LITHOSTRATIGRAPHIC MAP OF THE GREATER RED RIVER VALLEY, MINNESOTA AND NORTH DAKOTA

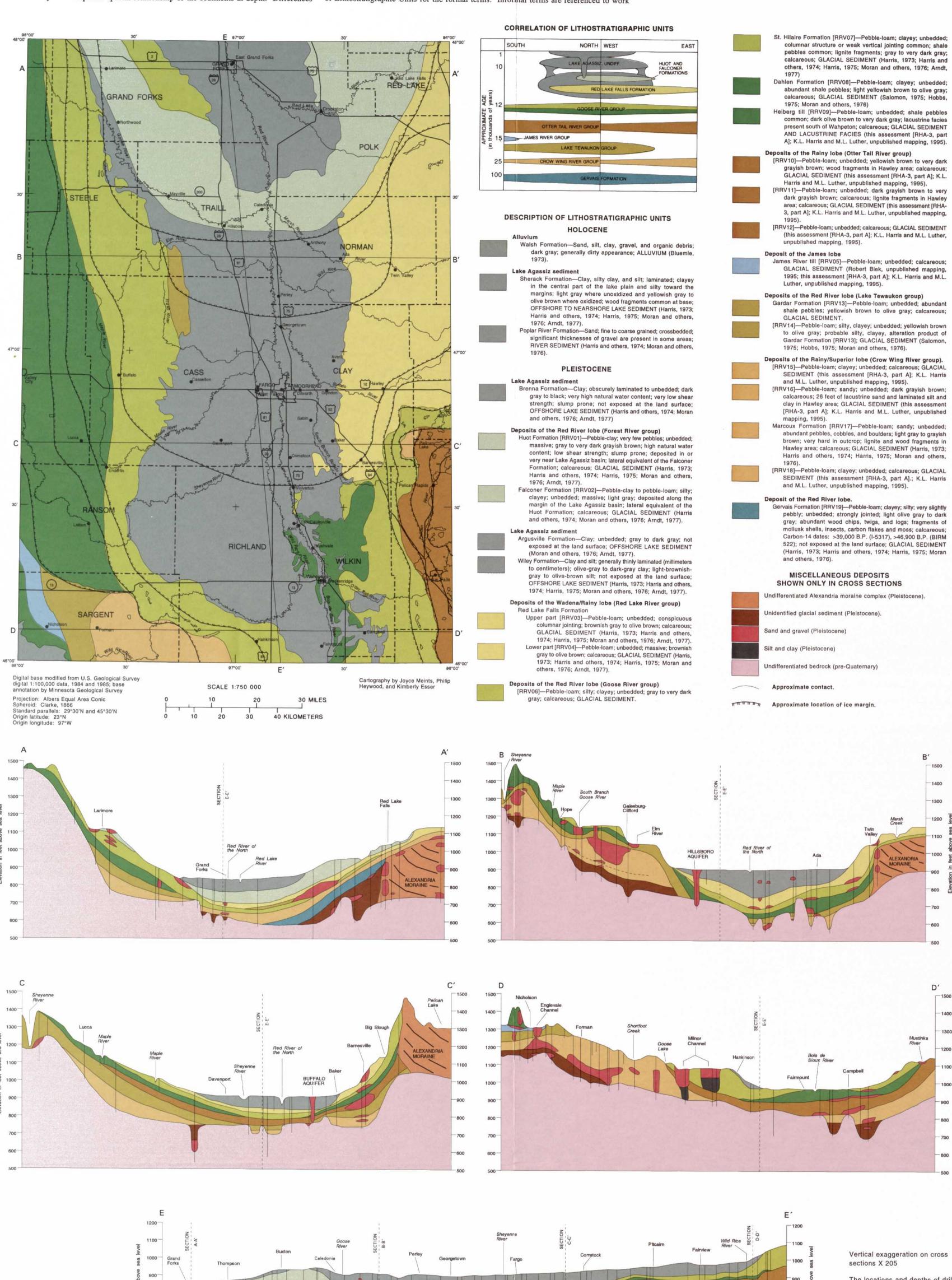
units interpreted to be present in the greater Red River Valley of Minnesota and North thin, patchy cover of fluvial or lacustrine sediment. Dakota. Map units were defined on the basis of lithology (texture and mineralogy) and space within the map area. Lake Agassiz lithostratigraphic units are not differentiated Dakota Geological Survey, and the lithostratigraphic map itself. Not all the data used to on this map; they are all shown by a single gray-colored map unit. Sediments in the construct the Interstate Highway 29 cross section (E-E') fell on the line of the section as some cases exposing older map units.

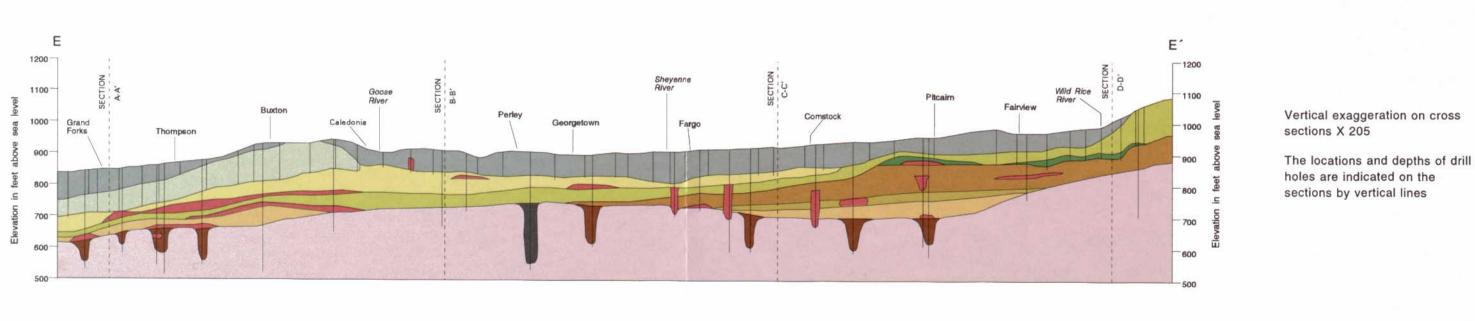
The scale of both the lithostratigraphic map and sections is 1:750,000. The vertical scale of the four cross sections has been greatly exaggerated (x 205) to show and informal terminology (formation, group, till). References are given in the Description

The lithostratigraphic map shows the generalized surface exposure of Quaternary exist between the lithostratigraphic map and cross sections in areas of eroded till with a in progress. Square brackets enclose stratigraphic units for the southern Red River

not be in perfect agreement. The stratigraphic nomenclature used on this plate is a mixture of formal (Formation) more clearly the interpreted spacial relationship of the sediments at depth. Differences of Lithostratigraphic Units for the formal terms. Informal terms are referenced to work

Valley map area that correlate with formal or informal units. Lobe names are informal The cross sections were constructed using topographic maps, drill logs from Minnesota terms. Geomorphic line symbols are not shown on this map to avoid clutter. The user is stratigraphic position. The time-distance diagram correlates the map units in time and Geological Survey water-well files, drilling and geophysical logs published by the North referred to Plate 1 of this atlas for line symbols in the southern Red River Valley, and to Harris (1987c) and Harris and Luther (1991) for line symbols for contiguous areas of North Dakota. General references on the Quaternary geologic history of the greater Red Lake Agassiz shoreline complex have been thinned or removed by shoreline erosion, in shown on the lithostratigraphic map. Consequently, cross section E-E' and the map may River Valley include Clayton and Moran, 1982; Harris, 1987a; Moran and others, 1976;





Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical Information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown

is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific Partial funding for this project was approved by the Minnesota Legislature M.L. 91, Ch. 254, Art. 1, Sec. 14, Subd. 4ffl. and M.L. 93, Ch. 172, Sec. 14, Subd. 11[q]) as recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources The University of Minnesota is an equal opportunity educator

Anderson, C.A., 1976, Pleistocene geology of the Comstock-Sebeka area, west-central Minnesota: Grand Forks, University of North Dakota, M.S. thesis, 111 p. Arndt, B.M., 1977, Stratigraphy of offshore sediment, Lake Agassiz, North Dakota: North Dakota Geological Survey Report of Investigation 60, 58 p. Bluemle, J.P., 1973, Geology and groundwater resources

REFERENCES CITED

of Nelson and Walsh Counties, North Dakota: Part I. Geology: North Dakota Geological Survey Bulletin 57, ----1991, The face of North Dakota (rev. ed.): North Dakota Geological Survey Educational Series 21, 177 p.; map, scale 1:1,000,000. Camara, M., 1977, Glacial stratigraphy of southeastern North Dakota: Grand Forks, University of North Dakota, M.S. thesis, 66 p. Clayton, Lee, and Moran, S. R., 1982, Chronology of Late Wisconsinan glaciation in Middle North America:

Quaternary Science Reviews, v. 1, p. 55-82.

Harris, K.L. 1973, Pleistocene stratigraphy of the Red Lake Falls area, Minnesota: Grand Forks, University of North Dakota, M.S. thesis, 117 p. -----1975, Pleistocene geology of the Grand Forks-Bemidji area, northwestern Minnesota: Grand Forks, University of North Dakota, Ph.D. dissertation, 142 p. —1987a, The Quaternary geology of the Grand Forks-

Red Lake Falls area, North Dakota and Minnesota: North Dakota Geological Survey Open File Report OF-87-1, 32 p.; two maps, scale 1:270,000. -1987b, Documentation for the data formats and programs used for computer-assisted glacial stratigraphy at the North Dakota Geological Survey: North Dakota Geological Survey Open File Report OF-87-2, 20 p. ——1987c, Surface geology of the Sheyenne River map area: North Dakota Geological Survey Atlas Series AS-15-A1, scale 1:250,000. Harris, K.L., and Luther, M.L., 1991, Surface geology of

Survey Atlas Series AS-14-A1, scale 1:250,000.

the Goose River map area: North Dakota Geological

Harris, K.L., Moran, S.R., and Clayton, Lee, 1974, Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota: North Dakota Geological Survey Miscellaneous Series 52, 47 p. Hobbs, H.C., 1975, Glacial stratigraphy of northeastern North Dakota: Grand Forks, University of North Dakota, Ph.D. dissertation, 42 p. Moran, S.R., Clayton, Lee, Scott, M.W., and Brophy,

J.A., 1973, Catalog of North Dakota radiocarbon dates: North Dakota Geological Survey Miscellaneous Series Moran, S.R., and others, 1976, Quaternary stratigraphy and history of North Dakota, southern Manitoba, and northwestern Minnesota, in Mahaney, W.C., ed., Quaternary stratigraphy of North America: Stroudsburg, Penn., Dowden, Hutchinson and Ross, p. 133-158. North Dakota Geological Survey, 1991, [N-File-a digital file of nearsurface stratigraphic data]: Bismarck, N.D.,

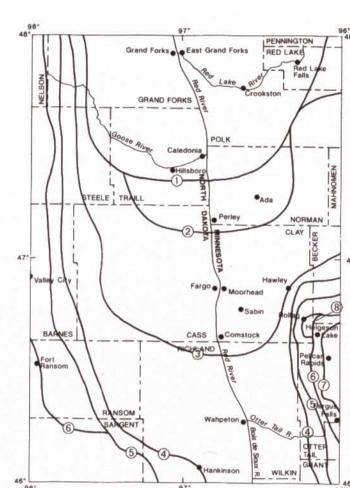
Perkins, R.L., 1977, The Late Cenozoic geology of westcentral Minnesota from Moorhead to Park Rapids: Grand Forks, University of North Dakota, M.S. thesis, 99 p. Sackreiter, D.K., 1975, Quaternary geology of the southern part of the Grand Forks and Bemidji Quadrangles: Grand Forks, University of North Dakota, Ph.D. dissertation,

Salomon, N.L., 1975, Pleistocene stratigraphy of Cavalier

and Pembina Counties, and adjacent areas, in Arndt, B.M., Geology of Cavalier and Pembina Counties, North Dakota: North Dakota Geological Survey Bulletin 62, Zohdy, A.A.R., and Bisdorf, R.J., 1979, Geoelectrical investigations with Schlumberger soundings of the Buffalo River aquifer, near Moorhead, Minnesota: U.S. Geological Survey Open-File Report 79-299, 243 p.

TABLE 1. Summary of information pertaining to the twenty lithostratigraphic units identified in the greater Red River Valley, Minnesota and North Dakota [See text for discussion of the computer-assisted techniques used to classify the data set. Abbreviations: CO, limestone and dolostone fragments; CY, clay; NS, normalized silt; NX, normalized crystalline, metamorphic, and carbonate rock fragments; SD, sand; SH, shale; SL, silt; XT, crystalline and metamorphic rock fragments]

Lobe, group, and formation (or other unit designation) Unit	Percentage of all samples	No. of samples	Texture in % SD-SL-CY	Lithology in % 1- to 2-mm sand XT-CO-SH	Normalized Texture SD-NS	l values in % Lithology NX-SH
Deposits of the Red River lobe Forest River group				/		
Huot Formation1	4	35	7-22-71	45-50-5	7-24	47-5
Falconer Formation2	1	10	12-39-49	38-38-24	12-44	50-24
Deposits of the Wadena/Rainy lobe Red Lake River group Upper Red Lake						00 24
Falls Formation3 Lower Red Lake	6	54	37-40-23	53-34-13	37-64	61-13
Falls Formation4	13	116	39-41-20	57-39-4	39-67	59-4
Deposits of the Red River lobe Goose River group						
RRV066	4	32	19-42-39	45-41-14	19-52	52-14
St. Hilaire Formation7	9	80	27-42-31	43-32-25	27-58	57-25
Dahlen Formation8	20	174	30-41-29	27-18-55	30-59	60-55
Heiberg till9	9	75	36-39-25	35-23-42	36-61	60-42
Deposits of the Rainy lobe Otter Tail River group					00 01	00 42
RRV1010	4	32	38-38-24	54-43-3	38-61	56-3
RRV1111	4	38	44-39-17	66-33-1	44-69	67-1
RRV12 12	3	26	46-35-19	50-31-19	46-65	62-19
Deposit of the Souris lobe James River group			1		40 00	02-15
RRV055	1	11	47-35-18	44-23-33	47-66	66-33
Deposits of the Red River lobe Lake Tewaukon group						55 (55
Gardar Formation13	6	55	30-43-27	16-11-73	30-61	59-73
RRV1414	3	27	20-42-38	14-12-74	20-53	53-74
Deposits of the Rainy and Superior lobes Crow Wing River group						
RRV1515	3	23	32-35-33	04 00 0		221 5
RRV1616	1	11		61-36-3	32-52	63-3
Marcoux Formation17	3	26	56-34-10	86-13-1	56-78	87-1
RRV1818	2	17	57-29-14	74-25-1	57-68	75-1
	~	17	30-39-31	49-36-15	30-55	58-15
Deposit of the Red River lobe Gervais Formation19	3	27	27-45-28	49-46-5	27-61	52-5
Jnassigned Superior lobe till						
Sebeka till20	1 =	12	68-20-12	93-7-0	68-64	93-0



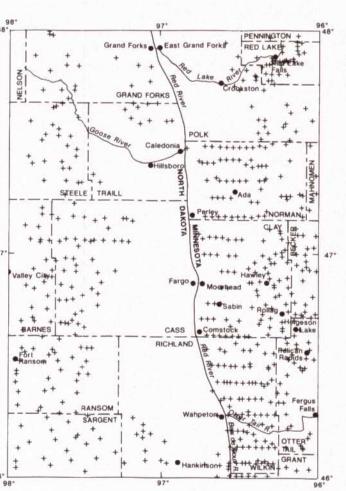
The margins probably mark stable but relatively short-lived recessional ice positions. Margins 1-6 are associated with the Red River and Wadena/Rainy lobes (ice advances from the north and northeast); margins 7 and 8 are associated with the Rainy and Superior lobes (ice advances from the northeast and east). In general, there is good correspondence of the ice margins with geomorphology and lithostratigraphy; however, in some places the relationship is less obvious. See Table 2 for a summary of information pertaining to individual ice margins.

TABLE 2. Ice margins, associated glacial events, and Quaternary units within the greater Red River valley, Minnesota and North Dakota. [Ice margins are shown in Figure 1. The geologic groups named in the table are part of an informal classification scheme.

Each geologic unit identified in the study area was assigned a study number preceded by the letters RRV for Red River Valley.

When available, the formal name of the unit is provided.

e rgin	Ice Advance	Geologic Group	Geologic Unit			
	Caledonia advance of the Red River lobe	Forest River	Huot Formation (RRV01); Falconer Formation (RRV02)			
	Perley advance of the Wadena/Rainy lobe	Red Lake River	Upper Red Lake Falls Formation (RRV03)			
	Comstock advance of the Wadena/Rainy lobe	Red Lake River	Lower Red Lake Falls Formation (RRV04)			
	Hankinson ice-marginal position of the Red River lobe	Goose River	St. Hilaire Formation (RRV06 & RRV07)			
	Rollag ice-marginal position of the River lobe	Goose River	Dahlen Formation (RRV08); Heiberg till (RRV09)			
	Fort Ransom ice-marginal position of the Red River lobe	Lake Tewaukon	Garder Formation (RRV13,RRV14)			
	Pelican Rapids ice-marginal position of the Rainy lobe	Otter Tail River	RRV10, RRV11, & RRV12			
	Helgeson Lake ice-marginal position of the Rainy and Superior lobes	Crow Wing River	RRV15, RRV16, RRV17 (Marcoux Formation), and RRV18			



COMPUTER-ASSISTED STRATIGRAPHIC MAPPING

units over long distances. The Technique. Sediment samples were textural analyses. differentiated on the basis of texture and lithology. The Data Base. QBASE, the data base used in These characteristics (correlation parameters) are mapping the Quaternary stratigraphy of the greater internally consistent, vary from unit to unit, and Red River Valley (Figure 2), combines relevant can be identified in the field. Six correlation information from the North Dakota Geological Survey's parameters were used to correlate glacial sediment stratigraphic data file, the N-File (NDGS, 1991), in the region. Textural analysis provided percentage with information generated for this assessment of composition of sand (SD), silt (SL), and clay (CY). the southern Red River Valley. Data include sample-Lithologic analysis of the coarse-sand fraction (1-2 site location, sample elevation, geologist's name, millimeters) provided the percentage composition project name, sample texture, and coarse-sand of crystalline and metamorphic (XT), limestone and lithology. Both surface and subsurface Quaternary dolostone (CO), and shale (SH) fragments. The deposits are represented; samples were collected six parameters were reduced to four to speed computer from surface exposures, hand-auger borings, soilprocessing and facilitate graphic presentation. Silt probe and power-auger holes, and continuous-core and clay values were combined to obtain normalized drilling (Rotasonic) by Quaternary geologists who silt (NS). Values for crystalline, metamorphic and have worked in the region in the last twenty years carbonate rocks were combined to obtain normalized (Harris, 1973; Harris and others, 1974; Harris, 1975; crystalline, metamorphic, and carbonate rock fragments Hobbs, 1975; Sackreiter, 1975; Salomon, 1975; (NX). The resulting four parameters (SD, NS, NX, Anderson, 1976; Moran and others, 1976; Arndt, SH) were used to characterize the tills present in 1977; Camara, 1977; Perkins, 1977; Harris, 1987a; the data set:

 $NX = \{[NX/(NX + CO)]*100\}$

Lobe, group, and formation Unit (or other unit designation)	Percentage of all samples	No. of samples	Texture in % SD-SL-CY	Lithology in % 1- to 2-mm sand XT-CO-SH	Normalized Texture SD-NS	l values in % Lithology NX-SH
Deposits of the Red River lobe Forest River group				7		
Huot Formation1	4	35	7-22-71	45-50-5	7-24	47-5
Falconer Formation2	1	10	12-39-49	38-38-24	12-44	50-24
Deposits of the Wadena/Rainy lobe Red Lake River group Upper Red Lake						33,21
Falls Formation3 Lower Red Lake	6	54	37-40-23	53-34-13	37-64	61-13
Falls Formation4	13	116	39-41-20	57-39-4	39-67	59-4
Deposits of the Red River lobe Goose River group						
RRV066	4	32	19-42-39	45-41-14	19-52	52-14
St. Hilaire Formation7	9	80	27-42-31	43-32-25	27-58	57-25
Dahlen Formation8	20	174	30-41-29	27-18-55	30-59	60-55
Heiberg till9	9	75	36-39-25	35-23-42	36-61	60-42
Deposits of the Rainy lobe Otter Tail River group					122	
RRV1010	4	32	38-38-24	54-43-3	38-61	56-3
RRV1111	4	38	44-39-17	66-33-1	44-69	67-1
RRV1212	3	26	46-35-19	50-31-19	46-65	62-19
Deposit of the Souris lobe James River group					10 00	02-10
RRV055	1	11	47-35-18	44-23-33	47-66	66-33
Deposits of the Red River lobe Lake Tewaukon group						
Gardar Formation13	6	55	30-43-27	16-11-73	30-61	59-73
RRV1414	3	27	20-42-38	14-12-74	20-53	53-74
Deposits of the Rainy and Superior lobes Crow Wing River group						7.5 (2.8)
RRV1515	3	23	32-35-33	61 06 0	00 50	
RRV16	1	11	56-34-10	61-36-3	32-52	63-3
Marcoux Formation17	3	26	57-29-14	86-13-1	56-78	87-1
RRV1818	2	17	30-39-31	74-25-1	57-68	75-1
	-		30-38-31	49-36-15	30-55	58-15
Deposit of the Red River lobe Gervais Formation 19	3	27	27-45-28	49-46-5	27-61	52-5
Unassigned Superior lobe till						
Sebeka till20	1 =	12	68-20-12	93-7-0	68-64	93-0

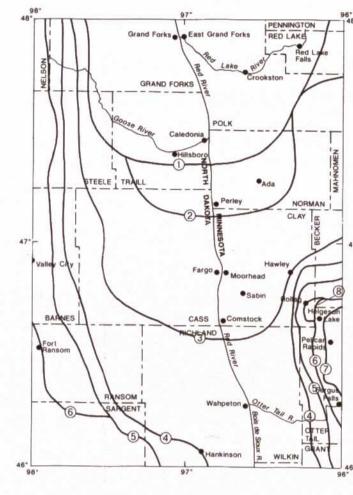


FIGURE 1. Approximate locations of ice margins in the greater Red River Valley of Minnesota and North Dakota.

Ice Advance	Geologic Group	Geologic Unit
Caledonia advance of the Red River lobe	Forest River	Huot Formation (RRV01); Falconer Formation (RRV02)
Perley advance of the Wadena/Rainy lobe	Red Lake River	Upper Red Lake Falls Formation (RRV03)
comstock advance of the Wadena/Rainy lobe	Red Lake River	Lower Red Lake Falls Formation (RRV04)
lankinson ice-marginal position of the led River lobe	Goose River	St. Hilaire Formation (RRV06 & RRV07)
tollag ice-marginal position of the led River lobe	Goose River	Dahlen Formation (RRV08); Heiberg till (RRV09)
ort Ransom ice-marginal position of the River lobe	Lake Tewaukon	Garder Formation (RRV13,RRV14)
elican Rapids ice-marginal position of the lainy lobe	Otter Tail River	RRV10, RRV11, & RRV12
lelgeson Lake ice-marginal position of the lainy and Superior lobes	Crow Wing River	RRV15, RRV16, RRV17 (Marcoux Formation), and RRV18

FIGURE 2. The general geographic distribution of stratigraphic data available in the QBASE data base for the greater Red River Valley of Minnesota and North Dakota. QBASE consists of information on about 700 samples that were collected in 1992-93 as part of the southern Red River Valley regional hydrogeologic assessment, as well as data on about 1400 samples from North Dakota that were compiled from the North Dakota Geological Survey's N-File data base. See the section on computerassisted mapping for further information. 0 10 20 MILES 0 10 20 30 KILOMETERS

A computer-assisted mapping method (Harris, A sequential data set was created that contained 1987b) was used to help characterize, interpret, and all sample data arranged by location (township, range, correlate tills in the greater Red River Valley. The section, and quarter section) and decreasing elevation region, which includes much of the southern Glacial for each sample site or borehole location. Natural Lake Aggasiz basin, has spawned numerous geologic associations (clusters) of the correlation parameters studies over the years. Most of these studies are in the data set were identified by interactive, iterative, local in extent. Correlations among the studies involve cross plotting. When a cluster was identified and judgements made without a quantifiable knowledge accepted, all member samples of that cluster were of the areal extent of the units present. The technique labeled in the sequential data set. The labeled, described here permits the integration of data bases; sequential data set listed all samples (identified and identification of lithostratigraphic units; interpretation unidentified) at each sample site, sorted by location of the stratigraphic relationships present in sample and depth. Stratigraphic order is inferred from the data derived from outcrops, boreholes, and surface order of occurrence of labeled samples in the data exposures; and correlation of the lithostratigraphic set, field observations, and drill-hole descriptions. See Table 1 for the results of the lithologic and

Harris, 1987c, Harris and Luther, 1991).

 $NS = \{[SL/(SL+CL)]*100\}$

Red River Valley Red River Valley LOCATION DIAGRAM

QUATERNARY STRATIGRAPHY

Kenneth L. Harris, Susan A. West, Barbara A. Lusardi, and Robert G. Tipping

1995

INTRODUCTION

The Quaternary stratigraphy plate presents an interpretation of the geologic history of the southern Red River Valley of Minnesota—the formal study area of this regional hydrogeologic assessment—as well as the greater Red River Valley of Minnesota and North Dakota (see location diagram). The larger regional context was sought to encompass the southern part of the basin of Glacial Lake Agassiz, and parts of the glaciated plains in Minnesota and North Dakota. The earth materials present at the surface in the region are Quaternary in age. They were deposited by glacial ice, or as sediment in lakes and rivers. The information presented characterizes the sediment and summarizes our interpretations of sediment origin and geologic history. Some aspects of this work have been studied for decades and involve direct and indirect input from many geologists; other aspects have developed over the last few years.

The Red River Valley is a bedrock valley veneered with Quaternary sediments Bluemle (1991) theorized that the valley formed by the westward migration of the ancestral Red River. This river eroded down to a resistant, west-sloping surface composed of Precambrian igneous and metamorphic rocks. It then migrated downslope along the buried Precambrian surface, preferentially eroding the younger (less resistant to erosion) sedimentary rocks. As a result, there is a bedrock scarp, the Pembina Escarpment, to the west of the Red River Valley, and a gently sloping, buried, eroded Precambrian bedrock surface to the east.

As part of this assessment, shallow test holes were drilled, and suitable outcrops described and sampled during the field seasons of 1991, 1992, and 1993. Rotasonic cores were recovered from deep test holes, as much as 300 feet (91 meters) deep, that were drilled during the winter of 1992. All samples were analyzed for texture and coarse-sand lithology in the spring of 1993. Computer analysis and stratigraphic interpretation were completed in 1993 and 1994. Maps of the bedrock surface and the maps and cross sections of the Buffalo aquifer were developed during 1993 and 1994.

This plate has several related sections. Foremost are the lithostratigraphic map and accompanying cross sections. Table 1 presents the results of textural and lithologic tests, which were used in part to define the twenty lithostratigraphic units portrayed on the map and sections. Figure 1 shows the approximate locations of ice margins in the greater Red River Valley of Minnesota and North Dakota. Table 2 lists the associations of individual ice margins with lithostratigraphic units. Figure 2 presents the data base of subsurface and surface information that was used, in part, to create the lithostratigraphic map. An accompanying text section describes the computer-assisted stratigraphic mapping method used for the greater Red River Valley. Figure 3 includes maps of the southern Red River Valley that show depth to bedrock and bedrock topography. Figure 4 focuses on the Buffalo aquifer in Wilkin and Clay Counties, Minnesota.

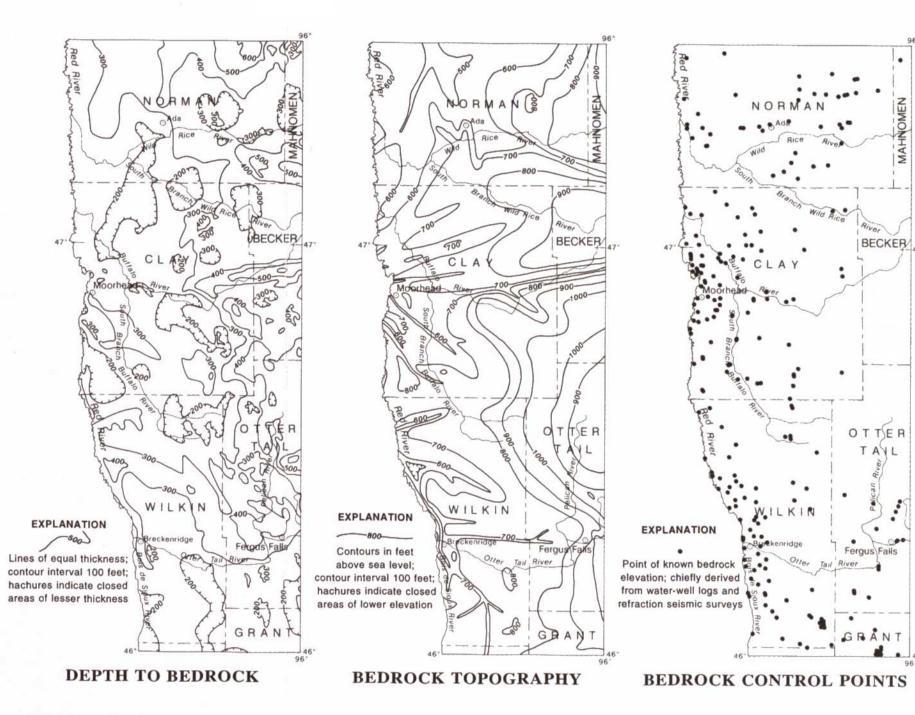


FIGURE 3. Maps of the southern Red River Valley, Minnesota, showing depth to bedrock, bedrock topography, and the locations of known bedrock elevation.

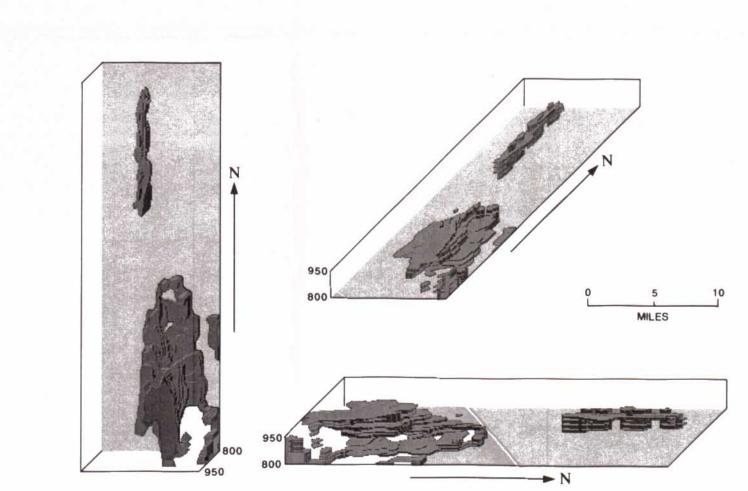
The topography of the bedrock surface was mapped using information drawn from well logs (descriptive records of the materials encountered during the drilling of water wells), refraction seismic surveys that were conducted by the Minnesota Department of Natural Resources. Division of Waters, and data provided by the North Dakota State Water Commission. The depth to bedrock map was produced by subtracting surface elevation from the interpreted elevation of the bedrock surface.

0 10 20 30 KILOMETERS

4A. Isopach map and lithologic cross sections of the Buffalo **EXPLANATION TO SECTIONS** The map and cross sections were constructed using information drawn chiefly from records of the earth materials penetrated during the drilling of water wells. The locations and depth of drill holes that fall on or near the lines of section are indicated by vertical Moorhead lines. The N-S cross section was constructed using wells along the crest of the aquifer, not necessarily along the generalized straight Vertical exaggeration x 50 path shown on the isopach map. Some of the wells penetrated multiple sediment types, suggesting multiple episodes of cut and fill in the formation of the aquifer. SCALE FOR SECTIONS A-A'-C-C' Vertical exaggeration x 50 WILKIN CO **EXPLANATION TO ISOPACH MAP** SCALE 1:300 000 undifferentiated bedrock

15 KILOMETERS

Vertical exaggeration x 100



4B. Computer modeling of the Buffalo aquifer.

These oblique views depict the shape and thickness of the sand and gravel body that forms the Buffalo aquifer and nearby sand and gravel bodies. The images were created in a computer using data from a surface resistivity survey that was conducted in 1979 by the U.S. Geological Survey (Zohdy and Bisdorf, 1979).

Resistivity measurements are useful for investigating buried earth materials because different earth materials offer varying resistance to current flow. The sand and gravel of the Buffalo aquifer is more resistive (higher resistivity values) than the surrounding silt and clay (lower resistivity values).

FIGURE 4. The Buffalo aquifer in Clay and Wilkin Counties, southern Red River Valley, Minnesota (Tps. 135-140 N., Rs. 48-49 W.)

The Buffalo aquifer is a narrow, sand-and-gravel-filled channel that is incised into the lake bed and underlying glacial sediment. It is interpreted to have been deposited in a tunnel valley by meltwater issuing from beneath the snout of a glacier. Water was probably discharged repeatedly and under great hydraulic pressure; the channel seems to undulate vertically as well as meander laterally. The tunnel valley discharged water and sediment to the south, probably into an ice-marginal lake, where it built a large fan (Wolverton Mountain).

The aquifer, which is also known locally as Sabin Ridge, Kings Trail, and River Sabin, merits attention owing to its importance as a local water supply. It is the primary source of water for the villages of Glyndon and Sabin, and a secondary source of water for the city of Moorhead. Large active and inactive gravel pits are common along the crest of the Buffalo aquifer where sand and gravel is at or near the surface. The entire Red River Valley is an area of intense agricultural activity, and farms along the crest frequently irrigate fields with water drawn from the aquifer.