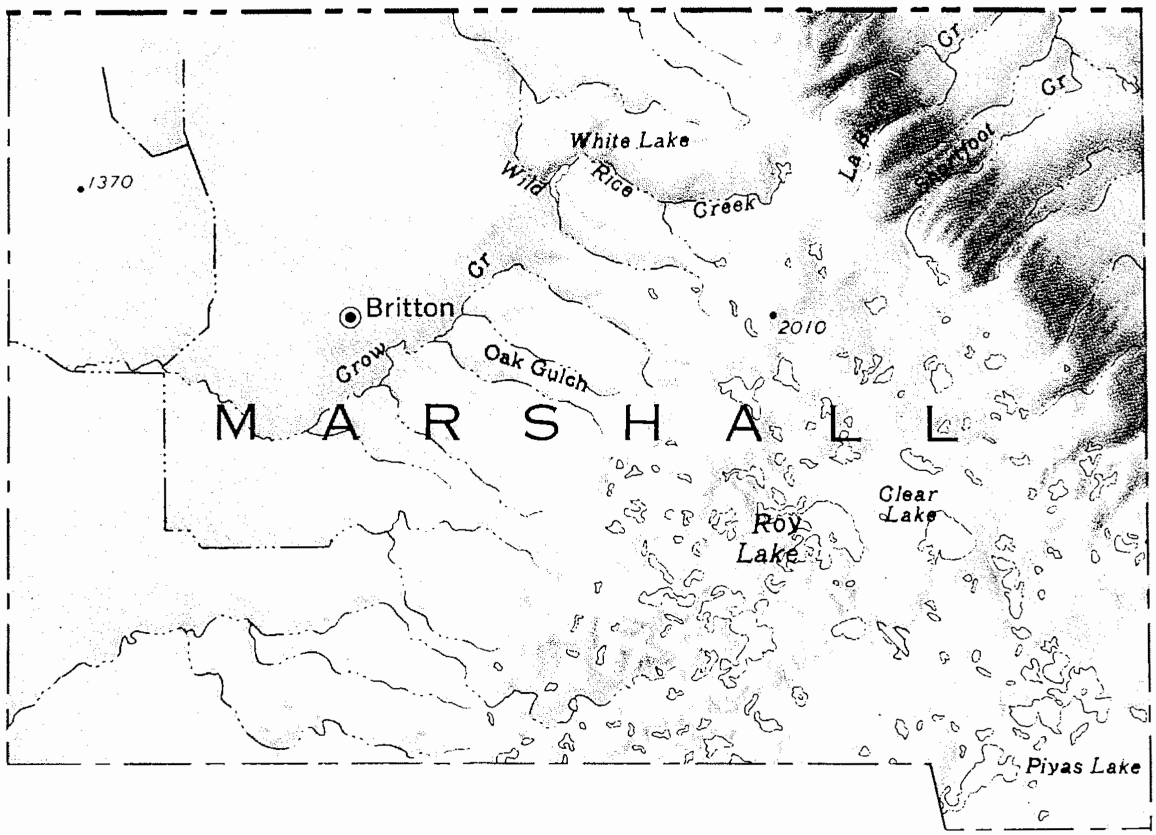
BULLETIN 23

GEOLOGY AND WATER RESOURCES OF MARSHALL COUNTY, SOUTH DAKOTA



PART I: GEOLOGY AND WATER RESOURCES

by Neil C. Koch

U. S. Department of the Interior - Geological Survey

Prepared in cooperation with the S. D. Geological Survey, Marshall County, and the Oahe Conservancy Sub-District.

Department of Natural Resource Development
South Dakota Geological Survey - 1975

STATE OF SOUTH DAKOTA
Richard Kneip, Governor

DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT
Vern W. Butler, Secretary

GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

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ABSTRACT

Marshall County, a recreational and agricultural County in northeastern South Dakota, has an area of 888 square miles (2,300 km^2).

Pleistocene glacial and lacustrine deposits of late Wisconsin age and Holocene (Recent) sediments make up most of the surficial deposits of the County. Glacial deposits as much as 805 feet (245 m) thick overlie sedimentary rocks of Cretaceous age.

Evidence suggests that the late Wisconsin ice margin halted four times during the period of deglaciation, thus causing major reshaping of the topography and drainage.

The surface water supply includes several small intermittent streams and numerous marshes, ponds, and lakes. Field analyses of water samples from 37 lakes and ponds indicated that most of the sampled lakes and ponds have a specific conductance of less than 1,000.

Glacial deposits of sand and gravel are the important water-bearing units in Marshall County. Of the six aquifers in drift that are described, the James, Veblen, and Coteau-lakes aquifers can provide yields of 500 gpm (32 l/s) or more to properly constructed wells. Analyses of water from 86 wells tapping the major aquifers show that the major constituents are calcium, sodium, bicarbonate, and sulfate.

The James aquifer underlies 220 square miles (570 km^2) of Marshall County. The aquifer ranges in depth from about 100 to 580 feet (30 to 177 m) below land surface. Water in the aquifer is under artesian pressure; the water surface ranges from 2 to 111 feet (1 to 34 m) below land surface. The aquifer contains an estimated 1½ million acre-feet (2 billion m^3) of water in storage.

The Veblen aquifer underlies 24 square miles (62 km^2) in the northeastern corner of the County. Water in the aquifer occurs under artesian conditions except in some places where the aquifer is at land surface and water-table conditions exist. Water levels range from 50 to 100 feet (15 to 30 m) below land surface. The thickness of the aquifer ranges generally from 40 to 69 feet (12 to 21 m) and well depths range from 80 to 158 feet (24 to 48 m) below land surface.

The Coteau-lakes aquifer, of widely varying thickness, underlies about 50 square miles (130 km^2) in the southeastern part of the County. It is at or near land surface and is hydraulically connected with Buffalo, South Red Iron, North Red Iron, Clear, and Roy Lakes. Water in the aquifer is under water-table conditions in some areas and under artesian conditions in others; water levels range from lake surface to 40 feet (12 m) below land surface.

Three minor aquifers, the Marday, Eden, and Roslyn, underlie all or part of the coteau.

The Dakota aquifer, consisting of sandstone of Cretaceous age, underlies all of Marshall County at depths of from 900 to 1,500 feet (274 to 457 m). Water in the aquifer is under artesian pressure and in low-lying areas many wells flow.

Water from the James, Veblen, and Coteau-lakes aquifers has medium to high salinity hazard, and ranges from low to high sodium hazard. Water from the Dakota aquifer is not suitable for irrigation because of its poor quality.

INTRODUCTION

Purpose and Scope

In July 1967, the South Dakota State Geological Survey and the U.S. Geological Survey began a 5-year cooperative study of the geology and water resources of Marshall, Day, and Brown Counties. This study is part of a cooperative program of the geology and water-resources evaluation in South Dakota. The progress of that program is shown in figure 1.

The purpose of this report is to provide information that can be used for planning the development of water supplies. This is a general appraisal of water resources; any large-scale development of ground water should be preceded by test drilling and determination of local aquifer characteristics. A geologic map and an evaluation of data concerning the geology and hydrology of the area, well inventories, chemical analyses of water samples, static water levels in wells, and test drilling were included in the study.

The basic data collected and used in preparation of this report will be published in a separate report that will contain well records, quality-of-water data, water level records, and well logs.

For those readers interested in using the metric system, metric equivalents of English units of measurements are given in parentheses. The English units used in this report may be converted to metric units by the following conversion factors.[1]

Acknowledgments

Appreciation is expressed to the residents and officials of municipal water facilities in Marshall County for providing needed data. Local well drillers also provided valuable information about water-bearing zones. The cooperation received from the U.S. Soil Conservation Service and County Extension Agent is also appreciated.

Previous Investigations

Flint (1955) described glacial deposits and mapped the surficial geology of eastern South Dakota. A ground-water study of Crow Creek-Sand Lake area was made by Koopman (1957). Hopkins and Petri (1963) studied ground water of the Lake Dakota plain area. The basic data from the same study were published in 1962 by Hopkins and Petri. Other water-resource reports that include parts of Marshall County were written by Rothrock and Ullery (1938) and Caddes (1947), who included data on lake-level fluctuations. Erickson (1955) described the artesian conditions of the bedrock formations.

Well-Numbering System

The well-numbering and location of wells and test holes are described by a latitude and longitude system and a numbering system based on the Federal land-survey of eastern South Dakota (fig. 2). The location number consists of township followed by N., range followed by W., and section number, followed by a maximum of four upper-case letters that indicate, respectively, the 160, 40, 10 and 2½-acre (65, 16, 4, and 1 ha) tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same tract. Thus, well 127N57W30AAAA (fig. 2) is in the NE¼NE¼NE¼NE¼, sec. 30, T. 127 N., R. 57 W.

The well-numbering system of the U.S. Geological Survey is based on the grid system of latitude and longitude. The number consists of 15 digits. The first six digits denote the degrees, minutes, and seconds of

[1]

From		Multiply by	To obtain	
Unit:	*Abbreviation:*		*Unit:*	*Abbreviation:*
Inch	(in)	2.54	Centimeter	(cm)
Foot	(ft)	0.3048	Meter	(m)
Square mile	(sq mi)	2.590	Square kilometer	(km^2)
Gallon	(gal)	3.78543	Liter	(l)
Mile	(mi)	1.609	Kilometer	(km)
Acre-feet	(acre-ft)	1233.	Cubic meter	(m^3)
Acre		0.4047	Hectare	(ha)
Gallons per minute	(gpm)	0.06309	Liters per second	(l/s)

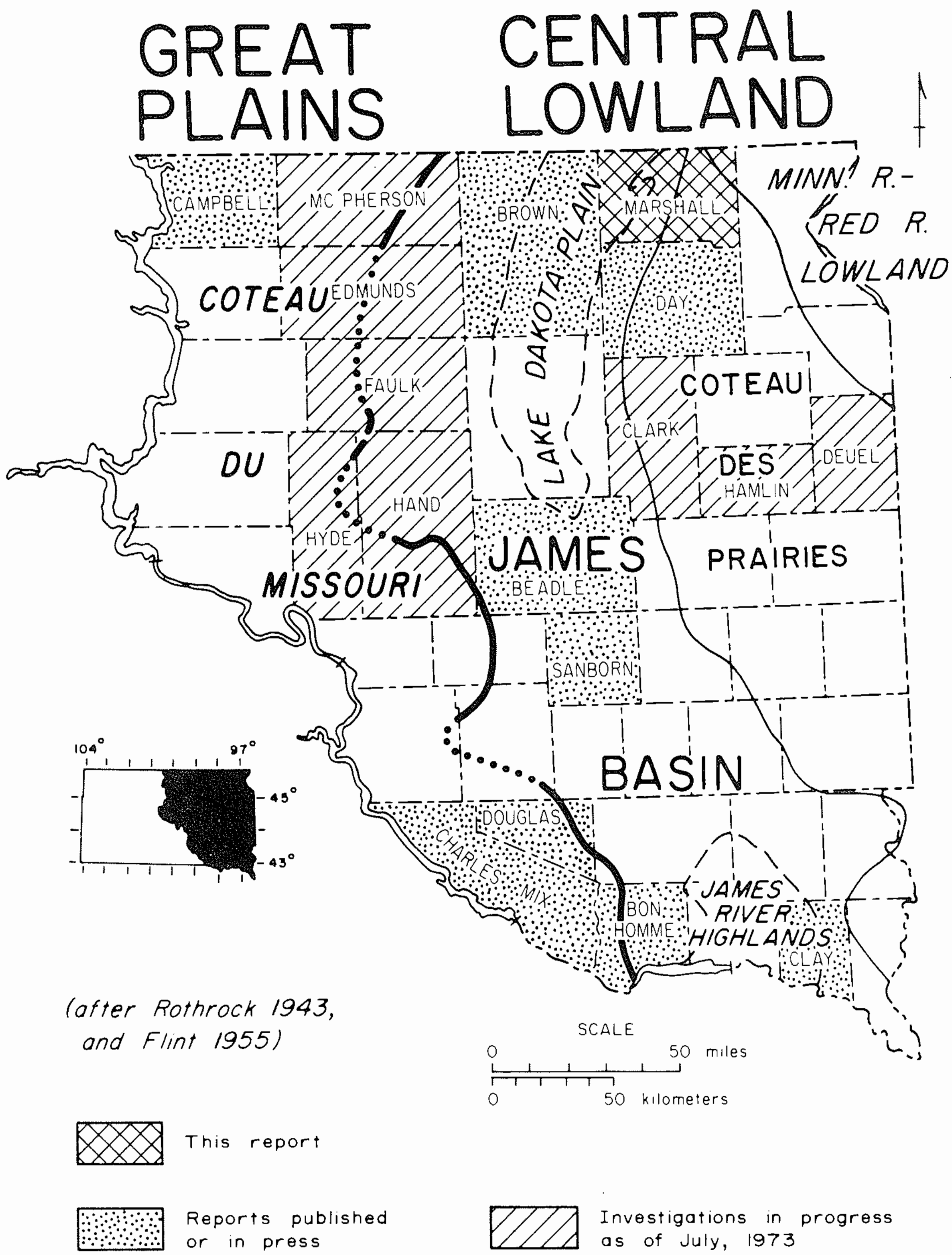


Figure 1. Index map of eastern South Dakota showing area of this report, status of county investigations, and major physiographic divisions.

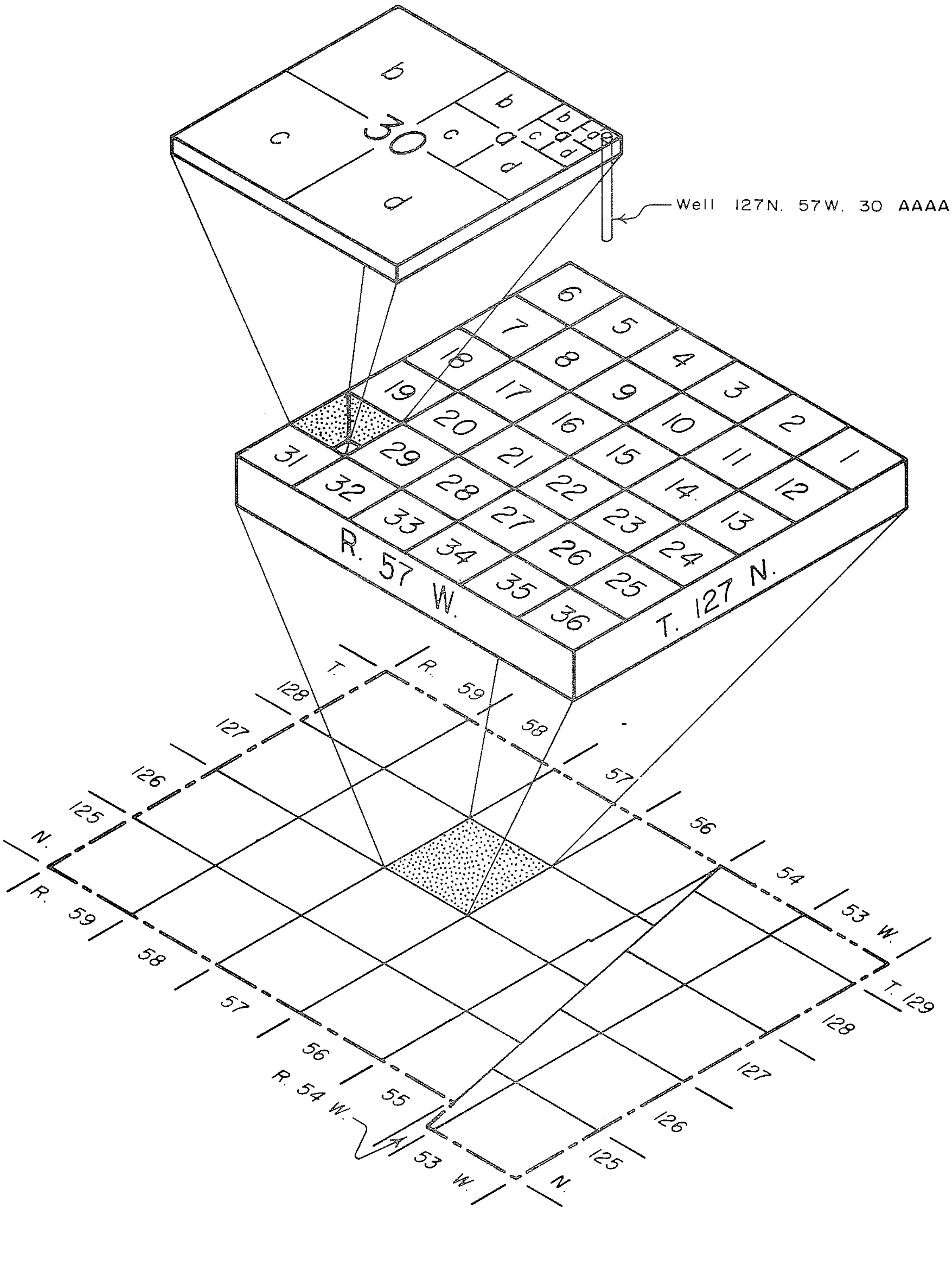


Figure 2. Well-numbering diagram.

dj

latitude. The next seven digits denote degrees, minutes, and seconds of longitude. The last two digits are sequential numbers for wells within a 1-second grid. The system provides the geographic location of the well and a unique number for each well.

GEOGRAPHY

Location and Size

Marshall County occupies 888 square miles (2,300 km^2) in northeastern South Dakota (fig. 1). The population in 1960 was 6,663, and in 1970 was 5,965. The eight towns in the County had a total population of 2,718 in 1960 and 2,296 in 1970; about one-half of the town population lived in Britton, the County seat. Three state highways (10, 23, and 25) and three railroads (the Chicago, Milwaukee, St. Paul and Pacific, the Burlington Northern, and the Soo Lines) cross the County.

Physiography and Topography

Marshall County is in the western lake section of the Central Lowland physiographic province (Fenneman, 1931). The County is in the following physiographic divisions: James River lowland, Lake Dakota plain (part of the James River lowland), Coteau des Prairies, and Minnesota River-Red River lowland (figs. 1 and 3).

In Marshall County the James River lowland, except for the Lake Dakota plain, is a westward-sloping terraced moraine between the Lake plain and the coteau. Near the end of the Ice Age the terraced moraine deposits were dissected by the large runoff from melting stagnant ice on the coteau. The melt water was carried by many streams which cut deep valleys and ravines locally called coulees.

The Lake Dakota plain is characterized by a very flat surface; local relief is rarely more than 10 feet (3 m). The Lake plain is part of the James River lowland but differs from it in that it is the floor of an ancient lake. South of the recessional moraine (shown as James River lowland in T. 128 N., R. 59 W. and T. 127 N., R. 58 W., in fig. 3), that divides the Lake Dakota plain, the surface is very flat; however, north of the recessional moraine the lake plain is interrupted by isolated patches of recessional moraine, the highest of which, located 6 miles (10 km) north of Britton, is about 65 feet (20 m) above the flat plain.

In the northwestern part of the County the lake floor is covered with windblown sand, which forms a hummocky dune topography.

The Coteau des Prairies is a high plateau of rugged morainal topography. Catlin (1840, p. 144-145) who saw the Coteau des Prairies in 1835, described it thus:

"This wonderful anomaly in nature, which is several hundred miles in length, and varying from fifty to an hundred in width, is undoubtedly the noblest mound of its kind in the world: it gradually and gracefully rises on each side, by swell after swell, without tree, or bush, or rocks, . . . and is everywhere covered with green grass, affording the traveller, from its highest elevations, the most unbounded and sublime views of - nothing at all, - save the blue and boundless ocean of prairies that lie beneath and all around him, vanishing into azure in the distance, without a speck or spot to break their softness."

This description is still true today although farm buildings and trees are also part of the picture in many areas of the coteau.

The coteau is a flatiron-shaped plateau that slopes gently westward and, near the point or nose at the North Dakota State line, slopes gently northward (fig. 4). The Des Moines lobe of the continental glacier advanced southwest in this area and deposited much drift on the eastern side of the coteau. The main force of the James lobe (on the west side of the coteau), however, was to the southwest, into a broadening valley; therefore, there was less piling of ice onto the western side of the coteau and thus less deposition of drift.

The coteau escarpments differ in slope and height. The eastern escarpment rises about 300 feet per mile (57 m/km), from an altitude of 1,400 to 1,750 feet (426 to 533 m) and the less prominent western escarpment rises about 200 feet per mile (38 m/km). Both slopes are cut by many valleys; the wider and deeper valleys are in the eastern slope.

The topography of the coteau was formed by the rock debris deposited from the melting of stagnant glacial ice. This produced high relief, numerous undrained depressions called sloughs or prairie potholes, and, in general, a hummocky topography. The highest point in the County is Pleasant Peak, which as an altitude of 2,080 feet (634 m) and is located in sec. 8, T. 127 N., R. 55 W.

The Minnesota River-Red River lowland is a generally flat, east-sloping ground moraine that contains isolated patches of recessional moraine. The lowest point in the County, at an altitude of 1,194 feet (364 m), is where Shortfoot Creek enters North Dakota.

Drainage

Marshall County is in three main drainage basins, as shown in figure 5: the Missouri River basin covers about 630 square miles (1,632 km^2), the Red River

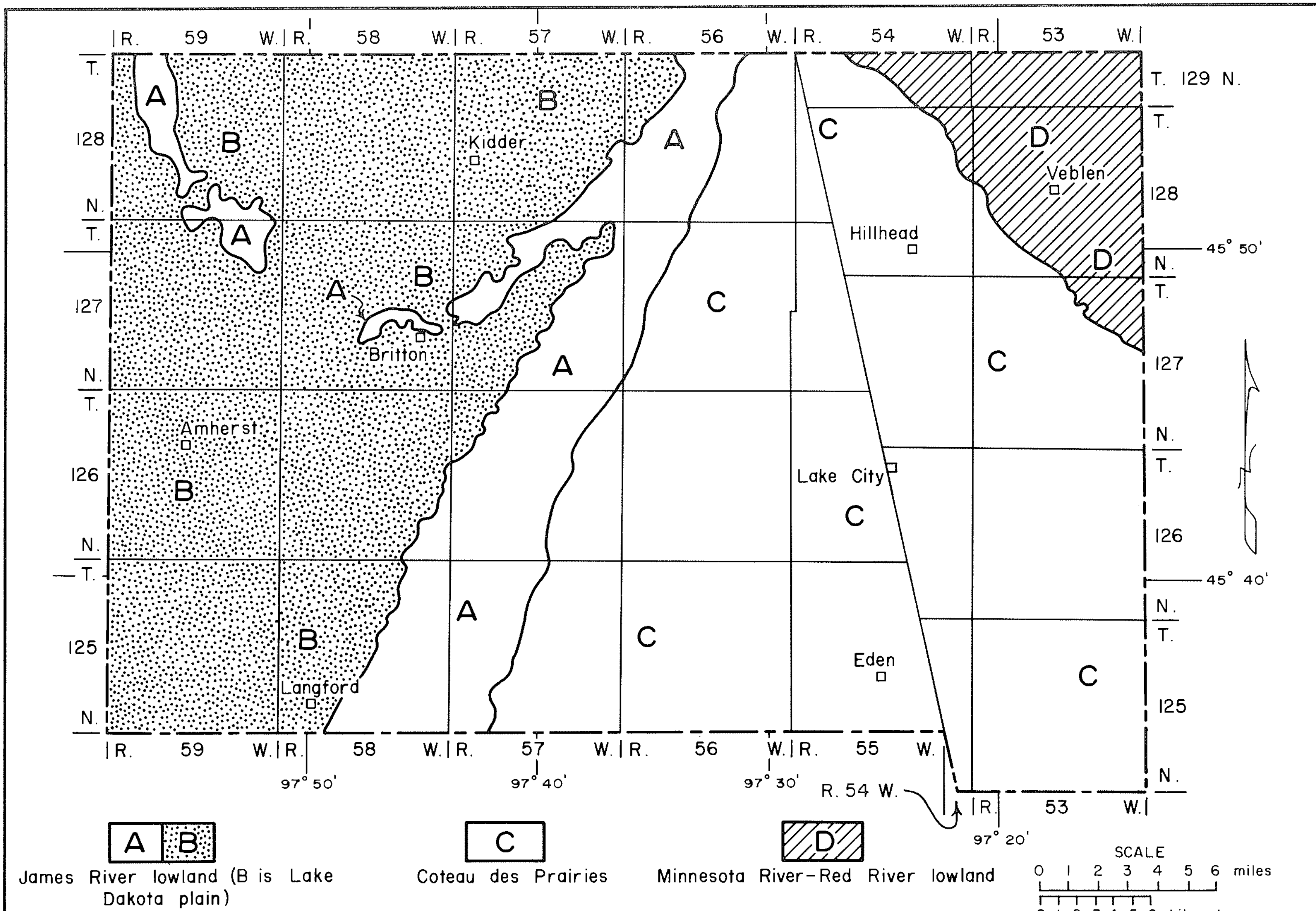


Figure 3. Map showing physiographic divisions.

Figure 4. Looking southwest at the eastern escarpment of the coteau near its northern end. Here the coteau slopes gently downward to the north where the continental ice split around an ancient highland to form the James and Des Moines glacial lobes.

of the North basin covers about 200 square miles (518 km^2), and the Upper Mississippi River basin covers about 58 square miles (150 km^2). All streams in Marshall County are intermittent.

About 230 square miles (596 km^2) of the Missouri River drainage basin has noncontributing or internal drainage. Thus no direct surface runoff from this area reaches the Missouri River. Within the noncontributing area about 60 square miles (155 km^2) is marshes, small ponds or potholes and lakes.

Drainage is well developed on the coteau slope west of the noncontributing area. Runoff from the coteau enters undrained or poorly drained sloughs on the lake plain. Manmade drains help move the runoff on the lake plain to Crow Creek and to Crow Creek ditch.

The Red River of the North basin can be divided into the Wild Rice basin (125 square miles or 324 km^2), which drains the northwestern part of the coteau, and the Labelle-Shortfoot basin (75 square miles or 194 km^2), which drains the northeastern part of the coteau.

The Wild Rice basin drains to the northwest. That part of the basin underlain by the coteau slopes northwest and has well-developed drainage. Where the basin is underlain by the lake plain, drainage is poorly developed. Many ditches and drains have been constructed to help move the runoff along Wild Rice Creek.

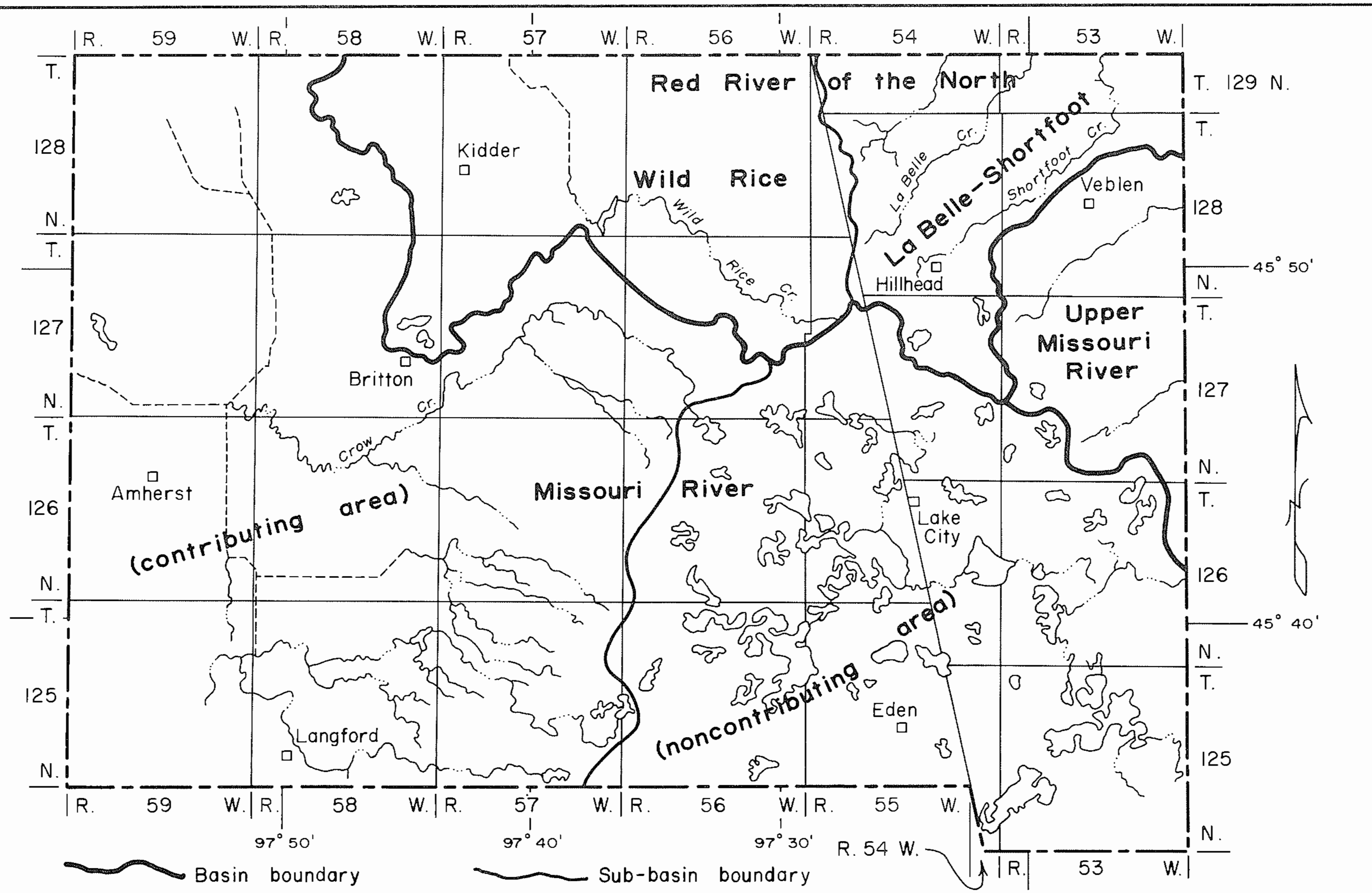


Figure 5. Map showing drainage basins in Marshall County.
(The "noncontributing" area lies within the boundaries of the Missouri River basin but, under existing climatic conditions, does not receive sufficient precipitation to develop runoff to the Missouri drainage.

The LaBelle-Shortfoot basin drains to the northeast. The drainage network is well developed; LaBelle and Shortfoot Creeks receive most of the runoff.

Upper Mississippi River drainage is to the northeast. The drainage on the coteau is poorly integrated; it consists of many poorly connected, water-filled depressions. The coteau slope is well drained by deep valleys, locally called coulees. Many of the coulees contain spring-fed streams. East of the coteau slope, runoff enters the Little Minnesota River, LaFrombois Creek, Munson Creek, and several unnamed creeks.

Climate

Marshall County climate is continental, with short summers and long winters. Summer temperatures reach the middle 30's°C (Celsius) which is equal to the high 90's°F (Fahrenheit) and winter temperatures usually drop to -32°C (-25°F) at least once each year. At the U.S. Weather Bureau Station in Britton the average annual temperature is 6.4°C (43.5°F) and the average annual precipitation is 18.33 inches (46.56 cm).

Soil

The many soil types and soil series mapped in Marshall County by Schultz (in press) fall into seven groups as defined in terms of the parent materials of the soil (see table 1). By examining the Marshall County soil map and using table 1 the parent material can be determined.

For example, most Group 3 soils form in windblown material, alluvium, or lacustrine deposits. Serden and Maddock soils develop in sand dunes.

Most Group 5 soil series form in Lake Dakota deposits except for the Sinai series, which develops in ice-walled lake deposits on the coteau.

The Buse series forms in till (Group 1) and the Sioux series in alluvium over sand and gravel (Group 4); however, the Sioux series can occur in small areas in Group 1 in association with the Buse soils.

GEOLOGY

The Precambrian basement rocks of Marshall County are overlain by 800 to 900 feet (244 to 274

Table 1. Parent Material and Related Soil Series in Marshall County

Group Number	Parent Material	Surface Soil Texture	Soil Series[1]
1	Glacial till	Silty clay loam Silt loam Loam Clay loam	Aastad, Buse, Forman, Hamerly, Parnell, Peever, Poinsett, Sieche, Tonka, Vallers, Waubay
2	Loess over till	Silt loam	Kranzburg
3	Lacustrine, alluvial, and wind-deposited sandy materials	Fine sand loam Loamy fine sand Fine sand	Arveson, Embden, Hamar, Hecla, Larson, Maddock, Serden, Stirum, Swenoda, Ulen, Venlo
4	Alluvium over sand and gravel	Loam	Arvilla, Benoit, Divide, Estelline, Fordvill, Renshaw, Sioux
5	Lacustrine deposits	Silty clay loam Silty loam Silty clay	Aberdeen, Bearden, Ben, Beotia, Colvin, Dovray, Exline, Great Bend, Harmony, Ludden, Sinai, Zell
6	Alluvium	Silty clay loam	Lamoure, Oldham, Playmoor
7	Shale	Loam	Edgely, Koten

[1] Includes areas ranging from excessively to very poorly drained soils.

m) of Cretaceous strata. Rocks that would represent more than 2 billion years of geologic history are missing. The geologic story of that long interval probably can never be known in detail, but studies in other parts of the upper Midwest show that Marshall County has repeatedly been above and below sea level. Hundreds, perhaps thousands, of feet of sediment were deposited during intervals of subsidence below sea level, only to be removed during later periods of uplift and erosion.

In Late Cretaceous time the area began its most recent uplift and rose above sea level before the end of the period (about 65 million years ago). Subsequent erosion has removed any recognizable trace of the uppermost Cretaceous strata and of any Tertiary sediments. The only deposits found that are younger than the marine Cretaceous Pierre Shale are those of the Ice Age and more recent time. The geologic strata in Marshall County are described in table 2 and shown on figure 6. Stratigraphic nomenclature and classifications used in this report are those of the South Dakota Geological Survey. They differ somewhat from usage adopted by the U.S. Geological Survey.

Pre-Pleistocene Geology

Precambrian

Rock samples from the Precambrian basement in Marshall County are of granite, a coarse-grained igneous rock. Other types of igneous and metamorphic rock may be present, but none have been found in any of the 13 wells known to have reached the basement.

Some rock samples are of fresh, unweathered granite composed of quartz, pink feldspar, and biotite or other dark-colored accessory minerals. Other samples show that the Precambrian basement is a former erosion surface as the samples show the effects of mechanical and chemical weathering. The upper part of a core from test hole 126N59W19DDD2 is highly fractured and the mineral grains show slight weathering or alteration. The lower part of the core is fresh granite. The upper part of a core from test hole 126N57W28BBC is highly weathered; the feldspar and accessory minerals are altered to a green clay containing relatively weather-resistant quartz. The core grades downward into fresh unweathered granite, and contains material similar to that found in Richland County, North Dakota (Paulson, 1953, p. 36).

The Precambrian basement begins from 906 to 1,113 feet (276 to 339 m) below land surface and its altitude ranges from 242 to 407 feet (74 to 124 m) above mean sea level. The topography of that surface apparently is of moderate relief and probably consists of peaks, granite domes, and gulches. Known relief is at least 127 feet (39 m) in the mile between test hole 126N57W28BBC, which entered granite at an altitude of 380 feet (116 m), and a well about 1 mile (1.6 km) north, which did not reach granite at a bottom-hole altitude of 253 feet (77 m). A mile south of the first test hole another well failed to reach granite at a bottom-hole altitude of 270 feet (82 m).

Cretaceous

Sand, silt, clay, and limestone were deposited during a period of submergence beneath the sea. These deposits were compacted by the weight of later deposited overlying sediment and the clay and sand became shale and sandstone. Except for the Dakota Formation, most of the bedrock is shale that contains thin lenses of silt, sand, or limestone. See table 2 for a description of all the bedrock formations.

The Dakota Formation, which overlies Precambrian rock throughout Marshall County, consists of sandstone with interbedded shale and siltstone.

The Greenhorn Limestone is the uppermost formation easily recognized by drillers and geologists because of the *"rough"* manner in which it drills and because of its characteristic deflection or *"kick"* on electric and gamma-ray logs. The Greenhorn is referred to by well drillers as caprock because of a hard limestone at or near the top of the formation. A structure contour map (fig. 7) of the Greenhorn Limestone, for that part of the County for which information is available, shows a regional dip to the southwest with a high in T. 126 N., R. 59 W., and parts of adjacent townships and in T. 128 N., R. 58 W. To the southeast from Amherst the slope is probably into a local basin or channel.

The Pierre Shale overlies the Niobrara Formation and is the uppermost bedrock in Marshall County except in the northeastern and north-central parts of the County where it has been removed by erosion. It is overlain by glacial drift in most of the County except where it crops out in deeper ravines along the western side of the coteau in T. 125 N., Rs. 57 and 58 W., and T. 126 N., R. 57 W., and in scattered patches along the eastern side of the coteau.

The erosion that preceded the advance of the Pleistocene glaciers over the area resulted in a topographic surface much like that shown in plate 1.

Pleistocene and Holocene Geology

Pleistocene Glacial Deposits

During the Pleistocene and Holocene Epochs glacial and post-glacial sediments were deposited. The

AGE		UNIT	LITHOLOGY	Thickness in feet
Quaternary	Holocene	Alluvium	*Sand, silt, and clay.*	*1–30*
Quaternary	Holocene	Loess	*Silt and fine sand.*	*1–5*
Quaternary	Holocene	Dune sand	*Fine sand.*	*1–30*
Quaternary	Pleistocene	Glacial deposits	*Glaciolacustrine sediments, glaciofluvial sediments, and till.*	*1–805*
Cretaceous	Pleistocene	Pierre Shale	*Shale.*	*1–260*
Cretaceous		Niobrara Formation	*Marl, chalk, shaly.*	*20–140*
Cretaceous		Carlile Shale	*Shale.*	*210–260*
Cretaceous		Greenhorn Limestone	*Limestone interbedded with limey shale.*	*40–75*
Cretaceous		Graneros Shale	*Shale interbedded with silt.*	*145–215*
Cretaceous		Dakota Formation	*Sandstone containg shale lenses.*	*165–330*
Pre-cambrian		Crystalline rocks	*Granite, usually weathered in upper part.*	?

Table 2. Summary of stratigraphic units found in Marshall County.

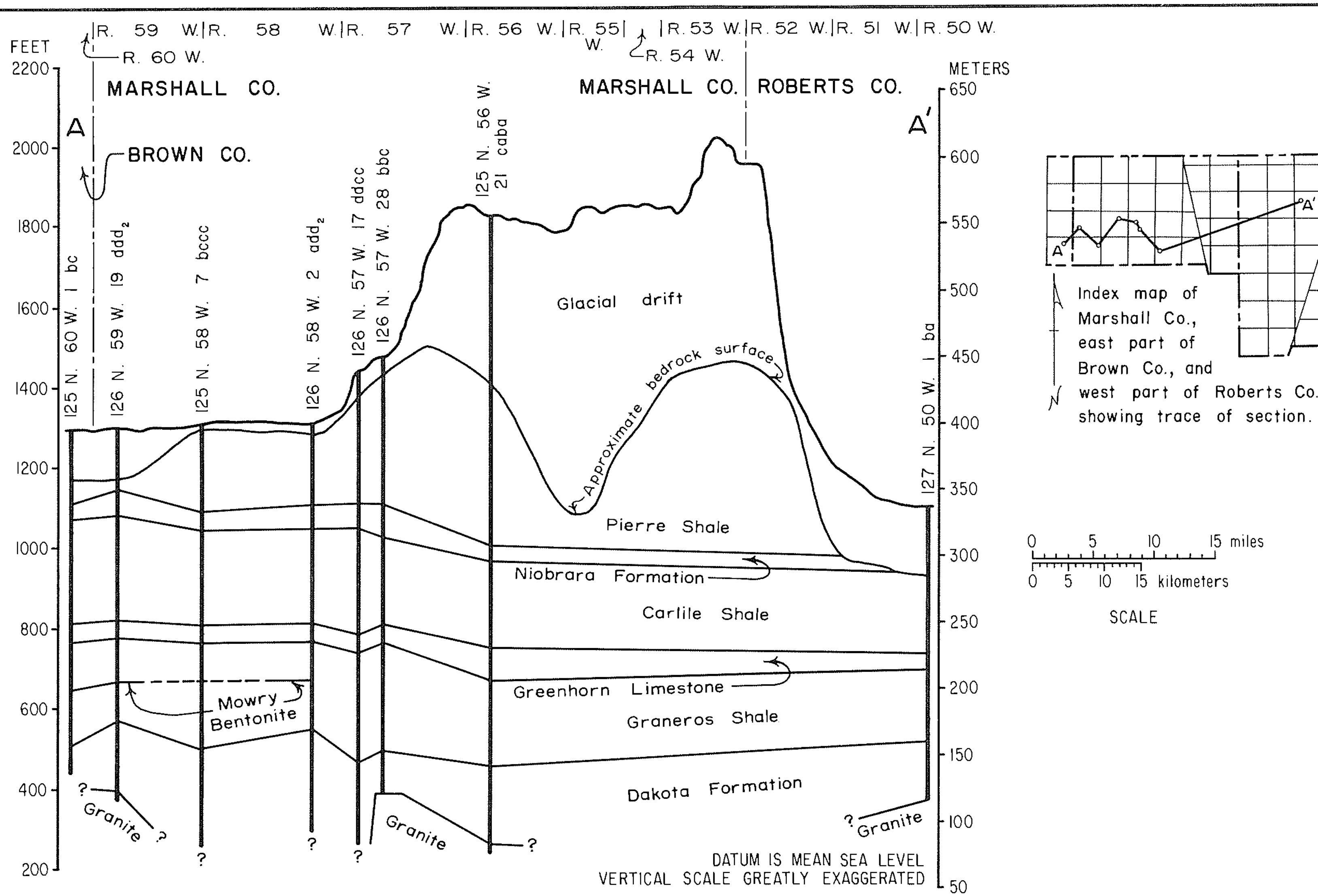
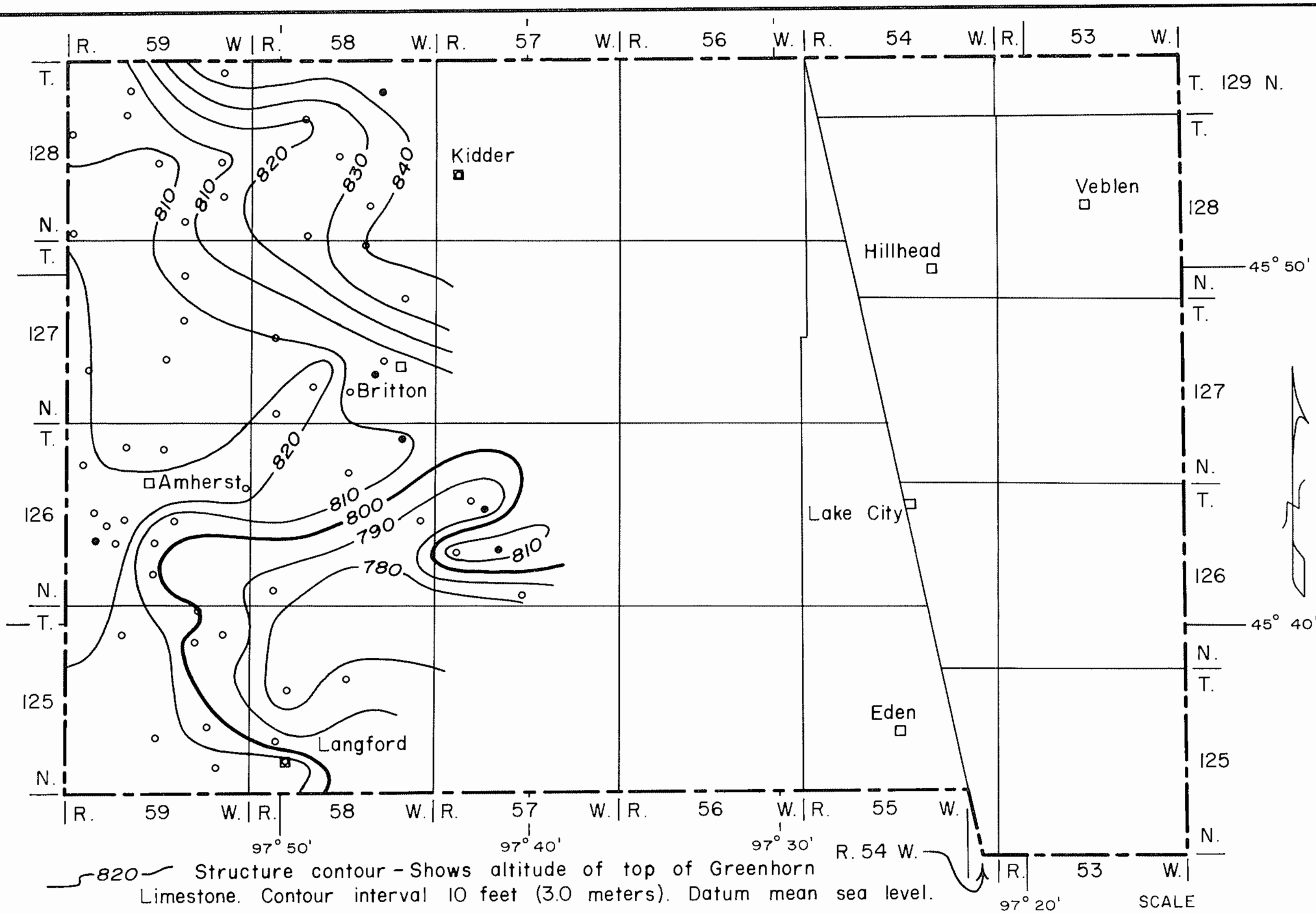


Figure 6. Generalized geologic section of rock units found in and east of Marshall County.



820 Structure contour - Shows altitude of top of Greenhorn Limestone. Contour interval 10 feet (3.0 meters). Datum mean sea level.

○ Control well-reported by driller.

● Control well with electric or gamma log.

Figure 7. Structure contour map on the Greenhorn Limestone.

glacial deposits in Marshall County are late Wisconsin in age. Buried glacial sediments older than late Wisconsin may be present but were not identified as such during this study.

The distribution of the various geologic deposits exposed at land surface in Marshall County is shown in plate 2. All these deposits, except for small scattered patches of Pierre Shale, were formed during or after the Ice Age.

Glacial deposits, called drift, are of three types: (1) till, a heterogeneous mixture of clay, silt, sand, gravel, and boulders; (2) glaciofluvial sediments, mainly stratified sand and gravel deposited by glacial melt water; and (3) glaciolacustrine sediments, usually clay, silt, and fine sand deposited in lakes by water.

Till

Slightly more than half the County is underlain by surficial deposits of till. Till can be classified on the basis of landforms as ground moraine, stagnation moraine, and end moraine (pl. 2).

Ground moraine is of low relief and has no linear pattern of deposition. It consists of a heterogeneous mixture of clay, silt, sand, gravel, and boulders. Small areas of stratified drift occur within the areas shown as ground moraine in plate 2.

A 3 to 5 mile (5 to 8 km) band of ground moraine borders the coteau (pl. 2). On the west side of the coteau the ground moraine is mantled by loess. Lake Dakota sediments overlie ground moraine in the western third of the County.

Stagnation moraine (also called *"dead-ice"* moraine, hummocky moraine, and collapse moraine) covers most of the coteau. It results from slow melting of a large mass of stagnant ice that is veneered with glacial sediments. The generally rugged topography has high local relief marked by knobs, kettles, and irregular depressions called *"potholes"* that contain lakes and marshes. The hills and depressions are closely spaced; slopes generally are steep. Stagnation moraine is composed mostly of clay till and heterogeneous mixtures of silt, sand, gravel, boulders, and poorly stratified sand and gravel. Associated with stagnation moraine are glaciofluvial sediments, glaciolacustrine sediments that form perched lacustrine deposits, and stagnation outwash.

End moraine is a ridgelike accumulation of drift built along the margin of a glacier. The term *"end moraine,"* as used in this report, includes terminal, recessional, and lateral moraines. End moraine consists mostly of till rich in clay, gravel, and boulders, and may include some minor deposits of stratified drift.

In Marshall County a large end moraine lies along the margins of the coteau, and remnants of two end moraines are in the central part of the coteau.

The Oaks moraine (fig. 8), a horseshoe-shaped recessional moraine, extends almost parallel to the coteau in the central part of the County, curves westward at Britton, and then curves northward into North Dakota at the northwestern corner of the County. The moraine contains a large amount of stratified drift, especially northeast of Britton. The Oaks moraine is a recessional feature because it was deposited when the glacier front temporarily halted its retreat as it melted back from the glacial maximum.

Glaciofluvial Sediments

Glaciofluvial sediments (outwash) consist mostly of stratified sand and gravel deposited by streams flowing from glaciers. They may be ice-contact deposits or sediments deposited away from the ice. Glaciofluvial sediments can be divided on the basis of landforms into outwash plain, valley outwash, terrace outwash, and stagnation outwash. Only about 4 percent of the County is covered with glaciofluvial sediments.

The material forming an outwash plain is deposited outward from an ice sheet by melt-water streams. In Marshall County, such deposits formed along the eastern edge of the coteau.

Deposits of valley outwash are beneath the flood plains of valleys (pl. 2). This type of deposit is found in stream valleys on the western side of the coteau and, in some places, is overlain by alluvium.

Terrace outwash was deposited as outwash plain or valley outwash, but subsequent downcutting of stream channels has left the deposits above the present floors of the valleys. Deposits of terrace outwash are found on the western side of the coteau in Tps. 127 and 128 N.

A noteworthy feature in the terrace outwash is a boulder pavement formed when the retreating glacier front temporarily readvanced, planing many large (20 in. or 51 cm. diameter) boulders in half. This glacial readvance also deposited from 5 to 10 feet (2 to 3 m) of till over the terrace outwash (fig. 9). Subsequent erosion has removed the overlying till locally exposing the boulder pavement (fig. 10) and has terraced the outwash deposit. Five to ten feet (2 to 3 m) of till overlie much of the valley and terrace outwash deposits in T. 127 N., Rs. 56 and 57 W. and T. 128 N., R. 56 W.

Stagnation outwash consists generally of poorly to well-sorted sand and gravel deposited frequently on top of stagnant ice.

Figure 8. Looking southeast across the Lake Dakota plain toward the Oaks moraine. The rolling, hummocky appearance of the Oaks moraine is typical of end moraines in Marshall County. About 6 miles (9.5 kilometers) northeast of Britton.

Sinuous ridges of sand and gravel, called *eskers*, mark the courses of streams that flowed beneath the ice sheet or in crevasses in the glacier. A good example of such stream-bed deposits, shown in figure 11, is a ridge about 20 feet (6 m) high and 30 to 40 feet (9 to 12 m) wide between South Red Iron Lake and Buffalo Lakes.

Glaciolacustrine Sediments

Glaciolacustrine sediments (glacial lake deposits) were deposited in lakes by glacial melt water. Most of such deposits in Marshall County are composed of laminated clay, silt, and sand; locally, coarse sand and gravel were deposited near the margins of some lakes. About 38 percent of the County is covered with glacial lake deposits.

The glaciolacustrine sediments of Marshall County may be divided into two groups: those now occupying low topographic positions and those now occupying high topographic positions. The latter are called *"perched"* lacustrine deposits because they commonly are found on hilltops.

By far the largest deposit of lacustrine sediments in the County is that of glacial Lake Dakota, which extended from near Oaks, North Dakota, to northern Beadle County, South Dakota, and covered the very flat, low-lying western part of Marshall County (pl. 2).

Perched lacustrine deposits are associated with the stagnation moraine and were deposited on stagnant or dead ice or within holes in dead ice (pl. 2). All perched lacustrine deposits found on the coteau are on hilltops; an example of such a deposit is shown in figure 12. These sediments were deposited in lakes

Figure 9. Boulders deposited on sand and gravel of terrace outwash, overlain by till.

completely supported or walled by ice. An exception was a large lake in the Eden area, which was ice walled on the north and west sides only.

Most of the perched lacustrine deposits consist of laminated clay and silt with sand and gravel along the margins except for three lakes in T. 127 N., R. 54 W., where the deposits consist mostly of sand and gravel that contain isolated patches of clay and silt.

Holocene Deposits

Holocene (post glacial) deposits in Marshall County include alluvium, loess, and dune sand.

Alluvium, deposited on flood plains and terraces of streams, commonly is stratified clay, silt, and sand. Only large areas of alluvium are shown on the geologic map (pl. 2). Many stream valleys contain patches of alluvium too scattered and too small to be shown.

Loess is windblown silt and fine sand. Dry sediments on the Lake Dakota plain were picked up by westerly winds and deposited on the westward-sloping ground moraine adjacent to the coteau. Loess deposits are not shown on the geologic map because the deposits are scattered, patchy, and commonly are only a few feet thick.

Dune sand is windblown fine sand. In Marshall County it was deposited in much the same manner as loess. Fine sand is heavier than silt, and therefore was not carried as far by the wind; it was deposited against the first high topography to the east, which was the Oaks moraine in northwestern Marshall County. Silt and some fine sand was blown farther east. Fine sand mantles lake deposits several miles east and south of the boundary shown on the geologic map (pl. 2).

Late Wisconsin Glacial History

Late Wisconsin Glaciation followed the same general pattern as previous glaciations. As the continental ice sheet advanced into South Dakota

Figure 10. A boulder pavement where the boulders have been planed by the ice. Striations are about N. 10° E. and the flat surface is horizontal in the direction of the striations. Located in the NE 1/4 sec. 28, T. 128 N., R. 56 W.

from the north and east, the ice front was split into two lobes by the highland now represented by the Coteau des Prairies. The larger, eastern segment of the ice sheet, called the Des Moines lobe, moved southward through Minnesota and into Iowa; as it grew, it also advanced westward, gradually climbing the slope of the highland. The smaller, western part of the ice sheet, called the James lobe, advanced west and south through the lowland now known as the James valley. As the two lobes advanced southward, the glaciers thickened and eventually over-rode the intervening highland, coalescing into a continuous expanse of ice that eroded the pre-existing land surface and buried the entire area beneath many hundreds of feet of ice. Flint (1955, p. 135) estimated that the minimum thickness of ice on the lowland near Aberdeen, 26 miles (42 km) southwest of Marshall County, was 1,200 to 1,600 feet (366 to 488 m); the thickness of the Des Moines lobe was greater.

As the growth of the ice sheet slowed, and as the rate of melting of the ice gradually increased to equal and, then to exceed the rate of glacial advance, the ice began to drop its enormous load of eroded rock and soil. Although great torrents of melt water carried much of the material away, the quantity of material was so large that enough remained to cover the area with a thick blanket of drift. Subsequent erosion and reglaciation modified the topography and drainage to the form found today.

The retreat of the ice, due to excess of melting over glacial advance, was not at a uniform rate. Occasionally the rate of glacial advance and the rate of melting were about equal for a period of years, and the margin of the glacier would temporarily stabilize in an area (a *"stillstand"*). More rarely, the rate of glacial advance exceeded the rate of melting for several years and the ice front would readvance and recover previously exposed areas.

Figure 11. Esker between Buffalo Lakes and South Red Iron Lake. Buffalo Lakes are to the left. Eskers are ridges of sand and gravel deposited in the beds of streams that flowed under the ice sheet or in crevasses in the glacier.

The position of the first stillstand known to have had a major influence on the development of the present topography and drainage of Marshall County is shown in figure 13. Melt water from the ice margin and from stagnant blocks of ice in front of the ice margin, was ponded by the jumbled terrain to form many lakes. A lake of about 5 square miles (13 km^2) formed at Eden. Sediments entering that lake were deposited on top of stagnant glacial ice. When the stagnant ice melted, the lake sediments collapsed to form a rolling topography that contained undrained depressions--essentially the topography found today.

The position of the ice margin during the second stillstand that had a major influence in developing the present topography and drainage is shown in figure 14. The area in front of the ice margin contained blocks of stagnant ice upon which melt water sediments were deposited. Melt water deposited sand and gravel in Tps. 125 and 126 N., R. 53 W.

A horseshoe-shaped drainage system (fig. 5), which now contains several lakes, developed between the ice margin shown in figure 14 and the end moraine at the ice margin shown in figure 13. The lakes are Buffalo, South Red Iron, North Red Iron, Clear, and Roy, and Cattail which drain into one another in that order. Today no drainage crosses the end moraine formed at ice margin 1 (fig. 13), whereas North Red Iron, Clear, and Roy Lakes receive runoff through developed drainage across the end moraine formed at ice margin 2 (fig. 14).

The location of the ice margin during the third stillstand that had a major influence in developing the present topography and drainage is shown in figure 15. Most of the ice-walled lake deposits found during this investigation are between ice margin 3 and the end moraine that had formed at ice margin 2. Most of the area in front of ice margin 3 lies within the

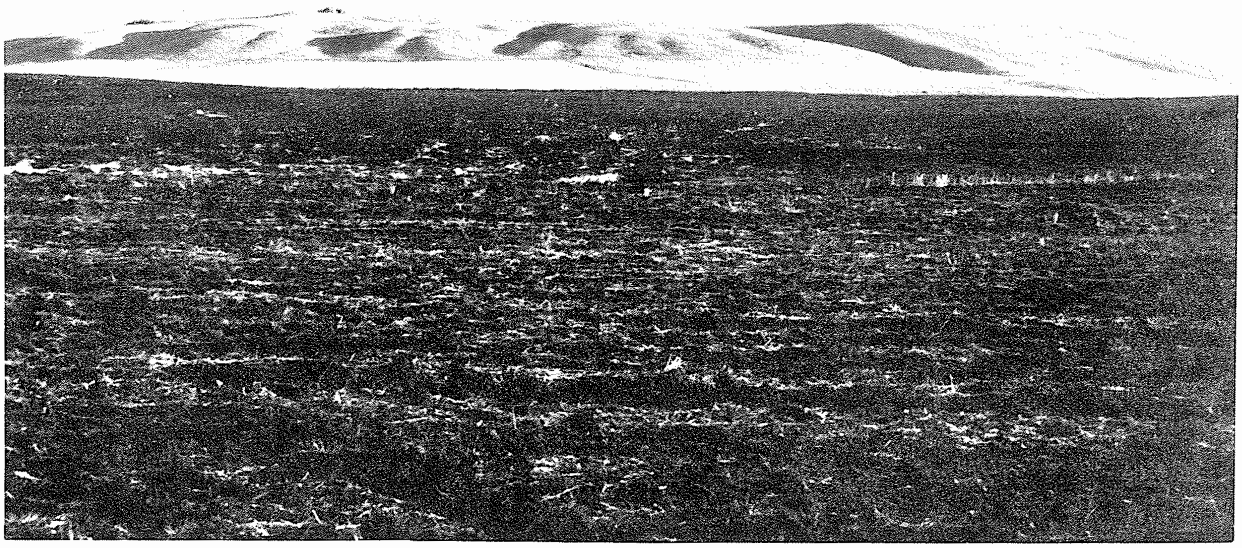


Figure 12. Perched lacustrine deposit located in sec. 6, T. 126 N., R. 55 W. The hilltop in the background is an ancient lake bed.

non-contributing part of the Missouri River drainage (fig. 5).

The continental ice sheet, though shrinking, had not yet become stagnant in this part of North America. Thus, ice continued to move west and south into the shrinking James and Des Moines lobes. Activity persisted long enough to develop an easily defined end moraine along the margins of the area covered by active ice. Because the ice sheet was, naturally, thinnest over topographically high areas and thickest in topographic lows, stagnation of the ice occurred first in high areas and active ice persisted longest in low areas. Thus end moraines, deposits of active ice, may be found at lower altitude than stagnation moraines. An example of this may be seen in R. 57 W. (see pl. 2).

The fourth, and last, significant halt in the retreat of the continental glacier in Marshall County caused the development of the Oaks moraine along the ice margin west of the coteau and of an end moraine in the northeastern corner of the County (fig. 16).

Lake Dakota remained a lake as long as melt water from the glacier provided enough water and the outlet remained blocked. When the active ice front retreated into North Dakota, melt water filled the area north of the Oaks Moraine until a channel was cut through the moraine in T. 127 N., R. 58 W. (fig. 3). Further retreat of the glacier ended the inflow of melt water and down-cutting of the lake outlet drained the lake. The drying lake silt and sand subsequently were blown eastward by wind which deposited the coarser material (mostly sand) against the Oaks moraine and the finer material (mostly silt) on the western slope of the coteau.

WATER RESOURCES

Water in Marshall County occurs in surface streams, ponds and lakes, and aquifers in surficial deposits and bedrock strata. Surface water and the ground water in surficial deposits originate as precipitation in or near the County. The amount of precipitation that falls, however, is much greater than the amount that runs off from the surface or is added

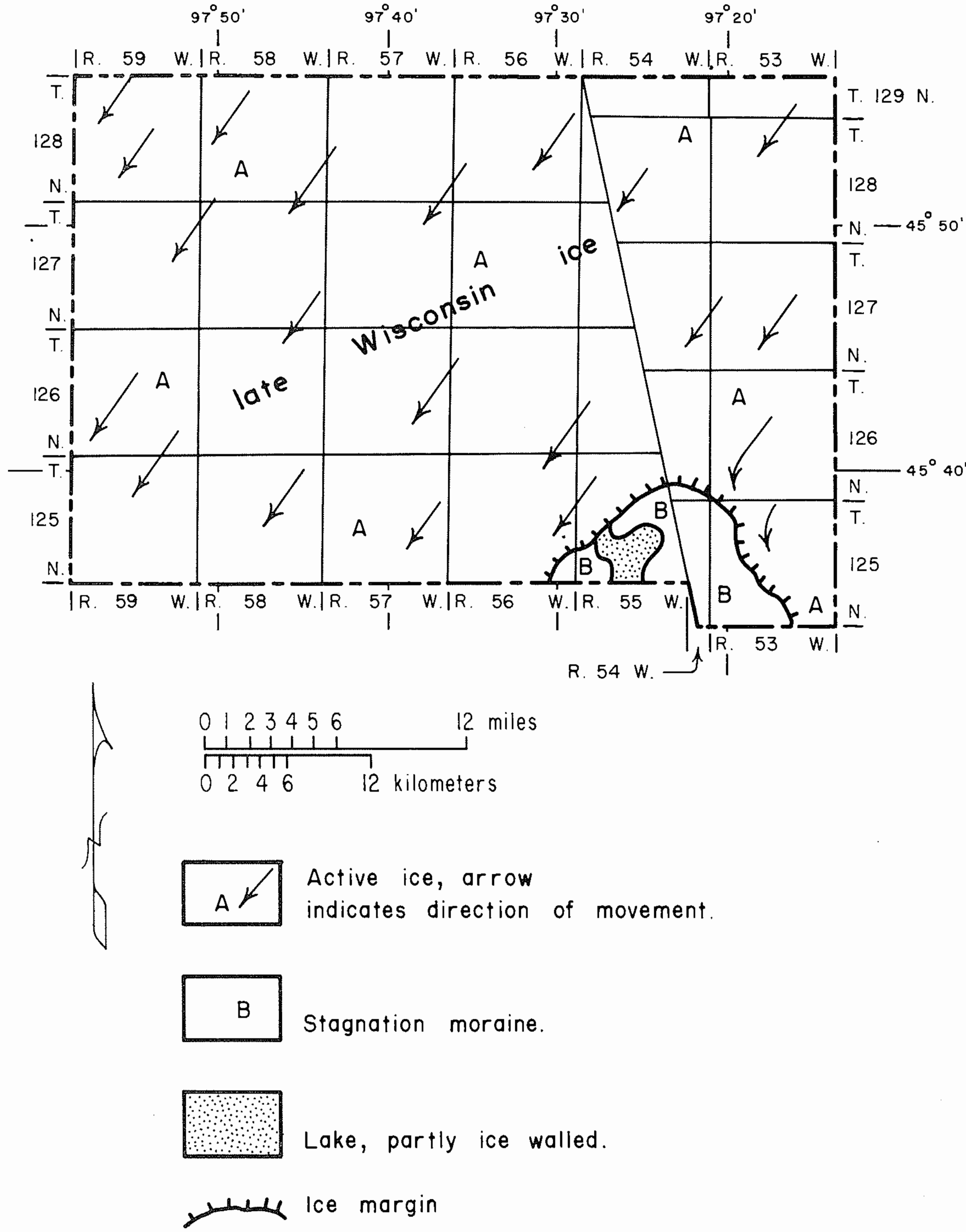


Figure 13. Map showing location of the first major stillstand of the retreating late Wisconsin ice in Marshall County.

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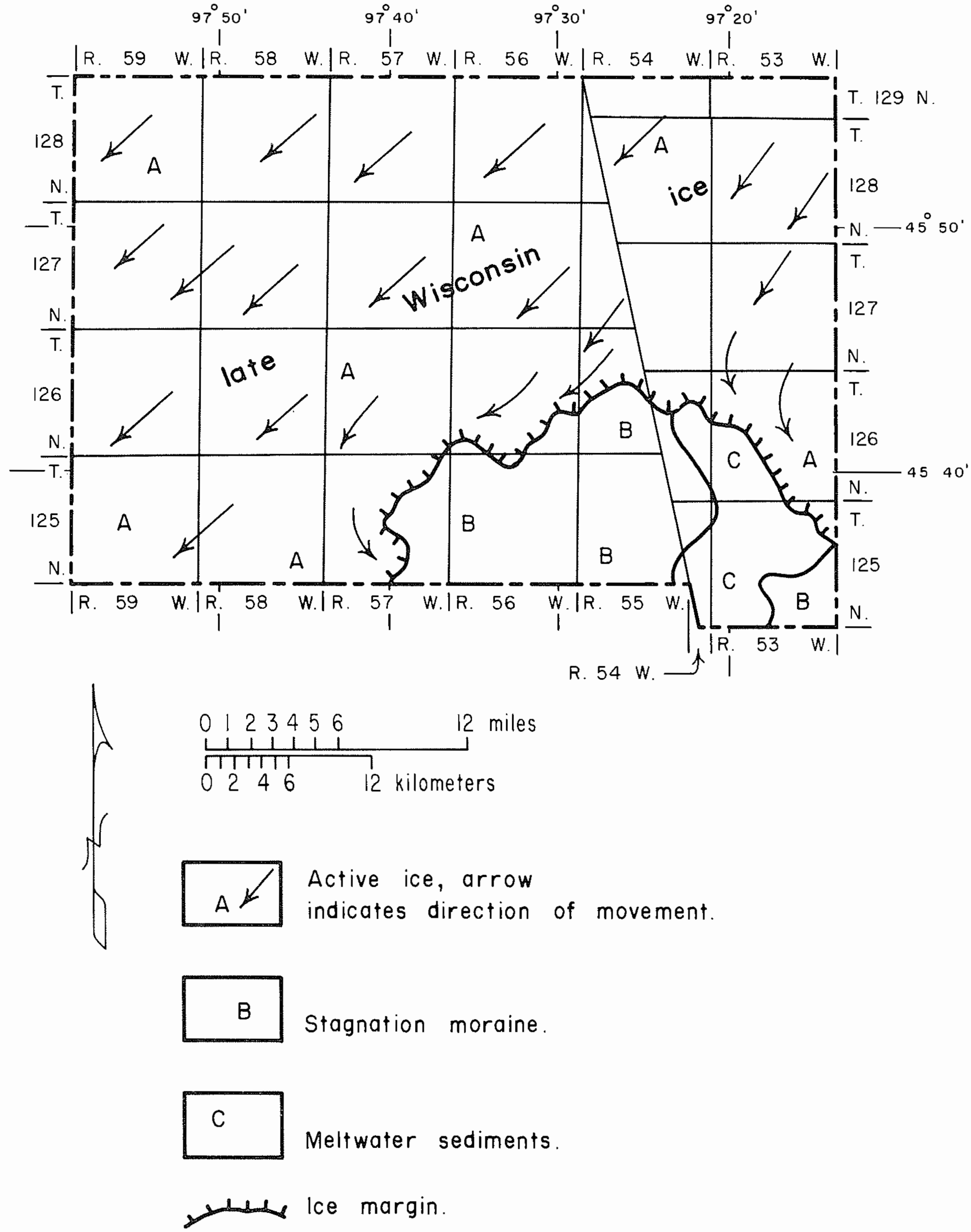

Figure 14. Map showing location of the second major stillstand of the retreating late Wisconsin ice in Marshall County.

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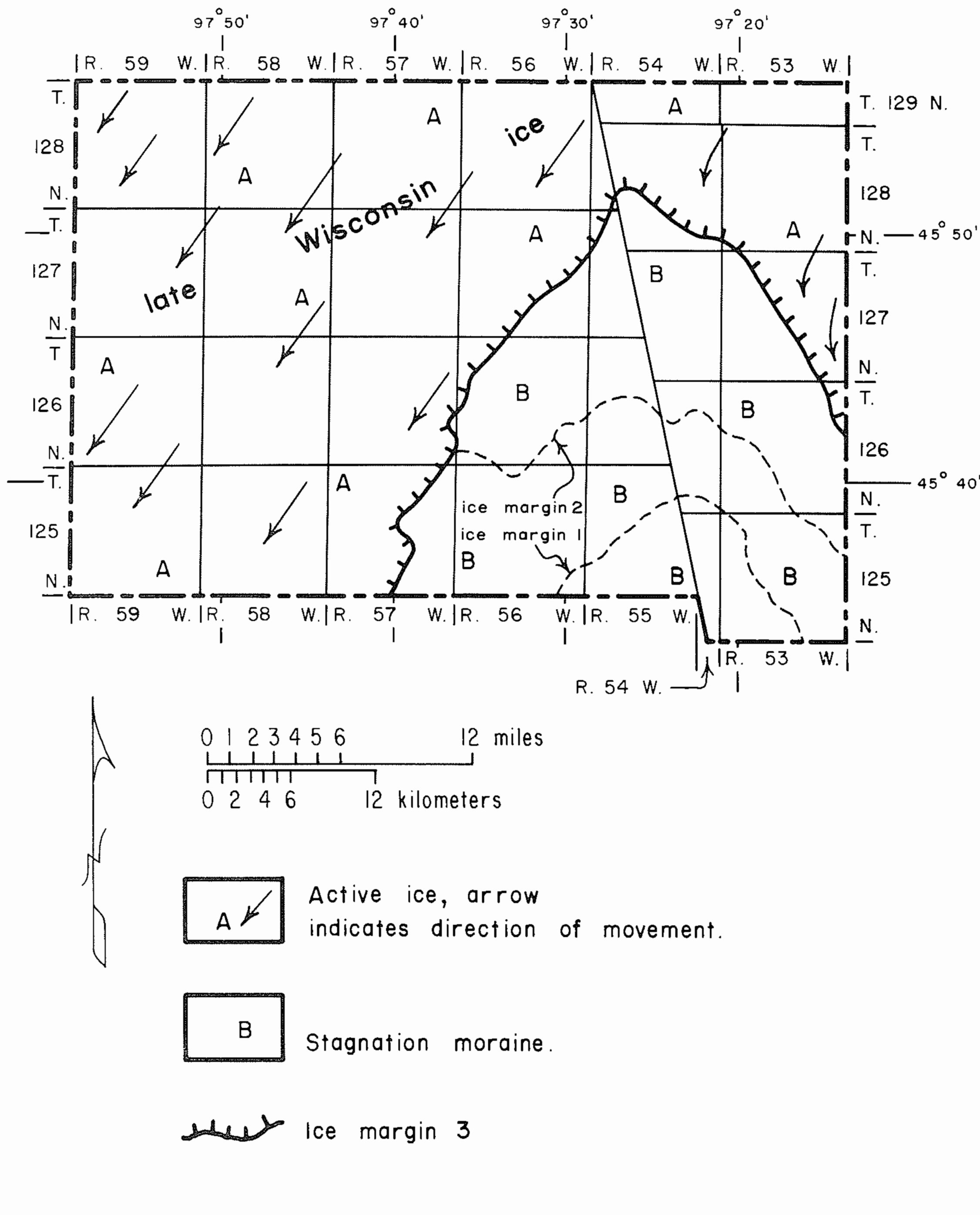

Figure 15. Map showing location of the third major stillstand of the retreating late Wisconsin ice in Marshall County.

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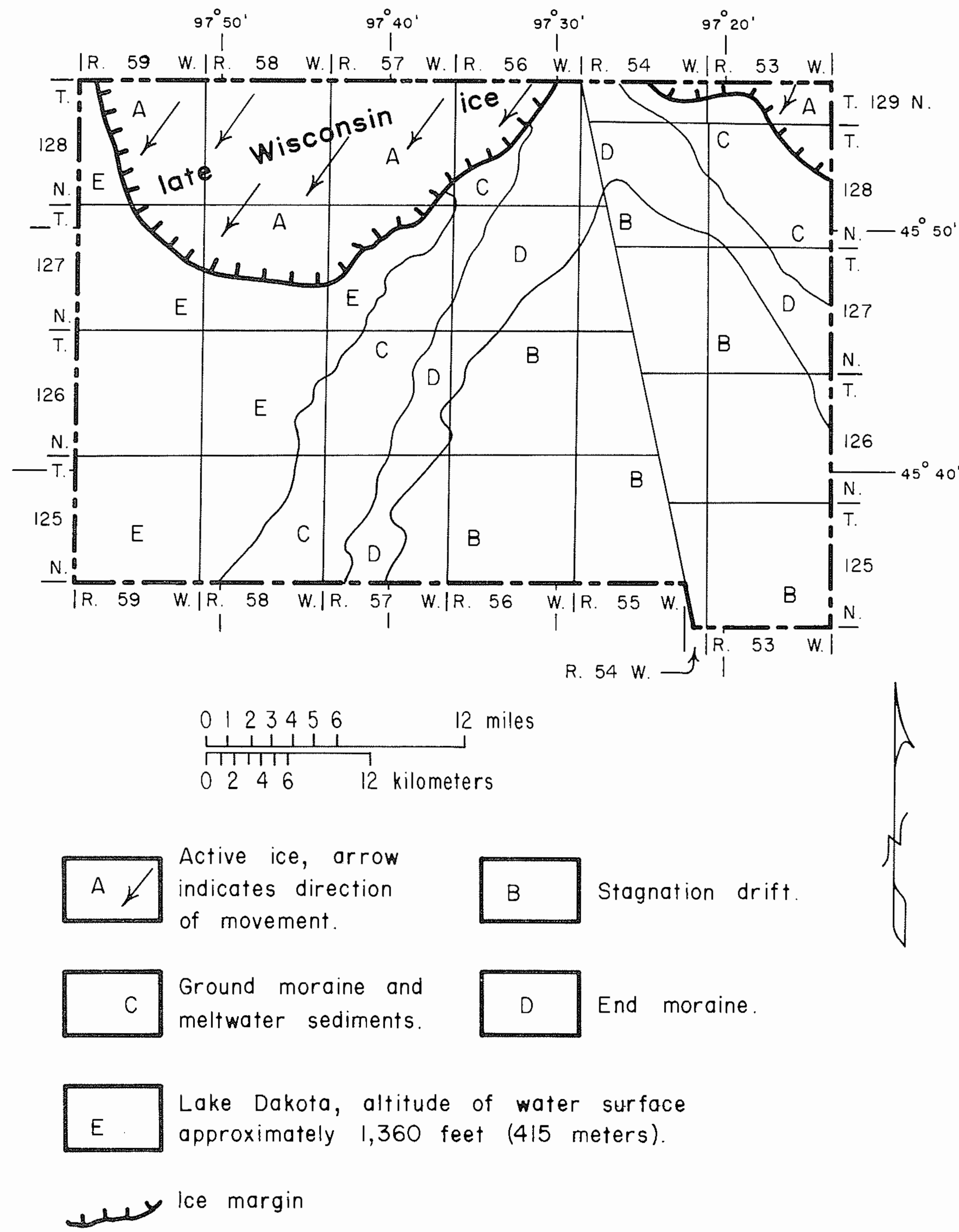

Figure 16. Map showing location of the fourth, and last, major stillstand of the retreating late Wisconsin ice in Marshall County.

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to storage in surface- and ground-water reservoirs. Most of the precipitation is returned to the atmosphere by evaporation and transpiration, which greatly reduce the amount of water available for use in the area.

Normal precipitation in Marshall County is about 868,000 acre-feet (1 billion m^3) annually. Of this amount, about 17,500 acre-feet (21.6 million m^3) leaves the area as surface runoff and 120,000 acre-feet (148 million m^3) is evaporated from lakes and ponds. Evapotranspiration from vegetation and soil accounts for about 700,000 acre-feet (863 million m^3). The remaining 30,500 acre-feet (38 million m^3) recharges the aquifers in the surficial deposits.

The surface runoff leaves the area through many small intermittent streams mostly in the spring from snowmelt and precipitation.

Ground water in Marshall County is obtained from confined bedrock deposits and from a complicated system of confined and unconfined aquifers in glacial drift. Aquifers in the glacial drift contain about 1.8 million acre-feet (2.2 billion m^3) of water in storage. They are separated or confined by a pebbly clay till. The till deposits are often discontinuous and lenticular making it difficult to differentiate between unconfined and confined aquifers. This situation results in varying degrees of hydraulic connection between the Coteau-lakes, Marday, Eden, and Roslyn aquifers. Where the confining till deposits are continuous and thick as between the James, Veblen, and Coteau-lakes aquifers, there is almost no hydraulic connection between the aquifers and it is easy to differentiate between them. The confined Dakota (bedrock) aquifer contains about 8.5 million acre-feet (10.5 billion m^3) of water in storage.

Recharge to the unconfined Coteau-lakes and Pierre Shale (bedrock) aquifers is mainly by infiltration of precipitation. Natural discharge is by evapotranspiration and by movement into other aquifers. The confined James, Veblen, Marday, Eden, Roslyn, and Dakota (bedrock) aquifers are recharged by subsurface inflow and by downward movement of precipitation through overlying lake plain silts. Natural discharge is by subsurface outflow.

Table 3 lists results of analyses of water from 86 wells tapping the major aquifers. The table gives, by aquifer, the number of determinations for each constituent analyzed and the average concentration of each constituent. The table should be used to obtain a general idea of the water quality of the major aquifers. For example, water from the Coteau-lakes aquifer is in general better for domestic or irrigation needs than water from the other aquifers. An explanation of the meaning and relation to use of important chemical properites is given in the appendix.

The salinity hazard and sodium hazard of water are shown in figure 17. The interpretation of these hazards for irrigation use is given in the appendix.

Surface Water Quantity and Quality

The surface water supply of Marshall County includes several small intermittent streams and numerous marshes, ponds, and lakes.

Most streamflow takes place in spring from snowmelt; flow may also occur throughout the year following periods of heavy precipitation. Except in spring, most streams are dry. Flooding from snowmelt is common along Crow Creek drainage ditch, particularly in T. 127 N., Rs. 58 and 59 W.

Streams in Marshall County originate on the coteau. Most of the streams on the east side of the coteau, and Wild Rice River and Crow Creek on the west side of the coteau, are fed by springs. However, total discharge from springs is about equal to stream losses, so rarely does any stream flow more than a mile or two downstream from a spring.

Marshes, ponds, and lakes cover 7 percent of the County. These water bodies can be classified as perched or ground-water connected. A perched lake is one above the water table; the water is slowed from percolating down to the water table by a zone of relatively impermeable material. A ground-water connected lake is one that is in hydraulic contact with ground water. The locations and sizes of the major lakes in Marshall County are given in table 4.

Specific conductance of the lake water may be an indication that a lake is perched or ground-water connected. Water from ground-water connected lakes normally has specific conductance less (usually much less) than 2,000 micromhos per centimeter at 25°C (μmhos/cm at 25°C), whereas water from perched lakes usually has specific conductance greater (commonly much greater) than 2,000 μmhos/cm. Of 42 lakes tested (see table 5), only five, Piyas, East Stink, West Stink, Cattail, and Indian seem to be perched.

Many small perched marshes, ponds, and lakes commonly called *"prairie potholes"*, occur on the coteau on the clayey ground, and on stagnation and end moraines. These surface-water bodies receive water from snowmelt and usually fill each spring. Water loss, mostly by evapotranspiration, causes many of the *"potholes"* to become dry by fall.

The larger lakes usually receive runoff from snowmelt and precipitation. Water loss is by

Table 3. Summary Of Chemical Analyses Of Ground Water From The Major Aquifers

(Results in milligrams per liter, except as indicated)

Constituent or property	James aquifer		Veblen aquifer		Coteau-lakes aquifer		Marday aquifer		Eden aquifer		Roslyn aquifer		Dakota aquifer	
	No. of analyses	Average[1]	No. of analyses	Average[1]	No. of analyses	Average[1]	No. of analyses	Average[1]	No. of analyses	Average[1]	No. of analyses	Average[1]	No. of analyses	Average[1]
Calcium (Ca)	17	100	14	142	8	122	7	219	4	198	7	153	29	21
Magnesium (Mg)	17	32	14	77	8	43	7	61	4	58	7	55	29	6.4
Sodium (Na)	17	244	8	116	8	15	7	89	4	64	7	127	28	986
Potassium (K)	17	12	7	10	8	6.9	7	10	4	9.8	7	14	23	14
Bicarbonate (HCO_3)	17	530	14	329	8	363	7	327	4	355	7	351	28	330
Sulfate (SO_4)	17	394	14	614	8	199	7	676	4	555	7	557	29	1137
Chloride (Cl)	17	53	13	27	8	4.4	7	5.2	4	6.7	7	7.6	29	413
Fluoride (F)	16	.4	8	.3	8	.3	7	.3	3	.4	7	.4	27	5.7
Nitrate (NO_3)	16	7	14	5	8	11	7	6	3	2.8	7	7.3	23	4.5
Iron (Fe)	17	.95	14	.46	8	.28	7	9.8	4	4.2	7	3.4	24	.31
Manganese (Mn)	11	.24	12	.88	8	.48	7	1.4	3	.44	7	.29	11	.03
Hardness as $CaCO_3$	17	385	14	666	8	450	7	803	4	730	7	606	29	79
Specific conductance (micromhos per cm at 25°C)	17	1631	8	1604	7	863	7	1589	3	1530	7	1494	17	4189
Percent sodium (percent)	18	50	8	23	8	6	7	17	4	16	7	32	28	95
Sodium-adsorption ratio (SAR)	17	5.3	8	1.1	8	.25	7	.8	4	.415	7	1.9	27	5.2
pH (units)	16	7.9	13	7.6	8	8.0	7	8.0	3	7.9	7	7.8	23	8.1

[1] Values shown for iron, manganese, sodium-adsorption ratio, and pH are median values.

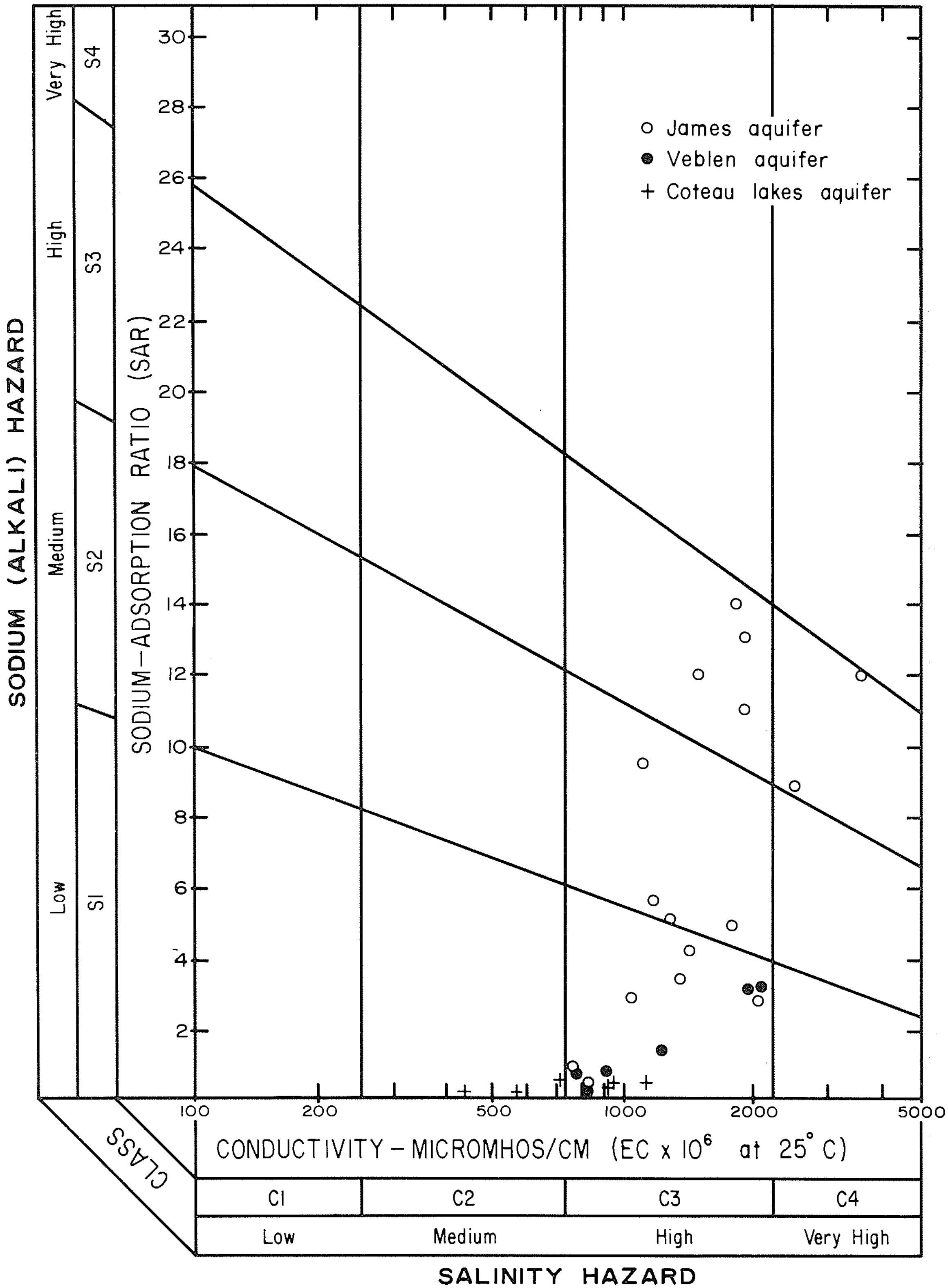

Figure 17. Diagram showing classification of ground water for irrigation use. (classification developed by United States Salinity Laboratory staff, 1954.)

Table 4. Location and Size of Major Lakes in Marshall County

Lake name (1)	Approximate surface area (acres) (2)	Maximum depth (feet) (3)	Location: Section (4)	Location: Township N. (5)	Location: Range W. (6)
Abraham	120		1	127	54
Buffalo	2,185	12	3, 4, 9, 10, 11, 16, 17	125	53
Bullhead	160		19	126	55
Cattail - also called Kettle	1,200		7, 18 1, 2, 11, 12, 13	125	55 56
Clear	1,200	19	13, 24	126	54
Cottonwood	224		9, 16	126	55
Crystal - also called Howley	112		30, 31	127	53
Dollar	20		26	127	54
Dumarce	200		24, 25	127	54
East Slough	90		4	126	55
East Stink	447		10, 11, 14	125	55
Emma	76		24	126	53
Flat	180		10	127	54
Four Mile	356	11	13, 14, 18, 19	126	56 55
Fort	160		2, 3	125	56
Goodbird	80		4, 5	126	53
Grey's	141		2, 11	126	53
Hickman Dam	40		1, 12	125	58
High	15		4	127	54
Hill	120		17, 20	127	53
Hoop	130		22	127	54
Horseshoe	70		32	128	54
Indian	600		1, 2, 11	125	56
Isabelle	150		22	127	54
Isabella	42		6	125	53
Island	160		10	126	53
Long	380		1, 2	126	54

Table 4 -- continued.

(1)	(2)	(3)	(4)	(5)	(6)
Mallard Slough	280		3, 4	125	56
Martha	100		13	125	53
Mud	200		2, 3	126	53
Ninemile	282	10	31, 32	127	55
North Red Iron	174	10	17, 20	126	53
Piyas	1,283		19, 20, 29, 30	125	53
Roy	1,694	18.5	20, 21, 28, 29	126	55
Sarah	70		21, 22	126	53
Silver	40		7, 18	127	55
Simons	40		6, 7	126	53
Sixmile	96	11	7	126	55
South Red Iron	640		20, 29, 32	126	53
Stink Slough	350		1, 2, 35, 36	126 127	56
Summit	10		14, 15	127	53
Turtlefoot	100		29	127	53
Two Island	85		5	126	55
Twomile	160		33, 34	126	56
West Stink	474		9, 10	125	55
White Lake	187	20	36	128	57
Wise Spirit	65		21	127	54
Total	14,988				

evapotranspiration. Lakes may receive ground water part of the year and at other times may discharge water to the ground.

Most of the small ponds and lakes on the coteau rarely discharge water to other lakes because of poorly developed drainage. Several of the larger lakes, however, have well-developed drainage and normally discharge water each spring. Buffalo, South Red Iron, North Red Iron, Clear, Roy, and Cattail Lakes are successively strung along one drainage. Cattail Lake, however, rarely overflows into the poorly drained area to the west.

Long-term records of lake levels may be used to help define the factors that influence changes in lake level. Records available for Buffalo, Clear, and Roy Lakes show good correlation of lake-level change with departure from normal precipitation (fig. 18). The amount and frequency of variation of precipitation is important to development of water supplies from these lakes. Buffalo Lake was a puddle in the winter of 1935 but by May 1936 it contained about 3 feet (0.9 m) of water (Rothrock and Ullery, 1938, p. 7). In May 1937 the lake depth increased to 7 feet (2 m) owing to above normal precipitation. The next 3 years the lake level declined about 2½ feet (0.8 m) owing to below normal precipitation. From 1941 to the summer of 1943 precipitation was much above normal and the lake depth increased to 12 feet (3.6

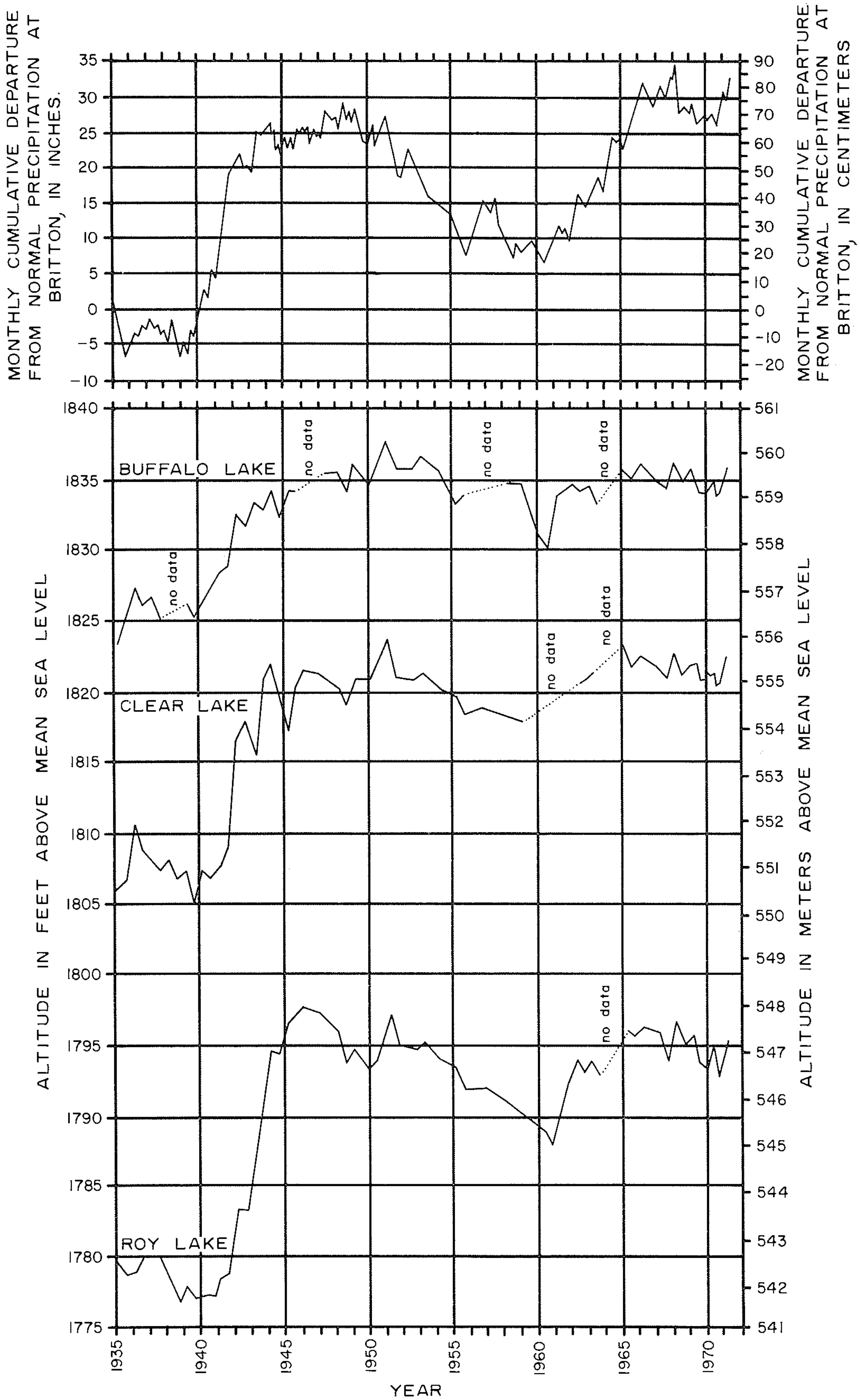

Figure 18. Hydrograph showing lake-level changes in selected lakes and departure from normal precipitation at Britton.

m). Above normal or near normal precipitation continued to 1952 and produced comparable changes of lake level. The highest level of Buffalo Lake on record occurred in 1952 when the lake depth reached about 17 feet (5.2 m). From 1952 through 1961, below normal precipitation resulted in a decline of lake depth of 7½ feet (2.3 m). From 1962 to 1967 above normal precipitation caused an increase in lake depth of 5½ feet (1.7 m). Near normal precipitation from 1967 to 1972 has maintained lake-depth changes within a seasonal range of 2 feet (0.6 m).

Lake-level changes in Clear Lake are similar to those in Buffalo Lakes in their response to precipitation (fig. 18). Clear Lake was dry in the fall of 1935 except for a few moist spots (Rothrock and Ullery, 1938, p. 6). It became nearly dry again in the fall of 1940 (Caddes, 1947, p. 8). The highest lake level occurred in 1952 when the lake depth reached about 18 feet (5.5 m).

Lake-level changes in Roy Lake follow the same major trends as in Buffalo and Clear Lakes. Roy Lake was dry during the drought in 1894; in 1910 it was a grassy slough (Rothrock and Ullery, 1938, p. 5). In the fall of 1939 the lake again nearly became dry. The highest lake level on record occurred in 1947 when the lake depth reached 21 feet (6 m).

Short-term lake-level changes in Roy Lake differ from those in Buffalo and Clear Lakes (fig. 18). In the spring of 1937 lake levels in Buffalo and Clear Lakes rose 4½ feet (1.4 m), whereas Roy Lake did not rise until the fall and then only by 1 foot (0.3 m). In 1941 Buffalo and Clear Lakes again rose, whereas Roy Lake did not rise until 1942. A possible reason for the lag in water-level change of Roy Lake compared to that of Buffalo and Clear Lakes is that the hydraulic connection between Roy Lake and the outwash deposits discharging ground water to the lake has lower transmissivity than at the other lakes. Therefore ground-water moves to the lake at a slower rate than it moves to the other lakes following periods of above normal precipitation. Water in Buffalo and Clear Lakes is almost surrounded by and is hydraulically connected to ground water in the outwash; thus precipitation that recharges the ground water in the outwash can move quickly to these lakes.

Field analyses, consisting of specific conductance, dissolved oxygen, pH, and temperature, were made of water samples from 37 lakes and ponds (table 5). Laboratory analyses were made of samples collected from Buffalo, Clear, Roy, and Ninemile Lakes. A lake study by Petri and Larson (undated) included periodic analysis of samples from Buffalo, North Red Iron, Roy, Clear, Piyas, and Fort Lakes.

Specific conductance measurements from 42 lakes and ponds ranged from 460 at North Red Iron Lake to 20,000 µmhos/cm at East Stink Lake. Specific conductance in 7 lakes or ponds exceeded 2,000 in 8 lakes or ponds ranged from 1,000 to 2,000, and in 27 lakes or ponds was less than 1,000. Petri and Larson reported that when the dissolved-solids concentration in lake waters was less than about 700 mg/l, magnesium, calcium, and bicarbonate predominated; but if it was more than 700 mg/l, magnesium, calcium, and sulfate predominated. An estimate of the dissolved-solids concentration in the lakes or ponds can be made by multiplying specific conductance by 0.7.

Water from Buffalo and Roy Lakes was analyzed in 1964, 1965, and 1970 as was water from Clear Lakes in 1961, 1962, 1963, and 1970. None of the lakes showed any appreciable change in water quality. Lakes that discharge water through an outlet each spring, such as these, have a tendency to flush the mineral constituents from the lake. Lakes such as East Stink Lake that do not discharge water except by evaporation and by ground-water seepage tend to increase in dissolved-solids concentration.

Ground Water Quantity and Quality

Aquifers in the Glacial Drift

All major aquifers in the unconsolidated materials that overlie the bedrock are deposits of glacial outwash and alluvium. These deposits, composed mostly of sand and gravel, comprise six major aquifers, here named the James, Veblen, Coteau-lakes, Marday, Eden, and Roslyn aquifers. The areal, topographic, and stratigraphic relations of these aquifers, and of some other water-bearing deposits of very limited or local extent, are shown in the sections of figure 19.

Till is not discussed as a major source of water because it has low permeability and in general will not yield large amounts of water. Where small sand lenses occur in the till yields of 1 to 5 gpm (0.06 to 0.3 l/s) of generally poor-quality water can be obtained.

James Aquifer

The James aquifer (fig. 20), in north-central Marshall County, has narrow channels that extend southwest into Brown County and southeast into Day County. The aquifer underlies about 220 square miles (570 km^2) in Marshall County and extends into North Dakota. The aquifer, composed mainly of buried outwash deposits and of alluvium from an ancient river, consists of sorted and stratified gravel, sand, and silt. The narrow channels that extend through central and southern Marshall County contain sand and gravel deposited by a preglacial river that had flowed north to Hudson's Bay. Water in the

Table 5. Chemical Analyses of Lake and Pond Waters
(Determined in the field)

Lake and date of collection (1)	Specific conductance (micromhos per centimeter at 25°C) (2)	pH (3)	Dissolved oxygen (DO) mg/l (4)	Temperature (°C) (5)
Abraham				
June 30, 1967	570			23.5
September 25, 1969	720	8.7	9.5	13.0
Buffalo (North Lake)				
June 30, 1967	900			
September 25, 1969	950	8.5	9.6	14.0
Buffalo (South Lake Section 10)				
June 30, 1967	610			24.5
September 25, 1969	620	8.2	9.4	13.5
Buffalo (South Lake Section 17)				
June 30, 1967	650			
September 25, 1969	670	8.5	9.5	14.0
Cattail (Section 7)				
June 30, 1967	3,000			
September 25, 1969	3,190	8.5	9.4	15.0
Clear				
June 30, 1967	630			24.5
September 25, 1969	625	8.7	7.3	13.0
Cottonwood				
June 30, 1967	610			
September 25, 1969	580	8.9	7.1	12.5
Crystal				
June 30, 1967	730			24.5
September 25, 1969	890	8.7	8.7	13.0
Dumarce				
June 30, 1967	740			24.5
September 25, 1969	770	8.6	8.1	12.5
East Stink				
June 30, 1967	9,000			
September 25, 1969	20,000	8.4	14.3	19.0
Flat				
June 30, 1967	980			23.0
September 25, 1969	1,050	9.2	9.0	13.0
Fourmile				
June 30, 1967	1,100			21.5
September 25, 1969	1,240	8.7	7.1	11.5
Grey's				
June 30, 1967	540			
September 25, 1969	575	8.6	6.4	12.5
Hickman Dam				
September 25, 1969	955	8.0	8.8	15.0
Hill				
June 30, 1967	610			18.0
September 25, 1969	780	8.2	9.5	13.5

Table 5 -- continued.

(1)	(2)	(3)	(4)	(5)
Hoop				
September 25, 1969	670	8.7	9.1	13.0
Indian (Section 2)				
June 30, 1967	2,800			
September 25, 1969	3,200	8.5	10.0	15.0
Island				
June 30, 1967	950			
September 25, 1969	1,085	8.7	7.6	12.0
Long				
June 30, 1967	600			24.0
September 25, 1969	680	8.3	9.0	12.5
Mud				
June 30, 1967	650			
September 25, 1969	760	8.7	7.1	12.5
Ninemile				
June 30, 1967	610			24.0
September 25, 1969	745	8.0	6.3	13.0
North Red Iron				
June 30, 1967	460			
September 25, 1969	510	8.6	6.9	13.5
Piyas				
June 30, 1967	2,400			
September 25, 1969	3,000	8.3	9.7	16.0
Roy				
June 30, 1967	1,190			21.0
September 25, 1969	1,100	8.9	5.6	13.5
Sixmile				
June 30, 1967	660			22.0
September 25, 1969	710	8.9	7.4	12.5
South Red Iron				
June 30, 1967	470			
September 25, 1969	540	8.7	6.5	14.0
Stink Slough				
June 30, 1967	1,180			22.0
September 25, 1969	1,630	7.6	1.7	10.0
Turtlefoot				
June 30, 1967	680			26.5
September 25, 1969	790	8.3	8.7	11.5
West Stink				
June 30, 1967	7,000			
September 25, 1969	10,600	8.7	7.6	14.5
White Lake				
September 25, 1969	960	8.2	9.8	15.5
Wise Spirit				
June 30, 1967	580			
September 25, 1969	695	8.7		

Table 5 -- continued.

(1)	*(2)*	*(3)*	*(4)*	*(5)*
Unnamed Lake or Pond				
125-53-5CCC				
June 30, 1967	1,400			
September 25, 1969	1,770	8.4	10.2	12.5
125-55-6A				
June 30, 1967	1,225			
September 25, 1969	1,500	8.6	11.1	15.5
125-56-25A				
June 30, 1967	1,350			
September 25, 1969	2,000	8.7	12	16.0
126-56-3B				
June 30, 1967	890			19.0
127-54-3				
June 30, 1967	730			24.0
127-54-16D				
June 30, 1967	720			23.5

aquifer occurs under artesian conditions and water levels range from 2 to 111 feet (1 to 34 m) below land surface.

The James aquifer contained about 1½ million acre-feet (2 billion m^3) of water in storage in 1971. Water in storage was estimated by using an average saturated thickness of 50 feet (15 m) and an estimated porosity of 20 percent.

Yields of 500 gpm (32 l/s) or more can be expected from properly constructed wells at locations where more than 40 feet (12 m) of medium or coarser sand occurs.

Thickness and distribution of the deposits that form the aquifer are shown in figures 19 and 20. The thickest part of the aquifer is in the narrow channel extending southeastward into Day County. The greatest known thickness of sand and gravel, 129 feet (39 m), was found at test hole 126N55W31CCCD.

In general, the James aquifer occurs at altitudes of 1,250 to 1,050 feet (381 to 320 m). In low-lying areas, the aquifer is at depths ranging from 100 to 190 feet (30 to 58 m) below land surface; at higher altitudes, on the coteau, it is 580 feet (177 m) or more below land surface.

Test-hole data indicate that permeable sedimentary deposits overlie the James aquifer in Rs. 58 and 59 W. Such cover varies from very permeable, well-sorted beds of very fine to coarse sand, to interbedded sand and clay layers, to sandy or very sandy or silty clay. Where the sand extends close to land surface, the water is under water-table conditions.

At least 50 wells tap the James aquifer on the lake plain where it is shallowest. Where it is deeply buried, as beneath the coteau, no wells have been finished in it.

Recharge to the James aquifer is by subsurface inflow from Brown County and possibly Day County and by percolation of rainfall and snowmelt through overlying lake plain sediments and till. Subsurface inflow is indicated by the direction the water moves, as shown on the map in figure 21. Most recharge to the James aquifer is by percolation of precipitation in Rs. 58 and 59 W. Identification of this area as an important source of recharge was by analysis of several types of data: test-hole logs, to evaluate overburden permeability; water-level measurements and precipitation data to determine the type and rapidity of response of the water surface to precipitation and snowmelt; and water-quality data, because salinity increases and general water quality deteriorates with increasing distance from the recharge area.

Fluctuations of water levels in wells are the result of changes in the amount of water stored in the aquifer. Changes in storage are caused by differences in the rates of recharge and discharge.

Water-level fluctuations in wells in the James aquifer are both seasonal and long term. Seasonal

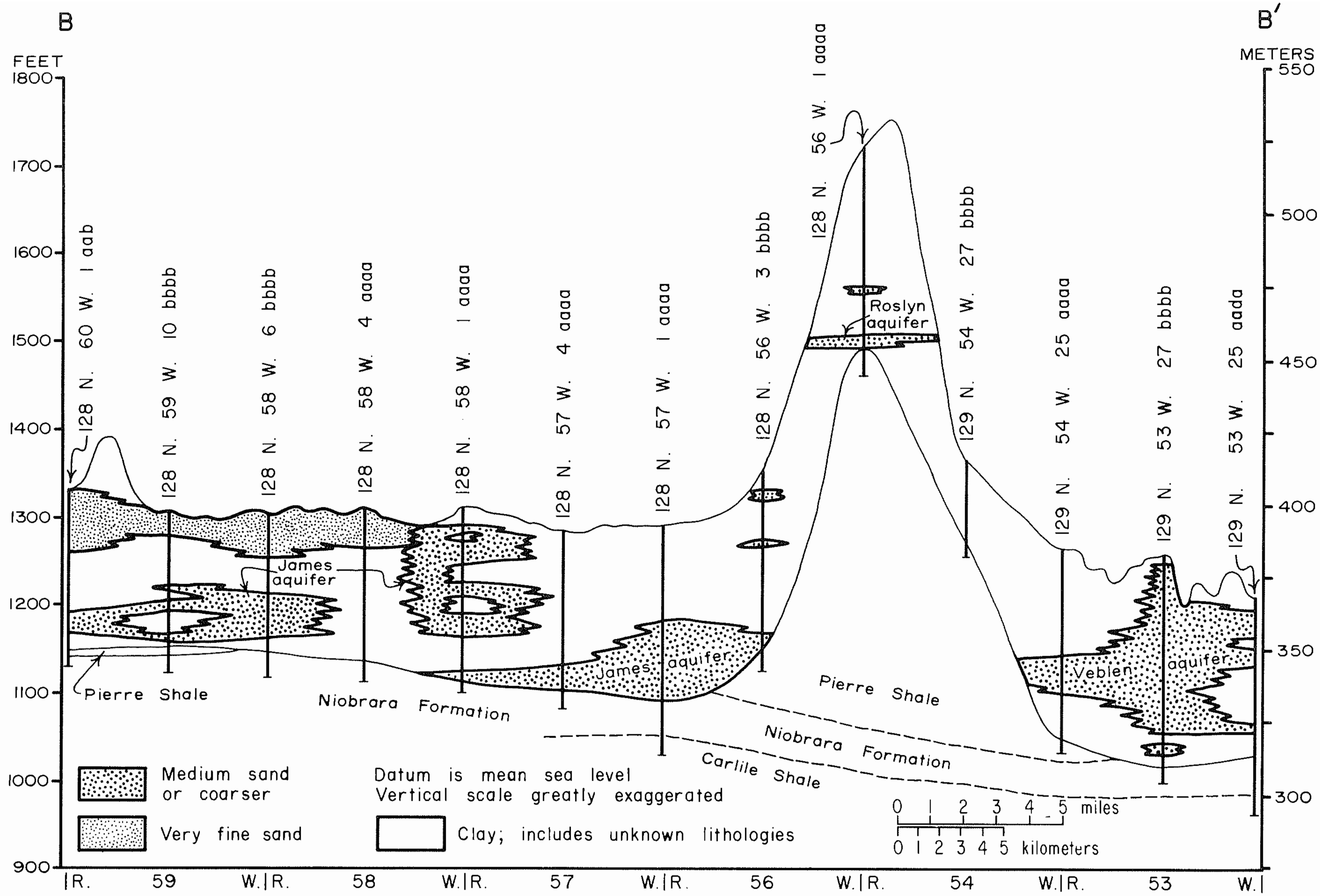

Figure 19-(B-B′). Lithologic sections B-B′ to F-F′ showing where major aquifers occur.

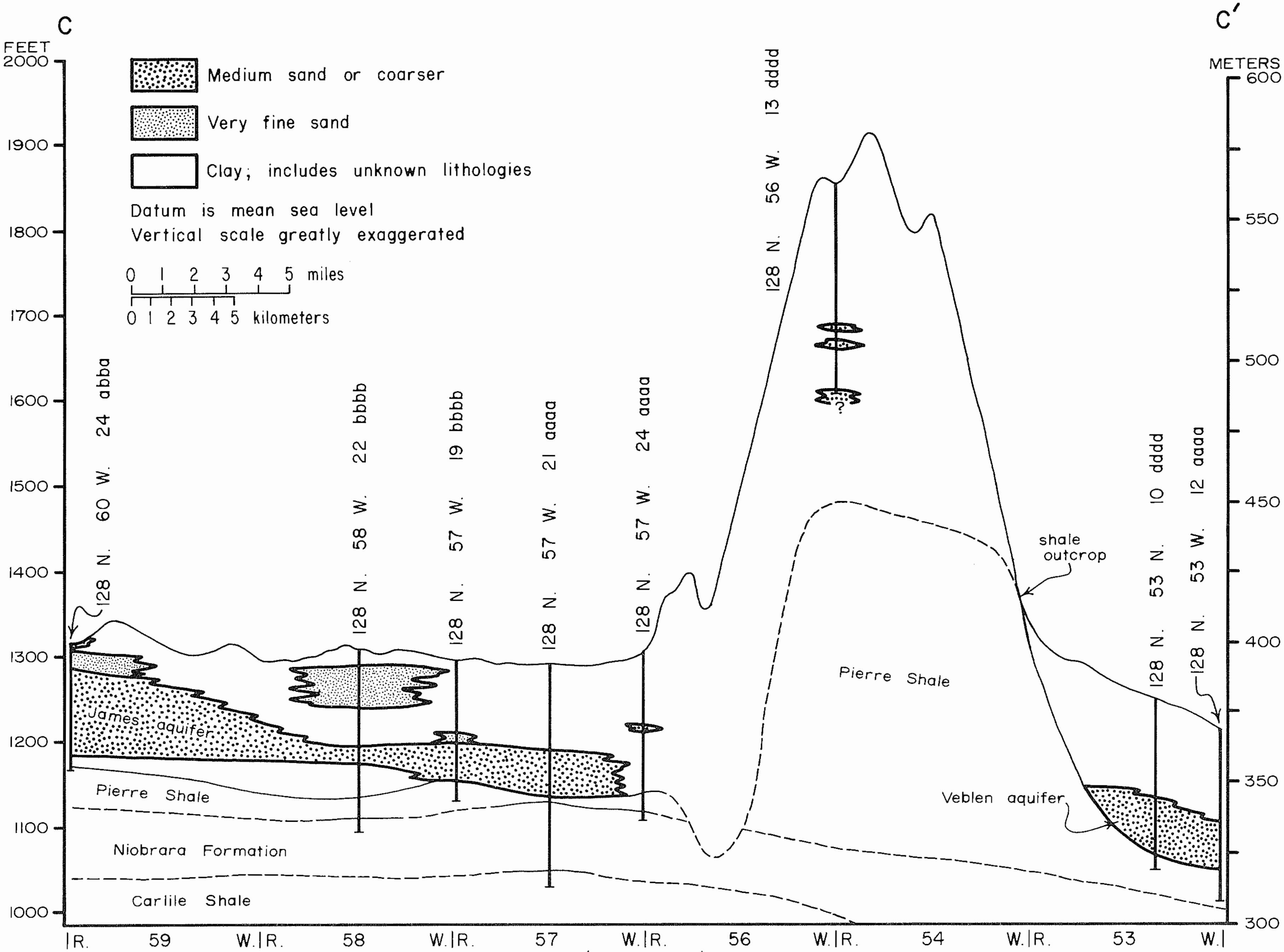

Figure 19-(C-C′). Lithologic sections B-B′ to F-F′ showing where major aquifers occur.

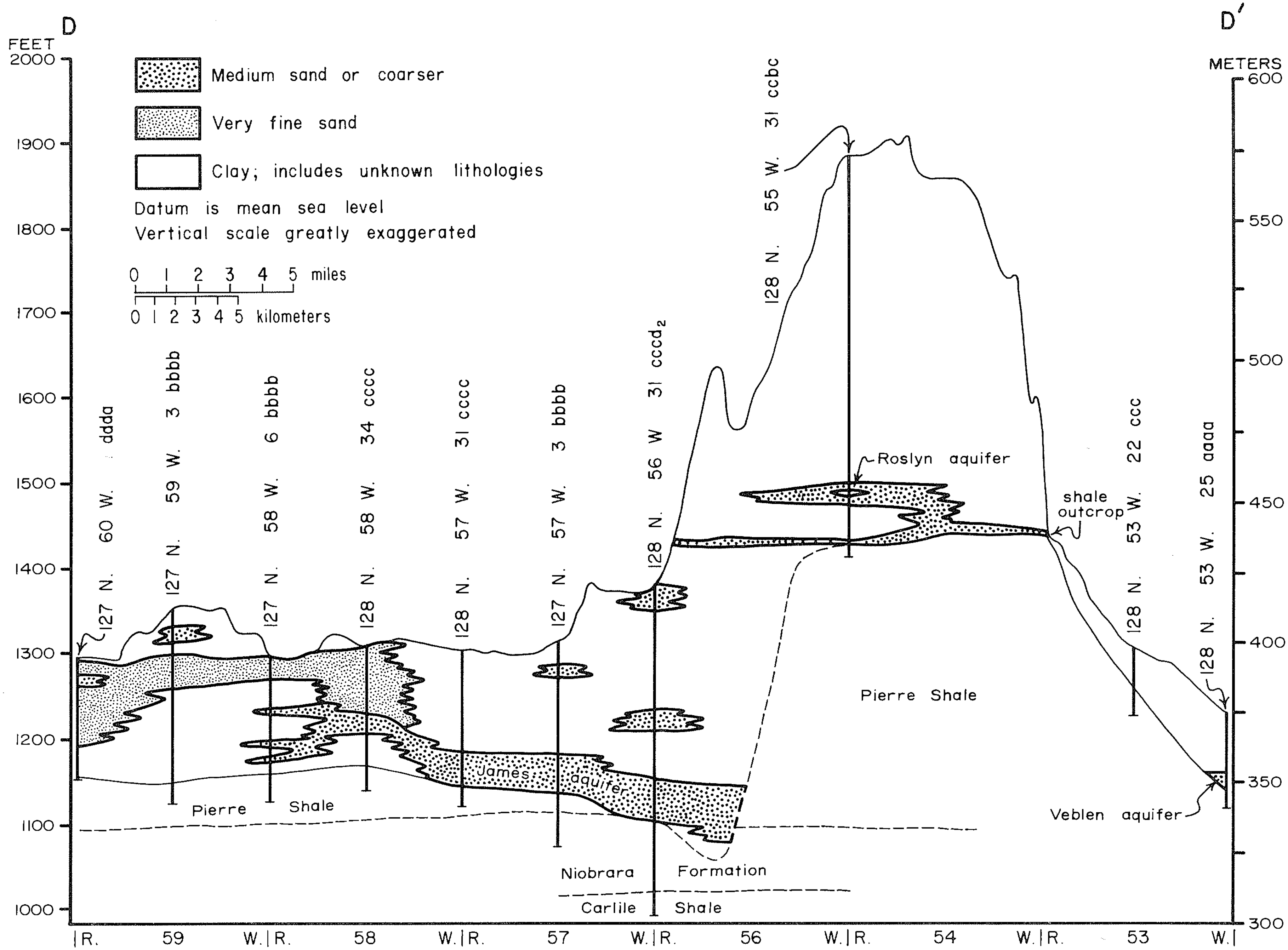

Figure 19-(D-D′). Lithologic sections B-B′ to F-F′ showing where major aquifers occur.

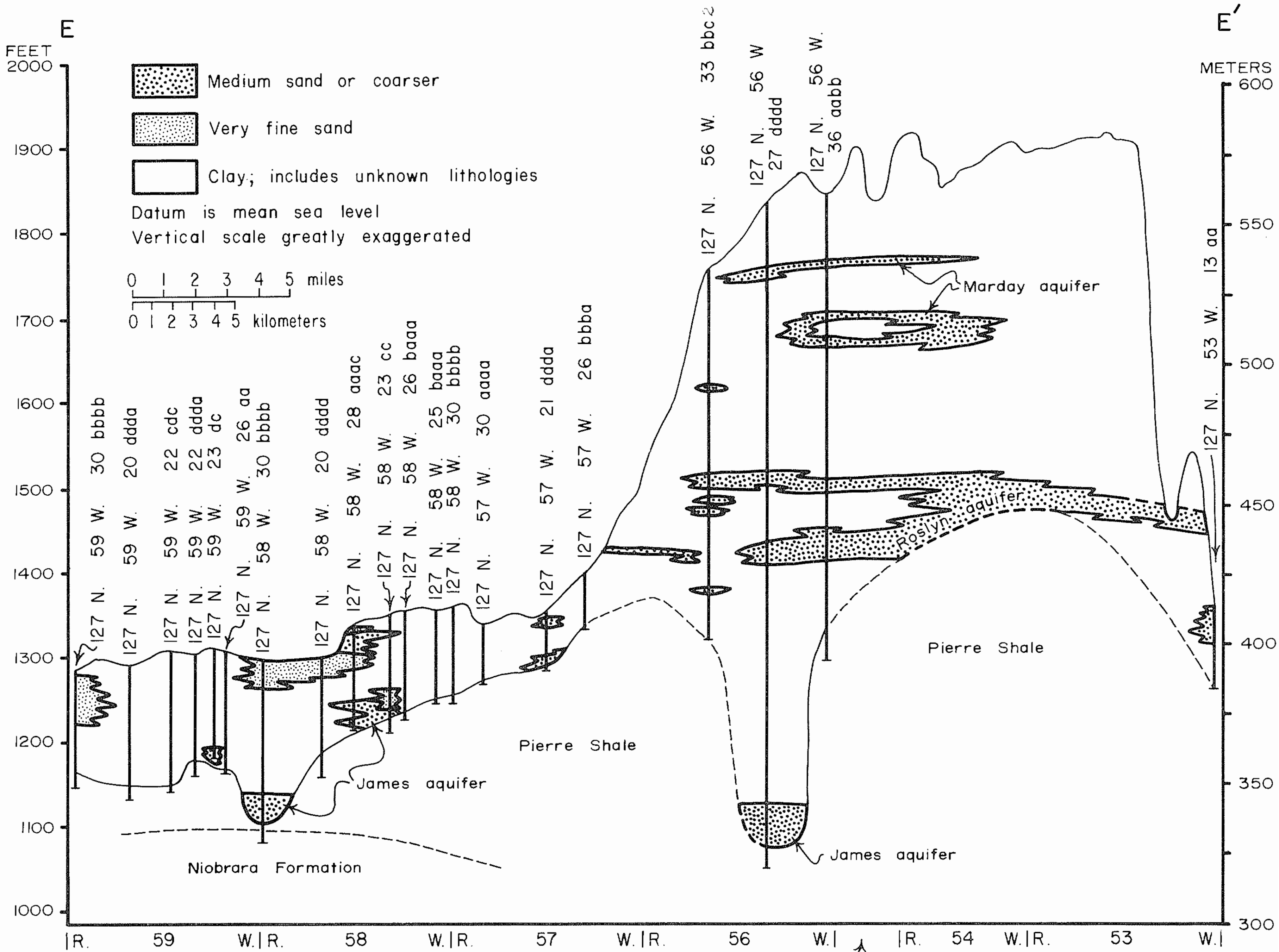

Figure 19-(E-E′). Lithologic sections B-B′ to F-F′ showing where major aquifers occur.

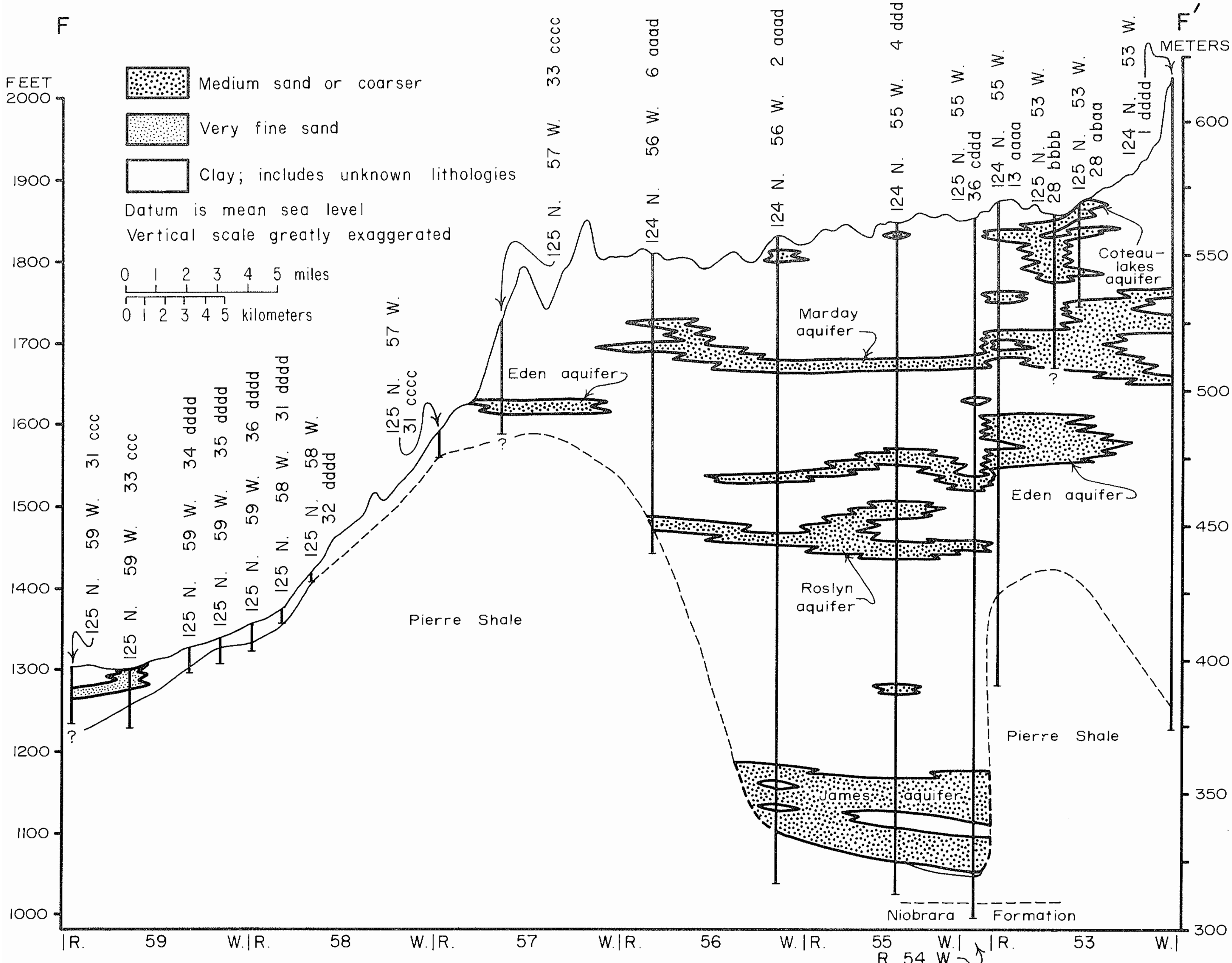

Figure 19-(F-F′). Lithologic sections B-B′ to F-F′ showing where major aquifers occur.

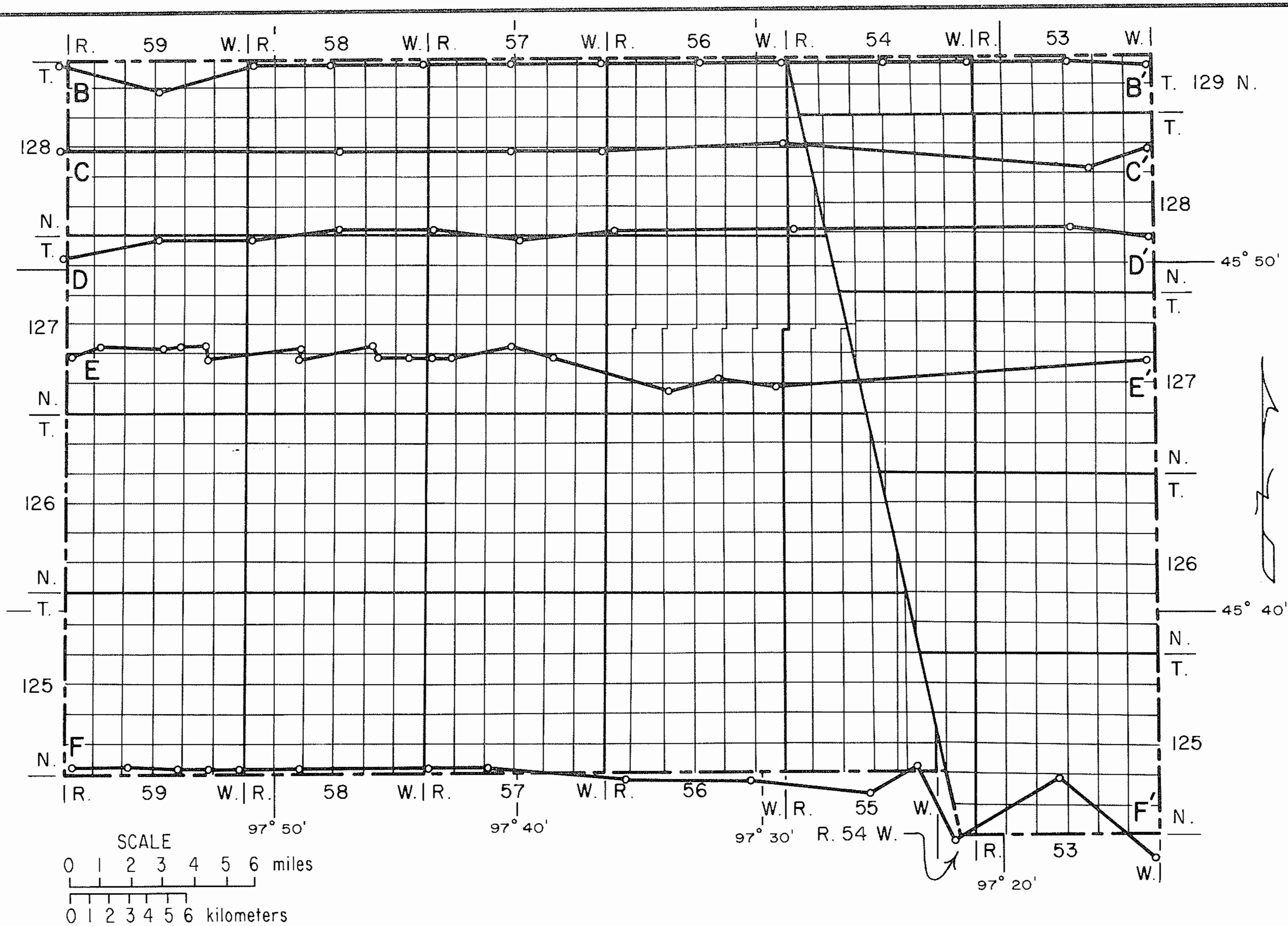

Figure 19-(I). Index map of Marshall County showing traces of sections B-B' to F-F'.

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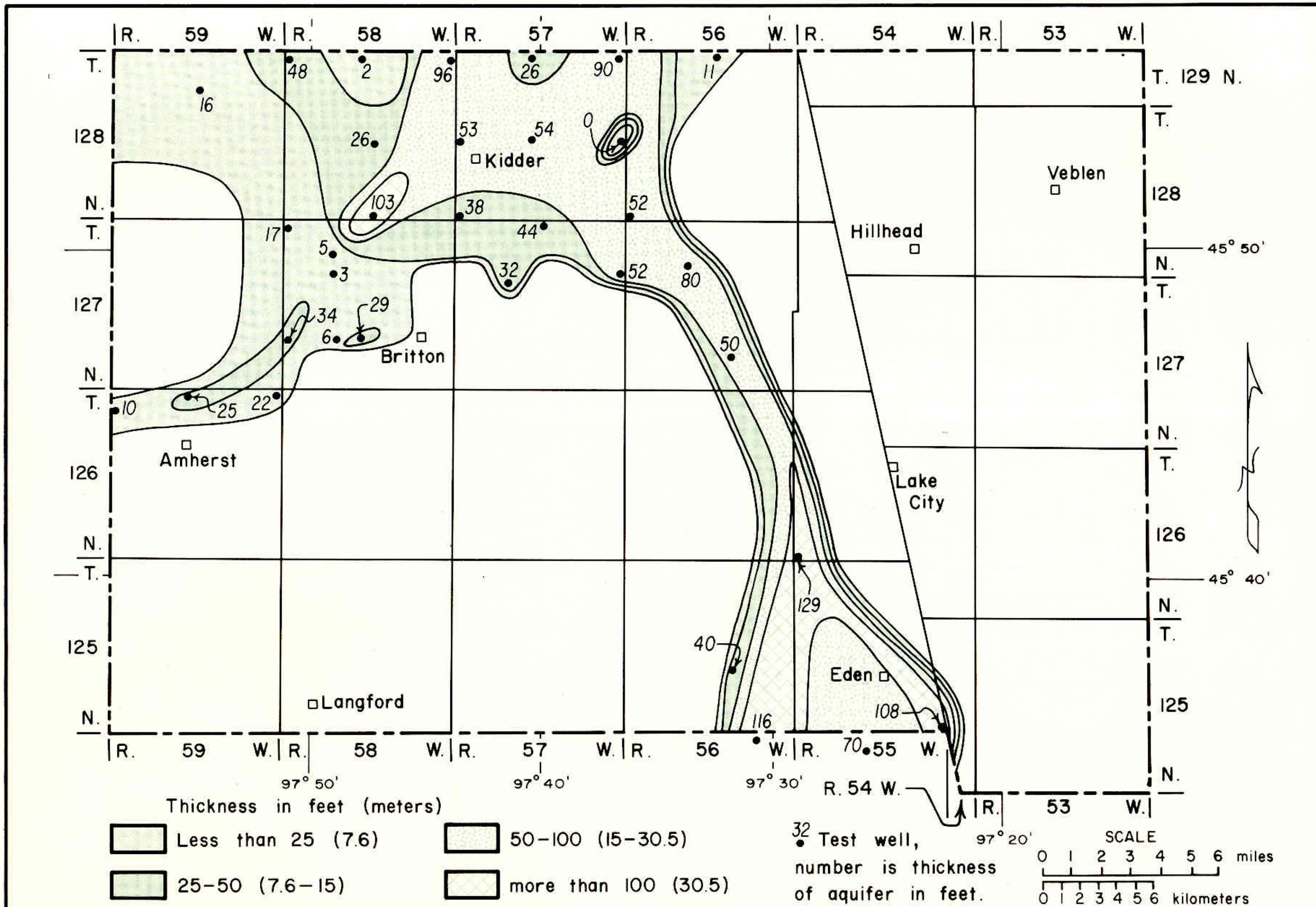
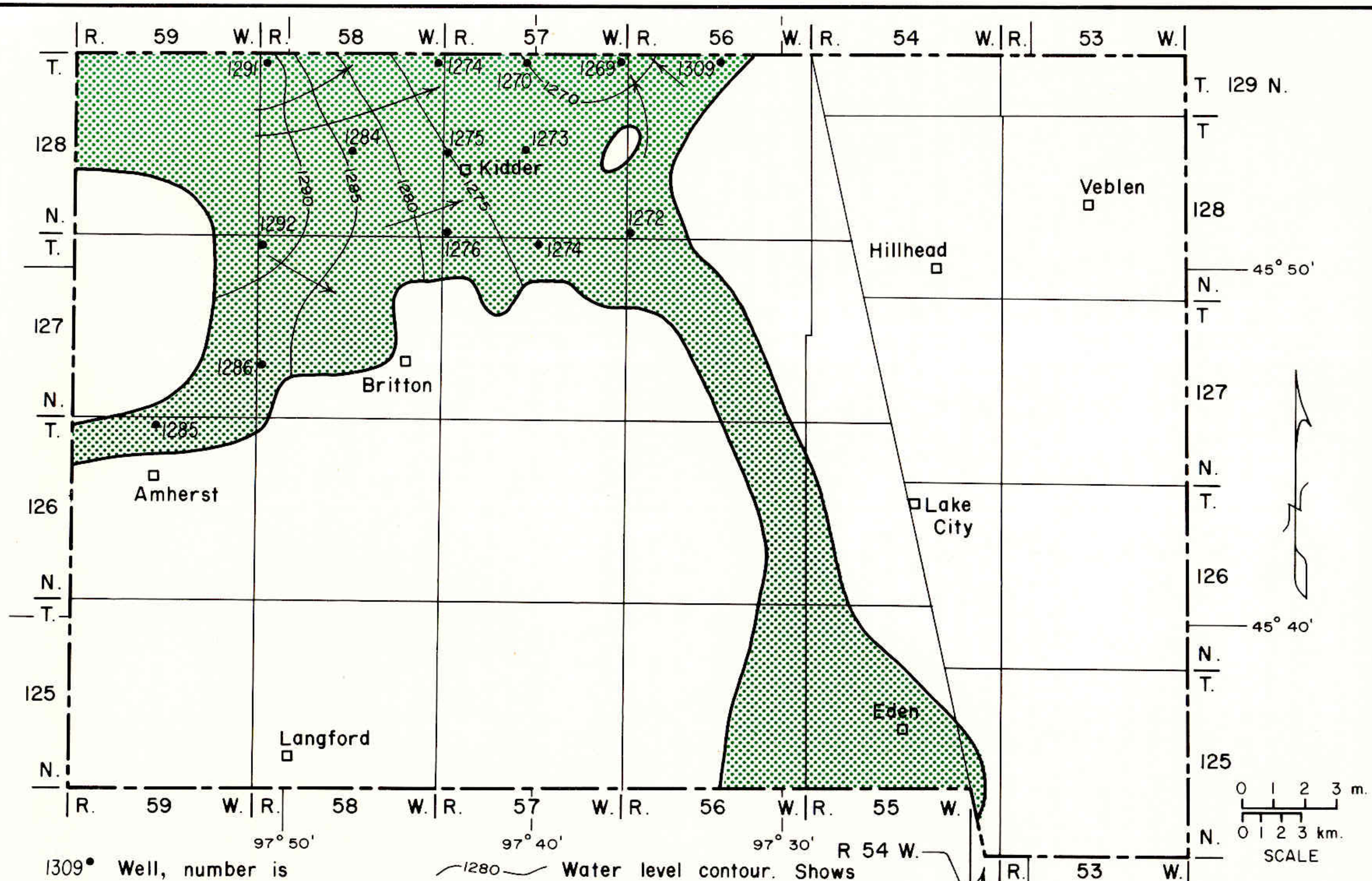


Figure 20. Map showing areal extent and thickness of the James aquifer.



1309• Well, number is altitude of water surface in feet above mean sea level.

1280 Water level contour. Shows altitude of water surface; contour interval is 5 feet (1.5 meters). Datum is mean sea level.

Aquifer boundary

Direction of water movement

Figure 21. Map showing altitude of the water surface and direction of ground-water movement in the James aquifer, November 1971.

fluctuations of water levels are caused by differences in recharge or discharge throughout the year. Water levels rise in the spring and early summer when recharge from percolation of snowmelt and spring rains is greater than discharge by subsurface outflow or evapotranspiration. Conversely, water levels decline from mid-summer to mid-winter when discharge is greater than recharge. This type of seasonal water-level fluctuation is shown in figure 22 for wells 128N58W22BBB, 127N58W6BBB, 126N59W4AAA, and 128N56W3BBBB, which are located in recharge areas.

Long-term fluctuations in water levels reflect cumulative differences in recharge and discharge for a period greater than 1 year. Water levels generally rise in years of above-normal precipitation and decline in years of below-normal precipitation. Because only 2 years of water-level measurements are available for the James aquifer, long-term fluctuations of water levels were difficult to evaluate; however, during 1971, as shown in figure 22, water levels declined about 0.5 to 1 foot (0.1 to 0.3 m). This drop in water level correlates with the period of below-normal precipitation that occurred much of the time from mid-1969 to October 1971, and may be an indication of the beginning of a long-term decline in water levels.

Natural discharge from the James aquifer is by subsurface outflow into North Dakota. The rate of movement is only a few tens of feet per year. Water moves from areas of recharge to areas of discharge as shown in figure 21.

The James aquifer may be discharging water to or receiving recharge from the Niobrara Formation near the North Dakota State line, where the Niobrara is in contact with the James aquifer. Although no wells are known to obtain water from the Niobrara in Marshall County, this study found that the formation does contain one or more permeable zones. The permeable zones in the Niobrara were detected when they took drilling water when penetrated. Water-quality data also suggest the possible mixing of water from the Niobrara with water from the James aquifer.

The predominant chemical constituents of water from the James aquifer can be used to classify the water into four groups (fig. 23).

Group 1 is in the western and southern parts of the aquifer, where water enters the aquifer from Brown County in T. 128 N. or recharges the aquifer by percolation through the overlying material. Sodium and bicarbonate predominate and hardness ranges from 110 to 260 mg/l.

Group 2 is in the central area where most recharge to the aquifer takes place. The predominant constituents in the water are calcium and bicarbonate, although magnesium and sulfate constitute a sizable part. Hardness in the water is high, 340 to 440 mg/l.

Group 3 is a mixed water east of the central major recharge area. The major constituents are sodium, calcium, and bicarbonate where the mixing is with water from the south and west and calcium and sulfate where the mixing is with water from the north. Magnesium is also an important constituent in the mixing area. Hardness ranges from 316 to 860 mg/l. In three samples the hardness is higher than in the major recharge area--the high hardness values might be due to water circulating through or coming from the underlying Niobrara Formation.

Group 4 is in the northern, eastern, and southwestern parts of the aquifer where sodium, sulfate, and bicarbonate predominate. In the north and east the aquifer is in contact with the underlying Niobrara Formation. Several test holes indicate that the Niobrara Formation is permeable; James aquifer water, therefore, may undergo a quality change as a result of mixing with water from Niobrara. The major change in quality is an increase in sulfate resulting in sodium, sulfate, and bicarbonate becoming the major constituents. Hardness ranges from 166 to 265 mg/l. In the southwestern part the James aquifer also may be connected with the Niobrara; however, the quality is somewhat different indicating that other factors may be involved. Hardness and chloride are considerably higher than elsewhere, possibly the result of local recharge through overlying drift.

The water in the James aquifer has high salinity hazard and ranges from low to high sodium hazard (fig. 17). Water of low sodium hazard is in the calcium bicarbonate type water area or in the mixed-water area to the northeast (fig. 23). Water of high sodium hazard is in the southern and eastern parts of the aquifer.

Field analyses of specific conductance, chloride, and hardness were made of water from 19 wells (table 6).

Veblen Aquifer

The Veblen aquifer underlies 24 square miles (62 km^2) in northeastern Marshall County and extends into Roberts County and into North Dakota (fig. 24). Probably only a small part of the aquifer is within Marshall County. It consists of buried outwash that is mostly sand and gravel. The outwash contained clay lenses at only one test hole (129N53W25AADA). Water in the aquifer occurs under artesian conditions except in some places where overlying clay layers are absent and it occurs under water-table conditions. Water levels range from 50 to 100 feet (15 to 30 m) below land surface.

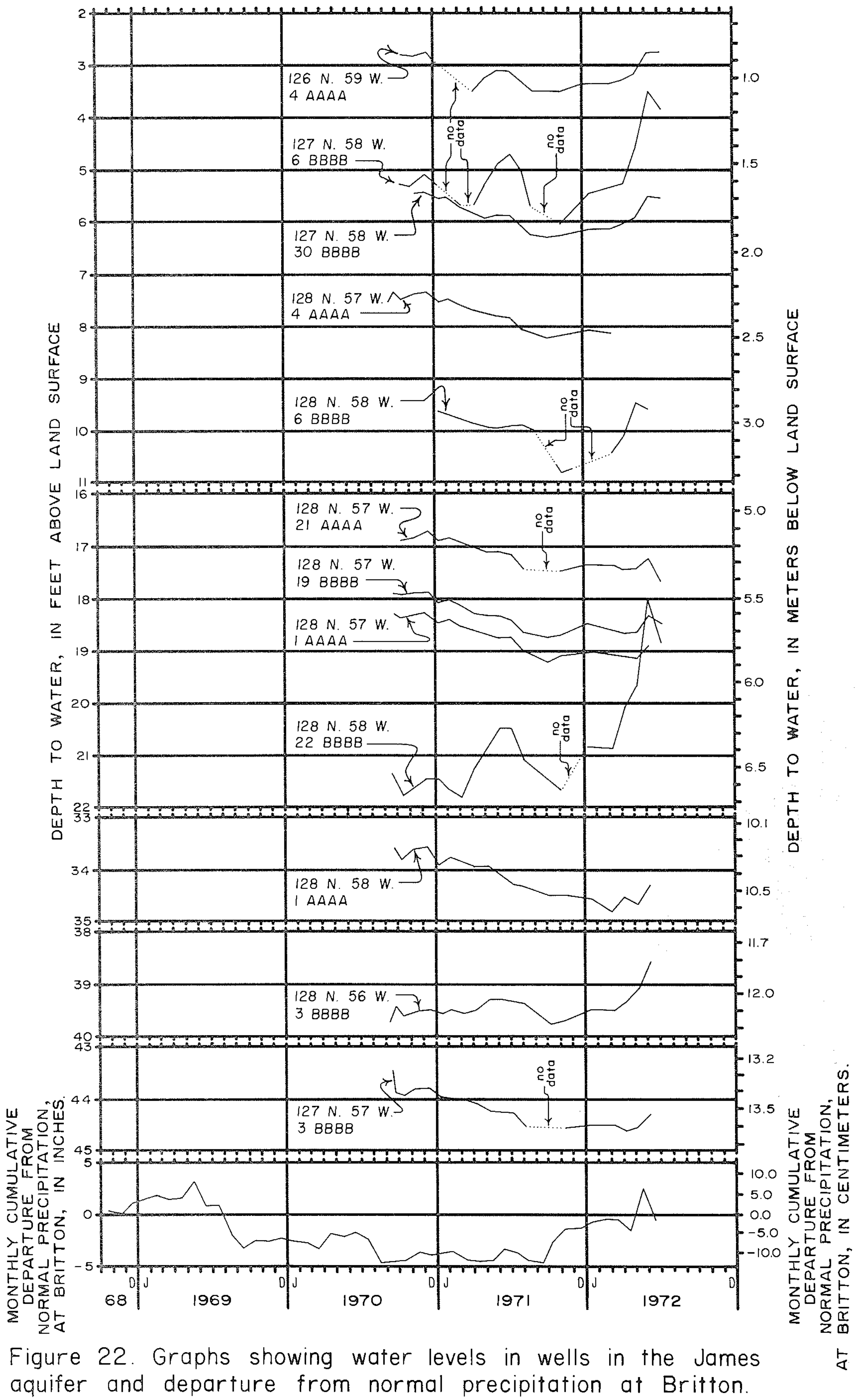


Figure 22. Graphs showing water levels in wells in the James aquifer and departure from normal precipitation at Britton.

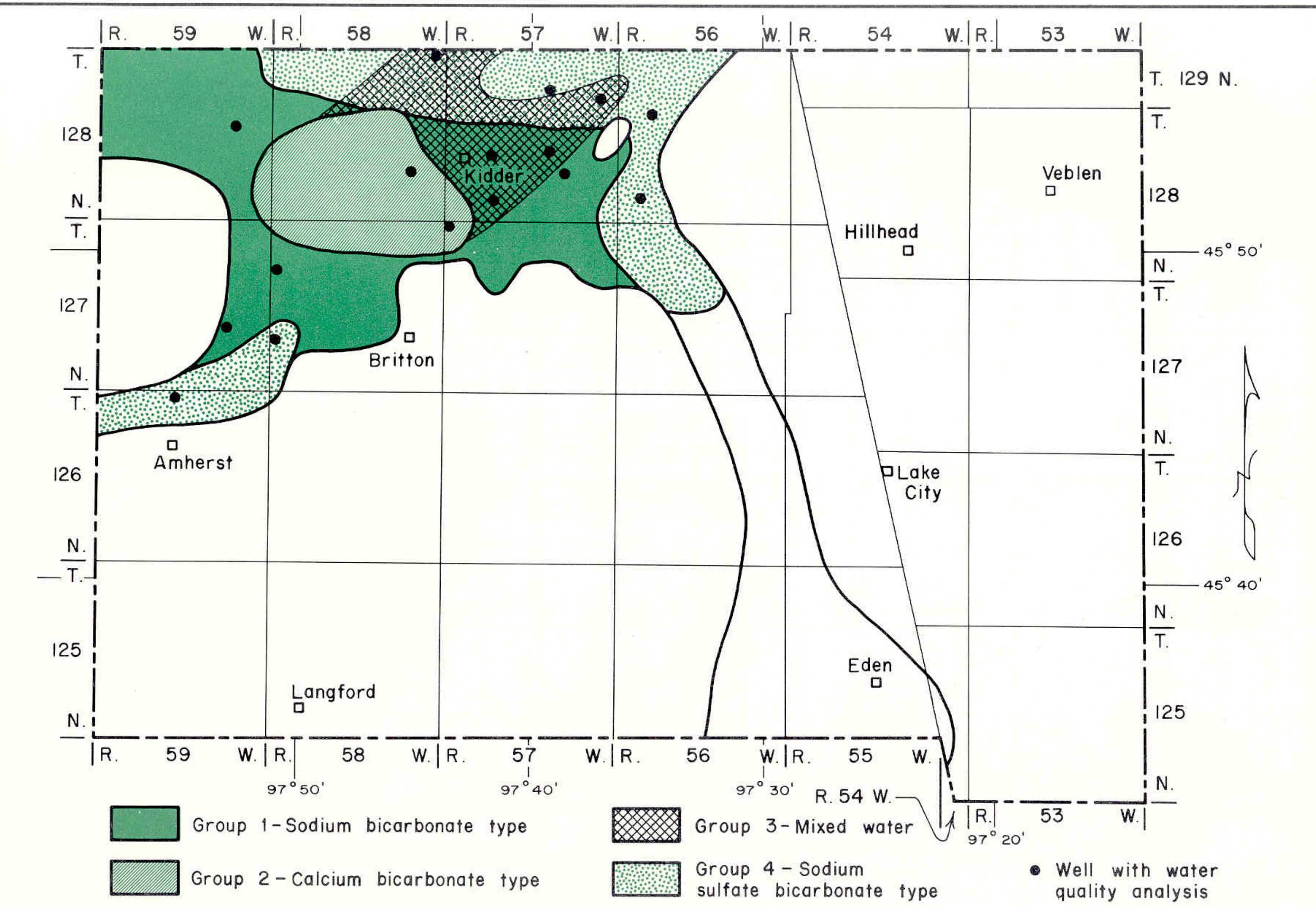


Figure 23. Map showing water types in the James aquifer.

Table 6. Chemical Analyses of Water from the James Aquifer

(Determined in the field)

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
127N57W7CCC2	98	1,630	8	960
127N59W23DCC	129	1,850	------	150
128N56W3ABB	200	1,580	8	1,200
128N56W7AAD	196	---------	76	460
128N56W7BAA	150	---------	152	480
128N56W17BCB	225	---------	110	260
128N56W19AAA	281	1,520	45	170
128N56W31AAA	318	1,570	98	190
128N57W2DDA	158	1,750	23	630
128N57W10DAB	168	1,300	45	290
128N57W12CDD	180	1,600	15	680
128N57W19DAB	157	950	15	390
128N57W22ADA	160	2,000	23	940
128N57W22DD2	160	1,200	23	290
128N57W26CBBA	152	1,140	23	130
128N57W32ADB	153	1,070	8	340
128N58W2CC	131	1,230	30	530
128N58W12AD	137	1,120	30	480
128N58W35DD2	63	1,000	30	230

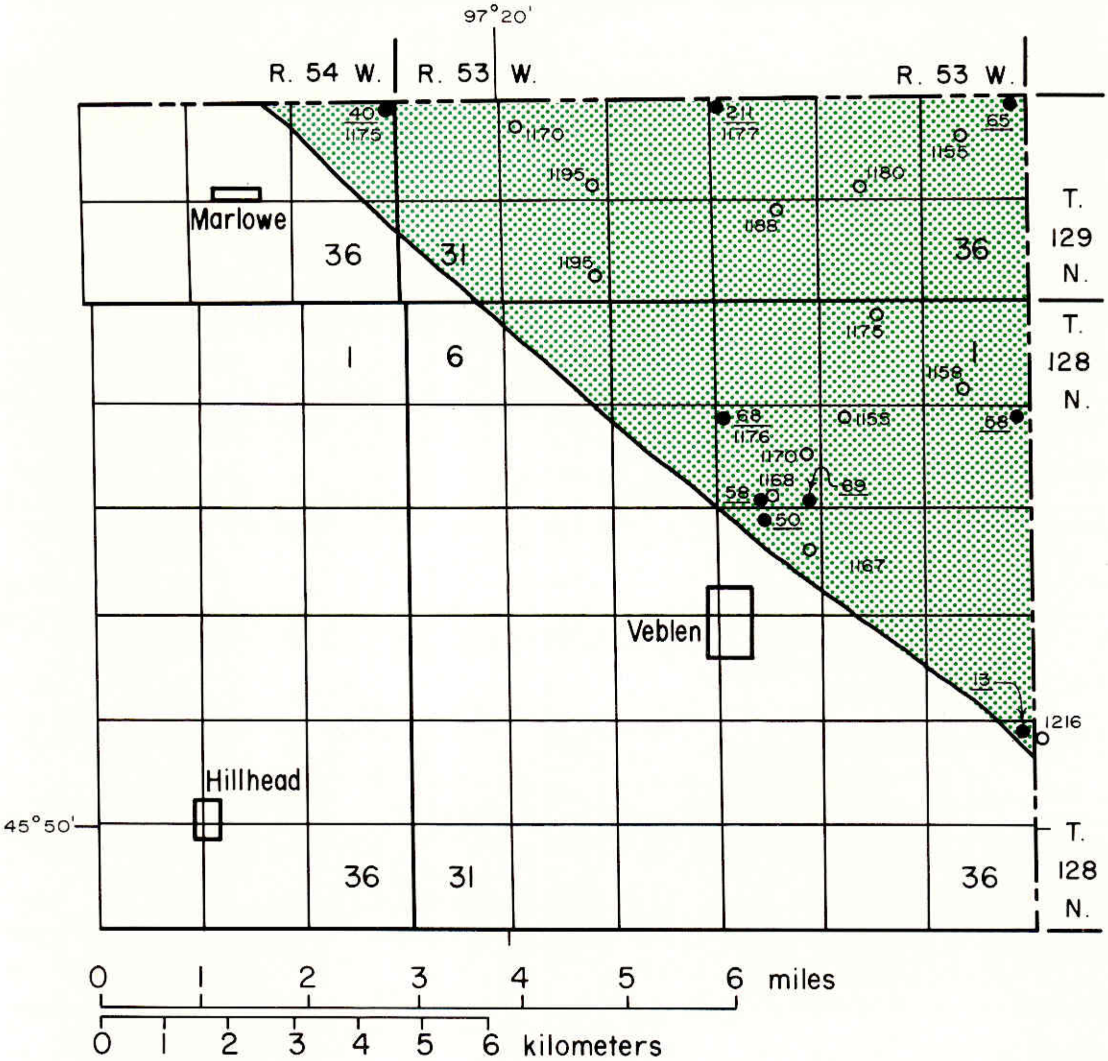
The Veblen and James aquifers are at about the same altitude but are separated by the coteau. In North Dakota where the coteau is absent the two aquifers might combine to form a single aquifer.

The Veblen aquifer in the County contained about 154,000 acre-feet (190 million m^3) of water in storage in 1971. Water in storage was estimated by using an average saturated thickness of 50 feet (15 m) and an estimated porosity of 20 percent.

In general, where the aquifer is buried it occurs at altitudes of 1,160 to 1,030 feet (354 to 314 m). It is at its highest altitude, except for near surface sands, along its western boundary and it slopes to the northeast at about 14 feet per mile (2.7 m/km). The greatest known thickness of sand and gravel is 211 feet (64 m), found at test hole 129N53W27BBBB. Elsewhere aquifer thickness ranges generally from 40 to 69 feet (12 to 21 m). Wells tapping the aquifer range from 80 to 158 feet deep (24 to 48 m).

Water in the Veblen aquifer is mostly under artesian conditions except in the north-central part. Here sand and gravel come to within 20 feet (6 m) of land surface and the aquifer has water-table conditions even though the water table may be as much as 55 feet (17 m) (well 129N53W25BDD) to 78 feet (24 m) (well 129N53W27BBBB) below land surface.

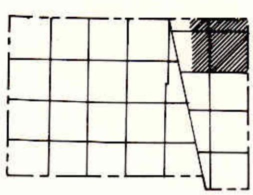
Recharge to the aquifer is by percolation of precipitation through the overlying till and outwash. The highest water levels were found in the north-central and the southernmost parts of the aquifer; this indicates that recharge occurs in those areas. In the recharge area in secs. 25 and 27, T. 129 N., R. 53 W., precipitation and snowmelt percolate



1155 o Domestic or stock well. Number is altitude of water surface in feet above mean sea level 1967-1968.

40/1175 ● Test well. Upper number is thickness of aquifer in feet; lower number is altitude of water surface in feet above mean sea level 1967-1968.

Veblen aquifer



Marshall County index map showing map location.

Figure 24. Map showing areal extent, thickness, and altitude of water surface of the Veblen aquifer.

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through about 60 feet (18 m) of outwash before reaching the water table. In the recharge area along the southwestern edge of the aquifer, the topographically higher Roslyn aquifer discharges water from springs. This water flows downstream onto permeable material overlying or connected to the Veblen aquifer. Here the water re-enters the ground and probably recharges the Veblen aquifer.

Recharge and discharge to the Veblen aquifer were in approximate balance during this study. Water levels in observation wells changed less than 1 foot (0.3 m) during most of the period, as is shown on figure 25. The exception to this was the sharp rise in water levels from April to June 1972 caused by above normal precipitation in May. Water-level changes of as much as 4½ feet (1.4 m) from early summer to late winter, shown by well 128N52W30BBBB (fig. 25), indicate that the southern corner of the aquifer quickly responds to changes in recharge and discharge. It is possible, however, that this well is not completed in the Veblen aquifer--the water-bearing sand is at higher altitude than that found in any test well penetrating the Veblen. Also, the water level at this well is 19 feet (6 m) higher than that in any other well known to tap the Veblen aquifer

Although the nearly flat water surface makes it difficult to determine the precise direction of water movement, natural discharge from the Veblen aquifer is probably by subsurface outflow into Roberts County and into North Dakota. These discharge areas are based on the location of the recharge areas in Marshall County. Study of the aquifer in North Dakota and Roberts County will be needed to understand these aquifer characteristics better.

In September 1971, a test of the aquifer's transmissivity was made using the Veblen city well (128N53W10CBBB). The well, screened in a sandy gravel[2] from 128 to 158 feet (39 to 48 m) below land surface, was pumped for 24 hours at an average rate of 135 gpm (9 l/s). Changes in water level in the aquifer were measured in four observation wells spaced at 92, 130, 175, and 3,100 feet (28, 40, 53, and 945 m) from the pumped well. Maximum drawdowns at the end of the test were 3 feet (1 m) in the pumped well and 1, 1, 0.85, and 0.50 feet (0.3, 0.3, 0.26, and 0.15 m) in the respective observation wells. Analysis of the data, using the Theis (1935) nonequilibrium formula, showed that here the aquifer had an average transmissivity of 120,000 gallons per day per foot (1.5 million l/day/m) and a storage coefficient of 0.0003.

Results of the aquifer test and other data indicate that in the Veblen aquifer, where medium or coarse sand occurs in sufficient thickness, wells could be developed for irrigation or other large-yield needs.

The Veblen aquifer yields water of two kinds: in the western part of the aquifer the major chemical constituents are calcium, sodium, and sulfate; and in the eastern part the major constituents are calcium, magnesium, and bicarbonate (fig. 26). In the western part of the aquifer specific conductance ranges from 1,100 to 2,130 μmhos/cm but in the eastern part it is only from 680 to 950. Hardness and chloride are also higher in the western part. See table 7.

In the western part of the aquifer, water is high in specific conductance, hardness, and chloride and sulfate concentration possibly because water recharging the aquifer has been in contact with the Pierre Shale. The eastern part of the aquifer is recharged by infiltration of water through overlying sands.

Water from the Veblen aquifer has high salinity hazard and low sodium hazard (fig. 17).

Coteau-lakes Aquifer

The Coteau-lakes aquifer underlies about 50 square miles (130 km^2) in southeastern Marshall County (fig. 27). The aquifer is an outwash deposit of sand and gravel that is at or near land surface. Topographic lows in the outwash (most probably glacial kettles) contain Buffalo, South Red Iron, North Red Iron, Clear, and Roy Lakes. These lakes are hydraulically connected with the aquifer. Water in the aquifer occurs in some places under water-table conditions and in other places under artesian conditions; and water levels range from that in adjacent lakes to 40 feet (12 m) below land surface.

The Coteau-lakes aquifer contained about 160,000 acre-feet (197 million m^3) of water in storage in 1971. Water in storage was estimated by using an average saturated thickness of 25 feet (7.6 m) and an estimated porosity of 20 percent.

The thickness and distribution of sand and gravel in the aquifer are shown on lithologic sections in figures 28 and 19. The greatest thickness of aquifer, 77 feet (23 m) of mostly gravel, was found at test hole 125N53W28BBBB (section H-H', fig. 28). The thickness of the aquifer varies widely. Less than 1 mile east it consists of 41 feet (12 m) of sand and gravel in three beds separated by thick deposits of clay.

The aquifer may extend farther northeast at North Red Iron Lake than is shown in figure 27. A test hole at 126N53W10DADA penetrated 40 feet (12 m) of sand and gravel at altitudes of 1,874 to 1,794 feet (571 to 547 m).

[2] A grain size analysis of this material made by Johnson Division, Universal Oil Products Co., Saint Paul, Minnesota, showed 18 percent gravel, 14 percent very coarse sand, 24 percent coarse sand, 37 percent medium sand, and 7 percent fine sand or clay.

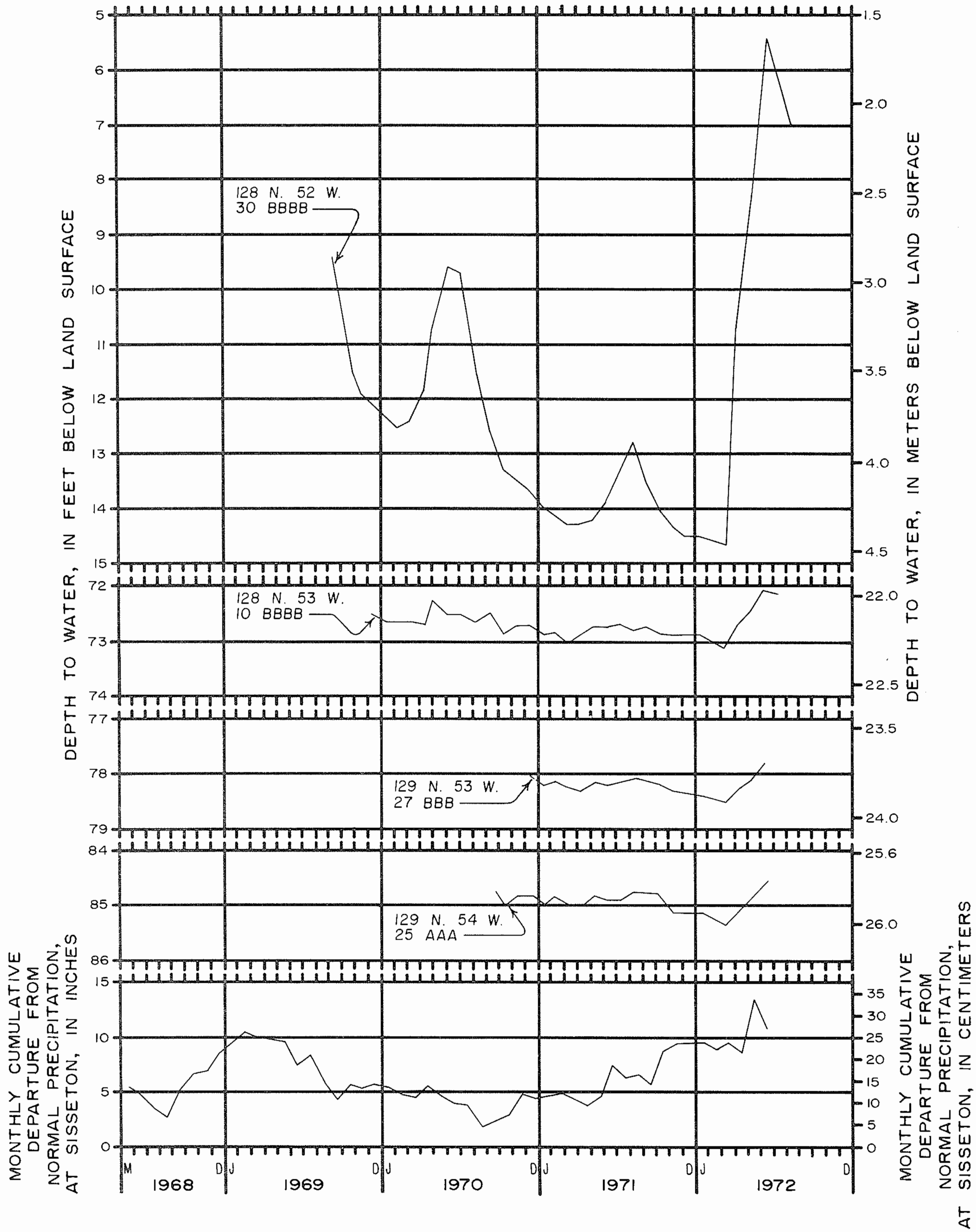

Figure 25. Graphs showing water levels in wells in the Veblen aquifer and cumulative departure from normal precipitation at Sisseton.

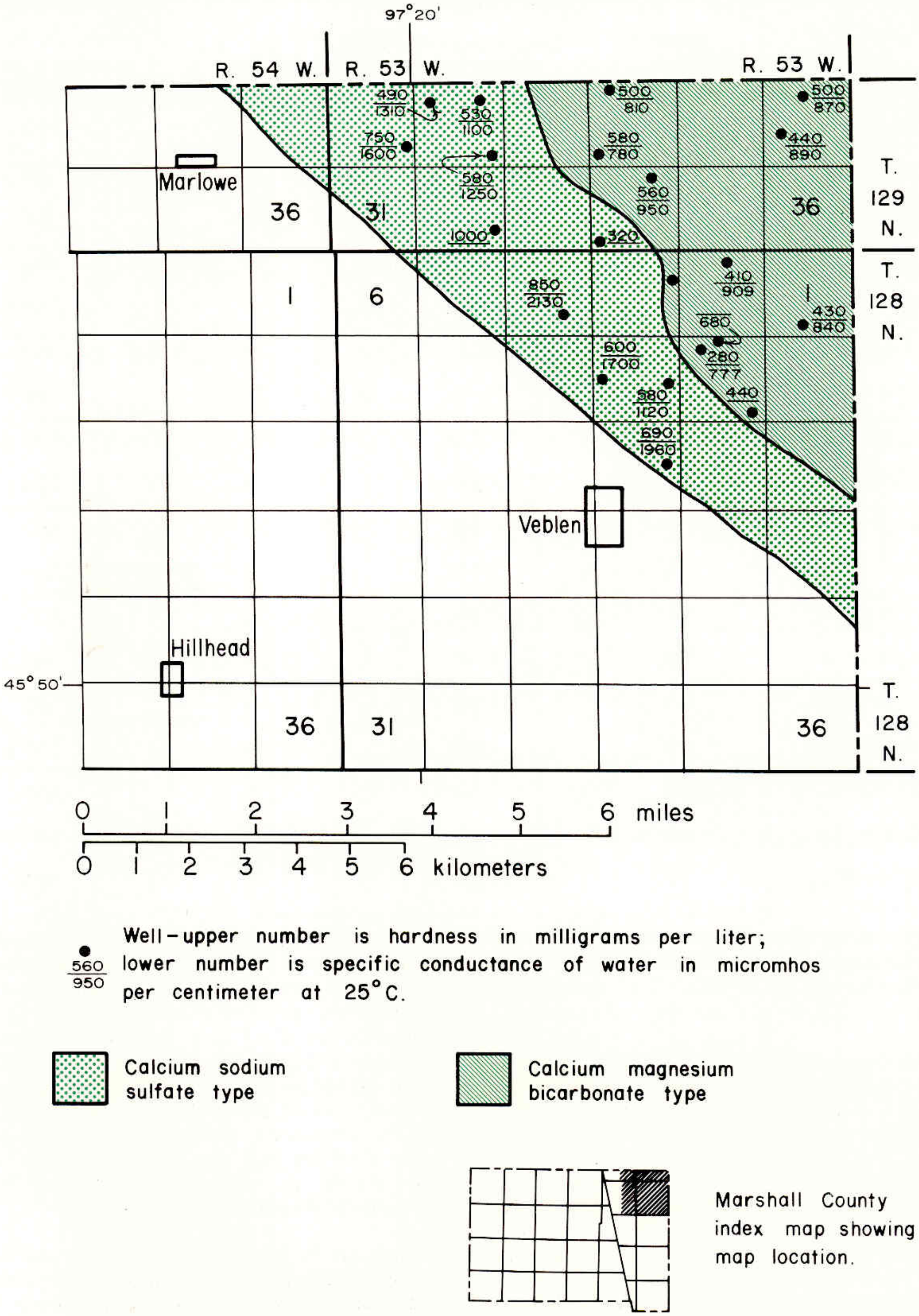

Figure 26. Map showing water types, specific conductance, and hardness of water in the Veblen aquifer.

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Table 7. Chemical Analyses of Water from the Veblen Aquifer

(Determined in the field)

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
128N53W2ABB	108	---------	30	1,100
128N53W3ADA	115	---------	8	380
128N53W4DBC	127	---------	30	840
128N53W10ADD	110	---------	15	580
128N53W11BBA	120	---------	8	340
128N53W11DDD	115	---------	15	440
128N53W15ADD	120	---------	38	790
129N53W25BDD	80	870	15	500
129N53W25CBA	112	890	8	530
129N53W27BBA	125	810	8	500
129N53W27CCC	100	780	8	580
129N53W29AAC	120	1,100	15	530
129N53W29BCA	135	1,400	23	700
129N53W29DDD	135	1,250	15	580
129N53W30DDBB	118	1,600	15	750
129N53W32DDA	124	---------	8	1,000
129N53W34ABB	108	950	91	560
129N53W34CCC	103	---------	15	320

South of Roy Lake the aquifer may extend farther than is shown in figure 27. Two test holes, 125N55W16DDD and 125N55W34CCC, show sand at altitudes of 1,800 to 1,775 feet (549 to 541 m).

The Coteau-lakes aquifer is exposed at land surface in most of T. 125 N., and around South Red Iron, part of North Red Iron, and Clear Lakes (fig. 27). West of these lakes the aquifer is overlain by till.

Artesian conditions occur in the aquifer north and east of Roy Lake and in a 2-square mile (5-km^2) area southwest of South Red Iron Lake (fig. 27). Flowing wells may be obtained in low-lying areas near Roy Lake. For example, there is a 40-foot (12-m) deep flowing well at the State Game, Fish, and Parks shop (126N55W20DBA).

The artesian head is so low that the sizes of the artesian areas readily change with fluctuations in recharge and discharge. In the vicinity of test hole 125N54W12AAA, for example, the aquifer would change from water-table to artesian conditions if the water surface rose more than 3 feet (1 m) from the level of 26 feet (8 m). When this hole was drilled, air flowed from it from a depth of 23 feet (7 m). This depth was just below the contact between the clay till and the outwash; the top 3 feet (1 m) of sand was dry. Air entered the spaces between the sand grains when the water table was low. As the water table rose, the air was trapped and compressed, to be released later through the test hole.

Recharge is by direct precipitation on lakes, percolation through the till cover or through outwash where exposed at the surface, surface runoff into lakes, and subsurface inflow. Snowmelt and spring and early summer rainfall contribute most recharge to the aquifer. Surface runoff from drainageways to the north and east, flowing into lakes connected to the

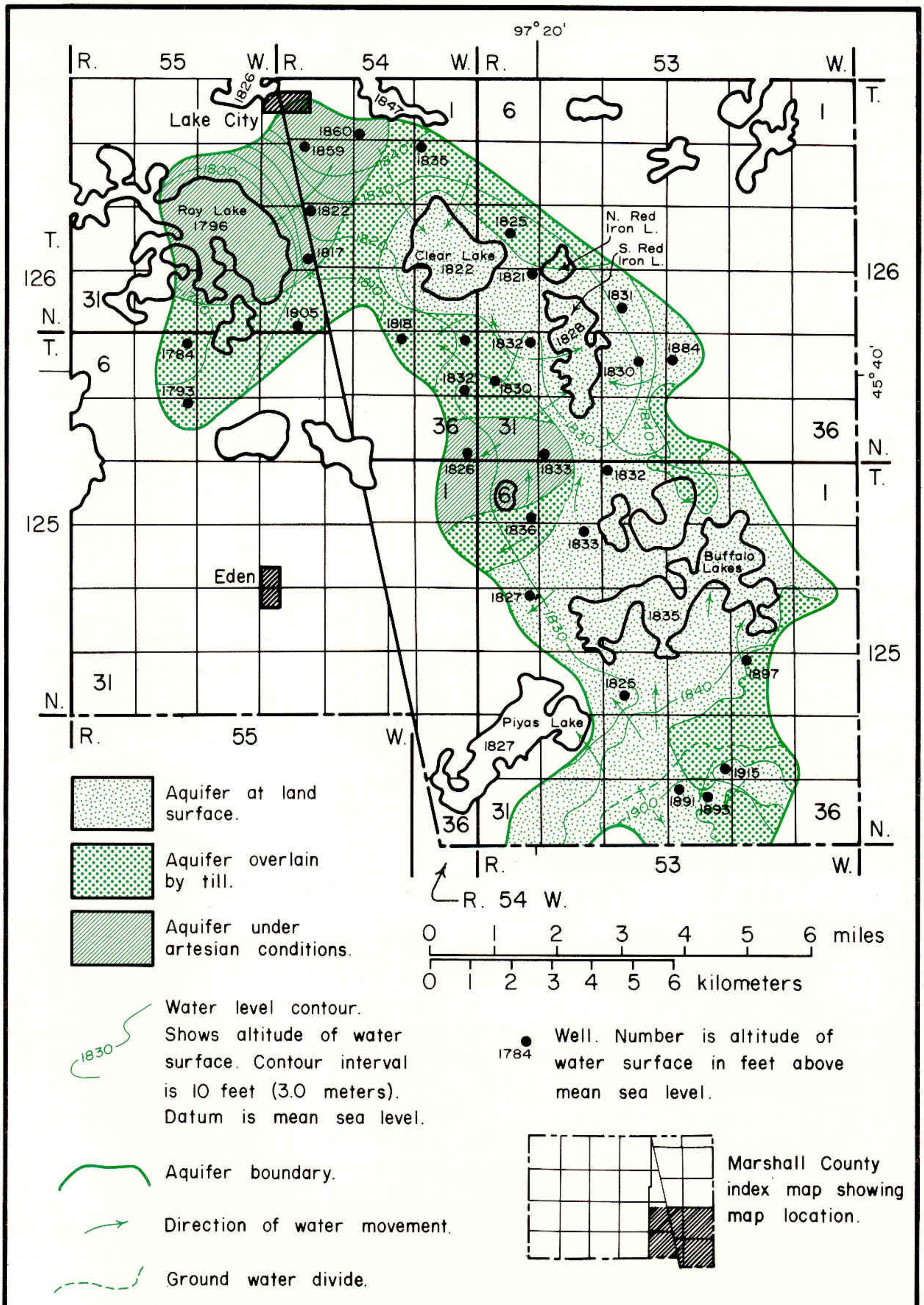

Figure 27. Hydrogeologic map of the Coteau-lakes aquifer.

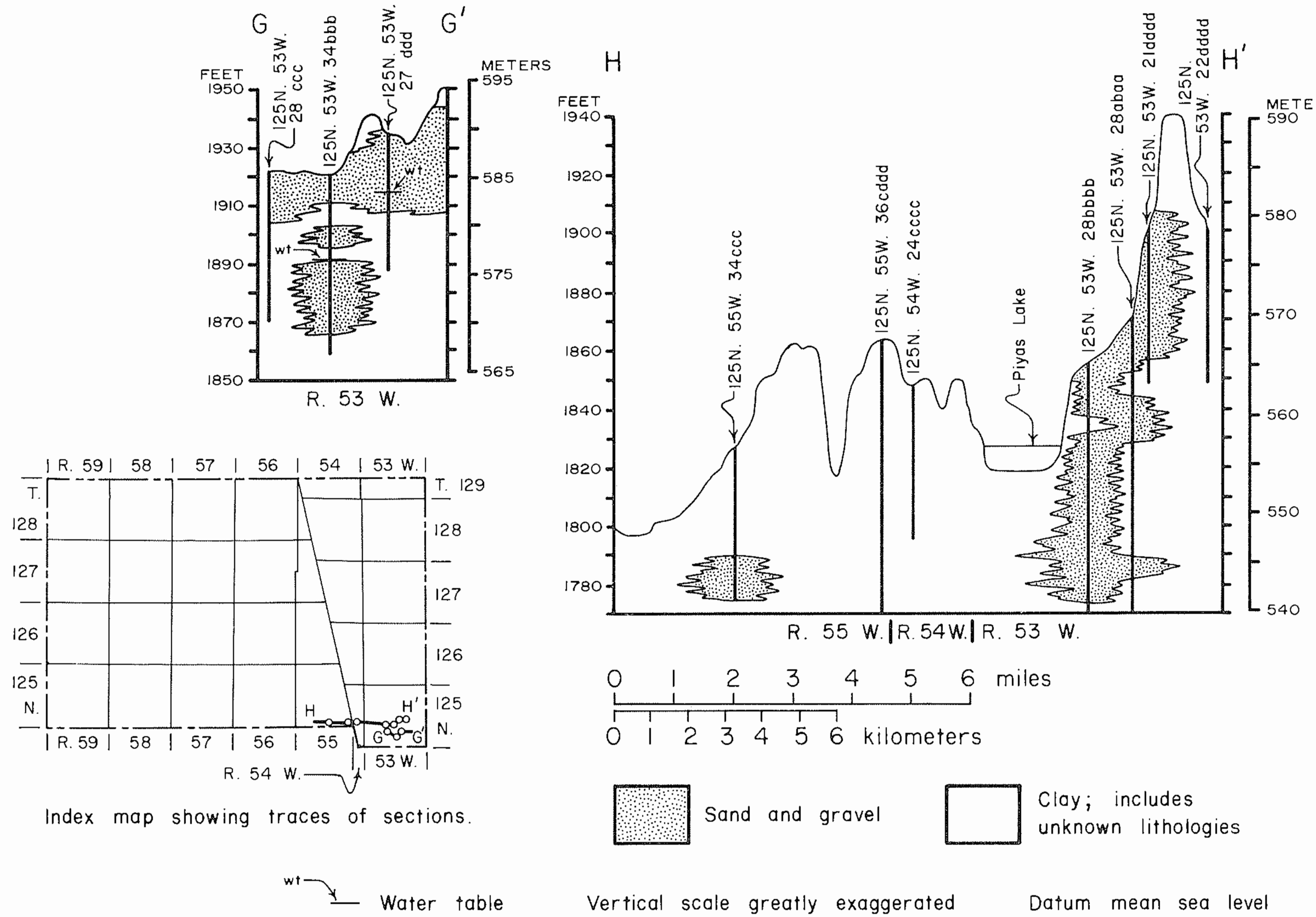

Figure 28. (G-G' and H-H'). Lithologic sections G-G' to K-K' showing where sand and gravel in the Coteau-lakes aquifer.

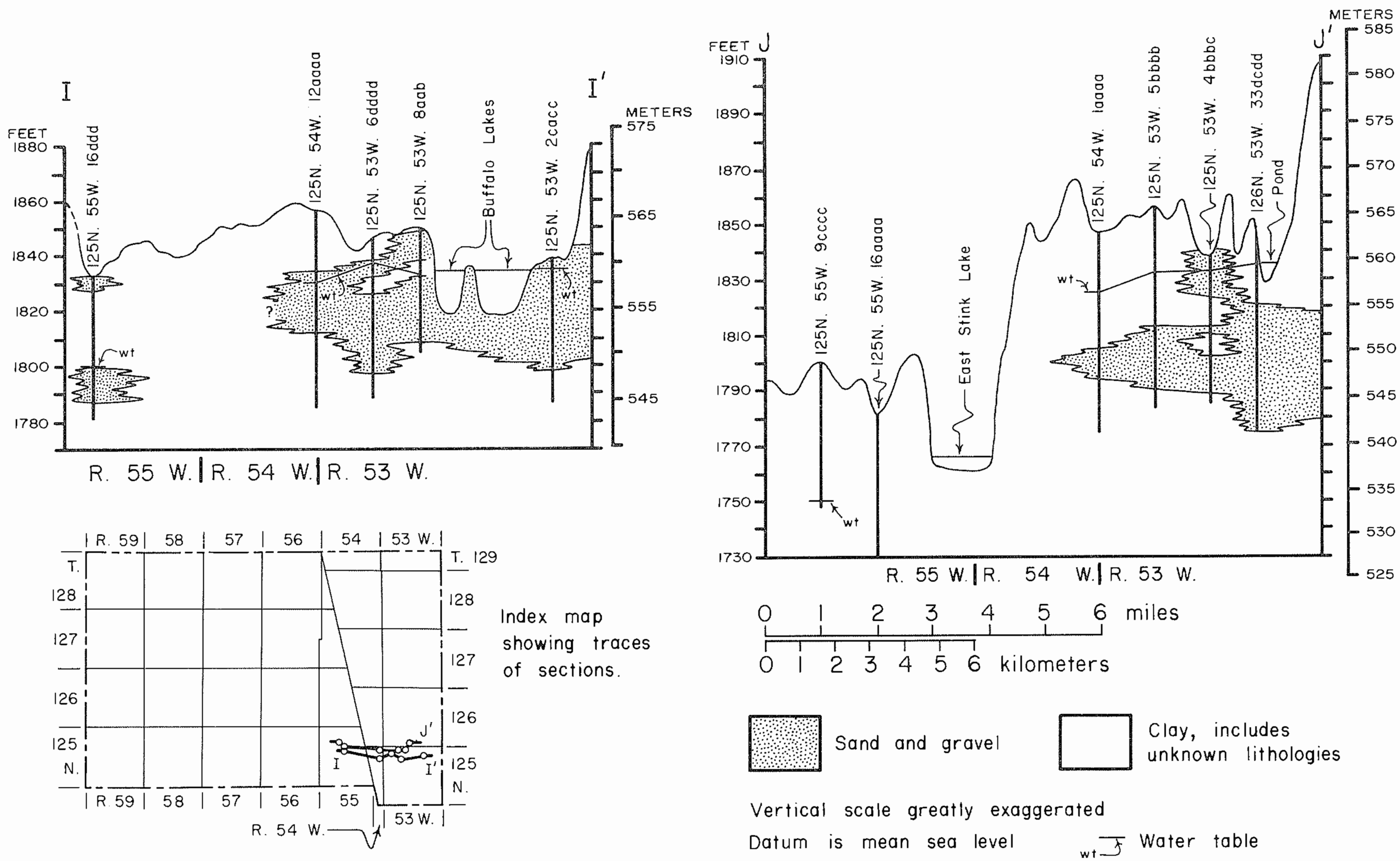

Figure 28. (I-I′ and J-J′). Lithologic sections G-G′ to K-K′ showing where sand and gravel in the Coteau-lakes aquifer.

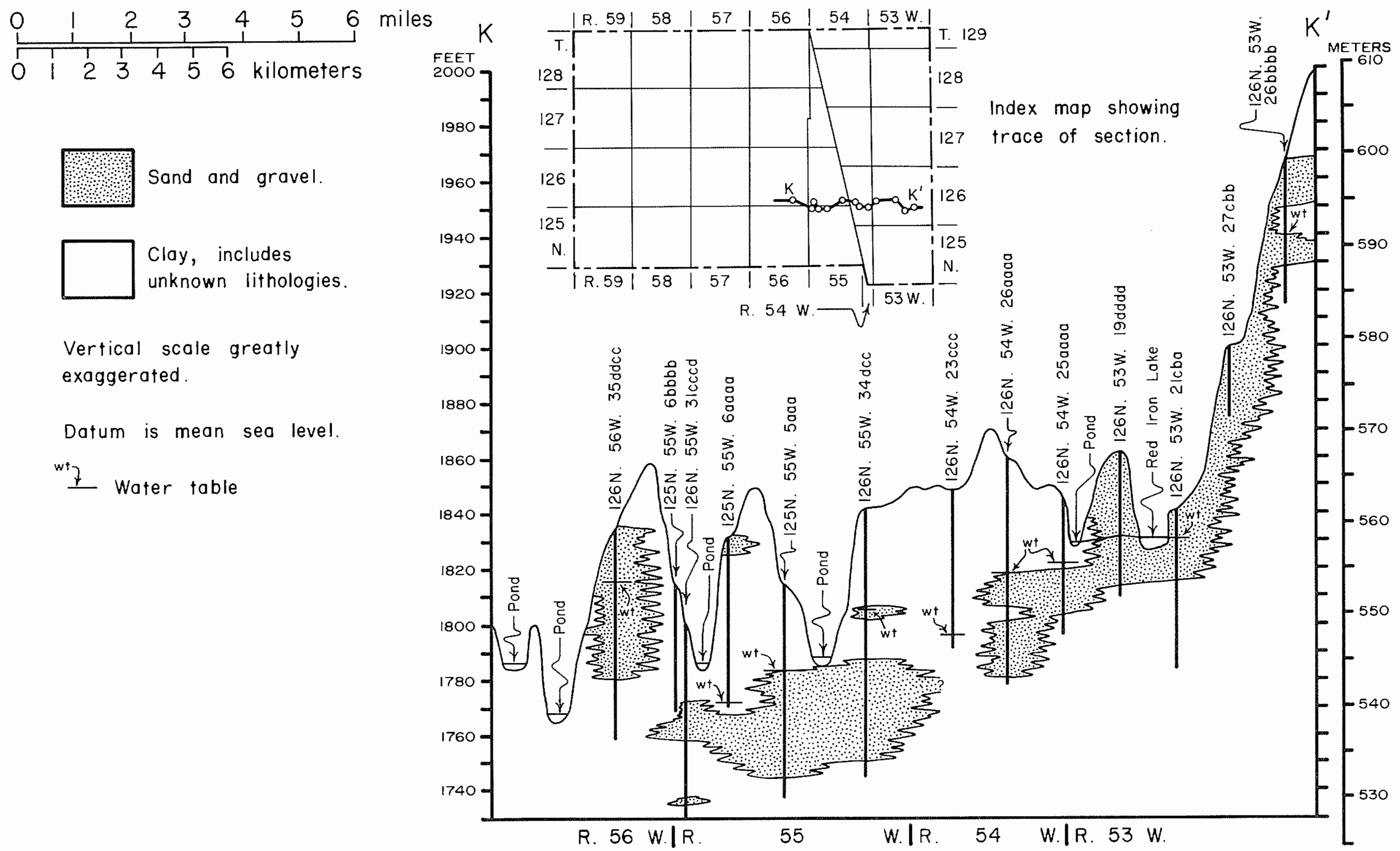

Figure 28. (K–K′). Lithologic sections G–G′ to K–K′ showing where sand and gravel occur in the Coteau–lakes aquifer.

aquifer, supplies much recharge (fig. 27). Little or no surface runoff enters the lakes from the west. Surface runoff in the area overlying the southern-most part of the aquifer carries water into Day County. Subsurface inflow is from the till area and from sands at higher altitude along the eastern side of the aquifer.

Water levels generally rise from March through June and thereafter decline to November, as shown in figure 29. In years when precipitation is above normal, water levels are high, but when preciptiation is below normal water levels decline. From May 1969 to August 1970 precipitation was, for the most part, below normal, which resulted in a water-level decline of about 1 foot (0.3 m).

Natural discharge from the Coteau-lakes aquifer is by evapotranspiration and by subsurface outflow. Evaporation from approximately 4,200 acres (1,700 ha) of lake surface amounts to about 12,600 acre-feet (15.5 million m^2) per year which is about 7,800 gpm (492 l/s). Subsurface outflow is to the west and to underlying aquifers.

Well yields of 500 gpm (32 l/s) probably can be obtained where the aquifer is sufficiently thick and has a good hydraulic connection with a lake.

Water in the Coteau-lakes aquifer is generally of calcium bicarbonate type except for one analysis that was of calcium sulfate type. When the ground water is discharged to lakes here, it changes to a magnesium bicarbonate type except in Roy Lake where it becomes magnesium sulfate type. Specific conductance, chloride concentration, and hardness of water in the aquifer generally are lower than in ground water in till adjacent to the aquifer (fig. 30 and table 8). Dissolved-solids concentration of water in the Coteau-lakes aquifer is low because recharge is by local infiltration of snowmelt and precipitation through shallow overlying drift; and water recharging the aquifer does not dissolve much mineral matter.

Water from the aquifer has medium to high salinity hazard and low sodium hazard (fig. 17).

Marday Aquifer

The Marday aquifer is a buried outwash deposit of sand and gravel south of T. 128 N. in the eastern part of Marshall County. (See fig. 31). The aquifer underlies about 290 square miles (751 km^2) of Marshall County and extends into Day and Roberts Counties. Water in the aquifer occurs under artesian conditions and water levels range from 25 to 260 feet (8 to 79 m) below land surface.

The thickness of the Marday varies from 5 feet (1.5 m) at test hole 126N54W34AAAA to 67 feet (20 m) at test hole 126N53W10DADA. The aquifer contains few clay lenses.

In general, the aquifer occurs at altitudes of 1,760 to 1,660 feet (536 to 506 m). (See figure 19). Wells tapping the Marday range in depth from 120 to 297 feet (37 to 91 m).

Water levels in the Marday aquifer range at altitudes of 1,820 to 1,740 feet (555 to 530 m). The highest water levels in the aquifer (indicating proximity to recharge areas) are in wells near Roy and Buffalo Lakes. This could indicate that recharge to the Marday may be coming from the Coteau-lakes aquifer in these areas.

The major cations and anions in the 14 samples of water collected from the Marday aquifer were calcium and sulfate except for one analysis that was calcium and bicarbonate. The specific conductance and hardness are lowest where the Marday aquifer underlies the Coteau-lakes aquifer (table 9).

Eden Aquifer

The Eden aquifer is a buried outwash deposit of sand and gravel in the southeastern part of the County (fig. 32). It underlies about 80 square miles (207 km^2) in Marshall County and extends into Day County. Water in the aquifer occurs under artesian conditions and water levels range from flowing to 132 feet (40 m) below land surface.

The thickness of the aquifer determined from six test holes ranged from 6 to 52 feet (2 to 16 m).

In general, the aquifer occurs at altitudes of 1,620 to 1,550 feet (494 to 472 m) and wells penetrating it range from 195 to 287 feet (59 to 87 m) deep.

The water-surface altitude was from 1,785 to 1,698 feet (544 to 518 m). Well 125N57W33AAA flows at a land surface altitude of 1,755 feet (535 m).

Well 125N55W7CDD, tapping the uppermost part of the Eden aquifer, and well 125N55W5CDB, tapping the lower part of the Marday aquifer, have water surfaces at an altitude of 1,785 feet (544 m). This same altitude of water surfaces of the two aquifers may mean that, in this area, the two aquifers are hydraulically connected through very permeable sandy till or through interconnected sand lenses. However, water levels in wells in the western part of the Eden aquifer are below those in the western part of the Marday aquifer.

Recharge to the Eden aquifer may be from percolation through overlying till and from the Marday aquifer where the till layer between these aquifers thins or becomes permeable.

The major cations and anions in water from the Eden aquifer are calcium and sulfate (table 3). Hardness ranges from 550 to 960 mg/l and specific

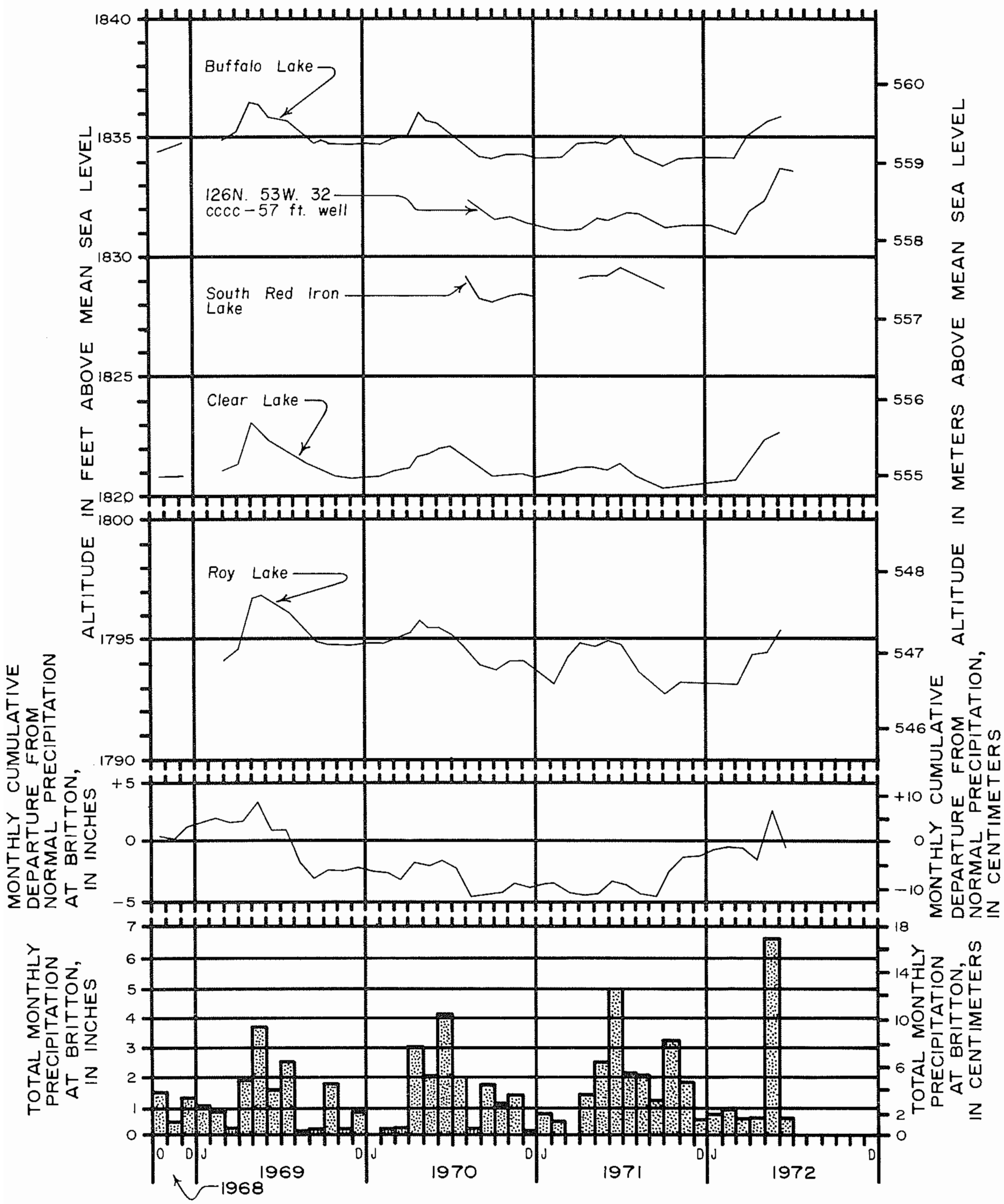

Figure 29. Graphs showing water levels in a well, lake levels in the Coteau-lakes aquifer, and precipitation at Britton.

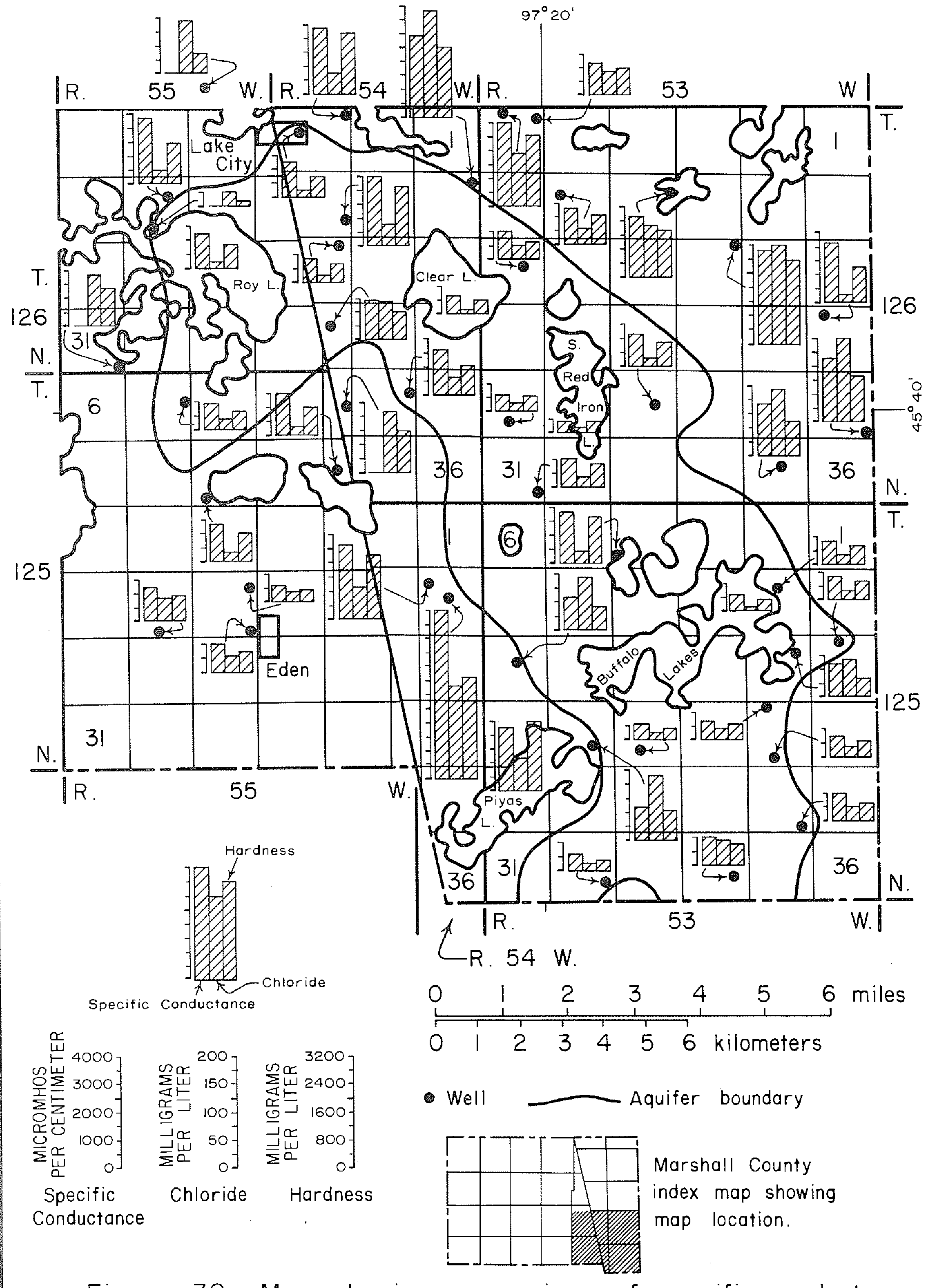

Figure 30. Map showing comparison of specific conductance, chloride concentration, and hardness of water in the Coteau–lakes aquifer with water in the surrounding area.

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Table 8. Chemical Analyses of Water from the Coteau-lakes Aquifer and Surrounding Shallow Ground Water
(Determined in the field)

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
125N53W2CBC2	18	3,000	220	1,600
125N53W4CCA	17	1,900	22	1,300
125N53W11BAB	25	920	15	560
125N53W13BAB	12	740	15	440
125N53W14ABAC	17	1,200	68	530
125N53W18CAA	20	1,300	98	650
125N53W20DBB	21	1,350	120	870
125N53W21CDA	65	590	8	360
125N53W23BACC	17	740	22	430
125N53W23CDB	23	750	15	440
125N53W26DDC	30	910	22	510
125N53W32DDBB	23	600	8	340
125N53W34DAD	46	1,130	45	680
125N54W12BBC	78	2,750	53	1,800
125N54W12BDDB	60	5,900	180	2,900
125N55W5ADD	50	960	15	580
125N55W9CCD	92	1,450	15	820
125N55W11CBD	37	1,500	15	800
125N55W20DCC	35	1,300	45	740
125N55W21AAD	83	610	15	310
125N55W21DDD	30	1,120	30	650
125N55W29ABB	80	3,000	15	2,400
126N53W6ADA	68	1,170	38	700
126N53W6BBC	35	3,000	91	2,000
126N53W8BCC	50	1,300	23	790
126N53W9ADB	52	2,200	91	1,300
126N53W15AAA	43	3,500	200	2,400
126N53W18DBB	60	950	23	500
126N53W25DDD	29	2,300	150	1,400

Table 8 -- continued.

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
126N53W28DBB	66	1,200	15	770
126N53W30CDC	17	580	15	410
126N53W31DDD	35	1,090	15	670
126N53W35ACC	23	1,900	120	1,000
126N54W3AAD	75	2,400	38	1,800
126N54W3CBCB	75	1,200	15	550
126N54W10DDB	90	2,600	36	1,700
126N54W12AAC	28	3,000	220	1,900
126N54W15ABD	40	1,000	15	580
126N54W22ACC	19	1,450	68	860
126N54W26ADD	55	1,590	30	840
126N54W27DBB	25	---------	110	1,200
126N55W9CBD	47	---------	98	630
126N55W20CDCA	63	2,460	23	1,200
126N55W20CDD	68	---------	23	86
126N55W31DDD	40	---------	91	1,000

conductance ranges from 860 to 1,600 µmhos/cm (table 10).

Roslyn Aquifer

The Roslyn aquifer (fig. 33) is a buried outwash deposit of sand and gravel that probably underlies most of the coteau except for a small area in the southeast corner of the County. It underlies about 400 square miles (1,036 km^2) of Marshall County and extends into Roberts and Day Counties. Water occurs under artesian or water-table conditions. Water levels in wells range from 156 to 350 feet (48 to 107 m) below land surface. The aquifer discharges some water through springs on the sides of the coteau.

The known thickness of the aquifer ranges from 3 to 50 feet (1 to 15 m).

In general, the Roslyn aquifer occurs at altitudes of about 1,530 to 1,400 feet (466 to 427 m). Wells tapping the aquifer range from 176 to 464 feet (54 to 141 m) deep except on the sides of the coteau where the outwash deposit crops out at land surface.

The altitude of the water surface in the Roslyn aquifer ranges from 1,700 to 1,434 feet (518 to 437 m).

Artesian conditions were found in only one small area in the vicinity of 126N56W1DDDD. Water-table conditions prevailed elsewhere.

Recharge to the Roslyn aquifer is from percolation through overlying drift, from the Eden aquifer where the till layer between these aquifers thins or becomes permeable, and from the Eden aquifer where sand lenses connect the two aquifers. Precipitation and surface runoff percolate to the aquifer where it is exposed at land surface (mostly on the sides of the coteau); this water quickly discharges from the aquifer, however.

Natural discharge is by subsurface outflow into Day and Robert Counties, by evapotranspiration, and by discharge of springs on the sides of the coteau. Throughout much of its extent the Roslyn aquifer is a basal glacial deposit that overlies shale except where the shale is incised by a pre-glacial drainage channel.

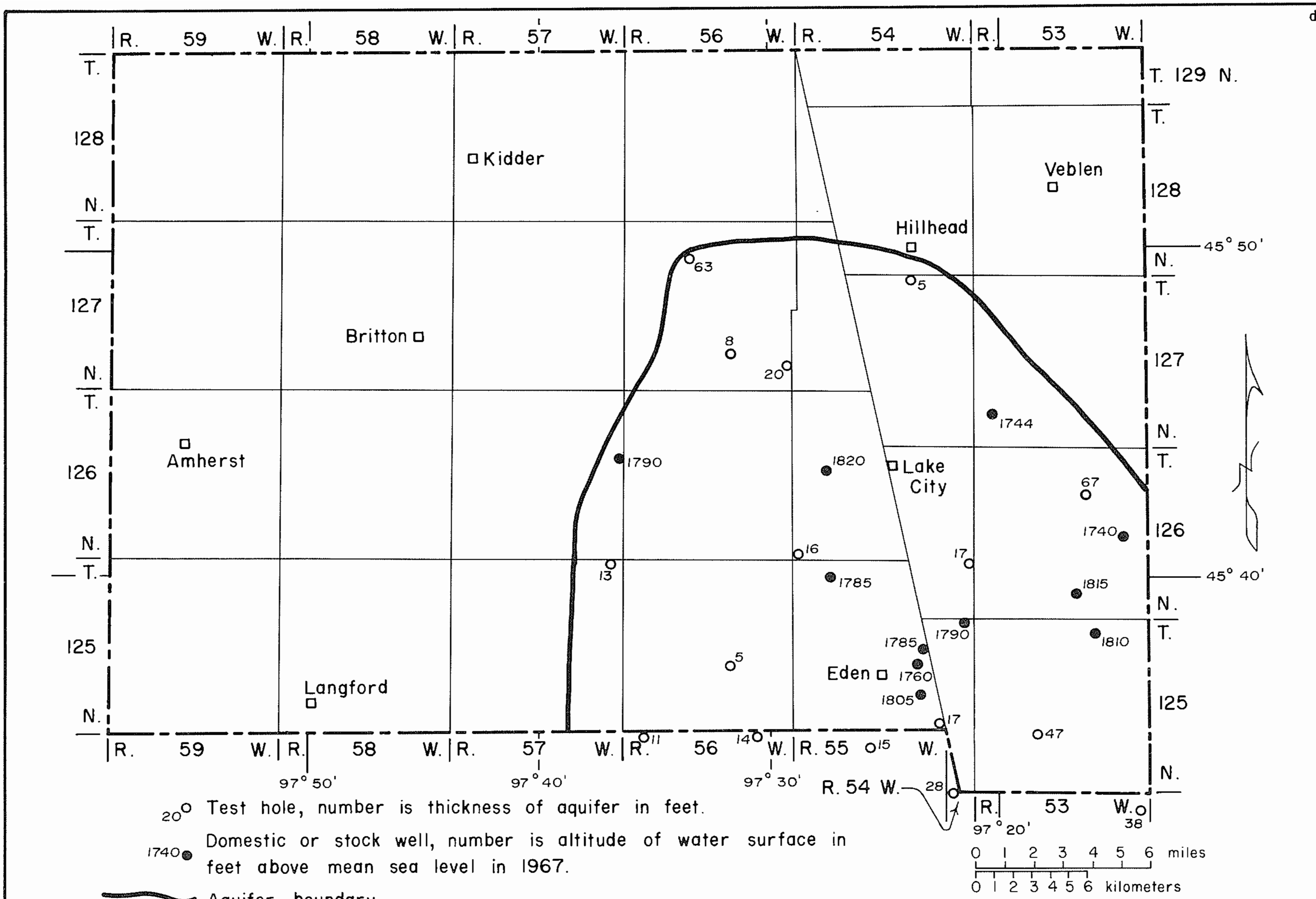

Figure 31. Map showing areal extent, thickness, and altitude of water surface of the Marday aquifer.

Table 9. Chemical Analyses of Water from the Marday Aquifer
(Determined in the field)

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
125N53W2CBC	120	920	8	530
125N54W1ACB	180	1,120	8	670
125N55W5CDB	155	1,250	23	530
125N55W23ABB	181	1,520	23	930
125N55W23CDC	190	1,400	8	790
125N55W26CDD	180	1,200	23	630
125N56W25CBB	135	1,700	61	890
126N53W24BBA	297	2,100	15	1,400
126N54W36DDDD	180	990	15	600
126N55W17CCD	235	---------	15	560
126N57W13ADD	180	2,200	23	940
127N53W29BCB2	269	1,850	15	1,100
127N53W30CDD	134	2,000	15	1,100

Springs discharge water from the aquifer where shale crops out along the sides of the coteau. Springs are most numerous on the east side of the coteau and in Tps. 127 and 128 N. on the west side.

The predominant constituents of water in the Roslyn aquifer are calcium and sulfate (tables 3 and 11). One well, 125N57W10BBC, has water predominant in sodium, bicarbonate, and sulfate. Other wells in the same area, some finished in the till and some finished in the Pierre Shale, had similar type water. Wells finished in till overlying the rest of the Roslyn aquifer had water with major constituents of calcium sulfate or calcium bicarbonate.

Hardness ranges from 210 to 870 mg/l and specific conductance ranges from 1,210 to 1,850 µmhos/cm.

Aquifers in the Bedrock

Pierre Shale Aquifer

Ground water moves downward through overlying unconsolidated material into the fractures, sand lenses, and other permeable zones in the Pierre Shale. These permeable zones generally are concentrated in the top 50 to 75 feet (15 to 23 m) of shale.

Wells are completed in Pierre Shale in the southwestern part of the County near Langford where overlying unconsolidated deposits are missing, are of insufficient thickness, or do not contain ground water in adequate quantity to supply a well. Some additional wells completed in shale are along the western side of the coteau in Tps. 125 and 126 N. Yields from wells in shale range from 1 to 5 gpm (0.06 to 0.3 l/s).

The major cations and anions in water from the Pierre Shale aquifer are sodium and sulfate. Shallow wells (less than 50 feet or 15 m deep) and deep wells alike (over 400 feet or 122 m deep) yield this type of water. Hardness ranges from 75 to 880 mg/l and specific conductance ranges from 2,200 to 3,100 µmhos/cm. Water in the deep wells had chloride concentrations of from 280 to 420 mg/l, whereas water from the shallow wells commonly contained less than 100 mg/l.

Water from the Pierre Shale is not suitable for irrigation and generally is of poor quality.

Dakota Aquifer

The Dakota aquifer consists of sandstone interbedded with shale which underlies all Marshall County at depths ranging from 900 feet (274 m) beneath the low-lying areas in the western and

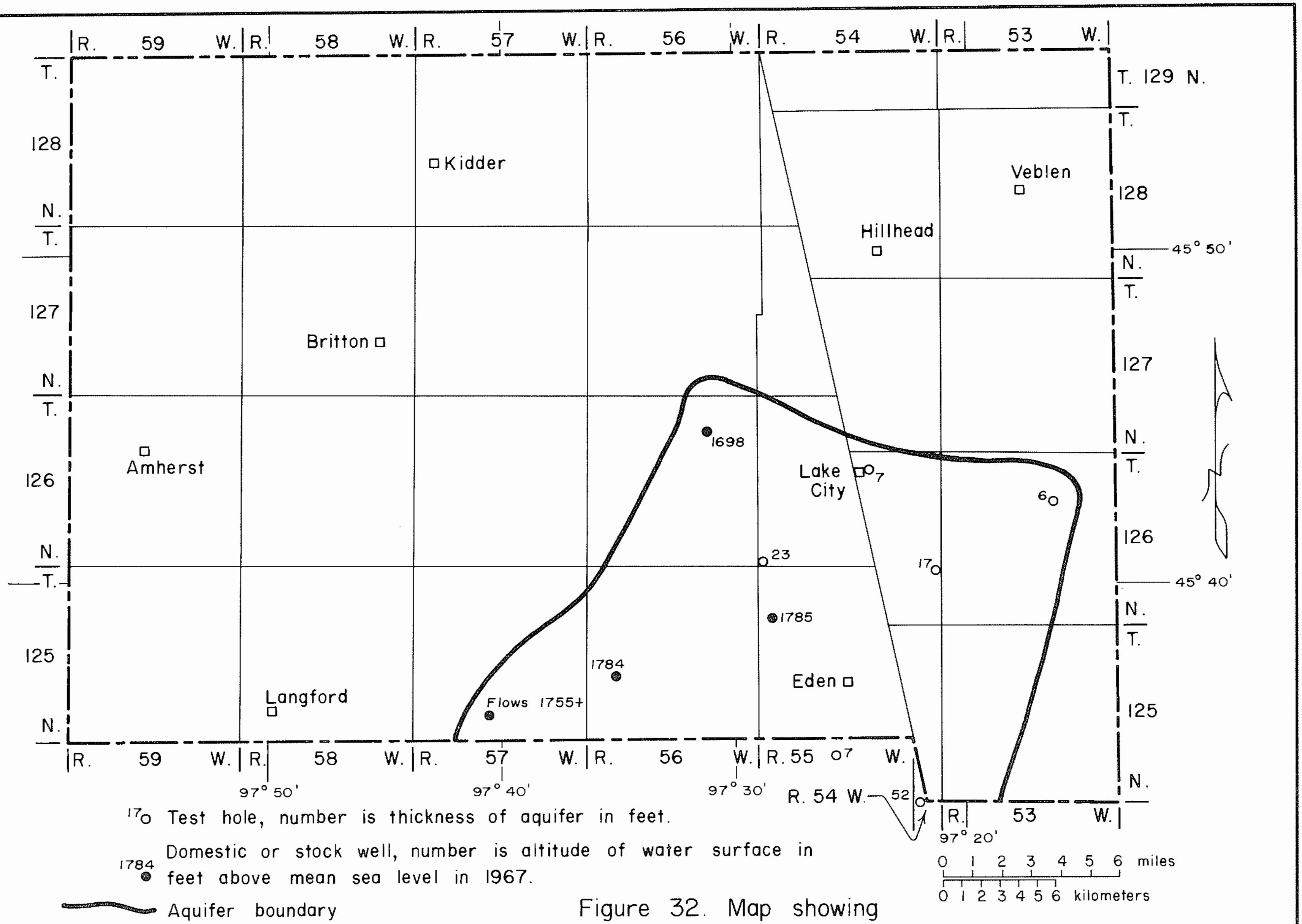

Figure 32. Map showing areal extent, thickness, and approximate altitude of water surface of the Eden aquifer.

Table 10. Chemical Analyses of Water from the Eden Aquifer

(Determined in the field)

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
125N55W7CDD	189	1,300	15	790
125N55W31AABC	269	1,500	23	640
125N56W14ACC	260	1,300	61	820
125N56W16CCCC	287	1,600	30	700
125N56W20ABD	245	1,600	61	750
125N56W20CCC	200	1,590	15	860
125N56W28CAD	276	1,280	61	630
125N56W31CCC	242	1,540	23	680
126N54W22DBB	195	1,400	15	960
126N56W11BBC	232	860	15	550
127N56W35CCB	250	---------	39	600

northeastern parts to 1,500 feet (457 m) below the high areas of the coteau. Water is under artesian conditions and in low-lying areas many wells flow. Yields of as much as 200 gpm (13 l/s) may be obtained from properly constructed wells.

Thickness of the Dakota aquifer ranges from 100 to 250 feet (30 to 76 m) depending on the topography of the underlying Precambrian surface. The sandstone is thinner, is finer grained, and is of lower permeability where it overlies topographic highs on the Precambrian surface.

Figure 34 shows the approximate altitude of the top of the Dakota aquifer, which, based on available information, is generally below 500 feet (152 m). The top of the well screen is usually placed at the top of the Dakota aquifer.

The source of recharge to the Dakota aquifer is a matter of controversy. Some geologists and hydrologists believe that the Dakota aquifer is receiving most of its recharge by upward leakage from underlying aquifers in central South Dakota. Other investigators favor downward leakage or other locations for recharge. Two of the more favored areas of recharge are the Black Hills and the Rocky Mountains. Within Marshall County, however, no other aquifer is known or believed to recharge the Dakota.

Prior to development, movement of water in the Dakota aquifer was from west to east, so that most subsurface inflow (recharge) would have been from the direction of Brown County. At that time the artesian water level was as high as 1,650 feet (503 m) above sea level at the Brown County line (Darton, 1909). Development of the aquifer brought about a large and rapid drop in artesian pressure that completely altered the pattern of water movement. Thus, at present, most subsurface inflow to the Dakota in Marshall County is from the east (probably Roberts County), with lesser amounts from Brown County and from North Dakota (fig. 35).

The drop in artesian pressure in the last 80 years may be as much as 350 feet (107 m). At Langford, for example, the artesian water level dropped from an altitude of 1,480 to 1,310 feet (451 to 399 m) since 1902; at Britton the drop was 260 feet (79 m), from 1,580 to 1,320 feet (482 to 402 m), in the same period. The rate of decline was very rapid at first (1890's and early 1900's) but has decreased markedly in recent years.

Observation well records indicate that the decline of water levels in wells tapping the Dakota aquifer in Marshall County has slowed (fig. 36). The slowing decline of artesian head in the Dakota aquifer is attributed to the decreased withdrawal of water; however, an increase in withdrawal would cause further lowering of water levels in wells. Decrease in withdrawal will cause water levels to rise, as can be seen in the graph for the Britton well shown in figure 36. In 1970 Britton changed its source of supply from the Dakota to surface water from White Lake.

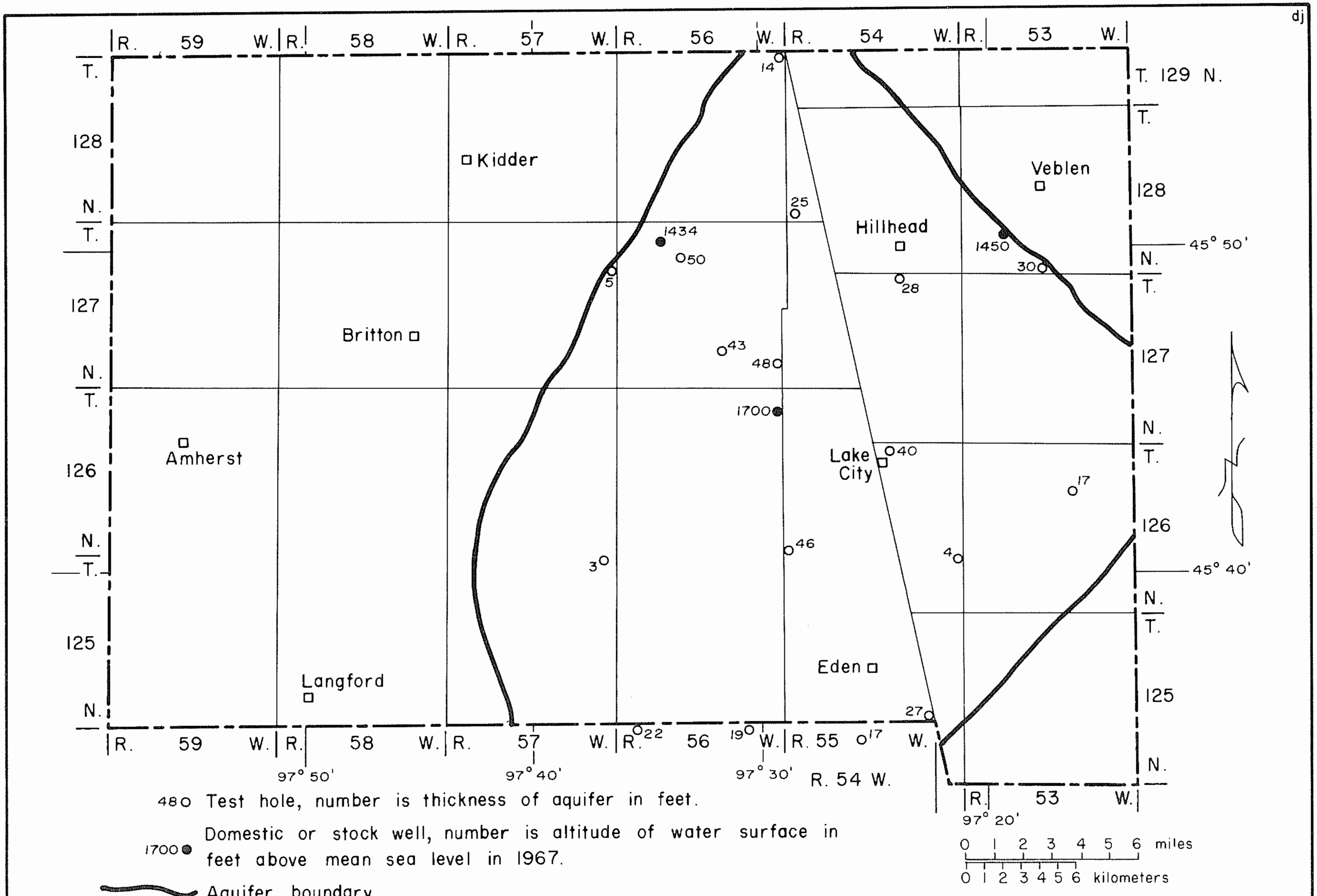

Figure 33. Map showing areal extent, thickness, and altitude of water surface of the Roslyn aquifer.

Table 11. Chemical Analyses of Water from the Roslyn Aquifer
(Determined in the field)

Location	Depth of well (feet)	Specific conductance (micromhos/cm at 25°C)	Chloride (mg/l)	Hardness as $CaCO_3$ (mg/l)
125N55W21BBD	464	1,530	23	670
125N55W23DBC	408	1,450	15	650
125N57W10BBC	200	---------	15	290
126N56W1DDD	416	1,300	15	510
127N56W5DCD	176	1,500	15	1,100
127N56W8DCA	285	1,350	15	630
127N56W34BDCA	420	1,550	15	670
128N53W29DCB	Veblen Spring	---------	38	910

In the 2 year period after pumping from the Dakota was discontinued the water level rose more than 20 feet (6 m).

Discharge from the Dakota is mostly through the 225 known municipal, domestic, and stock wells in Marshall County or by subsurface outflow to adjacent areas.

Water from the Dakota aquifer is a sodium sulfate type in the western part of the County and a sodium chloride type in the northeastern part. In the western part of the County specific conductance ranged from 3,480 to 4,050 μmhos/cm and hardness ranged from 48 to 150 mg/l. Chloride concentration ranged from 210 to 400 mg/l, and fluoride concentration ranged from 2.8 to 9.3 mg/l. In the northeastern part of the County water from two wells showed specific conductances of 6,900 and 9,770 μmhos/cm, and chloride concentration of 1,300 and 2,600 mg/l. Water from only one well was tested for fluoride concentration and hardness, and the values were 0.9 mg/l and 18 mg/l, respectively.

Water from the Dakota aquifer is not suitable for irrigation and is of very poor quality for most uses.

Water Use

Surface water in Marshall County is used mostly for recreation. The 40,000 acres (16,190 ha) of lakes, ponds, potholes, and marshes provide water for stock and wildlife and are one of North America's major waterfowl breeding areas.

About 25 percent of the water used in Marshall County in 1970 was from the six main glacial aquifers. Almost all the water was used for domestic and stock needs. One well, in the Eden aquifer, supplied water for the town of Eden.

The Dakota aquifer yielded about 20 percent of the water used in 1970. The amount used was about 100 million gallons (378 million l) for domestic and stock needs and for the towns of Langford, Amherst, Britton, and Kidder. However, about 355 million gallons (1.34 billion l) of water was discharged, mostly by flowing wells (table 12). Thus, about 255 million gallons (965 million l) of water discharged from the aquifer was not used.

Water use in Marshall County was estimated to be 408 million gallons (1.5 billion l) in 1950, 411 million gallons (1.6 billion l) in 1960, and 505 million gallons (1.9 billion l) in 1970.

Future Development

Surface water from lakes containing water of suitable quality could be used for irrigation; however, consideration should be given to the amount of lake-leveling lowering by withdrawal. For example, withdrawal of about 12 inches (30 cm) of water from Buffalo, Clear, and Roy Lakes to irrigate 160 acres (65 ha) during the growing season would lower the level of those lakes by approximately 1 inch.

The James, Veblen, and Coteau-lakes aquifers have the best potential for development in Marshall County. The present rate of withdrawal produces no lasting changes in their water levels.

More detailed information about areal extent, thickness, and potential recharge rates about the

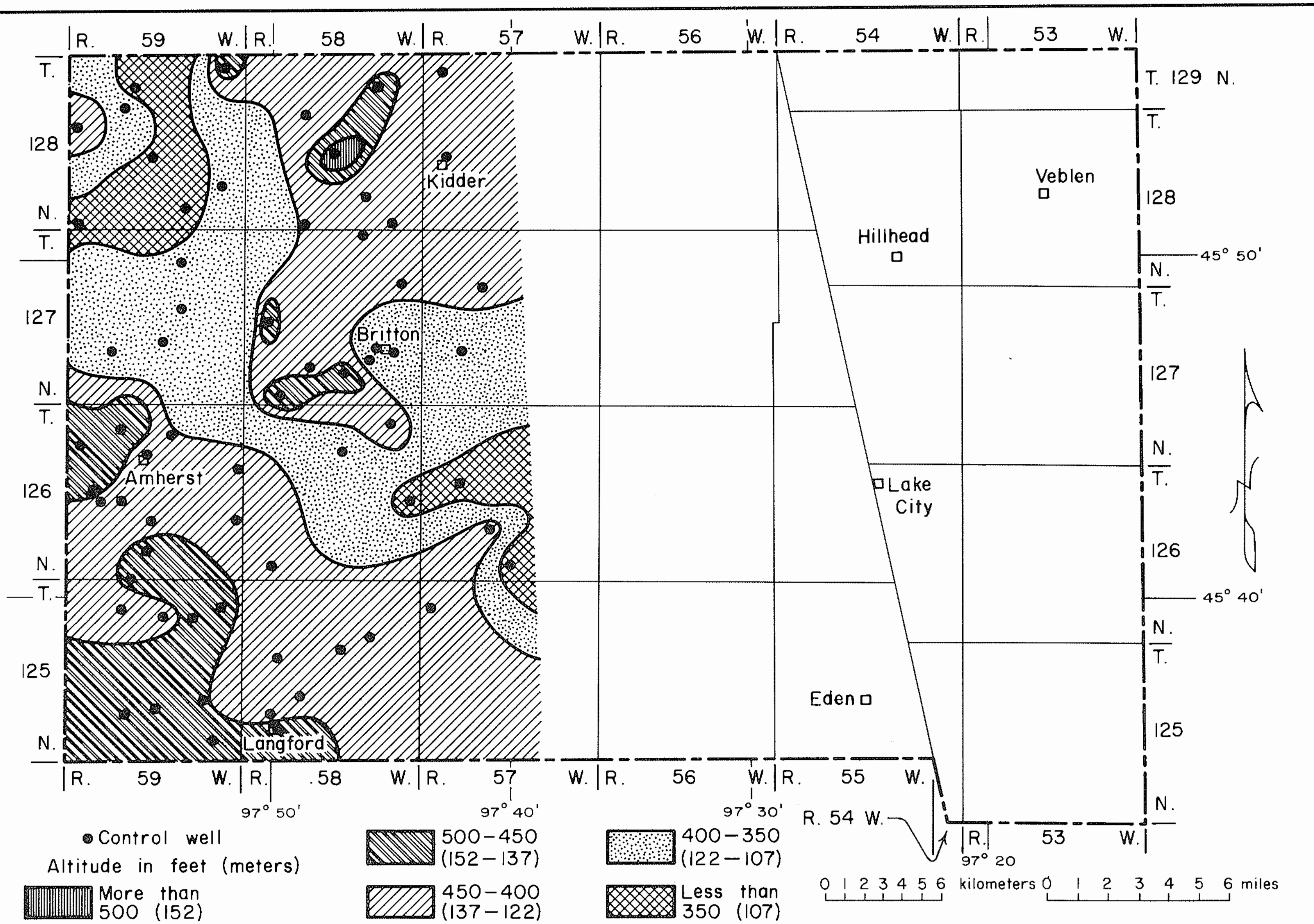

Figure 34. Map showing approximate altitude at the top of the sand in the Dakota aquifer. (based on the common practice of placing the well screen at the top of the aquifer)

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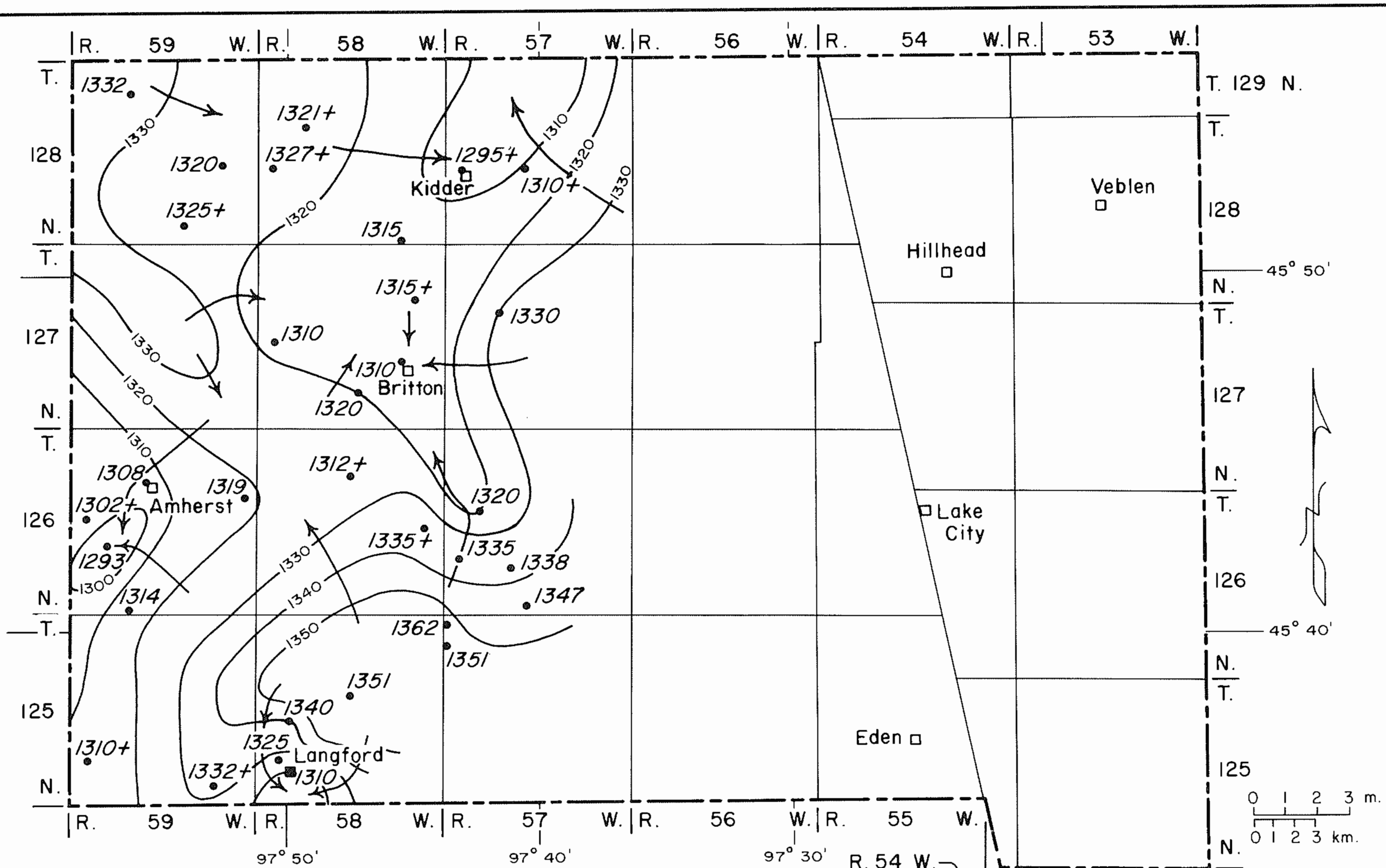

1325+ Well, number is altitude of water surface in feet above mean sea level. A plus sign (+) means water surface is higher than shown.

1330 Water level contour. Shows altitude of water surface. Cont. int.=10 ft. (3.0 m.). Datum is mean sea level.

Direction of water movement.

Figure 35. Map showing approximate altitude of the water surface and direction of ground-water movement in the Dakota aquifer, from 1962 to 1969.

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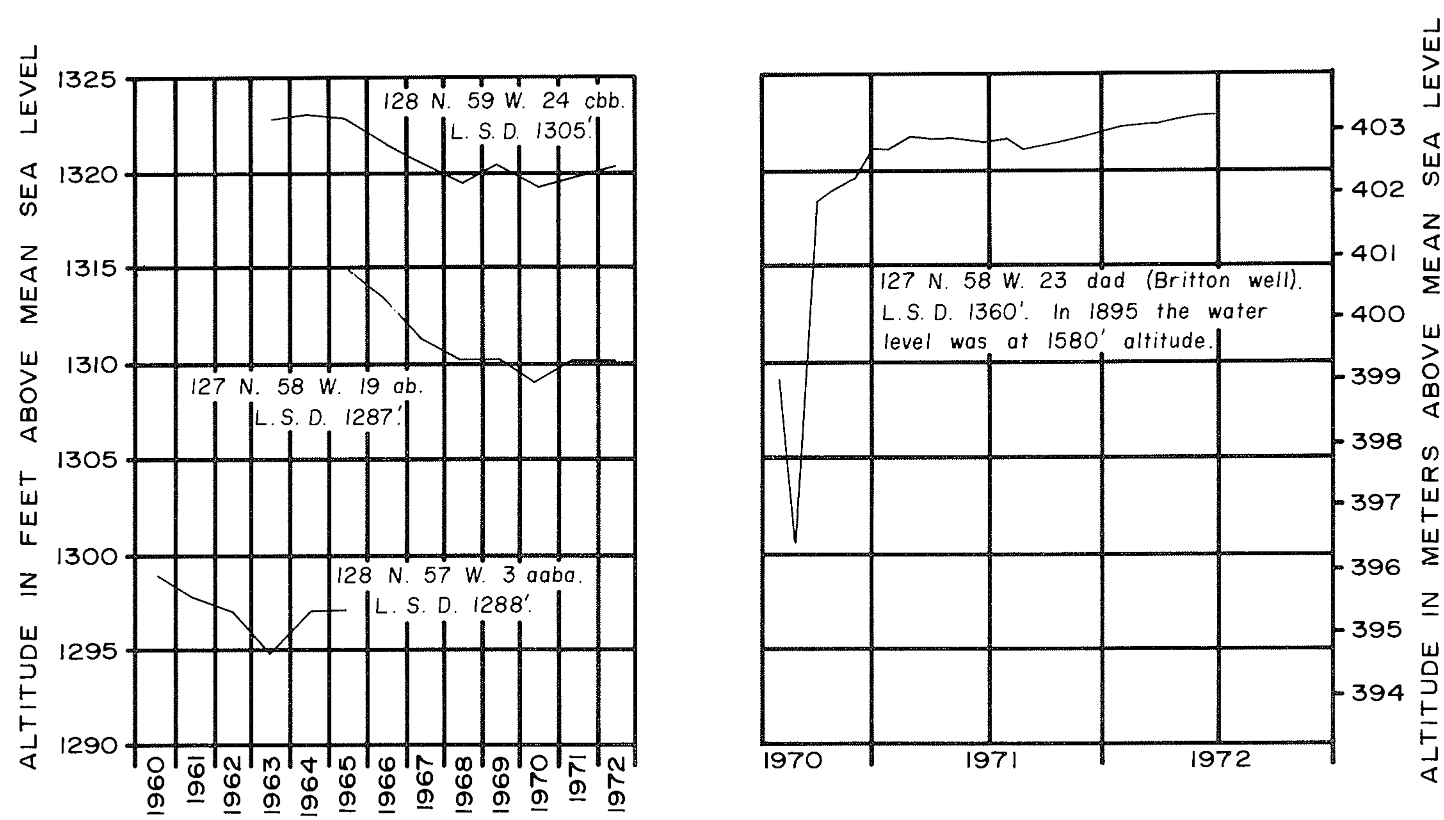

Figure 36. Graphs showing water levels in the Dakota aquifer.

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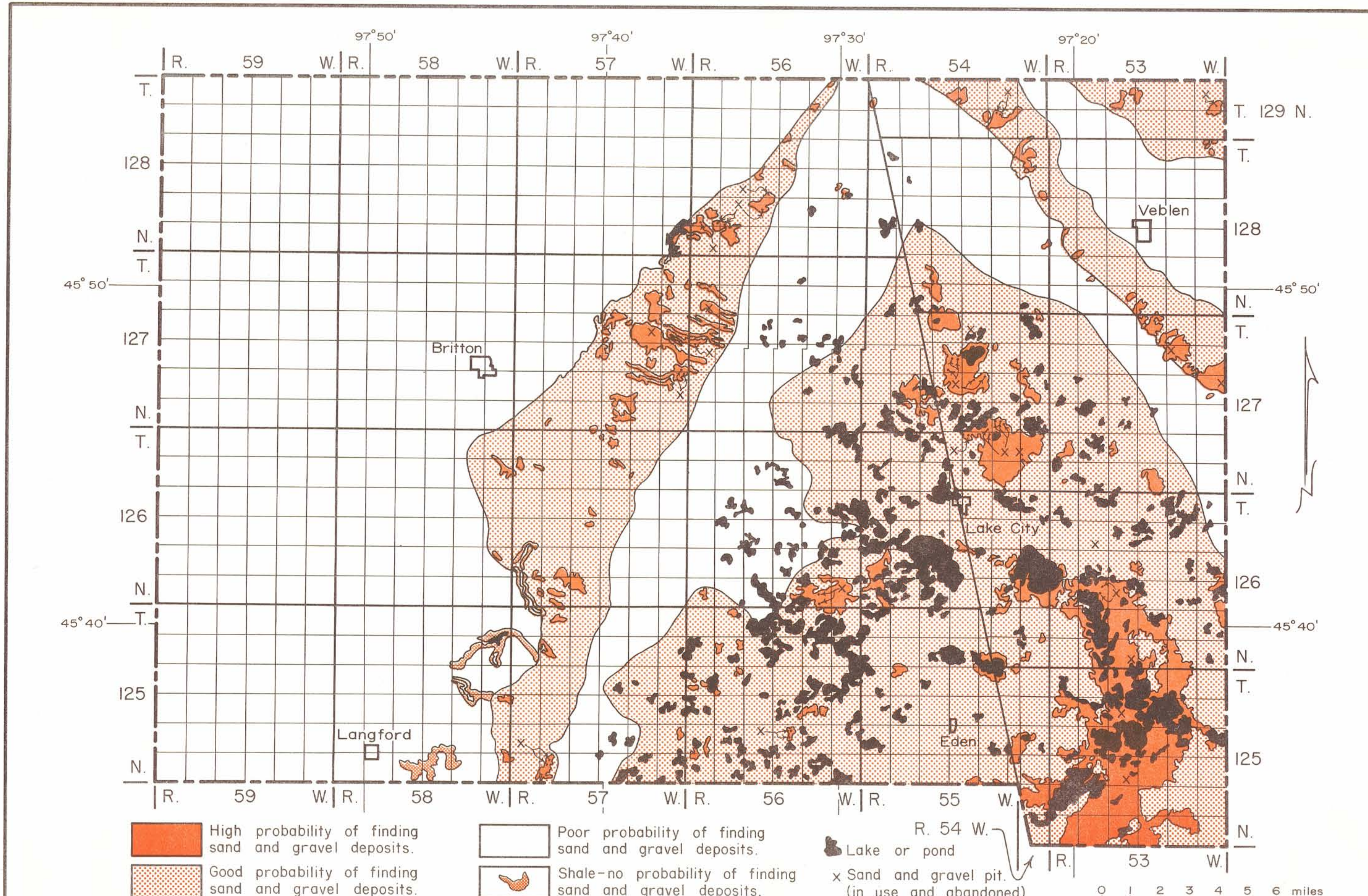

Figure 37. Map showing probability of sand and gravel occurrence.

Table 12. Water Use in Marshall County in 1970

Source	Area Underlain		Number of wells	Amount Withdrawn	
	Square miles	Percent of total		Million gallons	Percent of total
James aquifer	220	25	50	44	9
Veblen aquifer	24	3	24	21	4
Coteau-lakes aquifer	50	6	28	25	5
Marday aquifer	290	33	15	13	3
Eden aquifer	80	9	14	12	2
Roslyn aquifer	400	45	9	8	2
Dakota aquifer	888	100	225	355[1]	20[2]
Till, shale, minor aquifers, White Lake, and dugouts				282	55
Total				505[2]	100

[1] Amount removed from aquifer includes unused flow from flowing wells. An estimated 100 million gallons was used.

[2] Percentage or amount based on used portion.

Marday, Eden, and Roslyn aquifers would aid in planning future major developments.

MINERAL RESOURCES

Non-Metallic

Sand and Gravel

Figure 37 shows the probability of occurrence of sand and gravel deposits, and the locations of gravel pits. The map does not show the quality of the sand or gravel, and should be used only as a guide to further exploration of sand and gravel resources. The development of any specific site would depend upon material specifications for the desired use.

Oil and Gas

No tests have been made for oil or gas in Marshall County; however, several of the deep water wells in the western part of the County have penetrated the entire sedimentary sequence and no trace oil or gas was found.

Metallic

No metallic mineral deposits have been found in Marshall County.

To aid in the search for mineral deposits, a reconnaissance magnetometer survey has been made of the entire State. The magnetometer is an instrument used to measure changes in the earth's magnetic field; such changes frequently are caused by certain kinds of mineral deposits. A map showing residual anomalies (deviations from the "normal" magnetic field) is shown in figure 38. Major anomalies were found in the Langford and Veblen areas. The Langford anomaly had an intensity of 7,272 gammas in the SW¼SE¼ of sec. 12, T. 125 N., R. 59 W. A test hole at this location penetrated Precambrian rocks at a depth of 902 feet (275 m). The Precambrian rock samples recovered contained larger than normal amounts of magnetic minerals.

SUMMARY

About 900 feet (274 m) of Cretaceous rocks overlie the Precambrian basement in Marshall County. The Precambrian surface configuration consists of peaks or granite domes and gulches. Except for the Dakota Formation, most of the Cretaceous rocks are shale that locally contains thin lenses of silt, sand, or limestone. The Dakota Formation which overlies the Precambrian, consists of sandstone and interbedded shale and siltstone. The uppermost bedrock deposit is the Pierre Shale except in the northeastern and north-central parts of the County where it has been removed by erosion that has exposed the Niobrara Formation.

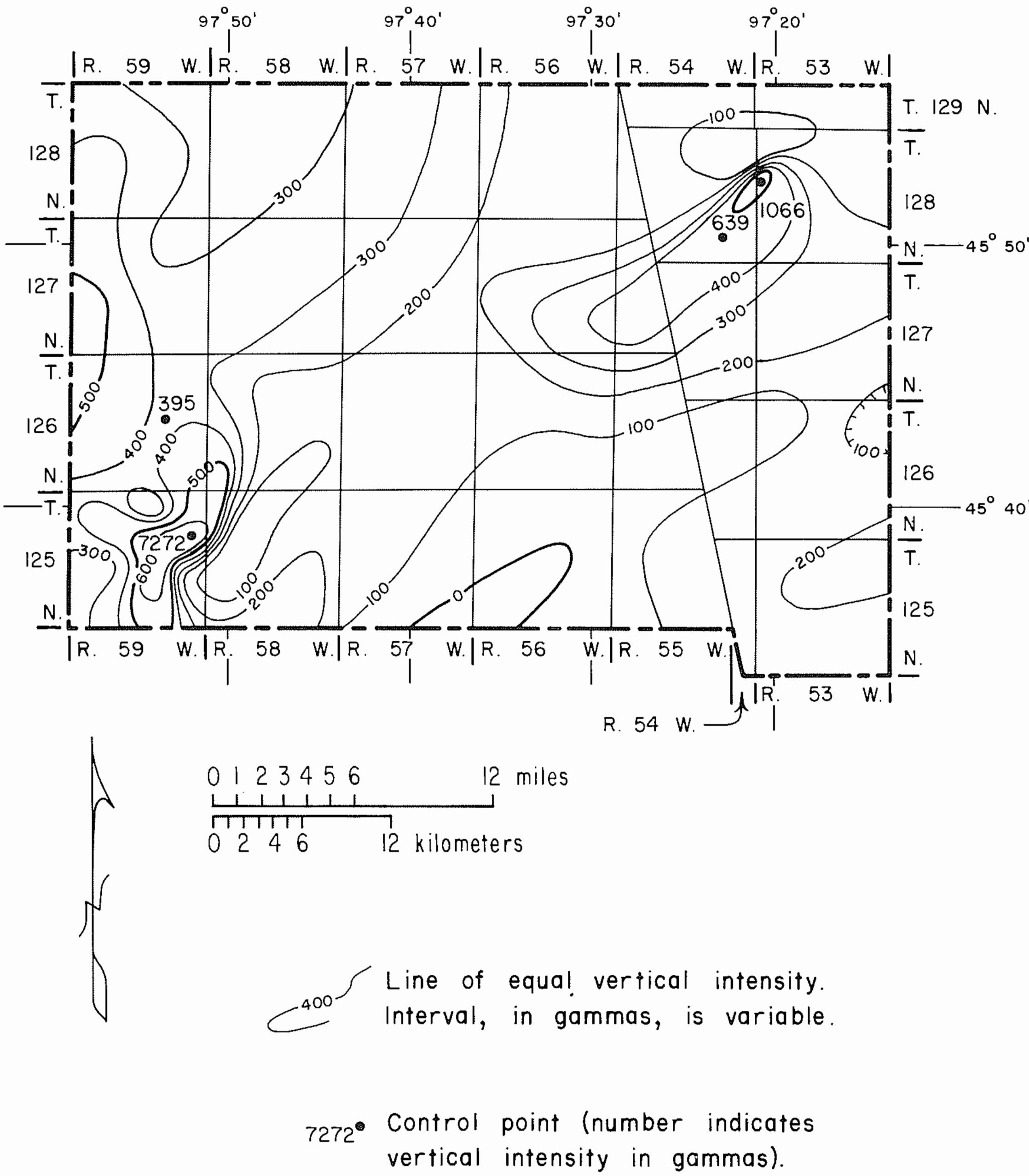

Figure 38. Magnetometer map of Marshall County. (after Petsch, 1967).

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Pleistocene glacial and lacustrine deposits of late Wisconsin age and Holocene sediments make up the surficial deposits. Glacial deposits having a known thickness of 805 feet (245 m) overlie sedimentary rocks of Cretaceous age. Evidence suggests that the late Wisconsin ice margin halted four times during the period of deglaciation and caused major reshaping of the topography and drainage.

The glacial material on what is now called the Coteau des Prairies consists mostly of stagnation moraine. This is evidenced by areas of collapsed outwash and the presence of ice-walled lake plains and collapsed lake plains.

To the west of the coteau, lacustrine sediments were deposited in a large lake called Lake Dakota.

In Marshall County a large end moraine extends along the margins of the coteau, and remnants of two end moraines are found in the central part of the coteau. The large horseshoe-shaped Oaks moraine extends across the Lake Dakota plain.

Surface water consists of many small intermittent streams and numerous marshes, ponds, and lakes. Streamflow takes place in spring from snowmelt and following periods of heavy precipitation; most of the year, however, streams are dry. The streams in Marshall County originate on the coteau. Seven percent of the County is covered by water in marshes, ponds, and lakes. Many small perched marshes, ponds, and lakes occur on the coteau in the clayey ground and on end moraines. Most of the larger surface-water bodies are hydraulically connected to aquifers.

Glacial deposits of sorted sand and gravel are the important water-bearing rocks in Marshall County. Of the six aquifers in drift, the James, Veblen, and Coteau-lakes aquifers can provide yields of 500 gpm (32 l/s) or more.

The James aquifer underlies 220 square miles (570 km^2) in Marshall County. It ranges in depth from 100 to 190 feet (30 to 58 m) below land surface in low-lying areas to more than 580 feet (177 m) below land surface on the coteau. Water in the aquifer is under artesian pressure and the water surface ranges from 2 to 111 feet (1 to 34 m) below land surface. The aquifer contains an estimated 1½ million acre-feet (2 billion m^3) of water in storage.

Recharge to the James aquifer is from ground-water inflow from Brown County and percolation of precipitation and snowmelt through overlying lake plain sediments and till in Rs. 58 and 59 W.

Discharge from the James aquifer is by subsurface outflow into North Dakota.

Sodium and bicarbonate predominate and hardness ranges from 110 to 260 mg/l where water enters the James aquifer from Brown County in T. 128 N. Where most of the recharge takes place calcium and bicarbonate predominate and hardness is high, 340 to 440 mg/l. In the mixed water east of the main recharge area the major constituents are sodium, calcium, sulfate, and bicarbonate and hardness ranges from 316 to 860 mg/l. Where the aquifer water is mixing with water from the Niobrara Formation, sodium, sulfate, and bicarbonate predominate and hardness ranges from 166 to 265 mg/l. The water in the James aquifer has high salinity hazard and ranges from low to high sodium hazard.

The Veblen aquifer underlies 24 square miles (62 km^2) in the northeast corner of Marshall County. Water in the aquifer occurs in some areas under artesian conditions and in other areas under water-table conditions and water levels range from 50 to 100 feet (15 to 30 m) below land surface. The thickness of the aquifer ranges from 40 to 69 feet (12 to 21 m). Well depths range from 80 to 158 feet (24 to 48 m) below land surface.

Recharge to the Veblen aquifer is from percolation through the overlying till and outwash. Discharge is by subsurface outflow into Roberts County and into North Dakota.

Water from the Veblen aquifer is of two types; the predominant constituents in the western part of the aquifer are calcium, sodium, and sulfate and in the eastern part of the aquifer are calcium, magnesium, and bicarbonate. The water has high salinity hazard and low sodium hazard.

The Coteau-lakes aquifer, in the southeastern corner of the County, underlies about 50 square miles (130 km^2). The aquifer, found near land surface, is hydraulically connected with Buffalo, South Red Iron, North Red Iron, Clear, and Roy Lakes. Water levels range from that in adjacent lakes to 40 feet (12 m) below land surface. Water occurs in some areas under water-table conditions and in other areas under artesian conditions. The thickness of the aquifer varies widely from place to place.

Recharge to the Coteau-lakes aquifer is by direct precipitation, percolation through the till cover, surface runoff into the lakes, and subsurface inflow. Discharge is by evapotranspiration and by subsurface outflow.

Major constituents in water in the Coteau-lakes aquifer are calcium and bicarbonate. The water has medium to high salinity hazard and low sodium hazard.

Three minor aquifers, the Marday, Eden, and

Roslyn, underlie each other in that order in eastern Marshall County.

Major constituents in water from the Marday, Eden, and Roslyn aquifers are calcium and sulfate.

The Marday aquifer underlies about 290 square miles (751 km^2). Well depths range from 120 to 297 feet (37 to 91 m) below land surface. Water in the aquifer occurs under artesian conditions and water levels range from 25 to 260 feet (8 to 79 m) below land surface.

The Eden aquifer underlies 80 square miles (207 km^2). Well depths range from 195 to 287 feet (59 to 87 m) below land surface. Water in the aquifer occurs under artesian conditions and water levels range from flowing to 132 feet (40 m) below land surface.

The Roslyn aquifer underlies 400 square miles (1,036 km^2). Well depths range from 176 to 464 feet (54 to 141 m) below land surface. Water in the aquifer occurs mostly under artesian conditions except for some places where water-table conditions exist. Water levels range from 156 to 350 feet (48 to 107 m) below land surface.

The Dakota aquifer underlies all Marshall County at depths ranging from 900 feet (274 m) below the low-lying areas to 1,500 feet (457 m) below the high areas of the coteau. Water in the aquifer occurs under artesian conditions. In low-lying areas many wells flow. Yields up to 200 gpm (13 l/s) may be obtained from properly constructed wells.

Major constituents in water from the Dakota aquifer are sodium and sulfate in the western part of the County and sodium and chloride in the northeastern part. The water is not suitable for irrigation.

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APPENDIX

Quality of Water

The chemical and bacterial content of water largely determines its acceptability for domestic, agricultural, and industrial uses.

The mineral constituents in the water determines its chemical quality. Rain water contains very few mineral constituents; but as water percolates into the ground, it dissolves minerals from soil and rocks. The amounts and kinds of minerals in water are dependent on the solubility of the rocks encountered. In Marshall County, mineral concentrations usually are less in water from shallow glacial aquifers than in water from deep glacial aquifers. A discussion of some important mineral constituents is given in the following table.

Source and Significance of Dissolved Mineral Constituents and Physical Properties of Natural Water

Property or Constituent	Source or Cause	Significance
Iron (Fe)	Many types of rock and soil. Iron pipes.	More than about 0.3 mg/l may cause red and brown staining of clothing, porcelain, and utensils. Gives water a bitter taste.
Manganese (Mn)	Some rocks and soils.	Same as iron in concentrations of 0.2 mg/l or more.
Calcium (Ca) and magnesium (Mg)	Most rocks and soils, especially limestone, dolomite, and gypsum.	Principal causes for hardness and scale-forming properties of water. Reduces the lathering ability of soap.
Sodium (Na) and potassium (K)	Most rocks and soils.	Imparts a salty or brackish taste when combined with chloride. Large quantities may reduce soil permeability and limit use for irrigation. (See section on Sodium Hazard).
Bicarbonate (HCO_3) and carbonate (CO_3)	Forms when carbon dioxide in water reacts with carbonate rocks. Produced in the soil by plants.	Raises the alkalinity and usually the pH of water. Releases corrosive carbon dioxide gas on heating.
Sulfate (SO_4)	From rocks and soils containing gypsum and anhydrite (Pierre Shale and till in Marshall County.	In water high in calcium and magnesium concentration it causes the formation of scale in boilers. May have a laxative effect and gives water a bitter taste in concentrations of more than 250 mg/l when combined with other ions, notably sodium or magnesium.
Chloride (Cl)	From rocks and soils; connate water, salt deposits, sewage.	Gives water a salty taste when combined with sodium in concentrations of more than 400 mg/l. In large quantities increases the corrosiveness of water.

Fluoride (F)	Some rocks and soils.	Concentrations over 1.5 mg/l may cause mottling of enamel of teeth of children. However, concentrations of about 1.1 mg/l can play a part in the reduction of tooth decay.
Nitrate (NO_3)	Organic matter, sewage, soil, and fertilizer.	An excess of 45 mg/l may cause methemoglobinemia or cyanosis "blue baby" in infants. High concentrations suggest organic pollution from sewage, decayed organic matter, nitrate in the soil, or chemical fertilizer. Because of this, concentrations are characteristic of individual wells and not of any one aquifer.
Dissolved solids (all mineral constituents)	Mineral constituents dissolved from rocks and soils.	Large concentrations unsatisfactory for many purposes, such as human consumption or irrigation uses. See Specific Conductance.
Hardness as $CaCO_3$	Caused mostly by dissolved calcium and magnesium.	Determines the ease with which soap suds are formed. For the purpose of this report the following classification is provided:

	Grains per gallon	*Milligrams per liter*
Soft	*0-3.4*	*0- 60*
Moderately hard	*3.5-7*	*61-120*
Hard	*7.1-10.5*	*121-180*
Very hard	*More than 10.5*	*More than 180*

Percent sodium (% Na)	Obtained by dividing the sodium concentration in milliequivalents per liter (meq/l) by total cation concentration and multiplying by 100.	When percent sodium is over 50 it causes some soils to become less permeable.
Residual Na_2CO_3 (RSC)	The amount in meq/l of HCO_3 and CO_3, in excess of Ca and Mg.	Same as percent sodium. A measure of black alkali hazard. Less than 1.25 meq/l safe for irrigation; 1.25 to 2.5 marginal; more than 2.5, not suited (depending on soil condition).
Sodium-adsorption ratio (SAR)	$SAR = \dfrac{Na^+}{\sqrt{\dfrac{Ca^{++} + Mg^{++}}{2}}}$ (in milliequivalents)	An index used in determining the suitability of water for irrigation.
Specific conductance (micromhos/cm at 25°C)	Mineral constituents in water measured by the capacity of water to conduct an electric current.	A water-classification system for livestock use is given below (South Dakota Agricultural Experiment Station, 1959, p. 10):

		Class / *Specific Conductance* *Excellent* — *0- 999* *Good* — *1,000-3,999* *Satisfactory* — *4,000-6,999* *Unsatisfactory* — *7,000 and over*
Hydrogen ion concentration pH	pH is the negative logarithm of the hydrogen ion concentration.	pH of 7.0 is neutral; above 7 is alkaline; below 7 is acid. Above pH7 water can be incrusting; below pH7 water can be corrosive. However, excessively alkaline waters may also attack metals.

The U.S. Public Health Service (1962) has established standards for drinking water used on common carriers in interstate traffic; and these standards have been adopted by the American Water Works Association as criteria of quality for public supplies. The standards for the mineral constituents are indicated in the following table. The Public Health Service established two types of limits:

(a) Limits which, if exceeded, shall be grounds for rejection of the supply. Substances in this category may have adverse effects on health when present in concentrations above the limit.

(b) Limits which should not be exceeded whenever more suitable supplies are, or can be made, available at reasonable cost. Substances in this category, when present in concentrations above the limit, are either objectionable to an appreciable number of people or exceed the levels required by good water quality control practices.

Chemical Constituents	**Recommended Limits (mg/l)**
Iron (Fe)	*0.3*
Manganese (Mn)	*.05*
Sulfate (SO_4)	*250*
Chloride (Cl)	*250*
Fluoride (F)	*1.5*[1]
Nitrate (NO_3)	*45*
Dissolved solids	*500*

[1] Based on annual average maximum daily air temperature of 58.3°F.

Water used for irrigation should not have a detrimental affect on the productively of the soil. The main water properties that effect soil productivity are the dissolved-solids concentration and the relative proportion of sodium to calcium and magnesium. Relatively small amounts of boron or other constituents can be toxic to certain plants.

The amount of dissolved solids in irrigation water and the soil properties determines the accumulation of salts in the soil. Salinity hazard is the tendency of water to cause an increase of salts in the soil. The specific conductance of the water is used to calculate the salinity hazard.

The relative proportion of sodium to calcium and magnesium in irrigation water can affect soil structure. Calcium and magnesium flocculate the soil, giving it looseness, providing for penetration of air and water, and good tillage properties. Sodium tends to deflocculate soil which produces packing, thus preventing or reducing the movement of air and water. The effect on soil of high concentrations of sodium in irrigation is called the sodium hazard which is determined by the SAR (sodium-adsorption ratio).

The salinity hazard and sodium hazard (U.S. Salinity Laboratory Staff, 1954) of water are shown in figure 17 which is interpreted as follows:

Salinity Hazard

Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used for irrigation if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown, usually without special practices for salinity control.

High-salinity water (C3) cannot be used for irrigation on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and salt-tolerant crops should be selected.

Sodium Hazard

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants, however, may suffer injury as a result of sodium accumulation in plant tissues even when exchangeable sodium values are lower than those causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management--good drainage, high leaching, and organic-matter additions. Soils containing gypsum might not develop harmful levels of exchangeable sodium from such water. Chemical improvements may be required for replacement of exchangeable sodium, except that improvements may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other additivies may make the use of such water feasible.