predominantly marine clastics, carbonates, and evaporites. Paleozoic sediments are dominantly carbonates, Mesozoic sediments dominantly clastics (Carlson, 1973).

Tertiary Sediments

The Tertiary Period is represented by predominantly nonmarine beds that thicken westward toward the Rocky Mountains. The thickening of these beds towards the center of the Williston Basin is evidence of tectonic control of sedimentation during their deposition (Royse, 1967).

The Cretaceous nonmarine Hell Creek Formation is the uppermost Mesozoic lithostratigraphic unit occurring in the subsurface of the study area. It is overlain by the Palocene Ludlow, Cannonball, possibly the Slope, Bullion Creek (formerly Tongue River Formation; Clayton and others, 1977), and Sentinel Butte Formations. The nonmarine Golden Valley Formation of late Paleocene to early Eocene age occurs nearby to the northwest, west, and southwest (Carlson, 1973). The Sentinel Butte Formation is the only Tertiary unit exposed within the study area.

A testhole drilled about 10 km northeast of Hazen (Groenewold and others, 1979; REAP 17, T. 145 N., R. 85 W., Sec. 34, SWNWNWNW) encountered both the Sentinel Butte-Bullion Creek and the Bullion Creek-Cannonball contacts. The marine clay-shale, silt, and sand of the Cannonball Formation was penetrated here at an elevation of 1394 feet above sea level, and the Bullion Creek Formation at an elevation of 1611 feet above sea level. Therefore, the Bullion Creek Formation is only about 217 feet (66 m) thick near the study area (Groenewold and others, 1979).

Although the above testhole was drilled an additional 260 feet (79 m), the base of the Cannonball was not encountered. According to Carlson (1973), the Ludlow-Cannonball contact in the subsurface below Mercer and Oliver Counties is probably intertonguing, with the nonmarine sediments of the Ludlow thickening westward as the Cannonball thins. The main difference in the subsurface between the two formations is the presence of lignite in the Ludlow.

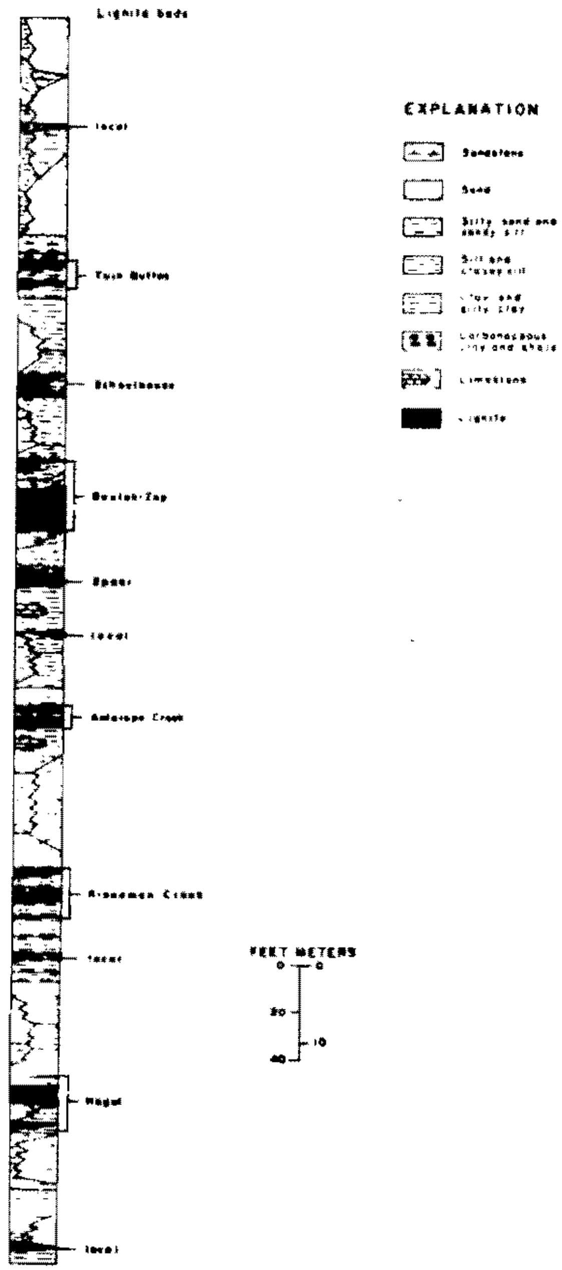
The contact between the Cannonball and Bullion Creek Formations in testhole REAP 17 was placed at the base of a lignite bed, whereas Carlson (1973) placed the contact in surface exposures in Oliver County at the base of a thick sand unit. The Bullion Creek-Sentinel Butte contact was picked at the top of a tan limestone lying just above the Tavis Creek lignite, according to criteria described by Groenewold and others (1979). The Bullion Creek in this testhole consisted predominantly of silty clay and clayey silt, with very fine-grained sand and silty sand. About 20 percent of the total thickness of the formation here was lignite and carbonaceous clay.

According to Carlson (1973, p. 23), the Bullion Creek Formation thickens to the west and northwest and is about 375-450 feet (114-137 m) thick in parts of Mercer and Oliver Counties. Groenewold and others (1979) agreed with this conclusion for at least western and northwestern Mercer County.

Good exposures of the Sentinel Butte Formation are found in the walls of abandoned lignite pits and mine sinkholes, in road, railroad, and stream cuts, and on highly eroded slopes of a few gullies. Well over 100 m of the formation are exposed in the area, including seven named lignite beds (fig. 4).

Fig. 4. -- Generalized stratigraphic section of the Sentinel Butte Formation exposed in the Beulah-Hazen area (from Groenewold and others, 1979). Almost the entire section, from the Hagel bed up is present in the 90 square miles encompassed by this study.

GENERALIZED STRATIGRAPHIC SECTION OF THE PART OF THE SENTINEL BUTTE FORMATION EXPOSED IN THE BEULAH HAZEN AREA



The total thickness of the Sentinel Butte Formation is 532 feet (162 m) in a testhole drilled about 13 km to the northwest of the study area (Groenewold and others, 1979; REAP 6, T. 146 N., R. 89 W., Sec. 36, SE). Carlson (1973, p. 26) also stated that the formation thickens in northwestern Mercer County "to slightly over 500 feet where a complete section is preserved."

The interbedded clay, silt, sand and lignite of the Sentinel Butte Formation is often referred to as "bedrock," but this should be understood as only a relative term as the sediment is in most cases only partially consolidated, lacking coherence and fissility of the finest-grained fraction. The exceptions are lenticular sandstone and limestone, and lignite. The distinction between sediments of the Sentinel Butte and younger sediments was usually clear. However, in several boreholes, bedrock material reworked by ice action was encountered beneath glacial drift. In other holes, silty sand and sandy silt similar to the late Cenozoic Charging Eagle Formation (Ulmer and Sackreiter, 1973), or a fine-grained fill (Qsd_2) described by Benson (1952, p. 119) was often difficult to distinguish from Sentinel Butte sediments.

Both lateral and vertical variability of the lithology were great within the Sentinel Butte, the thicker lignite beds generally being the only traceable subunits for any great distance. In outcrop, the formation is typically drab grey and brown, and, in general, it is similar to exposures of the Sentinel Butte in other parts of western North Dakota.

Quaternary Sediments

Preglacial sediments

Bluemle (1971) discussed fluvial sediments consisting of silts, sands, and gravels encountered beneath glacial drift in several testholes in northwestern McLean County. These sediments were thought to have been deposited by streams flowing northeastward in late Tertiary or early Pleistocene time. Because the sediments were not found at very great depths, it was assumed that the valleys they had once been deposited in have been destroyed, as late Pleistocene and Holocene erosion completely changed drainage patterns. For this reason, these deposits were thought to be older than fluvial sediments found in buried valleys. Possible examples on a local scale in the Beulah-Hazen area are found in testholes HB-93 and HB-137 (Appendix A), where gravelly sand derived wholly from local bedrock was encountered beneath glacial drift on present topographic highs. The sand was deposited in preglacial or possibly interglacial gullies, and is similar to present gully deposits as shown in the log of testhole HB-96.

Preglacial sediments may also exist in buried valleys in the study area (pl. 6). The buried valley that trends north from Beulah is capped by 10-20 m or more of glacial drift (HB-73, 74, 126 and 128; Appendix A), which is underlain by 25 m or more of predominantly fine, silty sand (pl. 4). Testholes HB-86, HB-119, and HB-127, a farm well located at T. 144 N., R. 88 W., Sec. 13, SWNWSW, and possibly a farm well located at T. 144 N., R. 88 W., Sec. 11, SWSWNE, all encounter this sand that apparently is derived wholly from local bedrock. The 15 m testhole HB-86 is entirely in this sand and was drilled near the border of the buried valley.

Glacial and interglacial sediments

Ulmer and Sackreiter (1973) worked out the detailed stratigraphy of late Cenozoic sediments exposed along bluffs of Lake Sakakawea 18-24 km north and northeast of the study area. Sediments representing three glaciations, and implying at least one more, were recognized and formally named. Benson (1952) had recognized earlier at least three fills in the Knife River area, which also represented three glaciations. Bluemle (1971) formally named all glacial material in North Dakota the Coleharbor Formation, with the type section in the same area later studied by Ulmer and Sackreiter. Bluemle recognized sediment from three separate glaciations at his type section. (Probable correlations of Pleistocene units described by these authors are given in Table I.) Carlson (1973) recognized two "tills" in Mercer County along the bluffs of Lake Sakakawea.

The oldest late Cenozoic unit recognized by Ulmer and Sackreiter is the Charging Eagle Formation. This formation is a fluvial deposit predominantly of silty sand and sandy silt. Pebbles are rare, but their lithologies suggest an origin to the northeast (Canadian Shield and Manitoba Lowland areas). This would imply that the formation was deposited after the first latest Cenozoic glaciation in the area (Ulmer and Sackreiter, 1973).

This formation was thought to be present in the Beulah-Hazen area, but without an erosional contact it was difficult to distinguish from the much older Sentinel Butte Formation, especially in the subsurface. An exposure southeast of Beulah (T. 144 N., R. 88 W., Sec. 36, SWNENE), comparable to the Charging Eagle, was found in a cutbank of the Knife River. Only about a metre of interbedded, grey silty sand, sandy silt, and clayey silt, which becomes finer-grained upward, was exposed at the water's edge. The sediment was poorly sorted with abundant lignite fragments up to small pebbles in size, as described by Ulmer and Sackreiter. The outcrop is in between the Beulah Gravel Pit and Section Line exposures (Benson, 1952). The clayey silt is overlain by coarse sand and gravel, probably equivalent to Benson's oldest fill (Qsd_1), and either the lower member of the Medicine Hill Formation or the lower member of the Horseshoe Valley Formation of Ulmer and Sackreiter (1973).

Sediment similar to that of the Charging Eagle was also encountered in the subsurface. Sandy silt to very fine silty sand with lignite and other pebbles were found above the Knife River floodplain in testholes HB- 120, 126, 136, and 149 and within the floodplain in HB-94, 116, 124, 141, and 165 (Appendix A). None of the holes were drilled deeply enough to penetrate bedrock, and undoubtedly some, if not all, of the sediment was younger than the Charging Eagle Formation. The lithology of the Charging Eagle is quite similar to a glacial fill deposit present in the Beulah-Hazen area that Benson referred to as Qsd_2. This younger deposit also consists of predominantly sandy silt to very fine silty sand, but is well sorted.

Benson (1952) concluded that the major "till" sheets in the Knife River area could not be separated except where they were interbedded with fluvial and glacio-fluvial fills. These conditions exist along the bluffs of Lake Sakakawea where Bluemle (1971) and Ulmer and Sackreiter (1973) recognized three "tills," or pebble-loams. The second pebble-loam, named the Mercer till by Bluemle (1971), and the upper member of the Horseshoe Valley Formation of Ulmer and Sackreiter (1973), was not recognized in Mercer County by Ulmer and Sackreiter. However, Carlson (1973) recognized two strongly jointed "tills," differentiated mainly by their color, in Mercer County. He called these the Mercer and Napoleon tills, which seem to be the equivalents of the two younger pebble-loam beds of Ulmer and Sackreiter.

A cutbank along Kinneman Creek at the eastern edge of the study area exposes what may be two pebble-loams; the lower pebble-loam is jointed and separated from the upper, unjointed pebble-loam by a possible boulder pavement (Benson, 1952; Groenewold and others, 1979). However, the lack of jointing in the upper may be due to weathering (Carlson, 1973), as is seen along the bluffs of Lake Sakakawea, and in other exposures within the Beulah-Hazen area. Ulmer and Sackreiter (1973) concluded that the younger two pebble-loam beds exposed in the region were jointed, whereas the older pebble-loam bed (upper member of the Medicine Hill Formation, and the Dead Man till of Bluemle) is unjointed.

Other exposures in the study area seem to reveal only one pebble-loam, and most, if not all of the pebble-loam exposed is of the same age. The pebble-loam in Benson's (1952) Section Line exposure probably is an older pebble-loam than that exposed elsewhere in the area. Good exposures of the surface pebble-loam are in the mine sink-hole area north and northeast of Beulah (fig. 12) and in cutbanks of the Knife River east and southeast of Hazen (fig. 5). The pebble-loam is composed of roughly equal amounts of silt, sand, and clay, with occasional pebbles, cobbles, and boulders. Carbonate pebbles predominate, but the pebble-loam contains igneous, metamorphic, and locally derived sedimentary rock fragments as well. In outcrop, it appears pale olive to grey brown, with characteristic orange iron oxide spots and small, black lignite fragments. The pebble-loam exhibits distinct columnar jointing in most outcrops.

The reddish middle member of the Snow School Formation of Ulmer and Sackreiter (1973) was not recognized in the study area. With the absence of this bed, the upper members of the Snow School and Horseshoe Valley Formations are difficult to distinguish. A dark layer at the top of the upper member of the Snow School Formation was also used as a distinguishing characteristic by Ulmer and Sackreiter. A good exposure of this dark layer can be seen in a cutbank opposite the Hazen city park in T. 144 N., R. 86 W., Sec. 20, NENW, in the top of a pebble-loam. Other investigators (Benson, 1952; Carlson, 1973; Groenewold and others, 1979) have attributed the surface pebble-loam to the time equivalent of the upper member of the

Fig. 5. -- Pebble-loam exposures. (A) Sharp contact between overlying pebble-loam and underlying cross-bedded, lignitic, quartzose, fine-grained sand exposed in a cutbank of the Knife River in T. 144 N., R. 86 W., Sec. 2, SWNWSE. The cross-beds in the sand indicate flow in the same direction as the present-day Knife River. (B) Exposure along Kinneman Creek (T. 144 N., R. 86 W., Sec. 12, SWNESE) showing four map units used in this study. A lignite bed (probably the Hagel) about 1 m thick is exposed at the base (unit J), overlain by about 3 m of clayey pebble-loam (unit F), which is overlain by over 2 m of medium to coarse-grained, silty, lignitic sand (unit E). The exposure is capped by wind blown sand (unit D), which is covered by vegetation. The units are described and mapped on plate 1.


D
E
F
J

Snow School Formation (Napoleon "till"), and although the evidence is not completely clear-cut, this conclusion is probably correct.

Older pebble-loam beds are probably present in the subsurface in the majority of the buried valleys in the study area. In a number of testholes, clay, silt, sand or gravel were found interbedded with pebble-loam. Changes in color, grain size, and lithology were also noted, but analysis was not sufficient to justify recognizing separate stratigraphic units. No buried oxidized drift was penetrated.

Large deposits of silt, sand, and gravel, as well as pebble-loam give evidence of the advance and retreat of ice sheets into the Beulah-Hazen area. The bulk of the deposits are restricted to the lowland areas, the valleys, and the diversion trenches. Ulmer and Sackreiter (1973) concluded that the silt, sand, and gravel units exposed along the bluffs of Lake Sakakawea could not be differentiated as to their respective time-stratigraphic positions without the presence of intervening pebble-loams. In the Knife River area, however, there is evidence for at least three separate fills.

As described by Benson (1952), the oldest fill exposed is near Beulah in the Knife River Valley, and consists of outwash sand and gravel. The second fill is predominantly fine to medium-grained sand and silt, largely locally derived. It is best exposed near Beulah and within the Zap branch of the Beulah trench (pl. 1, unit H). The third and youngest fill is extensively preserved in the Knife River Valley. It consists of both outwash and inwash sand and gravel and is similar to the first fill. Away from the Knife River Valley, it consists mainly of interbedded sand and gravel, but in terraces along the river it consists predominantly of fine to coarse-grained sand.

A number of holes were drilled into the third fill in this study (Appendix A; HB-58, 77, 158, 159). The sand is quite diverse, both in grain size, composition, and in color. Often the fill contains dark brown and black, organic-rich beds (fig. 6). The sand often appears reddish brown in weathered exposures (fig. 5). In a railroad cut in T. 144 N., R. 88 W., Sec. 35, NESWSE, several paleosols are exposed within a silty, organic-rich, fine-grained sand, a few with well developed, very clayey B2 horizons up to 25 cm thick. The organic accumulations probably indicate a cool, moist climate following the retreat of the glaciers.

The oldest fill of Benson, Qsd_1, is probably the stratigraphic equivalent of the lower member of the Horseshoe Valley Formation. The second fill, Qsd_2, is the approximate stratigraphic equivalent of the lower member of the Snow School Formation, and the third fill, Qsd_3, is younger than the Snow School Formation (Table I).

Postglacial sediments

Because formal stratigraphic classification of postglacial sediments in North Dakota is unsettled at this time (Groenewold and others, 1979, Appendix B), all sediments of this age will be included in the Oahe Formation in this study.

Fig. 6. -- Organic-rich, laminated sand. (A) Laminated, very fine-grained lignitic sand overlying medium to coarse-grained sand with small cobbles at the base (unit E, T. 144 N., R. 86 W., Sec. 2, SWSWSW). (B) Lignitic laminae in a very fine-grained sand of the Sentinel Butte Formation (T. 144 N., R. 88 W., Sec. 25, SENWNE). Lignitic laminae were common in Paleocene as well as Pleistocene sand in the study area. Each mark on the mattox handle represents 10 cm.

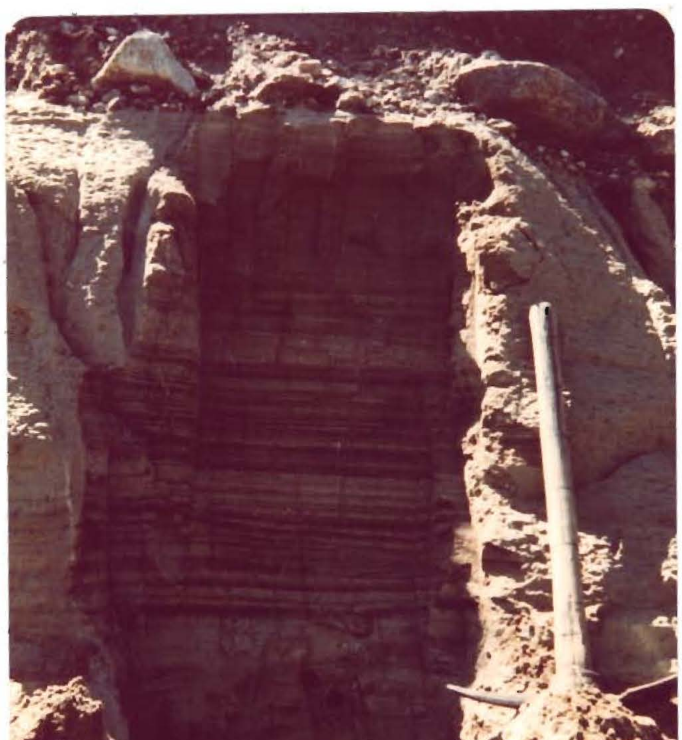


TABLE I

Pleistocene Units

Benson (1952)	Bluemile (1971)	Ulmer and Sackreiter (1973)
	Lostwood till	
Qsd_3 (third fill)		
	Napoleon till	Upper member of the Snow School Formation
		Middle member of the Snow School Formation
Qsd_2 (second fill)		
		Lower member of the Snow School Formation
	Mercer till	Upper member of the Horseshoe Valley Formation
[illegible] (first fill)		Lower member of the Horseshoe Valley Formation
	Dead Man till	Upper member of the Medicine Hill Formation
		Lower member of the Medicine Hill Formation
		Charging Eagle Formation

Wind blown sand and silt is present as a thin veneer over much of the more gently sloping areas near Beulah and Hazen, especially to the southeast of the major stream valleys. Prevailing winds during more arid postglacial periods blew a plentiful supply of fine-grained material from the floodplains of these valleys. Largely stabilized dunes consisting predominantly of fine to medium-grained sand dominate the east and southeast portions of the study area, and locally exceed 15 m in height. The dune sand is light yellow to dark brown, depending on the amount of carbonaceous material present. The thinner deposits are generally more silty and more carbonaceous and so are darker than the thicker deposits.

Loess deposits are minor in comparison and seldom are more than a metre thick (pl. 1, unit C). As seen in many mine sinkholes, the loess is often highly reworked and mixed with the slopewash or till below. Separate loess deposits were, therefore, difficult to distinguish.

Postglacial alluvium covers the floors of all the valleys in the Knife River area. This includes overbank flood deposits of sandy silt and clay, and fine to medium-grained, point-bar sand, with minor gravel and clay lenses. Organic silt and clay also is found on the valley floors in oxbow lake and ephemeral pond basins. Dark greyish brown, horizontal beds are common in the overbank flood deposits, representing buried soil profiles (fig. 14), and possibly may be correlated with separate members of the Oahe Formation (Clayton, Moran, and Bickley, 1976). It is usually difficult to distinguish Holocene alluvium from the underlying glacial-fluvial and lacustrine sediments.

Predominantly fine-grained slopewash is common throughout the more steeply sloping areas near Beulah and Hazen, often accumulating in gully bottoms to thicknesses of 5 m or more.

GEOLOGIC HISTORY AND DEPOSITIONAL ENVIRONMENTS

Preglacial History

The Paleocene Cannonball Formation represents that last influx of the sea into the Williston Basin. Following the model of Jacob (1973), the nonmarine Bullion Creek Formation was laid down in a predominantly fluvial, lower deltaic environment as channel, levee, crevasse-splay, flood basin, and swamp deposits adjacent to the Cannonball Sea. The Sentinel Butte Formation overlies the Bullion Creek and was deposited in much the same environment although probably was more removed from the Cannonball Sea, in an upper deltaic or lower alluvial plain environment (Johnson, 1973). The Golden Valley Formation of Paleocene to Eocene age was deposited after the Sentinel Butte, again in a predominantly fluvial environment (Groenewold and others, 1979). The presence of the predominantly fluvial White River Formation and younger sediments in the Killdeer Mountains area of neighboring Dunn County implies that Oligocene to Miocene deposits may also have extended into Mercer County (Carlson, 1973). If they were present, however, they, along with sediments of the Golden Valley Formation, have been removed by erosion from the study area.

The early Cenozoic climate in the Beulah-Hazen area, as reflected by abundant lignite beds and the subtropical to temperate fossil flora assemblage, was moist and very warm. The vast peat swamps (Benson, 1952) were inhabited by coniferous trees, ferns and aquatic plants. Deciduous leaves are found locally and are thought to have been washed into basins of accumulation from higher ground nearby. No fossils were seen in the study area, but Benson and others have reported remains of freshwater gastropods and pelecypods, and rare reptilian bones.

Lignite beds are the most consistent and easily correlated units in the Sentinel Butte due to their generally wide lateral continuity. However, lignite beds may also vary considerably in elevation over short distances (pls. 3 and 4) reflecting both the underlying topography at the time of deposition, and subsequent tectonic modification. A thick lignite bed may also split into two or more smaller beds (pls. 2 and 3; fig. 7). These characteristics make even correlation of lignite beds difficult with less than excellent exposures and subsurface information.

The thick and laterally continuous lignite beds in the Sentinel Butte must reflect long periods of widespread, uniform conditions in the flood basins during the Paleocene. A coal swamp forms where the water table remains consistently near or at the surface. If the water table rises or the substrate sinks with organic matter accumulation, large quantities of organic matter may be deposited and ultimately a thick coal may result. Given a peat to lignite compaction ratio of 4:1 (Ting, 1972), thick lignites such as the Beulah-Zap bed in this study area would require the accumulation of at least 20 m of organic matter.

Fig. 7. -- Exposure along the south-facing cutbank of Spring Creek (T. 144 N., R. 88 W., Sec. 28, SESENE) of the Kinneman Creek lignite bed, 3 km west of Beulah. Silt and clay at the base is overlain by 1.05 m of lignite followed by 2 m of coarsening-upward clay, silt, and sandy silt; 1.2 m of lignite; 0.3 m of fossiliferous sandy silt to very fine-grained silty sand; and about 7 m of massive, very fine to fine-grained sand. The exposure is capped in places by up to one metre or more of interbedded silt, sand, and gravel. The splitting of the Kinneman Creek bed into two seams is typical of lignite in the Sentinel Butte Formation (fig. 4).

If the water table rises too fast a lake may form, drowning the swamp and depositing clay over the paludal deposits. If little subsidence occurs and the water table remains about the same, little peat will accumulate. The swamp may be buried by clastics from encroaching streams, or destroyed by erosion (Moore, 1976).

Johnson (1973) and Jacob (1973) recognized fining-upward cyclic units in the Sentinel Butte that reflects these different processes. Johnson (p. 54) concluded that the "thicknesses of the cyclic unit and the individual beds in the unit depend upon the interrelation between the rate of supply of the clastic sediment, the rate of subsidence, the rate of production of organic matter, the rate of decomposition, and the location of the water table." Although sections had to be largely pieced together, fining-upward cyclic units were recognized in the Beulah-Hazen area as well (pls. 2, 3, 4, and 5).

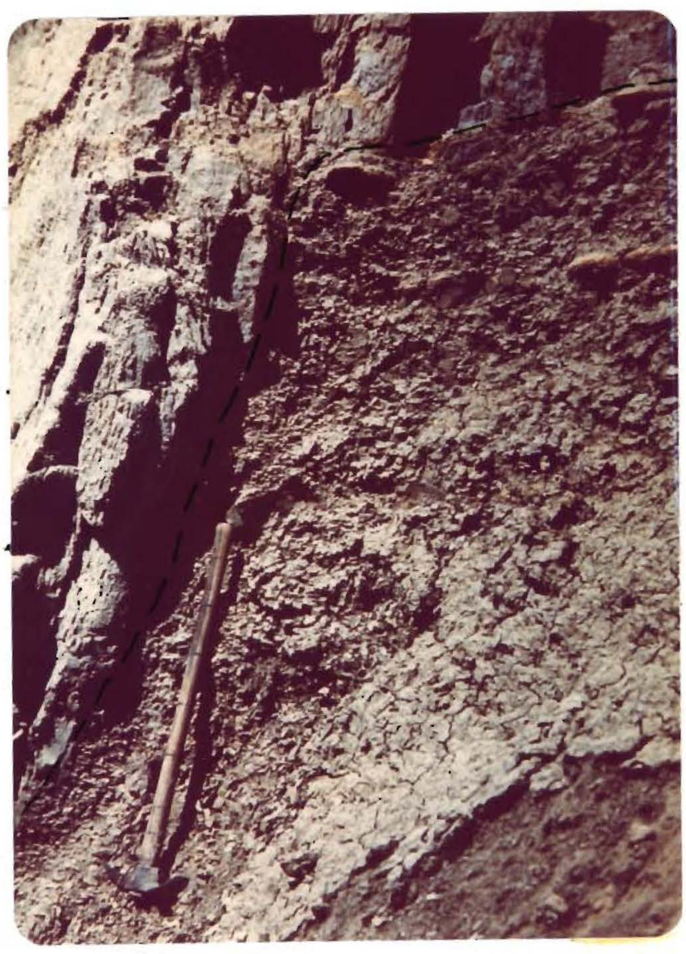
Exceptions to these predominantly fining-upward sequences do exist, however. For example, lignite is found directly over sand deposits in testholes in the area (HB-24, 47, 134, 137, and 142; Appendix A). Practically any combination of clay, silt, sand, and lignite can be recognized in deeper holes (Groenewold and others, 1979; REAP 12 and REAP 13, Appendix A-II). Coleman (1969), in his study of the modern Brahmaputra River, observed large peat-accumulation basins directly adjacent to areas of high clastic deposition. This was noted to result in peat deposits both underlying and capping large sand bodies.

Moore (1976) pointed out that paludal deposits may be time transgressive, that the lignite beds which now cover hundreds of square miles were laid down by a swamp whose margins or entire body migrated laterally. The swamp would move up or down slope, depending on submergence or emergence. This would account for the occurrence of interbedded fluvial clay, silt, and sand sandwiched between laterally more extensive lignite beds. The lignite may have been resistant to subsequent down-cutting stream channels (Jacob, 1973) during Sentinel Butte time, which would futher insure the lateral continuity of the lignite as compared to the less resistant clastic deposits. Good exposures of flood basin deposits, including several lignite beds, occur about 2 km south of Beulah in much of T. 143 N., R. 88 W., Sec. 1, NE; one such expposure was described by Benson (1952, p. 61).

The best exposures of the Sentinel Butte Formation within the boundary of this study are found in strip mine highwalls above the Beulah-Zap lignite bed in sections 8, 9, 16, and 17; T. 144 N., R. 87 W. The highwalls reveal poorly laminated silty and clayey flood basin deposits up to 15 m thick down cut and overlain by channel and crevasse-splay sand and sandy silt. The channel sand as described in a REAP testhole (Groenewold and others, 1979; REAP 12, Appendix A-II) is also at least 15 m thick and is cut down to within a metre of the underlying lignite. The sand is very fine and fine-grained, with carbonaceous beds.

A sharp contact was found between channel sand and flood basin deposits in Sec. 17, NWNWNE (fig. 8). The sand body is believed to

Fig. 8. -- Contact between channel sand and flood basin deposits. (A) Sharp contact between channel sand (upper left) and flood basin deposits (lower right) exposed in a strip mine highwall in T. 144 N., R. 87 W., Sec. 17, NWNWNE. (B) Close-up view of the same contact. Notice the massive nature of the sand (left), the thinly bedded flood basin sediment (right), and the truncated layers of iron concretions.



trend northwest, the eastern border running through the northwest corner of section 8, and the western border extending no farther than section 12 of T. 144 N., R. 88 W., and section 18 of T. 144 N., R. 87 W. The sand body is, therefore, probably only about 1.5 km in width.

The highwall in the northwest quarter of section 8 exposes what appears to be a thick crevasse-splay deposit that thins eastward towards flood basin deposits exposed in highwalls in the northeast quarter of section 8 and the southwest quarter of section 9. Although no distinct contact was observed, a channel sand seemed to be present in the western end of the exposure, and was observed in numerous mine sinkholes in the northeast quarter of section 7. Horizontal laminae and low-angle cut and fill structures seemed to dominate the greater part of the crevasse-splay deposit. Small-scale, ripple cross-stratification and climbing-ripple cross-stratification are preserved in sandstone and spherical concretions towards the top of the deposit in what is largely sandy silt. Several metres above the Beulah-Zap lignite bed the lignified remains of a stump in growth position is preserved. Its roots lie in laminated, lignitic, very fine sandy silt, and its trunk is buried in fine-grained sand. The contact between the silt and the sand is quite abrupt, probably indicating rapid burial. Plant fragments were found in bedding planes towards the top of the sand, and within the overlying sandy silt. Well preserved fossil deciduous leaves were found towards the eastern part of the exposure where the sand graded into a sandy silt.

The dominance of plane bedding, a thick sequence of fine laminated sand and silt, climbing ripples, and the buried tree trunk all indicate high sedimentation rates (Allen, 1970a; Jacob, 1973). These factors, along with the decreasing grain size away from the channel deposit, the sequence of plane bedding at the base to small-scale ripples at the top, small channels, and the association with fossiliferous silt beds all suggest a crevasse-splay deposit interbedded with natural levee deposits (Allen, 1965). Finely laminated and lignitic silt, sand, and silty clay often encountered in the subsurface throughout the study area apparently represent natural levee and crevasse-splay deposits within the Sentinel Butte Formation.

Bedding, for the most part, was obscure in the channel sand overlying the Beulah-Zap lignite bed, both in exposures in highwalls and mine sinkholes in sections 7, 8, and 17 of T. 144 N., R. 87 W. Kulland (1975) recognized large-scale, trough cross-strata near the base and large-scale, low to high angle straight cross-strata and small-scale cross-stratification elsewhere in the sand body exposed in the highwall in T. 144 N., R. 87 W., Sec. 17, NW. Cross-bed dip directions indicated a southeasterly flow. Kulland concluded that the sand body was laid down as lateral bars in a low-sinuosity stream channel.

The channel lag deposit in T. 144 N., R. 87 W., Sec. 7, SWNE (fig. 9), is composed solely of reworked iron concretions, although blocks of sandstone were observed in other portions of the same exposure. Evidence seemed to indicate deposition during Sentinel Butte time, towards the top of the channel sand overlying the Beulah-Zap lignite bed. Reworked

Fig. 9. -- Channel deposit in the Sentinel Butte Formation. (A) Channel lag deposit exposed in a mine sinkhole in T. 144 N., R. 87 W., Sec. 7, SWNE. The channel is bounded top and bottom by partially consolidated, very fine and fine-grained sand typical of the Sentinel Butte Formation. Coarse deposits exposed in the opposite side of the sinkhole contain cobble-size blocks of sandstone. (B) Close-up view of the rounded, detrital iron concretions in the channel lag deposit. Each mark on the mattox handle represents 10 cm.

clay fragments up tc cobble size were also observed in another mine sinkhole in the same channel sand, laid down in horizontal beds and as trough cross-stratification in small scour channels.

Plane beds seemed to be relatively abundant where bedding was preserved. According to Allen (1970 b), this is indicative of a low sinuosity stream. The concave-up base (fig. 8), large-scale planar cross-stratification at the base to plane bed and small-scale ripple cross-stratification at the top, and the apparent absence of channel plug deposits also indicate a low sinuosity stream (Johnson, 1973).

Jacob (1973), in his study of similar sand bodies in what is now the Bullion Creek Formation, noted that low-sinuosity deposits tended to be locally stacked on top of each other. Evidence for stacking below the sand body exposed in the strip mine highwalls occurs in REAP 12 (Groenewold and others, 1979; Appendix A-II), and in other testholes (HB-47, 49, 50, 51, and 99; Appendix A).

One testhole (HB-139; T. 144 N., R. 88 W., Sec. 36, SW) penetrated 22.5 m of very fine and fine-grained sand overlying lignite. This same sand and the pair of lignites below are exposed particularly well in T. 144 N., R. 88 W., Sec. 28, SENE (fig. 7). Evidence from other testholes and exposures indicates that this sand probably lies within a relatively narrow channel, as does the channel sand exposed in the strip mine highwalls. These thick, narrow sand bodies are probably a result of stream avulsion, downcutting and filling, rather than lateral migration and accretion over a wide area typical of a highly meandering stream. Because considerable time was necessary for the accumulation of the thick flood basin deposits in the Sentinel Butte, both frequency of stream avulsion and lateral accretion rates must have been relatively low.

Jacob (1973) concluded that the low-sinuosity stream deposits in the Bullion Creek Formation did not represent braided river deposits, which would have been more blanket-like, and have contained more irregularly arranged vertical sequences of sedimentary structures, and more trough cross-stratification. However, the possibility of deposition through large, braided river systems such as the present day Yellow River in China and the Brahmaputra River in Bangladesh, was not ruled out in the Beulah-Hazen area, due both to similarities in the lithology of the deposits and less than adequate preservation of sedimentary structures.

Coleman (1969) noted occasional deep, sand-filled indentations associated with scour pockets of node points, up to 120 feet (36.5 m) thick, beneath the floodplain of the Brahmaputra. The type of sediment of the banks tends to control the river pattern, which is braided only where the bank is easily eroded. The Brahmaputra produces moderate floods every four years, and catastrophic floods every 30-50 years. Each flood moves large quantities of suspended sediment into the adjacent flood basin. According to Coleman, the Brahmaputra changed course 200 years ago, and has formed a blanket of sand 60 feet (18 m) thick in the interim. The bed material is quite uniform in size and well-sorted throughout its extent.

The Brahmaputra may migrate laterally 2000 feet (610 m) over a short period of time. These characteristics are probably aptly applied to the origin of the thick (35 m) sand towards the top of the Sentinel Butte Formation in the northwestern part of the study area (fig. 4). The instability of a predominantly braided river would probably not allow for the thick accumulations of peat necessary for lignite beds such as the Beulah-Zap in the lower part of the Sentinel Butte Formation.

Perhaps the association of high and low-sinuosity stream deposits recognized by Johnson (1973) in the Sentinel Butte could be further understood by comparing the association between the high-sinuosity Ganges River and low-sinuosity, braided Brahmaputra River in the Bengal Basin.

Glacial History

Continental glaciation during the Pleistocene ended a long period of active erosion throughout North Dakota. Ice sheets hundreds of feet thick advancing from the north and northeast covered the Beulah-Hazen area an unknown number of times. Erosion during subsequent ice advances and interglacial periods removed almost all evidence but the youngest glacial deposits. Glacial history must, therefore, be pieced together from fragmentary evidence preserved on the flanks and within the fills of stream valleys, diversion trenches, and buried valleys.

Age of glacial drift

Benson (1952), as mentioned previously, recognized three glacial drifts in the Knife River Valley, mainly on the basis of exposed fills. Deposits from the first two glaciations were assigned to the early Wisconsinan, and the last glacial advance was attributed to the late Wisconsinan. Bluemle (1971) recognized four separate drifts in McLean County. The Dead Man and Mercer drifts were assigned a pre-Wisconsinan age, the Napoleon drift an early(?) Wisconsinan age, and the Lostwood drift a late Wisconsinan age.

Carlson (1973) agreed with the early Wisconsinan date for the Napoleon drift, and said the Krem moraine in northern Mercer County was of the same age. The moraine is located on the drainage divide and was, therefore, believed to be a remnant of the constructional topography once present throughout most of Mercer County. Groenewold and others (1979), however, pointed out, as did Benson (1952), the outwash trains associated with the Krem moraine and believed the moraine represented a younger unit than the deposits underlying the more subdued areas. A radiocarbon date (W-402) from gastropods in a marl bed within the Krem moraine indicated a late Wisconsinan age (11,220 ± 300 years B.P.), and was used to correlate the moraine with the Lostwood drift in McLean County. This date corresponds with radiocarbon dates of materials in the Lostwood drift elsewhere in North Dakota (Bluemle, 1971, p. 57).

Benson (1952, p. 113) believed that the drift in the Krem moraine could not be separated from the pebble-loam to the south, as outwash from the moraine apparently merges with outwash and fluvial deposits associated with the last glacial advance into the area. He, therefore, viewed the

Krem moraine as a local readvance of the last ice sheet. This would require a late Wisconsinan date for the Napoleon drift as well as the Lostwood drift in Mercer and McLean Counties.

The Mallard Island Member of the Oahe Formation (a loess deposit), according to Clayton, Moran, and Bickley (1976), is found only in areas not glaciated during the late Wisconsinan. The presence or absence of this member in loess deposits on the Krem moraine may be helpful in determining the age of the moraine.

Preglacial drainage

The Knife River flows in a preglacial valley that once extended east through McLean County where it joined with the ancestral Missouri River. Before the southward diversion of the Missouri, drainage was to the northeast towards the Hudson Bay in Canada (Bluemle, 1971). Advancing glaciers from the north diverted this northeastward drainage, creating deep trenches running perpendicular to the established stream valleys. A number of valleys were filled, whereas others were enlarged by additional water diverted from other streams, by meltwater from retreating ice sheets, and by water from increased precipitation during glacial periods. Plate 6 illustrates the major as well as a few minor features of the changes in drainage brought about by glaciation within and immediately surrounding the Beulah-Hazen area.

Both the major streams and their tributaries in the Knife River valley flow along synclinal axes formed in the underlying bedrock (Benson, 1952). The Knife River and Spring Creek follow the largest of the synclines that trend east-west, whereas major tributaries, such as Brush, Otter, and Brady Creeks, lie in minor synclines that trend to the northwest. The diversion trenches are also affected by underlying structure, as is evident in pl. 4. The locations of trenches or portions of trenches were also controlled by the locations of the margins of ice sheets.

Two buried valleys, one trending south through Beulah and one lying to the northeast of Beulah, probably represent preglacial tributaries of the Knife River. The valleys were recognized through exploratory drilling, and by sags in the topography. The valley fill deposits, consisting largely of pebble-loam, are bounded, for the most part, by gullies cut into bedrock. Figure 10 attempts to diagrammatically explain this phenomenon. Other buried valleys in the area, including the older valleys of Otter and Brady Creeks (pl. 6), could be either preglacial or interglacial in origin. The Renner trench (pl. 6), recognized and named by Groenewold and others (1979), is essentially buried, and must date from the Pleistocene.

Diversion trenches

The Zap and Hazen branches of the Beulah trench dominate the northern part of the study area (pl. 6). Other diversion trenches affecting the local glacial history are the South Fork and Elm Creek trenches to the southwest, and the Goodman Creek and Golden Valley trenches to the west (fig. 11). All these trenches and their histories were discussed extensively by Benson (1952) and Carlson (1973). Information from recent data is discussed here to augment and develop their conclusions.

The Beulah trench was carved by meltwater and water diverted from the

Fig. 10. -- Origin of gully-bound, buried valleys. (A) The old valley is filled with stagnant ice. Drainage that would normally flow down the valley, coupled with meltwater, begins to cut steep gullies on either side of the supraglacial "till". In this case the bedrock is more easily eroded than the till. Possibly boulder and cobble lags at the surface formed an armour over the thick till, forcing down-cutting streams to either side where the till was thin over bedrock (Moore, 1978). Eventually the new streams cut new valleys on either side of the buried valley. (B) Present relationship believed to exist in the two buried valleys north and northeast of Beulah (pl. 6). The vertical dimension is highly exaggerated in the diagram.

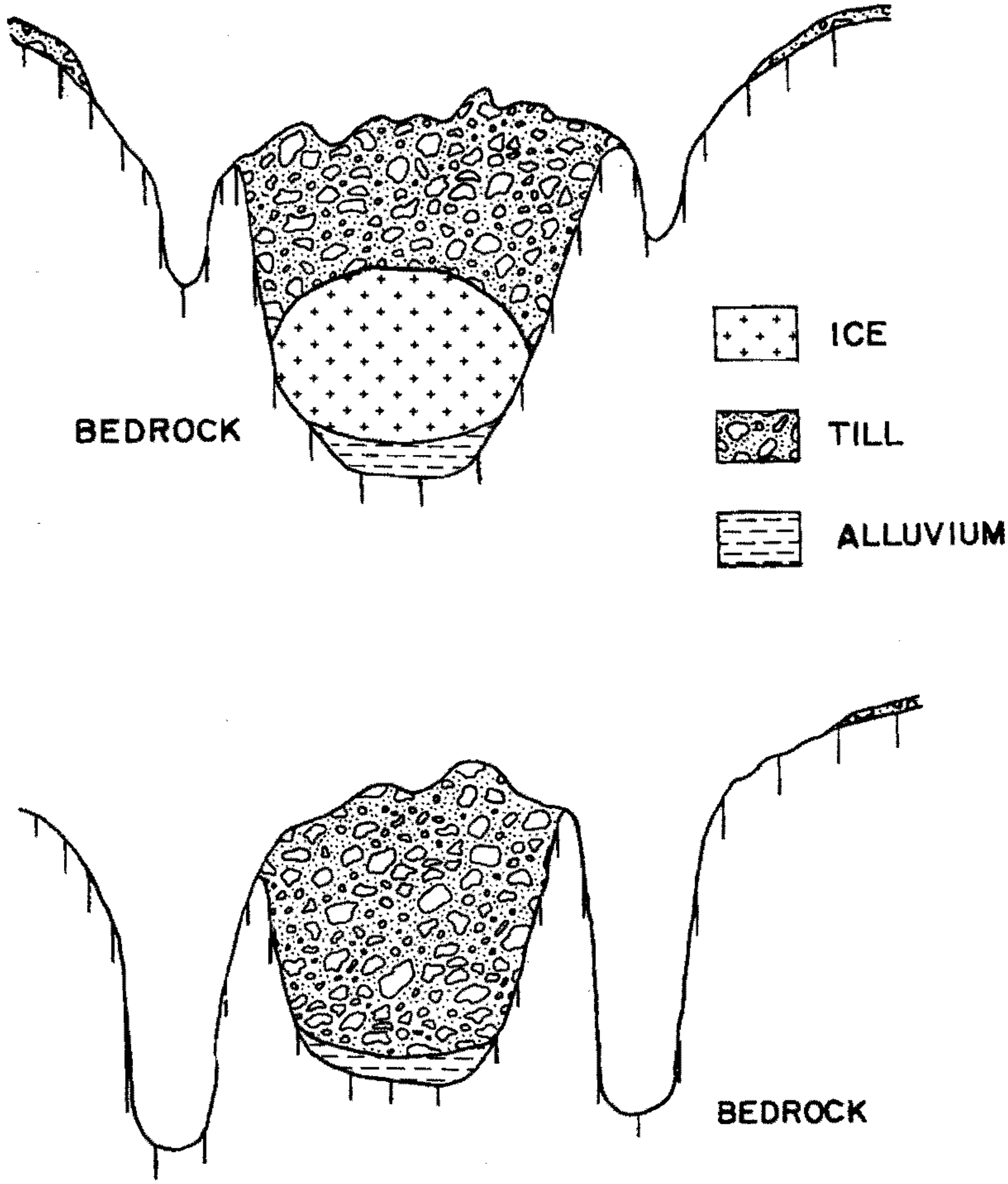
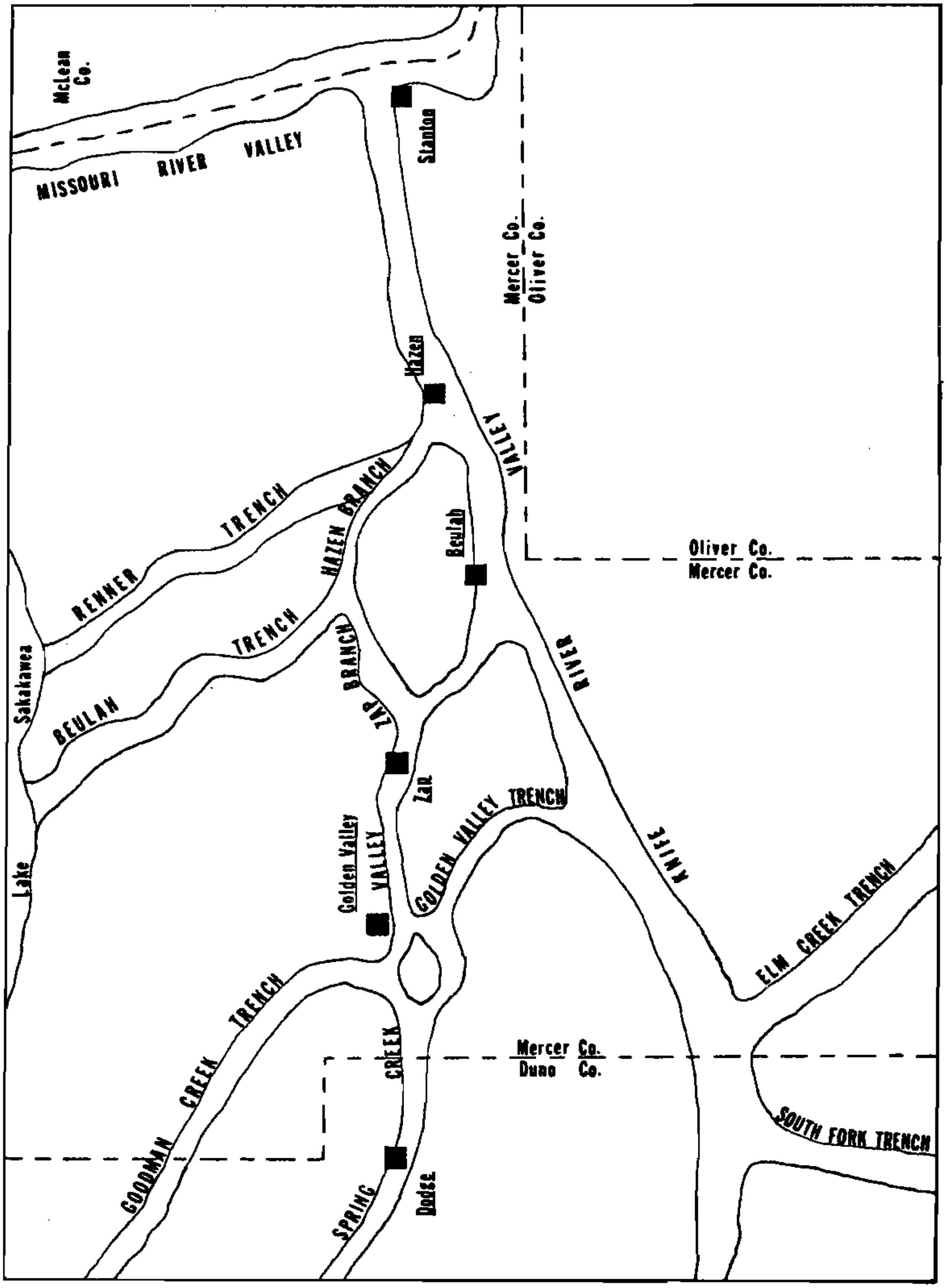

BEDROCK
ICE
TILL
ALLUVIUM
BEDROCK

Fig. 11. -- Sketch map of the approximate locations of the diversion trenches mentioned in this study.


McLean Co.
MISSOURI RIVER VALLEY
Stanton
Mercer Co.
Oliver Co.
Hazen
VALLEY
Beulah
Oliver Co.
Mercer Co.
TRENCH
RENNER
HAZEN BRANCH
TRENCH
BEULAH
Sakakawea
Lake
ZAP BRANCH
RIVER
Zap
GOLDEN VALLEY TRENCH
Golden Valley
VALLEY
KNIFE
ELM CREEK TRENCH
GOODMAN CREEK TRENCH
CREEK
SPRING
Mercer Co.
Dunn Co.
SOUTH FORK TRENCH
Dodge

Missouri River. The trench was thought to have been ice-marginal or nearly so by Benson as regional slope is to the east, and diverted waters would otherwise have flowed across a low area at the headwaters of Antelope Creek. From its shape and size, the Zap branch appears to have been the original route of the diverted water (pl. 6). The Hazen branch must have captured the flow as a tributary of the Antelope Creek drainage met an eastern tributary of the Beulah trench. Eventually it eroded to a lower base level than the Zap branch to capture the diverted Missouri River. The route was probably initially blocked by ice.

The Renner trench, nearly buried, is almost the twin of the Beulah trench (fig. 11). It, along with the route formed by the Goodman Creek and Golden Valley trenches, must have also carried water diverted from the Missouri River. These trenches may have all been initially formed by the same ice sheet, or by three separate ones. The Renner trench is not necessarily older than the Beulah trench, which may have been partially buried and reopened by later diversions. All three diversion routes predate the last ice advance as pebble-loam either fills the valleys (the Renner trench) or extends down the flanks.

Fine-grained fill

The second fill recognized by Benson (1952; Qsd_2) in the Knife River Valley was thought to have been laid down in ponded water behind an ice dam across the Missouri River, downstream from the mouth of the ancestral Knife. The lake formed in the Knife River Valley must have appeared similar to the present day Lake Sakakawea. However, the height of the ice dam must have fluctuated as the sediment laid down is both lacustrine and fluvial in origin, from clay to sand and gravel, although silty clay, silt, and fine sand are the dominant lithologies. Similar sediment has been logged in deep testholes drilled by the North Dakota State Water Commission in the Knife River Valley and many of the surrounding diversion trenches, including the South Fork and Elm Creek trenches (Croft, 1970; Klausing, 1976; and Trapp, 1971).

Mollusk shells were collected from a depth of 55-60 feet (17-18.5 m) in testhole 3656 in the Zap branch in a fine-grained sand. The entire assemblage was found to suggest deposition in slow-moving or standing water (Carlson, 1973, p. 36). The coarser deposits interbedded with the fine-grained and laminated clay, silt, and sand may represent slopewash or turbidite deposits within the lake.

The base of the fine-grained fill, from testholes (Croft, 1970), is at an elevation of 1545 feet in the Hazen branch (p. 169), at an elevation of 1692 feet in the Zap branch (p. 175), and at an elevation of 1707 feet at the divide of the two branches (p. 172). In the Beulah trench, the base is at an elevation of 1719 feet (T. 145 N., R. 88 W., Sec. 21; p. 220) and at an elevation of 1734 feet (T. 146 N., R. 88 W., Sec. 21; p. 233). Fine-grained sediments of this fill occur in all the deeper testholes in the Beulah trench, overlying either bedrock, thick medium and coarse-grained sand, or gravel.

The fine-grained fill is found on bedrock at a lower elevation than the coarse-grained sand in adjacent testholes. This implies that the coarse sand was an earlier fill, and that the trench was probably cut prior to the glacial advance that deposited the second drift of Benson (1952), or the equivalent Mercer "till" of Bluemle (1971) and Carlson (1973). The ice-dammed lake is believed to have formed shortly after the retreat of this second drift from the area (Benson, 1952, p. 128).

Testholes in the Golden Valley trench (Croft, 1970, p. 201-202) reveal up to 200 feet (60 m) of silty, fine- to medium-grained sand, probably equivalent to the fine-grained fill in the Beulah trench. Sand, silt, and clay in the Goodman Creek trench also appear equivalent to the fine-grained fill in the Beulah trench. Older fills are present in the Goodman Creek trench, including pebble-loam in the upper reaches in Dunn County (Klausing, 1976, p. 240).

Sandy silt and clay up to 256 feet (78 m) thick was penetrated in testhole 3663 in the Elm Creek trench in Mercer County (Croft, 1970, p. 72). In nearby testholes (3764 and 3664; Croft, 1970, p. 69) about 160 feet (49 m) of interbedded sand, silt, and clay was found to overlie up to 70 feet (21 m) of "questionable till". Similar lithologies were found in the South Fork trench in both Dunn and Stark Counties, and in other trenches to the west in Dunn County (Klausing, 1976; Trapp, 1971).

Lithologies in the Knife River Valley trench near Beulah and Hazen are more complex than in most of the diversion trenches (pls. 4 and 5).

Clayey silt and sand is present in the subsurface near Hazen down to an elevation of 1619 feet in testhole 3784, an elevation of 1587 feet in testhole 3747, and an elevation of 1531 feet in testhole 3739 (Croft, 1970). These sediments may represent deposition in a trench deepening to the south of Hazen (fig. 3). Similar lithologies are found at much shallower depths near Beulah. The base of a silty and sandy clay unit was found to be at about an elevation of 1712 feet in testhole 3741 (Croft, 1970, p. 189). Silty, sandy "claystone" was penetrated in numerous holes drilled by Bradley and Jenson (1962) around Beulah at elevations between 1730 and 1745 feet. This material is interpreted to be equivalent to the much thicker fine-grained fill in the diversion trenches.

Sandy silt and clay probably deposited in the same ice-dammed lake was found in the subsurface in the uplands surrounding Beulah (HB-119, 120, 126, 136, and 138; Appendix A). The small trench in which these deposits were laid down is shown in pl. 6. It probably formed when water was diverted around a stagnant ice block lying in the Knife River floodplain. The trench was probably cut after the valley trending south through Beulah was buried. The trench itself was filled with fluvio-lacustrine sediment followed by pebble-loam.

Downstream from Hazen is also evidence of a fine-grained fill in testholes south of the Knife River and west and southwest of the town of Stanton. Pebble-loam was identified in many of these testholes. In a few the pebble-loam appears interbedded with the fine-grained fill and may be contemporaneous with it as the ice dam fluctuated. Benson (1952, p. 124) identified what he thought to be exposures of the fine-grained fill in the Missouri River Valley both downstream and upstream from the mouth of the Knife River.

The Renner trench is believed to have been at least partially buried prior to the formation of the ice-dammed lake. Silt and fine-grained sand believed to be fluvio-lacustrine in origin is found on the flanks of the Hazen branch (HB-54 and in exposures in roadcuts), juxtaposed to thick pebble-loam fill in the older Renner trench (HB-55, HB-166; pl. 2). The Hazen branch was also probably cut after the Renner trench had been partially buried.

The Beulah trench, as well as the Goodman Creek and Golden Valley trenches, probably carried water diverted from the Missouri River down the Zap branch and south through the older Elm Creek and South Fork trenches (fig. 11). Later, when the way was cleared, diverted water was probably carried first through the Zap and then the Hazen branch east through the Knife River Valley to the Missouri trench. After an unknown number of glaciations and diversions of the northeastward-flowing drainage, diverted water and meltwater probably associated with the Mercer ice sheet cut a deep trench in bedrock, pebble-loam, and sand or gravel in predominantly pre-existing diversion valleys associated with the Knife River Valley.

The outlet to the east was blocked, presumably by a readvance of the ice sheet, and a lake rapidly began to form. An outlet to the southwest through the South Fork and Elm Creek trenches was apparently no longer available. Possibly drainage was blocked in the South Fork trench by glacial fill (testholes 4695 and 4694, Klausing, 1976, p. 78-81). This is not the explanation for blocked drainage in the Elm Creek trench at least as far south as testhole 3663 (Croft, 1970, p. 72), where the trench has apparently cut below the pebble-loam present in adjacent testholes.

Possibly this new trench was cut first down the Zap branch of the Beulah trench, down the Spring Creek Valley between Zap and Beulah, and around the nose southwest of Beulah (pl. 6), flowing southwest through the Elm Creek and South Fork trenches. No deep holes have been drilled through fill in either the section between Zap and Beulah or Beulah and the Elm Creek trench, but a deep trench must exist because of the geometry of the trenches flowing into these sections. The Hazen branch may then have been cut, probably for the first time. It diverted water from the Beulah trench east towards Hazen, and perhaps on into the Missouri trench. If this were the case, no new deep trench would have been cut between Beulah and Hazen, thus explaining the relatively shallow-based, fine-grained fill near Beulah. No deep holes are available in the Knife River Valley between Beulah and Hazen to verify this, and other explanations are possible.

Sedimentation rates within the lake were probably quite high as testhole data indicate as much as 60 m or more of fluvio-lacustrine deposits being laid down in what must have been a relatively short time. The steep sides of the diversion trenches would have provided much detritus to rapidly fill the deep gorges, and turbidite flows probably were a chief form of sediment distribution and accumulation. Still, the ice dam must have remained more or less in position for a number of years to allow such an extensive fill to accumulate.

The lacustrine fill was eroded extensively before the advance of the next and last ice sheet, which laid down the Napoleon "till". Fine-grained sandy silt is unconformably overlain by pebble-loam and outwash deposits in the lower flanks of the Zap branch of the Beulah trench from 15 m above the present floodplain to the subsurface beneath the floodplain. Evidence for this undulating unconformity is also found in shallow auger holes in the broad terrace east of Hazen (HB-155, 156, 157; Appendix A).

Much of this erosion may have occurred as the lake drained and a new base level was sought by streams flowing through the trenches. It could have also occurred as water from the Missouri River was diverted for the last time with the advance of the Napoleon drift sheet. The Missouri would have flowed down the Beulah trench through the Hazen branch to the Missouri trench at Stanton. In NDSWC testhole 3749, at the divergence of the Hazen and Zap branches, the fine-grained fill has been cut to a depth of 61 feet (18.5 m; an elevation of 1804) below the present floodplain, and the trench filled with gravel and then pebble-loam from the last ice advance. About 11 km downstream in the Hazen branch, the lacustrine fill was eroded to a depth of 98 feet (30 m; an elevation of 1662), and about 3 km farther downstream in the Knife River Valley near Hazen the fill was possibly cut as much as 166 feet (50.5 m; an elevation of 1569) below the present floodplain. Drainage may have once flowed through what appears to be an abandoned valley segment in T. 144 N., R. 87 W., Sec. 13, SW (pl. 6).

Logs from testholes HB-116 and HB-165 (Appendix A) west of Hazen reveal the presence of probable lacustrine sediment near the surface. This indicates that no deep trench has been cut through this segment of the Antelope Creek Valley since the deposition of the lake sediments. East of Hazen near Stanton the fine-grained fill has been partially or totally removed in the subsurface below the Knife River Valley.

Apparently, with the possible exception of the Beulah trench, none of the diversion trenches was used again to carry water diverted from the Missouri River. The South Fork and Elm Creek trenches were apparently blocked permanently through the deposition of the fine-grained fill, and diverted waters from the last ice advance must have used diversion trenches to the west in Dunn County (Moran and others, 1978). The trenches were, however, probably used to carry varying amounts of meltwater from the Napoleon and possibly the Lostwood ice sheets.

Coarse-grained fill

A younger, coarser-grained fill is clearly present in the Knife River Valley. A thick, fine- to coarse-grained sand forms a terrace south of the river from Beulah to the mouth of the Knife at Stanton. Carlson (1973) interpreted this terrace to be an inwash deposit laid down in meltwaters ponded up between the valley wall and stagnant ice lying within the Knife River Valley. This interpretation is only partially correct as sand must have formed a wall-to-wall fill upstream from Hazen (pl. 6). Abandoned valley segments are present in sections 25 and 26 of T. 144 N., R. 87 W.;

and in sections 28 and 33 of T. 144 N., R. 87 W. Auger holes (HB-30, 31, 32, and 58; Appendix A) show that these segments are filled with fine to coarse-grained sand.

Benson (1952) recognized this wall-to-wall fill southwest of Hazen, but also observed that deposits on opposite sides of the river from Hazen east to Stanton differed: those on the north side are predominantly thin, coarse-grained sand and gravel, whereas those on the south are finer-grained as is the wall-to-wall fill between Beulah and Hazen. Benson (p. 132) postulated that a "residual tongue of ice" lying in the northern part of the valley caused the formation of a kame terrace from Hazen to Stanton. He also identified a kame terrace of the same age on either side of the Missouri River.

The retreating ice sheet that laid down the last pebble-loam may have stabilized for a time along the Renner trench, the lower portion of the Hazen branch and the northern part of the Knife River Valley from Hazen to Stanton. Water was forced to flow to the south of the ice sheet, cutting a new channel into bedrock to the southeast of Hazen, and into the older, fine-grained fill to the east of Hazen (pls. 3 and 6). The sand-filled channel segment through sections 14 and 23 of T. 144 N., R. 87 W., was also cut at this time by meltwater flowing along the ice sheet from the northwest. The two channel segments in section 13 were blocked by ice (pl. 6, and HB- 38 and HB-111 in Appendix A).

As the ice marginal channel was filled, and the stagnant ice melted, the Knife River moved northward in its valley. Outwash flowing from the Krem moraine deposited sand and gravel over both pebble-loam and older lacustrine sand and silt in the Zap and Hazen branches of the Beulah trench, and over pebble-loam in the Renner trench. As the base level was lowered, the Knife River abandoned channel segments in the southern part of its old floodplain, forming the present one. Antelope Creek has formed its own modern floodplain in the Hazen branch.

The Otter and Brady Creek drainages probably carried meltwater during several different glaciations. As can be seen from pl. 6, the present streams only roughly parallel the older meltwater channels. It is uncertain if either of the valleys were used to carry diversion waters southward. The channel containing Brady Creek clearly joins a channel running into the southeastward-draining Square Butte Creek (Carlson, 1973, pl. 1). This long channel probably represents an ice marginal channel extending across the Knife River Valley and on up the Renner trench to the Missouri River (pl. 6). Drainage probably flowed south down the Renner trench, and north through the Brady Creek channel to the Knife River Valley, and southwest out the Elm Creek and South Fork trenches.

Postglacial History

Following the retreat of the last ice sheet, wind and running water have greatly modified the glacial deposits and underlying bedrock within the Beulah-Hazen area. Except for the diversion trenches, the present topography is probably similar to the preglacial topography. The Knife

River and its tributaries have left an older terrace within the modern flood-plains as the base level has fluctuated up and down during the thousands of years following glaciation. Slopewash has accumulated to significant thicknesses in many gullies (HB-51 and HB-83, Appendix A). Sand dunes east of Hazen and south of the Knife River were piled up by prevailing north-west winds during a warmer and probably more arid period about 4500-8500 years B.P. (Clayton, 1972, p. 65). Loess deposits that form a thin veneer over much of the uplands were also laid down in drier periods when hillslope stability was at a minimum.

Perhaps the most significant agent acting on the present topography in the Beulah-Hazen area is man. The large strip mines in the area, with even larger excavations planned for the future, will leave a lasting effect on the land for years to come. The following section concerns the application of geology to the relationship of man and his environment within the Beulah-Hazen area.

GEOLOGIC APPLICATIONS TO LAND-USE PLANNING

Geologic Hazards

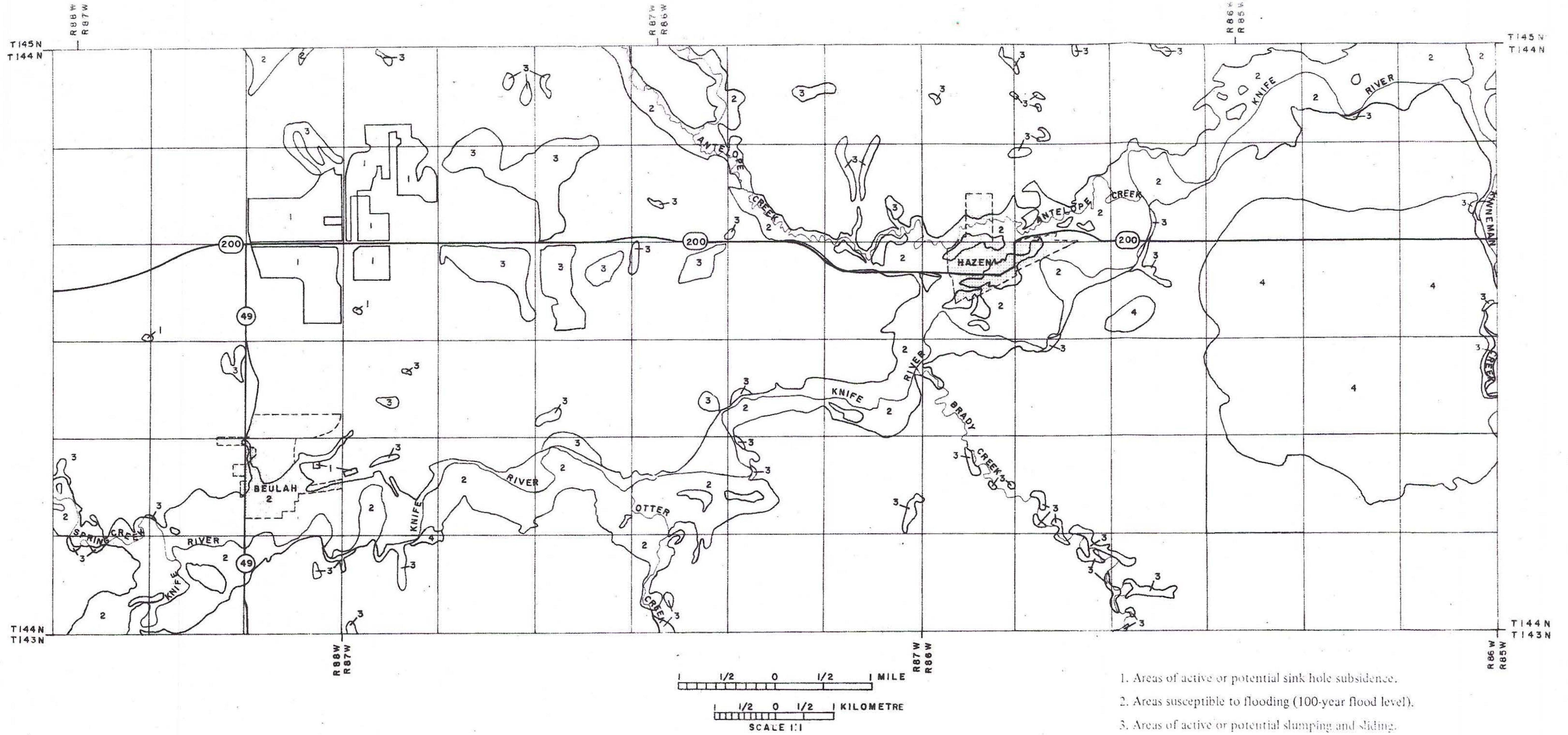
Geologic hazards in the study area are shown in figure 12. These include areas of mine sinkhole subsidence, flood susceptibility, unstable slopes, and drifting sand.

Flooding presents the most widespread and serious hazard in the Beulah-Hazen area. The area designated as an area of potential flooding on figure 12 reflects the 100-year flood frequency level as derived from aerial photos in the publication Knife River Flood Hazard Analysis (United States Department of Agriculture, 1977). Most flooding in the region occurs in the spring of the year as the result of rapid snowmelt, frozen soil, and ice jams in the river. Flooding also occurs following torrential thunderstorms in the summer. In Beulah, water from heavy downpours is funneled along small tributaries of the Knife River east and west of the town, occasionally causing extensive flooding. In Hazen, major flooding occurs when water flows toward the town from the northwest, along Antelope Creek and a smaller tributary. At present, a levee, built in conjunction with a bypass of State Highway 200 north of Hazen, is being considered to control this flooding.

Filling of land is sometimes done without regard for various subtle

Fig. 12. -- Hazard map of the Beulah-Hazen area.

1. Areas of active or potential sink hole substance.
2. Areas susceptible to flooding (100-year flood level).
3. Areas of active or potential slumping and sliding.
4. Areas of active or potential blowing and drifting sand.



1. Areas of active or potential sink hole subsidence.
2. Areas susceptible to flooding (100-year flood level).
3. Areas of active or potential slumping and sliding.
4. Areas of active or potential wind erosion.

drainageways that might exist, or without providing adequate channels or storm drains for the increased runoff due to paving. Proper development of subdivisions on uplands is needed to prevent minor flooding that would otherwise take place in depressions and blocked natural drainageways (Bergstrom, Piskin, and Follmer, 1976).

Pressure to build within the 100-year flood frequency level areas will probably become greater as development continues. This development should be closely regulated to avoid such problems as have resulted in Minot, North Dakota, and other expanding communities. Further discussion of flooding hazards is given by Harrison (1968) and United States Department of Agriculture (1977).

The rather unique mine sinkhole subsidence area lies about 2 km north and northeast of Beulah. The sinkholes have resulted from the collapse of overlying materials into lignite mine drifts. Collapse apparently began almost immediately after termination of mining and has continued to the present, thus creating a considerable hazard to any kind of construction. Initially, strata overlying a mine drift collapses creating a hole that increases in width below the surface. The roof quickly collapses and gradually the sides of the hole become less steep as slopewash accumulates in the bottom and plants begin to grow. Eventually the slopes become gentle enough to allow cattle into the holes (fig. 13). Recently collapsed holes are often fenced off to protect grazing stock.

A third type of hazard (fig. 12) is slumping and sliding, or mass movement, due to unstable slopes. Mass movement is caused by gravity,

Fig. 13. -- Mine sinkholes. (A) Recently collapsed mine sinkhole (T. 144 N., R. 87 W., Sec. 6, NESESW). Notice how the roof is held up by thin, jointed pebble-loam at the surface. (B) Older mine sinkholes (T. 144 N., R. 87 W., Sec. 6, SESESW).

and is controlled by the earth materials involved, friction, and the slope over which the mass is moving. This hazard is present in areas of steep slopes, which includes strip mine spoil piles and highwalls, and cutbanks along streams (fig. 14). Principal triggering events in Mercer County include heavy rains or large amounts of meltwater that reduce internal friction of the earth materials, unloading or undercutting of stable slopes by natural erosion such as by streams or springs, and alteration of natural slopes through the actions of man (Flawn, 1970).

No direct hazards due to slumping and sliding exist in the study area, except for a few residences and sections of road near advancing cutbanks of the Knife River and Spring Creek. Several of these areas were not mapped separately as areas of slumping and sliding as they also were within the 100-year flood level. In several places along the Knife River and Spring Creek, attempts are being made to impede erosion by lining the bank with rip-rap and junk cars. Otter, Brady, and Kinneman Creeks all show the scars of slumping and sliding along steep banks where slopes have been undercut. Smaller scale soil creep is also evident along these streams. Mass movement also occurs along steep slopes with springs at their bases, which serve to unload the toe of the slope.

The fourth and probably least significant hazard is that of blowing and drifting sand. The major area where this is of concern is to the east and southeast of Hazen. Here, sand, originally reworked during an arid period approximately 4500-8500 years ago (Clayton, 1972), has been

Fig. 14. -- Slump blocks along a cutbank in overbank flood deposits of the Knife River (T. 144 N., R. 87 W., Sec. 26, SWNW). A point bar is in the foreground.

deposited in longitudinal dunes. Local relief in the dune areas reaches 50 feet (15 m). Most of the area has been more or less stabilized by vegetation, although several areas now have blowouts and drifting sand, as in the eastern part of section 24 in T. 144 N., R. 86 W., where overgrazing has removed the natural cover. Brush, rotted hay, manure, and similar materials are used to impede the progress of drifting sand and help establish vegetation.

Most of the area of dunes is used for pasture and, given proper grazing practices, should remain stable. Attempts have been made to further develop land to the east of Hazen along State Highway 200. Should this development continue to expand south of the highway, in the form of new trailer courts or subdivisions, care must be taken to insure that the natural cover is not disturbed to such an extent that blowing sand becomes a problem. This danger could become severe given a change in the climate such as occurred in the 1930s.

Suitability Maps

Three interpretive maps describing suitability for sanitary landfills, septic tank systems, and general construction were compiled (figs. 15, 16, and 17). These were constructed using a color coding system first developed by Quay (1966) for presenting information about soils, and applied to environmental geology in Illinois by Hackett and McComas (1969), Gross (1970), Jacobs (1971), and Larsen (1973); and in North Dakota by Deal (1972) and Arndt and Moran (1974). The system borrows from the traffic stoplight, where green indicates favorable conditions; yellow, caution; and red, unfavorable conditions. In this study, the colors are represented G, Y, and R, and 1 and 2 affixed to the letters refer to different shades of the basic colors, or different kinds of limitations within the main color groups. For example, a G1 (green-one) rating indicates an area with the fewest limitations, whereas R2 (red-two) indicates an area with the most limitations. Each interpretive map has a corresponding explanation on the opposite page that briefly explains each rating and shows how the color scheme can be applied.

Sanitary landfills

The sanitary landfill is defined by the American Society of Civil Engineers (1959) as:

> A method of disposing of refuse on land without creating nuisance or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

The landfill is considered sanitary if it serves to contain and isolate fill material and prevent the contamination of surface and subsurface water. Water that comes into contact with decomposing wastes in a landfill becomes highly mineralized due to the leaching of soluble constituents from the refuse. Surface seepage of this polluted water, or leachate, may also contaminate surface water and produce undesireable odors. The production of leachate may be prevented or at least curtailed by keeping the wast as dry as possible. Locating the base of the landfill sufficiently above the water table and covering the fill with a well compacted, low-permeability material helps to prevent saturation by subsurface water and infiltration by precipitation (Arndt and Moran, 1974). The cover material also acts to prevent gas and fluids produced by chemical and biological action from escaping into the atmosphere, surface water, or subsurface water. In addition, it prevents insects, rodents, and other animals from access to the wastes (Flawn, 1970).

Locating the disposal site in materials of low permeability restricts the movement of leachate. Fine-grained materials such as clay, silt, and pebble-loam retard the movement of contaminants, thereby allowing for bacterial or chemical attenuation of the leachate by absorption and filtration. Clay minerals, in particular, have the ability to exchange ions with contaminants in the ground water, thus immobilizing different contaminant ions and reducing their concentrations in solution (Lindorff and Cartwright, 1977).

Topography is also an important factor in selecting disposal sites. Steep slopes should be avoided because of the increased ground water flow gradient and possible slope instability. Moderate slopes, however, would be acceptable as infiltration rates are less here than in more flat-lying areas. Ground water recharge areas, generally in the uplands, should be well above the water table and occur in relatively impermeable materials to insure proper retardation and filtration of leachate, which naturally moves downward with the ground water gradient towards underlying aquifers.

Discharge areas, although they retain the leachate and prevent it from reaching underlying aquifers, present a problem of surface pollution because they usually occur near a body of surface water such as a pond or stream (Groenewold, 1974). Areas of potential flooding should be avoided, including the bottoms and heads of gullies that may be well above the water table, to prevent the flushing of contaminants into nearby surface water.

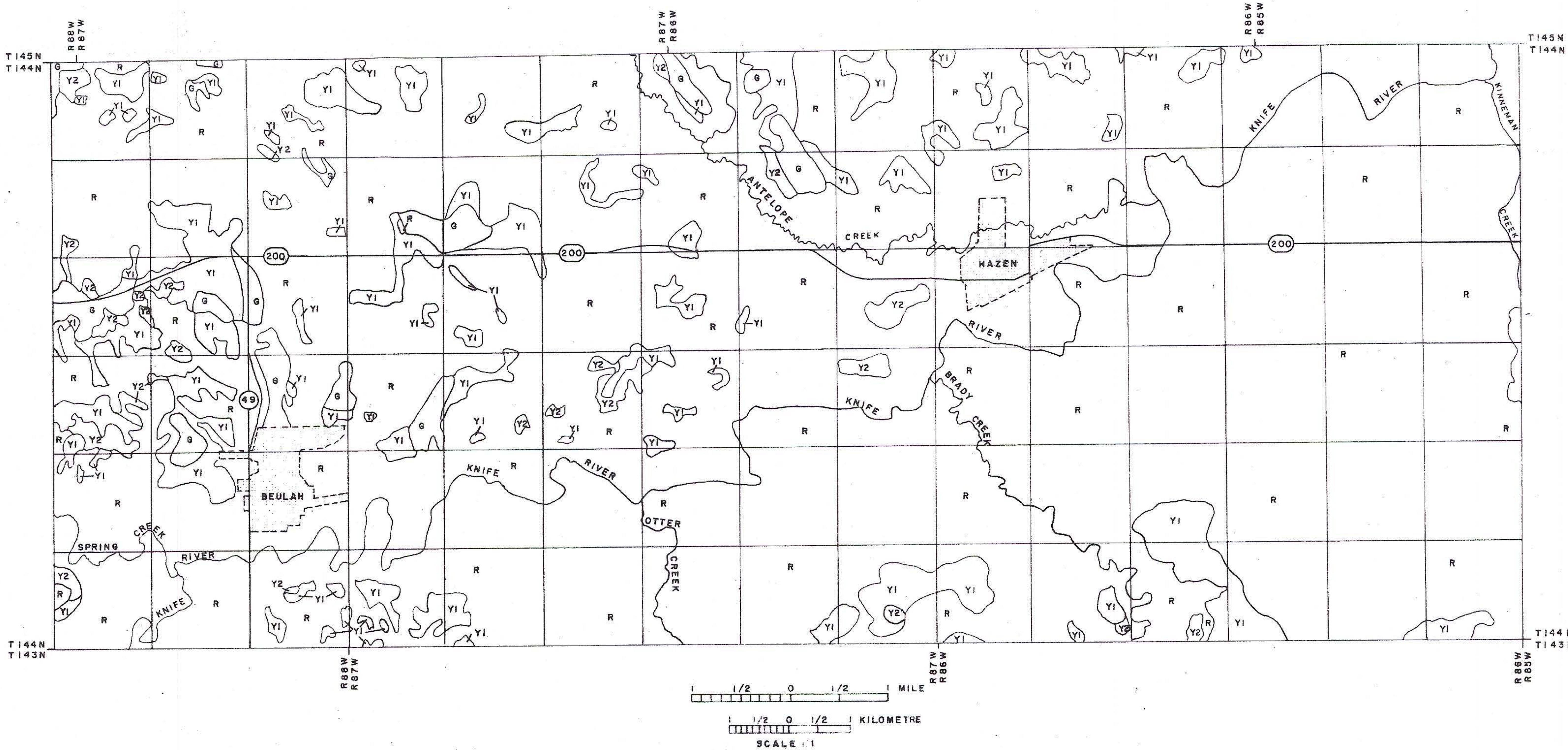
The cool, semi-arid climate of the Beulah-Hazen area is advantageous. Because of limited precipitation, leaching of fills is slight. A proper cover material prevents precipitation from entering and reacting with the waste material. (The use of cover materials having extreme shrink-swell characteristics should be avoided.) Cool temperatures tend to inhibit chemical reactions within the landfill. Although this tends to increase the amount of time needed for stabilization, it also prevents large amounts of leachate from being generated at any particular time. Earth materials at the landfill site should be easy to excavate and compact in both wet and very cold weather, as the landfill will probably be in use year round.

Lignite strip mines and underground mine sinkholes should be avoided as disposal sites unless contamination of surface water or access to a potential lignite aquifer can be prevented (fig. 18). The site of the present landfill north of Beulah, as well as the active lignite strip mines directly south of Beulah, are above the local water table and appear to be acceptable sites. The area of sand dunes east of Hazen is unsuitable for landfills because the sediment is highly permeable and, locally, the water table is high. All floodplains should be avoided. Old gravel pits are generally poor sites because the sediment here is highly permeable. Areas rated either Y1 or Y2 (fig. 15) should be suitable for disposal sites, provided proper investigation and development of the site is accomplished. Hughes (1972) has given further information concerning the siting and design of sanitary landfills.

Septic tank systems

Septic tank disposal systems consist of an enclosed holding tank and a drain-tile field. The tank receives the liquid wastes and allows solids to settle to the bottom, or to be liquified by anaerobic micro-organisms. The micro-organisms help to neutralize harmful contaminants within the tank, and condition the effluent for easy percolation into the soil by causing colloidal and dissolved organics to degrade into simpler organic compounds. The drainage-tile field filters solids and allows fluids to escape by seepage through open joints or perforations (Clark and Lutzen, 1971).

Septic tanks differ from landfills in the contaminants they release to the earth. A landfill yields a relatively small volume of effluent, in the form of a concentrated, mineralized liquid (leachate), and inorganic substances predominate over organic substances. Leachate may travel a considerable distance from the landfill site, but the overall area it affects is relatively small. In contrast, a septic tank system produces a relatively large volume of effluent that is mainly organic. Where large numbers of



G — Suitable disposal sites are available. These areas are characterized by at least 15 metres of relatively impermeable unsaturated material. Includes areas of pebble loam and loam over pebble loam where there is no evidence suggesting the occurrence of sand and gravel lenses. Boulders at or near the surface may provide some workability problems.

Y1 — Suitable disposal sites probably available; at least 9 metres of relatively impermeable unsaturated material. Includes areas of pebble loam and loam over pebble loam, with possible sand or gravel lenses at depth; pebble loam over relatively impermeable, soft bedrock; and areas underlain directly by relatively impermeable, soft bedrock. Also includes many areas where the principal limiting factor is the slope (9-15%), and areas where up to 1.5 metres of silty fine sand may overlay pebble loam. Clayey bedrock and boulders in some areas may provide some workability problems.

Y2 — Some suitable disposal sites available; at least 9 metres of relatively impermeable unsaturated material. Includes areas of 0.5 to 2 metres of sand or sand and gravel over pebble loam or relatively impermeable, soft bedrock. Sand at the surface provides poor cover, and may cause problems of seepage into the site.

R — Disposal sites likely to pose pollution hazards unless special engineering precautions are taken. Includes areas of less than 9 metres of unsaturated materials, areas of flooding and ponding, areas of steep (greater than 15%) slopes, and areas of materials having moderate to rapid permeability (sand, gravel, scoria, some sandy bedrock).

Fig. 15. -- Suitability of the Beulah-Hazen area for sanitary landfill.

G Suitable disposal sites are available. These areas are characterized by at least 15 m of relatively impermeable, unsaturated material. Includes areas of pebble-loam and loam over pebble-loam where evidence of the occurrence of sand and gravel is lacking. Boulders at or near the surface may provide workability problems.

Y1 Suitable disposal sites probably available: at least 9 m of relatively impermeable, unsaturated material. Includes areas of pebble-loam and loam over pebble-loam, with possible sand or gravel at depth; pebble-loam over relatively impermeable, partially consolidated sediment; and areas underlain directly by relatively impermeable, partially consolidated sediment. Also includes many areas where the principal limiting factor is the slope (9-15%), and areas where up to 1.5 m of silty fine sand may overlay pebble-loam. Clayey sediment and boulders in places may provide workability problems.

Y2 Suitable disposal sites may be available: at least 9 m of relatively impermeable, unsaturated material. Includes areas of 0.5-2 m of sand or sand and gravel over pebble-loam or relatively impermeable, partially consolidated sediment. Sand at the surface provides poor cover, and may cause problems of seepage into the site.

R Disposal sites are likely to pose pollution hazards unless special engineering precautions are taken. Includes areas of less than 9 m of unsaturated materials, areas of flooding and ponding, areas of steep (greater than 15%) slopes, and areas of materials having moderate to high permeability (sand, gravel, and scoria).

closely spaced systems occur, the total, accumulative effect of the dilute waste that is produced diffuses contamination widely. This may cause a general degradation of the ground water over a broad area (Larsen, 1973).

The principal factors in assessing the suitability of an area for septic disposal systems are the permeability of the materials, and depth to the water table. Low permeability, as in clayey materials, prevents proper filtration and leads to the clogging of the drain tiles. If the permeability is too high, filtration will be rapid and effluent will not be properly neutralized in the septic tank. Septic tank systems in areas of a high water table pose a potential threat to ground water quality. A high water table will also prevent proper movement of the effluent through the system.

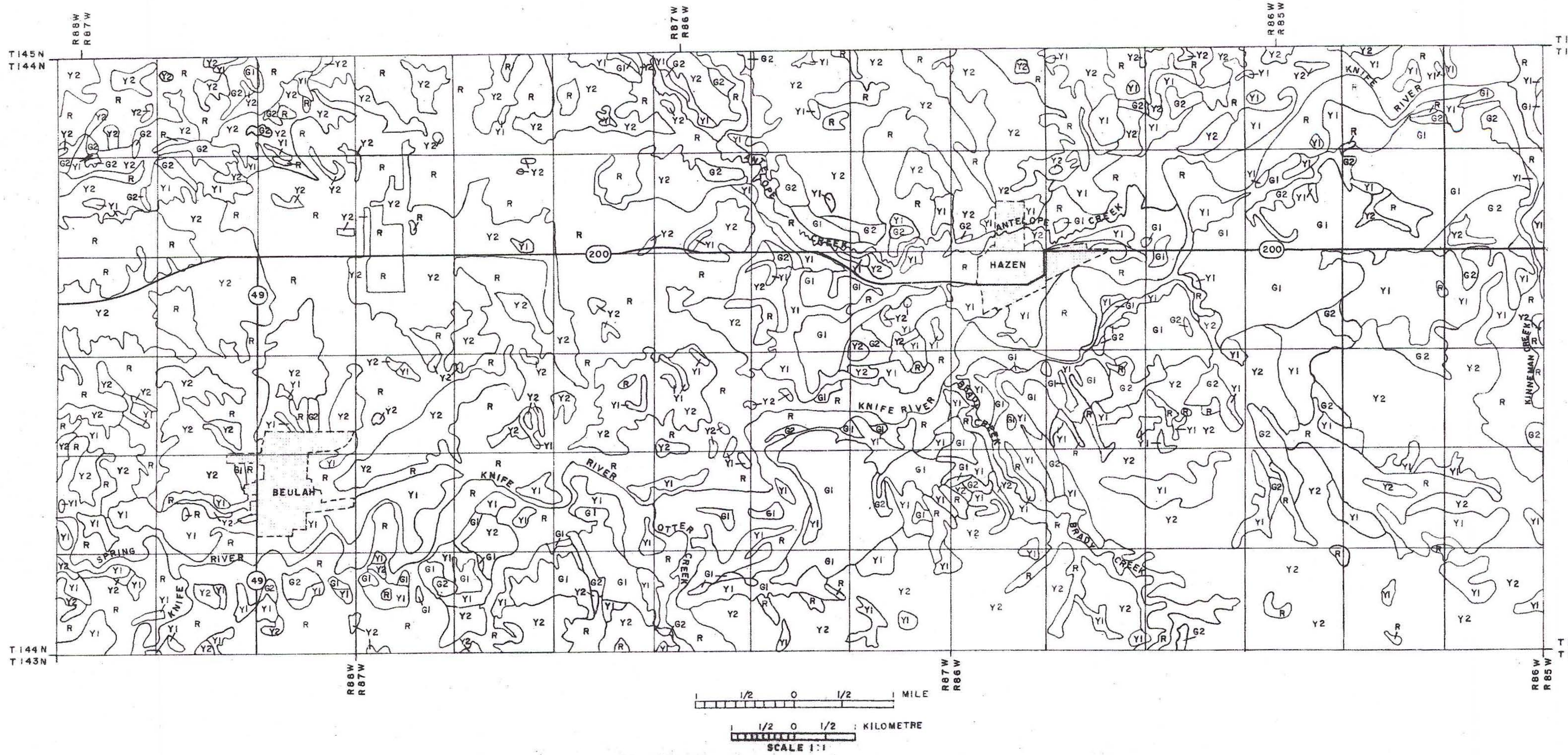
Topography is also an important consideration in the placement of septic tank systems. Where slopes exceed 20%, it is probable that effluent will surface downhill from the system, regardless of depth of burial (Franks, 1972). Filter fields should be placed such that surface runoff flows away from rather than into them. Areas susceptible to flooding should be avoided as the filter fields will clog, sometimes permanently. Systems should not be located near road cuts or other construction cuts, nor near any surface water or wells. The presence of boulders or bedrock gives rise to workability problems in installation of the system.

The septic tank and drainage filter field were developed primarily for rural areas. If this type of disposal system is to be employed in more populated areas, careful consideration of the earth materials and water table must be carried out to insure proper design and location of the septic tank system. Otherwise, ultimate failure may result if filtration capacity is exceeded by too many disposal systems. A sewage collector system ending either in a lagoon or mechanical treatment plant could replace a faulty septic tank system, but it would be much more economical to design and install adequate sewage systems before, rather than after development (Clark and Lutzen, 1971). For more extensive discussion of septic tank systems, see Franks (1972).

Many suitable sites for septic tank systems are available in the Beulah-Hazen area (fig. 16), provided that areas prone to flooding and areas of steep slopes are avoided. Proper spacing and design of the systems is essential, especially in areas of permeable sands and gravels.

Sewage lagoons

Sewage lagoons are shallow, flat-bottomed ponds built to hold sewage within a depth of 2-5 feet (0.6-1.5 m). The lagoon allows bacterial action to decompose the solids while the water evaporates. Thus, it is important that the lagoon either be located in materials of low permeability or have an impermeable liner to prevent leakage of the sewage into the ground water system or into surface waters. High water tables are undesirable due to the increased probability of ground water contamination. Areas susceptible to flooding should be avoided as sewage could be flushed into surface water systems during periods of high water. Presence of considerable organic matter in materials upon which a lagoon is built



G1 — Suitable sites [illegible] ... Silty [illegible] fine to medium sand, with some areas of silty coarse sand and gravel, and sandy silt. Caution should be exercised, especially in areas of courser sand and gravel, to insure proper spacing and location of the septic systems.

G2 — Suitable sites generally available; moderate to high permeability, low water table, moderate to gentle slopes, and no danger of flooding. Sandy silt and sandy silt over sand, and silty sand on moderate slopes. Pebble loam may occur at depths below 1.5 metres.

Y1 — Suitable sites probably available; moderate to high permeability, low to moderately low water table, gentle to moderately steep (15%) slopes. Includes areas of loam and loam over sand, pebble loam, or soft sandy bedrock. Also includes areas of less than 1.5 metres of silty sand over pebble loam or soft sandy bedrock, and areas of silty sand on moderately steep slopes. Rare instances of high water table and flooding could cause problems in these areas lying within floodplains.

Y2 — Some suitable sites may be available with proper spacing and design; moderate to low permeability, generally low water table, gentle to moderately steep (15%) slopes. Includes areas of silty clay loam, silt over pebble loam, thin (less than .5 metre) sand over pebble loam, pebble loam, pebble loam over soft bedrock, and soft sandy bedrock. Areas of windblown sand characterized by steep slopes and high permeability are also included. Occasional instances of high water table and flooding places stringent limitations on those areas lying within floodplains.

Suitable sites generally not available due to one or more of the following constraints: low permeability, high water table, steep slopes, or severe flooding hazard. Areas of soft [illegible]

Fig. 16. -- Suitability of the Beulah-Hazen area for septic tank systems.

G1 Suitable sites available: relatively high permeability, low water table, gentle slopes, and no danger of flooding. Silty, very fine to medium sand, with some areas of silty coarse sand and gravel, and sandy silt. Caution should be exercised, especially in areas of coarser sand and gravel, to insure proper spacing and location of the septic systems.

G2 Suitable sites generally available: moderate to high permeability, low water table, moderate to gentle slopes, and no danger of flooding. Sandy silt and sandy silt over sand, and silty sand on moderate slopes. Pebble-loam may occur at depths below 1.5 m.

Y1 Suitable sites probably available: moderate to high permeability, low to moderately low water table, gentle to moderately steep (15%) slopes. Includes areas of loam and loam over sand, pebble-loam, or partially consolidated, sandy sediment. Also includes areas of less than 1.5 m of silty sand over pebble-loam or partially consolidated, sandy sediment, and areas of silty sand on moderately steep slopes. Rare instances of high water table and flooding could cause problems in those areas lying within floodplains.

Y2 Suitable sites may be available with proper spacing and design: moderate to low permeability, generally low water table, gentle to moderately steep (15%) slopes. Includes areas of silty clay loam, silt over pebble-loam, thin (less than 0.5 m) sand over pebble-loam, pebble-loam over partially consolidated sediment, and partially consolidated, sandy sediment. Areas of windblown sand characterized by steep slopes and high permeability are included. Occasional instances of high water table and flooding places stringent limitations on those areas lying within floodplains.

R Suitable sites generally not available due to one or more of the following constraints: low permeability, high water table, steep slopes, or severe flooding hazard. Areas of partially consolidated, clayey sediment where permeability is the principal limiting factor may be a possible exception; in this case, extensive drain-tile fields may provide sufficient drainages.

could modify the desired biological action within it. Sewage lagoons should be located in areas of low relief, for ease of construction and to avoid high ground water drainage gradients that could cause leakage (Arndt and Moran, 1974). Prevailing winds should be taken into account in the siting of the sewage lagoon to prevent unpleasant odors from entering the community it serves.

A suitability map was not compiled for sewage lagoons. Generally, those areas rated as favorable for sanitary landfills (fig. 15) are also favorable for sewage lagoons, given a proper slope.

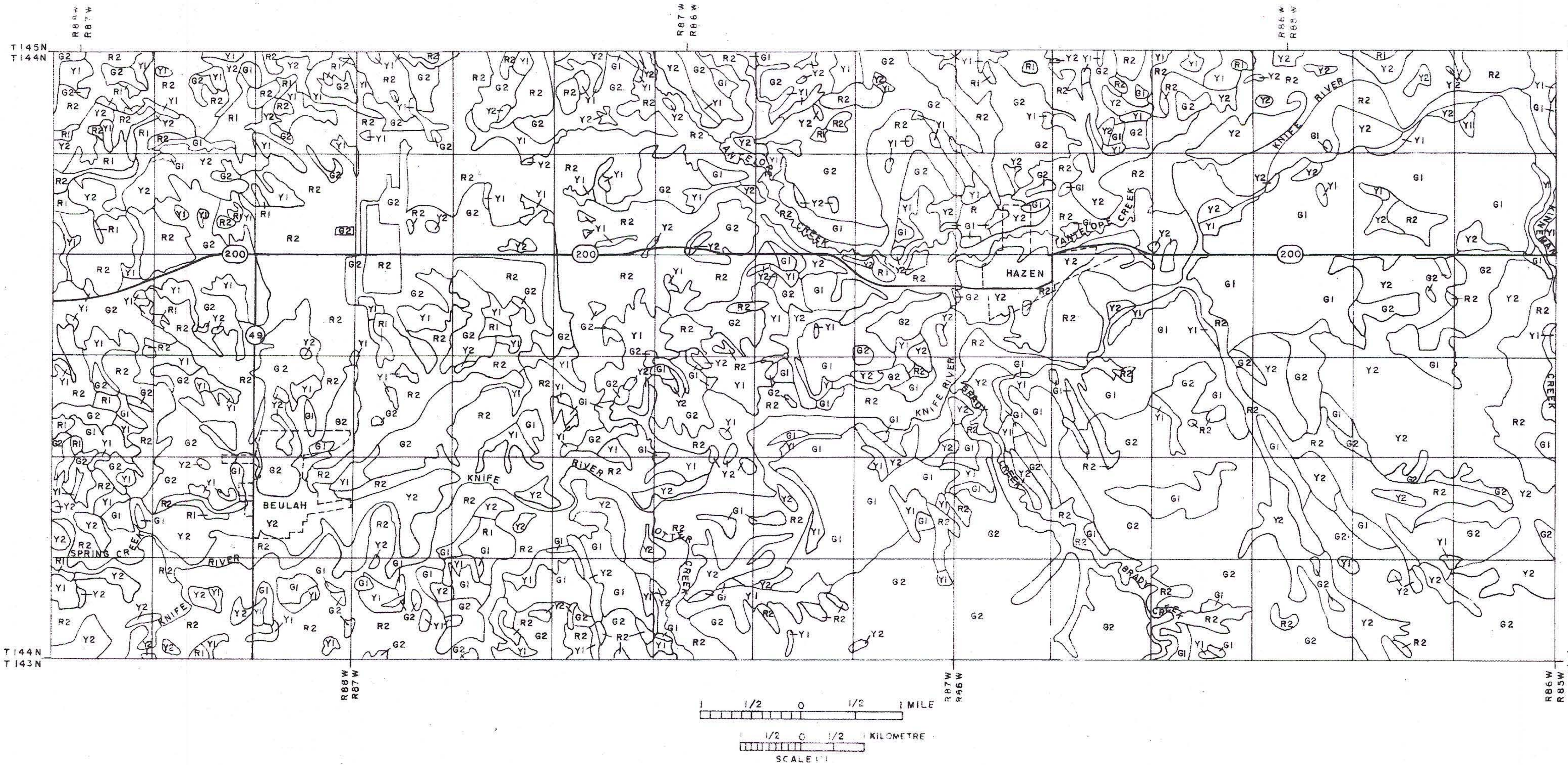
The disposal ponds for Beulah are southeast of town on the Knife River floodplain. The ponds have clay liners designed to prevent movement of effluent away from the site. They also had to be built up to lie above the 100-year flood level. Problems of leakage and an expanding population, however, are necessitating consideration of alternative sites to either augment or replace the present disposal ponds. Potential sites to the north and west are not feasible due to rugged terrain, flood hazard, or prevailing wind conditions. Areas to the east within the Knife River floodplain in sections 29 and 30 of T. 144 N., R. 87 W., seem to be the most suitable. However, borehole data indicate that permeable material is close to the surface in that area which, along with the flooding hazard, would require special engineering precautions to prevent surface and subsurface water pollution. A suitable site might also be developed south of the old rodeo grounds in section 30 of T. 144 N., R. 88 W., but sand at the surface could prove to be a problem.

Disposal ponds for Hazen are northeast of town. Except for occasional unpleasant odors downwind, this is an adequate site for sewage retention, and is presently being expanded to meet increasing demands. Soil and borehole data (HB-109, Appendix A) indicate that the lagoon is on thick deposits of relatively impermeable materials. The disposal ponds had to be built up to lie above the 100-year flood level. No other location near Hazen would be as suitable for a sewage lagoon due to either flooding hazards or prevailing winds.

General construction

General construction refers to residential and small commercial structures, road building, and other projects of similar size. Construction conditions within the study area were coded as shown in figure 17. All engineering interpretations were based on the known characteristics of earth materials similar to those found in the study area. Laboratory tests were not run on any of the samples collected during this study. For this reason, figure 17 should be used only as a general indicator of site suitability. A competent foundation engineer should be engaged to evaluate specific construction sites and insure proper design.

The engineering properties of the earth materials, water conditions, and slope angle were considered in evaluating the construction conditions within the study area. Table II gives the general engineering characteristics of each map unit represented on plate 1. Engineering properties considered include



Good construction conditions: high bearing capacity, low compressibility, low water table, good internal drainage, gentle to moderate slopes. Includes upland areas of soft sandy bedrock where the major limitation is workability and lowland areas and terraces of silty sand, sand, and sand and gravel where the major limitation is sidewall instability. Also includes areas of windblown sand having somewhat lower bearing capacities.

Good to moderate construction conditions: high bearing capacity, low compressibility, low water table, gentle to moderate slopes. Includes areas of pebble loam and areas where silt, loam, and sand and gravel overlie pebble loam. The presence of scattered boulders both at and below the surface may cause problems during excavation, compaction, and pile driving. Susceptibility to frost heave and moderate to high shrink-swell characteristics may cause some foundation problems. Dewatering of sand and gravel lenses may cause slope stability problems.

Moderate construction conditions: areas of sand, pebble loam, and soft bedrock limited in construction capabilities mainly by moderate to steep (9 to 15%) slopes. Includes areas of shallow (less than 1 metre) loam over scoria, where workability may be a severe problem. Also includes areas of shallow sandy silt and silt over soft sandy siltstone and siltstone, where fair to poor compaction, moderately low bearing capacity, and susceptibility to frost heave are principal limiting factors.

Moderate to poor construction conditions: moderate to low bearing capacity, moderate to low compressibility, fair to poor compaction, moderate shrink-swell characteristics, susceptibility to frost heave, low water table, and gentle to moderate slopes. Materials generally consist of clayey silt to very fine silty sand. Deeper excavations on the uplands may encounter workability problems. Quick conditions common on the floodplain. Clay lenses at depth on the floodplains may cause problems of differential settlement. Some areas are susceptible to flooding and high water tables.

Fig. 17. -- Suitability of the Beulah-Hazen area for general construction.

G1 Good construction conditions: high bearing capacity, low compressibility, low water table, good internal drainage, gentle to moderate slopes. Includes upland areas of partially consolidated, sandy sediment where the major limitation is workability, and lowland areas and terraces of silty sand, sand, and sand and gravel where the major limitation is sidewall instability. Includes areas of wind-blown sand having somewhat lower bearing capacities.

G2 Good to moderate construction conditions: high bearing capacity, low compressibility, low water table, gentle to moderate slopes. Includes areas of pebble-loam and areas where silt, loam, and sand and gravel overlie pebble-loam. The presence of scattered boulders both at and below the surface may cause problems during excavation, compaction and pile driving. Susceptibility to frost heave and moderate to high shrink-swell characteristics may cause foundation problems. Dewatering of sand and gravel lenses may cause slope stability problems.

Y1 Moderate construction conditions: areas of sand, pebble-loam, and partially consolidated sediment limited in construction capabilities mainly by moderate to steep (9-15%) slopes. Includes areas of shallow (less than 1 m) loam over scoria, where workability may be a severe problem. Includes areas of shallow sandy silt and silt over partially consolidated, sandy siltstone and siltstone, where fair to poor compaction, moderately low bearing capacity, and susceptibility to frost heave are principal limiting factors.

Y2 Moderate to poor construction conditions: moderate to low bearing capacity, moderate to low compressibility, fair to poor compaction, moderate shrink-swell characteristics, susceptibility to frost heave, low water table, and gentle to moderate slopes. Materials generally consist of clayey silt to very fine silty sand. Deeper excavations on the uplands may encounter workability problems. Quick conditions may occur on the floodplains. Clay lenses at depth on the floodplains may cause problems of differential settlement. A number of areas are susceptible to flooding and high water tables.

R1 Poor construction conditions: low bearing capacity, high compressibility, poor internal drainage, moderate to high shrink-swell characteristics, susceptible to frost heave, poor workability, and sidewall instability. Silty clay loam in swales and on floodplains; silty clay, clay loam, and silty clay loam over partially consolidated, clayey sediment on the uplands. Bearing capacity is moderately high where shallow to bedrock.

R2 Very poor construction conditions. Areas of organic-rich clays with low bearing capacity, high compressibility, high water table, poor internal drainage, high to very high shrink-swell potential, high water content, liquid limit, and plasticity index. Includes areas of high water table and poor drainage, areas of severe flood hazard, areas of blowouts and drifting sand, and areas of steep (greater than 15%) slopes.

TABLE II

Inferred Engineering Properties of the Map Units on Plate 1.

Unit	Water Table	Permeability	Shrink-Swell Properties	Compress-ibility	Bearing Capacity	Comments
A	High	Low	High to very high	High	Low	1. Poorly drained, subject to periodic flooding. 2. High water content, liquid limit, and plasticity index.
B	Usually below 3m	Low to moderate	Moderate	Moderate to high	Moderate to low	1. Many areas subject to periodic flooding. 2. Susceptible to frost heave. 3. Quick conditions may develop when sand lenses under pressure are exposed in deeper excavations. 4. Foundational problems may result from differential compaction of clay lenses at depth.
C	Low	Moderate	High	Low to moderate	Low to moderate	1. Highly susceptible to frost heave.
D	Low	High	Low	Low	Moderate	1. Bearing capacity relatively low without compaction. 2. High water table where the unit is thin or clayey. 3. Many slopes steep and unstable. 4. Poor sidewall stability.
E	Low	High	Low	Low	Moderately high	1. High water table where the unit is clayey or occurs near streams. 2. May be subject to periodic flooding. 3. Foundational problems may result from differential compaction of clay lenses at depth. 4. Poor sidewall stability.

TABLE II (cont.)

Unit	Water Table	Permeability	Shrink-Swell Properties	Compress-ibility	Bearing Capacity	Comments
F	Low	Low	Moderate	Low to moderate	High	1. Where consistently drained and dry, cracks formed within the unit increase the permeability. 2. Poor internal drainage. 3. Susceptible to frost heave. 4. Boulders at or near the surface may cause workability problems.
G	Low	High	Low	Low	High	1. Poor sidewall stability. 2. Cobbles may cause workability problems.
H	Low	Moderate to high	Moderate	Moderate	Low to moderate	1. Susceptible to frost heave.
I	Low	High	Low	Low	High	1. High permeability due to extensive fracturing within the unit. 2. Workability may be a problem, especially in excavations.
Jf	Low	Low	Moderately low to low	Moderately low to low	Moderately high	1. Clayey residual soils may overlie the unit and are characterized by low bearing capacity, high compress-ibility, moderate to high shrink-swell tendencies, and susceptibility to frost heave. 2. Workability may be a problem.
Jc	Low	Moderately low	Low	Low	High	1. High permeability at the surface. 2. Workability may prove difficult at depth.

bearing capacity, compressibility, compaction, shrink-swell characteristics, potential for frost heave, workability, and sidewall stability. Water conditions considered include position of the water table, internal drainage, and flooding potential. Slopes, except where adjacent to areas undergoing active erosion, are generally stable. Steep slopes often need to be altered, especially for high-density construction, which not only increases the cost of development, but may reduce the stability of the slope. Much basic material about engineering properties of the earth materials was derived from Weiser (1975), Arndt and Moran (1974), Flawn (1970), Gross (1970), and Terzaghi and Peck (1967).

Development in the Beulah area is presently predominantly north and northeast of town, where there are good foundation conditions and no danger of flooding. Further construction on the floodplain would be ill-advised as many areas are susceptible to flooding. Gravel deposits at the west edge of Beulah should be utilized prior to development over them in order to make the most efficient use of the land (fig. 18).

The areas north and northwest of Hazen are best suited for construction, mainly because of the general lack of flooding hazard there. The danger of flash flooding from gullies to the north and northwest of town should be considered, however, in planning the area's development. Settling problems have developed with several of the larger buildings in southeast Hazen as evidenced by cracks in the walls and foundations. City water well logs show 5-9 m of clay within 1-2 m of the surface. This material is probably

Fig. 18. -- Examples of short-sightedness in the Beulah-Hazen area. (A) Garbage thrown in this sinkhole (T. 144 N., R. 87 W., Sec. 7, NENENW) may contaminate water in a nearby stock well, and eventually affect the water quality of a number of farm wells as little filtering of contaminants is possible in a lignite aquifer. (B) Gravel exposed in this road cut in Beulah, although of relatively low quality, is no longer an available resource because of the housing development overlying it.

responsible for the differential settling of the buildings. This problem serves to illustrate the need for proper site investigation and foundation design, especially in areas of such wide sediment variability as the Knife River floodplain.

SUMMARY AND CONCLUSIONS

The necessity of land-use planning for rapidly expanding population centers is becoming increasingly clear. Economic and environmental factors are requiring decision-makers to ensure that land resources are protected, as well as used to their fullest capacity. Geological information in this report should be of value to such decision-makers. Proper land planning requires more than knowledge of the surficial materials, as can be found in county soil surveys. Man affects and is affected by the earth materials for some distance below him. For this reason the near-surface as well as the surficial earth materials were mapped in a 90-square mile area surrounding the growing west-central North Dakota towns of Beulah and Hazen.

The relative depth and thicknesses of a maximum of three earth material units were mapped to a depth of 9 m, at a scale of 1:24,000. Due to the wide sediment variability within the study area, some generalization in the near-surface was necessary. Where more than 3 units occurred within 9 m of the surface, the thicker units were typically represented. Contacts were given an error factor of ± 30 m or ± 60 m, depending on the amount of data and the complexity of the geology. Lithologic, lithostratigraphic, morphogenetic, and lithogenetic descriptions as well as the engineering properties of eleven map units within the study area should give an adequate representation of the earth materials present.

The partially consolidated clay to sand of the Sentinel Butte Formation (Paleocene) is the only named preglacial unit in the study area. The clayey silt to silty sand of the Charging Eagle Formation (Pleistocene) is thought to be present in an exposure south of Beulah, and in a few places in the subsurface. The Napoleon "till" of the Coleharbor Formation is probably the only pebble-loam present at the surface, whereas older beds of pebble-loam are found in buried valleys in the area. At least three separate fills believed related to Pleistocene glaciations are present. The oldest is mostly in the subsurface in the diversion trenches and in the Knife River Valley. A few exposures southeast of Beulah show coarse-grained, outwash sand and gravel. The second fill is exposed in the Zap branch of the Beulah trench, and occurs in the near-surface near Beulah and elsewhere in the study area. It consists predominantly of fine-grained sand and silt. The third fill is extensively exposed in a terrace on the south side of the Knife River and consists of fine to coarse-grained sand and gravel. Postglacial sediment was not differentiated in this study, but was included within the Oahe Formation.

Lithology and sedimentary structures within the Sentinel Butte Formation indicated deposition in a predominantly fluvial environment. Long periods of widespread, uniform, and often peat-forming conditions within large flood basins were interrupted by avulsion of low sinuosity streams, which may have been braided. Natural levee and crevasse-splay deposits were recognized at the surface and may be common in the subsurface.

The Krem moraine, about 6 km north of the study area, is possibly late Wisconsinan. Evidence also indicates that the moraine may represent a local readvance of the Napoleon ice sheet, necessitating a late Wisconsinan date for it as well. Two buried valleys were recognized to the north and northeast of Beulah, as well as the buried Renner diversion trench northwest of Hazen.

From its geometry, the Zap branch of the Beulah trench preceded the Hazen branch, which later captured the drainage. The Hazen branch was probably cut during the retreat of the late Cenozoic ice sheet that deposited the Mercer "till". A readvance of the ice sheet dammed the diversion water and formed a lake in the newly cut trench. The ice-dam must have remained in position for a number of years, for as much as 60 m of fluvio-lacustrine sediment was deposited in the diversion trenches and the Knife River Valley. Slopewash and turbidite flows were probably instrumental in sediment distribution and accumulation. The fill, in turn, was heavily eroded and downcut during the following interglacial and glacial periods.

A younger, coarse-grained fill was deposited largely within the Knife River Valley as the retreating Napoleon ice sheet forced the river to flow south of its present floodplain east and southeast of Hazen, and allowed a wall-to-wall inwash to form between Beulah and Hazen. As the ice marginal channel was filled and the ice melted, the Knife River moved northward and began to downcut and form its present valley. The resultant sand terrace was later reworked by winds during a more arid climate, forming large, longitudinal dunes southeast of Hazen.

Flooding, mine sinkhole subsidence, slumping and sliding, and blowing and drifting sand are existing or potential hazards in the area. Flooding is the most serious problem as much of both Beulah and Hazen lie within the 100-year flood level. Other hazards are less serious as they are removed from the population centers.

Conditions for sanitary landfills, septic tank systems, and general construction are represented on separate suitability maps using the traffic light approach: green for favorable conditions, yellow for caution, and red for unfavorable conditions.

Sanitary landfills should be located well above the water table in relatively impermeable material with a well-compacted, low permeability covering. The best sites are in areas of thick (15 m) pebble-loam in the uplands.

A material in which septic tank systems are properly located should be sufficiently permeable to allow proper filtration, but not so permeable so as to lead to ground water pollution. Other factors considered in septic tank sites include water table position, topography, and earth material workability.

Sewage lagoons should be located in materials of low permeability, in areas of low water table, no flooding hazard, and low relief. Prevailing winds should also be taken into account when evaluating a sewage lagoon site. Economically feasible sites for both Beulah and Hazen lie within or near the Knife River floodplain. The best site for Beulah is probably two km east of town, whereas the best site for Hazen is the present one.

The best construction conditions are in areas of sandy bedrock, sand and gravel, and pebble-loam. The worst conditions are in areas of organic-rich clays, high water table, severe flood hazard, drifting sand, and steep slopes. Most favorable construction sites are north of Beulah and Hazen. Further development in many areas within the floodplain of the Knife River, Spring Creek, and Antelope Creek is ill-advised due to occasional flooding.

APPENDICES

APPENDIX A

Lithologic Descriptions of Sediments in Auger Holes Drilled During This Study

Depth below surface is given in feet (3.28 ft = 1 m) rather than metres. Drill stem sections were in 5-foot lengths, which made depth estimates in feet for the different earth materials much simpler. Test holes are numbered in the order in which they were drilled. The letters HB prefixing each number refer to the towns of Hazen and Beulah. Elevation is given in feet above mean sea level.

Depth (ft.)	HB-1 T. 144 N., R. 86 W., Sec. 33, NENESE El. 1978
0-2	Loam.
2-6	Pebble-loam, sandy, clayey; lignitic; light olive brown.
6-12	Sand, fine-grained, silty, clayey; carbonaceous; light olive brown; poorly-sorted.
12-15	Sand, fine-grained, clayey; clay laminae; light brown; iron concretions.
15-20	Sand, fine-grained, silty; light brown to brown; iron concretions.
20-25	Sand, fine-grained, clayey; brown.
25-30	Sand, fine-grained, silty, clayey, to silt, sandy; brown to olive brown; clay pebbles, iron concretions.

Depth (ft.)	HB-2 T. 144 N., R. 86 W., Sec. 33, SESESE El. 2016
0-2	Loam, sandy; dark brown.
2-6	Pebble-loam; very lignitic; olive brown to olive grey.
6-8.5	Clay, silty; grey to light grey.
8.5-9	Clay, silty; grey; organic-rich with thin black laminae.
9-10	Sand, fine-grained, silty; brownish grey; clay laminae.
10-16	Sand, fine-grained, silty; olive grey to brown; clay and lignitic laminae, small iron concretions, selenite crystals.
16-30	Silt, clayey, sandy; olive brown; with very fine silty sand.

	HB-3 T. 144 N., R. 86 W., Sec. 33, SWSWSE El. 1948
0-1	Loam, sandy; brown to dark brown.
1-3	Pebble-loam, clayey, sandy; dark olive brown.
3-7	Pebble-loam, clayey, sandy; lignitic; olive brown.
7-35	Sand, very fine- to fine-grained; carbonaceous; light brown to brownish grey; compact; iron concretions; silty sand at about 25 feet.

	HB-4 T. 144 N., R. 86 W., Sec. 33, SESWSW El. 1892
0-1	Loam, fine-grained, sandy; dark brown.
1-5	Sand, fine-grained, gravelly; brown; poorly-sorted; pebble and granule gravel.
6-13	Sand, fine- to coarse-grained, gravelly; brown; poorly-sorted; pebbles, granules, and cobbles.

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Depth (ft.)	HB-4 (cont.)
13-15	Pebble-loam, sandy; brown to dark brown; very coarse texture.
15-17	Pebble-loam, sandy, clayey; lignitic; grey.
17-22	Pebble-loam, silty, clayey; grey.
22-25	Clay; grey.
25-30+	Lignite.
	HB-5 T. 144 N., R. 86 W., Sec. 32, NENESE El. 1893
0-5	Loam, fine-grained, sandy; dark brown to brown.
5-12	Pebble-loam, clayey; lignitic; iron-stained, olive brown and grey; selenite crystals.
12-17	Silt, sandy; iron-stained, olive brown with grey streaks.
17-21	Silt, sandy; olive brown; numerous grey clay balls.
21-25	Clay; grey and dark grey.
25-30	Silt and sand, very fine-grained; grey and dark grey; very thinly-laminated.
	HB-6 T. 144 N., R. 86 W., Sec. 32, SWSWSE El. 1922
0-20	Pebble-loam, silty, clayey; lignitic; olive brown; slightly coarse in upper 5 feet.
20-23	Pebble-loam, clayey; dark brown.
23-25	Loam, silty, clayey; olive grey; grey clay balls, dark brown silt laminae; poor samples.

(continued on next page)

Depth (ft.)	HB-6 (cont.)
25-30	Loam, silty, clayey; lignitic and scoriaceous; olive grey to olive brown; clay balls and iron concretions.

HB-7
T. 144 N., R. 86 W., Sec. 16, NWNWSW
El. 1780

0-4	Sand, silty; dark brown.
4-13	Sand, fine-grained, silty; brown; moderately-sorted; silt to medium-grained sand, with coarse sand, rare pebbles.
13-18	Sand, medium- to coarse-grained; lignitic and scoriaceous; reddish brown; moderately-sorted; a few large pebbles.
18-28	Sand, medium-grained, silty; dark brown; moderately-sorted; coarse sand with scoria and lignite pebbles; pebbles increasing downward; sand becomes coarser downward.
28-30	Pebble-loam, clayey; lignitic; olive brown.

HB-8
T. 144 N., R. 86 W., Sec. 16, NENESW
El. 1784

0-2	Sand, silty; dark brown.
2-8	Sand, fine- to medium-grained; brown to light brown.
8-11	Sand, coarse-grained; lignitic and scoriaceous; light reddish brown; moderately-sorted; fine to coarse sand.
11-15	Sand, coarse-grained; pebbly; scoriaceous; reddish brown; more poorly-sorted than above; a few cobbles.
15-17	Sand, medium- to coarse-grained, pebbly; scoriaceous; dark brown.
17-28	Sand, fine- to medium-grained, pebbly, lignitic and scoriaceous; orangish brown; moderately well-sorted; brown from 19-24 feet. (continued on next page)

Depth (ft.)	HB-8 (cont.)
28-35	Sand, fine- to medium-grained, silty; brown; moderately-sorted, with a few pebbles and granules.

HB-9
T. 144 N., R. 86 W., Sec. 16, SESESW
El. 1805

0-2	Loam, fine-grained, sandy; dark brown.
2-12	Sand, very fine- to fine-grained, silty; brown and light brown; a little medium-grained sand.
12-14	Clay, silty; iron-stained, brown and olive brown; a little fine-grained sand.
14-30	Sand, fine-grained, silty; lignitic and scoriaceous; dark brown to brown; a little medium-grained sand.

HB-10
T. 144 N., R. 86 W., Sec. 16, SWSWSW
El. 1788

0-2	Loam, sandy; grey-brown.
2-12	Sand, fine- to medium-grained; lignitic and scoriaceous; brown; a little coarse-grained sand.
12-15	Sand, medium-grained; lignitic and scoriaceous; dark brown; moderately-sorted, a few pebbles.
15-17	Sand, fine- to medium-grained, silty; very dark brown; small pebbles.
17-20	Sand, medium- to coarse-grained; lignitic and scoriaceous; dark brown; moderately-sorted.
20-21	Sand, medium- to coarse-grained, pebbly; dark brown and brown.
21-22	Silt, sandy; olive grey.
22-24	Sand, medium-grained; lignitic and scoriaceous; dark yellow-brown; a little coarse sand.

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Depth (ft.)	HB-10 (cont.)
24-28	Sand, medium-grained; lignitic and scoriaceous; dark brown; coarse sand and small pebbles present; moderately-sorted.
28-30	Pebble-loam, clayey; lignitic; grey.

HB-11
T. 144 N., R. 86 W., Sec. 5, SESESE
El. 1750

0-1	Loam, silty; grey-brown.
1-11	Pebble-loam, silty, clayey; light brown.
11-14	Silt, clayey; olive brown.
14-16	Silt; blue-grey; lignitic streaks.
16-17	Clay, silty; iron-stained, blue-grey.
17-18	Silt, sandy; iron-stained, olive brown; laminated.
18-18.5	Siltstone; lignitic; grey; well indurated.
18.5-22	Silt; lignitic; grey-brown.
22-26	Silt, sandy; olive brown; lignitic towards top.
26-27.5	Silt, coarse-grained; yellow-olive brown; iron concretions.
27.5-28.5	Clay; grey.
28.5-29	Lignite.
29-30	Silt; lignitic; dark grey.

HB-12
T. 144 N., R. 86 W., Sec. 4, NWNWSW
El. 1759

0-1	Loam, silty; brown.

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Depth (ft.)	HB-12 (cont.)
1-4	Silt, sandy; grey; loosely compacted.
4-6	Sand, fine- to medium-grained; brown and grey; coarse-grained sand, moderately-sorted.
6-9	Sand, medium-grained, pebbly; dark brown; moderately- to poorly-sorted, fine-grained sand to large pebbles.
9-22	Pebble-loam; lignitic; olive brown and grey; clay to cobbles.
22-28	Pebble-loam; lignitic; grey; less coarse than above (no cobbles).
28-30	Sand and silt, fine-grained; grey to olive brown; laminated.

HB-13
T. 144 N., R. 86 W., Sec. 5, NWNWSE
El. 1812

0-3	Pebble-loam; light olive brown.
3-18	Sand, very fine-grained, silty; light grey-brown; light brown in last 3 feet.
18-19.5	Silt, sandy; olive brown.
19.5-23	Lignite, silty; black; highly weathered.
23-30	Clay; lignitic; dark brownish grey to blue-grey; silty towards bottom.

HB-14
T. 144 N., R. 86 W., Sec. 5, SWSWSE
E. 1792

0-4	Pebble-loam, silty; light brownish grey to light grey; clay to boulders.
4-9	Silt, sandy to clayey; light greyish brown.
9-13	Clay, silty; brown and grey; laminated.

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Depth (ft.)	HB-14 (cont.)
13-15	Clay, silty; lignitic; brownish grey.
15-19	Lignite, silty; black.
19-22	Clay, silty; lignitic; brownish grey; poor samples.
22-23	Silt; iron-stained, olive brown; laminated.
23-30	Silt; grey; iron-banded near top, massive.

HB-15
T. 144 N., R. 86 W., Sec. 31, NENESE
El. 1913

0-1.5	Loam, fine-grained, sandy; light brown.
1.5-3	Sand, fine-grained, silty; brown; coarser grains present.
3-4	Pebble-loam, sandy; cobbles.
4-9	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
9-16	Clay, silty; iron-stained, yellowish brown; grey-brown towards bottom; numerous small concretions.
16-17	Sand, very fine-grained; blue-grey; cemented.
17-30	Sand and silt, very fine-grained; lignitic; blue-grey; iron-stained near bottom.

HB-16
T. 144 N., R. 86 W., Sec. 31, SESESE
El. 1940

0-2	Loam, fine-grained, sandy; brown; medium-grained sand present.
2-4	Pebble-loam, clayey, sandy; olive brown.
4-8	Pebble-loam, clayey; lignitic; olive brown.
8-13	Loam, fine-grained, clayey; dark brown to grey-brown.

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Depth (ft.)	HB-16 (cont.)
13-16	Silt; very dark grey-brown; hard.
16-23.5	Lignite.
23.5-25	Sand, very fine-grained, silty; lignitic; clay balls.
25-26	Silt; light blue-grey.
26-30	Silt to sand, very fine-grained; blue-grey.

HB-17
T. 144 N., R. 86 W., Sec. 31, SWSWSE
El. 1959

0-3	Loam, sandy; brown.
3-14.5	Pebble-loam, clayey; olive brown; scoria, lignite fragments, carbonate cobbles.
14.5-16	Silt, sandy; light brown.
16-30	Sand, very fine-grained, silty; light brown and light grey; loose, dry; fine-grained sand present.

HB-18
T. 144 N., R. 87 W., Sec. 36, NENENW
El. 1890

0-1	Loam, sandy; dark brown.
1-3	Pebble-loam, clayey, sandy; dark brown to brown.
3-10	Pebble-loam, clayey; olive brown; lignite, scoria, granitic fragments.
10-16	Sand, very fine-grained, silty; iron-stained, light brown.
16-19	Loam, clayey; highly lignitic; black.
19-22.5	Loam, clayey; dark grey-brown; mostly reworked lignitic silt and clay.

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Depth (ft.)	HB-18 (cont.)
22.5-24	Clay; lignitic; dark grey.
24-30	Clay; slightly silty; blue-grey.
30+	Siltstone; lignitic; light grey; hard.

HB-19
T. 144 N., R. 87 W., Sec. 36, SESENW
El. 1927

0-1	Loam, sandy; grey-brown.
1-4	Sand, fine-grained, silty; brown.
4-12.5	Pebble-loam, clayey; lignitic; olive brown; darkening downwards.
12.5-14	Sand, very fine-grained, silty; light brown; fine- and medium-grained sand, intercalated with silt.
14-30	Sand, very fine-grained, silty; yellow-brown; fine-grained sand, small iron concretions; dark yellow-brown from 20 to 22 feet, light yellow-brown from 22 to 24 feet, light brown from 24 to 30 feet.

HB-20
T. 144 N., R. 87 W., Sec. 36, SWSWNW
El. 1891

0-1	Sand, fine-grained, loamy; dark yellow-brown.
1-10	Pebble-loam, clayey; lignitic, scoriaceous; mottled grey and brown; clay to cobbles; metamorphic, granitic and carbonate rock fragments included.
10-18	Pebble-loam, clayey; olive brown.
18-20	Pebble-loam, clayey; olive grey-brown.
20-22	Pebble-loam, clayey; dark brownish grey.
22-30	Pebble-loam, clayey; dark grey.

Depth (ft.)	HB-21 T. 144 N., R. 86 W., Sec. 36, NWNWNW El. 1835
0-30	Sand, very fine- and fine-grained; brown; occasionally lignitic and silty.
	HB-22 T. 144 N., R. 87 W., Sec. 15, SESENE El. 1892 3 feet of pebble-loam exposed above hole.
0-6	Pebble-loam, clayey; lignitic; olive brown.
6-8	Sand, very fine to fine-grained, silty; brown.
8-9.5	Pebble-loam, clayey; lignitic; olive brown.
9.5-11	Silt, sandy; iron-stained, brownish grey.
11-17	Silt, sandy; iron-stained; lignitic (?), grey to dark grey.
17-20	Clay; light greenish grey.
20+	Hard rock; lithology unknown, poor return of samples.
	HB-23 T. 144 N., R. 86 W., Sec. 14, SWSWSW El. 1826 6 to 8 feet of pebble-loam exposed above hole.
0-1	Pebble-loam, olive brown.
1-4	Sand, very fine-grained, silty; grey to light brownish grey; laminated.
4-9	Clay; highly iron-stained, olive grey; a little silt.
9-13	Silt, very sandy; brown.
13-19	Sand, very fine-grained; blue-grey; thinly-laminated, silty and lignitic in spots; sand coarser in spots.
19-21	Silt, very sandy; dark grey.

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Depth (ft.)	HB-23 (cont.)
21-24	Silt and sand, very fine-grained; dark grey and blue-grey; laminated.
24-28	Clay; dark brownish grey.
28-30+	Lignite.

HB-24
T. 144 N., R. 87 W., Sec. 22, SESENE
El. 1845

0-1	Silt; brownish grey.
1-3	Clay; lignitic; dark grey.
3-5	Clay; dark grey.
5-14.5	Clay, silty; dark grey to brownish grey; laminated and iron-stained in spots, lignitic and grey towards bottom.
14.5-18	Lignite.
18-23	Silt, sandy; lignitic; grey-brown; grading downwards to very fine-grained sand.
23-26	Lignite.
26-30	Silt to sand, very fine-grained; lignitic; blue-grey; laminated.

HB-25
T. 144 N., R. 86 W., Sec. 20, SWSWSW
El. 1814

0-2	Sand, fine-grained, loamy; grey-brown.
2-5	Sand, fine- to medium-grained; brown; coarse sand and a few pebbles included.
5-8	Sand, fine- to medium-grained; grey-brown; coarse sand included.

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Depth (ft.)	HB-25 (cont.)
8-10	Sand, fine- to medium-grained; iron-stained, yellowish brown; coarse sand included.
10-12.5	Sand, medium-grained; reddish brown; fine-grained sand to pebbles.
12.5-14	Sand, medium-grained; brown; fine-grained sand to cobbles, mostly sand but many pebbles and cobbles; lignitic laminae.
14-14.5	Pebble-loam, clayey; dark grey-brown.
14.5-25	Pebble-loam, clayey; lignitic; dark grey.
25-27	Pebble-loam; grey; very wet.
27-30	Pebble-loam, sandy; lignitic; dark grey.

HB-26
T. 144 N., R. 86 W., Sec. 30, SESENE
El. 1828

0-5	Pebble-loam, silty; lignitic; light olive brown; clay to large pebbles.
5-14	Pebble-loam, silty; lignitic; iron-stained, olive brown and grey; many pebbles; small cobbles.
14-15	Clay, sandy; lignitic; iron-stained, olive grey to dark olive grey.
15-19	Pebble-loam, silty, clayey; olive brown; olive grey clay partings.
19-19.5	Clay; lignitic (?); olive grey.
19.5-26	Pebble-loam, clayey; iron-stained, olive brown; olive grey clay partings, several of which are probably several inches thick.
26-28	Sand, fine- to medium-grained; light olive brown; possible clay and silt partings.
28-30	Sand and gravel, very silty; olive grey-brown; cobbles abundant; very poorly sorted.

Depth (ft.)	HB-27 T. 144 N., R. 86 W., Sec. 31, NENENE El. 1854
0-1	Loam, fine-grained, sandy; dark brown.
1-9	Pebble-loam, sandy, clayey; lignitic; olive brown.
9-20	Sand, fine-grained; lignitic; brown; medium-grained sand present, well-sorted; wet at 13 feet; pebbles at 19.5 feet; possible 6-inch pebble-loam layer around 20 feet.
20-26	Sand, medium-grained; lignitic; grey-brown; fine-grained sand to a few cobbles; moderately- to poorly-sorted.
26-29.5	Pebble-loam, clayey; grey.
29.5-30	Sand, medium-grained, pebbly; grey-brown; very wet.

	HB-28 T. 144 N., R. 86 W., Sec. 19, SWSWSW El. 1752 Drilled in 3-foot ditch.
0-1	Loam, sandy; dark brown.
1-4	Silt and clay; brown; laminated (?).
4-6	Silt, sandy; light brownish grey; a few small pebbles.
6-9.5	Sand, very fine- to fine-grained, silty; light brown; coarser sand grains and small pebbles included.
9.5-11	Sand, fine- to medium-grained; lignitic; brown to dark brown; silty towards the bottom.
11-14	Sand, fine- to medium-grained; lignitic; brown to dark brown; silty towards the bottom.
14-15	Silt, sandy; grey-brown; medium-grained sand present; laminated (?).
15-22	Sand, fine- to medium-grained; lignitic; brown; iron-stained in spots, light grey-brown from 20 to 22 feet.

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Depth (ft.)	HB-28 (cont.)
22-30	Sand, medium-grained; lignitic; grey brown; fine-grained sand to cobbles; much coarse-grained sand, with pebbles and scoria fragments.

HB-29
T. 144 N., R. 86 W., Sec. 24, SWSWSE
El. 1749
Drilled in 2-foot ditch.

0-3.5	Loam, silty, clayey; dark grey-brown.
3.5-8	Sand, very fine-grained, silty; light brown; coarser sand grains present; carbonaceous around 5 feet.
8-14.5	Sand, very fine- to fine-grained; lignitic; light brown; medium-grained sand present, but moderately well-sorted.
14.5-16	Sand, fine- to medium-grained; lignitic; dark grey-brown; wet.
16-26	Sand, fine- to medium-grained; lignitic; brown; slightly silty; very wet.
26-30	Clay and silt, sandy; lignitic; blue-greenish grey; mostly clay and silty clay towards the bottom.

HB-30
T. 144 N., R. 87 W., Sec. 24, SWSWSW
El. 1780
Drilled in 2-foot ditch.

0-3	Silt, sandy; brown; silt to medium-grained sand.
3-5	Loam, pebbly; reddish brown; mostly silt to medium-grained sand; a few cobbles.
5-10	Sand, medium-grained; reddish brown; fine-grained sand to small pebbles, moderately well sorted.
10-13	Sand, fine- to medium-grained; reddish dark brown; a few large cobbles, and coarse-grained sand.

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Depth (ft.)	HB-30 (cont.)
13-19.5	Sand, fine-grained; carbonaceous; dark brown; medium- to coarse-grained sand included.
19.5-21	Sand, very fine- and fine-grained, silty; carbonaceous; very dark brown; coarser sand grains included.
21-28	Sand, fine-grained, silty; carbonaceous; reddish, very dark brown; moderately- to poorly-sorted, with pebbles and coarse-grained sand.
28-30	Sand, medium-grained, silty; carbonaceous; reddish, very dark brown; coarse-grained sand and pebbles included.

HB-31
T. 144 N., R. 87 W., Sec. 26, NENESE
El. 1797
Drilled in 3-foot ditch.

0-1	Loam, sandy; grey-brown.
1-7	Sand, very fine-grained, silty; light olive brown.
7-10	Sand, fine-grained, silty; light olive brown; medium-grained sand included; laminated.
10-14	Sand, fine- to medium-grained; lignitic; dark brown; coarse-grained sand included.
14-22	Sand, medium-grained, pebbly; lignitic; dark reddish grey-brown; carbonaceous laminations, scoria fragments, pebbles and cobbles, moderately- to poorly-sorted.
22-24	Sand, medium- to coarse-grained; lignitic and scoriaceous; reddish brown.
24-25	Sand, medium-grained, silty; lignitic and scoriaceous; very dark reddish brown.
25-30	Sand, medium-grained, silty; dark reddish brown; much coarse-grained sand, small pebbles, scoria and lignite fragments; sand looks 'oily'.

Depth (ft.)	HB-32 T. 144 N., R. 86 W., Sec. 36, SWSWSE El. 1769 Drilled in 1-foot ditch.
0-2	Loam, sandy; brownish grey; coarse-grained sand and pebbles included.
2-4.5	Sand, fine-grained, silty; light grey-brown; medium- to coarse-grained sand and small pebbles.
4.5-14	Sand, fine-grained; lignitic; olive brown; coarse-grained sand to small pebbles present; silty in spots; laminated, sandy silt layer at about 13.5 feet.
14-19	Sand, fine- to medium-grained, silty; lignitic and scoriaceous; reddish brown; coarse-grained sand and rare large pebbles.
19-21	Clay, silty; olive; rare sand-size scoria chips.
21-25	Loam, clayey; olive brown; laminated in spots; several dark brown carbonaceous layers; scoria and lignite fragments; rare coarse sand and pebbles.
25-30	Sand, fine-grained, silty; lignitic and scoriaceous; olive brown; wet.

	HB-33 T. 144 N., R. 87 W., Sec. 27, SESESE El. 1758 Drilled in 2-foot ditch.
0-4	Sand, very fine-grained, silty; light brown.
4-9	Sand, fine-grained, silty; lignitic; light grey-brown; medium-grained sand present; silt layer at about 8.5 feet.
9-19.5	Sand, fine- to medium-grained; lignitic; brown; coarse-grained sand and a few small pebbles; moderately well-sorted.
19.5-20	Clay, silty; olive grey.
20-22.5	Sand and gravel; reddish brown; fine-grained sand to large pebbles.

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Depth (ft.)	HB-33 (cont.)
22.5-27	Sand, fine- to medium-grained, gravelly; lignitic; brownish grey; coarse-grained sand and pebbles present.
27-30	Sand, medium-grained, gravelly; lignitic; brownish grey; coarse-grained sand, pebbles, and scoria chips present.

HB-34
T. 144 N., R. 86 W., Sec. 27, SWSWSE
El. 1750
Drilled in 3-foot ditch.

0-1	Loam, silty; grey-brown.
1-7	Sand, very fine-grained, silty; light grey-brown.
7-10	Sand, fine-grained, silty; light brown; silty layers in last foot.
10-13	Sand, fine- to medium-grained; lignitic; reddish brown; well-sorted.
13-19	Sand, medium-grained; lignitic; dark reddish brown; well-sorted, with coarse-grained sand. Last foot a pebble-cobble layer with cobble-sized lignite fragments.
19-30	No samples; drill flights indicated wet, dark brownish grey, medium-grained, gravelly sand.

HB-35
T. 144 N., R. 87 W., Sec. 34, SWNWNW
El. 1752

0-8.5	Sand, very fine-grained, silty; light brown.
8.5-12	Loam, very fine-grained, sandy; olive brown.
12-19	Sand, medium-grained, pebbly; lignitic; reddish brown; fine-grained sand to large pebbles, lignite cobbles; silty in spots; moderately- to poorly-sorted; thin olive brown clay at the bottom.
19-28.5	Poor samples; mostly sand and gravel, silt to cobbles, poorly-sorted; very blue-grey silt at the bottom.

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Depth (ft.)	HB-35 (cont.)
28.5+	Hard rock; possibly siltstone, probably large cobble in the gravel.

HB-36
T. 144 N., R. 87 W., Sec. 11, SWSWSE
El. 1767
Drilled in 2-foot ditch.

0-14	Loam, silty, clayey; olive grey-brown; rare small pebbles.
14-16	Loam, clayey; olive grey-brown; not as well sorted as above material; water at about 15 feet.
16-20	Loam, gravelly, silty; dark olive grey-brown; very wet; silt to large pebbles.
20-26	Sand, silty; olive brown; very wet; silt to pebbles, coarsening downwards.
26-30	Sand, very fine-grained, silty; iron-stained, olive to olive brown; wet; well-sorted; possibly gravelly towards the bottom.

HB-37
T. 144 N., R. 87 W., Sec. 14, NWNWNW
El. 1822
Drilled in 6-foot ditch.

0-10	Pebble-loam; olive brown; coarse-textured; clay to cobbles.
10-23	Pebble-loam, clayey; olive brown; coarse-textured; lignite, scoria, metamorphic and igneous rock fragments present.
23-30	Clay; iron-stained, olive brown to olive grey; silty in spots.

HB-38
T. 144 N., R. 87 W., Sec. 14, SESESW
El. 1787

0-2	Loam, silty; grey-brown.
2-4	Silt, sandy; light brown.

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Depth (ft.)	HB-38 (cont.)
4-9	Loam, gravelly, silty; light greyish brown.
9-12	Loam, sandy; dark brown.
12-15	Loam, gravelly, silty; grey-brown; very coarse material (large cobbles) in fine, sandy silt matrix.
15-20	Sand, fine-grained, grey-brown; well-sorted, with small pebbles.
20-30	Sand, fine-grained; lignitic and scoriaceous; reddish brown; well-sorted, with occasional pebbles; somewhat coarser in last 4 feet.

HB-39
T. 144 N., R. 87 W., Sec. 13, SWSWSW
El. 1824

0-2	Pebble-loam; light olive grey-brown.
2-7	Silt; iron-stained, light yellow-brown; iron concretions.
7-8	Clay, silty; lignitic; olive grey.
8-11	Sand, very fine-grained, silty; iron-stained, light olive brown; somewhat compacted.
11-12	Silt, sandy; light brown.
12-16	Sand, very fine-grained, silty; light olive brown; somewhat compacted.
16-18	Silt and sand, very fine-grained; iron-stained, light olive brown; laminated; hard iron concretion at 18 feet with selenite crystals.
18-21.5	Silt to silty clay; iron-stained, dark olive brown; laminated.
21.5-24	Clay; iron-stained, dark olive brown and dark olive grey; laminated; silty in spots.
24-31	Lignite.
31-35	Clay; iron-stained, blue-grey; lignitic at the top.

Depth (ft.)	HB-40 T. 144 N., R. 87 W., Sec. 14, NENESE El. 1758
0-1	Sand, fine-grained, silty; dark brown.
1-3	Loam, sandy, clayey; dark reddish grey-brown.
3-5	Sand, fine-grained, silty; dark reddish brown; coarser sand included; moderately well-sorted.
5-10	Sand, fine- and medium-grained; reddish brown; coarse-grained sand and pebbles included, especially in last foot.
10-12	Sand, fine-grained, silty; reddish brown; coarse-grained sand and small pebbles; wet.
12-16	Sand, fine- and medium-grained; reddish brown; coarse-grained sand and pebbles; wet.
16-19	Clay, silty; iron-stained, olive brown and olive grey; mottled.
19-30	Sand, very fine- and fine-grained, silty; olive brown; coarser grains included; very wet.

	HB-41 T. 144 N., R. 87 W., Sec. 14, NENENE El. 1761
0-6	Loam, silty; light grey-brown.
6-10	Loam, silty, clayey; dark olive grey-brown.
10-15	Loam, silty, clayey; olive brown; a little sand, scoria chips; wet.
15-18	Silt, sandy; olive brown and grey; laminated; very wet.
18-21	Sand, very fine-grained, silty; olive brown; very wet.
21-23	Silt, sandy; olive grey-brown; very wet.
23-30	Sand, very fine- to fine-grained, silty; olive brown; with medium-grained sand; very wet. Wet, fine-grained, lignitic sand towards bottom, well-sorted with a few pebbles.

Depth (ft.)	HB-42 T. 144 N., R. 87 W., Sec. 14, NENENE El. 1761
0-10	Pebble-loam; lignitic; olive brown; clay to cobbles.
10-17	Sand, very fine-grained, silty; light olive brown; well-sorted, with slightly coarser sand grains present.
17-30	Pebble-loam; lignitic; dark olive brown; last 5 feet uncertain, but probably the same.

HB-43
T. 144 N., R. 86 W., Sec. 6, SESENW
El. 1891
Drilled in 4-foot ditch.

0-7	Pebble-loam, clayey; lignitic; olive brown.
7-13.5	Sand, very fine-grained, silty; iron-stained, olive grey.
13.5-16.5	Lignite.
16.5-18	Silt and silty clay; lignitic.
18-21	Silt, sandy; lignitic; iron-stained, olive grey-brown; laminated.
21-25	Clay, silty; blue-grey; lignitic in spots.
25-30	Sand, very fine-grained, silty; olive grey-brown; iron concretions.

HB-44
T. 144 N., R. 86 W., Sec. 6, SWSWNW
El. 1840

0-2	Loam; dark brown; organic-rich.
2-5	Loam, silty; dark grey-brown.
5-7	Loam, silty; brown.
7-9	Loam, clayey; dark brown; clay to pebbles.
9-11.5	Loam, clayey; olive brown; clay to pebbles.

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Depth (ft.)	HB-44 (cont.)
11.5-16	Clay, silty; iron-stained, olive brown and dark grey; moderately-compacted.
16-20	Silt to silty clay; dark blueish grey; clay partings.
20-24	Sand, very fine-grained, silty; blue-grey; laminated in spots.
24-30	Silt; blueish grey; with very fine-grained sand.

HB-45
T. 144 N., R. 86 W., Sec. 6, NWNENW
El. 1919
Drilled in 1-foot ditch.

0-2	Pebble-loam, clayey; dark brown.
2-7	Pebble-loam, clayey; olive brown; grading downward to sand.
7-12	Sand, very fine-grained, silty; olive brown; wet.
12-13	Clay; olive brown and grey; poor samples.
13-15	Silt; purplish grey.
15-17	Clay; greenish grey.
17-22	Silt; iron-stained, olive to olive brown; compact.
22-24.5	Lignite (possibly thicker).
24.5-27.5	Clay; lignitic; dark grey.
27.5-28	Lignite; brownish; hard (possibly thicker).
28-30	Clay, silty; dark grey; lignitic laminae.

Depth (ft.)	HB-46 T. 144 N., R. 86 W., Sec. 6, NWNWNW El. 1962 Drilled in 1-foot ditch.
0-8.5	Silt and sandy silt; iron-stained, brown to olive brown; iron concretions.
8.5-13	Silt to silty clay; olive brown; compact; iron-stone concretion at 11 feet.
13-15.5	Silt; lignitic; purplish grey.
15.5-16	Lignite.
16-20	Clay; lignitic; dark grey.
20-22	Sand, very fine-grained; olive grey-brown; lignitic in spots.
22-29	Silt; iron-stained, olive brown; mottled, lignitic in spots, sandy towards the bottom.
29-30	Sand, very fine-grained, silty; olive brown; wet.

	HB-47 T. 144 N., R. 87 W., Sec. 15, SESESW El. 1920 Sandstone holds up knobs near the borehole.
0-1	Loam, fine-grained, sandy; dark brown.
1-4	Sand, very fine-grained, loamy; grey-brown.
4-18.5	Sand, very fine- and fine-grained, silty; lignitic; light brown; moderately well-sorted, with coarser grains; reddish brown, iron-stained beds.
18.5-20	Clay; lignitic; grey; fossil plant fragments.
20-22	Clay, silty; lignitic; dark brown.
22-26	Lignite; impure; clay layers present.
26-27	Sand, very fine-grained, silty; lignitic; dark grey.

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Depth (ft.)	HB-47 (cont.)
27-37	Sand and silt, very fine-grained, blue-grey; commonly lignitic and laminated.
37-39	Silt; grey.
39-40	Clay; grey.
40-40.5	Sand, very fine-grained; blue-grey.
40.5-44.5	Lignite; hard; possible clay parting between 42 and 43 feet.
44.5-50	Clay and silty clay; lignitic; dark blue-grey; hard drilling at 49 feet, possibly lignite.

HB-48
T. 144 N., R. 87 W., Sec. 15, NWNWSW
El. 1970

0-1	Silt; brown.
1-8	Silt, coarse-grained; very light yellow.
8-19	Sand and silt, very fine-grained; iron-stained, light brownish grey to light greyish brown; iron concretions.
19-27	Sand, very fine-grained, silty; light brownish grey; iron concretions.
27-39	Clay, silty; lignitic; dark grey; increasingly lignitic downwards, seams up to several inches around 36 feet; laminated; lignite towards the bottom.
39-41.5	Silt, coarse-grained; green; very fine-grained sand included. Hard rock at 41.5 feet, probably sandstone.

HB-49
T. 144 N., R. 87 W., Sec. 16, SESESE
El. 1990

0-7	Pebble-loam, clayey; lignitic; very light to light brown.

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Depth (ft.)	HB-49 (cont.)
7-8	Silt; reddish dark brown; appears scoriaceous, possibly burnt or weathered lignite.
8-10	Silt and silty clay; lignitic; grey and dark grey.
10-17	Sand, very fine-grained, silty; light grey-brown to light brownish grey; lignitic partings near the top.
17-30	Sand, very fine-grained; light brownish grey; well-sorted; lignitic partings in spots; iron-stained in spots; salt and pepper appearance.

HB-50
T. 144 N., R. 87 W., Sec. 22, SESENW
El. 1932

0-3	Pebble-loam; light olive brown; sandy towards the bottom.
3-34	Sand, very fine-grained; light greyish brown; well-sorted; becomes yellow-brown at about 22 feet as iron staining increases downwards; also more silty downwards, except in last 3 feet.
34-35	Lignite, hard.
35-39	Silt and silty clay; dark blue-grey; lignitic towards the top.
39-43	Sand, very fine-grained, silty; blue-grey; increasingly lignitic and laminated downwards.
43-45	Lignite.
45-46.5	Silt, coarse-grained, sandy; lignitic; green.
46.5-50	Clay and silt; lignitic; blue-green; fining downwards.

HB-51
T. 144 N., R. 87 W., Sec. 16, SWSWSE
El. 1929

0-9	Loam; dark brown; organic-rich; abundant scoria fragments up to cobble-size; laminated.

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Depth (ft.)	HB-51 (cont.)
9-15	Loam, fine-grained, sandy; reddish brown; abundant scoria fragments up to pebble-size.
15-45	Sand, very fine-grained, silty; brown; wet; becomes blue-grey at about 30 feet. Hard drilling at 45 feet, probably sandstone.

HB-52
T. 144 N., R. 87 W., Sec. 11, NWNWSW
El. 1777
Drilled in 3-foot ditch.

0-10	Loam, silty, clayey; light olive brown.
10-22	Pebble-loam, clayey; olive brown; top 5 feet relatively fine-grained, tends to coarsen downward; dolomite, greenstone, chert, and lignite fragments present; more lignitic towards bottom. Boulder at 22 feet.

HB-53
T. 144 N., R. 87 W., Sec. 4, NWNWNE
El. 1815
Drilled in 1-foot ditch.

0-2	Silt, sandy; light grey-brown.
2-5	Sand and gravel, silty; light brown; silt to cobbles.
5-17	Sand and gravel, reddish brown, poorly-sorted; fine sand to cobbles; silty towards the bottom; scoria and lignite fragments.
17-20	Pebble-loam, clayey; very lignitic; olive grey-brown.
20-30	Pebble-loam, clayey; lignitic; dark grey.

HB-54
T. 144 N., R. 87 W., Sec. 4, NENENE
El. 1808

0-1	Silt; grey-brown.

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Depth (ft.)	HB-54 (cont.)
1-11	Silt, coarse-grained; very light brown; a little very fine-grained sand.
11-35	Silt, coarse-grained, sandy; light brown; clayey in spots; olive brown below 19 feet; water near the bottom.

HB-55
T. 144 N., R. 87 W., Sec. 3, NENESW
El. 1820
Drilled in 2-foot ditch.

0-1	Loam, sandy; dark brown.
1-45	Pebble-loam, clayey; lignitic; olive brown; carbonate, sandstone, igneous, metamorphic, scoria and chert fragments; finer-grained and brown in color from about 25 to 35 feet, coarsest material being small pebbles; coarsens below 35 feet.

HB-56
T. 144 N., R. 87 W., Sec. 3, SESESW
El. 1788
Drilled in 1-foot ditch.

0-10	Loam, clayey; olive grey-brown; laminated; lignite and scoria grains present.
10-14	Sand and gravel, silty; grey-brown; very poorly-sorted, silt and very fine-grained sand matrix with abundant pebbles; wet.
14-30	Pebble-loam, clayey; olive brown; lignite and scoria fragments; last 10 feet mottled grey; selenite crystals included; water around 20 feet.

HB-57
T. 144 N., R. 87 W., Sec. 10, NENENE
El. 1780

0-19	Loam; olive grey-brown; organic-rich near the surface; laminated; generally fine-grained material, sand-size or less.

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Depth (ft.)	HB-57 (cont.)
19-24.5	Silt, sandy; olive brown; very wet.
24.5-29	Loam, clayey; olive brown; pebbles; very wet; possibly laminated.
29-30	Sand and gravel; dark brown.

HB-58
T. 144 N., R. 87 W., Sec. 33, NWNWNE
El. 1807
Drilled in 1.5-foot ditch.

0-13.5	Sand, fine-grained; brown; much very fine-grained sand, with medium- and coarse-grained sand, abundant lignite grains.
13.5-15	Sand, very fine-grained, silty; carbonaceous; dark brown; coarser grains present.
15-25.5	Sand, fine- and very fine-grained; brown; lignitic, dark brown, carbonaceous bed from 24 to 25 feet.
25.5-27	Sand, very fine-grained, silty; carbonaceous; dark brown; with coarser grains.
27-40	Sand, medium-grained, silty; lignitic; dark reddish brown; abundant scoria grains; carbonaceous, silty, and pebbly layers; much coarse-grained sand.
40-55	Sand, fine- to medium-grained, silty; very dark red-brown; moderately well-sorted, carbonaceous, lignitic, scoriaceous; pebble and cobble layers, much coarse-grained sand and small pebbles; general coarsening downwards; almost black in color, although somewhat lighter in the last 6 feet.

HB-59
T. 144 N., R. 87 W., Sec. 31, SENESE
El. 1893

0-9.5	Pebble-loam, clayey; grey-brown.
9.5-11	Clay, silty; iron-stained, olive grey.

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Depth (ft.)	HB-59 (cont.)
11-19	Silt; iron-stained, olive grey; laminated; clayey in spots; iron concretion at about 16 feet.
19-22	Silt, sandy; olive grey.
22-26	Silt and silty clay; olive grey; laminated.
26-34	Clay, silty; iron-stained, olive brown; with silt, iron concretions and selenite crystals.
34-39	Clay; dark olive grey; silty in spots; thin, silty, very fine-grained sand between 36 and 37 feet.
39-50	Clay; lignitic; dark grey; lignite laminae; silty in spots, olive brown silt with iron concretions from about 42 to 44 feet; light grey siltstone near the bottom.

HB-60
T. 144 N., R. 88 W., Sec. 1, SESENE
El. 1961

0-8.5	Pebble-loam, clayey; olive brown.
8.5-10	Sand, fine-grained; lignitic; iron-stained, red-brown and grey-brown.
10-10.5	Lignite, powdery.
10.5-11.5	Clay, silty; lignitic; grey; selenite crystals.
11.5-20	Silt, sandy; iron-stained, grey; selenite crystals.
20-22	Silt; dark grey.
22-25	Silt; olive grey to blue-grey.
25-32	Silt, sandy; iron-stained, olive grey; coarsening downwards.
32-34	Sand, very fine-grained, silty; light grey.
34+	Sandstone; too hard to drill.

Depth (ft.)	HB-61 T. 144 N., R. 88 W., Sec. 1, NENENE El. 1895
0-3	Loam; light brown.
3-11	Clay and silty clay; lignitic; grey to dark grey; iron concretions at 7 feet; silt layers.
11-11.5	Lignite; soft.
11.5-14.5	Silt and silty clay; lignitic; olive grey.
14.5-16	Clay, silty; lignitic; iron-stained, light grey.
16-20	Clay, lignitic; dark blue-grey to dark grey; slightly silty, with lignite laminae.
20-27.5	Silt and sandy silt; lignitic; dark grey to dark blue-grey; laminated.
27.5-33	Lignite; hard near the top.
33-38	Silt, sandy; very lignitic; blue-grey and grey; with very fine-grained silty sand, lignite laminae.
38-38.5	Lignite; brownish black.
38.5-40	Clay; lignitic; dark blue-grey.

	HB-62 T. 144 N., R. 88 W., Sec. 1, NWNWNE El. 1852
0-6	Loam, silty; light grey-brown.
6-15	Loam; olive brown to brown; scoria chips present.
15-16	Sand, fine-grained, silty; olive brown.
16-22	Loam, sandy; olive brown; last 2 feet very wet.
22-30	Loam, silty, clayey; olive brown; very wet; occasional scoria chips; laminated; sandy layers.

Depth (ft.)	HB-63 T. 144 N., R. 88 W., Sec. 12, NWNWNW El. 1904
0-14	Loam; grey-brown to dark olive grey-brown; pebbles, scoria chips; carbonaceous and laminated; last 5 feet somewhat coarser-textured.
14-30	Sand, very fine-grained, silty; lignitic; brown; medium and coarse scoria grains; well-sorted. Darker brown (more carbonaceous) at about 18 feet; pebble-cobble layer at 22 feet; brown sand from 24 to 26 feet, less silty and less carbonaceous than above; dark brown, silty, carbonaceous sand from 26 to 28 feet; less silty and less carbonaceous from 28 to 30 feet.

HB-64
T. 144 N., R. 88 W., Sec. 1, NWNWSW
El. 1863
Drilled in 1.5-foot ditch.

0-20	Loam, clayey; carbonaceous; grey-brown to dark olive grey-brown; scoria and lignite chips up to pebble-size; silty sand from about 4.5 to 6 feet.
20-25	Loam; olive grey-brown; wet.
25-30	Silt and clay; iron-stained, olive grey brown; possibly some sandy layers; wet.

HB-65
T. 144 N., R. 88 W., Sec. 1, NWNWNW
El. 1872

0-2	Sand, fine-grained, silty; grey-brown.
2-4	Sand, fine-grained, silty, pebbly; grey-brown; very fine- to medium-grained sand; with coarse-grained sand and abundant pebbles; moderately sorted.
4-7.5	Sand, medium- to coarse-grained; brown; moderately- to poorly-sorted, very fine sand to cobbles.
7.5-20	Pebble-loam, clayey; lignitic; iron-stained, olive brown.

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Depth (ft.)	HB-65 (cont.)
20-24	Silt, clayey; olive brown; dark grey clay balls.
24-26	Clay, silty; iron-stained, olive grey.
26-29	Silt; iron-stained, olive grey.
29-30	Sand, very fine-grained; lignitic; dark olive grey; well-sorted.

HB-66
T. 144 N., R. 88 W., Sec. 3, SESESW
El. 1895
Drilled in 2-foot ditch.

0-5	Loam, fine-grained, silty; olive brown; a few small pebbles.
5-30	Silt, coarse-grained; olive grey-brown; slightly sandy, a few small pebbles.
30-35	Silt, coarse-grained, sandy; olive grey-brown.
35-45	Sand, very fine-grained, silty; olive brown; well-sorted.
45-50	Silt, sandy; grey-brown; scoria chips up to large pebble- and small cobble-size, possibly a scoria gravel layer; thin beds of very fine-grained, wet sand towards the bottom.
50-55	Silt; iron-stained, olive grey; wet; slightly sandy.

HB-67
T. 144 N., R. 88 W., Sec. 3, SWSWSW
El. 1905

0-1	Silt, sandy; grey-brown.
1-19	Silt, coarse-grained; micaceous; light brown; more olive brown and wet around 10 feet.
19-23	Silt, sandy; lignitic; iron-stained, olive grey-brown; laminated; olive grey-brown clay about 6 inches thick near the top.
23-30	Silt, coarse-grained; micaceous; olive brown; well-sorted.

Depth (ft.)	HB-68A T. 144 N., R. 88 W., Sec. 3, NWSWNW El. 2080
0-8	Pebble-loam; light grey-brown.
8-17	Pebble-loam, clayey; lignitic; iron-stained, light olive brown. Boulders at 17, 11, 9 feet in four separate holes; probably buried boulder lag surface. No samples taken.

	HB-68B T. 144 N., R. 88 W., Sec. 3, SWNWNW El. 2085
0-11.5	Pebble-loam, clayey; lignitic; iron-stained, light grey-brown to light olive brown.
11.5-55	Sand, very fine- and fine-grained, silty; iron-stained; salt and pepper appearance; well-sorted; laminated; iron concretions towards the bottom. Orangish brown from 11.5 to 22.5 feet, olive brown from 22.5 to 39 feet, olive grey-brown from 39 to 47 feet, dark olive grey brown from 47 to 50.5 feet, and brown in the last 4 to 5 feet. Very little silt below 39 feet with the exception of a thin, dark grey, lignitic, silty clay layer at about 47 feet.

	HB-69 T. 144 N., R. 88 W., Sec. 16, NENESE El. 2085
0-5	Pebble-loam; light grey-brown.
5-25	Pebble-loam, clayey; lignitic; iron-stained, olive brown to grey-olive brown.
25-35	Sand, very fine- and fine-grained, silty; olive brown; salt and pepper appearance; well-sorted; dark grey, iron-stained, lignitic clay towards the bottom.
35+	Sandstone or iron concretions; too hard to drill.

Depth (ft.)	HB-70A T. 144 N., R. 88 W., Sec. 16, SESESE El. 2030
0-14	Pebble-loam. Boulders at 7 feet and 14 feet in three separate holes. No samples taken.
	HB-70B T. 144 N., R. 88 W., Sec. 15, SWSWSW El. 2040
0-5	Pebble-loam; light grey-brown.
5-7.5	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
7.5-18.5	Clay and silty clay; dark olive grey; laminated; iron-stained near the top; iron-banded, manganese-stained.
18.5-22	Silt and silty clay; iron-stained, dark olive grey; a little sandy silt.
22-24	Clay, silty; lignitic; dark brownish grey.
24-37	Silt and silty clay; lignitic; iron-stained, dark grey and olive grey; iron concretions and selenite crystals common.
37-41	Lignite; black.
41-50	Silt and sandy silt, coarse-grained; lignitic; iron-stained, olive grey and grey; laminated and iron-banded; iron concretions and selenite crystals; thin, hard, grey, calcareous siltstone near the bottom.
	HB-71 T. 144 N., R. 88 W., Sec. 15, SENESE El. 2035
0-4	Pebble-loam; light grey-brown.
4-11	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
11-11.5	Sandstone, fine- to medium-grained; yellow-brown.
11.5-13.5	Sand, very fine- and fine-grained, silty; yellow-brown.

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Depth (ft.)	HB-71 (cont.)
13.5-14	Clay, silty; olive grey; manganese- and iron-stained.
14-16	Sand, very fine- and fine-grained, silty; iron-stained; yellow-brown.
16-24	Silt and silty clay; iron-stained, olive grey and grey; iron concretions and selenite crystals; lignitic in spots.
24-27	Lignite; black; powdery.
27-31.5	Silt, sandy, coarse-grained; very lignitic; grey-brown; abundant thin lignite seams; iron concretions and selenite crystals.
31.5-35	Silt, sandy silt, and silty clay; lignitic; iron-stained, olive grey; iron concretions and selenite crystals.
35-48	Silt, fine- to coarse-grained, sandy; dark grey to blue-grey; laminated; becoming more bluish downwards.

HB-72
T. 144 N., R. 88 W., Sec. 14, NWSWNW
El. 2075

0-6.5	Pebble-loam, clayey; grey-brown changing to olive brown; sandy towards the bottom.
6.5-12.5	Sand, very fine- and fine-grained, silty; light yellow-brown changing to dark yellow-brown; salt and pepper appearance; well-sorted.
12.5-13	Iron concretion; orange; mostly silty material.
13-20	Silt; iron-stained, olive grey changing to olive grey-brown; iron concretions; laminated; occasionally sandy, compacted, and lignitic.
20-24	Clay, silty; iron-stained, olive grey; occasionally lignitic.
24-25	Lignite; with soft and lignitic, grey-brown, silty clay.

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Depth (ft.)	HB-72 (cont.)
25-26	Silt and silty clay; lignitic; olive grey; slightly sandy; selenite crystals.
26-30	Silt and sand, very fine-grained; olive grey; iron concretions and selenite crystals.

HB-73
T. 144 N., R. 88 W., Sec. 14, NWNWNE
El. 2038

0-1	Loam, fine-grained, sandy; dark grey-brown.
1-45	Pebble-loam, clayey; lignitic; iron-stained, olive grey-brown changing to dark olive brown; iron concretion fragments common.
45-50	Sand, very silty; olive brown; wet.
50-57	Pebble-loam, clayey; dark olive brown.
57-60	Sand, very silty; olive brown.

HB-74
T. 144 N., R. 88 W., Sec. 14, NENESE
El. 1970

0-4	Pebble-loam, clayey; light olive brown.
4-30	Pebble-loam, clayey; lignitic; iron-stained, olive brown to dark olive brown; pebbles and cobbles present, but not abundant.
30-40	Loam, fine-grained, clayey; yellow olive brown; silt-clay pebbles; coarse sand grains and small pebbles; sandy layer from 30-32 feet.
40-50	Pebble-loam, clayey; olive brown; relatively fine-grained although a few cobbles are present.

Depth (ft.)	HB-75 T. 144 N., R. 88 W., Sec. 13, NENENE El. 2052 Drilled in 3-foot ditch.
0-7.5	Pebble-loam, clayey; lignitic; olive grey-brown to olive brown-grey; clay to cobbles.
7.5-19	Sand, very fine- and fine-grained; olive brown; salt and pepper appearance; well-sorted, somewhat silty; iron concretions and iron-stained in places, especially the last 2 feet.
19-19.5	Clay; lignitic; dark grey-brown.
19.5-22	Silt and silty clay; lignitic; iron-stained, dark grey; iron concretions and laminated, silty sand in places.
22-22.5	Silt and sand, very fine-grained; iron-stained, olive grey, olive brown; laminated.
22.5-26	Siltstone; calcareous; light blue-grey; well-indurated.
26-32.5	Clay, silty; dark grey; slightly bluish, lignitic toward bottom.
32.5-33+	Lignite; pyritic; too hard to drill.

	HB-76 T. 144 N., R. 88 W., Sec. 24, NWNWNE El. 1980 Boulders and cobbles at the surface.
0-4.5	Silt; brown to olive brown; a little very fine-grained sand.
4.5-13.5	Sand, very fine-grained, silty; light olive brown; coarsening downward to a fine-grained sand; coarser sand grains and small pebbles become more abundant downwards, larger pebbles and cobbles towards the bottom.
13.5-43	Pebble-loam, sandy, clayey; lignitic; iron-stained, olive grey-brown to olive grey; clay to cobbles; small pebbles of local derivation abundant.
43-44.5	Clay, silty; olive grey, mottled grey.

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Depth (ft.)	HB-76 (cont.)
44.5-46.5	Loam, clayey; dark olive brown; a few coarse sand grains.
46.5-50	Clay, silty; iron-stained, olive grey, mottled grey; lignitic clay loam at the bottom.

HB-77
T. 144 N., R. 86 W., Sec. 19, NENESE
El. 1815
Drilled in 3.5-foot ditch.

0-2	Sand, very fine-grained, silty; light olive brown; with fine- and medium-grained sand.
2-25	Sand, very fine-grained; olive brown; with fine- and medium-grained sand, a few coarse sand grains; layers of dark brown, carbonaceous silt, especially from 14 to 17 feet; olive brown, sandy silt layers also common.
25-30	Sand, very fine- to fine-grained, silty; carbonaceous; dark brown; with medium- and coarse-grained sand.
30-35.5	Sand, very fine-grained, silty; carbonaceous, lignitic, scoriaceous; reddish dark brown; with medium- and coarse-grained sand.
35.5-37.5	Sand, fine-grained, silty; carbonaceous, lignitic, scoriaceous; reddish, very dark brown; moderately-sorted; silt to pebbles and small cobbles.
37.5-42	Sand, very fine- to fine-grained, silty; carbonaceous, lignitic, scoriaceous; dark reddish brown changing to very dark reddish brown; pebble-sized lignite fragments towards the bottom; with medium- and coarse-grained sand.
42-43.5	Sand, fine- to medium-grained; dark reddish brown; a few large pebbles.
43.5-44.5	Sand, very fine- to fine-grained, silty; dark reddish brown; with olive brown, sandy silt; a cobble layer at the bottom.

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Depth (ft.)	HB-77 (cont.)
44.5-60	Sand, fine- to medium-grained, pebbly; carbonaceous, lignitic, scoriaceous; dark reddish brown; moderately poorly sorted, silt to large cobbles; cobble-sized lignite fragments. Blue-grey, sandy silt at the bottom.

HB-78
T. 144 N., R. 86 W., Sec. 29, NWNWNE
El. 1860
Drilled in 3-foot ditch.

0-8.5	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
8.5-11.5	Loam, clayey; iron-stained, olive yellow-brown; reworked local material; no lignite; all coarse material consists of iron concretions.
11.5-12	Clay; lignitic.
12-15	Silt, sandy; iron-stained, olive grey; laminated; lignitic towards the top.
15-19	Sand, very fine-grained, very silty; olive brown.
19-23	Sand, very fine-grained; cemented; blue-grey; hard drilling.
23-27	Sand, very fine-grained, silty; iron-stained, olive bluish grey to olive brown.
27-38	Clay, silty, and silt; dark grey; lignitic towards the bottom.
38-43	Lignite; black to brownish black.
43-50	Clay, silty, to silt, sandy; dark grey; laminated; lignitic towards the top.

Depth (ft.)	HB-79 T. 144 N., R. 86 W., Sec. 29, NENESE El. 1900 Drilled in 2-foot ditch. Scattered cobbles at the surface.
0-1	Sand, silty; light olive grey.
1-6.5	Sand, very fine-grained, silty; olive grey-brown.
6.5-7	Sand, very fine-grained, silty; carbonaceous.
7-17	Sand, very fine-grained, silty; iron-stained, olive grey to olive grey-brown.
17-20	Sand, cemented; blue-grey; hard drilling.
20-35	Sand, very fine-grained, silty; iron-stained, blue-grey; laminated; iron concretions.
35-38	Lignite; black.
38-38.5	Sand, very fine-grained and silty, to silty clay; lignitic; laminated.
38.5-43	Lignite.
43-50	Clay, silty clay, and silt; lignitic; blue-greenish grey; poor samples.
	HB-80 T. 144 N., R. 86 W., Sec. 33, NWNWNE El. 1950 Drilled in 2-foot ditch.
0-1	Loam, silty; grey-brown.
1-6.5	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
6.5-36	Sand, very fine-grained, silty; iron-stained, olive brown and yellow-olive brown; slightly cemented in places; olive grey silt layers around 18 feet, and from 34 to 36 feet; slightly darker downwards.
36-47	Sand, very fine-grained, very silty; iron-stained, dark olive brown; laminated; iron concretions.

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Depth (ft.)	HB-80 (cont.)
47-50	Sand, very fine- and fine-grained, silty; iron-stained, olive brown.

HB-81
T. 144 N., R. 86 W., Sec. 10, SWSWSW
El. 1780

0-7	Sand, very fine-grained, silty; brown; coarser grains present, especially towards the bottom; very dark brown to black and carbonaceous in the last foot.
7-9	Sand, fine-grained, silty, pebbly; dark reddish brown; moderately sorted, silt to large pebbles.
9-10	Clay; greenish grey; wet.
10-12.5	Lignite.
12.5-19	Silt, silty clay, and sandy silt; iron-stained; lignitic near the top; mostly poor samples.
19-21	Lignite.
21-49.5	Clay and silty clay; dark grey to blue-grey; wet. Possible thin lignite 33.5 to 34 feet; probable lignite from 44 to 45 feet bounded by olive grey silty clay. Possible silt layers in the clay, and possibly sand towards the bottom. Too hard to drill at 49.5 feet, probably sandstone.

HB-82
T. 144 N., R. 87 W., Sec. 10, SESESW
El. 1890
Drilled in 3-foot ditch.

0-5	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
5-6.5	Lignite; soft.
6.5-7	Clay, silty; lignitic; dark grey.

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Depth (ft.)	HB-82 (cont.)
7-16.5	Silt and sandy silt; iron-stained, olive brown to yellow-olive brown; laminated; iron concretions.
16.5-19.5	Lignite; soft.
19.5-22	Clay, silty; dark grey; lignitic near the top.
22-24	Silt and sandy silt; iron-stained, olive grey; laminated.
24-26	Silt and sandy silt; dark olive grey; lignitic in places.
26-30.5	Silt and silty clay; dark grey, grey, and olive grey; lignitic in places.
30.5-34	Clay; dark grey; lignite laminae.
34-50	Clay, silty clay, and silt; grey; hard, compact; thin, very light grey siltstone layer around 44 feet; lignitic clay in the last 5 feet.

HB-83
T. 144 N., R. 87 W., Sec. 9, SESESE
El. 1850

0-17	Loam to clay loam; iron-stained, olive brown to olive grey-brown; pebble-sized lignite, scoria, and iron concretions.
17-22	Clay; dark olive grey to dark grey; thin layers of lignite near the top.
22-27	Lignite; very hard.
27-29.5	Clay; lignitic; dark grey.
29.5-34.5	Silt to sandy silt; bluish grey.
34.5-38	Clay, silty; bluish grey; at least one light grey siltstone layer.
38-41	Lignite; hard; wood fragments present.
41-44	Silt, sandy; blue-greenish grey; lignitic towards the top.

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Depth (ft.)	HB-83 (cont.)
44-46	Clay, silty; dark grey; lignitic in spots.
46-50	Sand, very fine-grained, silty; blue-grey; laminated; lignitic in spots; silt and sandy silt present.

HB-84
T. 144 N., R. 87 W., Sec. 9, NENWSE
El. 1947

0-1.5	Loam, silty; grey-brown.
1.5-11.5	Pebble-loam, clayey; lignitic; iron-stained, olive brown.
11.5-17.5	Clay, silty, to sandy silt; iron-stained, dark grey to olive grey.
17.5+	Hard rock, siltstone or sandstone; too hard to drill.

HB-85B
T. 144 N., R. 87 W., Sec. 7, SESESE
El. 2028

0-1.5	Loam, silty; grey-brown and brown.
1.5-34.5	Pebble-loam, clayey; iron-stained, olive brown; large pebbles noticeably present; dark olive brown from 15 to 22 feet; more sandy in the last 4 to 5 feet.
34.5-40	Sand, very fine- and fine-grained, silty; olive brown.

HB-86
T. 144 N., R. 88 W., Sec. 24, SWNWNW
El. 1903

0-4	Loam, sandy; lignitic; olive brown to olive grey-brown.
4-36	Sand, very fine- and fine-grained, silty; lignitic; iron-stained, olive brown; with medium- and coarse-grained sand; moderately well-sorted except for occasional cobble-sized iron concretions and thin, lignitic, iron-stained, sandy, dark grey clay layers; (continued on next page)

Depth (ft.)	HB-86 (cont.)
	sand size detrital iron concretions common; dark grey-brown and carbonaceous from 26 to 29 feet, dark olive brown from 29 to 36 feet.
36-40	Sand, very fine- to fine-grained, silty, pebbly; reddish brown.
40-50	Sand, very fine- to fine-grained, silty, pebbly; dark olive grey-brown; dark grey lignitic clay layers; sandstone and iron concretion cobbles included.

HB-87
T. 144 N., R. 87 W., Sec. 5, NENESW
El. 1962

0-2	Loam, silty; grey-brown.
2-3.5	Loam; reddish grey-brown.
3.5-13.5	Sand, fine-grained, very silty; scoriaceous; reddish orange; moderately- to poorly-sorted; chips of lignite in the last 6 inches.
13.5-15	Silt to sandy silt; dark olive grey.
15-20	Clay, silty; lignitic; olive grey and dark olive grey.
20-24	Silt, sandy; blue-green; laminated.
24-28.5	Silt, sandy; to sand, very fine-grained and silty; lignitic; blue-grey; wet; laminated.
28.5-31	Silt; lignitic and sandy.
31-34	Clay, silty; blue-green; possible silt layers.
34-50	Silt to sandy silt; blue-grey; compact; hard and lignitic in places.

Depth (ft.)	HB-88 T. 144 N., R. 87 W., Sec. 4, NENESW El. 1880
0-3.5	Loam, silty; grey-brown to brown.
3.5-19	Pebble-loam, clayey; lignitic; iron-stained, olive grey changing to dark olive grey-brown; mottled grey.
19-22	Clay, silty; olive grey-brown; thin, woody lignite layers included.
22-24	Lignite.
24-25.5	Clay; dark grey to olive grey; lignitic towards the top.
25.5-33	Silt and silty clay; iron-stained, olive grey-brown to olive grey; a little sandy silt; lignitic in spots; selenite crystals and iron concretions.
33-35	Clay; dark grey.
35-40	Silt; lignitic; dark grey to dark olive grey; lignite laminae and iron concretions.
40-44	Sand, very fine-grained, silty; brown; iron concretions.
44-45	Silt, coarse-grained; olive grey.
45-50	Lignite; with dark olive grey, lignitic, silty clay parting; a little dark grey-brown silt.
50-55	Silt to sand, very fine-grained; pyritic; blue-grey; lignitic near the top; laminated.

	HB-89 T. 144 N., R. 88 W., Sec. 2, SENENW El. 1965
0-1	Loam, silty; grey-brown.
1-23	Pebble-loam, clayey; light olive brown to dark olive brown; somewhat lignitic; coarse materials range from coarse sand to small pebbles; only rare cobbles.

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Depth (ft.)	HB-89 (cont.)
23-25.5	Clay, silty; dark olive grey and olive grey-brown.
25.5-37.5	Sand, fine- and very fine-grained, silty; grey; salt and pepper appearance; laminated; thin cemented sand around 27 feet; olive grey below 31 feet.
37.5-50	Silt; iron-stained, olive grey and grey; laminated; sandy layers in the last 5 feet.

HB-90
T. 144 N., R. 88 W., Sec. 2, SESESW
El. 1910

0-3	Loam, fine-grained, sandy; grey-brown.
3-6.5	Sand and gravel; light reddish brown; sand mostly fine-grained; silt to small cobbles present.
6.5-30	Silt, coarse-grained; iron-stained, light olive brown; very fine-grained sand in places; laminated, iron banded; very well-sorted. Slightly carbonaceous and clayey around 12 feet; more clayey, finer grained, and slightly darker in the last 4 feet, along with iron-stained silty clay layers.
30-40.5	Sand, very fine-grained; carbonaceous; olive brown to dark brown; well-sorted, somewhat silty; olive grey, iron-stained clay layers in the last 5 feet.
40.5-45	Silt, coarse-grained; olive brown; a little very fine-grained lignitic sand; grey, iron-stained silty clay layer near the bottom.

HB-91
T. 144 N., R. 88 W., Sec. 3, SESESE
El. 1870

0-12.5	Loam, silty; dark grey-brown; generally silt-size material with occasional sand and pebble-sized scoria fragments.
12.5-18	Loam, sandy; dark grey-brown; scoria chips.
18-30	Loam, clayey; dark grey-brown; a few scoria chips; fine-grained sand present, especially in the last 3 feet.

Depth (ft.)	HB-92 T. 144 N., R. 88 W., Sec. 22, SESENW El. 1960
0-4.5	Loam; grey-brown.
4.5-7	Silt; light grey to olive grey; laminated.
7-8.5	Silt; iron-stained, yellow-brown; iron concretions.
8.5-15.5	Silt to silty clay; lignitic; iron-stained; laminated; clay from 10 to 11 feet.
15.5-22	Clay, silty; lignitic; dark grey to dark brownish grey; thin lignite layer(s) at about 20 feet.
22-31.5	Silt and coarse-grained silt; grey to dark grey.
31.5-34.5	Clay, silty; grey; hard, increasingly calcareous downwards.
34.5+	Limestone; too hard to drill.

	HB-93 T. 144 N., R. 88 W., Sec. 22, SWSWSW El. 1937
0-1	Loam, silty; grey-brown.
1-16	Pebble-loam, clayey; light olive brown from 1 to 8 feet, olive yellow-brown from 8 to 16 feet; sandy from 6 to 7 feet.
16-20	Sand, fine- to medium-grained; brown; moderately-sorted, with coarse-grained sand and pebbles.
20-34	Sand, fine- to medium-grained; lignitic and scoriaceous; brown; better sorted than above, with coarse-grained sand and small pebbles; pebble and small cobble layers from 26 to 27.5 feet. Pebbles and small sandstone cobbles in the last 4 to 5 feet.
34-34.5	Silt; dark grey.
34.5+	Siltstone or sandstone; too hard to drill.

Depth (ft.)	HB-94 T. 144 N., R. 88 W., Sec. 27, SWSWNW El. 1795
0-2	Loam, sandy; greyish brown.
2-6.5	Loam, silty; grey-brown.
6.5-15	Sand, very fine- to fine-grained, silty; brown; a little medium-grained sand; well-sorted.
15-22	Sand, very fine- to fine-grained, silty; brown; less well-sorted than the above; medium- and coarse-grained sand, pebbles, and a few cobbles; carbonaceous layers.
22-35	Pebble-loam, clayey; dark grey; scoria chips and other pebble-sized material.

	HB-95 T. 144 N., R. 88 W., Sec. 27, NENENW El. 1917
0-2	Loam; brownish grey.
2-3	Loam; light yellow-brown.
3-9	Silt, sandy; light olive brown, mottled olive grey; a little silty, very fine-grained sand.
9-12.5	Silt; iron-stained, olive yellow-brown.
12.5-13.5	Clay; lignitic; dark grey, mottled olive grey.
13.5-16.5	Lignite; soft.
16.5-22	Silt, coarse-grained; lignitic; iron-stained, light olive grey-brown.
22-29	Silt, sandy; light olive brown; laminated; lignitic in places; thin lignite around 29 feet.
29-35	Clay and silty clay; dark grey to dark greenish grey; lignitic in places; thin lignite around 33 feet.
35-50	Clay, silty, to coarse-grained silt; dark grey to blue-grey; laminated; sandy towards the bottom.

Depth (ft.)	HB-96 T. 144 N., R. 88 W., Sec. 27, NENENE El. 1850
0-5	Loam, fine-grained; grey-brown.
5-13.5	Loam; dark olive brown; pebble-sized scoria chips.
13.5-18	Sand, very fine-grained, silty; brown; scoria chips. Pebbly layer from 16-17.5 feet consisting of scoria, sandstone, and iron concretions.
18-25	Sand, very fine- to fine-grained, silty; iron-stained, orange to yellow-brown; salt and pepper appearance.
25-27.5	Lignite.
27.5-37	Silt and silty clay; dark blue-grey to grey; laminated; lignitic in spots; a little sandy silt.
37-40	Lignite; hard; water.
40-50	Clay and silty clay; lignitic; dark grey to blue-grey; silt laminae towards the bottom.

	HB-97 T. 144 N., R. 87 W., Sec. 19, NENWSE El. 1900
0-4.5	Pebble-loam, clayey; light grey-brown.
4.5-16.5	Sand, fine-grained, pebbly; grey-brown; medium- and coarse-grained sand and small pebbles common.
16.5-34	Sand, very fine- to fine-grained; olive brown; salt and pepper appearance; somewhat silty; iron concretions and staining around 26 feet.
34-36	Lignite.
36-40	Clay and silty clay; grey to dark grey.
40-46	Silt and sandy silt, coarse-grained; blue-grey to grey; laminated possibly a little silty clay at the bottom. (continued on next page)

Depth (ft.)	HB-97 (cont.)
46-51	Lignite.
51-55	Clay and silty clay; olive grey to grey.

HB-98
T. 144 N., R. 87 W., Sec. 18, SESENW
El. 2025

0-3	Loam, silty; grey-brown.
3-10	Pebble-loam, clayey; light olive grey-brown to olive brown.
10-22	Silt to sand, very fine-grained; iron-stained, olive yellow-brown; salt and pepper appearance.
22-37	Silt to sand, very fine-grained; iron-stained, olive grey; salt and pepper appearance; calcareous, cemented sand from 28.5-29.5 feet.
37+	Sandstone; too hard to drill.

HB-99
T. 144 N., R. 87 W., Sec. 18, NENESE
El. 1963

0-13	Pebble-loam, clayey; olive grey-brown, mottled grey; very clayey towards the bottom; not much coarse-grained material other than lignite and scoria chips.
13-28	Sand, very fine- to fine-grained; olive brown to olive grey-brown; somewhat silty; salt and pepper appearance.
28-30	Sand, very silty; olive brown.
30-38	Sand, very fine- to fine-grained, silty; olive brown to brown; coarse sand-sized scoria, lignite, and iron concretions (extraneous?).
38-40	Sand, very fine-grained, very silty; grey-brown.
40-50	Sand, very fine- and fine-grained, silty; olive brown to olive grey-brown; salt and pepper appearance.

Depth (ft.)	HB-100 T. 144 N., R. 87 W., Sec. 19, NENESE El. 1918
0-2	Pebble-loam, clayey; light olive brown.
2-6	Pebble-loam, clayey, sandy; light olive brown.
6-19	Pebble-loam, clayey; dark olive brown and olive grey-brown; not much coarse material, mostly clay balls and iron concretions, a few small cobbles; not much lignite apparent; dark, carbonaceous layer at 18 feet.
19-30	Pebble-loam, clayey; olive grey-brown; more pebbly than the above, with cobbles and lignite fragments.
30-50	Pebble-loam, clayey; brown to grey-brown; not as much coarse material as above.

	HB-101 T. 144 N., R. 87 W., Sec. 30, SESENW El. 1770
0-15	Loam, clayey; grey-brown changing to olive grey-brown; a few coarse sand grains and small pebbles; fining downwards; mottled grey towards the bottom.
15-25	Clay and silty clay; blue-grey to grey; sandy near the top; mottled olive grey and brown; wet.
25-27	Loam, silty, clayey; grey to blue-grey; fine-grained sand present; very wet.
27-30	Sand, fine-grained, very silty; dark grey; a few coarse sand grains; very wet.

	HB-102 T. 144 N., R. 87 W., Sec. 30 SENENE El. 1770
0-1.5	Loam, fine-grained, sandy; light brown.
1.5-5	Sand, fine- to medium-grained, silty; lignitic; brown; well-sorted, with coarse-grained sand and small pebbles.

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Depth (ft.)	HB-102 (cont.)
5-11.5	Sand, fine- to medium-grained, silty; dark brown; a few large pebbles and rare cobbles.
11.5-15	Sand, fine-grained; brown; very well-sorted; very fine- and medium-grained sand present.
15-18.5	Sand, fine- to medium-grained; brown.
18.5-19.5	Clay, silty; greenish grey and dark grey.
19.5-25	Sand, fine-grained, silty; dark grey; well-sorted, with coarse-grained sand and small pebbles; wet.
25-30	Clay, silty, sandy; olive grey to grey; with very fine-grained sand and coarse-grained, sand-sized lignite.

HB-103
T. 144 N., R. 87 W., Sec. 19, NESESE
El. 1890

0-20	Pebble-loam, clayey; very light brown changing to olive brown at 6 feet; mostly fine-grained material, not much lignite.
20-24	Loam, silty, clayey; olive grey-brown; very few sand grains.
24-32	Pebble-loam, clayey; dark olive brown; small pebbles common; lignite fragments.
32-35	Loam, silty, clayey; olive grey-brown; minor sand.
35-40.5	Loam, silty, clayey; olive grey-brown; very fine-grained sand with minor coarse-grained sand; a few cobbles.
40.5-50	Silt; iron-stained, olive brown, olive yellow-brown, and olive grey; laminated; iron concretions.

Depth (ft.)	HB-104 T. 144 N., R. 87 W., Sec. 30, SESESE El. 1768 Drilled in 2-foot ditch.
0-4.5	Loam, sandy; grey-brown to brown.
4.5-7	Loam; olive grey.
7-15	Sand, fine-grained; lignitic; brown; very well-sorted, with very fine-grained sand; carbonaceous layer at 11 feet.
15-21	Sand, fine-grained; brown; medium- to coarse-grained sand and pebbles.
21-27.5	Sand, fine- to medium-grained; dark brown; pebbles common, a few small cobbles.
27.5-30	Sand and gravel; dark brown.

	HB-105 T. 144 N., R. 86 W., Sec. 7, SESENE El. 1744
0-5	Loam, silty; grey-brown.
5-8.5	Loam, sandy; brown; coarse-grained sand and small pebbles.
8.5-15	Pebble-loam, sandy, clayey; olive brown; last 2 feet mostly fine-grained material with an absence of any large pebbles.
15-20	Clay and silty clay; light grey to grey; a little lignite towards the top.
20-43	Silt to sandy silt; olive grey; compact, grey silty clay layer(s) in the interval from 35 to 40 feet.
43-43.5	Lignite.
43.5-52	Clay and silty clay; lignitic; grey.
52-54	Lignite; hard; water.
54-55+	Clay; difficult to drill.

Depth (ft.)	HB-106 T. 144 N., R. 86 W., Sec. 7, SWSESE El. 1741
0-5	Loam, pebbly; grey-brown.
5-24.5	Clay and silty clay; grey to olive grey; iron concretions, iron-stained in places; thin weathered lignite or lignitic clay at the top; thin, wet lignite at about 15.5 feet.
24.5-25	Sandstone; very hard; 6 to 8 inches thick.
25-30	Sand, very fine-grained, silty; olive brown.
30-33.5	Silt and sandy silt; lignitic; blue-grey; laminated.
33.5-35.5	Lignite; water.
35.5-40	Clay, silty; blue-grey; lignitic towards the top.
40-45	Silt to sandy silt; blue-grey.
	HB-107 T. 144 N., R. 86 W., Sec. 5, SWNWNW El. 1852
0-7.5	Pebble-loam; light olive brown to grey-brown; a few cobbles.
7.5-28.5	Pebble-loam, clayey; olive brown, changing to dark olive brown at 16 feet; mottled grey.
28.5-35	Silt; iron-stained, olive yellow-brown; laminated; iron concretions; light yellow-brown, laminated, sandy silt towards the bottom.
	HB-108 T. 144 N., R. 86 W., Sec. 5, NWNWNE El. 1902
0-9.5	Pebble-loam, clayey; light grey, changing to olive brown at 5 feet.
9.5-17.5	Silt and silty clay; iron-stained, olive grey-brown.

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Depth (ft.)	HB-108 (cont.)
17.5-22.5	Clay and silty clay; iron-stained, grey to olive grey.
22.5-23	Clay; lignitic; grey.
23-32	Silt, sandy, to very fine-grained, silty sand; lignitic; iron-stained; olive grey changing to dark olive brown at about 28 feet; laminated.
32-33	Siltstone; grey to light blue-grey; calcareous.
33-36	Silt, sandy, to very fine-grained, silty sand; olive grey to blue-grey.
36-41	Lignite; water.
41-47	Clay and silty clay; light bluish grey to grey; wet.
47-50	Silt; light bluish grey; wet.

HB-109
T. 144 N., R. 86 W., Sec. 8, SESENW
El. 1740

0-5	Loam, fine-grained; light brown.
5-13	Loam, silty, clayey; grey-brown; a little fine-grained sand.
13-25	Loam, clayey; olive brown.
25-30	Sand, fine-grained, silty; brown; well-sorted; coarse-grained sand to small pebbles present.

HB-110
T. 144 N., R. 86 W., Sec. 9, NWNWNE
El. 1730
Drilled in 1.5-foot ditch.

0-6	Loam, silty, clayey; light olive brown; only very fine-grained sand present.

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Depth (ft.)	HB-110 (cont.)
6-20	Loam, silty, clayey; olive grey-brown, mottled grey; sand present but rare.
20-30	Sand, very fine- to fine-grained, silty; lignitic; olive grey; very well-sorted; wet; dark brown carbonaceous layer at the top; blue-grey towards the bottom.

HB-111
T. 144 N., R. 87 W., Sec. 13, NENESW
El. 1782

0-5	Loam, sandy; grey-brown; a little medium- and coarse-grained sand.
5-8.5	Sand, fine- to medium-grained, pebbly; reddish grey-brown; moderately-sorted, silt to large pebbles.
8.5-19	Pebble-loam, sandy, clayey; dark olive brown; lignite rare; no cobbles.
19-35	Pebble-loam, clayey; lignitic; iron-stained, olive brown; mottled grey; clay to cobbles.
35-46	Pebble-loam, clayey; dark grey to olive grey; lignite and scoria pebbles common.
46-55	Clay, silty; dark grey; cohesive and tough; bluish grey downwards.

HB-112
T. 144 N., R. 87 W., Sec. 24, SWNWNW
El. 1792

0-1	Loam, silty; grey-brown.
1-4	Loam; light olive brown.
4-13	Silt, sandy; iron-stained, light grey to light olive grey; iron concretions; silt and clay layers.
13-13.5	Sand, very fine-grained, silty; iron-stained, light grey; salt and pepper appearance.

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Depth (ft.)	HB-112 (cont.)
13.5-14+	Sandstone, very fine-grained; calcareous; too hard to drill.

HB-113
T. 144 N., R. 86 W., Sec. 6, SESESW
El. 1828
Drilled in 2-foot ditch.

0-9	Pebble-loam, clayey; lignitic; iron-stained, olive brown; many cobbles.
9-11	Pebble-loam, clayey; olive brown; finer grained than above, mostly only small pebbles; no noticeable lignite.
11-18.5	Loam, fine-grained, sandy, clayey; olive grey-brown; only rare coarse-grained sand and small pebbles; no lignite.
18.5-24	Clay, silty; grey to dark grey; laminated; iron-stained near the top.
24-28	Clay, silty; lignitic; dark brownish grey.
28-33.5	Lignite; hard; black; brownish black in spots.
33.5-36.5	Clay and silty clay; lignitic; dark grey.
36.5-41.5	Lignite; mostly brownish black.
41.5-50	Silt, sandy, to silty clay; blue-grey; laminated; lignitic in places.

HB-114
T. 144 N., R. 86 W., Sec. 7, SESENW
El. 1763
Drilled in 3-foot ditch.

0-5	Loam, fine-grained, sandy; grey-brown to olive grey-brown.
5-14	Pebble-loam, sandy, clayey; dark olive brown; pebble-cobble layer from 6 to 8 feet.

(continued on next page)

Depth (ft.)	HB-114 (cont.)
14-18.5	Pebble-loam, sandy, clayey; brown; more pebbly than above.
18.5-30	Clay to silt; blue-grey to grey; 2-inch-thick siltstone at about 25 feet; thin lignite from about 28.5 to 29 feet, underlain by lignitic clay.

HB-115
T. 144 N., R. 86 W., Sec. 4, SESWNE
El. 1740

0-6	Loam; grey-brown.
6-10	Pebble-loam, clayey; dark olive brown.
10-23	Silt, coarse-grained; olive brown; very well-sorted.
23-28	Clay, silty; iron-stained, olive grey-brown to olive grey; compact.
28-28.5	Lignite; wet.
28.5-36.5	Clay and silty clay; greenish grey to blue-grey.
36.5-37.5	Lignite; wet.
37.5-48	Silt, sandy; blue grey; possibly a little clay below the lignite.
48-49.5	Lignite; wet.
49.5-50	Clay; grey.

HB-116
T. 144 N., R. 86 W., Sec. 18, NWSWNW
El. 1748
Drilled in 1.5-foot ditch.

0-21	Loam, clayey, sandy, very fine-grained; dark grey-brown to dark olive grey-brown; olive brown and wet from 6 feet; mottled dark grey; increasingly sandy downwards. Quite wet from about 12 feet.

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Depth (ft.)	HB-116 (cont.)
21-30	Sand, very fine-grained, silty; olive grey-brown; fine, medium, and coarse-grained sand; very wet; lignite, and scoria grains; blue-grey sandy clay from about 26 to 27 feet, mottled olive green.
30-53	Silt and clay, sandy; blue-grey, mottled olive green; very wet.
53-60	Clay, sandy; blue-grey; very tough.

HB-117
T. 144 N., R. 87 W., Sec. 24, NWNENE
El. 1745

0-10	Silt, sandy; light brown to brown; a little fine sand.
10-15	Sand, fine- to medium-grained; brown; somewhat silty; coarse sand present.
15-18	Sand, medium-grained, silty; dark brown; a little coarse sand, much fine sand.
18-30	Sand, medium-grained, pebbly, silty; scoriaceous and lignitic; dark brown; small pebbles; thin olive brown sandy clay with grey mottling between 25 and 30 feet. Wet from about 28 feet.
30-42	Sand, fine-grained, silty; brownish grey to olive grey; medium and coarse sand grains, no pebbles; very wet.
42-50	Sand, fine-grained, pebbly, silty; brownish grey to olive grey; wet; small cobbles in last two feet.

HB-118
T. 144 N., R. 86 W., Sec. 7, SESESW
El. 1747

0-20	Loam; light grey-brown to dark grey-brown; only very fine sand present; cohesive at about 6 feet; more clayey from about 10 feet; the last 5 feet olive brown in color and very cohesive; water at about 20 feet.

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Depth (ft.)	HB-118 (cont.)
20-37.5	Sand, fine-grained, silty; olive brown; rare coarse-grained sand; very wet.
37.5-40	Clay, silty; dark grey; brown mottling.

HB-119
T. 144 N., R. 88 W., Sec. 25, NWNENW
El. 1841
NE corner of schoolyard.

0-20	Pebble-loam; lignitic; iron-stained, olive brown to dark olive brown; a few cobbles.
20-25	Pebble-loam, sandy; dark brown; contains much fine to coarse sand.
25-35	Loam, clayey, silty; iron-stained, olive brown; only very fine sand present, no pebbles; thin clay layers.
35-41	Sand, very fine, very silty and clayey; olive brown; a little fine-grained sand.
41-50	Sand, very fine, silty; brown to dark brown; loose, dry, very dirty appearance; coarse sand to small pebble-size lignite chips; mica flakes noticeably present; possibly clayey in spots.

HB-120
T. 144 N., R. 88 W., Sec. 26, SESENW
El. 1815

0-6	Loam, fine-grained; grey-brown and light brown; few pebbles.
6-19	Pebble-loam, sandy; brown; many small pebbles; not noticeably lignitic; nearly the same as the above material.
19-30	Silt, sandy to clayey; blue-grey; olive mottling.
30-44	Silt, sandy; blue-grey.
44-46	Clay and sandy silt; blue-grey; a few lignite grains.

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Depth (ft.)	HB-120 (cont.)
46-52	Silt, sandy, clayey; blue-grey; lignitic and pebbly.
52-60	Sand, very fine, silty; lignitic; blue-grey; wet; rare, coarse lignite grains.

HB-121
T. 144 N., R. 88 W., Sec. 26, SWSWNE
El. 1805

0-6	Loam; dark grey-brown; a few small pebbles.
6-21	Loam; olive brown; small pebbles but no cobbles; lignite rare; cohesive.
21-24	Sand, fine-grained, very silty; olive brown; wet.
24-30	Clay to sandy silt; blue-grey; lignite fragments; green near the top.

HB-122
T. 144 N., R. 88 W., Sec. 26, NWNWNE
El. 1894

0-1.5	Loam; organic; dark brown.
1.5-50	Pebble-loam, sandy; lignitic; iron-stained, olive brown; dark olive brown at about 25 feet; carbonate cobbles, scoria, iron concretion, greenstone, and carbonate pebbles.
50-70	Pebble-loam; dark grey; as above, but wet, possibly a thin sandy layer at 50 feet; drills somewhat easier.
70-75	Clay, silty, to sandy silt; dark bluish grey.

Depth (ft.)	HB-123 T. 144 N., R. 88 W., Sec. 36, SWNESE El. 1790
0-22	Sand, fine, silty; dark brown and brown; medium and coarse sand and a few pebbles, rare small cobbles.
22-25	Sand, fine, silty; lignitic; very dark brown.
25-33.5	Sand, fine to medium, silty; dark brown; coarse sand and small pebbles present; very wet.
33.5-40	Gravel, cobbly; no samples; hard drilling.

	HB-124 T. 144 N., R. 88 W., Sec. 35, NWNWNW El. 1778
0-5	Sand, fine to medium, silty; lignitic; brown and dark brown.
5-7	Sand, very fine to fine, silty; light brown; with coarser grains.
7-10	Sand, very silty; scoriaceous and lignitic; grey-brown; rather poorly-sorted, very fine to very coarse sand and very fine gravel.
10-10.5	Clay, sandy; olive grey.
10.5-15	Sand, medium-grained; brown; very fine to coarse sand, much fine sand, a few small pebbles; little silt.
15-23.5	Sand, medium-grained; lignitic; brown; a little silt, much coarse sand and a few scoria chips and small flat pebbles, moderately well-sorted; wet.
23.5-24	Clay, sandy; very organic; black.
24-37.5	Gravel, coarse; large pebbles and small cobbles.
37.5-50	Silt, sandy, to very fine silty sand; micaceous; blue-grey; lignitic in spots; cohesive.

Depth (ft.)	HB-125 T. 144 N., R. 88 W., Sec. 34, SWSWSESW El. 1794
0-6.5	Sand, very fine to fine, very silty; brown; moderately well-sorted, with medium and coarse grains.
6.5-15	Silt, sandy; olive brown and grey-brown; laminated; coarsening downwards; last 3 to 4 feet laminated with fine brown sand.
15-21	Sand, fine-grained; brown; very well-sorted, with very fine and medium sand.
21-23	Sand, medium-grained, pebbly, silty; dark brown; lignite and other pebbles; much coarse sand; wet.
23-29.5	Sand, coarse-grained, very pebbly; dark brown; scoria, lignite, and other pebbles; a few small cobbles; much medium sand; brownish grey to dark grey in the last 3 feet or more; wet.
29.5-30	Silt, sandy; blue-grey.
30-35	Gravel; no samples; drilled like cobbly gravel.

	HB-126 T. 144 N., R. 88 W., Sec. 24, SWNWSWSW El. 1845 (approx.)
0-1.5	Silt, sandy; dark brown.
1.5-6	Silt, sandy, cobbly; light grey.
6-9	Pebble-loam, sandy; lignitic; iron-stained, olive brown.
9-12.5	Sand, fine to medium, silty; lignitic; brown; a few pebbles and coarse sand grains.
12.5-14	Sand, medium to coarse, silty, pebbly; reddish brown; moderately-sorted.
14-24	Pebble-loam, sandy; lignitic; iron-stained, olive brown; many pebbles and cobbles.

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Depth (ft.)	HB-126 (cont.)
24-35	Pebble-loam; brownish grey; lignite, scoria, and carbonate pebbles; first 2 to 3 feet appear to be more a sandy silt, lacks pebbles but same consistency as pebble loam; dark grey from about 30 feet with many pebbles.
35-40	Silt, clayey, to silty clay; blue-grey; olive clay inclusions.
40-50	Silt, sandy, to very fine silty sand; blue-grey; coarse sand-size lignite and fine mica flakes; appears laminated; drills somewhat easier than pebble-loam; olive clay inclusions; wet in the last foot or more.

HB-127
T. 144 N., R. 88 W., Sec. 24, NWNENWSW
El. 1894
Drilled in 4-foot ditch.

0-10	Pebble-loam; lignitic; iron-stained, olive brown.
10-12.5	Sand, fine-grained, silty; olive brown; medium to coarse sand and pebbles present; moderately well-sorted.
12.5-15.5	Sand, medium-grained, silty, pebbly; cobble layer at top, cobbles also in the sand; all sand sizes, much coarse sand.
15.5-30	Pebble-loam; iron-stained, dark olive brown to dark brown; many lignite pebbles.
30-37	Loam, clayey; olive grey-brown; a few small pebbles; tough.
37-40	Clay, silty; olive brown.
40-50	Sand, fine-grained, silty; lignitic; very dark brown; dry; coarser sand and pebbles present; olive brown and grey, lignitic, sandy clay to clayey sand stringers common; sand grey-brown in last few feet.

Depth (ft.)	HB-128 T. 144 N., R. 88 W., Sec. 14, NESENENE El. 2020 (approx.) Drilled in 3-foot ditch.
0-6	Loam; dark grey-brown; grading down to pebble-loam.
6-42	Pebble-loam; lignitic; iron-stained, olive brown; carbonate and other cobbles not of local origin; pebbles common but fewer with depth; dark olive brown from about 20 feet.
42-43	Clay, silty; slightly purplish grey; hard; slightly lignitic.
43-57	Lignite; black.
57-60	Silt, sandy; olive grey to blue-grey.

	HB-129 T. 144 N., R. 86 W., Sec. 3, NESWSWSW El. 1726
0-10	Silt, sandy, very fine-grained; light brown; sand grains getting somewhat coarser downwards.
10-11	Sand, very fine to fine, silty; light brown.
11-22.5	Sand, medium-grained; brown; well-sorted; generally getting coarser with depth; small lignite and scoria chips; wet in the last 2 feet.
22.5-23	Clay, silty; olive brown.
23-25	Sand, medium-grained; brown; well-sorted; wet.
25-29	Sand, medium-grained, silty, pebbly; dark grey; lignite and scoria pebbles; wet.
29-30	Gravel; wet.

Depth (ft.)	HB-130 T. 144 N., R. 86 W., Sec. 3, NENWNWNE El. 1754 (approx.)
0-12	Loam, clayey; light grey-brown to olive brown; with small lignite grains and coarse sand.
12-16	Loam, clayey; brown; moist; small pebbles, many scoria chips and a few lignite grains.
16-25	Loam, clayey; olive brown; wet; tough; a few lignite grains but no pebbles, few scoria chips; most sand very fine; getting wetter downwards.
25-26.5	Loam, sandy, pebbly; olive brown; pebbles angular; much water.
26.5-30	Loam, clayey; olive brown; very wet; no pebbles. Last 2 feet or more quite lignitic with a few small pebbles.

	HB-131 T. 144 N., R. 86 W., Sec. 3, NENENE El. 1745
0-9	Loam, clayey; lignitic; olive brown.
9-20	Loam; dark grey-brown to dark brown; moist; very coarse sand, scoria pebbles, and a few lignite grains present; wet in the last 4 feet.
20-28	Pebble-loam; dark brown; many more pebbles than above, noticeably lignitic; occasional small cobbles in the last 2 feet; wet and more pebbly with depth.
28-30.5	Sand, gravelly.
30.5-50	Sand, fine-grained, silty; iron-stained, blue-grey to blue; olive mottling, lignite laminae; somewhat cemented in places; moist and cohesive.

Depth (ft.)	HB-132 T. 144 N., R. 86 W., Sec. 1, NWNWNWNW El. 1720 Drilled in 2-foot ditch.
0-5.5	Loam, clayey; olive grey brown.
5.5-12	Sand, very fine to fine, silty, clayey; brown.
12-17.5	Sand, fine to medium; brown; dark brown organic layers and grey clayey layers; not as cohesive as above sand; general coarsening downwards.
17.5-25	Sand, medium to coarse, silty; lignitic and scoriaceous; dark brown and dark grey-brown; wet; with very coarse sand; 6-inch-thick olive grey sandy clay layer at about 21 feet.
25-35	Sand, medium to coarse, pebbly; dark grey; fine sand to fine gravel; much very coarse sand, somewhat silty; very wet.
	HB-133 T. 144 N., R. 86 W., Sec. 8, NWSWSWSE El. 1730 Drilled in 6-foot ditch.
0-14	Loam, sandy, clayey; olive grey-brown; cohesive; laminated; a little fine sand; a little iron-stained grey clay towards bottom.
14-21	Sand, fine-grained; brown; very well-sorted, much very fine sand; coarsens downwards.
21-25.5	Sand, medium-grained; lignitic; grey-brown; much coarse and very coarse sand and fine sand; wet.
25.5-26	Clay, grey; small wood fragments.
26-35	Sand, medium-grained; grey; very wet; small lignite pebbles and much coarse and very coarse sand; clayey beds in sand; a few wood fragments.

Depth (ft.)	HB-134 T. 144 N., R. 88 W., Sec. 12, SWSWNW El. 1981 Drilled in 6-foot ditch.
0-6	Silt, sandy; olive brown to grey.
6-8	Sand, very fine-grained, very silty; grey.
8-10	Silt, clayey; dark grey; soft.
10-11	Clay, silty; dark grey; hard.
11-12	Silt, clayey; dark grey; soft.
12-17.5	Clay, silty, and clay; dark grey; hard; thin, buff-colored hard rock at 17.5 feet.
17.5-23	Clay, silty, and clay; lignitic; dark brownish grey; hard; several very thin lignite beds.
23-30	Sand, very fine-grained, silty; blue-grey; fine sand and lignitic laminae present.
30-32	Clay, silty; lignitic to very lignitic; dark brownish grey; hard to very hard.
32-49	Lignite; black; hard drilling; samples mostly dry powder.
49-55	Silt, sandy; lignitic; light grey-brown; grading down to blue-grey, very fine, silty sand.

	HB-135 T. 144 N., R. 88 W., Sec. 24, SESENE El. 1920 (approx.)
0-1.5	Silt, sandy; brown.
1.5-42.5	Pebble-loam; lignitic; light grey-brown to olive brown to olive grey-brown; occasional cobbles, especially towards the top; granite-gneiss, greenstone, carbonate, iron concretion, and chert; becoming generally darker and finer-grained downwards with occasional cobbles.

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Depth (ft.)	HB-135 (cont.)
42.5-52	Sand, fine- to medium-grained; iron-stained, olive grey-brown; slightly silty; salt and pepper appearance with small cemented balls of sand; hard, lignitic, and very fine towards the bottom.
52-57.5	Clay and silty clay; lignitic; dark bluish grey; thin lignite seams present.
57.5-59.5	Lignite.
59.5-63	Clay, silty; lignitic; dark blue-grey.
63-65	Lignite.
65-70	Silt, sandy, and silt; bluish grey; hard.

HB-136
T. 144 N., R. 88 W., Sec. 24, SENESE
El. 1856 (approx.)

0-2	Silt, sandy; dark brown.
2-4	Gravel, cobbly; very poorly-sorted, silt to cobbles.
4-28.5	Pebble-loam; lignitic; iron-stained, olive brown to olive grey-brown; many pebbles.
28.5-30	Silt, sandy, very fine-grained; light greyish brown; cohesive.
30-32	Sand, fine-grained, silty, pebbly; dark brown; water.
32-40	Pebble-loam, sandy; lignitic; iron-stained, olive brown.
40-44	Silt, sandy, to very fine silty sand; grey to bluish grey; olive green clay inclusions; detrital lignite grains up to small pebble-size and rare coarse iron concretion grains.
44-50	Sand, fine-grained; grey-brown; wet; coarse and very coarse sand present; occasional small pebbles towards the bottom.

Depth (ft.)	HB-137 T. 144 N., R. 88 W., Sec. 24, NENWNWSE El. 1902 (approx.) Boulders at the surface.
0-5.5	Sand and gravel; light grey-brown to red-brown; silty, very fine to very coarse sand; gravel up to cobble size.
5.5-8.5	Pebble-loam; lignitic; olive brown.
8.5-10	Sand, fine to medium, pebbly; brown; pebbles consist of fragments of iron concretions, sandstone, and limestone.
10-13	Sand, fine to medium; olive brown; well-sorted; pebble-free; loose.
13-17.5	Sand, fine to medium, pebbly; brown; iron concretion, sandstone, limestone, and scoria pebbles; sandstone cobbles with selenite crystals towards the bottom.
17.5-22.5	Clay, silty; lignitic; dark grey; laminated towards the middle with very fine sandy silt; iron concretions present.
22.5-24.5	Lignite; poor quality.
24.5-30.5	Silt, sandy, and very fine silty sand; iron-stained, olive grey-brown; laminated; iron concretions with large selenite crystals present.
30.5-33.5	Clay, silty; dark grey; lignitic in places, especially towards the bottom; hard.
33.5-37	Lignite; black; hard.
37-40	Sand, very fine-grained, silty; grey-brown.
40-42	Silt, sandy; blue-grey.
42-50	Clay to silt; dark grey; hard.

Depth (ft.)	HB-138 T. 144 N., R. 88 W., Sec. 24, SESWSWSE El. 1830 (approx.)
0-6.5	Sand and gravel, cobbly; light grey-brown; interbedded with fine- to medium-grained, pebbly sand.
6.5-27	Pebble-loam; lignitic; olive brown; small pebbles present.
27-34	Clay, silty; iron-stained, light brown; very fine sandy silt to clay present.
34-45	Silt, sandy, very fine-grained; light brown; cohesive, moist, pliable; fine mica flakes; dark grey around 40 feet.
45-50	Sand, very fine-grained, very silty; dark grey; moist and pliable; a little fine sand; occasional coarse and very coarse lignite grains; wet towards the bottom.

	HB-139 T. 144 N., R. 88 W., Sec. 36, NWSWSWSW El. 1880
0-74	Sand, very fine and fine, silty; light grey; moist and slightly cohesive from near the top; iron-stained brown in several places; occasional concretions consisting of iron-cemented sand; light olive grey from about 20 feet, olive grey-brown from about 25 feet; thin iron-cemented zones at 33 and 37 feet; more a silty fine sand from about 40 feet; iron-cemented zones between 50 and 55 feet and at 59 feet; getting darker brown and less silty with depth; more silty and slightly finer around 60 feet; blue-grey in the last 10 feet or more, with cemented sand; salt and pepper appearance.
74-75+	Lignite; water.

	HB-140 T. 144 N., R. 88 W., Sec. 36, NWNESENW El. 1840 South of grandstand.
0-6	Sand, fine to medium, silty; dark grey-brown to grey-brown; coarse sand present.

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Depth (ft.)	HB-140 (cont.)
6-20.5	Pebble-loam, very sandy; dark olive brown; iron concretion, scoria, and clay pebbles; occasional iron concretion and sandstone cobbles.
20.5-33	Sand, fine-grained, silty; olive yellow-brown to olive brown; much very fine sand; iron-stained brown in places; salt and pepper appearance.
33-36.5	Lignite; moist.
36.5-38	Clay, silty; dark grey.
38-41.5	Lignite.
41.5-42	Clay, silty; lignitic; dark brownish grey.
42-50	Silt and very fine sandy silt; blue-grey; laminated and lignitic in places; very fine silty sand towards the bottom.

HB-141
T. 144 N., R. 87 W., Sec. 30, SWSWNW
El. 1769

0-7	Loam to clayey loam; grey-brown; last foot appeared to be more a pebble-loam; lignitic, with a greenstone cobble.
7-11	Sand, very fine-grained, silty; brown; with fine sand.
11-17.5	Sand, coarse-grained, silty, pebbly; reddish brown; pebble-cobble layer near the top; very fine to very coarse sand; many scoria chips.
17.5-18	Clay, silty; olive grey.
18-22	Sand, medium to coarse, silty, pebbly; dark brown; much fine sand and silt; very wet.
22-30	Sand, fine to medium, silty; olive grey; with coarse sand and occasional small pebbles; very wet.
30-35	Sand, very fine and fine, silty; blue-grey; cohesive, drills tough; occasional very coarse sand grains and lignite up to small pebble size.

Depth (ft.)	HB-142 T. 144 N., R. 87 W., Sec. 20, SESWNWNE El. 1986
0-6	Pebble-loam; light grey-brown; very loose; with cobbles.
6-11	Lignite; powdery; slightly damp.
11-19.5	Silt, sandy, very fine-grained; iron-stained, light grey to light olive grey.
19.5-20	Sand, very fine-grained; cemented.
20-36	Silt, sandy, very fine-grained; grey; iron-stained, and iron-cemented in places; olive yellow-brown and hard around 33 feet; occasional small selenite crystals.
36-38	Silt, sandy, very fine-grained; blue-grey; hard.
38-39	Silt, sandy, very fine-grained; olive grey-brown; lignitic laminae.
39-42	Sand, very fine-grained, silty; olive grey-brown; lignitic laminae.
42-46	Silt, sandy, very fine-grained; olive brown; thinly laminated in places.
46-50	Silt, sandy, very fine-grained; dark grey to bluish grey; laminated.

	HB-143 T. 144 N., R. 87 W., Sec. 33, SWSWSWSW El. 1927 Drilled in 1-foot ditch.
0-1	Silt, sandy; dark brown.
1-9	Pebble-loam; very lignitic; iron-stained, olive brown; granite, carbonate and flint pebbles.
9-10	Siltstone, sandy; very hard.
10-14	Silt, sandy, very fine-grained; brown; iron-stained in spots.
14-15	Silt and iron concretions; orangish brown.
15-17.5	Lignite; soft.

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Depth (ft.)	HB-143 (cont.)
17.5-19	Silt and clayey silt; lignitic; light brownish grey to light greenish grey.
19-31	Silt to clayey silt; light green; light blue-green in places; relatively indurated; thin lignitic zone around 30 feet.
31-40	Silt and clayey silt; dark bluish grey to dark grey; indurated; very fine sandy silt around 36 feet.
40-50	Silt and very fine sandy silt; dark grey; with thin limestone; last 5 feet or more mostly very fine sandy silt; hard, laminated in places; approaching very fine silty sand.

HB-144
T. 144 N., R. 87 W., Sec. 36, SWSWSW
El. 1908
Drilled in 1-foot ditch.

0-0.5	Loam, sandy, fine-grained; dark brown.
0.5-16	Pebble-loam; lignitic; iron-stained, olive brown; many pebbles and small cobbles; carbonate, greenstone, granite, scoria, iron concretion and others.
16-32	Silt, sandy, very fine; iron-stained, light olive brown; pliable, soft and loose; harder with depth; iron concretions at 20 and 24 feet.
32-34	Clay, silty; lignitic; dark grey-brown.
34-37.5	Lignite.
37.5-39	Clay; lignitic; dark grey.
39-43.5	Clay, silty, to silt; blue-grey to dark bluish grey; laminated in places.
43.5-46	Lignite; poor quality.
46-50	Silt, sandy, very fine; light blue-greenish grey; lignitic towards top.

Depth (ft.)	HB-145 T. 144 N., R. 86 W., Sec. 19, SENWNWSW El. 1751 (approx.)
0-4.5	Sand, fine-grained, silty; dark grey-brown to grey-brown; with medium sand.
4.5-5.5	Sand, very fine-grained, silty; light brown.
5.5-9.5	Sand, fine-grained; light brown; loose; very well-sorted, with medium sand.
9.5-13	Sand, medium-grained; light brown; well-sorted, with coarse and very coarse sand and occasional small pebbles; thin clayey layer at about 13 feet.
13-24.5	Sand, medium-grained; lignitic; brown to reddish brown; moderately well-sorted; coarse and very coarse sand, small pebbles, rare scoria chips; much fine sand; sandy clay layers at 15 and 21 feet; wet from about 21 feet.
24.5-25	Clay; grey.
25-31	Sand, medium-grained; grey brown; as sand above; wet.
31-45	Sand, medium to coarse, pebbly; dark grey; small pebbles, rare lignite cobbles; wet.

	HB-146 T. 144 N., R. 86 W., Sec. 28, NENENENE El. 1879
0-5	Sand, very fine to fine, silty; dark grey-brown to brown; medium and a little coarse sand; occasional very coarse quartz grains.
5-11.5	Pebble-loam; lignitic; iron-stained, olive grey-brown; lower foot or more reworked bedrock.
11.5-17.5	Clay, silty, to silt; iron-stained, olive grey-brown to grey; iron concretions present; lignitic at about 14.5 feet; dark olive grey from 15 feet.
17.5-22	Silt, sandy, and silt; olive grey and grey; laminated.

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Depth (ft.)	HB-146 (cont.)
22-29	Clay, silty, and clayey silt; grey to dark olive grey; hard, limy zones; lignitic towards bottom.
29-35.5	Lignite; very hard drilling from 31 feet; water in last two feet.
35.5-40	Silt, sandy; slightly greenish grey; lignitic in spots; approaching very fine silty sand from 37 to 39 feet.
40-48	Silt and silty clay; grey; silt 40 to 42 feet, silty clay 42 to 45 feet, silt 45 to 48 feet.
48-48.5	Lignite.
48.5-50	Silt, sandy; greenish grey.

HB-147
T. 144 N., R. 86 W., Sec. 25, NWSWSWNW
El. 1904 (approx.)

0-6	Sand, fine-grained; brown; very fine to medium sand common, with coarse and occasional very coarse sand; somewhat silty; grey from about 3 feet, wet from 4.5 feet; black, and very lignitic and organic near the bottom.
6-9	Sand, clayey; iron-stained, grey-brown; sandy clay towards bottom.
9-12	Sand, fine to medium; grey; a few pebbles; wet.
12-13.5	Pebble-loam; lignitic; dark grey.
13.5-15.5	Sand, fine to medium, pebbly; grey; very wet.
15.5-20	Pebble-loam; lignitic; dark grey.
20-28	Sand, medium-grained, pebbly; dark grey; much coarse sand; wet.
28-35	Silt, sandy, to very fine silty sand; bluish grey; hard at 28 feet.

Depth (ft.)	HB-148 T. 144 N., R. 86 W., Sec. 34, NENENE El. 1952
0-1.5	Silt, sandy; grey-brown.
1.5-16	Silt, sandy, and silt; brown and olive grey-brown; very thinly laminated; iron concretion layers at 2.5 and 12.5 feet.
16-19.5	Sand, very fine and fine, silty; brown.
19.5-31	Sand, fine-grained, silty; blue-grey; relatively cohesive, moist; carbonate-cemented sand 25 to 27.5 feet, hard drilling; sand finer from 25 feet.
31-34	Lignite; hard; water near the bottom.
34-40	Silt and clayey silt; blue-greenish grey.
40-42	Lignite; interbedded with clay.
42-50	Clay, silty; light blue-grey; possibly a little clayey silt.

	HB-149 T. 144 N., R. 86 W., Sec. 36, SWSWNW El. 1974
0-3.5	Sand, fine-grained, silty; grey-brown to brown; loose; well-sorted; very fine to medium sand present.
3.5-11	Sand, medium-grained; brown; much fine sand, occasional coarse grains; clayey layer around 9 feet; sand coarser below with a few very coarse grains.
11-16	Pebble-loam, sandy; very iron-stained, olive grey-brown.
16-22	Pebble-loam; dark grey; carbonate and metamorphic cobbles.
22-25.5	Sand, fine-grained, silty; olive grey-brown; wet; coarse sand present.
25.5-35	Clay, silty, to sandy silt; dark olive grey; cohesive and tough, but easy drilling; detrital lignite up to small pebble size present; appears lignitic or organic in places.

Depth (ft.)	HB-150 T. 144 N., R. 86 W., Sec. 35, SESWNWNE El. 1979
0-1.5	Loam; very organic; black.
1.5-6	Sand, fine to medium; brown; well-sorted; wet from about 4.5 feet; pebbles at bottom.
6-9	Sand, clayey, to sandy silt; brown; lignitic around 8.5 feet; iron concretions.
9-24	Clay, silty; blue-greenish grey to bluish grey; indurated; siltstone at 22 feet; thin lignite seams from 23.5 to 24 feet.
24-29	Silt, clayey, and silty clay; blue-grey to grey.
29-36	Silt to very fine sandy silt; blue-grey to grey; a little clayey silt.
36-40	Silt and clayey silt; blue-grey to grey; thin siltstone at about 38 feet.
40-47	Silt and very fine sandy silt; blue-grey to grey.
47-50	Lignite; hard.
50-55	Silt and clayey silt; lignitic; silty clay directly below lignite.
55-60	Silt; hard; cemented.
60-75	Silt and very fine sandy silt; mostly sandy silt in last 10 feet; cemented slightly in places. Possible lignite in last 4 inches.

	HB-151 T. 144 N., R. 86 W., Sec. 25, NWNWNWNW El. 1936
0-8	Sand, fine-grained; brown; much very fine and medium sand; a few coarse grains and rare very coarse grains.
8-19.5	Pebble-loam; lignitic; iron-stained, brownish grey; many pebbles and carbonate cobbles.
19.5-25	Silt to clayey silt; light olive grey; indurated.

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Depth (ft.)	HB-151 (cont.)
25-31	Clay and silty clay; dark grey and olive grey; tough; lignitic in spots.
31-32	Lignite; water.
32-40	Silt, coarse-grained; blue-grey; thinly laminated; lignitic in spots; approaching sandy silt.
40-46	Silt, sandy; blue-grey; lignitic in spots; generally coarsening downwards from 32 feet.
46-50	Clay, silty, and clayey silt; dark grey; with thin, light grey siltstone.
50-55	Silt, sandy; blue-grey; possible thin lignite.

HB-152
T. 144 N., R. 86 W., Sec. 36, SESENW
El. 2045

0-2	Sand, fine-grained, silty; dark brown to brown; medium and coarse sand present.
2-11	Pebble-loam; lignitic; iron-stained, light grey-brown to olive brown.
11-15.5	Pebble-loam; very iron-stained, brown; thin black clay directly below.
15.5-20.5	Silt; olive; slightly lignitic.
20.5-23.5	Clay, silty; olive grey; lignitic towards bottom with very thin lignite seams.
23.5-25	Sand, very fine, silty, and very fine sandy silt; olive grey.
25-38	Silt, coarse-grained, and very fine sandy silt; blue-grey; laminated and lignitic in places; a little clayey silt.
38-42	Clay, silty; grey; indurated.

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Depth (ft.)	HB-152 (cont.)
42-46	Silt and clayey silt; grey.
46-49	Silt, coarse-grained, and very fine sandy silt; grey to greenish grey; laminated.
49-50	Lignite; mostly poor quality, appears to have clay partings; water.
50-55	Silt, coarse-grained; blue-green; approaching very fine sandy silt; lignitic at the top.

HB-153
T. 144 N., R. 86 W., Sec. 36, NWNENW
El. 1992 (approx.)
Drilled in 1.5-foot ditch.

0-2	Sand, fine-grained, silty; brown; medium and coarse sand present; pebbles at bottom.
2-5.5	Pebble-loam; lignitic; iron-stained, olive brown; mottled grey; pebbles and cobbles.
5.5-7.5	Silt, sandy; brown.
7.5-9	Sand, very fine, silty; olive brown.
9-11	Silt, clayey; olive brown and bluish grey.
11-20	Silt and coarse silt; grey to bluish grey.
20-24.5	Clay and silty clay; bluish grey; indurated; brownish grey, lignitic, and hard towards bottom.
24.5-25	Lignite; hard; poor quality.
25-30	Clay, silty; dark olive grey; thin lignite at 27 feet, possibly other very thin lignite seams.

Depth (ft.)	HB-154 T. 144 N., R. 86 W., Sec. 12, SWSWSESW El. 1840 (approx.)
0-2.5	Sand, fine-grained, silty; brown; medium to very coarse sand present, with rare small pebbles.
2.5-16	Pebble-loam; lignitic; iron-stained, mottled grey.
16-17.5	Sand, very fine-grained, silty; brown; wet.
17.5-19.5	Silt, sandy, to clayey silt; olive grey.
19.5-30	Pebble-loam; olive grey-brown; pebbles small and mostly lignite, but other pebbles not of local origin; changing to dark grey at about 23 feet; large limestone cobble at 23 feet.
30-37	Clay, silty, to clayey silt; dark olive grey; tough; lignite pebbles; more a pebble-clay-loam in lower part.
37-48	Sand, very fine to fine, silty; olive brown; very wet; coarse grains present; pebbly in last 5 feet.
48-50	Pebble-loam; very lignitic; grey; scoria pebbles.

	HB-155 T. 144 N., R. 86 W., Sec. 11, SESESESW El. 1796
0-10	Sand, fine-grained; brown; somewhat silty, much very fine sand; medium sand present, occasional coarse grains.
10-18.5	Sand, fine-grained; brown; as above, but appears less silty.
18.5-22	Sand, fine-grained, silty; very dark brown; moderately well-sorted; much medium and coarse sand, with very coarse grains (mostly scoria).
22-25	Sand, medium to coarse; greyish brown; much very coarse sand (quartz and scoria), moderately well-sorted; wet.
25-32	Sand, coarse-grained; greyish brown; with very small pebbles; layer of large pebbles at 27 feet; wet.

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Depth (ft.)	HB-155 (cont.)
32-34.5	Pebble-loam; dark grey; lignite pebbles but also pebbles not of local origin; olive blue-grey clay layers included.
34.5-42	Sand, medium-grained, silty; olive grey-brown; wet; much coarse sand.
42-50	Silt, coarse-grained; dark olive grey; very uniform; tough.

HB-156
T. 144 N., R. 86 W., Sec. 11, SWNWNWSE
El. 1774

0-3	Sand, very fine-grained, silty; grey-brown to brown; with coarse sand.
3-5.5	Sand, very fine to fine, silty; grey-brown; with coarser grains.
5.5-11	Sand, fine to medium, silty; brown to orangish brown; moderately well-sorted; much coarse sand, with very coarse sand; wet.
11-15	Sand, fine to medium, silty; chocolate brown; quite wet; cobble at 12 feet.
15-41	Pebble-loam; lignitic; dark grey; mostly small pebbles; water at 26 feet from thin, very fine silty sand parting.
41-47	Sand, medium-grained; wet; silt to very coarse sand and large pebbles included.
47-50	Silt, sandy; bluish grey; cohesive.

HB-157
T. 144 N., R. 86 W., Sec. 11, NWNWNWNE
El. 1753 (approx.)

0-1.5	Sand, very fine, silty; dark brown; with coarser grains.
1.5-3	Sand, fine to medium; brown; with coarser sand and small pebbles.
3-5.5	Sand, fine to medium, pebbly; brown; large pebbles and small cobbles present.

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Depth (ft.)	HB-157 (cont.)
5.5-7	Sand, fine to medium; dark grey-brown; somewhat silty, with coarse sand.
7-9.5	Sand, fine-grained; light grey-brown; somewhat cleaner than above.
9.5-11	Sand, fine-grained, silty; organic; dark grey-brown to black; with coarser grains.
11-12.5	Sand, medium-grained; light grey-brown; very well-sorted.
12.5-15.5	Sand, fine to medium, silty; lignitic and organic; dark grey-brown to black.
15.5-20	Sand, fine-grained; light grey-brown; much medium sand, with coarse and very coarse sand.
20-23.5	Sand, fine-grained; yellow-brown; loose; very well-sorted, with very fine and medium sand.
23.5-25	Sand, medium-grained; yellow-brown; well-sorted; with coarse sand.
25-29	Sand, medium-grained, silty; organic; black; lignite clasts, from large pebble to cobble size; wetter towards bottom.
29-38	Pebble-loam, clayey; lignitic; dark bluish grey; carbonate and greenstone pebbles present, but lignite predominates.
38-49	Sand, fine-grained; grey; very well-sorted, much very fine sand; lignite grains present but mostly quartz; small lignite chips; small lignite cobble near bottom.
49-50	Silt, clayey, and silt; dark olive grey; lignite and chert pebbles in clayey silt at top.
50-54.5	Sand, fine to medium; grey; well-sorted; occasional very coarse quartz grains; small lignite chips and rare lignite cobbles.
54.5-58	Sand, medium-grained; grey; not quite as well-sorted as above; small flat pebbles common; sand more coarse and wet towards bottom with larger pebbles.
58-60	Silt, clayey, to coarse silt; dark olive grey; tough.

Depth (ft.)	HB-158 T. 144 N., R. 86 W., Sec. 10, SESESWSE El. 1785
0-1.5	Sand, fine-grained; brown; coarse sand common.
1.5-11	Sand, coarse-grained; brown; dark grey-brown and organic at the top; much fine and medium sand; loose; very coarse sand common; sand more yellow-brown from 5 feet; small pebbles towards bottom.
11-16	Clay, silty; iron-stained, olive grey-brown.
16-20	Silt to clayey silt; iron-stained, olive grey-brown.
20-25	Pebbly clay-loam; grey-brown; mottled blue-grey; only small local pebbles; lignite, scoria, and iron concretions.
25-30	Pebbly clay-loam; dark grey; only large pebbles are scoria; silty clay-loam in places.
30-34	Sand, very fine to fine, silty; yellow-brown; coarse and very coarse sand grains.
34-40.5	Sand, very fine, silty; yellow-brown; loose; well-sorted; occasional coarse and very coarse sand grains; thin light brownish grey clay at bottom.
40.5-65	Sand, fine to medium; lignitic; brown; somewhat silty, occasional coarse sand; dark yellowish brown from 46 feet, dark greyish brown and wet in last 5 feet or more; quite uniform; possible lignite cobbles towards bottom.

	HB-159 T. 144 N., R. 86 W., Sec. 16, SESESENE El. 1785
0-4	Sand, fine to medium; greyish brown; somewhat silty, with coarse sand.
4-7.5	Sand, medium-grained; greyish brown; coarse sand common, with very coarse sand and small pebbles.
7.5-13	Sand, coarse-grained; brown and dark brown (vari-colored); all sand sizes present, very coarse sand and small pebbles common.

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Depth (ft.)	HB-159 (cont.)
13-20	Sand, very coarse, silty; organic; black and very dark brown; all sand and pebble sizes present; lignite, iron concretion, and flint cobbles.
20-30	Sand, medium to coarse; brown; very well-sorted, no silt; thin, iron-stained, light brownish grey silt layer at about 27.5 feet.
30-36	Sand, fine to medium; light brown and grey-brown; with coarse sand.
36-42	Sand, fine-grained; light olive brown.
42-50	Sand, fine-grained; dark grey-brown and brown; somewhat silty; medium sand common, with coarse sand, rare pebbles and a lignite cobble.

HB-160
T. 144 N., R. 86 W., Sec. 19, SENENW
El. 1742 (approx.)
Drilled in 3-foot ditch.

0-14.5	Silt, coarse-grained, to very fine sandy silt; light grey-brown to grey-brown; moist and cohesive from 7 feet; fine sand present.
14.5-20.5	Sand, fine to medium; brown; well-sorted.
20.5-22.5	Sand, medium-grained; dark brown; coarse sand common; wet.
22.5-28.5	Clay; blue-grey, mottled olive brown; sandy and silty in first 2 to 3 feet; small wood fragments present.
28.5-38	Sand, coarse-grained; dark grey-brown; all sand grades present; many small lignite chips and small pebbles; very wet.
38-40	Gravel, cobbly.

HB-161
T. 144 N., R. 86 W., Sec. 8, SESWSWSW
El. 1738

0-5	Silt; grey-brown; a little very fine and fine sand.

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Depth (ft.)	HB-161 (cont.)
5-9.5	Sand, very fine, silty; brown; well-sorted; loose.
9.5-15	Loam, silty; grey-brown; cohesive; mostly only very fine sand.
15-18.5	Pebbly clay-loam or gravelly-clay; angular pebbles.
18.5-25	Silt, clayey; olive yellow-grey; iron concretion.
25-32	Silt, sandy; olive grey-brown; cohesive; water from about 30 feet.
32-35	Silt, sandy; blue-grey; lignitic laminae; coarse sand present (?).
35-40	Clay and lignite; large, angular, pebble-size fragments of lignite.
40-45	Silt, coarse-grained to very fine sandy silt; grey; lignitic laminae; possible detrital lignite grains.

HB-162
T. 144 N., R. 86 W., Sec. 9, SWSESWSW
El. 1728
Drilled in 5-foot ditch.

0-4	Sand, fine-grained, silty; dark brown; with medium sand.
4-9	Sand, fine to medium; brown; very well-sorted; loose; thin, olive grey silty clay at bottom.
9-13	Sand, medium-grained; brown; well-sorted; with coarse sand.
13-15	Sand, coarse-grained, pebbly; dark brown; large pebbles; thin, iron-stained grey silt layer at bottom.
15-18	Sand, medium to coarse; orangish brown; pebbles, very coarse sand common.
18-18.5	Clay; bluish grey.
18.5-25	Sand, medium to coarse; brownish grey; very coarse sand, small pebbles, and small lignite chips common; wet; dark grey and very wet from about 20 feet.

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Depth (ft.)	HB-162 (cont.)
25-29.5	Gravel; cobbly from 28 to 29.5 feet; little or no samples.
29.5-35	Sand, medium to coarse, pebbly; brownish grey; most pebbles and lignite chips are small, but several large pebbles present; very wet.

HB-163
T. 145 N., R. 86 W., Sec. 28, NENENENE
El. 2012
Drilled in 3-foot ditch.

0-1	Loam; dark grey-brown.
1-4	Pebble-loam; light grey-brown.
4-14.5	Pebble-loam; lignitic; iron-stained, olive brown; numerous small pebbles.
14.5-25	Silt, sandy; olive brown to brown; loose at first, becoming more wet and cohesive with depth; laminated in places; rare coarser grains.
25-33.5	Pebble-loam; brown.
33.5-34	Lignite; wet.
34-34.5	Clay; lignitic; dark bluish grey.
34.5-43.5	Silt, sandy; bluish grey to grey; a little tougher and tighter around 40 feet, more a coarse silt.
43.5+	Siltstone; too hard to drill.

HB-164
T. 145 N., R. 86 W., Sec. 33, NENENE
El. 1952 (approx.)
Boulders at surface.

0-11.5	Pebble-loam; lignitic; iron-stained, olive brown; weathered to about 4.5 feet.

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Depth (ft.)	HB-164 (cont.)
11.5-14	Clay; lignitic; dark grey; hard.
14-20	Clay to clayey silt; lignitic; brownish grey; thin lignite seams.
20-25	Silt and very fine sandy silt; iron-stained, olive grey-brown; laminated; with clayey silt; pyritic iron concretions at the top.
25-30	Silt to very fine sandy silt; iron-stained, blue-grey and olive yellow-brown; thinly laminated and lignitic; thin sandstone at about 29.5 feet.
30-32	Sand, very fine, silty; bluish grey; laminated.
32-35	Silt, clayey, to silt; bluish grey; hard; with silty clay.
35-42	Silt, sandy; blue-grey; thinly laminated and lignitic.
42-43	Silt; blue-grey.
43-48	Silt, clayey, to silty clay; hard, with limy zones.
48-49.5	Clay, silty; lignitic; brown; thin lignite seams and large pyrite nodules.
49.5-54	Clay, silty; light blue-grey; hard; lignitic in spots.
54-59	Lignite with parting(s); water.
59-65	Silt and clayey silt; grey; hard.

HB-165
T. 144 N., R. 87 W., Sec. 13, NESENW
El. 1751

0-4	Sand, very fine, very silty; greyish brown; with coarser sand.
4-5.5	Sand, medium-grained, very silty; reddish grey-brown; with coarser sand.
5.5-7	Sand, clayey; iron-stained, dark grey.

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Depth (ft.)	HB-165 (cont.)
7-9	Sand, medium-grained, silty, pebbly; reddish brown; moderately-sorted; wet.
9-18.5	Sand and gravel, cobbly; orangish brown; much coarse material, but generally poor quality gravel; moderately poorly-sorted; wet.
18.5-30	Silt, clayey, to silty clay; iron-stained, mottled grey, olive grey to grey; tough and cohesive.

HB-166
T. 144 N., R. 87 W., Sec. 2, SWSESWSE
El. 1845

0-1	Silt, sandy; brown.
1-5.5	Pebble-loam; light grey; occasional cobbles.
5.5-11.5	Pebble-loam; lignitic; iron-stained, olive brown.
11.5-18	Pebble-loam; dark olive grey brown; mostly small pebbles with occasional large pebbles present, a number of which are not of local origin.
18-45	Pebble-loam; olive brown; as above; rare cobbles, little lignite present; more a pebbly clay-loam.
45-50	Pebble-loam; dark olive grey-brown; as above with a few lignite cobbles.
50-55	Pebble-loam; dark brownish grey; as above.
55-70	Pebble-loam; dark grey; a little more lignitic; occasional lignite cobbles and large pebbles not of local origin.

Depth (ft.)	HB-167 T. 144 N., R. 86 W., Sec. 9, SWSWSWSE El. 1764 Drilled in 9-foot ditch.
0-8.5	Sand, medium to coarse, silty; varicolored, dark to light brown; much very coarse sand, with small pebbles; lignitic with lignite pebbles in last 2 feet.
8.5-12.5	Sand, very coarse; orange; well-sorted, with many small pebbles.
12.5-19	Sand, very coarse, pebbly; dark orangish brown; not as well-sorted as above with several large pebbles and small cobbles; wet, silty, and very dark, slightly orangish brown from 15 feet.
19-24	Pebble-loam; lignitic; dark grey; with pebbles not of local origin; saturated with water.
24-29	Silt, clayey; olive blue-grey; tough; iron concretion at 28.5 feet.
29-33.5	Silt, clayey, to silt; blue-grey; limy zones, hard at 31 feet.
33.5+	Too hard to drill; limy material.

APPENDIX B

Test Hole Data From Outside Sources

Lithologic descriptions have been interpreted and generalized for presentation in the cross sections (pls. 2, 3, 4, and 5). See the respective references for the original and more detailed descriptions.

North Dakota State Water Commission (NDSWC) test hole descriptions (Croft, 1970):

Depth (ft.)	NDSWC 1667 T. 144 N., R. 88 W., Sec. 36, NWNWNW El. 1775
0-5	Sandy silt and clay; poorly consolidated.
5-42	Sand and silty sand; poorly consolidated.
42-52	Sandy silt and clay; poorly consolidated.
	NDSWC 2677 T. 144 N., R. 86 W., Sec. 18, NESESW El. 1741
0-9	Sandy silt and clay; poorly consolidated.
9-63	Sand and silty sand; poorly consolidated.
63-100	Sandy silt and clay; poorly consolidated.

Depth (ft.)	NDSWC 2678 T. 144 N., R. 86 W., Sec. 18, SESESW El. 1736
0-1	Sandy silt and clay; poorly consolidated.
1-10	Sand and silty sand; poorly consolidated.
10-19	Sand and gravel.
19-39	Sandy silt and clay; poorly consolidated.
39-59	Sand and gravel.
59-61	Sandy silt and clay; poorly consolidated.
61-67	Sand and silty sandy; poorly consolidated.
67-96	Sandy silt and clay; poorly consolidated.
	NDSWC 2679 T. 144 N., R. 86 W., Sec. 18, SENESW El. 1737
0-1	Sandy silt and clay; poorly consolidated.
1-39	Sand and silty sand; poorly consolidated.
39-42	Sandy silt and clay; poorly consolidated.
42-63	Sand and gravel.
63-80	Sandy silt and clay; poorly consolidated.
	NDSWC 3739 T. 144 N., R. 86 W., Sec. 19, NENWNE El. 1735
0-68	Sand and silty sand; poorly consolidated.
68-78	Sand and gravel.
78-85	Sandy silt and clay; poorly consolidated.
85-95	Sand and gravel.

Depth (ft.)	NDSWC 3740 T. 144 N., R. 86 W., Sec. 20, NWSWNW El. 1800
0-8	Sand and silty sand; poorly consolidated.
8-16	Sandy silt and clay; poorly consolidated.
16-73	Sand and silty sand; poorly consolidated.
73-100	Silt and clay; consolidated.

	NDSWC 3741 T. 144 N., R. 88 W., Sec. 36, NWNWSW El. 1770
0-2	Sandy silt and clay; poorly consolidated.
2-22	Sand and silty sand; poorly consolidated.
22-58	Sandy silt and clay; poorly consolidated.
58-95	Sand and silty sand; poorly consolidated.

	NDSWC 3742 T. 144 N., R. 88 W., Sec. 36, NWSWSW El. 1790
0-36	Sand and silty sand; poorly consolidated.
36-44	Sandy silt and clay; poorly consolidated.
44-70	Sand and silty sand; poorly consolidated.
70-74	Sandy silt and clay; poorly consolidated.
74-115	Sand and silty sand; poorly consolidated.

Depth (ft.)	NDSWC 3743 T. 144 N., R. 88 W., Sec. 25, SWSWSW El. 1775
0-42	Sand and silty sand; poorly consolidated.
42-48	Sandy silt and clay; poorly consolidated.
48-76	Sand and gravel.
76-94	Sand and silty sand; poorly consolidated.
94-100	Sand and gravel.
	NDSWC 3748 T. 144 N., R. 86 W., Sec. 18, SENENW El. 1739
0-8	Sandy silt and clay; poorly consolidated.
8-28	Sand and silty sand; poorly consolidated.
28-33	Sandy silt and clay; poorly consolidated.
33-60	Sand and silty sand; poorly consolidated.
60-99	Sandy silt and clay; poorly consolidated.
	NDSWC 3749 T. 144 N., R. 88 W., Sec. 1, NWNWNW El. 1865
0-2	Sandy silt and clay; poorly consolidated.
2-33	Pebble-loam.
33-41	Sandy silt and clay; poorly consolidated.
41-61	Sand and gravel.
61-100	Sandy silt and clay; poorly consolidated.

Depth (ft.)	NDSWC 3755 T. 144 N., R. 88 W., Sec. 2, NENENW El. 1880
0-61	Sand and silty sand; poorly consolidated.
61-115	Sandy silt and clay; poorly consolidated.

	Farm well (O. Mattheis) Log from Ray Mohl (Croft, 1970) T. 144 N., R. 87 W., Sec. 4, SWNWNW El. 1950
0-5	Pebble-loam.
5-65	Silt and clay; consolidated.
65-69	Lignite.
69-94	Silt and clay; consolidated.
94-99	Lignite.
99-111	Silt and clay; consolidated.
111-112	Lignite.
112-131	Sandy silt to sand; consolidated.
131-145	Silt and clay; consolidated.
145-151	Lignite.
151-155	Silt and clay; consolidated.
155-156	Lignite.
156-160	Silt and clay; consolidated.

Depth (ft.)	City Well A Log from Schnell, Inc. (Croft, 1970) T. 144 N., R. 88 W., Sec. 25, SWNE El. 1780
0-9	Sandy silt and clay; poorly consolidated.
9-22	Sand and silty sand; poorly consolidated.
22-25	Sand and gravel.
25-29	Sand and silty sand; poorly consolidated.
29-33	Sand and gravel.
33-97	Sand and silty sand; poorly consolidated.
97-99	Sandy silt and clay; poorly consolidated.
99-103	Sand and silty sand; poorly consolidated.

	Farm Well (C. Schnaidt) Log from Ray Mohl (on file with the North Dakota Geological Survey) T. 144 N., R. 88 W., Sec. 13, SWNWSW El. 1820
0-26	Sandy silt and clay; poorly consolidated.
26-59	Sand and silty sand; poorly consolidated.
59-60	Sand and gravel.
60-85	Sand and silty sand; poorly consolidated.
85-92	Sand and gravel.
92-95	Sand and silty sand; poorly consolidated.
95-100	Silt and clay; consolidated.

Depth (ft.)	City Well B Russill Drilling 2 (on file with the City of Beulah) T. 144 N., R. 88 W., Sec. 25, SWSWNE El. 1778
0-10	Sandy silt and clay; poorly consolidated.
10-15	Sand and silty sand; poorly consolidated.
15-45	Sand and gravel.
45-50	Sandy silt and clay; poorly consolidated.
50-80	Sand and gravel.
80-102	Sandy silt and clay; poorly consolidated.

	Carlson (1973, p. 68) Measured Section T. 144 N., R. 88 W., Sec. 36, SWSW El. 1985
	Lignite (Beulah-Zap Bed).
0-5.5	Silt and clay; consolidated.
5.5-8.5	Lignite.
8.5-43.5	Silt and clay; consolidated.
43.5-47	Lignite.
47-49	Silt and clay; consolidated.
49-51.5	Lignite.
51.5-59.5	Silt and clay; consolidated.
59.5-79.5	Covered interval.
79.5-85	Sandy silt to sand; consolidated.
85-89	Silt and clay; consolidated.
89-131.5	Sandy silt to sand; consolidated.

Depth (ft.)	Meyer Measured Section T. 144 N., R. 87 W., Sec. 12, NWNE; and T. 144 N., R. 87 W., Sec. 1, SWSE El. 1940
0-12.5	Silt and clay; consolidated.
12.5-15	Lignite.
15-17.5	Silt and clay; consolidated.
17.5-19.5	Lignite.
19.5-39.5	Sandy silt to sand; consolidated.
39.5-47.5	Silt and clay; consolidated.
47.5-49.5	Lignite.
49.5-60	Silt and clay; consolidated.
60-62	Lignite.
62-72	Silt and clay; consolidated.
72-97	Sandy silt to sand; consolidated.
97-100	Lignite.

B74 - 7478
Log from the Montana Bureau of Mines (on file with the North Dakota Geological Survey)
T. 145 N., R. 87 W., Sec. 28, SWSWSWSW
El. 1988

0-10	Pebble-loam.
10-12	Sand and gravel.
12-14	Silt and clay; consolidated.
14-26	Lignite.
26-45	Silt and clay; consolidated.

(continued on next page)

Depth (ft.)	B74 - 7478 (cont.)
45-81	Sandy silt to sand; consolidated.
81-83	Lignite.
83-122	Sandy silt to sand; consolidated.
122-127	Lignite.
127-147	Silt and clay; consolidated.
147-149	Lignite.
149-161	Sandy silt to sand; consolidated.
161-169	Lignite.
169-174	Silt and clay; consolidated.
174-181	Lignite.
181-190	Silt and clay; consolidated.
190-195	Lignite.

REAP 8 (Groenewold and others, 1978; Appendix A-II)
T. 145 N., R. 86 W., Sec. 16, SESESESE
El. 2025

0-20	Sandy silt to sand; consolidated.
20-34	Silt and clay; consolidated.
34-46	Lignite.
46-55	Silt and clay; consolidated.
55-57	Lignite.
57-76	Silt and clay; consolidated.
76-139	Sandy silt to sand; consolidated.

(continued on next page)

Depth (ft.)	REAP 8 (cont.)
139-141	Silt and clay; consolidated.
141-150	Sandy silt to sand, consolidated.
150-168	Silt and clay; consolidated.
168-171	Lignite.

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PLATE I SURFICIAL AND NEAR-SURFACE EARTH MATERIALS MAP OF THE BEULAH-HAZEN DETAILED STUDY AREA

EXPLANATION

A	Silty clay and clay, highly organic.
B	Sandy silt and clay, organic near surface, with lenses of silty sand and clay.
C	Silt, slightly sandy and clayey, unbedded.
D	Sand, very fine to medium-grained, very well sorted, loose.
E	Sand and silty sand, fine to coarse-grained, will sorted, with lenses of gravel and clay.
F	Silty, sandy, pebbly, bouldery clay (pebble-loam), with gravel, sand, silt and clay lenses.
G	Sand and gravel, silty, poorly sorted.
H	Silt, coarse-grained, to very fine-grained sand; very well sorted, interbedded with silty clay and silty sand.
I	Scoria, with some clay, sand and lignite. Designated I_1 where overlain by thin (less than 1 metre) sandy silt and clay.
Jf	Silt, silty clay, and clay; partially consolidated, with lignite and carbonaceous beds, and minor limestone.
Jc	Sand, silty sand, sandy silt, and sandstone; very fine to medium-grained with lignite and carbonaceous beds.

Jf and Jc = J in the subsurface.

Letters and numbers are combined to show relative depths and thicknesses of a maximum of 3 units to a depth of 9 metres. For example, A_{3BC} represents a maximum of 3 metres of unit A overlying unit B, unit C at a maximum depth of 9 metres. A_{9B} represents a maximum of 9 metres of unit A overlying unit B. See text for further discussion.

less than

——— ± 30 metres reliability

- - - - ± 60 metres reliability

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PLATE 2 CROSS SECTION N-N', BEULAH-HAZEN DETAILED STUDY AREA

EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
HB	1976-77	NDGS	Auger Rig
NDSWC	1969	NDSWC	Rotary Rig
Form Well	1956	Mohl Drilling	?

EXPLANATION

Coleharbor & Oahe Formations (Undifferentiated)

- FA — Sandy silt and clay, with some clay and silty clay, organic at surface, poorly consolidated
- CA — Sand and silty sand, very fine to coarse grained, well sorted, poorly consolidated
- G — Sand and gravel, occasionally silty, poorly sorted
- PL — Pebble loam

Sentinel Butte Formation

- FB — Silt and clay, consolidated.
- CB — Sandy silt to sand, very fine to medium grained consolidated
- Lig — Lignite
- SC — Scoria

Contact dashed where inferred.

Surficial geology in accordance with Plate 1.

Some stratigraphic interpretation from test holes not included in cross section

Refer to figure 3 for cross section location.

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PLATE 3 CROSS SECTION M-M', BEULAH-HAZEN DETAILED STUDY AREA

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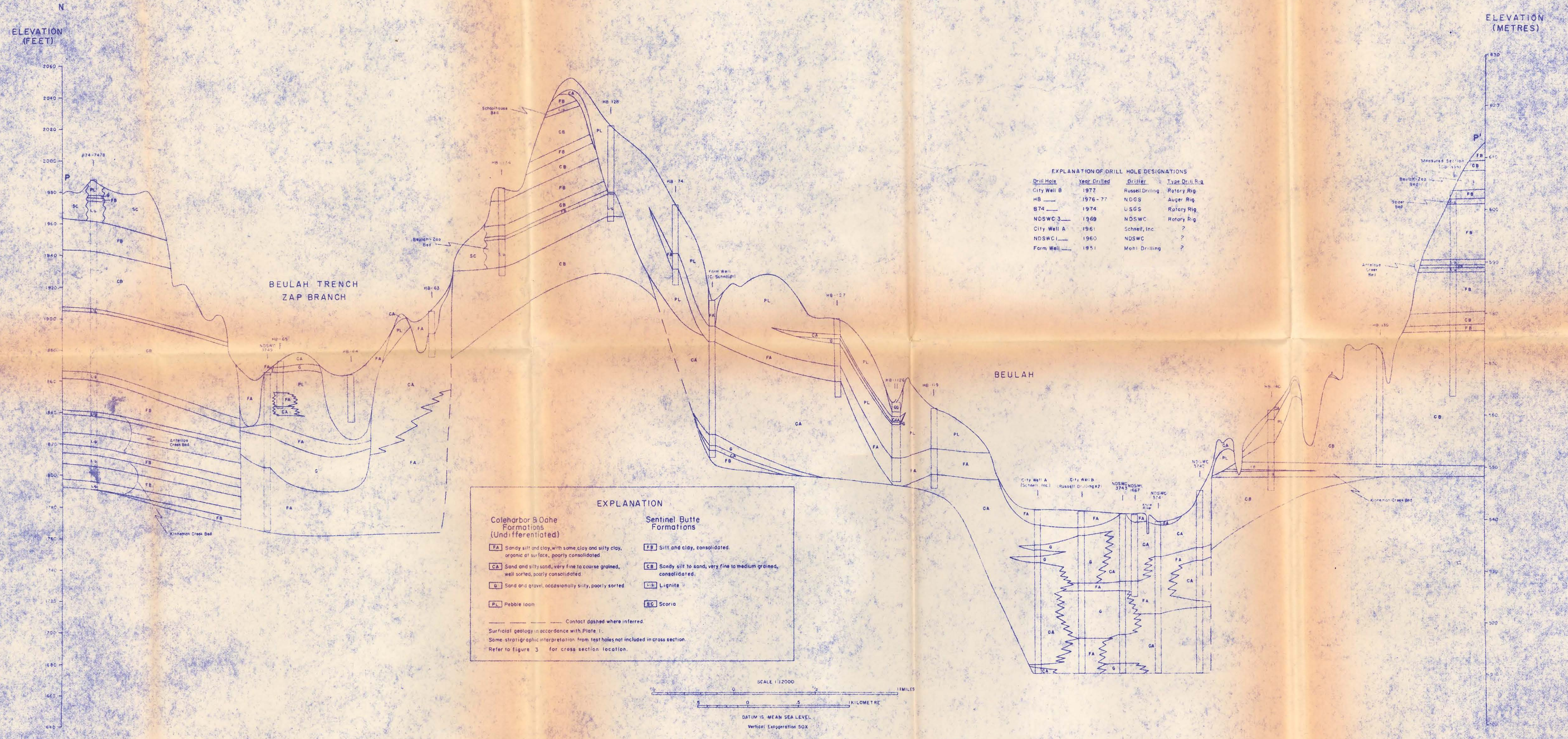
PLATE 4 CROSS SECTION P-P', BEULAH - HAZEN DETAILED STUDY AREA



EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
City Well B	1977	Russell Drilling	Rotary Rig
HB ___	1976-77	NDGS	Auger Rig
B74 ___	1974	USGS	Rotary Rig
NDSWC 3___	1969	NDSWC	Rotary Rig
City Well A	1961	Schnell, Inc	?
NDSWC I___	1960	NDSWC	?
Form Well ___	1951	Mohl Drilling	?

EXPLANATION

Coleharbor & Oahe Formations (Undifferentiated)

- FA Sandy silt and clay, with some clay and silty clay, organic at surface, poorly consolidated.
- CA Sand and silty sand, very fine to course grained, well sorted, poorly consolidated.
- G Sand and gravel, occasionally silty, poorly sorted
- PL Pebble loam

Sentinel Butte Formations

- FB Silt and clay, consolidated.
- CB Sandy silt to sand, very fine to medium grained, consolidated.
- LIG Lignite
- SC Scoria

— — — — Contact dashed where inferred.

Surficial geology in accordance with Plate 1.

Some stratigraphic interpretation from test holes not included in cross section.

Refer to figure 3 for cross section location.

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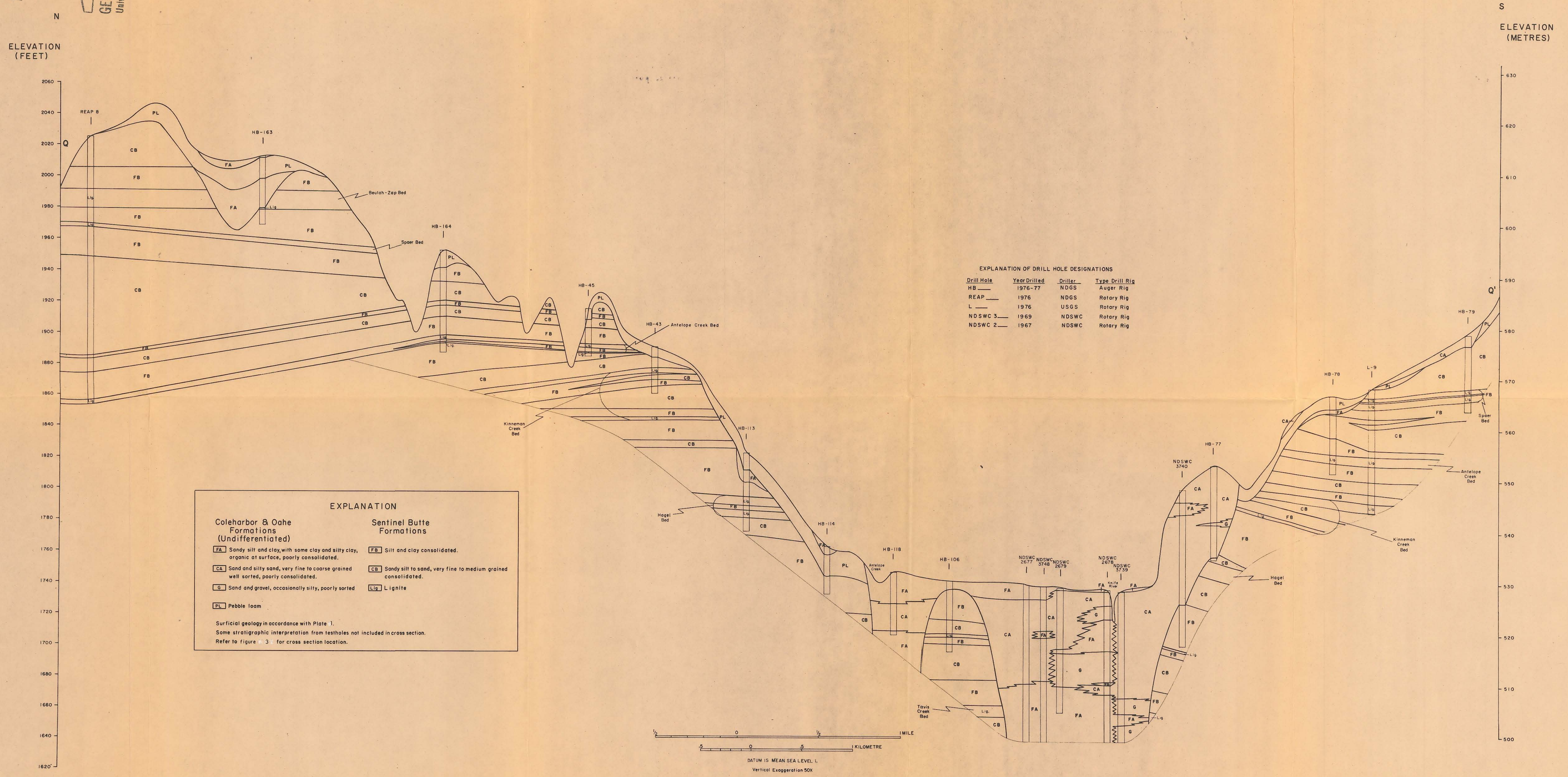
PLATE 5 CROSS SECTION Q-Q', BEULAH-HAZEN DETAILED STUDY AREA



EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
HB ____	1976-77	NDGS	Auger Rig
REAP ____	1976	NDGS	Rotary Rig
L ____	1976	USGS	Rotary Rig
NDSWC 3____	1969	NDSWC	Rotary Rig
NDSWC 2____	1967	NDSWC	Rotary Rig

EXPLANATION

Coleharbor & Oahe Formations (Undifferentiated)

- FA Sandy silt and clay, with some clay and silty clay; organic at surface, poorly consolidated.
- CA Sand and silty sand, very fine to coarse grained well sorted, poorly consolidated.
- G Sand and gravel, occasionally silty, poorly sorted
- PL Pebble loam

Sentinel Butte Formations

- FB Silt and clay consolidated.
- CB Sandy silt to sand, very fine to medium grained consolidated.
- Lig Lignite

Surficial geology in accordance with Plate 1.
Some stratigraphic interpretation from testholes not included in cross section.
Refer to figure 3 for cross section location.

PLATE 6

PRESENT AND PAST VALLEYS OF THE BEULAH - HAZEN AREA

PLATE 6
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