SOUTH DAKOTA GEOLOGICAL SURVEY
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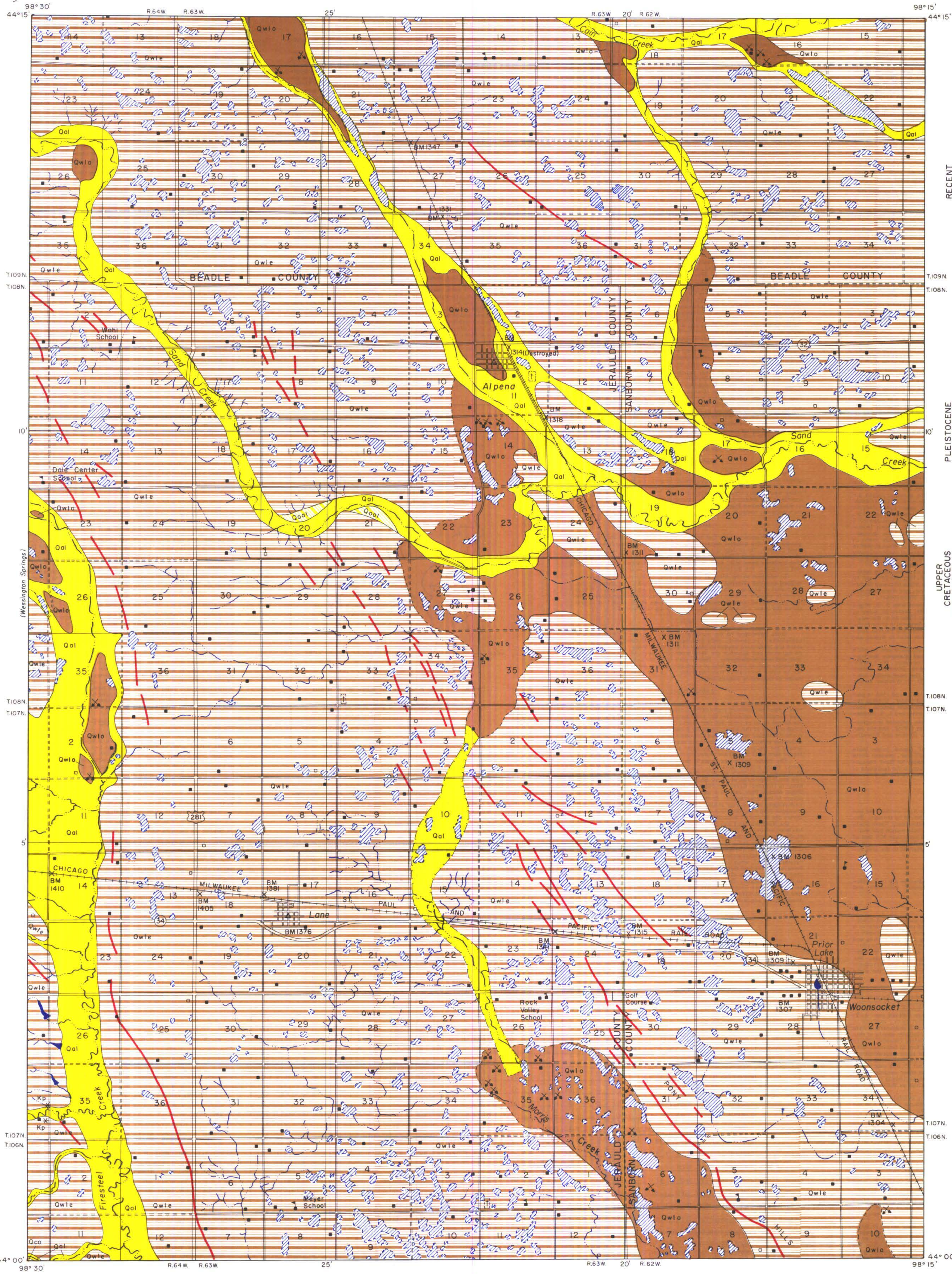
STATE OF SOUTH DAKOTA
NILS BOE, GOVERNOR

GEOLOGY of the WOONSOCKET QUADRANGLE SOUTH DAKOTA



EXPLANATION

QUATERNARY

RECENT

Qal — Alluvium
(Semistratified deposits of sand, silt, and clay, humic, brown to black; in stream flood plains, lakes and ponds; 0-60 feet thick.)

Qco — Colluvium
(Chiefly reworked till; consists of brown to dark-gray clay with rock fragments, partly stratified; forms plain at foot of Coteau; Found only in extreme southwest corner of area; 0-6 feet thick.)

Qoal — Older Alluvium
(Humic sand and gravel, poorly sorted, semistratified, oxidized; occurs as terrace deposits along Sand Creek southwest of Alpena; 0-5 feet thick.)

PLEISTOCENE — LATE — WISCONSIN

Qwlo — Outwash
(Stratified deposits of poorly sorted sand and gravel; may have interbedded lacustrine deposits; 0-90 feet thick.)

Qwle — End Moraine
(Boulder-clay till, olive-brown to olive-gray, calcareous, compact, mostly blocky, contains carbonized wood in places, characterized by rolling to rugged topography.)

UNCONFORMITY

CRETACEOUS — UPPER CRETACEOUS

Kp — Pierre Shale
(Gray to black, fissil to blocky marine shale; crops out in tributary to Firesteel Creek in southwest part of area.)
small outcrop.

Ice-Marginal Channel
Meltwater channel from which sand and gravel has been partly or wholly removed, locally occupied by alluvium.

Major Morainal Crest

Gravel Pit

X BM 1309
Bench Mark
(monument showing exact altitude above sea-level)

Triangulation Station
(monument marking exact geographic location)

House, School, Church

House, School, Church (abandoned)

Cemetery

Intermittent stream

Intermittent lake

Lake

Drainage ditch

Geologic Contact
(dashed where approximately located)

Geology by Fred V. Steece 1959, 1961, 1962

Assisted by Jim D. Hammell, 1959; Richard Brown, 1961; James A. McMeen, 1962

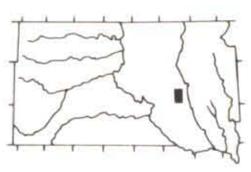
Base adapted from Army Map Service Huron and Mitchell 1° x 2° Topographic maps (scale 1:250,000)

Drafted by Elizabeth H. Garnos

TRUE NORTH — MAGNETIC NORTH — 10°00'
APPROXIMATE MEAN DECLINATION, 1960

Scale 1:62 500

1 ½ 0 1 2 3 4 Miles

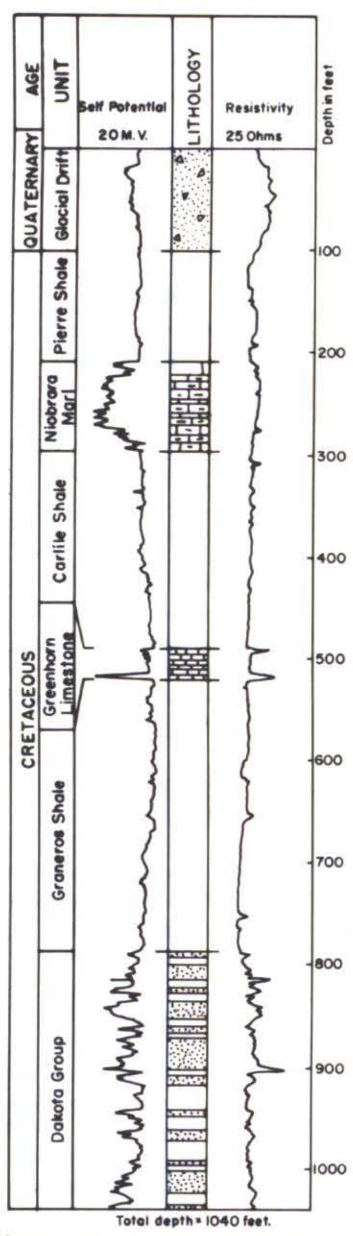


Vermillion, South Dakota
1967

GEOLOGY OF THE WOONSOCKET QUADRANGLE
SOUTH DAKOTA

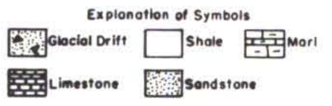
by
Fred V. Steece

Figure 1
Geologic Column of Woonsocket Quadrangle



Total depth = 1040 feet.
(Lithologic and electric logs from Fred Meyer farm well, drilled in 1952; NE, NW, sec. 22, T.109N, R.63W., Beadle County; Elevation = 1340 feet.)

Explanation of Symbols



INTRODUCTION

The Woonsocket quadrangle includes about 215 square miles in Jerauld, Sanborn, and Beadle Counties in east-central South Dakota. The area lies in the James Basin division (Rothrock, 1943) of the Central Lowland physiographic province (Fenneman, 1946).

The topography of the area is characterized by rolling to hummocky morainic deposits, broad sand and gravel plains, and flat-bottomed alluvial valleys. The most conspicuous feature in the area is the Pony Hills moraine that traverses the center of the area from northwest to southeast and is seen as a bold hummocky stony ridge as much as 80 feet in height three miles west of Woonsocket. This moraine lies abreast of a number of smaller ridges with similar trends; most of these ridges dwindle in height toward the northwest to broad swells only about 15 to 20 feet higher than the surrounding terrain.

A less conspicuous series of morainic ridges parallel Firesteel Creek on the east. Generally, these ridges do not exceed about 20 to 30 feet in height. The Woonsocket Outwash Plain that lies partly in the mapped area and extends eastward for several miles, is relatively flat over most of its extent. In the northern end of this sand and gravel plain, however, the surface is gently undulating owing to its construction in contact with glacial ice. Also contributing to the irregular surface is an uneven mantle of wind-blown sand. The smaller sand and gravel plain in the south part of the mapped area, called the Cuthbert Outwash by Rothrock (1946), likewise has a nearly level surface except in the northern part where undulations are present. The valleys of Firesteel and Sand Creeks and several smaller creeks have cut shallow trenches into the glacial drift. The valleys have flat bottoms that are underlain by alluvial deposits. The remainder of the mapped area is a rolling glacial till plain that is typically youthful, and is characterized by numerous closed depressions and adjacent hummocks.

Drainage is controlled by the streams already mentioned, all of which empty eventually into the James River east and southeast of the mapped area.

The maximum relief of the area is about 180 feet from 1,480 feet on the morainic ridges about a mile north of Dale Center School, to about 1,300 feet on the sand plain near Woonsocket.

Woonsocket (population 1035 census of 1960), Alpena (population, 407), and Lane (population, 99) are the only towns in the quadrangle. Woonsocket is the county seat of Sanborn County and is an important shopping and marketing center.

The area is served by north-south U. S. Highway 281, and by east-west State Highway 32 through Alpena, and State Highway 34 through Woonsocket. In addition, all-weather blacktop roads connect Alpena with U. S. Highway 81 four miles to the west, Woonsocket with Mt. Vernon 20 miles to the south, and Woonsocket with Wessington Springs 16 miles to the west. This last road parallels State Highway 34 and in the former site of the highway. Two lines of the Chicago, Milwaukee, St. Paul and Pacific Railroad cross at Woonsocket, providing freight service also to Alpena and Lane.

The climate of the area is sub-humid and is characterized by wide ranges and large daily fluctuations in temperature, and relatively low precipitation. The average annual precipitation at Forestburg, the nearest reporting station, from 1931 to 1955 was 20.31 inches, occurring mainly as rainfall in the spring and early summer months. The mean annual temperature for the same period was 46.4 degrees F. (U. S. Weather Bureau Records).

This study, conducted in the summer of 1960, 1961, and 1962 is part of the State Geological Survey's program of ground-water, mineral resources, and Pleistocene geological investigations in South Dakota. That part of the area in Beadle County was mapped by the writer and L. S. Hedges in 1962 (Hedges, in preparation). This area has been included in regional studies by Todd (1896), Rothrock (1946), and Flint (1955), and the part lying in Sanborn County has been studied in detail (Steece and Howells, 1965).

The work was begun under the direction of Allen F. Agnew, former State Geologist, and was completed under Duncan J. McGregor, present State Geologist. The writer wishes to thank Lynn S. Hedges for field consultation in 1962. The writer expresses his appreciation to the residents of the area, who extended numerous courtesies and permission to enter on their lands.

GEOLOGY

Glacial drift of the Pleistocene Epoch (Great Ice Age) mantles the entire area except in small areas where it has been removed by erosion. Beneath the glacial deposits are Cretaceous marine sedimentary Pierre Shale and Niobrara Marl that make up the bedrock surface. Information from wells and test holes in and around the quadrangle shows more than 900 feet of Cretaceous rocks beneath the glacial drift. No wells in the area penetrate the Precambrian basement rocks, but wells adjacent to the area record its depth and character.

Surficial Deposits

The surficial deposits of the Woonsocket quadrangle are of Pleistocene and Recent ages and include glacial drift, alluvium, colluvium, and glacial lake deposits.

Pleistocene Deposits

Glacial drift includes all the material transported and deposited directly or indirectly by glacial ice. Till is a mixture of rock fragments in a clay-rich matrix, that makes up the bulk of the glacial drift. Outwash is a stratified drift, chiefly sand and gravel resulting from the sorting and accumulation of glacial debris by the washing action of glacial meltwaters. Outwash deposits occur in valleys (valley trains), in broad aprons (outwash plains), and interbedded with till and other glacial materials. The glacial drift in the Woonsocket quadrangle is of early and late Wisconsin ages (Steece, 1964b; Steece and Howells, 1965). However, the early Wisconsin drift is not exposed at the surface.

Late Wisconsin Deposits.--Glacial lake sediments occupy closed depressions on the end moraine and outwash surface locally in the area and consist of light-colored silt, clay and marl. These deposits commonly contain the remains of Mollusks, Charophytes, and Ostracodes, but some of this material is barren of fossils. At one locality in SW¼SE¼ sec. 3, T. 107 N., R. 62 W. light-gray lacustrine marl one foot thick, exposed in a stock-water dugout, contains a rich paleofauna. A radiocarbon date (W-1033, Ives and others, 1964) determined from Mollusk shells at this locality placed the age at 10,060±300 yr. B. P. (Before Present; 1950 is zero year). The fossiliferous layer is overlain by 1½ feet of brownish-gray sandy clay presumably of colluvial origin deposited since approximately 10,000 years ago. Thus at this latitude, South Dakota was being transformed from glacial to post-glacial conditions about 10,000 years ago. Although no dates are available for other lacustrine deposits in the mapped area, it is assumed that the lake sediments contained in surface depressions are approximately of the same age as the dated one, because they all have similar faunas.

The light-colored lacustrine deposits are usually overlain by variable thicknesses of dark accretionary silts and clays that have washed into the depression since the beginning of post-glacial time.

Late Wisconsin outwash deposits underlie the surface of about one-sixth of the mapped area in the east-central and southeast parts. These deposits, chiefly sand with some gravel, generally have a nearly level surface (in contrast to the surrounding uplands) except for small areas where undulating topography exists. The outwash plain from one to four miles south of Alpena exhibits this rolling surface. Likewise the northern part of the Woonsocket and Cuthbert Outwash Plains have uneven surfaces. In places the valley outwash has been dissected by streams, leaving terraces and small islands of outwash material standing above the adjacent stream floodplain. Scattered throughout the Woonsocket Outwash Plain are till islands representing the tops of end moraines, protruding through the sand and gravel. Some of these stand as much as 30 to 40 feet above the surrounding outwash plain. The outwash near these till islands is usually thin. The outwash deposits in the mapped area have a maximum thickness of 90 feet but average about 30 feet. Thickest outwash is in the Woonsocket Outwash Plain and thinnest deposits are beneath terraces and remnants adjacent to valleys.

The outwash deposits in the mapped area owe their origin to meltwater from late Wisconsin ice. Some of the outwash such as that represented by remnants along Firesteel and Sand Creeks was deposited by meltwaters from melting ice north and northwest of the quadrangle. The Woonsocket and Cuthbert outwash deposits were laid down by melting ice within the area; the former when the ice stood at the Pony Hills and associated morainal ridges, and the latter when the ice retreated to a site immediately north of the Woonsocket Outwash Plain.

Test holes in the Cuthbert outwash deposits reveal buried oxidized zones that suggest two periods of deposition for this deposit. No similar weathering zone is known to exist in the Woonsocket outwash deposits. As already mentioned, snail shells in marl overlying the Woonsocket Outwash are 10,060±300 years old. Wood from 10 feet deep in the Cuthbert Outwash at a locality about 7½ miles to the southwest in SW¼SW¼ sec. 8, T. 106 N., R. 62 W. (about half a mile south of the quadrangle) was dated at 12,680±300 years B.P. (Sample W-1757, Dr. Meyer Rubin, U. S. Geological Survey, Washington, D. C.). It is possible that if the Woonsocket Outwash was deposited in two increments like the Cuthbert deposit that the lower part was deposited approximately 12,680 years ago and that the upper part was deposited shortly before 10,060 years ago. The till beneath the Woonsocket Outwash in NE¼ sec. 26, T. 108 N., R. 63 W. is dated at 12,530±350 years B.P. (Sample W-987, Ives and others, 1964).

The greater part of the glacial drift in the quadrangle is till. The surface expression of the till is end moraine of various degrees of development. Excellent end moraine is exhibited in the Pony Hills and the associated ridges to the northwest. The discontinuous ridge lying immediately east of Firesteel Creek is not as well developed as the Pony Hills moraine system, but is still recognizable as end moraine. A third area of end moraine lies in the northeast part of the mapped area immediately north of the Woonsocket Outwash, about two miles northeast of Alpena.

The areas between these morainic ridges are shown on the map also as end moraine even though no large linear ridges occur. There is, however, an alignment of small ponds and hummocks parallel to the trend of the bordering morainic ridges that classifies this land form as end moraine.

Five halts in the late Wisconsin ice retreat are recorded by land forms and deposits in the quadrangle. The first halt is marked by the valley of Firesteel Creek which was originally formed as an ice-marginal channel and by the end moraine east of the creek. From this location the ice margin retreated to the Pony Hills moraine system. The deep smooth-walled valley of Sand Creek upstream from this moraine and the meltwater channel 1½ miles east of Lane were formed by this stillstand of ice. The basal part of the Cuthbert Outwash may have been deposited at this time by meltwaters from the front of the ice adjacent to the plain and through the meltwater channeling into it. When the ice retreated from this halt to its next position in the northern part of the present site of the Woonsocket Outwash Plain, the meltwater channel was abandoned. The ice there built several moraines that were later mostly covered by outwash sand and gravel except for the till islands shown on the map. (See Steece and Howells, 1965, fig. 8). The ice then retreated to a position along the north side of the Woonsocket Outwash marked in part by the low morainic ridge two miles northeast of Alpena, by the eastern two miles of Sand Creek valley (an ice marginal valley) and by the tributary valley northward through Alpena and beyond. This last valley is also an ice marginal valley. Further retreats are marked by Cain Creek and the alluvial valley in the northeastern part of the quadrangle.

Late Wisconsin drift in this area ranges from 0-150 feet in thickness, but the average is probably about 50 feet.

Early Wisconsin Deposits.--Beneath the late Wisconsin glacial deposits lie glacial materials known to be older than late Wisconsin by stratigraphic position and zones of oxidation indicating subaerial weathering. These older deposits have been identified as early Wisconsin (Steece and Howells, 1965; Steece, 1964b), although they are probably not as old as earliest Wisconsin, that is, Altonian, (Frye and Willman, 1960); Farmdale, (Leighton, 1965); Rockian, (Frye, Willman and Black, 1965); and "Early" Wisconsin (Goldthwait, 1958); but they may be the equivalent of Tazewell (Ruhe, 1952). The early Wisconsin materials are mainly outwash sands and gravels, and some till. No glacial deposits older than early Wisconsin are known to occur within the mapped area, and therefore these deposits lie directly on the Cretaceous bedrock. As much as 65 feet of buried outwash and 95 feet of till occur beneath the late Wisconsin deposits in the area. The distribution and stratigraphic relations of these early Wisconsin deposits are shown for Sanborn County (Steece and Howells, 1965) and for southwestern Jerauld County (Steece, 1967). The character of these early Wisconsin deposits is unknown except for drill-hole information in and adjacent to the area; no exposure in the area reveals early Wisconsin drift. Oxidized zones, recognized by sharp changes in color (usually from grays to browns or yellows) of materials penetrated by bore holes at depth, distinguish these deposits as older than late Wisconsin. In the Wessington Springs quadrangle, adjacent to the Woonsocket quadrangle on the west, early Wisconsin deposits are at the surface in the southwestern part of the area (Steece, 1967). Where they are at the surface several lines of evidence strongly support the older age of these deposits. It is probable that the early Wisconsin drift at the surface in western Jerauld County is buried in this quadrangle by the younger late Wisconsin drift. Several test holes show more than one buried oxidized zone in a bore hole. This would suggest that two drifts of early Wisconsin age lie below the surficial late Wisconsin deposits. An alternative explanation as outlined by Steece (1967) suggests the possibility that this lowest older drift is Illinoian in age. More detailed information is needed to assign these deposits a definite age designation.

Recent Colluvium

Colluvium occupies less than 40 acres in the extreme southwestern corner of the quadrangle. The colluvium is part of a broad mantle of this same material found at the base of the Wessington Hills that lie about 3½ miles west of this corner of the quadrangle. The colluvium making up the mantle in the Wessington Springs quadrangle, next adjacent on the west, is mainly reworked Pierre Shale and till (Steece, 1967). The colluvium is dark colored, compact and plastic, and as much as 6 feet thick.

Recent Alluvium

Alluvium underlies the flat bottoms of the main stream valleys in the quadrangle. The alluvial deposits are best developed along Firesteel and Sand Creeks. These deposits range in thickness from 3 to 12 feet and probably average about 5 feet. The alluvium is composed of dark humic clay that contains some silt, sand, and rarely gravel; it is commonly stratified and compact. The surface of the alluvial deposits is level.

In addition to the alluvial deposits mentioned, two small terraces mapped as older alluvium occur in the valley of Sand Creek about 3 miles southwest of Alpena. This material is poorly sorted humic gravel that is probably closely related to the Wisconsin outwash discussed below and may be reworked outwash material. The terraces stand about 5 to 10 feet above the lower alluvial level and are fairly smooth-topped.

Soils

Soils developed on the surficial deposits vary in their agricultural usefulness. In general, soils developed on deposits mapped as end moraine are productive except in stony or undrained areas. Soils developed on outwash and alluvium are less productive because of excessive and poor drainage respectively. Heavy clay soils are developed in hundreds of swales dotting the surface of much of the map-area. These soils cannot be tilled because of standing water, or in the absence of water, because of excessive soluble salts.

Bedrock Deposits

Beneath the glacial drift are sedimentary rocks of Cretaceous age and igneous and sedimentary rocks of Precambrian age. Although no well in the area completely penetrates the sedimentary section, the Cretaceous rocks are known to be at least 940 feet thick. The Precambrian basement in the southern half of the area is probably Sioux Quartzite, and that in the northern half probably igneous rocks that underlie the Sioux (Steece, 1962). The following stratigraphic information is based on wells and test holes in and around the mapped area. The geologic section and electric log of the Fred Meyer farm well (fig. 1) are representative of the rocks in the quadrangle.

The Pierre Shale lies beneath the glacial drift in the western two-thirds of the mapped area (fig. 2). In the remaining third, the Niobrara Marl forms the bedrock surface. The only bedrock outcrops in the area are two small exposures of Pierre Shale on either side of a small valley tributary to Firesteel Creek, in SE¼ sec. 34, T. 107 N., R. 64 W. The Pierre Shale ranges from zero to a maximum of 200 feet thick in the southwest corner of the quadrangle. In the mapped area, the Pierre Shale is light- to dark-gray marine clay shale. In adjacent areas, a marl layer occurs in the upper Pierre and possibly also in the lower part. In addition, bentonite layers are scattered throughout the Pierre.

The Niobrara Marl lies beneath the Pierre Shale except where the latter has been removed in the eastern one-third of the mapped area (fig. 2). The Niobrara is light- to medium-gray calcareous marl occasionally grading into chalk. The term chalk or chalkstone is applied to this formation by well drillers and local residents. The Niobrara is very easily recognized in drill cuttings by its light-gray color and slight speckling. The marl is calcareous, that is, when treated with dilute acid it will effervesce. The Niobrara is about 90 feet thick in the mapped area. The Carlile Shale is dark-gray to black marine clay-shale. In many respects the Carlile is similar to the Pierre Shale. The Carlile does not subcrop in the area, but to the south in southern Sanborn County and northern Davison and Hanson Counties the Carlile directly underlies the glacial drift. In the east half of the quadrangle a sandstone layer, known as the Codell Sandstone Member of the Carlile Shale, occurs near the top of the Carlile Formation. The sandstone is not present in the western half of the quadrangle and is apparently absent from the Fred Meyer farm well locality (fig. 1). The Codell is approximately 30 feet thick in the Alpena City water well, and 25 feet thick in the South Dakota Game, Fish and Parks Department well at Twin Lakes, about 7 miles south-southwest of Woonsocket. Whether the Codell Sandstone was penetrated by the wells at Woonsocket is unknown. Where the Codell Sandstone is in contact with the Niobrara Marl, the two formations form a hydrologic unit. This hydrologic unit, or aquifer, supplies water to wells in parts of Sanborn County (Steece and Howells, 1965). The Carlile Shale is approximately 180 feet thick in the quadrangle.

Below the Carlile lies the Greenhorn Limestone, which is a well-known and easily recognized strata underlying much of the Great Plains. The Greenhorn is composed of layers of dense fragmental limestone, usually brown or gray, interbedded with light-gray and gray-brown calcareous shale or marl. The marl has a characteristic speckled appearance and the whole formation is calcareous. The formation is easily identified by a sharp deflection on the electric log (fig. 1). In this area the Greenhorn is about 30 to 40 feet thick.

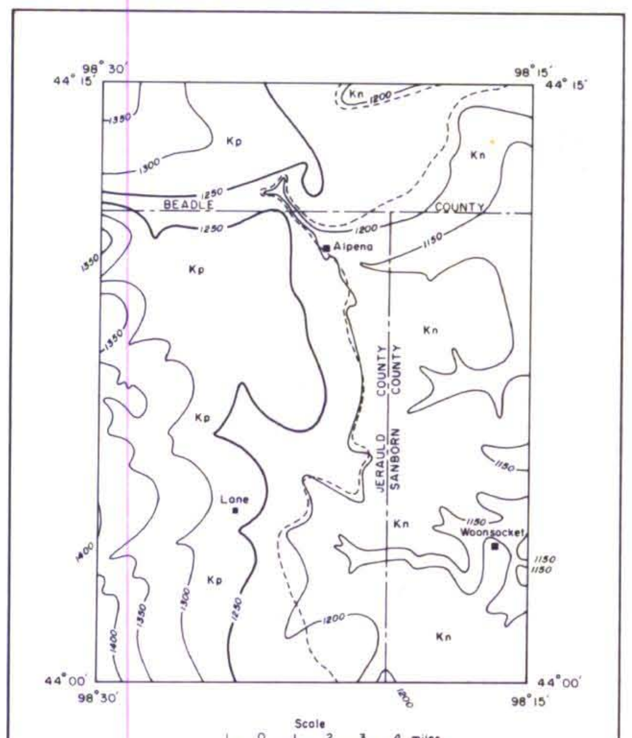
Beneath the Greenhorn lies the Graneros Shale, a sequence of gray shales with an occasional interbed of sandstone or limestone. The Graneros is also a marine deposit and is essentially a clay-shale like the Carlile and the Pierre. The Graneros Formation is 265 feet thick in the Fred Meyer farm well (fig. 1) but the average thickness in the area is about 200 feet.

The lowermost Cretaceous formation in the quadrangle is the Dakota Group, consisting of alternating layers of white to buff sand or sandstone and gray shales. The varied lithology is shown in figure 1. Aquifers in the Dakota Group are important as sources of ground water and are discussed below. The Dakota sequence is more than 255 feet thick in the mapped area. Since no well within the quadrangle has reached the Precambrian basement, on which the Dakota lies elsewhere in adjacent areas, the exact thickness of the Dakota is unknown.

Beneath the Cretaceous sedimentary deposits lie rocks of Precambrian age. It is not known with accuracy the composition of the basement rocks in the mapped area. Granite or granitic rocks have been penetrated west and north of the area and Sioux Quartzite makes up the basement south and east of the area. This quadrangle probably lies on the Sioux Quartzite granite contact.

A test hole 3 miles west of Wessington Springs (SE cor. sec. 9, T. 107 N., R. 65 W.) revealed about 100 feet of residual clay overlying the Precambrian granite. It is not known whether this deposit extends into the Woonsocket quadrangle. Several wells in the northeastern Sanborn County (Steece and Howells, 1965) penetrated volcanic igneous rocks that probably represent high areas protruding through the Sioux Quartzite (Steece, 1964a), or else, are situated just north of the quartzite area. The date of one of these rocks was measured by the Rubidium-Strontium whole-rock method at 1.64±0.09 billion years.[1] The age of the Sioux Quartzite is about 1.2 billion years (Goldich and others, 1959), and is therefore the younger of the two.

1/ "This radiometric age date is the result of a cooperative dating program on buried basement rocks between Crustal Studies Laboratory of the University of Texas, and the Isotope Geology Branch, U.S. Geological Survey."



1350 — Contour on bedrock surface (contour interval = 50 feet)

(Dashed line is approximate boundary between bedrock formations beneath the glacial drift; Kp = Pierre Shale, Kn = Niobrara Marl; Beadle County information from Hedges, in preparation)

Figure 2. Bedrock Map of the Woonsocket Quadrangle.

STRUCTURE

The Woonsocket quadrangle lies on the north flank of a large buried Precambrian highland known as the Sioux Ridge (Steece, 1962). The Precambrian surface in the northwest part of the mapped area lies on a relatively flat bench that trends northeastward into a low in central Beadle County. From the northwest corner the basement slopes gradually upward toward the southeast, and about 20 miles to the southeast in northern Hanson County, rises abruptly onto the crest of the Sioux Ridge. From the mapped area northwestward the basement rocks slope gradually to the northwest into the Williston Basin.

The Precambrian rocks range in elevation from 150 feet above sea level in the northwest corner of the mapped area to about 600 feet in the southeast, with a slope of about 20 feet per mile. Because of the northwest slope of the Precambrian surface in the Woonsocket quadrangle, the Cretaceous rocks are slightly thicker toward the northwest and slightly thinner in the southeast part, although the change in thickness is negligible. However, in southern Sanborn and northern Davison and Hanson Counties, the Cretaceous rocks thin rapidly and rise to the crest of the Sioux Ridge. Thus in the mapped area the Cretaceous rocks have a slight regional dip toward the northwest and a slight regional thinning toward the southeast.

MINERAL RESOURCES

The most important natural resources of the area are ground water and sand and gravel.

Ground Water

Nearly all earth materials that lie below the water table contain varying amounts of interstitial water. The amount of water that is contained in a rock depends on the amount of pore space between the particles making up the rock. The size, shape and arrangement of these particles control the permeability of the rock. Permeability in turn is a measure of the ability of a rock to allow the passage of water through interconnected pore spaces. Many rocks such as clay and shale are porous and store large amounts of interstitial water. The pore spaces in these rocks are, however, extremely small or not interconnected and thus will not readily allow the passage of water. On the other hand, materials such as sand and gravel, if well sorted as to size of the constituent particles, are highly permeable, as well as very porous, and easily allow water to flow through them.

The water table is present nearly everywhere beneath the earth's surface and represents the upper surface of the zone of saturation. Ground water is derived from precipitation that falls on the ground surface. This water is absorbed by earth materials, runs off as surface water in streams, or is evaporated and transpired by plants. Absorbed water percolates downward to the water table and, in permeable material, moves down gradient and is then said to be in transient storage.

Permeable outwash sand and gravel deposits in the mapped area lie both at the surface and buried beneath younger glacial materials. The map shows the distribution of the outwash deposits that lie at the surface. The part of the Woonsocket Outwash Plain lying in Sanborn County is described in detail by Steece and Howells (1965). This outwash ranges from 0 to 90 feet thick and averages about 30 feet. For the most part the outwash is fine grained, although there are layers of coarse gravel especially in the northern part of this deposit. The Cuthbert Outwash likewise has been described in detail (Steece and Howells, 1965). This outwash deposit also is mainly sand but gravel layers occur, particularly in the northern part. The other outwash deposits scattered throughout the area are generally thin and limited in extent. Although small, many of these outwash deposits contain relatively coarse gravel. In addition most of them lie in valleys or low areas and therefore, much of the material lies below the water table, and is therefore saturated. Numerous gravel pits in the outwash deposits in the mapped area contain water supplied by seepage from the surrounding saturated gravels.

In addition to the surface outwash deposits in the mapped area there are buried outwash deposits lying beneath both surface outwash and till. Extensive buried outwash deposits underlie till and outwash in parts of the area in Sanborn County. These buried outwash materials range from 0 to 90 feet in thickness and extend into Beadle County to the north (Hedges, in preparation) and probably extend at least to Firesteel Creek in Jerauld County.

Most of the outwash deposits both at the surface and buried, probably would serve as sources of shallow ground water. Where these deposits are coarse, well sorted, and saturated, they may yield large supplies of water to high-capacity wells that are required for irrigation, industrial, or municipal uses. Test drilling and test pumping at specific locations would prove the utility of the aquifer at a particular location. Because of the lack of detailed test hole information on the buried outwash deposits, no estimate of the ground water in storage can be made with any real meaning.

Water obtained from the glacial drift aquifers is of a sodium-calcium bicarbonate or sulfate type, with high total solids content (table 1). Glacial drift water is hard, has a moderately high magnesium content, and has a wide range in nitrate and chloride (table 1). Excessive concentrations of sodium, sulfate, nitrate, and fluoride may have adverse physiological effects if water containing too much of these ions is consumed for prolonged periods. Excessive sodium may be harmful to persons on salt-free diets. High concentrations of sulfate may produce a laxative effect on humans. Water containing nitrate in amounts exceeding 10 parts per million (ppm) may contribute to the disease known as cyanosis or "blue baby" in infants whose feeding formulas contain this water. Fluoride in excess of the recommended limit may cause dental fluorosis, a dark mottling of tooth enamel, if water with this constituent in excess is used for drinking over prolonged periods of time.

Excessive concentrations of boron may have adverse effects on certain plants. Many plants are susceptible to high concentrations of sodium salts when greatly in excess of salts of other cations.

The alluvium in the mapped area while probably holding large amounts of absorbed water, contains too much clay and silt to be considered as an aquifer, although sandy or gravelly zones may occur that would supply water to low-yield wells. Likewise, fine sand layers enclosed in glacial till are no doubt scattered through the area, but these usually are not large enough or coarse-grained enough to supply much water, nor is it possible to predict their location.

Ground water is stored in several of the bedrock formations in the mapped area. Fractured, jointed, or cavernous zones in the Niobrara Marl render the formation sufficiently permeable to supply moderate amounts of water to wells. Water from the Niobrara is generally soft and of a sodium bicarbonate type. The water is high in chloride and contains excessive total solids (table 1). The Niobrara Marl ranges from 150 to 250 feet below the land surface in the mapped area. Where the Niobrara Marl and the Codell Sandstone Member of the Carlile Shale are in contact, they form a hydrologic unit and supply water to wells. The town of Woonsocket obtains its water supply from this aquifer. Aquifers in the Greenhorn Limestone in adjacent areas, (Steece and Howells, 1965) produce small amounts of water. The water is usually moderately mineralized and is of the sodium sulfate type (table 1). The Greenhorn Limestone lies from 450 to 480 feet below land surface in this area.

The well known Dakota Group sandstones produce mineralized water throughout central South Dakota. In the Woonsocket quadrangle wells completed in the Dakota may flow in most places. Water from the Dakota is of a calcium-sodium sulfate type, is hard, and is generally high in total solids (table 1). Water from the bedrock aquifers is not suited for irrigation use because of general poor quality and because these formations are not permeable enough to support high-capacity wells. The towns of Lane and Alpena obtain water supplies from the Dakota Group.

Sand and Gravel

Sand and gravel deposits occur locally in the mapped area. The Woonsocket and Cuthbert outwash deposits are sandy, and only locally contain gravel, mainly in the northern parts of the two deposits. Gravel has been quarried from parts of the Cuthbert Outwash, particularly in secs. 26, 35, and 36, T. 107 N., R. 63 W. Gravel is obtained from the outwash south of Alpena, and much of this area is underlain by sand and gravel. The deposit at Alpena has been quarried about a mile northwest of town. This outwash contains considerable oversized material that might lend itself well to a rock-crushing operation. Gravel operations have also been carried on in secs. 16 and 17, T. 109 N., R. 62 W.; secs. 17 and 20, T. 109 N., R. 63 W.; sec. 35, T. 108 N., R. 64 W; and sec. 2, T. 107 N., R. 64 W.

The water table is fairly high in all of the outwash deposits and consequently ground water would hamper deep gravel quarrying unless drag-line operations were employed. Sufficient gravel thickness is available in most of the deposits mentioned to support drag-line quarrying. An estimated 530,000,000 cubic yards of sand and gravel, including the predominantly sandy Woonsocket and Cuthbert outwash deposits, is available from the outwash deposits in the mapped area.

The glacial gravels in the area are composed mainly of igneous, metamorphic, and carbonate rocks, with local constituents such as clay-ironstone, shale, and chalk making up a minor part. In addition, the gravel at several localities, particularly the deposit near Alpena in sec. 3, T. 108 N., R. 63 W., contains a greater percentage of chert and other rocks of presumably non-glacial origin than is usual in glacial gravels. Chert and soft particles such as shale, chalk, and clay-ironstone are deleterious constituents for concrete aggregate.

Table 1.--Analyses of water from wells in the Woonsocket quadrangle, and vicinity (results in parts per million).

WELL	LOCATION	Depth (feet)	Source	Silica	Iron	Manganese	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Fluoride	Nitrate	Boron	Total Solids	Hardness $CaCO_3$	pH	Analyst
U. S. Dept. of Health, recommended standards for drinking water				--	0.3	0.05	--	125	--	--	--	-	500[1]	250	0.9[2] 1.7	10	--	1000[1]	--	--	
R. Patterson	SE¼SE¼ sec. 11, T. 107 N., R. 62 W.	25	Q	21	0.09	1.3	205	119	381	25	549	0	1250	26	0.6	122	0.48	2530	1000	8.1	U[3]
E. Reiner	SE¼SE¼ sec. 15, T. 107 N., R. 64 W.	32	Q	--	0.08	0	40	26	220	--	--	-	561	20	0.2	0	--	1064	205	--	C
C. Robeson	NE¼NW¼ sec. 8, T. 108 N., R. 62 W.	38	Q	25	4.9	--	278	135	247	14	545	0	1220	54	0.1	15	0.93	2510	1250	8.1	U[3]
Test Hole	SW¼SW¼ sec. 33, T. 108 N., R. 62 W.	75	Q	--	--	--	28	31.6	210	6.0	330	0	250	20	0.6	6.0	--	880	200	--	U[3]
City of Woonsocket	NE¼NE¼ sec. 28, T. 107 N., R. 62 W.	163	Kn-Kcc	--	0.1	0.6	13	3	484		708	-	349	85	0.9	2.5	--	1371	48	7.6	H
E. Nelson	SE¼SE¼ sec. 10, T. 108 N., R. 62 W.	220	Kn-Kcc	14	0.1	0.05	21	6.7	729	8.1	622	0	42	826	0.9	4.7	22	1930	80	7.7	U[3]
D. Fredericks	SE¼SW¼ sec. 28, T. 107 N., R. 61 W.	400	Kg	7.7	0.94	[illegible]	9.3	1.2	699	6.3	713	0	817	104	3.4	0.3	6.2	2060	28	7.8	U[3]
City of Woonsocket[4]	SW¼SE¼ sec. 21, T. 107 N., R. 62 W.	775	Kd	12	0.55	--	212	58	316	22	142	0	1200	74	2.8	0.2	--	2050	762	7.1	U[3]
J. Simms Estate	SE¼SW¼ sec. 6, T. 108 N., R. 62 W.	717	Kd	6	1.4	--	241	69	332		161	-	1250	104	2	--	--	2200	885	--	U[3]
City of Alpena (well E-2)	SW¼NE¼ sec. 11, T. 108 N., R. 63 W.	900	Kd	--	3.0	0	214	59	357	23.5	176	-	1233	90	2.3	0	--	2149	782	7.2	H
City of Lane (well No. 2)	SW¼ sec. 17, T. 107 N., R. 63 W.	780	Kd	--	10.5	0	7	2	800	11.0	1247		67	467	0.7	0		2105	43	8.3	H
City of Lane (well No. 3)	SW¼ sec. 17, T. 107 N., R. 63 W.	830	Kd	--	2.2	0	208	67	332	23.0	159		1233	71	2.2	3		2136	798	7.2	H

1/ Modified for South Dakota by State Dept. of Health, Pierre (written communication, Feb. 5, 1962).
2/ Optimum
3/ See Steece and Howells, 1965
4/ Bath house well at Woonsocket

Source: Q, Glacial Drift; Kn-Kcc, Niobrara Marl-Codell Sandstone; Kg, Greenhorn Limestone; Kd, Dakota Group.

Analyst: U, U. S. Geological Survey; C, State Chemical Laboratory; H, S. Dak. Dept. of Health, 1961 (See references).

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