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This study describes the surface configuration of Goodhue County and attempts to determine the origin of that configuration. The research has a descriptive portion--an objective examination of land surface configuration and the composition and distribution of rock material underlying that surface, and a theoretical portion--a speculative examination of the factors controlling the land surface configuration and discussion of the probable origin of that configuration.

I found that the configuration of any land surface is described in terms of drainage and topography and that the origin and age of any land surface is determined by an examination of the materials making up that surface, the present and past processes acting on that surface, and the

amount of time available for the processes to act. I also found that the age of land surface configuration is distinct from the age of the underlying materials and that the degree to which configuration of any land surface is dependent on structure, process, and time is dependent on the scale of the investigation and the surface itself.

The surface of Goodhue County ranges in elevation from approximately 670 feet to 1275 feet. The southern two-thirds of the county is a broad upland; the northern third of the county is slightly lower and more dissected. The county has a dendritic and well-integrated drainage system and is underlain by virtually flat-lying sedimentary rocks and thick deposits of glacial drift.

The surface configuration of Goodhue County is the result of: (1) geographic location near the center of North America and alongside its major river; (2) marine deposition during the early Paleozoic; (3) minor folding and faulting during the later Paleozoic; (4) extensive solution and erosion during the late Paleozoic and/or parts of the Mesozoic; (5) fluvial deposition during the Cretaceous; (6) glacial and glaciofluvial deposition during the early and middle Pleistocene; (7) aeolian deposition and mass movement late in the Pleistocene; and (8) fluvial erosion and deposition during the late Pleistocene and Recent.

Origin and Configuration of the Present-Day Land Surface, Goodhue County, Minnesota

by

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Typed by Constance Jefferson Sansome

FRONTISPIECE

View of the Land Surface Near the Town of Hay Creek, Goodhue County, Minnesota

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ORIGIN AND CONFIGURATION OF THE PRESENT-DAY LAND SURFACE, GOODHUE COUNTY, MINNESOTA

I. INTRODUCTION

Definition and Rationale

The intent of this study is to describe the surface configuration of Goodhue County and to determine the origin of that surface. The research is in two major parts: (1) a descriptive portion, and (2) a theoretical portion. The descriptive portion is an objective examination of the land surface configuration (Section II) and the composition and distribution of rock materials underlying that surface (Section III). The theoretical portion is a speculative examination of the factors controlling the land surface configuration and a discussion of the probable origin of that surface (Sections IV and V). Both parts of the research are of equal importance, although the first part of the research can stand alone and the second cannot. The descriptive portion of this research is a problem of geometry, physical geography, and stratigraphy. The theoretical portion is a problem of physical geology, historical geology, and geomorphology.

I chose this study for several reasons. (1) I desired a problem of regional scale involving consideration of a long span of geologic time and demanding integration of knowledge from several fields of scientific inquiry. (2) I wanted a problem the solution of which would give me a fund of knowledge, both factual and methodological, which I could easily communicate to other people and readily transfer to other regions. (3) I wished to learn more about the geology and geomorphology of Goodhue County. (4) I wished to "sharpen my vision" on the whole field of geomorphology--to learn to see land surfaces more analytically, to ask and attempt to answer, for a particular region, some of the major questions of that field and to read more intelligently in that field. (5) I chose this study because it touches on an integral part of human experience--the sense of place, a feeling which I wished to strengthen in myself and foster in others.

I chose a landscape problem regional in nature and integrative in approach because it demands a broad understanding of physical geography, physical geology, and historical geology. It demands a broad knowledge of geologic features, materials, and processes. Its solution draws on the fields of glacial geology, structural geology, sedimentology, stratigraphy, field geology, physiography, and soil science. The regional nature of the problem also demands developing the ability to see land at a regional scale--on the ground, on maps and photographs, in cross-section--and to recognize which characteristics of the land surface and its origin are relevant for observation and consideration at that scale.

I wanted to learn to describe the configuration of a land surface, determine its origin, and examine the interrelationships between the factors which control land surface origin and evolution. I wanted to take this knowledge of land surface description, analysis, and development, apply it to similar problems in other areas, and transmit it, through teaching and writing, to the curious layperson and introductory student.

I wanted to learn more of the geology and geomorphology of Goodhue County, an area for the Midwest of considerable geologic and geomorphic diversity. A detailed study of this county should produce new information about the geology and geologic history of all southeastern Minnesota and help answer the following questions. (1) What are the major structural controls on the surface configuration of Goodhue County? (2) What, in more detail than previously known, is the structural framework of Goodhue County? (3) What accounts for the present dendritic drainage and the uncommon entrenched bedrock meanders? (4) Why is the northeast part of the county so heavily dissected compared to the southwest part? (5) How much of the land surface configuration is the result of depositional activity and how much of erosional activity? (6) What is the extent and timing of karst development in the county? (7) How old is the land surface of Goodhue County? (8) How has the land surface configuration changed through time?

I wanted, while studying the particulars of Goodhue County, to answer some of the broader questions of geomorphology. (1) How does one describe the configuration of a land surface? (2) How does one determine the origin and age of a land surface? (3) What does the configuration of a land surface tell of its origin and age? (4) What do the underlying materials tell of its origin and age? (5) What are the major factors controlling the configuration of any land surface? (6) How much is a particular land surface dependent on the structure, composition, texture, and distribution of the underlying materials? (7) What role do geologic processes play in land surface configuration? (8) What role does catastrophism play in the development of a land surface? (9) How does land surface configuration change through time?

I chose to study Goodhue County, a particular land area near my home, because it would strengthen my sense of place, increase my understanding of and appreciation for my geologic and geographic setting. I wanted to gain technical knowledge of the land surface, yet retain a sense of wholeness or poetry about the landscape--of holsteins walking across steep and closely cropped hillsides of spreading juniper and large tilted dolomite blocks, of cleanly plowed and undulating uplands seamed with hidden and intermittent watercourses, of deep and broad valleys edged by rock bluff, hardwood forest, and tiny goat prairie. I hoped, through the strengthening of my own sense of place, to learn to foster it in others, to encourage their curiosity about, enlarge their knowledge of, and increase their appreciation for their natural surroundings.

Finally, while pursuing this study, I found that I hold several beliefs concerning land surfaces, the mapping of land surfaces, and the field of geomorphology. (1) I believe that land surfaces must be analyzed geometrically before they can be analyzed genetically. I believe objective and geometric classification of a land surface must precede speculative, derivative, and genetic classification of that land surface and must not be confused with it. (2) I believe that land surfaces are polygenetic--they arise through the interaction of varying structures and processes, and change continuously through time. (3) I believe it is time to reintegrate the fields of geography and geology, actually to reintegrate many of the sciences, and that often the most interesting and valuable studies are those which demand a broad interdisciplinary approach.

(4) I believe that geomorphology, although caught in a "no-man's land" between geology and geography, is a distinct and valid science.

Background

My interest in land surfaces began in childhood and culminated in two science fair projects--"The Stratigraphy and Physiography of the Minnetonka Area" (Jefferson, 1961) and "The Face of the Land: Physiographic Regions of Minnesota" (1962). I became increasingly interested in southeastern Minnesota during my undergraduate years at Carleton College, Northfield, Minnesota. During 1972, while at the University of Minnesota, I wrote a master's thesis, a portion of which was on the stratigraphy of the Sogn quadrangle, Goodhue County (Sansome, 1972).

By late 1979, having completed my doctoral course work and become increasingly interested in landscape development, I began work on the origin and configuration of the present-day land surface of Goodhue County. The county remains an area of interest because it has been little studied and exhibits a considerable amount of geologic and geomorphic diversity.

During the summer and fall of 1980, with financial assistance from the Minnesota Geological Survey, I travelled throughout Goodhue County, became familiar with the land surface, located and examined numerous exposures of both consolidated and unconsolidated materials, located and catalogued several hundred well logs, produced a base map (at the scale of 1:62,500), and drew preliminary maps of the drainage, topography, bedrock topography, and overburden thickness. In the latter half of 1983, having passed doctoral preliminary examinations and written Minnesota Underfoot: A Field Guide to the State's Outstanding Geologic Features, I returned to the work on Goodhue County. Between September 1983 and June 1984 I outlined the remainder of the doctoral work, completed examination of exposures and well logs, and worked on the maps and their legends. During the fall of 1984, I re-examined the most significant exposures, located several new exposures, re-evaluated certain speculations concerning those exposures, collected necessary samples, and drew a preliminary surficial geology map. I talked extensively with Howard Hobbs, Quaternary geologist with the Minnesota Geological Survey, Eric Force, geologist associated with the U. S. Geological Survey studying the margins of North America's Cretaceous seaway, and with Herbert E. Wright, Jr., glacial geologist and limnologist with the University of Minnesota, Minneapolis.

Methodology

The field and laboratory work for this study consisted of locating, sampling, and measuring exposures of both consolidated and unconsolidated materials, textural and compositional analysis of field samples, and examination, interpretation, and correlation of well logs. The location, sampling, and measurement of field exposures was carried out during parts of 1981 and 1984. Exposures were located by map examination, auto, foot, and air reconnaissance. The physiographic position, surface elevation, bedrock elevation, overburden thickness, lithology and texture of the unconsolidated and consolidated materials were noted at each exposure. Selected exposures were measured and sampled. Where necessary, textural analysis of sand, silt, and clay content consisted of manual texturing of unconsolidated materials and visual approximation for consolidated materials. The angularity of larger clasts was noted where important. Composition of consolidated materials was determined through use of a 10x hand lens. Well logs provided by the Minnesota Geological Survey were examined, often reinterpreted in light of field data and after construction of various stratigraphic cross-sections, located, and placed on the Data Base Map.

Mapping was a major part of this research. Ten principal maps were produced: the Base Map (Plate I), Planimetric Map (Plate II), Data Base Map (Plate III), Drainage Map (Plate IV), Topographic Map (Plate V), Map of Bedrock Geology (Plate VI), Map of Bedrock Topography (Plate VII), Map of Overburden Thickness (Plate VIII), Map of Surficial Geology (Plate IX), and Map of Geomorphic Regions (Plate X). A pair of cross-sections (Plate XI) and two secondary maps were produced: the Reference Map (Plate XII) and the Slope Map (Plate XIII). All maps were drawn at a scale of 1:62,500. The Planimetric Map, Drainage Map, and Topographic Map were derived from the Base Map, which in turn was compiled from the twenty-eight 7.5 minute U. S. Geological Survey topographic sheets representing Goodhue County. The Data Base Map, Map of Bedrock Geology, Map of Bedrock Topography, Map of Overburden Thickness, Map of Surficial Geology, Map of Geomorphic Regions, Reference Map, and Slope Map are original.

Selecting the scale for the study was crucial. United States Geological Survey topographic sheets at a scale of 1:24,000 are available for the entire county, and at a scale of 1:62,500 for approximately one-third of the county. A bedrock geology map at a scale of 1:250,000 (Sloan and Austin, 1966), a Quaternary geology map at a scale of 1:500,000 (Hobbs and Goebel, 1982), and soils maps at a scale of 1:15,840 (Poch, 1976) are also available. The U. S. Geological Survey is beginning to compile county topographic maps at a scale of 1:100,000 and the Minnesota Geological Survey is using this scale for a new county atlas series. Production, however, of the Goodhue County map at the scale of 1:100,000 has not been scheduled. It appeared, in consultation with the Minnesota Geological Survey, that the scale of 1:62,500 would be a good intermediate scale for this project. The Base Map was thus produced by trimming, taping together, and photographically reducing the 7.5 minute quadrangles.

Acknowledgements and Related Research

This study would not have been possible without the faith and patience of several persons: my academic advisor J. G. Johnson (Oregon State University), my mentor H. E. Wright, Jr. (University of Minnesota), my friend and spouse, Kenneth N. Sansome. I thank the Minnesota Geological Survey for their financial assistance and their unflagging interest in the study--most especially thanks to Matt Walton, Director, John Splettstoesser, Howard Hobbs, Bruce Olson, Bruce Bloomgren, and Betty Keeler. I thank Eric Force (U. S. Geological Survey, Reston, Virginia) for a most instructive day in the field and continuing information on the Cretaceous environment. I thank the other members of my graduate committee. And finally I thank my children, Nick and Dain, for their patience with road cuts and unbounding enthusiasm for gravel pits.

I am indebted to all previous geologic investigators in Goodhue County and surrounding area. N. H. Winchell, state geologist, pioneered work in Minnesota and Frank Leverett built on that foundation in the succeeding generation. In 1872, Winchell produced a Preliminary Geological Map of Minnesota, and in 1888 published with the assistance of Warren Upham Geology of Minnesota, Volume 2. In 1932, the U. S. Geological Survey published Frank Leverett and Frederick Sardeson's paper entitled "Quaternary Geology of Minnesota and Parts of Adjacent States". M. G. Frey wrote on the Red Wing area in 1937, O. G. Lundstrom on the Pine Island-Mazeppa region in 1938, and Cowie on the Zumbro valley in 1941. In 1944, George Thiel wrote the Geology and Underground Waters of Southern Minnesota. W. E. Crain wrote on the Red Wing quadrangle in 1957, G. S. Austin on the clays of Goodhue County in 1963, and Ruhe and Gould on the glacial geology of the Dakota County area in 1964. Vick et al. wrote on the buried bedrock valley of the Cannon River in 1980.

I am also indebted to the Minnesota Geological Survey, the Agricultural Experiment Station, and the Soil Conservation Service. The Minnesota Geological Survey, in recent years, has supported and published: (1) a bedrock geology map of southeastern Minnesota (Sloan and Austin, 1966, scale 1:250,000); (2) The Geology of Minnesota: A Centennial Volume (Sims and Morey, eds., 1972) in which Austin reviews the lithology and nomenclature of the Paleozoic rock formations in southeastern Minnesota (p. 459-473) and the present knowledge of Minnesota Cretaceous rocks

(p. 509-512); Wright reviews the Quaternary history and physiography of Minnesota (p. 515-547, 561-578); and (3) an investigation entitled "Revised Keweenawan Subsurface Stratigraphy of Southeastern Minnesota" (Morey, 1977). The Agricultural Experiment Station, University of Minnesota, published the Minnesota Soil Sheet: St. Paul Sheet, scale 1:250,000, in 1973. The Soil Conservation Service, U. S. Department of Agriculture, published the Soil Survey of Goodhue County, Minnesota (Poch, 1976). The soils are mapped on aerial photographs at a scale of 1:15,840 and provide by far the most detailed and recent information on the land surface of the entire county.

Since the late 1970's, the Minnesota Geological Survey has begun a new round of bedrock and Quaternary geologic mapping. Studies resulting to date from this effort, and of direct aid to this study include: (1) maps of the surficial geology of Minnesota--Geologic Map of Minnesota: Quaternary Geology, scale 1:3,168,000 (Goebel and Walton, 1979), and the Geologic Map of Minnesota: Quaternary Geology, scale 1:500,000 (Hobbs and Goebel, 1982). As part of this endeavor, the Minnesota Geological Survey has also initiated a series of county atlases, a program of which this study will become a part. During 1982, they published the geologic atlas of Scott County (Balaban and McSwiggen, eds.), and during 1984 an atlas of Winona County (Balaban, and Olson, eds.). At present, they are preparing an atlas of Olmsted County.

Other geologic investigations, reports, and conferences particularly useful in the present research include:
(1) Cobban's work on the Cretaceous rocks of Minnesota and adjacent areas (Cobban and Merewether, 1983); (2) Ruhe's work <u>The Quaternary Landscapes of Iowa</u> (Ruhe, 1969);
(3) Alexander's work on the karst of southeastern Minnesota (Alexander, 1984); and (4) information presented and exchanged by speakers and participants at the working conference "Pleistocene Geology and Evolution of the Upper Mississippi Valley" (Winona State University, 1985).

Goodhue County

Goodhue County is located in southeastern Minnesota, near the center of North America. It is bordered on the east by the Mississippi River and drained wholly by that river and its tributaries. The county ranges in elevation from 667 (normal pool level) feet on the shores of the Mississippi River at Lake Pepin, to 1275+/-5 feet on the uplands in the south central part of the county. The total relief of the county is thus 608+/-5 feet. Along the Mississippi bluffs, the local relief commonly attains 300-350 feet. The surface varies from nearly level on the uplands and valley floors to nearly vertical on the valley sides. The southern two-thirds of the county is a broad upland maintaining an elevation of approximately 1100-1200 feet. In the northern third of the county, the uplands are slightly lower and more dissected. Valleys are deep, broad, and commonly lie 100-300 feet below the upland surface.

The county has a dendritic and well-integrated drainage system. The perennial streams consist of the Mississippi River and its tributaries--the Vermillion River, Cannon River and its tributaries (the Little Cannon River, Prairie Creek, and Belle Creek), Spring Creek, Hay Creek, Bullards Creek, Wells Creek, North Fork of the Zumbro River and its tributaries (Spring Creek and Clear Creek), and the North Branch Middle Fork Zumbro River and its tributaries (Dry Run Creek and Devlin Creek). Numerous intermittent streams enter these main streams. The Cannon drains the northern part of the county, the Zumbro drains the southern part. Both rivers flow eastward into the Mississippi, as do the smaller streams between the two--Spring Creek, Hay Creek, Bullards Creek, and Wells Creek. The Vermillion River flows briefly as a yazoo to the Mississippi in the extreme northeastern part of the county. The county has no natural lakes except within the valley of the Mississippi, but has one large reservoir, Lake Byllesby, and numerous small farm reservoirs and natural springs.

Goodhue County (see Plates I and II) is irregular in outline and encompasses 782 square miles, twenty-two townships, and all or portions of twenty-eight U. S. Geological Survey 7.5 minute topographic sheets. It has a population of 34,763 (Minnesota Department of

Transportation, 1979). Red Wing (population 12,834) (ibid.) is the county's largest town. Smaller towns include Cannon Falls, Zumbrota, Pine Island, Kenyon, Wanamingo, Goodhue, and Dennison. Lake City is shared with Wabasha County. The county is well-serviced by federal and state highways: U. S. highways 61 and 63 follow a segment of the Mississippi along the east side of the county; U. S. highway 52 runs northeast-southwest through the center of the county; state highways 50, 19, and 60 run east-west and state highways 56, 57, and 58 run north-south. There is an extensive network of paved and unpaved secondary roads. The county is primarily agricultural with most of the land under tillage or pasture. Farming consists of corn, hay, soybeans, and livestock (Poch, 1976, p. 127). The land, where steep and still wooded, has been extensively logged.

Goodhue County is located on the northern edge of the Interior Lowlands (Lobeck, 1941) approximately sixty miles south of the Laurentian Upland. The county lies midway between the Wisconsin Dome to the east and the Iowa-Missouri Basin to the west. Underlying the whole county and cropping out along streams and in roadcuts are platform sandstones, shales, limestones, and dolomites of early Paleozoic age. These rocks, nearly flat-lying, show a slight monoclinal dip to the west of approximately ten feet per mile (Thiel, 1944; and Sloan and Austin, 1966). A gentle anticline, some fifteen miles in length, centering in the Goodhue-Bellechester area, differentially eroded and partially filled with Cretaceous clay, and a vertical fault of 150 feet displacement at Barn Bluff in Red Wing markedly interrupt this general pattern (ibid.) (see Sloan and Austin map, Appendix A, Figure #2). Underlying the Paleozoic rocks are Precambrian clastics (Craddock, in Sims and Morey, 1972, p. 417) and below those, volcanics and plutonics. Overlying the Paleozoic rocks and Cretaceous sediments are deposits of the Pleistocene and Recent. These latter deposits, up to several hundred feet thick, include glacial and glaciofluvial materials, loess, colluvium, and alluvium.

The county has a humid continental climate, of warm moist summers and very cold dry winters. The mean temperature for June-July-August is 68.5° F, although the temperatures frequently rise above 90° F. The highest recorded temperature is 109° F. The mean temperature for December-January-February is 17.1° F., although the temperatures frequently fall below -20° F. The record low is -45 ° F. Northern slopes are shady, cool, and moist, whereas steep south- and west-facing slopes are comparatively sunny, warm, and dry. Thunderstorms occur approximately forty times each year. Average annual rainfall is 28.5 inches, with a range of 12.74 inches in 1910 to 42.12 inches in 1968. Snows commonly occur from early November through mid-April. Average snowfall is 34.3 inches. (Poch, 1976, p. 126-127).

Goodhue County sits astride the Midwest prairie-forest border. Native vegetation consists primarily of prairie and wet prairie in the south and west, and brushland (brush prairie, aspen-oak land, oak openings and barrens) and hardwood forest (big woods and river-bottom forest) in the north and east (Marshner, 1930) (see Appendix A, Figure #8). Today most of this native vegetation has been replaced by row crops and pasture. Only tiny remnants of prairie remain on steep rocky slopes, scattered pieces of brushland on Mississippi terraces, and patches of forest along limited stretches of the major rivers and streams.

Soils of the county are generally deep and fertile, developed under forest and grassland on a thick mantle of glacial drift and outwash, bedrock residuum, loess, and alluvium (Poch, 1976, p. 122) (see Appendix A, Figure #7). The soils vary in maturity, generally having formed in the past 3000 to 20,000 years (ibid., p. 124). The youngest soils are found on present flood plains, the oldest on drift and loess-covered uplands. Five of the ten soil orders occur in Goodhue County. Most of the county is covered by the dark-colored Mollisols, formed under grasses, and the clay-enriched Alfisols, formed under forest. Lesser areas of the young mineral Entisols and Inceptisols occur on benches, flood plains, or steep slopes. Small scattered patches of the organic Histosols are found on hillside seeps and in the valleys of major streams.

II. CONFIGURATION

Description of Land Surface

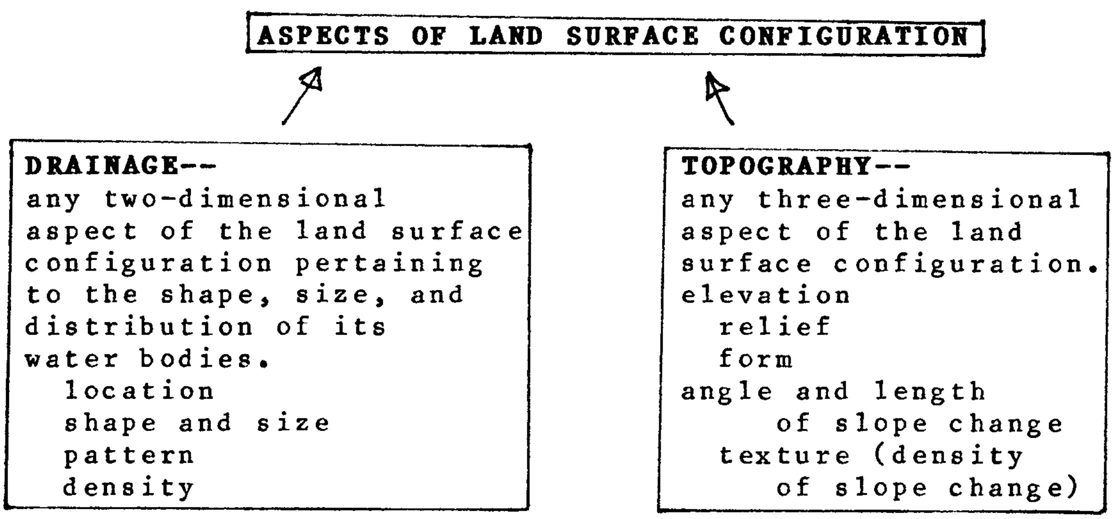
Land surfaces and landscapes may be described in many ways. The concern here is for an objective geometric description of land surface configuration: a description of form, unencumbered with suppositions about process and origin. An objective description of land surfaces is accomplished through the use of maps, cross-sections, photographs, and numbers.

Many aspects of land surface configuration can be objectively described--the height of hills, depth of valleys, breadth of uplands, pattern, length, and density of streams. These aspects may be placed in two categories: drainage and topography. Drainage is considered here as any two-dimensional aspect of the land surface pertaining to the form and distribution of its water bodies. Drainage pattern, drainage density, and configuration of lakes are all considered a part of drainage. Topography is considered here as any three-dimensional aspect of the land surface. Elevation, relief, angle and length of slope, and density of slope change are considered a part of topography. The regional scale of this study precludes consideration of detailed aspects of landform configuration such as convexity and concavity of hillslopes, and length and width of stream meanders.

Drainage concerns the number, size, shape, and location of lakes and streams. It involves a description of drainage systems, drainage basins, drainage patterns, and drainage densities. It is concerned with the: (1) length and branching of streams; (2) proportion of perennial to intermittent streams; (3) continuity and integration of the drainage net; and (4) description of individual drainage basins and streams and comparison of one to another. Drainage pattern and density are portrayed by maps, photographs, and charts. Measures of length are in feet and miles, of area in acres and square miles, of angle in degrees, and of density in miles per square mile. (Note: the English system of measure, agreed on in consultation with Matt Walton, Director of the Minnesota Geological Survey, is used throughout this study because most available information is given in this system. All measures will be converted to the metric system when the scale of the principal maps has been changed to 1:100,000 and this material becomes part of the Minnesota Geological Survey County Atlas Series.)

Topography concerns elevation and relief, planar form, and slope of a land surface. Elevation refers to height of land above sea level; relief refers to the difference in elevation within a specified area. Elevation and relief are best portrayed through topographic maps, oblique view drawings, stereoscopic aerial photographs, and cross-sections. Planar form refers to length and width, or shape, of the land surface at a particular elevation. It is best depicted on shaded topographic maps. Slopes are characterized by form (length, width, height, angle, and surface configuration), pattern, and density. Slopes are best depicted on topographic maps, oblique photographs and drawings, topographic cross-sections, and varying types of slope maps.

Figure #1



Aspects of land surface configuration are most effectively communicated through the use of maps and cross-sections, the primary means of portraying surface configuration in this study. The Drainage Map is composed of lines which indicate the location, size, shape, permanence, and intermittence of lakes and streams. The Topographic Map is composed of contour lines--lines connecting points of equal elevation. The Slope Map indicates, through numbering, the texture, density of elevation change, of the land surface. Cross-Sections A-A' and B-B' show the widths, lengths, and heights of hills and valleys.

In this study the measurements of drainage and topography, length of streams and height of hills, as derived from the drainage and topographic maps and cross-sections, are objective. The aspects of drainage and topography, chosen to be mapped, cross-sectioned, or photographed, are subjective. The measurements are theoretically objective--the decision of what to measure is not. Decisions of what to measure and the aspects of form worthy of description or measurement, are dependent on the scale of the study, the ends of the study, and the judgement and experience of the investigator.

Drainage of Goodhue County

Aspects of the surface drainage of Goodhue County are shown on the Drainage Map (Plate IV). County borders and the location, size, and configuration of lakes, reservoirs, streams (both perennial and intermittent) and drainage basins are all found on the Drainage Map. Permanent water bodies and county borders are also found on the Planimetric Map (Plate II). Small scale and miscellaneous drainage features such as farm ponds, hillside seeps, and springs are found only on the Base Map (Plate I). Direction, pattern, and density of stream flow may be determined from this drainage information.

Both the Planimetric and Drainage maps were drawn by selecting features from the Base Map. The drainage divides found on the Drainage Map, however, came only indirectly from the Base Map. The divides were located by tracing the hillcrests between major river systems.

Salient features of the drainage include: (1) location, size, and configuration of permanent water bodies; (2) size and shape of drainage basins; (3) pattern of the drainage net; (4) direction of stream flow, length of streams, proportion of permanent to intermittent streams; (5) continuity and integration of the drainage net; and (6) drainage density and variation in drainage density across the county.

The permanent water bodies of Goodhue County consist of segments of four large rivers, the whole of four smaller rivers and all or segments of several lakes and one reservoir. The four large rivers are the Mississippi, Vermillion, Cannon, and Zumbro. The four smaller rivers are Spring, Hay, Bullard, and Wells creeks. The named natural lakes are North, Sturgeon, Clear, Larson, Goose, Grotes, and

Pepin. There are several smaller, unnamed lakes. The reservoir is Lake Byllesby. All of these waters, except Grotes Pond, flow through perennial or intermittent waterways into the Mississippi, although not all do this within the county.

The Mississippi River, the master stream of this county and much of North America, enters the county from the northwest, flows from northwest to southeast along the northeast edge of the county, and leaves the county in the east. The Vermillion River enters the county from the north and flows as a yazoo stream to the Mississippi in the extreme northeastern part of the county. It empties into the Mississippi south of Prairie Island. The Cannon River enters the county from the west, flows from west to east across the northern part of the county, and joins the Mississippi, through numerous distributaries, downstream from the mouth of the Vermillion River and upstream from Red Wing. Spring and Hay creeks begin within Goodhue County and flow northward across the northeastern part of the county. They join the Mississippi at Red Wing. Bullard and Wells creeks begin within Goodhue County and flow from southwest to northeast across the eastern part of the county. Bullard Creek joins the Mississippi at Wacouta; Wells Creek joins the Mississippi at Frontenac. The North Fork Zumbro River enters Goodhue County from the west; the North Branch Middle Fork Zumbro enters the county from the south. Both streams flow from west to east across the southern part of the county. They continue east and south out of the county, join together in Wabasha County, and empty into the Mississippi at Kellogg, downstream from Lake City.

Lake Pepin, a broadening of the Mississippi, begins near Wacouta and continues southward along the county line to Lake City. North, Sturgeon, Clear, Larson, Goose, and several smaller lakes lie alongside Prairie Island, between the Vermillion and Mississippi rivers. Grotes Pond and several unnamed lakes are found between Wacouta and Frontenac, between the mouths of Bullard and Wells creeks. Byllesby Reservoir is located on the Cannon River immediately west of Cannon Falls.

In total, Goodhue County covers 782 square miles, sixteen of which are open water (Goodhue County Department of Highways, 1975). The Mississippi River, Lake Pepin, and Byllesby Reservoir, the largest bodies of water, border the county. North Lake, with approximately 1120 acres of open water, is the largest lake wholly within the county. The Cannon, with approximately twenty-nine miles of perennial flow, as measured with the American Map Corporation Map Measurer, is the longest river within the County. The Zumbro River has approximately twenty-eight miles of perennial flow within Goodhue County.

There are four large drainage basins within Goodhue County. Each of these is a part of the far larger Mississippi River drainage basin. These basins outlined on the Drainage Map and listed from north to south are the:

(1) Vermillion; (2) Cannon; (3) Spring-Hay-Bullard-Wells; and (4) Zumbro. The Vermillion occupies a small area in the northern part of the county, the Cannon occupies a large area in the northwestern and north central part of the county, the Spring-Hay-Bullard-Wells occupies most of the eastern part of the county, and the Zumbro occupies approximately the southern one-third of the county. The largest of these basins is the Zumbro, which covers approximately 303 square miles, the smallest is the Vermillion which covers approximately twenty-seven square miles. The Cannon covers approximately 298 square miles, and the Spring-Hay-Bullard-Wells drainage basin covers approximatley 185 square miles.

The Mississippi River, a 6th order stream (Strahler ordination--Small, 1978, p. 220) within Goodhue County, drains all of central North America. It begins in northern Minnesota and empties into the Gulf of Mexico; tributaries flow eastward from the Rockies and westward from the Appalachians. The Vermillion River, a 3rd order stream in this county, begins in western Dakota County, flows northeastward to near Hastings, then turns directly southeastward and parallels the Mississippi before flowing into Goodhue County. The Cannon River, here a 5th order stream, begins in eastern Le Sueur County and flows eastward across that county, then northeastward across Rice County before entering Goodhue County. Spring, Hay, Bullard, and Wells creeks are fully within the study area and were previously described. Spring and Wells creeks are 2nd order streams; Hay and Bullard are 3rd order streams. The Zumbro, a multiple and irregularly branched stream, and a 4th order stream in Goodhue County, begins in Rice and Dodge counties and flows eastward, northward, and in a few places southeastward across those counties, Goodhue County, and Wabasha County, before entering the Mississippi at Kellogg.

The drainage pattern of Goodhue County is predominantly dendritic. A particularily good example of this dendritic pattern is the whole of the Little Cannon River. A rare exception to this pattern is the mouth of the Cannon River.

The largest streams of Goodhue County generally flow from west to east, including from northwest to southeast and southwest to northeast. The smaller streams, particularily the intermittent streams, flow in many directions. Stream length varies considerably, from a fraction of a mile for the small intermittent tributary streams to many miles for the master streams. By far the greatest stream distance is in intermittent flow. The ratio, by eye, of perennial stream length to intermittent stream length is less than 1:10.

The drainage of Goodhue County displays good continuity and integration: streams are well-spaced and except in rare instances, flow into one another and on to the Mississippi. An example of the continuity and integration of the drainage net is seen in the drainage of Wells Creek, where numerous well-spaced and unnamed tributaries flow into Clear Creek which in turn flows into Wells Creek and then into the Mississippi River. A rare instance of an isolated stream segment is seen in the center of section 26, Minneola Township. Grotes Pond is a rare isolated lake.

The density of the drainage pattern, the sum of the stream lengths divided by the area of the drainage basin or study area ($Dd=\Sigma L/A$), varies somewhat across the face of the county. The average density for the county, determined by eye, the use of a template, and the Map Measurer is 1.7 miles per square mile for all streams, intermittent and perennial, and .08 miles per square mile for the perennial streams alone. In general the density is greatest near the divides and least near the master streams. High drainage densities are seen between the Little Cannon River and Belle Creek and at the upper ends of streams flowing into Spring Creek, Hay Creek, Wells Creek, and the Zumbro River. Low drainage densities are seen between the mouths of Hay and Spring creeks, near the Little Cannon River and Prairie Creek, southeast of Wells Creek, and in the southwest part of the county.

Topography of Goodhue County

Major aspects of the topography of Goodhue County are shown on the Topographic Map (Plate V). Data from the Planimetric Map (Plate II)--the county outline and perennial water bodies--are also shown. The Topographic Map shows the elevations of the land surface at 100 foot contour intervals. More detailed topographic information is found on the Base Map (Plate I).

The Topographic Map was constructed by tracing all information off the Planimetric Map and by tracing the 100 foot contour lines off the Base Map. The 100 foot interval was selected, in consultation with the Minnesota Geological Survey, as most appropriate for this study: smaller intervals crowd the map, larger intervals do not produce enough information. The 100 foot interval matches that of the Minnesota Geological Survey atlases of Scott and Winona counties.

Examination of the Topographic Map reveals the elevation, relief, and planar form of the Goodhue County land surface. The elevation of the county ranges from less than 700 feet in the northeast to more than 1200 feet in the central and southwest. Total relief for the county is greater than 500 feet. Local relief ranges from less than 100 feet in the southwest and east central parts of the county to greater than 300 feet in the northeast.

The simplest and broadest surface forms are found in southwest and east central Goodhue County. The most complex forms are found in the northeast, along and several miles to the west of the Mississippi River between Red Wing and Lake City. The southwest and east central parts of the county are occupied by a broad upland cut by the Zumbro River; the northeast is occupied by a complex, almost labyrinthine system of interconnected channels. Other noteworthy surfaces are the broad flat areas along Prairie Creek, the lower reaches of the Little Cannon River, the Mississippi River northwest of Red Wing, and the area surrounding Lake City. The margins of all forms and surfaces are intricately dissected. There are few isolated depressions or elevations.

The lowest elevations of Goodhue County, those under 700 feet, are found along the northeastern margin of the county, along the Mississippi River, and in the lower reaches of the Cannon River, Spring, Hay, and Bullard creeks, and into a channel in Florence Township. The highest elevations, those over 1200 feet, are found in the central and southwestern parts of the county. The greatest relief is found in the northeast and the least relief in the east central and southwest. In the northern part of the county the 800 foot contour line outlines the floors of many large valleys and the 1000 foot contour line outlines the small uplands. Farther south the 1000 foot contour line outlines the valleys and the 1100 foot contour outlines the uplands--the 1200 foot contour marks small high portions of the uplands. In general, the southern two-thirds of the county lies over 1100 feet; the northern third, including the northeastern part of the county, lies below 1100 feet.

The relationship between the length, width, and height of land surface features is called slope. The frequency or density of slope change can be called texture (Cushing, oral communication, October 1985). Slopes can be straight or curved along both length and width. Field examination has revealed that most slopes are curved, with convex slopes occupying the upper parts of the landscape and concave slopes occupying the lower, and that small areas of the highest uplands, broad valley floors, and the rare cliff face are nearly straight. Texture ranges from open to dense.

Slopes can be mapped in several ways, each map a derivative of a topographic map. Relief can be mapped to give a sense of slope height. Height and length of slope can be mapped together to indicate gradient or angle of slope. Frequency of slope change can be mapped to give a measure of texture.

The Slope Map (Plate XIII) shows the frequency of slope change. This textural aspect of slope best characterizes a land surface for descriptive and genetic studies. The texture map was constructed through use of a grid three miles square, placed on the Topographic Map. A diagonal was drawn across the grid, the number of contour lines crossing the diagonal were counted, then the grid was given a number according to the number of crossings--the more crossings, the higher the number. Examination of this map reveals that slope change is greatest in the northeast and north central parts of the county and least in the southwest and southeast parts of the county. Slopes change rapidly on a line running north-south through the center of the county and very little in the extreme northern tip of the county. Slopes change most rapidly along the major valleys and least rapidly on the broad high uplands and wide valley floors.

Topography can also be examined in cross-section. Cross-sections indicate elevation, relief, and slope. Two cross-sections (Plate XI) were drawn through Goodhue County. Their locations were chosen, through visual examination of the Base and Topographic maps, in an attempt to illustrate the county's topographic diversity. Cross-Section A-A' cuts through both the highest and lowest, the least dissected and most dissected, areas of the county. Cross-Section B-B' crosses the major north-south valleys. The cross-sections, based on the Topographic and Drainage maps, have horizontal scales of 1:62,500 and vertical scales of 1:4,800; their vertical exaggeration is approximately thirteen times. Location of the cross-sections is marked on the Reference and Topographic maps.

Examination of the cross-sections reveals that: (1) the surface of the northeastern part of the county is very rugged compared to that of the southwest; (2) most of the land in the southwestern two-thirds of the county is over 1100 feet in elevation; in the northeastern one-third most of land is under 1000 feet; (3) in the southern two-thirds of the county the valley sides are gently sloping; in the northeast the valley sides are very steep; (4) most land above 1000 feet is gently sloping, whereas that below is steep, with the exception of valley floors which are nearly flat.

Interrelationship of Drainage and Topography

The interrelationship of drainage and topography is best seen by examination of the Base Map (Plate I). The map has a contour interval of ten feet for most of the county, but twenty feet for the northeastern part of the county.

The salient aspects of the Base Map, relating drainage and topography, follow: (1) A dendritic drainage pattern is found throughout the county. (2) The county's only natural lakes occur within the Mississippi valley or valleys closely associated with the Mississippi. (3) The county's greatest relief is found alongside its principal streams. (4) The general upland surface slopes to the north and the northeast, and the principal streams, except for the Mississippi, run from west to east and south to north. The Mississippi River runs from northwest to southeast. (5) Drainage and slope densities vary across the county. Drainage density is greatest near the drainage divides and least near the master streams. It is also generally greatest in the central part of the county and least in the northwest. Slope density is greatest in the north and northeast and least in the central and southwest. (6) The valleys of most perennial streams are deep, broad, steepsided, flat-floored, and often bordered by terraces. The valleys of intermittent streams are shallow, narrow, and either steep- or gentle-sided; terraces are not evident at the map scale. (7) Elevation, slope, and drainage change across the county. The land in the southwest is high, gently sloping, and minimally drained; in the center it is not as high, slopes gently, and is well-drained; in the northeast it is lower, steeply sloping, and well-drained; within the Mississippi valley it is low, nearly level, and well to very poorly drained. (8) Beside these broad areas of differing elevation, drainage, and topography, there are smaller distinctive areas--some flat, others steep, rolling, or knobby. Certain small areas show elongate rather than broad landforms; others show entrenched rather than normal valleys. Flat areas appear on the upland near Cannon Falls, on the valley floor near Stanton and Zumbrota, in an intermediate position near Lake City. Rolling landscape appears near Pine Island, knobby landscape near Goodhue. Elongate landforms appear on the upland near Cannon Falls and on the valley floor near Prairie Island. A segment of Belle Creek has an entrenched rather than normal valley.

III. MATERIALS OF THE SURFACE AND SUBSURFACE

Introduction

Consolidated and unconsolidated materials are found on the surface and in the subsurface of Goodhue County. The consolidated materials consist primarily of limestone, dolomite, sandstone, siltstone, and shale. The unconsolidated materials consist primarily of gravel, sand, silt, and clay.

Published maps of the geologic materials of Goodhue County vary in scale and intent. The maps and their legends combine objective, descriptive information with speculative, genetic information. These maps are found in Appendix A. The Sloan-Austin map of bedrock geology (1966, scale 1:250,000, Figure #2) indicates that the bedrock is virtually flat-lying, minimally faulted, and of clastic and crystalline texture. The rocks are marine and terrestrial in origin, Cambrian, Ordovician, and Cretaceous in age. Cambrian rocks occur in the eastern part of the county, Cretaceous in the east-central, and Ordovician rocks throughout the remainder of the county. The surficial and

Quaternary geologic maps of Leverette and Sardeson (1932, scale 1:500,000, Figure #4), Goebel and Walton (1979, scale 1:3,168,000, Figure #5), and Hobbs and Goebel (1982, scale 1:500,000, Figure #6), although varying greatly in detail, indicate that the unconsolidated materials consist principally of alluvium, colluvium, loess, terrace sands and gravels, glacial outwash, glacial drift, and bedrock residuum. They also indicate that these materials are of Pleistocene and Holocene age, with the youngest materials occupying the central parts of broad valleys and upland drainageways. The soils map of Goodhue County (Poch, 1976, scale 1:253,440) (Appendix A, Figure #7) indicates that the soils are of Recent origin and varying depth. They have developed over the past 3000 to 20,000 years on loess, glacial till, outwash, and bedrock residuum (Poch, 1976, p. 122-124).

I produced a set of four maps at a uniform scale of 1:62,500 to gain a more detailed, cohesive, and integrated understanding of how the rock materials of Goodhue County affect land surface configuration. These maps--the Map of Bedrock Topography (Plate VII), Map of Overburden Thickness (Plate VIII), Map of Bedrock Geology (Plate VI), and Map of Surficial Geology (Plate IX)--were produced after the examination and analysis of 392 field exposures and 480 well logs. Construction of these maps is discussed in Appendix D.

Bedrock Topography and Overburden Thickness

An examination of the Map of Bedrock Topography reveals that the bedrock surface varies from an elevation of 498 feet at Red Wing to 1172 feet south of Wanamingo, is lowest in the northeast and highest in the central, south central, and southwest, and is dissected by broad and deep valleys, up to 500 feet deep and two miles across. It also reveals a complex pattern of bedrock valleys and bedrock islands in the northeast part of the county and very poor control on the bedrock surface near Lake City and Goodhue and in parts of the Mississippi, Cannon, Little Cannon, Belle Creek, Hay Creek, and Zumbro valleys.

An examination of the Map of Overburden Thickness reveals that the overburden varies in thickness from zero to greater than 300 feet, and is generally greatest on the uplands and in the valleys and least on the valley walls. It also reveals that the heaviest upland overburden is in the southwest part of the county where it is frequently more than 100 feet and almost always greater than fifty feet thick, and the least upland overburden is in the northeast where it rarely exceeds ten feet in thickness. The central part of the county has an upland overburden ranging from ten to 100 feet in thickness. The centers of major valleys have an overburden of fifty feet or more and commonly attain thicknesses of greater than 100 feet. Two buried valleys, one running northwest from Kenyon and another running south from Belle Creek to near Zumbrota, have overburden in their centers of over 200 feet. Valley sides commonly have overburden of less than ten feet. Control on the bedrock surface is most limited where overburden is thickest.

Sinks observed in the field, but of too small scale to appear on the Maps of Bedrock Topography and Overburden Thickness, are important to a consideration of land surface development. The sinks, to tens of feet in depth and filled with unconsolidated material, unreworked Windrow Clay, glacial drift, and loess, occur in the Prairie du Chien Dolomite (see Appendix C, Figure #11).

A comparison between the Maps of Bedrock Topography and Overburden Thickness, and the Base, Drainage, and Topographic maps, reveals several aspects of the relationship between the bedrock surface, overburden thickness, and present-day land surface. (1) The largest scale features of the present-day surface are a reflection of the bedrock surface. Where the elevation of the present-day surface is highest, there also the bedrock surface is highest; where the elevation of the present-day surface is lowest, there also the bedrock surface is lowest. Where present relief is greatest, bedrock relief is also greatest. Where the present-day surface is cut by large valleys, there also the bedrock surface is cut by large valleys.
(2) Although the largest scale features of the present-day land surface are a reflection of the bedrock topography, the

largest scale features of the bedrock topography are not always reflected in the present-day topography. Note the buried valleys northwest of Kenyon and between Belle Creek and the North Fork Zumbro River. (3) Present-day relief is not as extreme as bedrock relief. (4) Most landforms of the uplands and valley floors are formed in overburden. Valley walls are commonly formed in bedrock.

Consolidated Materials

In Goodhue County, platform sedimentary rocks of early Paleozoic age unconformably overlie volcanic and clastic rocks of the Keweenawan (Craddock, _in_ Sims and Morey, 1972, p. 417) and are in turn unconformably overlain by fluvial sediments of Cretaceous age, and glacial, fluvial, glaciofluvial, lacustrine, colluvial, and aeolian sediments of the Pleistocene and Recent. The Sloan-Austin map of bedrock geology (Sloan and Austin, 1966) (Appendix A, Figure #2), and Schwartz' and Austin's stratigraphic columns of southeastern Minnesota (Appendix A, Figure #3), show the generalized structure, composition, distribution, age, and stratigraphic relationships of the individual rock units.

I constructed the Map of Bedrock Geology (Plate VI) so that I could have a map corresponding in scale to my other maps. I also knew from field experience and well log perusal that the Windrow Formation consists primarily of unconsolidated material, and that there is more structure in Goodhue County and deeper bedrock valleys than indicated on the Sloan-Austin map.

Examination of the Map of Bedrock Geology, its legend, and the accompanying cross-sections, and their relationship to the Base Map, reveals that: (1) Virtually flat-lying, relatively thin, minimally faulted rocks of Cambrian and Ordovician age underlie Goodhue County. (2) Cambrian rocks --sandstones, shales, limestones, and dolomites of the Dresbach, Franconia, St. Lawrence, and Jordan formations--occur as the uppermost units in the northeastern part of the county in the valleys of the Mississippi and Cannon rivers, Belle, Spring, Hay, Bullard, and Wells creeks.
(3) Ordovician rocks--dolomites, limestones, sandstones, and shales of the Prairie du Chien Group, St. Peter, Glenwood, Platteville, Decorah, and Galena formations--occur throughout the remainder of the county. (4) Approximately two-thirds of the county is underlain by limestones and dolomites of the Galena, Platteville, and Prairie du Chien formations. Approximately one-sixth of the county is underlain by sandstones of the St. Peter and Jordan formations. The remainder of the county is underlain by the mixed lithologies of the Dresbach, Franconia, St. Lawrence, and Decorah formations. (5) The thickest and most resistant units, the Galena Formation and the Prairie du Chien Group, have the greatest area of exposure on the bedrock surface.
(6) The thinnest unit, the St. Lawrence Formation, has the

least area of exposure on the bedrock surface. (7) Although the rocks of Goodhue County are basically flat-lying and minimally faulted, there are several interruptions to this pattern. A general dip to the west of approximately ten feet per mile is interrupted in the east center by the Red Wing anticline and in the northeast by the Red Wing fault. The anticline has been breached; the fault is a short east-west dip slip fault of approximately 150 feet displacement (see Appendix C, Figure #7). The general structure is also interrupted by numerous minor changes in degree and direction of dip--the rocks are locally warped into broad gentle swells and swales--and the possibility of a substantial flexure, or fault, along the course of Belle Creek.

Certain small scale bedrock features, noted in the field, but unable to be shown on the maps or cross-sections, include unconformities on the bedrock surface, joints and joint trends, and miscellaneous solution features. Unconformities cutting across one or more formations commonly occur in the northern part of the county. These unconformities, seen in roadcuts, their form entirely obscured on the land surface by unconsolidated materials, vary in size to tens of feet in depth and width. The largest and most pronounced of these unconformities, seen at We-037, was not successfully photographed; a smaller and much less pronounced unconformity is seen in Appendix C, Figure #8. Jointing occurs in the thick carbonate units--

the Galena, Platteville, Shakopee and Oneota formations (see Appendix C, Figures #8, #9, and #11). I did not measure the trends of these joints. However, Bruce Olson (April 3, 1986, oral communication) of the Minnesota Geological Survey reports that for southeastern Minnesota there are two major conjugate sets of joints. One of these sets trends from thirty to fifty degrees east of north and fifty to seventy degrees west of north. The other set trends north-south and east-west. Solution features, most apparent in the Prairie du Chien Dolomite, less so in the Galena Limestone, and least in the Platteville Limestone, occur as joint enlargements, small sinks, and scattered caves (see Appendix C, Figure #9). Joint enlargements occur wherever the carbonate units are exposed. Open sinks in the Galena Formation, up to several feet across and ten feet deep, occur on the surface in the eastern part of the Sogn quadrangle. Larger filled sinks, up to twenty feet across and thirty feet deep, occur on the top of the Prairie du Chien rocks in the Goodhue East quadrangle. The latter sinks have no surface expression and are seen only in road cuts and quarries. Small caves, just large enough to squeeze into, occur in the Prairie du Chien rocks of the Welch quadrangle near the mouth of Belle Creek and immediately inland from Prairie Island. There is no known cave system in the county and there appears to be little if any open underground drainage system.

A comparison between the Map of Bedrock Geology and the Base, Drainage, and Topographic maps reveals several aspects of the relationship between the structure, distribution, composition, and age of the bedrock units and the surface configuration of Goodhue County. (1) The elevation of the land surface appears to be a reflection of the thickness and resistance of various rock units. The uplands are generally supported by thick carbonate units, the Galena Limestone and the Prairie du Chien Dolomite. The valleys cut deeply into the thin and less resistant underlying units. (2) Variation in slope angle and length appears, at least along the valleys of Prairie Creek, the Little Cannon River, Belle Creek, and the Mississippi River, to reflect the thickness and resistance of the various rock units. Long gentle slopes form on the Decorah Shale, short steep slopes on the Platteville Limestone, long nearly flat but sometimes short and very steep slopes on the St. Peter Sandstone, wide benches on the top of the Prairie du Chien Dolomite, and high, very steep slopes within that dolomite. (3) The configuration of bedrock valleys is related to bedrock thickness and resistance. The valleys commonly are narrow, deep, meandering, and entrenched where cut into the Prairie du Chien Dolomite--note the lower part of Belle Creek and the central part of the Cannon River. The valleys are broad and shallow where they cut into the St. Peter Sandstone--note the valley of Prairie Creek, upper Belle Creek, and the central part of the North Branch Zumbro River. (4) The county's overall dendritic drainage pattern appears to have little to do with the bedrock structure, but rather is developed in the overlying unconsolidated materials.

(5) The grid-like pattern of the bedrock valleys may reflect the fracture pattern of the underlying rocks. The Mississippi, Cannon, Little Cannon, and Zumbro rivers, and Belle, Spring, Hay, Wells, and Bullard creeks follow joint trends. Belle Creek may also follow a fault.

Unconsolidated Materials

Numerous kinds of unconsolidated material are found in Goodhue County. Three maps, at scales of interest to this study, depict tle surficial and/or Quaternary geology of Goodhue County: (1) Map of Surface Formations of Minnesota, 1916, by Leverette and Sardeson (scale 1:500,000) (Leverette and Sardeson, 1932); (2) Geologic Map of Minnesota: Quaternary Geology, 1979, by Goebel and Walton (scale 1:3,168,000); and (3) Geologic Map of Minnesota: Quaternary Geology, 1982, by Hobbs and Goebel (scale 1:500,000). A fourth set of maps depicts the county's soils (Soil Survey of Goodhue County, Minnesota, 1976, scale 1:15,840). The first three maps delineate the composition and distribution of geologic materials occuring on the surface of Goodhue County. Their legends elucidate the probable stratigraphic sequence, genesis, and age of those materials. Copies of the Goodhue County segment of those maps and legends are seen in Appendix A, Figures #4, #5, and #6. A general soils map of the county is seen in Appendix A, Figure #7.

These maps and legends indicate that Paleozoic rock is exposed along some of the major streams in the northern part of the county, glacial drift ("old gray"), older than the Wisconsinan and possibly Kansan in age, covers the upland in much of the county, younger glacial drift, possibly Illinoian in age ("old red") occupies a small area in the northern part of the county, glacial outwash, younger than the old gray drift, and possibly from Wisconsinan ice, occupies the extreme northwest corner of the county, glacial outwash in the form of terrace sands and gravels, occupies the edges of many valleys, loess occurs in various parts of the county, recent alluvium occupies the centers of large valleys and soils have formed on all of these materials. These maps, however, vary considerably--most notably in the presence and distribution of loess, the presence and distribution of colluvium, and the presence and distribution of bedrock residuum.

I constructed the Map of Surficial Geology (Plate IX) so that I could resolve the disparate information found on the Leverette-Sardeson, Goebel-Walton, and Hobbs-Goebel maps, have a map corresponding in scale to my other maps, and learn firsthand how the surficial materials appear in the field, how they relate to one another, and how they affect the land surface.

During fieldwork, well log examination, and map and cross-section construction, I found that: (1) The present-day land surface is a composite of bedrock and surficial materials, its configuration inherited from the original depositional form of those underlying materials and resulting from the interaction of erosional processes and time on the composition and distribution of those materials and forms. (2) Most unconsolidated materials found at the surface are Pleistocene and Recent in age and the micro-features, e.g. small hills, ridges, and valleys, are usually younger than these materials. The surface macro-features, such as the uplands and bedrock valleys, are far older than the surface materials. (3) The older surficial materials are found on the higher parts of the landscape, and the younger surficial materials are found in the lower parts of the landscape. (4) Where glacial drift is thickest, the elevations are greatest. (5) Where glacial drift is thinnest, the relief is greatest. (6) Slopes are gentler where the underlying material is unconsolidated and steeper where underlying material is consolidated. (7) The occurrence and age of the Windrow Formation is not well documented and needs to be studied in greater detail. (8) The surface in the eastern and northeastern part of the county appears to be excessively eroded as compared to the rest of the county.

I also found that: (1) most of the Goodhue County land surface is indeed developed on glacial till, although glacial outwash occurs in limited areas of the northwest and north; (2) there are several glacial drifts exposed within the county and some are separated by stonelines; well logs reveal that several other drifts and stonelines may exist in the subsurface; (3) there is a distinctive reddish sand and gravel in the northern part of the county which is probably the Illinoian outwash indicated on former maps, but which occurs over a larger area than previously noted; (4) the central parts of stream valleys and upland drainageways is indeed filled with recent alluvium; (5) loess, a fine grayish silt, covers a great deal of the surface in the central part of the county, occurs sporadically elsewhere, and is found within terrace sands and gravels at Red Wing (We-04) and Lake City (LC-01) and within colluvial deposits near Welch (We-05); (6) bedrock is exposed at or very close to the surface in the walls of many large valleys; (7) loess, colluvium, and drift obscure large but very local unconformities on the bedrock surface; and (8) many of the older unconsolidated units are truncated by younger unconsolidated units.

Details of the surficial materials, seen in the field but too small to be mapped, include sinks in the top of the Prairie du Chien Group which are filled with Windrow Clay, a knobby landscape near the town of Goodhue, "cleaned noses" of Platteville Limestone covered only with loess and soil, alongside the Little Cannon River, scattered erratics, huge angular blocks of dolomite on some steep hillsides, knobs of

Prairie du Chien Dolomite sticking up through thick layers of unconsolidated materials east of Cannon Falls, peat-like organic materials overlying the Windrow near Goodhue, clays and silts underlying the loess in the Kenyon Quarry (K-06), and an orange layer of sand in the Goodhue County Highway Department quarry (Wa-03).

Examination of the Map of Surficial Geology, its legend, and the accompanying cross-sections reveals the following: (1) The surficial materials of Goodhue County are compositionally and texturally diverse, and include boulders, cobbles, gravels, sands, silts, clays, and mixtures of these. (2) The surficial materials are genetically diverse--they are of marine, glacial, fluvial, glaciofluvial, colluvial, residual, and aeolian origin. (3) The surficial materials are of differing age--Ordovician, Cretaceous, Pleistocene, and Recent. (4) Most of the county has developed on glacial and aeolian material, smaller areason glaciofluvial and fluvial sediments, and very limited areas on residual and colluvial material. (5) Glacial till and loess occur at the surface in most of the southwest, central, and northern parts of the county. Glacial outwash occurs sporadically in the northeastern part of the county, between Kenyon and Dennison, and in a limited area between Zumbrota and Concord. Fluvial materials occur alongside all streams and within all major valleys. Residual material occurs sproradically at the top of steep slopes. Colluvial material occurs on and at the base of steep slopes alongside major valleys.

A comparison between the Map of Surficial Geology, the accompanying cross-sections, and the Base, Drainage, and Topographic maps reveals several aspects of the relationship between thickness, distribution, composition, and age of the surficial units and the surface configuration of Goodhue County. (1) The elevation of the land surface reflects not only the elevation of the bedrock surface, but also the thickness of the overburden. (2) The relief and variation in slope reflect the configuration of the bedrock surface, the depositional form of the unconsolidated materials, and the lithological composition and textural character of the unconsolidated materials. (3) The drainage pattern reflects both the configuration of the bedrock surface and the erosional form of the unconsolidated materials.
(4) Particular kinds of unconsolidated materials have affected the land surface configuration in particular and distinctive manners. The glacial till has left a gently undulating or rolling upland surface cut in many places by the drainageways of intermittent streams, the outwash has left small knolls and ridges on the lower more subdued northern uplands. The Windrow Formation has left knobs on the plain-like surface between Goodhue and Bellechester. The terrace sands and gravels have left well-drained benches high above modern rivers. The loess has blanketed upland surfaces and filled small irregularities in that surface.

The colluvium has decreased the steep slopes on the walls of bedrock valleys and left colluvial fans on valley floors. The alluvium underlies nearly level surfaces alongside all streams. (5) The composition and distribution of unconsolidated materials affects the land surface configuration, e.g. the thickness of till commonly determines the general elevation of the land surface. However, the land surface configuration also affects the distribution of particular unconsolidated materials, e.g. loess commonly fills old saddles, colluvium forms on steep slopes, and alluvium forms in valleys. (6) There is a complex history of erosion and deposition of all unconsolidated materials in Goodhue County.

Miscellaneous Remarks

Several aspects of Goodhue County geology and geomorphology are evident after completion of all maps. There is a considerable variety of sedimentary rocks in Goodhue County. There is a considerable variety of unconsolidated materials on the surface of Goodhue County. There is relatively little variation in geologic structure in Goodhue County. There may be some difference of depositional and/or erosional process between the eastern and western parts of the county. The time of exposure of the surface to surface processes appears to be relatively uniform throughout the county. These observations lead to the following conclusions: (1) the great variation in material and little variation in geologic structure allows material composition and texture to play a greater role in land surface configuration than it might in other areas; (2) the surface configuration of Goodhue County is dependent on the distribution and composition of both consolidated and unconsolidated materials; and (3) the surface materials of Goodhue County are fairly young, yet certain of the surface features may be quite old--erosion of the bedrock surface could go back into the Paleozoic.

IV. PROCESS AND TIME

Introduction

Process and time, as well as material (structure), affect the land surface configuration of Goodhue County. Process refers to those geologic activities which modify structure. Time is the dimension over which processes act to alter structure. Land surface configuration is the result of processes modifying structure over time.

Geologic processes are both endogenic, that is, occurring within the earth, and exogenic, occurring on the surface of the earth. The endogenic processes are diastrophism and volcanism; the exogenic processes are weathering, erosion, and deposition. Both types of processes are controlled by heat and gravity; both act to build-up and to break down the land surface. The type, frequency, intensity, and duration of endogenic processes is controlled primarily by the position of the area in relation to lithospheric plates, plate junctions, and hot spots. The type, frequency, intensity, and duration of exogenic processes is controlled primarily by climate, which is in turn controlled by geographic location, geomorphic position, and physiographic aspect.

Time is the factor allowing for the evolution or change of land surface configuration. Processes interact among themselves and with structure during all times, and changes in land surface configuration lead to other changes in land surface configuration. Without time and change, structure alone would dictate land surface configuration.

Process in Goodhue County

Processes--diastrophism, volcanism, weathering, erosion, and deposition--affect the surface configuration of Goodhue County. Streams are the primary agents operating today to change surface configuration. Stream erosion appears virtually everywhere--the entire land surface is intricately and dendritically dissected. A myriad of small stream courses cut into the glacial and post-glacial materials. Broad, deep, and locally meandering valleys cut into Paleozoic bedrock. The streams occupying these valleys, often dark-colored, clay- and silt-laden, indicate active transport of material. Stream deposition, although of far lesser impact than stream erosion, is presently significant in shaping the surface in the vicinity of Prairie Island. Sheet wash, slumping, groundwater solution, weathering, and wind erosion are also taking place at present, but their impact on the mappable land surface is minimal.

Certain processes, active in the past, have greatly influenced the surface configuration of Goodhue County. Listed in order of decreasing significance--marine deposition, stream erosion, glacial deposition, stream deposition, downslope movement, glaciofluvial deposition, tectonic movement, groundwater solution, and wind deposition--all have influenced the surface configuration of Goodhue County. Some type of sheetwash or wind erosion may also have had a considerable impact on the surface. Marine deposition is responsible for the bedrock of Goodhue County. This deposition, in the form of horizontal, thin, areally persistent, relatively soft rocks, has influenced the drainage pattern, angle of slope, and position of slopebreaks. Past stream erosion has been responsible for the large bedrock valleys. Glacial deposition has influenced the heights of uplands. Stream deposition has partially filled bedrock valleys, built terraces along many streams, and formed levees, bars, deltas, and islands in the Mississippi valley. Downslope movement has produced steep colluvial slopes along the major valleys. Glaciofluvial deposition has left patches of outwash between White Rock and Welch. Diastrophism has been responsible for the Red Wing anticline which, breached, has filled with Cretaceous sediment leaving a subdued landscape. Faulting may have influenced the course of Belle Creek. Wind deposition, in the form of loess, has filled old hollows. Groundwater solution has enlarged joints in carbonate rocks. Sheetwash or wind erosion are perhaps responsible for the "residual" surface in the northeast and east central parts of the county (see discussion on p.76-77).

Processes, present and past, of minimal impact on the present-day surface include glacial and marine erosion, all types of coastal processes, biological processes, and volcanism. At this scale and in this area, exogenic processes are of far more significance in land surface development than are the endogenic processes.

Time in Goodhue County

The passage of time has also had an effect on the surface configuration of Goodhue County. Although the effect of time on this scale is difficult to ascertain, five general statements can be made concerning its effect on surface configuration. (1) The present drainage pattern has undoubtedly evolved over time, and during that time has become more integrated. (2) Relief has changed over time, and since glaciation--the most recent episode of major deposition in the county--has probably increased. (3) Approximately ninety million years, the time since deposition of the Upper Cretaceous Windrow Formation, has been available to produce the present-day land surface configuration in Goodhue County. (4) Certain aspects of land surface configuration, e.g. the small upland drainageways, are younger than the materials found within them. Other aspects of surface configuration, e.g. isolated bluffs and the large bedrock valleys, are far older than the materials found on and within them. (5) Materials on the higher parts of the landscape are older than materials on the lower parts of the landscape.

Geologic History of Goodhue County

This geologic history of Goodhue County has been compiled from the literature, well logs, field observation, and the Maps of Bedrock and Surficial Geology. Evidence for this history comes from the geologic materials and the surface configuration of Goodhue County and surrounding areas.

During the late Precambrian, the Keweenawan, as documented by the rocks of the Fond du Lac and Hinckley formations (Craddock, _in_ Sims and Morey, 1972, p. 417), as seen in well log RW-W23 and others, Goodhue County was part of a broad deltaic plain crossed by a series of meandering streams (Morey, _in_ Sims and Morey, 1972, p. 440). These streams flowed east and southeast from an old granitic highland into a half graben-like basin, a segment of the Lake Superior syncline (see Appendix A, Figure #1).

Following prolonged erosion at the end of the Keweenawan, as documented by the profound unconformity on the top of the Keweenawan rocks, Paleozoic seas advanced northward across central North America and by Late Cambrian time had covered Goodhue County and extended as far north as Taylors Falls. The basal formations of this sequence, the Dresbachian sandstones of the Mt. Simon, Eau Claire, and Galesville formations, are conformably overlain by the Franconian and Trempealeauan Ironton, Franconia, St. Lawrence, and Jordan formations (Austin, in Sims and Morey, 1972b., p.460) (Austin nomenclature, see Appendix A, Figure #3). These rocks all record the transgression and regression of a shallow epeiric sea.

During Early Ordovician time, as documented by the dolomite and sandstone of the Prairie du Chien Group, which rests conformably on the Upper Cambrian rocks, the seas cleared and deepened (ibid., p. 467). At times, however, during deposition of the Shakopee Formation, Goodhue County was a tidal flat, as documented by the occurrence of stromatolites, snails (Ophileta), cephalopods (Aphetoceras), ripplemarks, mudcracks, and flat-pebble conglomerates (Sansome, 1972, p. 501). After Prairie du Chien time, the seas retreated from Goodhue County and much of central North America. A regional unconformity marks this retreat.

During the Middle Ordovician, seas again advanced northward across central North America. Along the northern margin of this advancing sea was deposited the St. Peter

Sandstone. As the sea moved northward it deposited, conformably and in order, rocks of the Glenwood, Platteville, Decorah, and Galena formations. This sea was warm, shallow, and teaming with invertebrates. Varying depth, sediment influx, agitation, and organic production led to varying lithologies.

Sometime after the Middle Ordovician and presumably after the Devonian, the Paleozoic seas retreated from Goodhue County and all of southeastern Minnesota. The youngest Paleozoic rocks in the county are those of the Middle Ordovician Galena Formation. Farther south are Middle and Upper Ordovician rocks of the Dubuque and Maquoketa formations. Along the extreme southern edge of the state, in Mower County, are Middle Devonian rocks of the Cedar Valley Formation. Seas have apparently remained off Goodhue County and all of eastern Minnesota from that time to the present.

Sometime during the middle or late Paleozoic, and possibly during the early or middle Mesozoic, folding and faulting took place in Goodhue County and surrounding areas. The Red Wing and Belle Plain faults cut Precambrian, Cambrian, and Ordovician rocks and are truncated by Pleistocene sediments. The Red Wing-Rochester anticline involves all Paleozoic formations up to and including the Galena Formation. It does not involve Cretaceous sediments of the Windrow Formation. If a fault exists alongside Belle Creek, it also cuts the Paleozoic formations.

Sometime during or after the presumed Paleozoic folding and faulting of Goodhue County rocks, came a times of erosion and solution. Late Cretaceous sediments of the Windrow Formation appear in outcrop resting unconformably on the eroded top of the Red Wing-Rochester anticline and in channels and sinks of the Galena and Prairie du Chien dolomites (C-04 and GE-06). Erosion occurred between the Middle Devonian and Late Cretaceous. The most likely times of erosion were during the Permian and Triassic when the continents were relatively high. The extent of erosion can only be known, however, when the subsurface extent of the Windrow Formation is better known: at present this extent is not known because much of the Windrow has probably been classified as fluvial, glaciofluvial, or undifferentiated Quaternary deposits. Solution most likely occurred, possibly during the Jurassic and certainly during the Cretaceous, when warm epi-continental seas encroached from the west and Minnesota experienced a warm moist climate (Austin _in_ Sims and Morey, 1972a., p. 511).

During most of the Mesozoic, much of central North America, including Goodhue County, remained high. However, later in the Mesozoic, seas again trangressed central North America, and by Late Cretaceous time extended all the way from the Gulf of Mexico to the Arctic Ocean. The eastern margin of this seaway crossed western Minnesota. Goodhue County, several hundred miles east of the seaway, appears to have been a low landscape at least partially covered by a meandering stream (E. Force, oral communication, October 17, 1984). The Windrow sediments, laid down on the eroded and dissolved surface of Paleozoic rock, represent deposits of this stream.

During the Tertiary, Goodhue County and the rest of Minnesota remained high and underwent only mild erosion. Except for a few lake sediments and iron ores, no rocks or landforms have been recognized from this time. It is possible, however, that the Windrow Formation is of Tertiary age (Austin, in Sims and Morey, 1972a., p. 512).

During the Quaternary, the climate changed dramatically. Glaciers advanced and retreated across Minnesota, moving back and forth from the northeast, north central, and northwest. Evidence for age of the till, outwash, and terrace gravels comes from the texture and composition of the materials, and the texture of the land surface developed on the materials. In Goodhue County, subsurface materials may record the very poorly known movement of the Nebraskan ice; they may also provide evidence of pre-Nebraskan glaciation. (Note: At present, in Minnesota, glacial materials deposited before the Wisconsinan are simply referred to as pre-Wisconsinan. I have, however, retained the terms Nebraskan, Kansan, and Illinoian because there is a great difference in the age, texture, and physiographic expression of these materials. I do not wish to obscure these distinctions by grouping them together.) Surface tills and outwash and miscellaneous landforms record the advance and retreat of the somewhat better known movement of Kansan and Illinoian ice. Kansan ice apparently covered the entire county leaving varying thicknesses of drift throughout the county. Melting of Illinoian ice spread outwash into the northern areas of the county. Terrace sands and gravels, along the Mississippi, Cannon, and Zumbro rivers, record the melting of Wisconsin ice to the north and west.

Late in the Pleistocene, after ice had left Goodhue County but still remained in the state, and during the Recent, winds blew off the retreating glaciers and across barren outwash plains and distributed loess throughout the county. Terraces were constructed and benches cut along the major streams. Downslope movement was active along the major valleys. Sheet wash and/or wind erosion may have lowered the surface in the eastern part of Goodhue County. A succession of tundra, taiga, mixed forest, deciduous forest, and prairie clothed the land (Sansome, 1983, p. 212). Soils formed.

Since about 1830 or 1850, when man began to clear and cultivate the land, there has been a renewed cycle of alluviation. Open fields have permitted great amounts of runoff which has carried topsoil downslope and dropped it in side ravines and valleys. Base level of the major streams, lowered after the Pleistocene, has moved rapidly up the side streams cutting deeply into this soft material. Most side valleys have a knickpoint ranging to more than fifteen feet in height.

Today, sheetwash and stream erosion continue from the fields, although at a lesser rate than thirty years ago. Alluviation continues in the valleys. The knickpoints continue their rapid retreat, sometimes at the rate of tens of feet per year. Man extracts, transports, and redeposits rocks and gravel, destroys, moves, and buries erratics, cuts and fills for roads and homes, and dams the intermittent streams.

Figure #2

STRATIGRAPHIC COLUMN
AND ORDER OF GEOLOGIC EVENTS FOR GOODHUE COUNTY

Recent	cutting of knickpoints deposition of alluvium formation of soils
Late Pleistocene	deposition of loess, colluvium, and Wisconsinan outwash cutting and deposition of benches and and terraces along major streams
Pleistocene	erosion of glacial drift in northeast deposition of Illinoian ("old red", stony) drift in north deposition of Kansan drift ("old gray") throughout county probable deposition of Nebraskan drift
Tertiary	erosion? deposition of Windrow Formation?
Cretaceous	deposition of Windrow Formation
Middle Paleozoic to Cretaceous	erosion and solution of Paleozoic rocks (erosion most likely in Permian and Triassic, solution most likely in Jurassic and Cretaceous)
Middle to Late Paleozoic?	folding and faulting
Ordovician	deposition of Galena Formation deposition of Decorah Formation deposition of Platteville Formation deposition of Glenwood Formation deposition of St. Peter Sandstone erosion deposition of Prairie du Chien Group
Cambrian	deposition of Jordan Sanstone deposition of St. Lawrence Formation deposition of Franconia Formation deposition of Ironton Sandstone deposition of Galesville Sandstone deposition of Eau Claire Formation deposition of Mt. Simon Sandstone
Precambrian	deposition of Hinckley Formation deposition of Fond du Lac Formation

V. ORIGIN OF THE LAND SURFACE

Discussion

Figure #3

FACTORS CONTROLLING LAND SURFACE CONFIGURATION

Time
- synchroneous
- progressive

***Process**
- endogenic (diastrophism, volcanism)
- exogenic (weathering, erosion, deposition)

LAND SURFACE CONFIGURATION

****Structure**
- geologic structure (configuration of bedrock surface, thickness of overburden; thickness, inclination, persistence, and distribution of rock units)
- geologic materials (consolidated, unconsolidated; composition, texture, distribution)
- geographic location, geomorphic position, physiographic aspect)

* **Process** is powered by heat and gravity; endogenic process is dependent primarily on the position of the area in relation to the earth's lithospheric plates, plate junctions, and hot spots; exogenic processes are dependent primarily on climate, which in turn is dependent on geographic location and physiographic aspect.

** **Structure** is dependent on past processes.

The configuration of the present-day land surface of Goodhue County, as elsewhere, is a result of the interaction of structure and process over time. Structure, in this study, refers to the geologic structure and materials making up the land surface, and the geomorphic position and aspect of that surface. Process refers to the geologic activities that modify the structure: these activities include diastrophism, volcanism, weathering, erosion, and deposition.

There are three major questions concerning the origin of the land surface configuration in Goodhue County. (1) What effect does structure have on the land surface configuration? (2) What effect does process have on the land surface configuration? (3) What effect does time have on the land surface configuration? An attempt is made to answer each of these questions in the following paragraphs.

An examination of the Maps of Bedrock Geology, Bedrock Topography, Overburden Thickness, and Surficial Geology and the comparison of those maps to the Base, Drainage, and Topographic maps reveals that the geologic structure of Goodhue County has greatly affected the county's surface configuration. The configuration of the bedrock surface, thickness of overburden, near horizontal bedding, relatively thin, yet areally persistent rock units, and the faulting, folding, fracturing and solution of the rocks have affected elevation, relief, drainage pattern, and slope.

The configuration of the bedrock surface and the thickness of overburden have affected elevation, relief, drainage pattern, and slope. Bedrock topography controls the larger scale features of the county; the thickness and configuration of overburden controls the majority of smaller scale features. Comparison of the Base Map with the Maps of Bedrock Topography and Overburden Thickness supports the following conclusions: (1) Where the elevation of the land surface is lowest, the elevation of the bedrock surface is lowest. (2) Where present relief is greatest, relief on the bedrock surface is also greatest. (3) Where the present surface is cut by large valleys, there also the bedrock surface is cut by large valleys. (4) The closer the bedrock surface is to the present-day surface, the greater control the bedrock topography has on the present-day topography. (5) Although the largest scale features of the present surface are heavily controlled by features of the bedrock surface, this is not always true in reverse. Several large bedrock valleys have no reflection in the present-day surface. (6) The thicker the unconsolidated materials, the greater their effect on the present-day surface. (7) Minimal thicknesses of unconsolidated materials control the distribution of discrete landforms.

The generally soft, horizontally bedded, relatively thin, yet areally persistent rock units have affected drainage pattern and slope. Field observation and the comparison of the Base Map with the Map of Bedrock

Topography support the following conclusions: (1) The generally horizontal and areally persistent beds may have helped give rise to the dendritic drainage pattern. (2) The drainage pattern has, in turn, promoted the development of an integrated topography. (3) The relatively thin, yet variant thicknesses of rock units have contributed to the position, location, and frequency of slopebreaks. (4) The horizontal bedding has allowed for development of such flat-topped features as the Stanton mesas, and Barn, Sorin's, and Rattlesnake bluffs.

Field observation and comparison of the Base Map with the Map of Bedrock Geology show that fractures, folds, and solution have affected the surface configuration. Fractures, faults and joints, may have affected drainage. Joints may have influenced the location of the Mississippi and other major rivers. A fault may have also influenced the location of Belle Creek. The Red Wing fault has not affected the present-day land surface. The Red Wing-Rochester anticline has affected the location of the Windrow Formation, which in turn has produced a subdued topography. Solution has enlarged joints and produced sinks in both the bedrock surface and land surface.

The diversity in composition and texture of rock materials has affected the relief, drainage pattern, and slope of Goodhue County. Comparison of the Base Map with the Maps of Bedrock Topography, Bedrock Geology, and Surficial Geology indicate that: (1) consolidated materials have affected surface configuration on a far larger scale than unconsolidated materials; consolidated materials are the upland-, valley-, and cliff-formers; unconsolidated materials commonly control angle and density of slope and the form of most small scale features; (2) the steepest slopes are supported by consolidated materials; the gentle slopes are supported by unconsolidated or very loosely consolidated materials; (3) the varying mechanical resistance of the rock units partially controls major features of the land surface--uplands and long stretches of valley floors are commonly underlain by the most resistant beds (the carbonates); (4) very soft rock units, such as the Decorah Shale, have a minimal area of exposure, both on the present-day surface and on the buried bedrock surface; and that (5) particular rock units affect configuration in particular ways--a) limestone and dolomite support the uplands, form the cliffs, and undergo solution, (b) shale weathers readily, slumps, and forms gentle slopes, and (c) sandstone disaggregates readily, is easily carried away, and is commonly found on cliffs, alongside valleys, and on broad benches.

The distribution of material has affected density of drainage and density and angle of slope. Comparison of the Base Map with the Map of Surficial Geology indicates that spatial distribution of material, along with the passage of time and placement in the drainage net, has given rise to varying densities of drainage. Note the difference in drainage density between the terrace sands near Lake City and along Prairie Creek and the glacial till near Dennison. The comparison also reveals the spatial distribution of material, along with the passage of time and placement in the drainage net, has also affected the density and angle of slope. Note the bedrock bluffs along the Mississippi and the alluvial material within the Mississippi valley. Field, map, and cross-section work indicate that the vertical variation in materials, e.g. stratigraphic placement, has over time affected lateral variation and has given rise to differing angle of slope.

Geographic location, geomorphic position, and physiographic aspect affect the elevation, relief, and slope of Goodhue County. Geographic location dictates elevation and affects relief. It also heavily influences climate, which in turn heavily influences process, which in turn heavily influences surface configuration. Geomorphic position relates to elevation and controls slope. Physiographic aspect relates to density, direction, and inclination of slope and thus affects climate, which as noted above affects process, which in turn affects all aspects of surface configuration.

Geologic processes, past and present, have had a substantial impact on the surface configuration of Goodhue County. Marine deposition in the form of flat-lying sedimentary rocks has influenced the drainage pattern, angle of slope, and position of slopebreaks. Glacial deposition, outwash and till, has influenced the relative heights of upland surfaces. Stream erosion has intricately and dendritically dissected the land. Stream deposition has affected surface configuration along the courses of the major rivers and streams. Wind deposition has, in the form of loess, obscured irregularities of older surfaces. Some type of sheetwash or wind erosion appears to have greatly affected the earstern part of the county (see discussion on p. 76-77). Downslope movement has produced steep colluvial slopes. Diastrophism has been indirectly responsible for a subdued topography near the town of Goodhue.

Time has also had an effect on the surface of Goodhue County. Time elapsed since glaciation has allowed drainage nets to become more integrated and relief to increase.

General Speculation Concerning Land Surface Origin

Observations of the Base, Drainage, and Topographic maps, and the Maps of Bedrock Geology, Bedrock Topography, Overburden Thickness, and Surficial Geology lead to speculations concerning the origin of the land surface configuration in Goodhue County. These observations and speculations are presented in the following paragraphs. They are used to support further speculations found in the following subsection.

Examination of the Base and Topographic maps reveals that the land surface is highly dissected and well-integrated, the slopes vary from gentle to steep, and the elevation, relief, and texture of the surface changes across the county. These observations suggest that the county's mid-scale surface features are controlled by stream erosion and that the variation in slope is primarily due to location in relation to principal streams. Slope variation, however, may also be due to variation in structure, process, or time. The variation in elevation, relief, and texture of the land surface is certainly due to proximity to principal streams, and probably also due to variation in underlying geologic structure and material, past and present processes, nature of the vegetation, and time of exposure.

Examination of the Base and Drainage maps reveals that the drainage pattern is well-integrated and predominately dendritic, there are few lakes or wetlands in the county, and that the major rivers and streams flow in a limited number of directions and the smaller ones in all directions. It also reveals that the major streams flow in deep, broad, and flat-floored valleys, the smaller streams flow in narrow, shallow valleys, and that the drainage density changes across the county. These observations support the following conclusions: (1) The stream pattern has had sufficient time to become well-integrated. (2) The surface may originally, after glacial deposition, have had few lakes and wetlands. It is more likely, however, that low wet areas did exist and that they were either drained or filled since that time. (3) The control on valley location of major streams is different than that on the smaller streams. (4) The major streams flow in valleys which were carved before the current cycle of erosion. The lesser streams flow in valleys carved during the present cycle of erosion. (5) The nature and amount of precipitation, composition and permeability of underlying materials, topography, nature of vegetation, differing amounts of time for development, relationship to major streams, and biases in map-making may all account for the variation in drainage pattern and density.

Examination of the Map of Bedrock Geology reveals that basically flat-lying, areally persistent, and relatively thin-bedded rocks of differing compositions form the uppermost consolidated units of Goodhue County. These rocks, of early Paleozoic age, have been deformed by slight tilting and minor faulting. These observations support the following conclusions: (1) Much of the variation in topography and drainage of Goodhue County could be due to variation in lithology. (2) Particular aspects of the land surface configuration could have developed anytime during the past approximately 450 million years. (3) Climate and geologic processes affecting Goodhue County have varied greatly over geologic time. (4) Faults, folds, and minor flexures may affect surface configuration.

An examination of the Map of Bedrock Topography reveals that there is more relief on the bedrock surface than on the present-day surface, most major surface features--the large valleys and uplands--are controlled by configuration of the bedrock surface, small features of the land surface are controlled by thickness of overburden, and that several large bedrock valleys--e.g. those northwest of Kenyon, south of Kenyon, and north of Zumbrota--have no reflection in the present-day surface. An examination of the Map of Overburden Thickness reveals that overburden thickness varies throughout the county, is generally thickest in the southwest and central parts of the county and thinnest in the north and northeast. Overburden is also generally thickest on the floors of major valleys and the tops of broad uplands, and thinnest on valley sides and the tops of small uplands. The examination also reveals that topography of the uplands and valley floors is controlled in the southwest by unconsolidated materials and in the northeast by configuration of the bedrock surface.

These observations support the following conclusions: (1) The surface configuration of Goodhue County has changed through geologic time. (2) The base level of Goodhue County has varied over geologic time. (3) There has been a considerable amount of erosion and later deposition since the bedrock was laid down. (4) Bedrock valleys are older than the current cycle of erosion. (5) Certain aspects of land surface configuration are younger than the surface materials; other aspects of land surface configuration are older than the surface materials. (6) Varying amounts of overburden were deposited in different parts of the county, or generally the same amount was deposited everywhere, and erosion has differentially removed it.

Observation of the Map of Surficial Geology reveals that the surficial materials of Goodhue county are compositionally, texturally, and genetically diverse--they are of marine, glacial, fluvial, glaciofluvial, colluvial, lacustrine, and aeolian origin. The surficial materials are also of differing ages--Ordovician, Cretaceous, Pleistocene (Kansan, Illinoian, Wisconsinan), and Recent. Observation also reveals that most of the surface has developed on glacial till and loess. These observations support the following conclusions: (1) details of surface configuration could be due to diversity of composition, structure, and texture of the underlying material; (2) configuration of the land surface could be due to differing age of surface material; (3) the microfeatures of the present-day surface are Pleistocene or Recent in age; (4) the macrofeatures may be of any age younger than the Middle Ordovician.

Detailed Examination of Land Surface Origin

Numerous questions remain concerning the origin of the land surface configuration in Goodhue County. These questions fall into six categories: (1) origin of the overall land surface; (2) origin of drainage features; (3) origin of topographic features; (4) integration of drainage and topography; (5) origin of small scale and miscellaneous features; and (6) age and evolution of the land surface. All questions, except for set five, arise from examination of the Base, Drainage, and Topographic maps. The questions concerning small scale surface features arise from field observation. Answers to these questions come from examination of the characteristic as well as seemingly anomalous features and materials.

Origin of the Overall Land Surface of Goodhue County

The following questions concern the overall land surface of Goodhue County: (1) Why does the elevation of the county range from approximately 670 feet to approximately 1275 feet? (2) Why is its relief approximately 600 feet? (3) Why is the land surface so irregular, yet well-integrated, the margins of the uplands and valleys so intricately dissected? (4) Why is the land surface higher in the southwest than in the northeast? (5) Why is the relief greater in the northeast than in the southwest? (6) Why are there distinct geomorphic regions in the county?

(1) Elevation is dependent on location and relief. Goodhue County is located in the interior of North America bordering its major river, underlain by relatively soft rocks and sediments, and has been exposed to subaerial

erosion for a substantial portion of the past 450 million years.

(2) Relief is dependent on the location of an area in relation to major drainageways, structure and composition of the underlying rock, processes at work on the land surface, and time during which these processes have been at work. In Goodhue County the rocks are nearly horizontal and relief is not a reflection of geologic structure. Thickness of unconsolidated materials, mainly glacial drift, varies greatly across the county. This additional material affects elevation and total relief, but not local relief. Composition of materials varies greatly across the county, but the drainage is dendritic which indicates that material composition has not greatly affected relief. It is possible that the northeastern portion of the county has been exposed to erosion longer than the southwestern portion--that glaciers covered the southwestern area at a later date. However, there is Kansan age drift throughout the county, and in a few, relief-wise unnotable places there is Illinoian drift. Time is thus not a major factor determining relief. Relief is primarily the reflection of differential stream erosion and placement in the North American drainage net.

(3) The irregular, integrated, intricately dissected land surface is the result of stream erosion on a relatively uniform surface over an extended period of time. No other

depositional or erosional process can explain this kind of topography.

(4) The land surface is higher in the southwest than in the northeast because the bedrock surface is higher in the southwest than northeast and, more importantly, the unconsolidated materials overlying the bedrock are far thicker in the southwest than in the northeast. Why then are the unconsolidated materials far thicker in the southwest than the northeast? Perhaps they were deposited in this manner due to irregularity of a single depositional event. Perhaps there were a greater number of depositional events in the southwest than northeast. This cannot be proven, however, without exhaustive subsurface work. Perhaps the unconsolidated materials in the southwest were laid down at a later date than those of the northeast, and consequently less eroded. Surface configuration however does not readily support this idea. Perhaps, as I believe, the unconsolidated materials were laid down in the same manner, at the same time, and at approximately the same thickness in both the southwestern and northeastern portions of the county. Process must then have been different in the two areas. The northeast part of the county has undergone far more erosion than the southwest: evidence for this exists in the thinness of the overburden, the "residual" aspect of the remaining drift (at least in exposure the eastern drift is more coarsely textured than that to the west). This "excessive" erosion was caused by the proximity

of this area to the Mississisippi River and some as yet unexplained sheetwash or wind erosion. Hobbs suggests, for a similar landscape in Winona County, that soil flow over permafrost may account for such a surface (Plate #3, in Balaban and Olson, 1984). I find no evidence of such flow. Could this surface be equivalent to the Iowan Erosional Surface? I know of no one who can answer that question.

(5) The bedrock surface has more relief than the present-day surface, and since that surface is closer to the present-day surface in the northeast than in the southwest, the northeast has more relief. Why then does the bedrock surface have more relief than the present-day surface? The bedrock surface has had more time to undergo than the present-day surface and the base levels at those earlier times were far lower than today.

(6) The geomorphic regions, shown on the Map of Geomorphic Regions (Plate X), differ from each other because of differing process and time. They all have or have had the same underlying structure--basically flat-lying, marine, Paleozoic rocks overlain by Cretaceous fluvial sediments, in turn overlain by Pleistocene glacial drift. Regions I and H, the Steep Slopes and the Red Wing Upland, developed before and during Wisconsinan time, mainly by stream erosion controlled by the Mississippi River. Region G, the Eastern Upland, has developed since "Kansan" time, mainly through stream erosion and some sort of sheet wash or wind erosion. Regions F, E, and D, the Central, Welch, and Cherry Crove

uplands, have also developed since "Kansan" time, but do not show the excessive erosion of the Eastern Upland. The three regions are distinguished from one another by elevation, relief, amount of dissection, and thickness of overburden. Region C, the Cannon Valley Outwash, arose during late Wisconsinan time through deposition of outwash from the Des Moines Lobe. Regions B and A, the Tributary Valleys and the Mississippi Valley, are dominated by constructional fluvial landforms. Their surface has arisen during and since the late Wisconsinan and is the youngest in the county.

Origin of Drainage Features in Goodhue County

The following questions concern the drainege of Goodhue County: (1) Why is the drainage pattern well-integrated? (2) Why is the drainage pattern dendritic? (3) Why are there exceptions to this integration and pattern? (4) Why are there few lakes but many streams in the county? (5) Why is the drainage of a particular density? (6) Why does the drainage density vary across the surface of the county? (7) Why do the major streams flow in a limited number of directions, yet the smaller streams flow in all directions?

(1) The drainage pattern is well-integrated because structure and process are and have been fairly uniform throughout the county. There has also been enough time for integration to develop.

(2) Dendritic drainage patterns form on compositionally uniform surfaces, of moderate to low relief (Small, 1978, p.

217). Goodhue County could be characterized this way. The soft yielding materials and low relief produced the drainage pattern.

(3) There are exceptions to the well-integrated and dendritic pattern. Some streams, e.g. several near Zumbrota and west of Lake City and a stream east of Mineral Springs, come to abrupt endings before reaching the main stream. They have flowed into a main valley and sunk into highly permeable fluvial deposits. Wells and Hay creeks have a strange-looking pattern of flow possibly because of stream piracy (H. Hobbs, oral communication, October 1984) or, as I believe, by following different routes down an abandoned Mississippi channel. The mouth of Spring Creek, near Red Wing, has been deflected downstream by terraces built-up along the Cannon River. The same thing has occurred at the mouths of the Little Cannon River and Belle Creek. The mouth of the Vermillion River has been deflected downstream by terraces and levees of the Mississippi River. The Cannon River breaks into distributaries as it enters the Mississippi because it flows onto and into terrace sands and gravels.

(4) Two possibilities exist to explain why there are few lakes, but many streams in Goodhue County--either the surface formed in that way, that is without isolated depressions which could become lakes, or the surface became that way. Although it is possible that the uplands of Goodhue County have always been lakeless, it is unlikely.

Most glaciated areas have numerous isolated depressions, which, given enough rainfall or groundwater, become lakes. The lakes that once existed on the upland surface of Goodhue County were either drained through integration of the drainage net or filled with aeolian, alluvial, lacustrine, and paludal materials. At exposure K-06, stratified silts and clays, apparently lacustrine in origin, occur underlying loess. Other similar sequences undoubtedly occur in the subsurface.

(5) Drainage density depends on the nature of the underlying material, type of drainage pattern, placement of area within the drainage net, and time for drainage pattern development. The particular and general drainage density of Goodhue County is the result of all these variables.

(6) Drainage density changes across the surface of Goodhue County due to varying surficial material--e.g. density is greater on loess and till than on terrace sands and gravels--and differing placement in the drainage net, e.g. density is greatest along drainage divides and least along major streams.

(7) The major streams of Goodhue County and all of southeastern Minnesota flow in a limited number of directions, generally west to east, southwest to northeast, and northwest to southeast, yet the smaller streams flow in all directions. The large valleys cut into bedrock and may be joint controlled; the small valleys cut into unconsolidated material and are not subject to such control.

Origin of Selected Topographic Features of Goodhue County

The following questions concern the topography of Goodhue County: (1) Why are there some notable exceptions to the generally well-integrated and intricately dissected surface of Goodhue County? (a) Why are there numerous small isolated uplands between Red Wing and Lake City? (b) Why are the edges of the major valleys, particularly that of the Mississippi, so straight? (2) Why are there are a few deep, broad, and flat-floored valleys in the county? (3) Why are there numerous small valleys? (4) Why is there an east-west trending escarpment in the White Rock quadrangle? What is the age of this escarpment?

(1) The numerous isolated bluffs between Red Wing and Lake City are erosional remnants of a once continuous upland. This upland has been cut by the Mississippi River, its side channels, and its tributaries. The isolated bluffs may once have been islands in a far larger glacial or interglacial Mississippi River. The edges of major valleys, particularly that of the Mississippi, are comparatively straight because these valleys are cut into bedrock and may follow fracture patterns in that rock.

(2) The deep, broad, and flat-floored valleys, as recorded in numerous well-logs within the valleys of Prairie Creek, the Zumbro, and the Mississippi, are cut deep into bedrock and partially filled with fluvial sediments. These

deep, flat-floored valleys indicate a period of downcutting followed by a period of deposition.

(3) The small valleys are cut into the unconsolidated materials of the uplands. These valleys are so numerous because the unconsolidated materials are easily eroded and there has been sufficient time, runoff, and slope to erode them.

(4) The east-west trending escarpment found in the White Rock quadrangle, poorly seen on the map but strikingly seen in the field, is composed of St. Peter Sandstone capped by Platteville Limestone. It marks the eastward extent of the Platteville Formation in Goodhue County. The escarpment appears both on the surface and in the subsurface, westward from here into Rice County and southward into Iowa. No one knows how or when the escarpment formed, although it appears to have formed because of erosion along the Mississippi valley. Many feel that it is a Pleistocene feature (H. Hobbs, oral communication, August 1985). I believe the escarpment may have originally formed before or during the Cretaceous, during erosion and solution of the Prairie du Chien Dolomite and Galena Limestone: Windrow sediments occur above the escarpment and in the Galena Limestone at outcrop C-02; the escarpment is covered by "old gray drift" near Pine Island. It has been partially exhumed during the Quaternary.

Integration of Drainage and Topography

The following questions concern the integration of drainage and topography in Goodhue County: (1) Why do the large valleys have underfit streams? (2) Why are there some large valleys without streams? (3) Why do some streams have entrenched meanders and others do not? (4) Why do certain valleys suddenly narrow? (5) Why do some large valleys, or parts thereof, have terraces and others do not? (6) Why are certain small areas of the county flatter, steeper, more lake-filled, more topographically complex--or generally unusual physiographically--when compared to the county as a whole?

(1) The large valleys of Goodhue County were cut by high capacity and possibly high volume streams. Since that time base level has risen, stream volume and capacity have diminished, and fluvial materials have begun to fill these bedrock valleys. Today low volume, low capacity streams flow as underfit streams in these large old valleys.

(2) There are some large valleys without streams--e.g. that running through the town of Hay Creek--because the valleys were cut under a different regime than at present and have been abandoned.

(3) Certain streams have entrenched meanders while others do not because of formation under differing conditions. Meandering depends primarily on stream gradient and load. It may also depend on the nature of the underlying materials, flow regularity, and geologic history.

The north-south valley of Belle Creek with its entrenched meanders has a different history, mode and time of formation, than the east-west and broad open valley of the Cannon. Howard Hobbs speculates that the Cannon and Belle Creek valleys both formed late in the Pleistocene. The former valley, however, is broad and open because the Cannon River carried outwash eastward from the melting Des Moines Lobe ice while Belle Creek did not (H. Hobbs, oral communication, spring 1984). I believe that although the Cannon valley formed as Hobbs speculates and during the Quaternary, the Belle Creek valley may have formed long before the Quaternary--certainly, the "old gray drift" fills the subsurface southward extension of the valley--perhaps even during the pre-Windrow erosion interval. After glaciation segments of the valley were exhumed.

(4) Certain valleys, e.g. those of Belle Creek, the Zumbro River, and Dry Creek, suddenly narrow. Examination of the Map of Bedrock Geology indicates that the valleys are particularly broad where they cross the St. Peter Sandstone and particularly narrow where they cross the Prairie du Chien Dolomite. The sandstone erodes easily, the dolomite erodes with difficulty--valleys in the St. Peter would naturally be far less confined than those in the Prairie du Chien.

(5) Some large valleys, or segments thereof, have terraces and others do not: either terraces formed only in certain places or, although they formed everywhere, they

remain only in certain places. Where terraces occur abundantly and markedly along certain segments of a river and not along other downstream segments of that same river--e.g. the Cannon, Zumbro, and Mississippi rivers--it is apparent that the terraces once existed along the entire river. Where terraces are far more marked along some rivers than other rivers--e.g. Prairie Creek versus Belle Creek--it indicates a different depositional and/or erosional history of the entire valley. The terraces along Prairie Creek are due to a great influx of outwash material from the melting of the Wisconsinan ice. Belle Creek heads east of that ice margin and did not receive such outwash.

(6) Certain small areas of the county are flatter, steeper, more lake-filled, and more topographically complex than the county as a whole. These areas have had somewhat different, and point specific histories as compared with the rest of the county. The particularly flat areas alongside Prairie Creek are broad sand and gravel terraces. The flat area north of Lake Byllesby is an apron of glacial outwash. The flat area east of Cannon Falls and south of the Cannon River is a washed, and perhaps reworked, surface of St. Peter Sandstone. The flat areas near Lake City are Mississippi terraces. The elongate landforms alongside Prairie Island are Mississippi levees, bars, and islands. Prairie Island itself is an old terrace. The complex network of lakes and islands near the mouth of the Cannon River are part of the delta built by the Mississippi River

at the upper end of Lake Pepin. Lake Pepin has resulted from blockage of the Mississippi River by Wisconsin's Chippewa River. The points near Lake City have resulted from longshore deposition.

Origin of Small Scale and Miscellaneous Features

The following questions arise from field observations concerning surface features too small to appear on the Base, Drainage, or Topographic maps: (1) What is the age of karst in Goodhue County? (2) Why are erratics evident only in certain areas of the county? What is the significance of these erratics and their distribution? (3) Why do large blocks of dolomite occur on some hillsides? (4) Why are there are numerous, small, rounded, and isolated hills in the vicinity of Goodhue? (5) Why are there pronounced knickpoints on most small streams?

(1) Sinkholes and other solution features occur primarily in the Galena Limestone and the Prairie du Chien Dolomite. At least some of these sinks developed before deposition of the Windrow Formation. Prairie du Chien sinks, at exposure GE-06, are filled with unreworked Windrow Clay. Loess and a thin coarse till overlies this clay. A channel in the Galena Formation, at exposure C-02, is filled with Windrow Conglomerate. I believe much of the solution took place in the early to middle Cretaceous--Minnesota had a moist semi-tropical climate at that time, as documented by clay formation in Red Wood Falls (Sansome, 1983, p.124).

There is also evidence for Cretaceous age karst in the subsurface of the eastern Dakotas, and there is also much Cretaceous-age karst in other parts of the world (E. Force, oral communication, October 1984). The karst however could have occurred any time since the Devonian. Solutional activity was probably renewed during the Pleistocene.

(2) Erratics, found only in certain areas of the county, indicate that there glacial drift has been partially or wholly eroded and has not been covered by younger material. Absence of large erratics may also indicate that agricultural man has been hard at work breaking, moving, and burying them. Within any particular area, large erratics are more common in pastures and woodlots than in fields.

(3) Large blocks of dolomite occur on hillsides along the Cannon valley near Welch and on bluffs between Red Wing and Lake City. These dolomite blocks, angular and fresh-looking, have fallen from the Prairie du Chien Dolomite capping the valley walls and bluffs. The blocks, resulting from physical weathering and downslope movement, have fallen during the Late Pleistocene and Recent.

(4) Leverette and Sardeson (1932) believed the numerous, small, and isolated hills in the vicinity of Goodhue to be kames. Field examination, however, reveals that some are composed of Windrow Formation and are erosional rather than depositional features.

(5) Pronounced knickpoints occur along most small streams in Goodhue County because of a great drop in the

level of the Mississippi. This occurred approximately 10,000 years age during southward release of waters from Glacial Lake Agassiz. Since that time knickpoints have migrated up the major valeys and into the smaller side valleys.

Age and Evolution of the Land Surface of Goodhue County

The following questions concern the age and evolution of Goodhue County's land surface: (1) How old is the land surface of Goodhue County? (2) How has the land surface changed through geologic time? (3) What is the history of the bedrock valleys and drainage pattern, the uplands, and the "White Rock escarpment?"

(1) Certain aspects of the land surface of Goodhue County are older than the materials on that surface. Other aspects of surface configuration are younger than the materials on that surface. The bedrock valleys are older than the Quaternary and Recent materials filling them. They may also be older than any glacial material in the county and older than the Cretaceous Windrow Formation. The upland drainageways are younger than the glacial drift and loess which they cut. The configuration of the land surface as a whole may be said, as it is for many areas, to have arisen during and since the Late Pleistocene, however this statement simplifies matters too much and is highly misleading.

(2) A long discussion of how the land surface of Goodhue County has changed through time is found on pages 55-61. Briefly: (1) during the Late Precambrian streams flowed into a graben-like structure that cut across all of Goodhue County; (2) during the early Paleozoic, shallow seas advanced and retreated across the county; (3) during the later Paleozoic and most of the Mesozoic the surface underwent erosion and solution; (4) during the Late Cretaceous a meandering stream crossed the county; (5) during the Tertiary the surface underwent mild erosion; (6) during the Pleistocene glaciers advanced and retreated across the county, leaving behind till and outwash, melting and carving, or simply enlarging large bedrock valleys. (7) during the Late Pleistocene and Recent, terrace sands and gravels, colluvium, and loess were deposited within the county, rivers continued to flow through the bedrock valleys and small intermittent streams began to branch out across the uplands; and (8) during Recent times there has been continued integration of the upland drainage net and renewed downcutting of the valleys.

(3) The bedrock valleys appear to have a long history of cut and fill beginning perhaps as early as the late Paleozoic. The overall dendritic drainage pattern is, however, a fairly recent development, cut as it is into glacial materials. The uplands appear have inherited their general form from bedrock erosion during or before the early Pleistocene and from glacial deposition throughout the

Pleistocene. Small scale forms result from late Pleistocene and Recent stream erosion. The "White Rock escarpment" may have formed since retreat of the "Kansan" ice, but may also be an exhumed feature, originally formed sometime in the long interval between the Devonian and the Cretaceous.

In Review

Six significant events have shaped the surface of Goodhue County: (1) marine deposition during the early Paleozoic; (2) folding and faulting, erosion and solution of bedrock after deposition of the Ordovician Prairie du Chien Group and before deposition of the Cretaceous Windrow Formation; (3) fluvial deposition during the Cretaceous; (4) glacial and glaciofluvial deposition during the Pleistocene; (5) multiple periods of stream erosion probably before and certainly after deposition of the Windrow Formation; and (6) stream deposition toward the end of the Pleistocene and into the Recent.

VI. SUMMARY, CONCLUSIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

Summary and Conclusions

I undertook this study for five reasons. All were realized. (1) I found that this study, regional in nature and involving the consideration of a long span of geologic time, demanded the integration of knowledge from several fields of scientific inquiry. I drew liberally from general, physical, and historical geology, geomorphology, stratigraphy, glacial geology, field geology, structural geology, physical geography, landform geography, soil genesis, and soil geography. (2) I gained a general knowledge of land surfaces and developed a methodology for their analysis, both of which I can transfer to other persons and apply to other situations. (3) I learned a considerable amount about the geology of Goodhue County and all southeastern Minnesota, and in so doing further developed my field abilities, read broadly, thought at length, and added substantially to my knowledge of geology, geography, and the process of scientific inquiry. I did not, however, learn all I wished to know about the Cretaceous and Quaternary history of Goodhue County and consequently suggest these as topics for further research. (4) I "sharpened my vision" on the entire field of geomorphology, reading widely and considering at depth the underlying precepts of landscape analysis. (5) I heightened my knowledge, if not my sense, of place.

My original beliefs--that (1) geomorphology rightfully includes both descriptive and speculative aspects, (2) landscapes are polygenetic, (3) science needs more integrative and interdisciplinary studies, and that (4) geomorphology is a valid science--were upheld throughout the entire study. I confirmed my belief that science needs more integrative and interdisciplinary studies, a topic discussed under "suggestions for further research".

I answered the major geologic questions presented by this study. (1) How does one describe the configuration of a land surface? How does one describe that of Goodhue County? (2) How does one determine the origin and age of a land surface? How does one do that for Goodhue County? (3) What does the configuration of a land surface tell us of its origin and age? What does the configuration of the land surface of Goodhue County tell us of its origin and age? (4) What do the materials underlying a land surface tell us of the origin and age of that land surface? What do the materials of Goodhue County tell us of the origin and age of that surface? (5) What are the major controlling factors on the configuration of any land surface? What are the major factors controlling the land surface configuration of Goodhue County? (6) How much of a particular land surface is dependent on: (a) the structure, composition, texture, and distribution of the underlying materials; (b) the nature and intensity of present and past processes; (c) the passage of time? What are the major factors responsible for the land surface configuration of Goodhue County? (7) What role does catastrophism play in land surface development? What role has it played in the development of the surface in Goodhue County?

The configuration of any land surface, as well as that of Goodhue county, is described through the geometry of that surface--the height, length, and width of its surface features. It is described in terms of drainage and topography. Drainage and topography, or slope, are described in terms of pattern and density. The most successful method of land surface description employs maps. Photographs, diagrams, graphs, and written descriptions can also be useful.

The origin and age of any land surface, including that of Goodhue County, is determined by: (1) an examination of the materials making up that surface--an examination of their structure, composition, distribution, and then the determination of their origin and age; and (2) an examination of the present-day processes affecting the surface, followed by an extrapolation of those processes into the past through knowledge of past climates and evidence from the underlying materials. The origin of a land surface is distinct from its age. The age of a land surface, that is, the age of the land surface configuration, is as a whole usually older than the youngest and younger than the oldest materials exposed on that surface. However, the age of individual features may be, and commonly is, younger than the youngest materials and older than the oldest materials exposed on that surface.

The configuration of a land surface may tell us of the structure underlying the land surface, the processes that have acted on and are presently acting on the surface, and the length of time during which these processes have been at work. Knowledge of structure, process, and time in turn tells of land surface age and origin. The drainage pattern --form, density, and integration of the pattern--tells something of the composition, texture, and distribution of materials making up the surface, the geologic structure of those materials, the climate under which the drainage pattern was developed, and the time the pattern may have taken to develop. The topography immediately distinguishes a primarily erosional landscape from a primarily depositional landscape. Slope tells of structure of the surface, processes past and present at work on that surface, and lengths of time those processes have been at work. Variation in topography, as variation in drainage, is due to differences in origin and age. The configuration of the land surface in Goodhue County tells us that: (1) streams have played an important role in its development both in the present and in the past; (2) the surface is made up of soft or horizontally bedded sediments; (3) the land surface is old enough for the drainage system to have become well-integrated; and (4) structure, process, and time have varied across the surface of the county.

Knowledge of the materials underlying a land surface tells of the origin and age of that surface. An understanding of the origin, particularily the original form of the underlying materials, helps determine if the present surface is primarily depositional or erosional; an understanding of the age of the underlying materials helps put outside limits on the age of the land surface. The geologic structure often indicates why the hills and valleys have their particular shapes, patterns, and densities. The composition and distribution of the underlying materials may indicate why the configuration of the surface varies from one place to the next. The age and geologic struture of the underlying materials places limits on age of the present-surface. Knowledge of the materials underlying Goodhue County indicate that the land surface is heavily influenced by the deposition and later erosion of glacial till, that the bedrock surface heavily influences the configuration of the larger features of the present-day surface, and that the age of individual features ranges from perhaps Cretaceous to Recent.

The major factors controlling the configuration of any land surface are structure, process, and time. Structure refers to geologic structure, composition, thickness, and distribution of underlying materials, geographic location, geomorphic position, and physiographic aspect. Process includes past and present processes, endogenic and exogenic processes. Time is the dimension over which structure and process interact. Land surface configuration is the result of processes acting on structure over time. The factor most controlling land surface configuration is dependent on the scale of the investigation and on the particular area of the investigation. Structure, composition, and distribution of underlying material exerts the greatest influence on the surface configuration of Goodhue County--bedrock topography greatly influences the largest scale topographic features of the county, thickness of surficial deposits heavily influences the mid-size features, and composition of surficial materials has influenced variation in slope. Process, particularly that of channelled stream flow, has also greatly influenced the surface configuration, yet the integrated dendritic pattern of that drainage has arisen partially because of the underlying structure. Time and process together may have caused the distinction between the highly dissected northeast portion of the county and the minimally dissected southwest and central portions.

The degree to which the configuration of any land surface is dependent on (1) the structure, composition, texture, and distribution of underlying materials, (2) the present and past processes, and (3) the passage of time is dependent on the scale of investigation and the surface itself. Structure, composition, texture, and distribution of underlying materials are perhaps most influential in areas where structure and material vary greatly and where process and time are relatively uniform. Process is the most significant factor controlling land surface configuration in areas where structure and process are relatively uniform. Time is most important where structure and process have remained relatively uniform, but time of exposure has varied. In Goodhue County the structure and composition of underlying materials have greatly influenced the surface configuration. Exogenic process, particularily stream erosion, and the passage of time have also influenced this surface.

The role of catastrophism in the origin of the overall land surface of Goodhue County is negligible. A 1978 downpour of approximately eight inches in six hours, which flooded the towns of Dennison and White Rock, raised the level of Belle Creek by forty-two feet, and washed out the Minnesota highway 19 bridge over that creek, left no evidence mappable at the study scale. I found no mappable evidence of other catastrophic events.

Three other thoughts worth noting here occurred to me while completing this study: (1) There are numerous prejudices built into this study which may have heavily influenced its findings. (2) A study of this magnitude is immensely difficult for one person to handle. (3) There are several methodological changes I would make when undertaking a similar study.

The scale of this study greatly influences the weighting of land surface configuration toward control by materials. Process and time would be more influential at other scales of investigation. The scale of the investigation also guides the inclination of analysis and description through mapping rather than quantitative measurement and graphing, which may also have biased the study toward materials and away from processes. Selection of cross-section locations and characteristic and non-characteristic features was done in a subjective manner. I relied on my geologic experience and judgement, and believe this to be the best method of selection for this particular study. Others may, however, choose different locations and features.

The magnitude of this study was extremely difficult to handle. I believe, however, that large and integrative studies must be undertaken, and when undertaken must be overseen by one individual. Suggestions for facilitating such a study follow: (1) The principle investigator should have experience on a similar project. (2) A computer should be used to record, collate, and catalogue all field and well data. (3) A team approach could be used. Two people would study the influence of structure on the land surface--one person studying consolidated materials, the other studying unconsolidated materials. One person would study the influence of process on land surface configuration, and another study the influence of time. A fifth person would draft the diagrams and maps into final form. A sixth person would coordinate the study. (4) The study would be completed in eighteen to twenty-four months.

Suggestions for Further Research

There are three broad areas, somewhat philosophical in nature, in which I suggest further research. The first and most significant of these suggestions revolves around the conviction that scientists need to recognize and acknowledge the necessity for and then carry out more integrative and interdisciplinary studies. The second suggestion concerns the desirability of studies similar to the current study, but on varying scales. The third suggestion encourages comparative studies of land surface configuration and origin.

There is a need for more integrative and interdisciplinary studies of all kinds. Geology, as numerous other sciences, has become so specialized that most modern contributions to it are analogous to placing bricks onto a large and complex building. However, it is also appropriate to question the structure of the building, and perhaps begin to erect new structures and buildings. There is a need to more closely examine the underlying framework and assumptions. There is a need to acknowledge the value of general geologic and geomorphic studies. In the medical field, recognizing that primary care is vital, the general pracitioner has come of age as the Family Physician. The same recognition for the "general geologist", or better, the competent geologist-ecologist-geographer would be useful.

There is a need for studies similar to the current study, but on varying scales. As the current study, these future studies should involve the configuration and origin of different land surfaces, keeping distinct the descriptive and theoretical aspects of geomorphology. Studies done on larger scales could more closely determine the control that any particular facet of structure or exogenic process has on land surface configuration; studies done on smaller scales might more closely determine the control that a particular facet of process or time has on land surface configuration.

There is a need for more comparative studies concerning the origin and configuration of land surfaces in differing areas of the world. Numerous studies have been published concerning the effect of climate on land surfaces, but it would also be valuable to study the affect of a particular process or length of time on the land surface, holding, as far as possible, other variables as constants. Robert Ruhe (Ruhe, 1969) has done the latter in his study of Iowan landscapes, basing many of his conclusions on a variation in drainage and slope development. It would be interesting to extend this concept to, and test its validity in, numerous other settings.

More studies similar to the current study--distinguishing between land surface configuration and the origin of such configuration, attempting to recognize, weigh, and integrate all factors controlling land surface configuration--would be of value. These studies are of value as modern attempts to integrate geology and geography, as bases for studies designed to aid in land use decisions, and as bases for the aforementioned comparative studies.

There are six areas in which I suggest further research in reference to the geology of southeastern Minnesota and Goodhue County: (1) continued mapping, at a scale of 1:100,000 or more, of the bedrock geology and topography of southeastern Minnesota; (2) an updated study of the Cretaceous record in southeastern Minnesota, including study of the pre-and post-Windrow surfaces; (3) a detailed study of the Quaternary record in southeastern Minnesota, with particular emphasis on the configuration of the pre-Quaternary surface, and the composition, distribution, and correlation of the pre-Wisconsin drifts; (4) a detailed study of the location, history, and development of the bedrock valleys of southeastern Minnesota; (5) a detailed study of the terrace history of the Cannon, Zumbro, Whitewater, and Root rivers and the relationship of those terraces to the wasting of the Des Moines Lobe of the

Wisconsin glaciation; and (6) a study of the location and significance of the Platteville escarpment throughout southeastern and east central Minnesota.

Sloan and Austin (1966) mapped the bedrock geology of southeastern Minnesota on a scale of 1:250,000. Today there is the possibility of and the need for more refined and detailed mapping. Far more subsurface data is available today than twenty years ago. Planning commissions are requesting more detailed information on the composition and configuration of the bedrock underlying their counties. The Minnesota Geological Survey is beginning to meet this need in their county atlas series. This mapping effort needs to be continued.

Because of the far greater availability of subsurface data, the growing interest in the middle and late Cretaceous environments of central North America, and the possibility that Cretaceous materials may be far more prevalent in the subsurface and that Cretaceous events have had far more effect on the present-day land surface than heretofor recognized, it is desirable to revise and refine the Sloan (1964) and Austin (1972b., in Sims and Morey) studies of the Cretaceous in southeastern Minnesota. Field exposures should be carefully sought and examined, and wells should be carefully logged and correlated. Suspect material should be dated.

Actually, very little modern study, outside that of Ruhe and Gould, 1954, in Dakota County and Hobbs, 1984, in

Winona County (Balaban and Olson, 1984), has been done on the glacial and Quaternary history of southeastern Minnesota. I am not familiar with any major study of the pre-Quaternary surface of Minnesota. A detailed study needs to be carried out on this surface and on the extent, distribution, composition, age, and correlation of pre-Wisconsin drifts in southeastern Minnesota. This material needs to be meshed with studies by the Wisconsin, Illinois, and particularly the Iowa geological surveys.

Detailed mapping of the bedrock valleys in the Twin Cities metropolitan area has been carried out by Payne (1965), Bloomgren (1985), and Jirsa, Bloomgren, and Olson (1986, in press) of the Minnesota Geological Survey. This effort should be extended to all of southeastern Minnesota. Mapping of these valleys is vital to an understanding of groundwater flow and land surface development. An analysis of sediments filling these valleys would lead to a greater understanding of the bedrock valleys' configuration and origin.

A modern and detailed study of the distribution, location, elevation, correlation, and composition of terraces along the large rivers of southeastern Minnesota, the Cannon, Zumbro, Whitewater, and Root, and the relationship of these terraces and river histories to deposits of the Des Moines Lobe, could aid in tracing the wasting of the Wisconsin ice across southern Minnesota.

A detailed study of the location, age, and significance of the Platteville escarpment in southeastern and east central Minnesota, tied into similar studies in Wisconsin and Iowa, could throw light on early Wisconsin, older Quaternary, or perhaps even Tertiary or Cretaceous history of the Upper Mississippi Valley. This study could also tie into an expanded understanding of the extent and origin of the Iowan Erosion Surface.

Study of the pre-Windrow and pre-Quaternary surfaces and the ages of the bedrock valleys and Platteville escarpment should help illuminate the problem of how to handle major regional unconformities a hundred million years or more in duration. It should also examine the theory of peneplain development.

Several suggestions follow for miscellaneous and smaller scale research problems concerning the geology of Goodhue County: (1) a study of the occurrence, origin, and age of colluvium in the county; (2) a study of the interrelationship of the colluvium, loess, and terrace deposits of the county; (3) a quantitative study of the amount of material carried by both channelled and unchannelled water within the county; (4) a study relating the mapped landscape regions (Agricultural Experiment Station, 1973) to the geologic origin and age of those regions; and (5) a study of the solution and solution history of the rocks, particularly the Prairie du Chien, Platteville, and Galena formations in Goodhue County, and the relationship of that solution to the solution of the Galena, Maquoketa, and Dubuque formations in Fillmore County.

REFERENCES CITED

(1) Agricultural Experiment Station, University of Minnesota, 1973. Minnesota Soil Atlas: St. Paul Sheet. Miscellaneous Report 120-1973, booklet 57 p., and map: Soil Landscapes and Geomorphic Regions: St. Paul Sheet (scale 1:250,000).

(2) Alexander, E. Calvin, Jr., 1984. Southeastern Minnesota Karst Hydrology. M.G.W.A. Fieldtrip, Oct. 27, 1984 (unpublished). (includes Milske, J. A., E.C. Alexander, Jr., and R. S. Lively, 1983. Clastic Sediments in Mystery Cave, Southeastern Minnesota. NSS Bull. 45: 55-75.)

(3) Austin, G. S., 1963. Geology of Clay Deposits, Red Wing Area, Goodhue and Wabasha Counties, Minnesota. Minnesota Geological Survey Report of Investigations 2, 23 p.

(4) ____________________, 1972a. Cretaceous Rocks, in Sims, P. K., and Morey, G. B., eds. Geology of Minnesota: A Centennial Volume, Minnesota Geological Survey. p. 509-512.

(5) ____________________, 1972b. Paleozoic Lithostratigraphy of Southeastern Minnesota, in Sims, P. K. and Morey, G. B., eds. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, p. 459-473.

(6) Balaban, N. H., and McSwiggen, Peter, L., eds., 1982. Geologic Atlas, Scott County, Minnesota. Minnesota Geological Survey, County Atlas Series Map C-1, University of Minnesota, St. Paul (6 plates).

(7) Balaban, N. H., and Olson, Bruce, M., eds., 1984. Geologic Atlas, Winona County, Minnesota. Minnesota Geological Survey, County Atlas Series, Atlas C-2, University of Minnesota, St. Paul (8 plates).

(8) Bloomgren, Bruce, 1985. Bedrock Geologic and Topographic Maps of the Minneapolis-St. Paul Urban Area, Minnesota. Minnesota Geological Survey. Misc. Map M-57 (2 plates, scale 1:48,000).

(9) Cobban, William A., and Merewether, E. A., 1983. Stratigraphy and Paleontology of Mid-Cretaceous Rocks in Minnesota and Contiguous Area. U. S. Geological Survey Prof. Paper 1253, 52 p.

(10) Cowie, Roger, H., 1941. Geology of the Zumbro Valley Region. Ph.D. Dissertation, University of Minnesota, 125 p.

(11) Craddock, Campbell, 1972. Keweenawan Geology of East-Central and Southeastern Minnesota, in Sims, P. K. and Morey, G. B., eds. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, p. 416-424.

(12) Crain, William, E., 1957. Areal Geology of the Red Wing Quadrangle. M. S. thesis, University of Minnesota, 105 p.

(13) Cushing, Edward J. Professor of Botany and Ecology, University of Minnesota, Twin Cities Campus.

(14) Force, Eric R. Geologist and Resource Specialist, U.S. Geological Survey, Reston, Virgina.

(15) Frey, Maurice Gordon, 1937. Geology of the Red Wing District, Minnesota. M. S. thesis, University of Minnesota, 36 p.

(16) Goebel, J. E., and Walton, Matt, 1979. Geologic Map of Minnesota: Quaternary Geology. Minnesota Geological Survey, Minneapolis (scale 1:3,168,000).

(17) Goodhue County Department of Highways, 1975. General Highway Map: Goodhue County (scale 1 inch approx. equal to 5.33 miles).

(18) Hobbs, Howard C. Quaternary Geologist, Minnesota Geological Survey, Minneapolis.

(19) Hobbs, Howard C., and Goebel, Joseph E., 1982. Geologic Map of Minnesota: Quaternary Geology. Minnesota Geological Survey (scale 1: 500,000).

(20) Jefferson, Constance L., 1961. Stratigraphy and Physiography of the Minnetonka Area. The Minnesota Journal of Science, published by the Minnesota Academy of Science, vol. V, no. 1, p.40-42.

(21) Jirsa, M. A., B. A. Bloomgren, and B. M. Olson, 1986 (in press). Bedrock Geology and Topography of the Seven County Metropolitan Area, Minnesota. Minnesota Geological Survey, Misc. Map M-55 (2 plates, scale 1:5,000).

(22) Leverett, Frank, and contributions by F. W. Sardeson, 1936. Quaternary Geology of Minnesota and Parts of Adjacent States. U. S. Geological Survey Prof. Paper 161, 149 p.

(23) Lobeck, A. K., 1941. Geologic Map of the United States. C. S. Hammond & Co., Maplewood, New Jersey (scale 1:5,000,000).

(24) Lundstrom, Orville Glebe, 1938. Geology of the Pine Island--Mazeppa Region. E.M. in Geology, thesis, University of Minnesota.

(25) Marshner, Francis J., 1930. The Original Vegetation of Minnesota. U.S. Department of Agriculture. North Central Forest Experiment Station, 1974 (map scale 1:500,000).

(26) Minnesota Department of Transportation, 1979. General Highway Map of Goodhue County (scale 1 inch = 4 miles).

(27) Morey, G. B., 1972. Petrology of Keweenawan Sandstones in the Subsurface of Southeastern Minnesota in Sims P. K., and Morey, G. B., eds. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, p. 436-449.

(28) ________________, 1977. Revised Keweenawan Subsurface Stratigraphy, Southeastern Minnesota. Minnesota Geological Survey Report of Investigations 16, University of Minnesota, St. Paul, 67 p.

(29) Olson, Bruce. Stratigrapher, Minnesota Geological Survey, Minneapolis.

(30) Payne, C. Marshall, 1965. Bedrock Geologic Map of Minneapolis, St. Paul and Vicinity. Minnesota Geological Survey, Misc. Map Series M-1 (scale 1:24 000).

(31) Pleistocene Geology and Evolution of the Upper Mississippi Valley: A Working Conference. Winona State University, August 13-16, 1985.

(32) Poch, George R., 1976. Soil Survey of Goodhue County, Minnesota. U. S. Department of Agriculture, Soil Conservation Service, 129 p. and 118 plates.

(33) Ruhe, Robert V., 1969. Quaternary Landscapes in Iowa. Iowa State University Press, Ames, 255 p.

(34) Ruhe, Robert V., and Gould, Laurence M., 1954. Glacial Geology of the Dakota County Area, Minnesota. Geological Society of America Bulletin, v. 65, no. 8, p. 769-792.

(35) Sansome, Constance J., 1972. Minnesota Geology: A Laboratory and Field Manual for a First Course in Geology with an Elaboration on the Ordovician Stratigraphy of Sogn Quadrangle, Goodhue County. M.S. thesis, University of Minnesota, 575 p.

(36) ________________, 1983. Minnesota Underfoot: A Field Guide to the State's Outstanding Geologic Features. Voyageur Press, Bloomington, Minnesota, 224 p.

(37) Sims, P. K. and Morey, G. B., eds., 1972. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, St. Paul, 632 p.

(38) Sloan, R. E., 1964. The Cretaceous System in Minnesota. Minnesota Geological Survey Report of Investigations 5, University of Minnesota, Minneapolis, 64 p.

(39) Sloan, R. E., and Austin, G. S., 1966. Geological Map of Minnesota: St. Paul Sheet. Minnesota Geological Survey (scale 1:250,000).

(40) Small, R. J., 1978. The Study of Landforms: A Textbook of Geomorphology. Cambridge University Press, Cambridge, 502 p.

(41) Thiel, George A., 1944. The Geology and Underground Waters of Southern Minnesota. Minnesota Geological Survey Bulletin 31, The University of Minnesota Press, Minneapolis, 506 p. (Goodhue County p.193-205).

(42) Vick, Timothy, Clinton Cowan, and Daniel Packer, 1981. Geophysical Survey of Buried Bedrock Topography Associated with the Cannon River System around Northfield, Minnesota. Carleton College, Northfield, Minnesota, unnumbered pages.

(43) Winchell, N. H., 1872. Preliminary Geological Map of Minnesota, Minnesota Geological and Natural History Survey scale 1" = 20 miles).

(44) Winchell, N. H., and Upham, Warren, 1888. The Geological and Natural History Survey of Minnesota 1882-1885. Vol. II, Chapt. II, The Geology of Goodhue County, p. 20-61.

(45) Wright, H. E., Jr. Director of the Limnological Research Center, and Regents' Professor of Geology, Botany, and Ecology, University of Minnesota, Twin Cities Campus.

(46) ________________, 1972. Physiography of Minnesota in Sims, P. K., and Morey, G. B., eds. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, pp. 561-578.

(47) ________________, 1972. Quaternary History of Minnesota in Sims, P. K., and Morey, G. B. eds. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, p. 515-547.

APPENDICES

APPENDIX A

MAPS AND DIAGRAMS BY OTHERS

Appendix A--Figure #1

Austin's Diagram of the Major Structural Features in Southeastern Minnesota, 1972 (from Austin, 1972b, in Sims and Morey, p. 461).

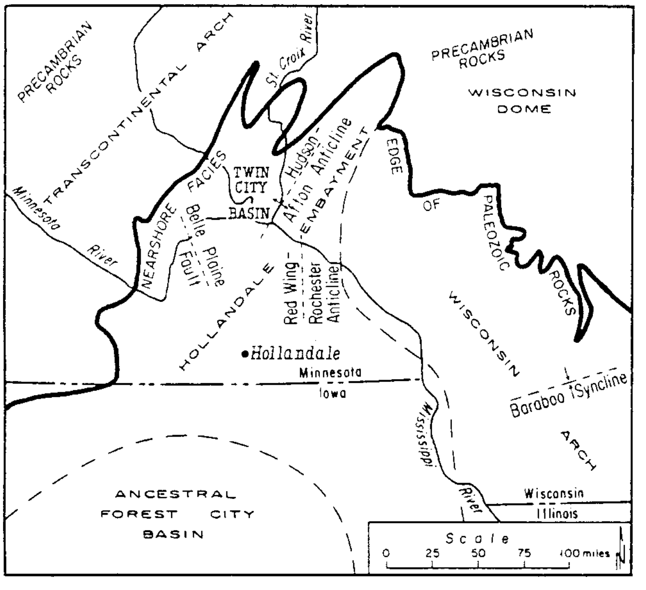
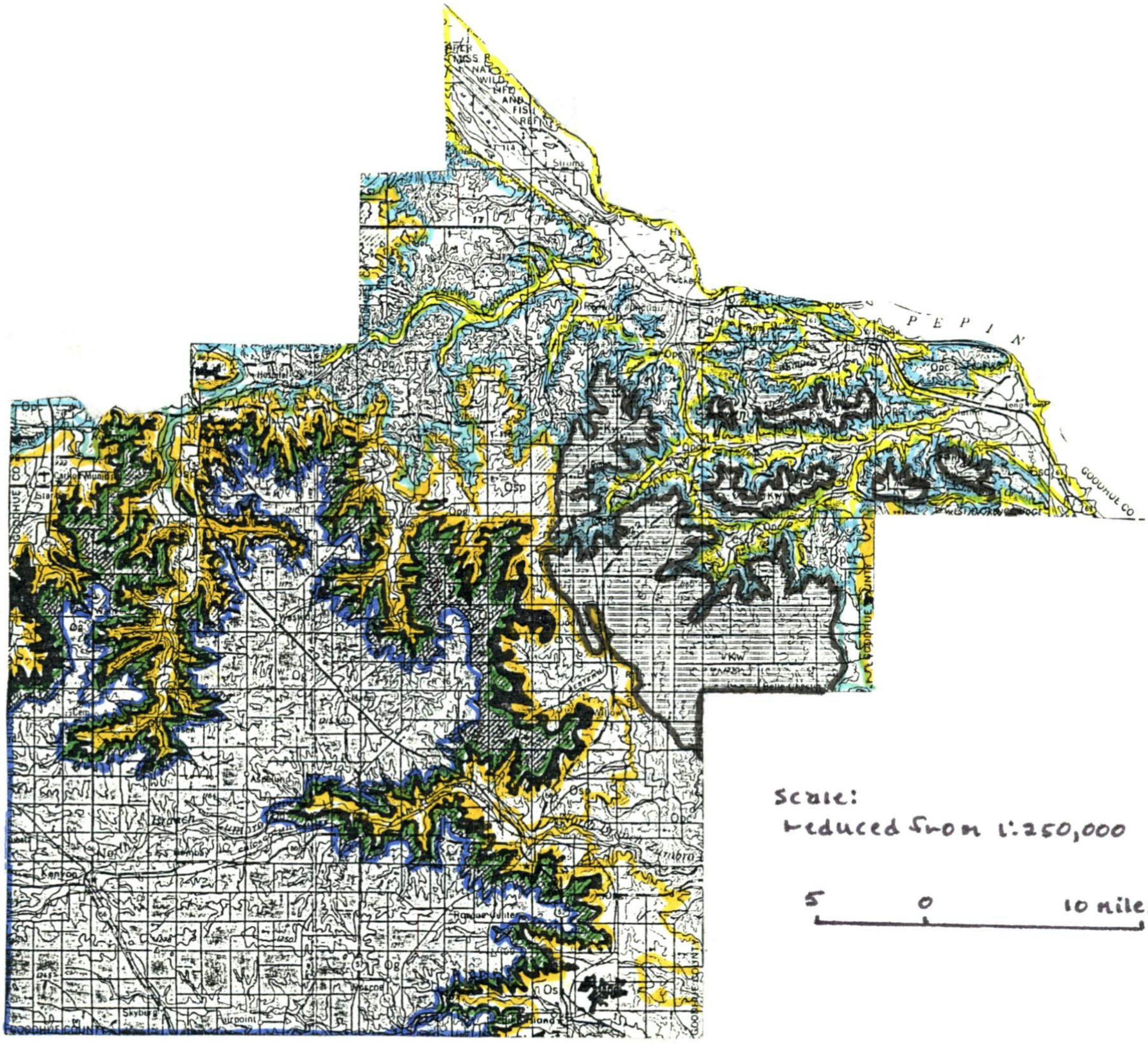


Figure VI-3. Map showing the major structural features in southeastern Minnesota and adjacent parts of Wisconsin and Iowa (modified from Austin, 1970b).

Appendix A--Figure #2

Sloan and Austin's <u>Geologic Map of Minnesota: St. Paul Sheet</u>, 1966, Goodhue County portion.

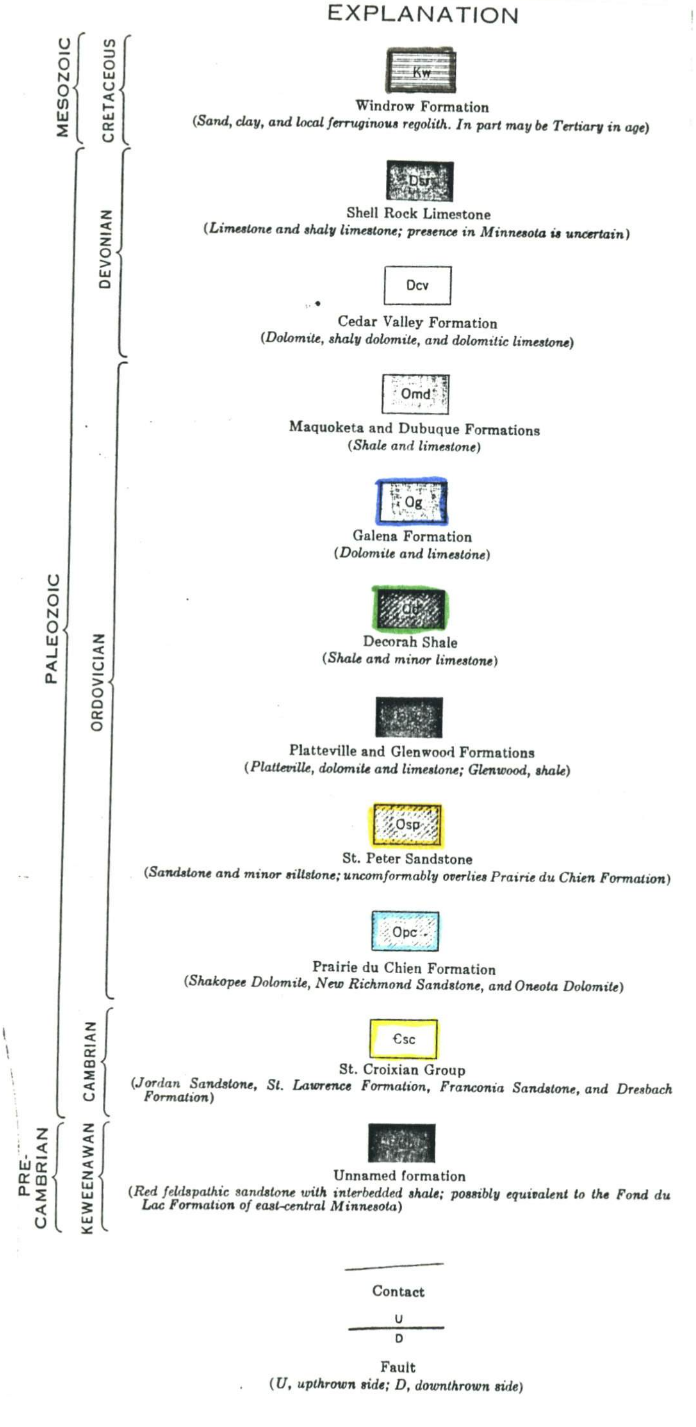


Scale:
reduced from 1:250,000

5 0 10 miles

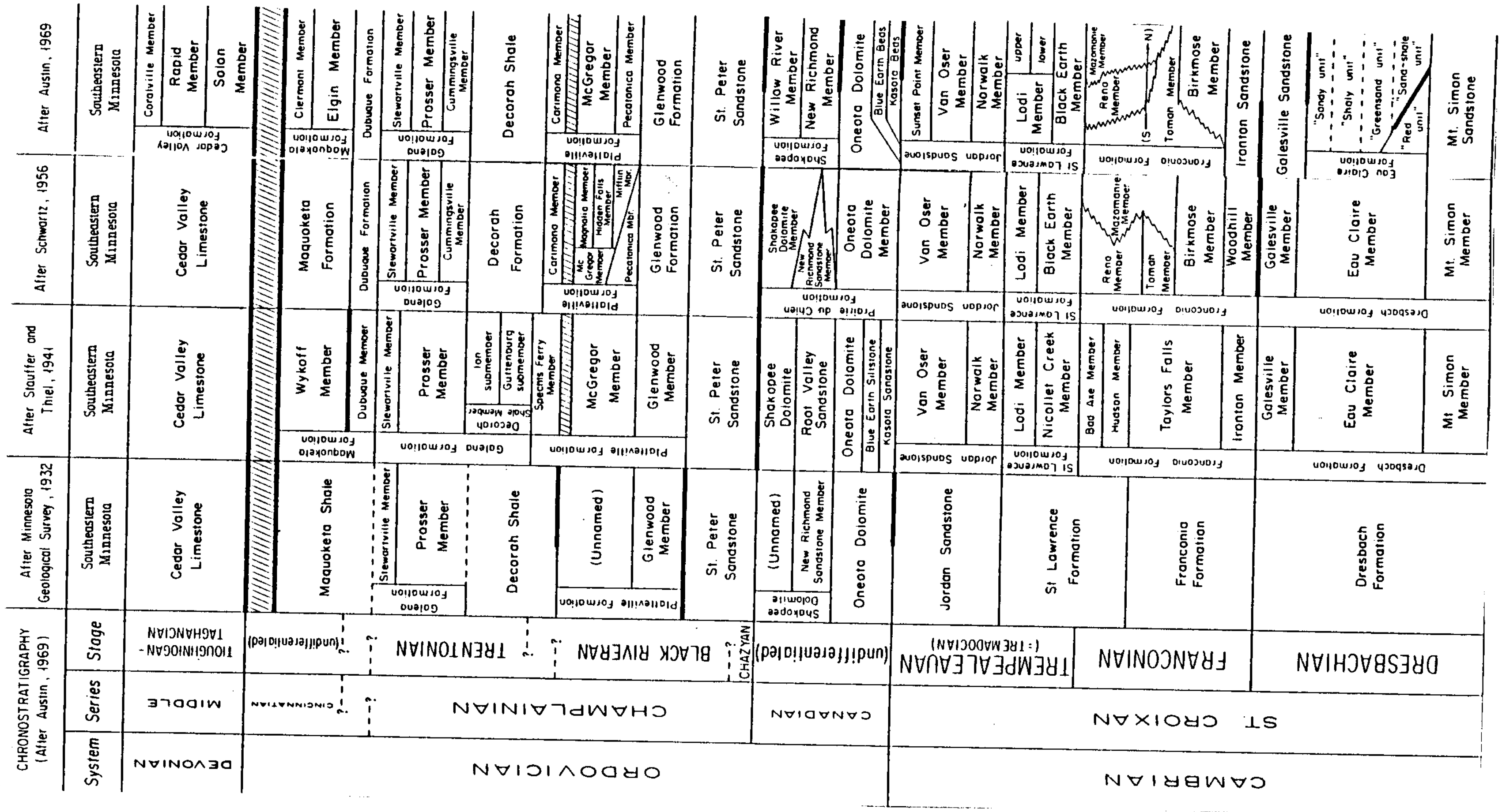
Appendix A-Figure #2

Explanation for Sloan-Austin Map



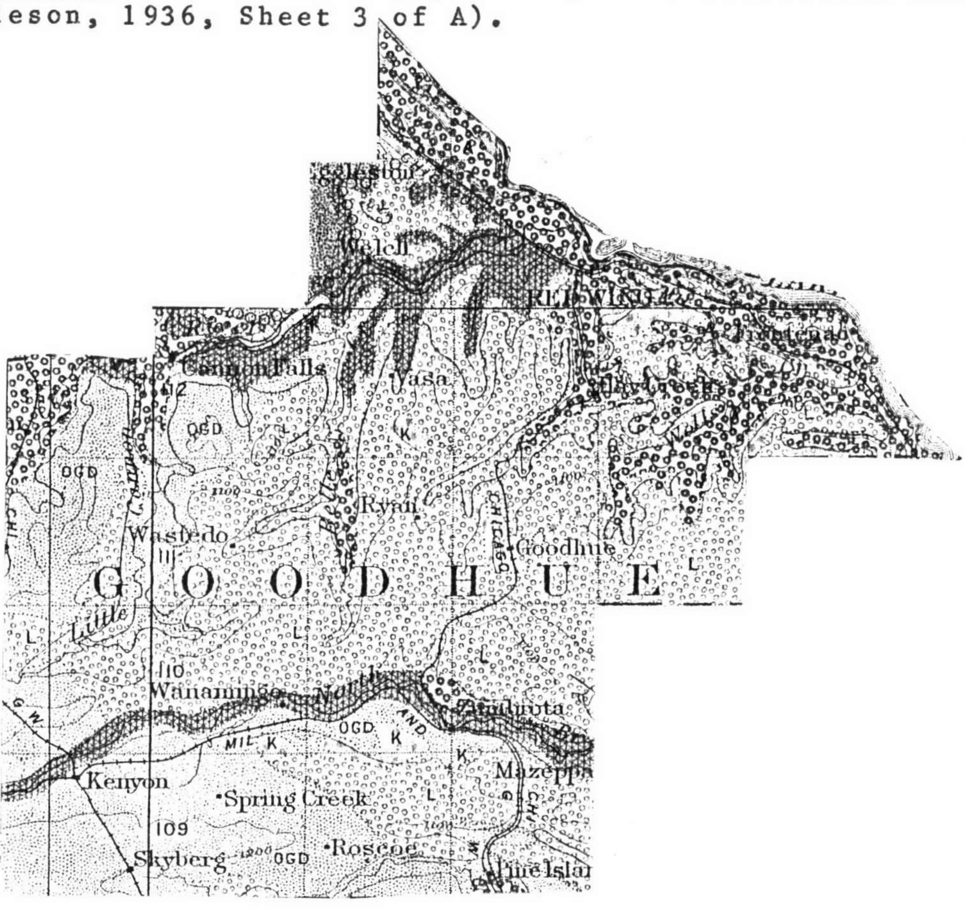
Appendix A--Figure #3

Schwartz', 1956, and Austin's, 1969, Stratigraphic Columns and Classifications of Paleozoic Rocks in Southeastern Minnesota (from Austin, 1972b, in Sims and Morey, p. 460).



Appendix A--Figure #4

Leverette and Sardeson's <u>Map of Surface Formations of Minnesota</u>, Goodhue County portion, 1916 (Leverette and Sardeson, 1936, Sheet 3 of A).



LEGEND

Old gray drift	OGD	*A drift older than the Wisconsin, brought in by the Western or Keewatin icefield. Calcareous except the leached surface. Soil usually clay loam. Drainage more nearly perfect than in younger drift. Includes occasional gravel knolls* (K).
Old red drift	ORD	*A drift older than the Wisconsin, brought in by the Middle or Patrician icefield. Largely stony to gravelly loam soil. Includes ridges and knolls* (K).
Loess	L	*A fine silt loam older than the Wisconsin drift, covering part of the old drifts in southeastern and southwestern Minnesota, also the driftless upland of southeastern Minnesota. Deposited largely by wind. Soil highly productive.*
Moraines (a) Sandy (b) Clayey	MS K / MC	*Rolling to gently undulating deposits laid down at border of ice sheet; composition variable ranging from very stony and sandy material to heavy clay with few stones. In each group, Sandy and Clayey, there is much variation. All classes of moraines are fair to good farm land. Some steep hillsides and some swamps occur in the strong moraines. Kames are isolated gravelly hills or groups of hills marked* (K.) *They contain much good road material.*
Outwash gravel in plains or aprons	S / A	*Gravel or pebbly sand spread with level surface outside the moraines by water escaping from the ice sheet. Soil usually light and crops on it easily affected by drouth. In some places the ice readvanced over the outwash introducing clay enough to greatly increase the fertility, notably so in southern Wadena County. Not highly productive unless intelligently cultivated. Areas of sandy gravel marked* (S) *are not so definitely related to the ice border waters. Areas marked* (A) *are alluvial worked over deposits.*
Rock outcrops	R / PR	*Paleozoic rocks* (PR); *older rocks* (R). *Paleozoic areas marked* (PR) *usually have a good soil; but areas marked* (R) *are largely of little agricultural value. Not all are shown.*

scale: reduced from 1:500,000

SCALE: miles

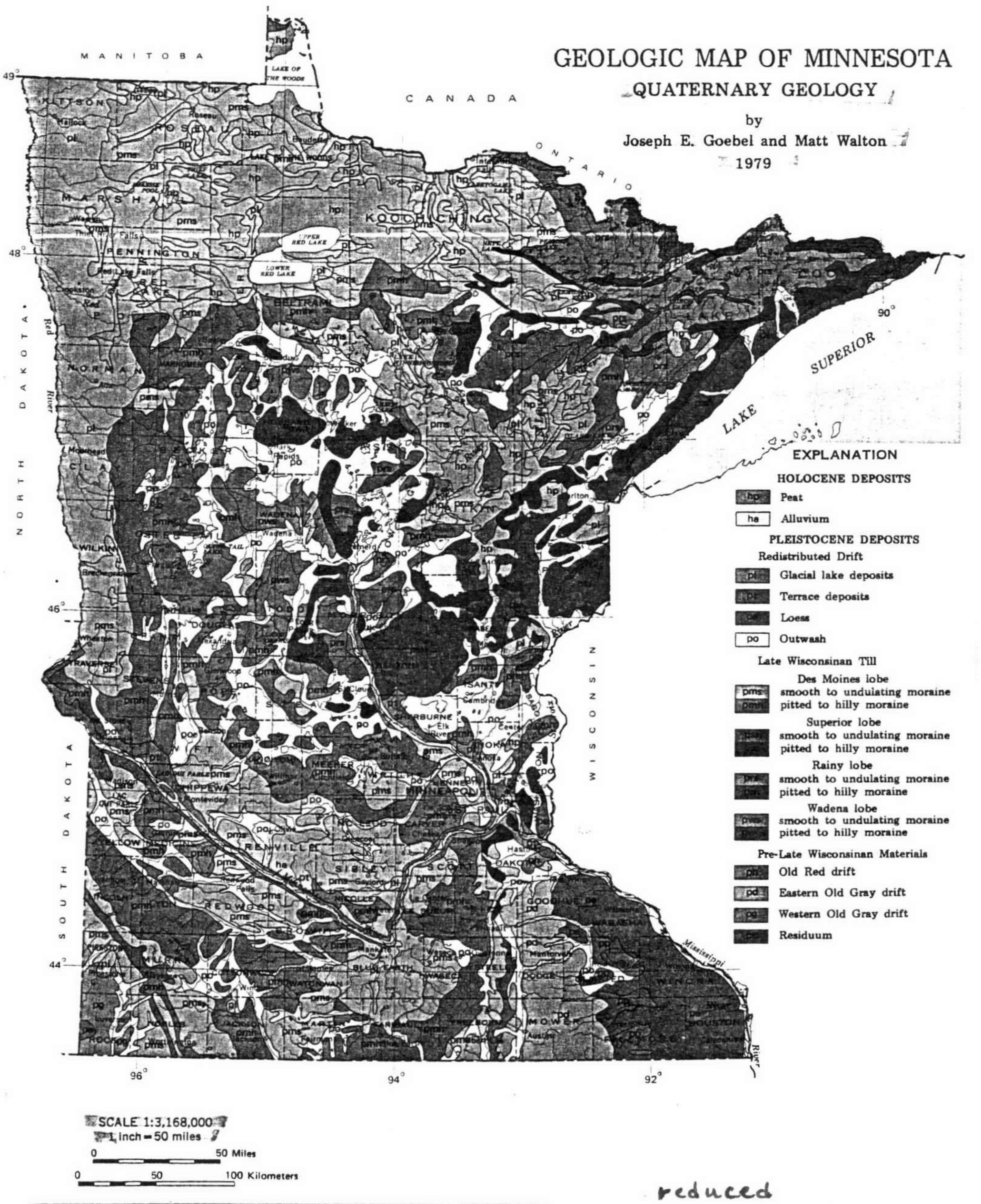
8 7 6 5 4 3 2 1 0 8 16 24

Appendix A--Figure #5

Goebel and Walton's <u>Geologic Map of Minnesota: Quaternary Geology</u>, 1979.

Minnesota Geological Survey
University of Minnesota
Matt Walton, Director

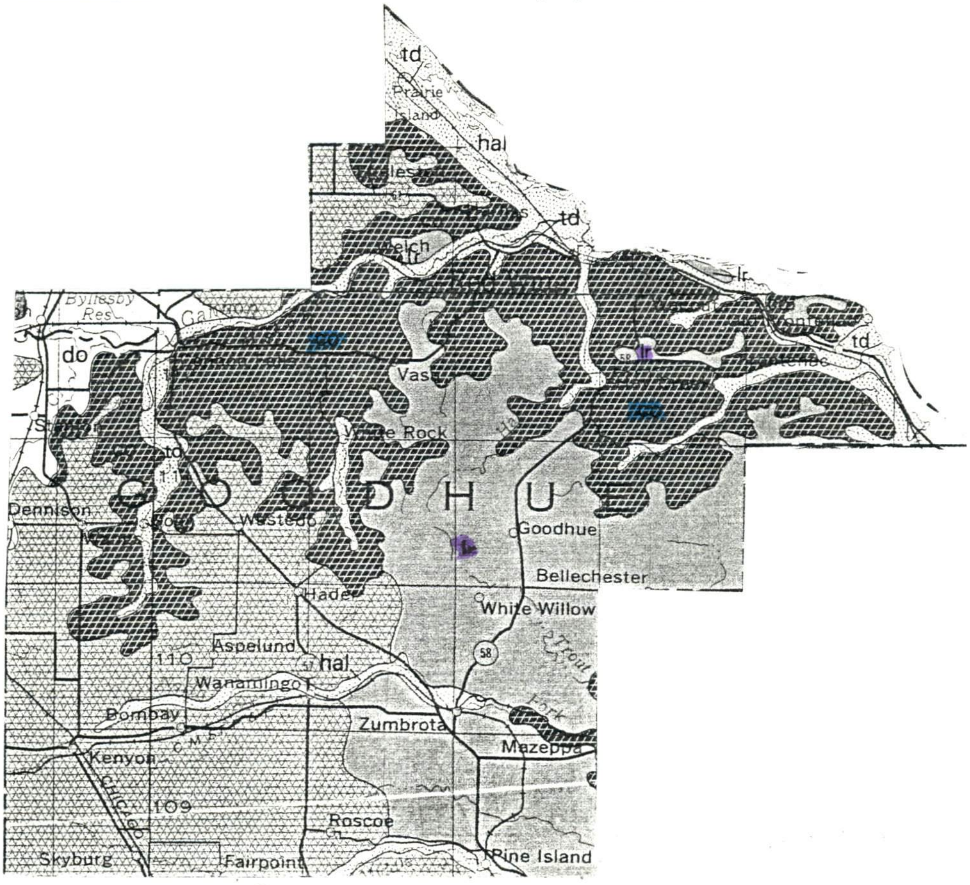
STATE MAP SERIES S-4



reduced

Appendix A--Figure #6

Hobbs and Goebel's Geologic Map of Minnesota: Quaternary Geology, 1982 Goodhue County portion.



DESCRIPTION OF MAP UNITS

hal — ALLUVIUM (HOLOCENE)—*sand and gravel, silt, and clay deposited in channels and floodplains of modern streams. Mapped only where the width of the floodplain exceeds about half a mile. Narrow valleys containing outwash or terrace units, as well as alluvium, are mapped as the dominant unit.*

td — TERRACES (HOLOCENE TO PLEISTOCENE)—*remnants of former channels and floodplains above the levels of present floodplains, and below the levels of adjacent moraine or outwash surfaces. Predominantly sand and gravel, but finer grained material also occurs, especially in the terraces along small tributaries of the Mississippi River. Parts of some terraces are scoured surfaces rather than deposits.*

COLLUVIUM (HOLOCENE TO PLEISTOCENE)—*unsorted slope sediment composed largely of rock rubble in a matrix of finer grained material. Bedrock outcrops commonly present.*

DEPOSITS ASSOCIATED WITH THE DES MOINES LOBE (PLEISTOCENE, LATE WISCONSINAN)—*gray calcareous drift (buff to brown where oxidized); shale and limestone clasts generally common, derived from Manitoba and eastern North Dakota; combined silt and clay typically exceeds 50% of till.*

do — OUTWASH—*undivided as to moraine association.*

DEPOSITS INFERRED TO BE PRE-WISCONSINAN IN AGE

RED DRIFT (PLEISTOCENE, PRE-WISCONSINAN)—*traditionally assigned to the Illinoian Glaciation; predominantly ice-contact stratified drift.*

pdd — GRAY DRIFT (PLEISTOCENE, PRE-WISCONSINAN)—*traditionally assigned to the Kansan Glaciation; may contain two or more separate drift sheets. Dissected, locally loess-covered.*

WEATHERING RESIDUUM OVER BEDROCK (PLEISTOCENE, PRE-WISCONSINAN)—*Loess-covered; includes remnants of highly eroded old drift and slopewash sediment.*

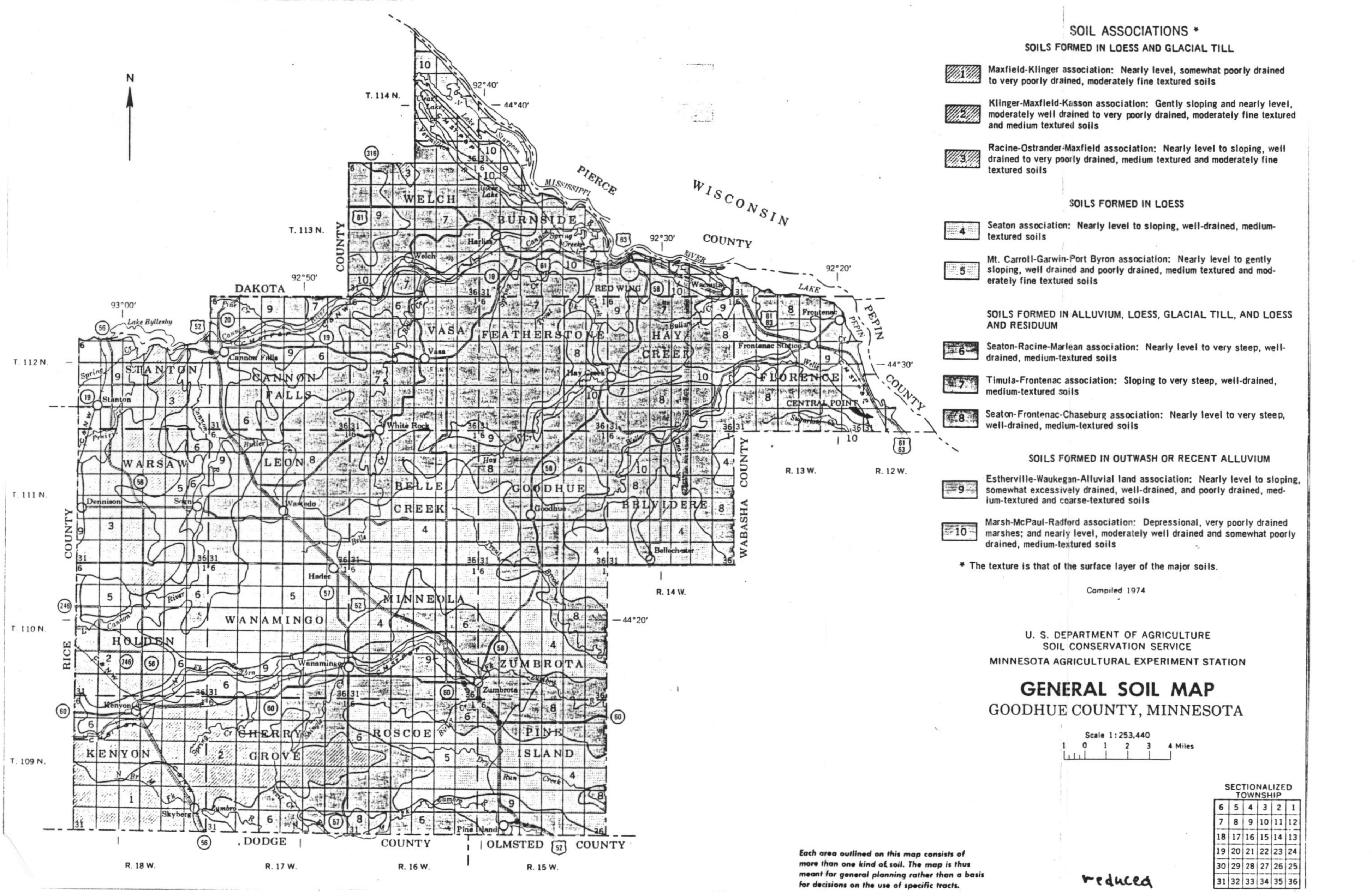
Scale: Miles

4 0 8

reduced from 1:500,000

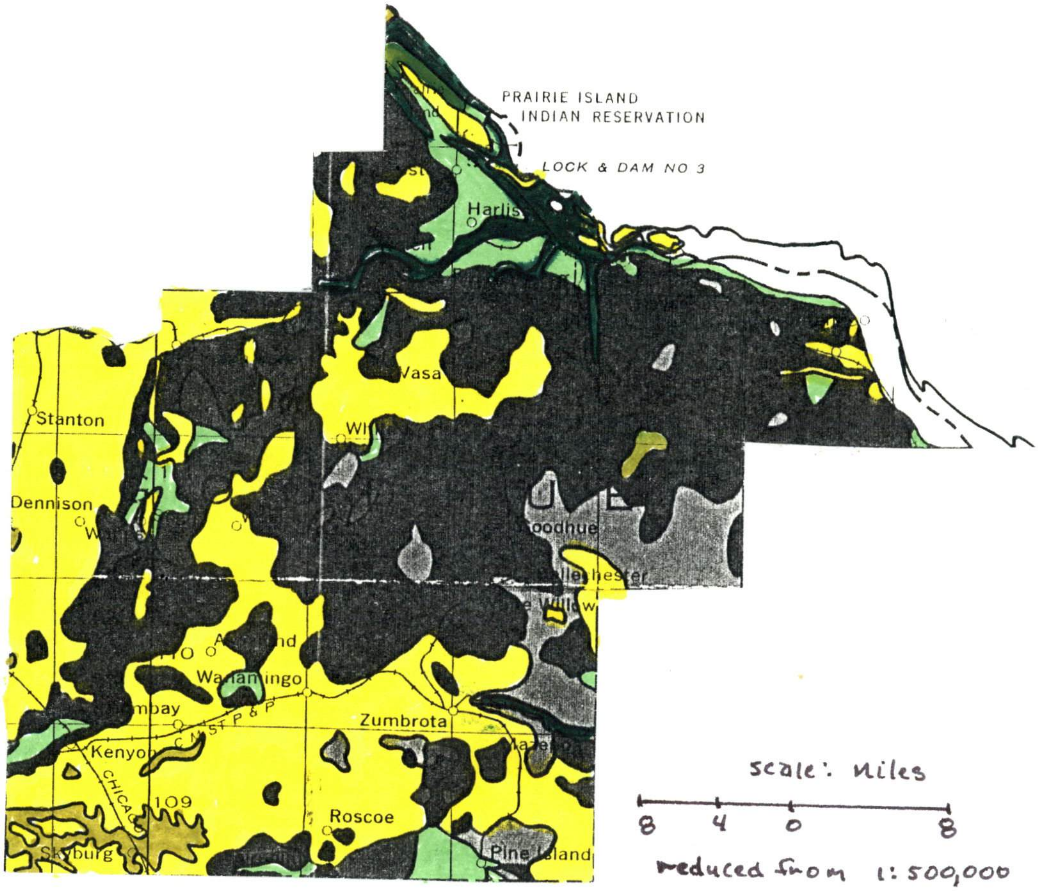
Appendix A--Figure #7

Poch's <u>General Soil Map: Goodhue County, Minnesota</u>, 1974 (from Poch, 1974, following p. 129).



Appendix A--Figure #8

Marshner's Map <u>The Original Vegetation of Minnesota</u>, 1974, Goodhue County portion.



GRASSLAND

PRAIRIE

WET PRAIRIES, MARSHES AND SLOUGHS: Marsh-grasses, Flags, Reeds, Rushes, Wild Rice, with Willow and Alder-brush in places.

BRUSHLAND

BRUSH PRAIRIE: Grass and Brush of Aspen, Balm of Gilead and little Oak and Hazel in the North but mainly Oak and Hazel in the South.

ASPEN-OAK LAND: Aspen, generally dense, but small in most places, with scattered Oaks and few Elms, Ash and Basswood.

OAK OPENINGS AND BARRENS: Scattered trees and groves of Oaks (mostly Bur Oak) of scrubby form with some brush and thickets and occasionally with Pines.

HARDWOOD FOREST

BIG WOODS: Oaks (Bur, White, Red and Black), Elm, Basswood, Ash, Maple, Hornbeam, Aspen, Birch, Wild Cherry, Hickory, Butternut, Black Walnut, etc., with some White Pine.

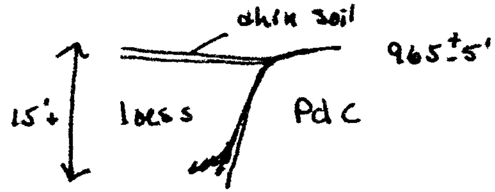
RIVER-BOTTOM FOREST: Elm, Ash, Cottonwood, Boxelder, Oaks, Basswood, Soft Maple, Willow, Aspen, Hackberry, etc., with occasional Pines and Arborvitae in the Pine Region.

APPENDIX B

SAMPLES OF FIELD AND WELL DATA

We-025

Location: NW1/4, SE1/4, Sec 9 Welch twp. **SECTION:**



Date: 10/20/80

Type: exposure. loess overlying PdC

PP: alongside of valley tributary to Cannon

EBS: 965 +/- 5' (highest top)

TBF: PdC

TO: 0 ± >15'

CRT: —

Comments: 18 ± 2' high roadcut, unconformable. Loess all the way to the top on the south side of the cut; PdC all the way to the top on the north side of the cut. Road cut is on the west side of a north-south road. The surface between the loess and the PdC is nearly vertical. PdC also crops out across the road with EBS of 970 ± 5'. The PdC is high here relative to several miles farther west.

Stream across road is cut into ≈10' of alluvium. N. red oak & paper birch. grazed.

Appendix B--Figure #1
Sample Field Data Card

Appendix B--Figure #2
Sample Well Log, from the Minnesota Geological Survey

MINNESOTA GEOLOGICAL SURVEY
WATER WELL DATA BASE. 84/02/14.

UNIQUE NO.: 165304
WELL NAME : RICHARD ERSLAND

COUNTY : GOODHUE DATE ENTERED:
ADDRESS : 421 RED WING KENYON
QUADRANGLE: WEST CONCORD 7.5 MINUTE WC- W10 *

TOWNSHIP : 109 NORTH UTM-EASTING : 0
RANGE : 18 WEST UTM-NORTHING: 0
SECTION : 34/BABDBB UTM-ZONE : 0
LATITUDE : LONGITUDE :
LOCATED BY: NAME ON MAILBOX

ELEVATION : 1241 FT. WATER LEVEL : 245 FT.
DEPTH : 419 FT. DATE : 79/10/17
COMPLETED : 79/10/17 AQUIFER(S) : PRAIRIE DU CHIEN GROUP

WELL USE : DOMESTIC
DRILLER : (AND/OR DATA SOURCE) CANNON WELL CO.
CASING : STEP DOWN
: 004 INCH TO 0379 FEET
SCREEN
MAKE/TYPE: NONE

PUMP
MAKE/NO. : STA-RITE VIP
SIZE : 001.5 HP. 00230 VOLTS CAPACITY : 00010 G.P.M.
TYPE : SUBMERSIBLE DROP PIPE : 00357 FT.

REMARKS : PUMPAGE TEST DATA NOT AVAILABLE

GEOLOGIC LOG

DEPTH INTERVAL (IN FEET)		LITHOLOGY		STRATIGRAPHIC UNIT SYSTEM/GROUP/FORMATION	AGE	HARDNESS	COLOR	DRILLER'S DESCRIPTION
0	4	SOIL,ORGANIC		QUATERNARY UNDIFF.	QUA			DIRT
4	25	CLAY		TILL	QUA			CLAY
25	30	CLAY		TILL	QUA		YELLOW	CLAY
30	100	CLAY		TILL	QUA		BLUE	CLAY
100	150	CLAY		TILL	QUA			CLAY
150	155	SAND	5' thick	FLUVIAL DEPOSIT	QUA			SAND
155	165	CLAY	10' thick	TILL	QUA			CLAY
165	180	GRAVEL	15' thick	FLUVIAL DEPOSIT	QUA			GRAVEL
180	225	SHALE		DECORAH	ORD			SHALE
225	245	LIMESTONE		PLATTEVILLE	ORD			LIMEROCK
245	248	SHALE		GLENWOOD	ORD			SHALE
248	355	SANDSTONE		ST.PETER	ORD			SANDROCK
355	419	DOLOMITE		PRAIRIE DU CHIEN GROUP	ORD			LIMEROCK

APPENDIX C

PHOTOGRAPHS

Appendix C--Figure #1

General upland surface near Kenyon.
Note the broad, gentle, and open slopes.

Appendix C--Figure #2

Little Cannon Valley, south of Sogn.
Note the gentle and cultivated valley
floor, the steep, pastured, and
partially wooded valley sides.

Appendix C--Figure #3

General upland surface near Goodhue. Note the nearly level surface, interrupted by knolls of Windrow sediments. In the distance, immediately west of Goodhue, is the St. Peter-Platteville escarpment, covered by a moderate thickness of glacial drift.

Appendix C--Figure #4

Land surface near Stanton. Note the flat and very broad floor of the Prairie Creek valley. It is interrupted by a mesa of St. Peter Sandstone overlain by Glenwood Shale and capped by Platteville Limestone.

Appendix C--Figure #5

Mississippi River, natural levees, bluff, and Lake Pepin. This aerial photograph was taken looking east-southeast. Red Wing is behind the wing strut.

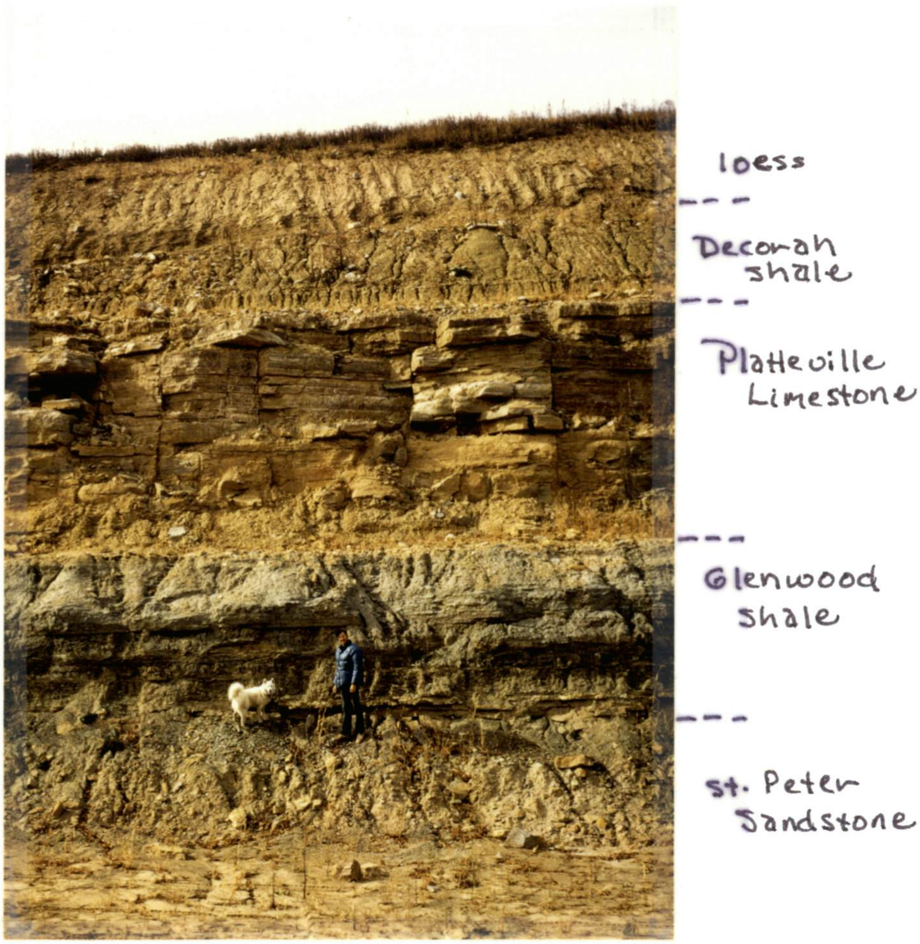
Appendix C--Figure #6

Distributaries at the mouth of the Cannon River. Between Red Wing and Prairie Island, the Cannon River sinks into the alluvial material and terrace sands and gravels of the Mississippi River valley.

Appendix C--Figure #7

Barn Bluff from downtown Red Wing. The bluff, probably once an island in a far larger glacial Mississippi River, is composed of the Franconia, St. Lawrence, Jordan, Oneota, and Shakopee formations. It is cut by the Red Wing fault. The high angle dip slip fault, seen behind the bridge on the right side of the photograph, cuts the greenish sandstone of the Franconia Formation and the buff siltstone of the St. Lawrence Formation.

Appendix C--Figure #8



Ordovician rocks exposed in a road cut southeast of Cannon Falls, WR-03. The white St. Peter Sandstone is overlain, conformably and sequentially , by the greenish Glenwood Shale, the buff-colored Platteville Limestone, and the gray-green Decorah Shale. The Decorah Shale is partially eroded and unconformably overlain by buff-colored loess. The six foot tall man is standing on the Glenwood-St. Peter contact.

Appendix C--Figure #9

Rocks of the Galena Formation in a quarry near Roscoe, exposure C-05. The Galena Formation is a thick-bedded and fractured dolomite. Note the small active sink at the center of the photograph.

Appendix C--Figure #10

Sediments of the Windrow Formation, near Goodhue. Note the interstratified sands, silts, clays, and clay pebbles. This photograph is taken at exposure GE-040.

Appendix C--Figure #11

Sink in the Prairie du Chien Dolomite, filled with Windrow Clay. The roadcut, GE-06, is approximately 1.25 miles southeast of Belvidere Mills.

Appendix C--Figure #12a and #12b

Glacial, glaciofluvial, and aeolian materials overlying the Platteville Limestone and Decorah Shale, northwest of White Rock. This roadcut, WR-04, exposes the Platteville Limestone overlain by a thin and highly weathered, perhaps reworked, gray-green layer of Decorah Shale, in turn unconformably overlain by a layer of buff and partially cemented glacial till left by northwestern source ice, a layer of reddish sand and gravel left by outwash of northeastern source ice, and a layer of light gray loess.

pg. 135 with
Appendix C Figure
#12b East

Appendix C--Figure #12a and #12b

Glacial, glaciofluvial, and aeolian materials overlying the Platteville Limestone and Decorah Shale, northwest of White Rock. This roadcut, WR-04, exposes the Platteville Limestone overlain by a thin and highly weathered, perhaps reworked, gray-green layer of Decorah Shale, in turn unconformably overlain by a layer of buff and partially cemented glacial till left by northwestern source ice, a layer of reddish sand and gravel left by outwash of northeastern source ice, and a layer of light gray loess.

Appendix C--Figure #13

Terrace sands and gravels overlain by loess. This exposure, LC-05, is immediately northwest of Lake City.

APPENDIX D

COMMENTS ON MAP CONSTRUCTION

The Base, Planimetric, Drainage, and Topographic maps were constructed using information from the U. S. Geological Survey topographic sheets. The Data Base and Slope maps, Cross-Sections A-A' and B-B', and the Maps of Bedrock Geology, Bedrock Topography, Overburden Thickness, Surficial Geology, and Geomorphic Divisions are original. All maps were drawn on mylar and can be superimposed on each other.

Construction of the Base Map (Plate I), Planimetric Map (Plate II), Drainage Map (Plate IV), Topographic Map (Plate V), and the Slope Map (Plate XIII) are discussed within the body of the dissertation.

The Data Base Map (Plate III) was produced by tracing the county outline and permanent water bodies off the Base Map and noting the location of each field observation and well log. Field observations and well log locations were first placed on the individual quadrangle maps, then the Base Map, and finally the Data Base Map.

Once the Data Base Map was complete, overlay maps showing the elevation of the bedrock surface, thickness of the overburden, and thickness and sequence of consolidated and unconsolidated units at data locations were produced. These overlay maps (#3A and #3B), used as working maps only and not included with this report, were used in conjunction with the Base and Topographic maps, soils maps, and field observations to produce, in order, the draft Maps of Bedrock Topography, Overburden Thickness, Bedrock Geology, and Surficial Geology. Final maps were produced, once all draft maps were complete, through a continual refinement process.

The Map of Bedrock Topography (Plate VII) was constructed in three steps. (1) Paper for the Map of Bedrock Topography was placed over Map #3A, and logical contouring was done at 100 foot intervals--an interval selected as most appropriate since larger intervals did not give enough information and smaller intervals obscured the map and resulted in a margin of error larger than the interval. (2) This draft map was then placed over the Topographic Map and corrected so that in no place was the bedrock surface higher than the land surface. (3) Map refinement and completion took place after the draft maps of overburden thickness, bedrock geology, and surficial geology had been drawn.

The Map of Overburden Thickness (Plate VIII) was constructed in three steps. (1) Paper for the Map of Overburden Thickness was placed over Map #3B and logical contouring was done on variable thickness intervals--mapping uniform thicknesses did not make sense since the effect on the land surface between two and fifty feet of overburden is considerably greater than between one hundred two and one hundred fifty feet. (2) This draft map was then placed over the Topographic Map and corrected so that no conflicts existed between the two maps and knowledge of field conditions. (3) General trends of overburden thickness were compared with general trends of the bedrock topography and corrected so that in no place was the overburden thickness in conflict with the buried valleys.

I made several major decisions while drawing the Maps of Bedrock Topography and Overburden Thickness. Where deep "holes" appeared in the bedrock surface, holes which could not be recording errors, I believed them to indicate buried valleys rather than sinks--the known sinks of Goodhue County are only tens, not fifties of feet in depth, and buried valleys are well-substantiated in the nearby Twin Cities. I eliminated as many isolated bedrock hills as possible, preferring an integrated drainage system, since the bedrock in Goodhue County is generally soft and flat-lying, and erosion is possible over a long span of geologic time. Although I could have mapped overburden thickness by substracting the elevation of the bedrock surface from the elevation of the land surface, I chose not to do this because of the necessity for intervals of varying thickness and the desire not to compound errors.

Construction of the Map of Bedrock Geology, once field and well log information had been gathered and placed on the Data Base Map, consisted of four major steps: (1) selecting the mapping units; (2) sketching the contacts between formations from field and well data; (3) correcting the map by placing it over the Map of Bedrock Topography; and (4) refining the map, where overburden is very thin, by placing it over the Base Map. The choice of mapping units was fairly straightforward--the Paleozoic stratigraphy of southeastern Minnesota is well-known, the formations, except for those of the Prairie du Chien Group, easily recognized in Goodhue County, and except for the Glenwood Shale, thick enough to map at my chosen scale. I thus mapped the Galena, Decorah, Platteville-Glenwood, St. Peter, Jordan, St. Lawrence, Franconia, and Dresbach formations, and the Priaire du Chein Group. I used the Schwartz terminology (Austin, 1972b., <u>in</u> Sims and Morey, p. 460) (see Appendix A, Figure #3) for the Cambrian formations because much of the information on these lower formation comes from well logs which use this terminology. The Cretaceous Windrow Formation, considered as bedrock by Sloan and Austin, consists primarily of unconsolidated clay, sand, and gravel. In the well logs it is indistinguishable from till, fluvial deposits, and loess. It consequently does not appear on the Map of Bedrock Geology.

Construction of the Map of Surficial Geology consisted of seven major steps: (1) field work; (2) well log interpretation; (3) placement of information from the field work and well logs onto Map #3B; (4) selection of mapping units; (5) close examination of soils sheets; (6) use of information from Map #3B and the soils sheets to map the surficial materials onto the Map of Surficial Geology, an overlay of the Base Map; and (7) refinement of the map after completion of the Maps of Bedrock Geology, Bedrock Topography, and Overburden Thickness.

Well log interpretation proved difficult because, for example, many logs recorded only undifferentiated glacial drift--a classification which included glacial till, glacial outwash, loess, and Windrow sediments. The choice of mapping units proved a challenge because unconsolidated units are often thin and discontinuous and are not standardized. I needed units which were recognizable in the field, mappable, and objectively described. I needed to decide whether to map soils and loess. I needed also to decide what thicknesses of material were worthwhile to map. I did not map soils which form a thin cover over the entire county and do not affect overall land surface configuration. Much the same reasoning pertains to loess, but I did not map it where I where I had insufficient information to know exactly what it overlies and where, according to the soils maps, it is greater than five feet thick. Other surficial units were mapped regardless of their thickness. Developing the legend for the Map of Surficial Geology also proved challenging. I needed to understand the stratigraphic sequence of unconsolidated materials and speculate about their origin and age.

The Map of Geomorphic Regions and the Cross-Sections A-A' and B-B' could be constructed once the Maps of Bedrock Topography, Bedrock Geology, Overburden Thickness, and Surficial Geology were complete. The Map of Geomorphic

Regions (Plate X) was drawn, after consideration of my knowledge of land surface origin in Goodhue County, as an overlay of the Base Map. The Cross-Sections (Plate XI) were drawn through direct use of the Topographic Map, Map of Bedrock Geology, Map of Bedrock Topography, and relevant well logs.

Numerous aspects of data availability and distribution have affected map accuracy. The distribution of outcrops, exposures, and wells is non-random. Outcrops occur along valley sides and on steep upland slopes; exposures occur along roadways, in gravel pits, and in quarries; wells show population dispersal. The areas of best mapping control are near Zumbrota, Pine Island, Red Wing, Kenyon, Hay Creek, Cannon Falls, and along the east side of the Little Cannon River, alongside Belle and Prairie creeks, and near Welch; the areas of poorest control are on the uplands between Zumbrota and Kenyon, between Belle Creek, Spring Creek, and Hay Creek, and surrounding the town of Goodhue.

APPENDIX E

COMMENTS ON SCALE OF STUDY, EDUCATIONAL BACKGROUND OF INVESTIGATOR, AND AVAILABLE TECHNOLOGY

Scale, educational background of investigator, and available technology influence the findings of any study. Of these parameters, scale is most important for any areal study. Scale determines many of the findings concerning the role which structure and materials, time, and process play in landscape development.

I chose a scale of 1:62,500 for this study because of the kinds of questions I was asking, the kinds of observations I wished to make, and the kinds of features I wished to map and analyze. I wished to know about the controls on a land surface rather than a landform.

The scale of 1:62,500 enhanced my ability to anlayze the affect of material and structure on land surface configuration, but limited my ability to analyze the affect of processes and time on land surface development. Endogenic processes and time demand analysis of large areas at smaller scales. Exogenic processes often demand analysis of a small area at a larger scale.

Educational background and available technology also influence the conclusions drawn from any study. In this particular study, my background in Paleozoic stratigraphy and Quaternary geology and the presence of Cretaceous sediments in my study area, biased me toward analysis of all post-Precambrian time. Lack of technological support limited my ability to conduct geophysical work, detailed subsurface logging, and radiometric dating. I relied heavily on mapping and the megascopic analysis of physiographic and stratigraphic features and relationships.