Origin, Distribution, and Development of Bog Iron in the Rochford District, North-Central Black Hills, South Dakota

Preliminary Report 177, May 1970

United States
Department of the Interior
Bureau of Mines

This is a preliminary report prepared for administrative use by the Department of the Interior and Federal and State Agencies cooperating in the planning and development of the Missouri River Basin. It is not for general distribution.
ORIGIN, DISTRIBUTION, AND DEVELOPMENT OF BOG IRON

IN THE ROCHEFORD DISTRICT, NORTH-CENTRAL

BLACK HILLS, SOUTH DAKOTA

by

Kenneth V. Luza1/

CONTENTS

Abstract and introduction ........................................ 1
Acknowledgments ................................................. 1
Purpose and methods of investigation .............................. 2
Location and access ............................................... 3
Physiography ..................................................... 3
Previous work .................................................... 4
Mining history .................................................... 4
Regional geological setting ....................................... 5
Bedrock geology in the Rochford district ......................... 6
Bog iron deposits ................................................ 6
Consolidated bog iron deposits .................................. 7
Unconsolidated bog iron deposits ................................. 7
Gravel conglomerate ............................................. 8
Occurrence ....................................................... 8
Origin ............................................................ 10
Age .............................................................. 10

CONTENTS—Continued

<table>
<thead>
<tr>
<th>Distribution of bog iron deposits</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swilley Draw</td>
<td>11</td>
</tr>
<tr>
<td>Black Fox</td>
<td>11</td>
</tr>
<tr>
<td>South Fork of Rapid Creek</td>
<td>12</td>
</tr>
<tr>
<td>Long Draw - Maitland Draw</td>
<td>13</td>
</tr>
<tr>
<td>Hop Creek</td>
<td>15</td>
</tr>
<tr>
<td>Solomon Gulch</td>
<td>17</td>
</tr>
<tr>
<td>Iron Hills</td>
<td>18</td>
</tr>
<tr>
<td>Bloody Gulch</td>
<td>19</td>
</tr>
<tr>
<td>Summary</td>
<td>21</td>
</tr>
<tr>
<td>Chemical data</td>
<td>21</td>
</tr>
<tr>
<td>Hop Creek</td>
<td>22</td>
</tr>
<tr>
<td>Iron Hills</td>
<td>22</td>
</tr>
<tr>
<td>Swilley Draw</td>
<td>23</td>
</tr>
<tr>
<td>Solomon Gulch</td>
<td>24</td>
</tr>
<tr>
<td>Bloody Gulch</td>
<td>24</td>
</tr>
<tr>
<td>Conclusions</td>
<td>24</td>
</tr>
<tr>
<td>Origin of the bog iron deposits</td>
<td>25</td>
</tr>
<tr>
<td>Mining development</td>
<td>26</td>
</tr>
<tr>
<td>Summary and conclusions</td>
<td>27</td>
</tr>
<tr>
<td>References</td>
<td>29</td>
</tr>
</tbody>
</table>

ILLUSTRATIONS

Frontispiece. Rockford district as seen from Paleozoic escarpment to the west

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Follows</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Location map of the Rockford district</td>
<td>4</td>
</tr>
<tr>
<td>2. Consolidated bog iron composed of organic remains (right), metamorphic clasts, limonite, and goethite</td>
<td>8</td>
</tr>
<tr>
<td>3. Unconsolidated bog iron intercalated with stream gravel</td>
<td>8</td>
</tr>
<tr>
<td>No.</td>
<td>Description</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Geologic map of lower Bloody Gulch, Rochford, S. Dak.</td>
</tr>
<tr>
<td>2.</td>
<td>Isopach map of bog iron in Bloody Gulch</td>
</tr>
<tr>
<td>3.</td>
<td>Location of auger holes in Bloody Gulch</td>
</tr>
<tr>
<td>4.</td>
<td>Monthly comparison of chemical parameters in Hop Creek</td>
</tr>
</tbody>
</table>
PLATES—Continued

No. | Follows page
--- | ---
5. Monthly comparison of chemical parameters in Iron Hills | 22
6. Monthly comparison of chemical parameters in Swilley Draw | 24
7. Monthly comparison of chemical parameters in Solomon Gulch | 24
8. Monthly comparison of chemical parameters in Bloody Gulch | 24

TABLES

No. | Page
--- | ---
1. Bog iron ore production from the Rochford district, 1893-1962 | 5
2. Chemical analyses of the South Fork of Rapid Creek (Ole Green homestead) bog limonite from S 1/4 sec 7, T 2 N, R 3 E, Lawrence and Pennington Counties | 13
3. Results of sampling Long, Maitland, and Lessering Draws bog limonite, sec 19, T 2 N, R 3 E, Pennington County | 16
4. Average of U. S. Bureau of Mines chemical analyses of bog iron taken from the Hop Creek deposit, 1944 | 17
ABSTRACT AND INTRODUCTION

Deposits of consolidated and unconsolidated bog iron crop out in some of the major streams and their tributaries near Rochford and Nahant in the northern Black Hills of South Dakota. The consolidated bog iron is hard, is black to dark brown, and consists of metamorphic clasts mixed with aggregates of goethite and organic matter. Unconsolidated bog iron ranges in color from yellow to yellow-brown and is composed of clay-size limonite mixed with silt- to sand-size clasts of quartz, garnet, amphibole grains, phyllite and graphite schist fragments, and opaline cement.

The immediate source of the iron for the bog iron deposits is an older iron-rich gravel conglomerate that rests unconformably on Precambrian rocks and mantles valley walls and ridge tops as much as 200 feet above present valley floors. The conglomerate is composed of poorly sorted angular schist and quartzite fragments, a matrix of limonite and detrital angular quartz, and a colloform hematite cement. Mechanical erosion of the gravel conglomerate frees iron oxide that is transported downstream, both in solution and in suspension, and subsequently deposited in a bog environment. Analyses of water that flows above, within, and below bog iron deposits indicate that pH is the most important variable controlling iron transport. Where streams have a pH between 6.0 and 7.2, most of the iron is transported in suspension; where the pH ranges from 3.0 to 4.0, most of the iron is in solution.

Auger and shallow seismic data on the Bloody Gulch deposit of unconsolidated bog iron reveal a lenticular shape having a maximum length of 800 feet and a width that ranges from 10 to 150 feet. The bog iron occurs beneath a 6-inch soil horizon and has an average thickness of 4 feet. Alternating layers of limonite and gravel rest on 10 to 15 feet of gravel that overlies Precambrian graphite schist and quartzite.

The most efficient and economical mining method is by dragline and bucket. Stream contamination must be counteracted by constructing settling ponds and neutralizing ponded water. Reclamation, after mining, is accomplished by backfilling and reseeding mined areas.

ACKNOWLEDGMENTS

I wish to thank the U. S. Bureau of Mines for supporting my investigation under a research grant. I want to thank Dr. J. P. Gries, who directed the project, for his aid. Particularly I wish to express my appreciation to Dr. E. C. Bingler for many stimulating discussions during the course of this study. Also, I desire to extend my appreciation to my field assistant, R. K. Farrar.
PURPOSE AND METHODS OF INVESTIGATION

The purpose of this study was to investigate the origin, occurrence, and distribution of bog iron deposits in the Rochford district of the northern Black Hills. Bog iron mining techniques also were considered.

Initially, this report was submitted as a thesis to the Graduate Division, South Dakota School of Mines and Technology, in partial fulfillment of requirements for an M.S. degree in geological engineering. It is being published informally by the U. S. Bureau of Mines, which supported the study, in order to make the results more widely available to Federal and State agencies.

The study of bog iron deposits in the Rochford district included the location and description of nine bog iron deposits, monthly collection of 50 water samples, microscopic study of rock samples from the deposits, X-ray fluorescence analysis of 22 bog iron samples for iron content, and the collection and study of bog iron material from 88 auger holes.

Water samples were collected from the streams that flow through Bloody, Swilley, Iron Hills, Hop Creek, and Solomon Gulches. The water samples were collected in polyethylene bottles and subsequently assayed for total iron, suspended iron, soluble iron, Eh, and pH determinations. The iron determinations were made colorimetrically using a spectrophotometer of the Department of Geology and Geological Engineering, South Dakota School of Mines and Technology. The instrument limits range from 0.00 to 5.26 parts per million. Measurements of pH and Eh were made with a portable pH meter. Because of the inaccessibility of some of the deposits investigated and the cumbersome construction of the pH meter, it was necessary to bring the samples into the laboratory. A comparison study of field and laboratory measurements indicated that pH measurements deviated ±10 percent from the laboratory values while Eh values deviated ±50 percent from laboratory values.

In addition to the water sampling program, an augering program was devised to determine the stratigraphy and to sample systematically a selected bog iron deposit. Eighty-eight auger holes were drilled with a hand auger on the Bloody Gulch bog iron deposit. The holes ranged from 1 to 13 feet deep and averaged 5 feet deep. The holes were drilled on 100-foot centers with slight variations depending upon the surface expression of the bog iron and the valley limits. At each hole, augering was done in 1-foot increments. After each foot, the auger was pulled out of the hole and the cuttings were examined and described.2/

Selected cuttings were retained for further examination and X-ray analysis.

Total iron content was determined by X-ray fluorescent spectrometer on 22 auger samples. Because of sampling technique and sample preparation errors, the values obtained may be in error as much as ±10 percent.

The geology, topography, and auger hole positions in lower Bloody Gulch were mapped by telescopic alidade and plane table. A geologic map was drafted at a scale of 1 inch to 200 feet. The South Dakota State Highway Department under the supervision of Phillip Lidel, in April 1968, made a refraction seismic survey that supplements the geologic mapping.

LOCATION AND ACCESS

Rochford district is in the north-central Black Hills near the town of Rochford, S. Dak. (fig. 1). The area of investigation is in townships 1 and 2 north, ranges 2, 3, and 4 east, in Pennington and Lawrence Counties. The district is approximately 35 miles west of Rapid City and 20 miles south of Lead, S. Dak., and is serviced by the Deadwood branch of the Chicago, Burlington & Quincy Railroad.

PHYSIOGRAPHY

The Rochford district encompasses an area of approximately 100 square miles. Rochford, for which the district is named, is in the east-central portion of the district. Minnesota Ridge, Castle Peak, Reynolds Prairie, and the Paleozoic escarpment are the principal topographic features in this district. Minnesota Ridge, 6.6 miles northeast of Rochford, strikes northwest and extends for almost 3 miles. Castle Peak, which has an elevation of 6,352 feet, lies 2.75 miles due south of Rochford. The third prominent topographic feature, Reynolds Prairie, is a large unforest area 5.6 miles southwest of Rochford. Approximately 7.5 miles west of Rochford is the Paleozoic escarpment, which trends north-south and continues toward the west, increasing in elevation from 6,300 to 6,700 feet.

The North and South Forks of Rapid Creek and the North Fork of Castle Creek are the three major perennial streams in this district. The North Fork of Rapid Creek drains to the south and joins with the east-flowing South Fork of Rapid Creek 1 mile northwest of Rochford. Rapid Creek continues eastward and empties into the Cheyenne River. The North Fork of Castle Creek flows from west to east in the southern portion of the Rochford district, merging with Rapid Creek approximately 2 miles northeast of Mystic. These streams are in a youthful downcutting stage and flow in numerous intrenched meander loops, which suggests that Rapid Creek and Castle Creek are superimposed upon an older stage of geomorphic development.
The bog iron deposits of the Rochford district are in alluvial valleys that range in elevation from 5,200 to 5,900 feet. The Bloody Culch deposit occurs at an elevation of 5,200 feet in the eastern portion of the district. The westernmost or Black Fox Campground deposit is exposed at an elevation of 5,900 feet. The remaining bog iron deposits are exposed at intermediate elevations.

PREVIOUS WORK

Darton (1909, 1919) and Darton and Paige (1925) described the geology of the Rochford district. They noted lithologic similarities between the Rochford and Lead districts. C. C. O'Harra (1916) mapped structural trends in the Rochford district and recognized the similarity between the Lead and Rochford districts. In 1934, Harder mapped in detail a portion of the Rochford district. Since Harder's work, Master's thesis by Lane (1951) and Wilson (1951) have described the structure and lithology adjacent to the area Harder mapped.

Bog iron deposits in the Rochford district probably first were noted by Newton and Jenney in 1875. Descriptions and chemical analyses of the bog iron later were reported by Connolly and O'Harra (1929). However, it was not until 1952 that several of the bog iron deposits were located and described (Cole, 1952). More recently, Harrer (1966) further described the occurrence and distribution of bog iron deposits in a report on the iron resources of South Dakota.

MINING HISTORY

Limonite bog iron deposits of the Rochford district were important producers of iron ore utilized in manufacturing paint pigment and metallurgical flux, and as an additive in making type 2 cement. Between 1893 and 1894, 165 carloads of bog iron ore was shipped to smelters at Omaha, Nebr., and Kansas City, Mo. Local smelters used small quantities of bog iron ore for fluxing purposes, but no records of consumption are available.

In 1901, the Mineral Paint Works at Custer, S. Dak., calcined, ground, and shipped to Aurora, Ill., about 150 tons of bog iron ore. From 1902 to 1903, 500 tons of such ore was treated by the Custer plant and shipped to Aurora, Ill. Records of subsequent output are not available because of the destruction of the Custer mill by fire.

The bog iron deposits in the Rochford district have been mined intermittently since 1903. In 1925, 500 tons of bog iron ore was shipped from the Hausle deposit (Hop Creek) to George Mepham Corp., East St. Louis, Ill. (Cole, 1952). Subsequent production from the Hausle mine totaled 3,500 tons of bog iron from 1939 to 1941. From 1941 to 1944, 2,988 tons of bog iron was shipped from the Lessering property.
FIGURE 1. - Location map of the Rochford district.
(Maitland and Long Draws) to East St. Louis, Ill. In 1945, Lor Mining Co., Minneapolis, mined and shipped 4,162 tons of bog iron from the Rochford district. Since 1954, Pete Lien and Sons and others have trucked bog iron from the Rochford district to the State Cement Plant in Rapid City, S. Dak., where the ore still is being used as an ingredient in manufacturing type 2 cement.

A summary of the bog iron production from the Rochford district is given in table 1:

<table>
<thead>
<tr>
<th>Year</th>
<th>Tonnage (long tons)</th>
<th>Value (dollars)</th>
<th>Dollars/ton</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>34,000</td>
<td>113,000</td>
<td>3.32</td>
<td>Cement additive.</td>
</tr>
<tr>
<td>1961</td>
<td>22,000</td>
<td>100,000</td>
<td>4.55</td>
<td>Cement additive.</td>
</tr>
<tr>
<td>1949-1951</td>
<td>33,188</td>
<td>-</td>
<td>-</td>
<td>Cement additive.</td>
</tr>
<tr>
<td>1945</td>
<td>4,162</td>
<td>1,038</td>
<td>-</td>
<td>Cement additive.</td>
</tr>
<tr>
<td>1944</td>
<td>577</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1942</td>
<td>1,098</td>
<td>32,499</td>
<td>3.26</td>
<td>Paint pigment.</td>
</tr>
<tr>
<td>1941</td>
<td>2,150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1940</td>
<td>640</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1939</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1893-1938</td>
<td>13,700 (est.)</td>
<td>-</td>
<td>-</td>
<td>Paint pigment; smelter flux.</td>
</tr>
</tbody>
</table>

No production: 1946-1947
1926-1938
1911-1924
1895-1900


REGIONAL GEOLOGIC SETTING

The Black Hills area is an elliptical northwest-trending dome 125 miles long and 60 miles wide situated in a region of nearly horizontal beds. A Precambrian core is composed of complexly deformed schist, amphibolite, pyrite-pyrrhotite graphite slate and schist, granite, and pegmatite. Thirty-five hundred feet of outward-dipping Paleozoic and Mesozoic limestone, sandstone, and shale flank the Precambrian core.
BEDROCK GEOLOGY IN THE ROCHFORD DISTRICT

Early geologic mapping suggested that the Rochford district is underlain by four distinct metamorphic units named the Poorman, Homestake, Ellison, and Flagrock Formations (Harder, 1934). The Poorman Formation, regarded as the oldest formation in this district (Hosted and Wright, 1923), is made up of a thick series of gray to black micaceous, garnetiferous, graphitic phyllite and schist. The next oldest formation, the Homestake Formation, is a medium-grained, brown, quartz-mica-carbonate schist that often contains the amphibole cummingtonite. The Ellison Formation is composed of a sequence of schist, phyllite, and dark gray quartzite. Rocks of this formation are composed principally of quartz and biotite with varying amounts of orthoclase and albite. The youngest lithologic unit, the Flagrock Formation, is the most lithologically diverse. It consists of soft, black, "sooty" slate, soft yellowish-brown iron-stained phyllite, gray quartzite, gray micaceous phyllite, and cummingtonite schist (Harder, 1934). This sequence of graphitic schist and phyllite is very uniform and serves to identify the Flagrock Formation.

Recent mapping suggests that the Poorman and Homestake Formations may not be present in the Rochford area, and the iron-rich units previously identified as Homestake Formation may lie within the Flagrock and Grizzly Formations. Under this interpretation, the rocks exposed in Bloody Gulch (Pl. 1) would be included within these two stratigraphic units (McGehee and Bayley, 1969).

Structural geology of metamorphic rocks within the Rochford district is extremely complex. The Precambrian metamorphic rocks contain structures related to several periods of metamorphism and deformation. The area near Rochford includes a series of anticlines and synclines with minor folds on their flanks, all plunging steeply to the southeast. The major folds of the district have a large wave length to amplitude ratio. Some of the minor folds, on the flanks of the larger folded structures, are tightly compressed. In general, the minor folds reflect the style of the major fold structures (Harder, 1934).

BOG IRON DEPOSITS

Bog iron is an earthy yellow to red to brownish-black mixture of iron oxides and hydroxide, organic material, and sand- to clay-sized detritus. Iron silicate, sulfate, and carbonate are often present in accessory to trace amounts. In the Rochford district, bog iron deposits often contain varying amounts of phosphorus. E. C. Harder (1919) believes that phosphorus, when found in bog iron deposits, occurs as the iron phosphate, vivianite. Organic matter, when present, consists of plant remains such as leaves, sticks, and tree and plant roots, which may be in part or entirely replaced by limonite.
In many parts of the United States, bog iron deposits are referred to as ocher (Barksdale, 1930; Huddle, 1941). Ocher is a clayey and unconsolidated form of the minerals limonite and hematite combined with substantial amounts of other metallic oxides, clay, and silica. The presence of hematite is chiefly responsible for the red color in red ochers, whereas limonite yields the yellow, orange, and brown varieties. As a rule, the color of ocher and bog iron depends upon the valence state of the iron and upon the degree of hydration (Barksdale, 1930).

Consolidated Bog Iron Deposits

The typical consolidated bog iron of the Rochford district is hard, is black to dark brown, has a clinkery appearance, and usually contains about 50 percent iron. This bog iron generally is well cemented and contains numerous cavities. Some of the cavities are circular and have a mean diameter of 1 millimeter; others are elongated, range in length from 3 to 4 millimeters, and are aligned vertically. The cavities are not interconnected and often are lined with a black, vitreous mineral, possibly goethite. In some samples, the cavities are filled with limonite.

Consolidated bog iron is composed of clastic Precambrian rock fragments, clay- to silt-size limonite and quartz, and a black vitreous mineral tentatively identified as goethite. The clastic portion consists of quartz, schist fragments, phyllite fragments, and scattered mica flakes. The clastic material varies in size from 2 to 0.5 millimeters, but the mean size is 1 to 0.5 millimeter in diameter. Most of the samples of consolidated bog iron include 5 to 15 percent clastic material. Limonite coats the clastic material and fills the interstices between individual grains. Randomly dispersed among the clastic material is a black vitreous mineral that appears to be goethite. This black mineral ranges in size from 1 millimeter to less than 0.5 millimeter and forms aggregates. The mean size of the aggregates is probably slightly less than 1 millimeter. Goethite also lines some of the cavities.

Plant remains, wood, and leaves are common within consolidated bog iron. The largest plant fragment observed was 10 centimeters long and 1.3 centimeters wide. Mosses and leaves are sometimes recognizable among the clastic and limonitic material (fig. 2). In most samples, the organic remains are totally replaced by limonite. In some instances, the plant remains are partially leached, leaving a void space.

Unconsolidated Bog Iron Deposits

Unconsolidated bog iron, sometimes called ocher, also is found in the Rochford district. This type of bog iron occurs as isolated pockets within consolidated bog iron and as 1- to 2-foot horizons intercalated with stream gravel (fig. 3).
The color of unconsolidated bog iron is yellow to yellow-brown when dry and brown to reddish-brown when wet. The yellow color of the unconsolidated variety is principally due to the mineral limonite, whereas the brown color of the consolidated bog iron is chiefly due to the presence of goethite.

Unconsolidated bog iron is composed of silt-size limonite, clay, silt- to sand-size Precambrian rock fragments, and opaline cement. Unconsolidated bog iron has a higher percentage of clastic material than the consolidated variety. The Bloody Gulch unconsolidated bog iron deposit contains up to 65 percent clastic material, which consists of silt- and sand-size quartz, garnet, amphibole grains, and phyllite and graphitic schist fragments. Nearly all of this clastic material is derived from nearby Precambrian rocks.

The iron, which is mostly limonite, is present in the silt- and clay-size fraction as orange-colored aggregates. The limonitic aggregates are less than 0.5 millimeter in diameter and probably contribute largely to the total iron content.

Opal is found in both fine and coarse fractions in unconsolidated bog iron. It occurs as a reddish-brown, vitreous, and isotropic material. The opal probably developed contemporaneously with the bog iron and acts as a weak cementing agent.

Unlike consolidated bog iron, unconsolidated bog iron usually is almost devoid of plant material. The bog iron deposit on Bloody Gulch contains no visible organic matter. However, an unconsolidated bog iron deposit on the North Fork of Castle Creek contains a great deal of organic matter. Intricate patterns of mosses and plant remains are preserved and totally replaced by limonite (fig. 4).

GRAVEL CONGLOMERATE

Occurrence

A ferruginous gravel conglomerate is associated with both types of bog iron. Cole (1952) described this unit as a slate-schist pebble and boulder conglomerate.

The unit was classified as a gravel conglomerate following Folk's classification (Folk, 1961). The gravel conglomerate is composed of angular to subangular clasts of metamorphic rock fragments, of which 80 percent are schist and phyllite, 12 percent metamorphic quartz, and 8 percent vein quartz (fig. 5). Approximately 92 percent of the clasts have an intermediate diameter greater than 2 millimeters. The diameter size distribution of intermediate clasts from representative samples is given below:
FIGURE 2. Consolidated bog iron composed of organic remains (right), hematite, and goethite.
FIGURE 3. – Unconsolidated bog iron intercalated with stream gravels.

FIGURE 4. – Unconsolidated bog iron collected on the North Fork of Castle Creek, showing an intricate pattern of mosses and plant remains.
FIGURE 5. — Hand specimen of gravel conglomerate illustrating the angular to subangular metamorphic clasts.

FIGURE 6. — Photomicrograph illustrating the matrix composed of detrital quartz and limonite, metamorphic clasts, and colloform hematite cement (field diameter 3 mm).
<table>
<thead>
<tr>
<th>Grain size (phi)\textsuperscript{1/}</th>
<th>Grain size (mm)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>64</td>
<td>1</td>
</tr>
<tr>
<td>-5 to -4</td>
<td>36</td>
<td>12</td>
</tr>
<tr>
<td>-4 to -3</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>-3 to -2</td>
<td>8</td>
<td>47</td>
</tr>
<tr>
<td>-2 to -1</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Greater than -1</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

\textsuperscript{1/} Phi - A logarithmic mean particle diameter obtained by using the negative logs of the class midpoints to the base 2.

A cumulative curve was constructed from the above estimates for determining graphical mean diameter, sorting, and skewness parameters. The gravel conglomerate has a graphic mean diameter of -2.7 phi, an inclusive graphic standard deviation of 1.05 phi, and a graphic skewness of -0.224. The magnitude of the preceding parameters indicates a mean diameter equivalent to small pebble size, poor sorting, and moderate negative skewness or an excess of coarse material (Folk, 1961).

A matrix of silt-size, angular grains of quartz and limonite fills the spaces between clasts. The clastic quartz is very angular and randomly distributed in the matrix. The matrix is concentrated within the void spaces between clasts.

The clasts and limonite matrix are cemented by hematite. The cement surrounds the metamorphic clasts and matrix and lines void spaces between the schist fragments. The hematitic cement is red and has a colloform texture. It was formed after the clasts and matrix attained their present spatial arrangement. Perhaps the percolation of ground and surface waters hydrated some of the limonitic matrix. The hematite was transported in solution and precipitated around clasts, matrix, and voids (fig. 6). In some outcrop exposures of gravel conglomerate, a botryoidal texture is visible.

The gravel conglomerate crops out both above and within the present stream levels in Hop Creek Gulch, Swilley Draw, Iron Hills Gulch, Bloody Gulch, Solomon Gulch, Maitland Draw, and Long Draw. Where the conglomerate is above the present stream, it rests unconformably on steeply dipping Precambrian metamorphic rocks, whereas conglomerate within the stream channel is interfingered with alluvial material.

When the conglomerate weathers, a crude stratification is readily visible (fig. 7). The stratification results from the shingling effect of flat and elongated, crudely aligned, phyllite and schist clasts. This structure is accentuated when matrix and cement are preferentially removed by eroding agents.
The thickness and extent of the conglomerate is highly variable. This unit ranges in thickness from 1 foot to 20 feet and crops out as a veneer on the sides of valley walls that may extend as much as 200 feet above the flowing streams. On the west side of Hop Creek Culch, the conglomerate crops out in 10-foot, step-like ledges above Hop Creek until it is a maximum of 200 feet above the creek. The conglomerate, which crops out as discontinuous exposures up the Hop Creek drainage, decreases in altitude above the drainage until it intersects the present drainage. This is a very common occurrence on other drainages where this unit is exposed.

The dip of bedding within the gravel conglomerate ranges from 2 to 30 degrees. In most outcrops, the dip is nearly horizontal and parallel to the slopes on which the conglomerate is deposited.

**Origin**

Unlike conglomerates of fluvial origin, the ferruginous gravel conglomerate is very heterogeneous, is poorly sorted, and has highly angular clasts. The conglomerate has negligible internal stratification and parallels the surface on which it rests. Exposures of the conglomerate are sometimes continuous up the sides of valley walls and are interfingered with valley alluvium in the bottom of small stream valleys. A similar occurrence is described by Lattman (1960) in Beaverdam Run valley near Altoona, Pa. At this location, the interfingering was produced by mass wasting of soil on the valley slopes downward into the bottom of the valley where the stream was accreting. This colluvium is also wedge-shaped and parallels the surface on which it rests, as does the gravel conglomerate in the Rochford district.

Gravel conglomerate in the Rochford district probably stems from a mixture of accumulated colluvial debris and limonitic soil that developed on the Precambrian surface. The limonite matrix represents the reworking of an early formed residual soil. As the soil and broken bedrock moved downslope, the soil infiltrated between the interstices of the metamorphic clasts. The conglomerate later was cemented by hematite during induration.

**Age**

There is some conjecture concerning the age of this ferruginous gravel conglomerate. Cole (1952) casually suggested that it represents the remnants of the basal Deadwood conglomerate, which is locally rich in hematite. However, Kulik (1965) found the basal Deadwood conglomerate to consist of pebbles and boulders of rounded quartzite and hematite and to be almost devoid of schist fragments. Unlike basal Deadwood Formation, the conglomerate is very heterogeneous and consists of highly angular fragments of schist, phyllite, and quartzite that range in size from silt to boulders. In the Rochford district, the conglomerate rests unconformably on Precambrian rocks. North of the district near the Tomahawk
FIGURE 7. - Shingling effect of the conglomerate observed in the field.

FIGURE 8. - Distribution of bog iron deposits.
Country Club, similar gravel conglomerate unconformably overlies late Tertiary volcanic and contains volcanic clasts. Thus the conglomerate is probably much younger than the Cambrian Deadwood Formation.

DISTRIBUTION OF BOG IRON DEPOSITS

Bog iron deposits occur in a 54-square-mile area near the town of Rochford (fig. 8). Bog iron deposits in Hop Creek Gulch, Swilley Draw, South Fork of Rapid Creek, Black Fox area, Iron Hills Gulch, Bloody Gulch, Long Draw, and Maitland Draw were studied. In some instances, the deposits are genetically different. However, they all were formed in a swamp or bog or sluggish watercourse environment close to outcrops of ferruginous gravel conglomerate.

Swilley Draw

The Swilley Draw bog iron deposit is in sec 9, T 2 N, R 3 E, Lawrence County (fig. 8). The deposit lies along a small southeast-flowing tributary of the North Fork of Rapid Creek.

Bog iron crops out where the creek first appears on the surface, and it is continuously exposed down the drainage for approximately 2,000 feet. The deposit, which is less than 1 foot thick where first exposed, increases to a maximum thickness of 8 feet lower in the drainage. The width of the deposit ranges from 4 feet near its upper end to a maximum of 40 feet near the lower end.

The bog iron has a yellow-brown to brown color that is principally attributable to the minerals goethite and limonite (Harrer, 1966). Most of the bog iron is the hard, clinkery, consolidated variety. However, some is of the unconsolidated type. Layers of ocher, 1 to 2 feet thick, rest on consolidated bog iron near the downstream edge of the deposit.

Bog iron in this gulch rests unconformably on ferruginous gravel conglomerate, which extends up the drainage beyond the first exposure of the bog iron for a few hundred feet. Most of the conglomerate rests on Precambrian bedrock and crops out on the southeastern flank of the valley. Conglomerate outcrops extend continuously up the valley wall for approximately 30 feet above creek level. The northwestern flank of the valley, however, is almost devoid of conglomerate.

Most of the bog iron in this gulch was removed by mining; thus details of the stratigraphy are lost.

Black Fox

A bog iron deposit crops out near both the Black Fox Campground and the junction of Rhoads Fork with the South Fork of Rapid Creek in sec 11, T 2 N, R 2 E, Lawrence County (fig. 8). The deposit, which
begins above the campground and extends approximately 500 feet down the drainage, is in a marshy, densely forested, poorly drained environment adjacent to Rhoads Fork Creek at an elevation of 5,900 feet. The width of the deposit ranges from approximately 5 feet near the upper end to a maximum of 40 feet downstream.

Much of the deposit is exposed at the surface. Where the deposit is not exposed, it is covered by a 6- to 12-inch layer of recent organic debris composed of decaying spruce trees, swamp grasses, and tree roots. Auger data indicate that the deposit has an average thickness of 3 feet. However, a 10-foot well dug near the campground penetrated 9 feet of bog iron (Harrer, 1966). Most of the bog iron in this deposit is unconsolidated limonite and clay.

Ferruginous gravel conglomerate crops out in the drainage near the southwest end of the bog iron deposit. The conglomerate is similar in composition, matrix, size distribution, and cement to the gravel conglomerate described on page 8. It is composed of phyllite and quartzite clasts, limonitic detrital matrix, and hematite cement. Moreover, it differs slightly from the other conglomerates in that it contains yellow clay galls, which appear as yellow patches scattered throughout that material exposed at or below the water table. Formation of the galls appears to have resulted from some chemical process that attacked the matrix. The conglomerate is exposed at the upstream end of the bog iron deposit and extends only a few feet down the drainage. The stream is eroding the limonite matrix and hematite cement within the conglomerate and transporting this material downstream in suspension and solution.

Transported iron is accumulating in shallow ponds below the conglomerate exposures, and the ponded water has a pH of 3.2 and is slightly oxidizing.

**South Fork of Rapid Creek**

Irregular lenses of bog iron crop out along the north side of the South Fork of Rapid Creek in secs 7, 8, 17, and 18, T 2 N, R 3 E, in Lawrence and Pennington Counties (fig. 8). They are composed of yellow to reddish-brown iron oxide mixed with organic material and sand-size clasts of schist, phyllite, and quartzite fragments. The principal iron mineral within the bog iron is limonite, which occurs in the fine fraction. It is dispersed throughout the bog iron and fills interstices between clasts.

Bog iron occurs as two separate deposits on this drainage (Cole, 1952; Harrer, 1966). Both deposits are exposed in the marshy parts of the wide, gently sloping valley of the South Fork of Rapid Creek. Goethite, yellow to reddish-brown in color, is the principal iron mineral.
One of the deposits, on the old Edward G. Dungey ranch, is 5 miles west-northwest of Rochford. Bog iron is partly exposed in a 500-by 1,000-foot area largely covered by 2 feet of soil and alluvium and underlain by alluvial gravel. Analyses of samples (slightly diluted by overburden) from shallow auger holes yield values of from 32.7 to 46.66 percent iron, 0.020 to 0.034 percent phosphorus, 0.03 to 3.11 percent sulfur, and 2.49 to 30.05 percent silica (Harrer, 1966).

The second bog iron deposit is on the Ola Green ranch and is exposed on the north side of the creek one-half mile up the drainage from the Dungey deposit. The ore consists of pulverulent yellow ocher and consolidated yellow-brown to brown bog iron. The ochrous bog iron is mainly composed of limonite, but the principal iron mineral in the consolidated bog iron is goethite. The deposit is approximately 50 feet wide and 300 feet long, and its lateral extent is limited by Rapid Creek to the south and the north flank of the valley to the north. The bog iron is thickest in the middle of the valley and thins toward the valley margins. Cole (1952) reported that this deposit is at least 7 feet thick.

Bureau of Mines samples from the Green bog iron deposit, collected in 1945, indicate that the average iron content is approximately 50 percent. Table 2 contains chemical analyses of samples taken from the Green deposit (Harrer, 1966).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Chemical analyses, percent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe (dry)</td>
<td>P</td>
</tr>
<tr>
<td>1</td>
<td>52.62</td>
<td>0.006</td>
</tr>
<tr>
<td>2</td>
<td>48.96</td>
<td>0.027</td>
</tr>
</tbody>
</table>

No ferruginous gravel conglomerate is exposed near the Green and Dungey bog iron deposits.

**Long Draw - Maitland Draw**

Consolidated bog iron crops out in Long Draw and Maitland Draw in secs 19 and 20, T 2 N, R 3 E, Pennington County (fig. 8). The bog iron deposit in Maitland Draw is at Lessering mine No. 1 on the Iron Lode unpatented claim. Samples from this deposit are reddish-brown to brown,
consolidated, and composed of aggregates of goethite mixed with sand and silt-size phyllite, schist, vein quartz, and metamorphic clasts. Silt- to clay-size limonite surrounds the clasts and goethite aggregates and appears to act as cementing agent binding the clasts and goethite aggregates together. Wood and plant remains occur with the clasts, goethite, and limonite cement, but the pieces of wood appear to be randomly oriented and totally replaced by limonite. In some samples from this bog iron deposit, the plant remains are coated by goethite and filled with limonite.

The bog iron deposit in Maitland Draw is approximately 1,000 feet long and ranges in width from 10 to 50 feet. The smallest width is at the upstream end from where it widens down the drainage until the stream changes direction from east to northeast. At the turning point, the bog iron deposit narrows to 10 feet. Bog iron rests on a black soil that emits a hydrogen sulfide odor near the upstream edge of the deposit; farther down the drainage, bog iron overlies ferruginous gravel conglomerate.

Gravel conglomerate mantles the north side of the drainage. It rests on steeply dipping Precambrian phyllite and extends only a few hundred feet up the drainage beyond the uppermost exposure of bog iron. The bedding in the conglomerate dips down the valley and crops out discontinuously above the bog iron deposits. At the upper end of the deposit, the conglomerate is 30 feet above the drainage. It dips beneath the deposit down the drainage.

Alluvial debris rests on the bog iron and ranges in thickness from 0 feet near the downstream end to 4 feet at the upstream end. The overburden at the upstream edge of the deposit (Cole, 1952) thins laterally in addition to horizontally thinning down the drainage. Mining of this deposit in the mid-1940's was terminated because of the increase of overburden up the drainage.

The bog iron deposit in Long Draw occurs at Lessering mine No. 2, which is part of the Lucky Strike Lode unpatented claim. The brownish-yellow bog iron contains aggregates of goethite, sand-size metamorphic clasts, organic matter, and a limonite cement. The yellow color indicates that the limonite content is much higher than in the Maitland Draw deposit. Long Draw deposit lies within the stream channel and is 1,000 feet in length. The uppermost exposure of bog iron in the drainage has a maximum width of 25 feet; this width remains fairly constant down the drainage for about 300 feet until it broadens to 75 feet and then remains constant for 700 additional feet. The maximum thickness occurs in the middle of the deposit, but there is little thinning up the drainage until the deposit width narrows to 25 feet. There, the thickness gradually decreases from 3 feet to less than 1 foot. The deposit also thins toward the margins of the valley.
Ferruginous gravel conglomerate is exposed on both sides of the valley, being thickest near the juncture of the Maitland Draw and Long Draw drainages. It thins and disappears a few feet beyond the lower end of the Long Draw bog iron deposit and extends horizontally up the Long Draw drainage for approximately 1 mile. Although conglomerate crops out on both sides of the drainage, it is exposed more often on the north side of the valley. Only in the vicinity of the bog iron deposit is the conglomerate exposed in the stream channel.

Long Draw deposit also is mined out. Remnants of bog iron and the ferruginous gravel conglomerate are now being eroded. Iron within these units is transported downstream in solution and in suspension, and is being deposited in an area where the drainage has ponded behind present and relic beaver dams.

The quality of bog iron ore mined from the Maitland and Long Draw deposits is represented in table 3 (Harrer, 1966).

**Hop Creek**

A bog iron deposit that crops out in the NW\(^2\)W\(^2\), sec 15, T 2 N, R 3 E, Pennington County, is here referred to as the Hop Creek deposit (fig. 8). The deposit, on the Albert Hausle ranch, was known as the Star and Double Star claims and the Mike Hausle mine. This deposit was one of the early sources of shipments of bog iron from the district. Approximately 3,500 tons of bog ore was shipped between 1924 and 1941 (Harrer, 1966).

The Hop Creek deposit, which crops out in and along the narrow gulch of Hop Creek, varies in texture, degree of consolidation, and iron content. The well-consolidated bog iron has a "fused" appearance. It is massive, hard, and nearly pure limonite whereas the unconsolidated bog iron is powdery, soft, plastic limonite diluted by organic bog debris and sand- and gravel-size clasts of Precambrian rock fragments.

The Hop Creek deposit is approximately 3,000 feet long. It is 20 feet wide at the north end of the deposit and 40 feet wide at the south end of the deposit. Approximately 2,000 feet from the north end of the deposit, the width decreases to about 15 feet and remains constant down the drainage. However, the deposit widens to about 75 feet where the South Fork of Rapid Creek and Hop Creek join. The thickness of the Hop Creek deposit averages 6 feet but ranges from 1 foot near the north end of the deposit to 10 feet near the middle of the deposit to 5 feet near the lower end of the deposit. There is little variation in cross-valley thickness.

Composition of the bog iron mined from this location is shown in table 4. The data represent average results from the Bureau of Mines channel samples taken in 1944 (Harrer, 1966).
### TABLE 3. - Results of sampling Long, Maitland, and Lessering Draws bog limonite, sec 19, T 2 N, R 3 E, Pennington County

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Chemical analyses, percent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Lode</td>
<td>Fe 55.7 P .027 S - 3.2 SiO₂ 23.3 Loss 3.73</td>
<td>Bureau of Mines bulk sample of shipping ore, 1942.</td>
</tr>
<tr>
<td>Lucky Strike</td>
<td>49.0 P .021 S 1.71 SiO₂ 4.23 Loss 23.3 3.73</td>
<td>Bureau bulk sample across pit face, avg. 5.5 ft thick, 1942.</td>
</tr>
<tr>
<td>Lucky Strike</td>
<td>49.0 P .021 S 1.57 SiO₂ 4.23 Loss 23.3 3.83 4.99</td>
<td>Bureau composite of 6 channel samples, 1944.</td>
</tr>
<tr>
<td>Lucky Strike</td>
<td>53.7 P .004 S 1.28 SiO₂ 4.00 Loss 20.83 9.00</td>
<td>Bureau grab sample of shipping ore, 1942.</td>
</tr>
<tr>
<td>Lucky Strike</td>
<td>49.7 P .022 S 1.76 SiO₂ 3.95 Loss 23.40 3.33</td>
<td>Bureau bulk sample across pit face, avg. 3.5 ft thick, 1942.</td>
</tr>
<tr>
<td>Lucky Strike</td>
<td>49.7 P .022 S 1.51 SiO₂ 3.95 Loss 23.40 3.33 4.74</td>
<td>Bureau composite of 6 channel samples, 1944.</td>
</tr>
</tbody>
</table>

The ore also contained traces of manganese, some acid-soluble silica, water-soluble calcium, and sulfate.

TABLE 4. - Average of U.S. Bureau of Mines chemical analyses of bog iron taken from the Hop Creek deposit, 1944

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>51.30</td>
</tr>
<tr>
<td>P</td>
<td>.015</td>
</tr>
<tr>
<td>S</td>
<td>1.04</td>
</tr>
<tr>
<td>Si</td>
<td>3.68</td>
</tr>
<tr>
<td>Moisture</td>
<td>3.64</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>21.30</td>
</tr>
</tbody>
</table>

The iron-cemented gravel conglomerate crops out in Hop Creek Gulch, occurring 200 feet above the creek on the west side of the valley and 80 feet above the creek on the east side of the valley approximately 1,400 feet north of the Peterson ranch. The conglomerate extends horizontally up the drainage on the west side of the valley for approximately 700 feet. On the east side of the valley, it is exposed for only approximately 100 feet. The outcrops are fairly continuous horizontally and vertically. The conglomerate crops out 2,000 feet beyond the northernmost extent of the bog iron deposit, where it is only 5 feet thick, occurs 20 feet above the present drainage, and is continuously exposed for about 225 feet. The conglomerate is discontinuously exposed up the drainage for approximately 1 mile north of the bog iron deposit, but is not exposed beneath the stream beyond the north end of the bog iron deposit. Conglomerate exposures are continuous from the northernmost extent of the bog iron to where Hop Creek empties into the South Fork of Rapid Creek. Gravel conglomerate within the stream channel was exposed by mining in the early 1960's by Pete Lien and Sons.

Solomon Gulch

The Solomon Gulch deposit is in secs 21 and 22, R 3 E, T 2 N, Pennington County (fig. 8). The creek in Solomon Gulch is a small north-flowing tributary of the South Fork of Rapid Creek. The deposit has been mined, but no record now exists of the amount of ore extracted.

The deposit is exposed below a stock dam in SE1/4, SE2, sec 21, R 3 E, T 2 N, Pennington County, and continues downstream for approximately 3,000 feet. The deposit is 10 feet wide just below the stock dam, widens rapidly to 25 feet down the drainage, and remains fairly uniform in width down the rest of the drainage to where the bog iron terminates. The bog iron ranges from 0 to 5 feet in thickness, being thinnest near the south end and margins of the deposit. Downstream, the thickness increases rapidly from 0 to 5 feet and remains relatively uniform until the deposit terminates.
The bog iron is the unconsolidated type and consists of limonite mixed with clay and silt-to-sand-size clasts of Precambrian rocks; it has a brownish-yellow to yellow color due principally to the presence of limonite. In places, small leaf and root fragments, now totally replaced by limonite, are scattered throughout the bog iron.

Exposures of ferruginous gravel conglomerate occur within the stream channel below the stock dam and on the west side of the drainage 1 to 3 feet above the present stream. The conglomerate is discontinuously exposed a few feet above the stream down the west side of the drainage for almost 2 miles. A younger gravel conglomerate is exposed on the west side of the drainage in the vicinity of water station 3 (fig. 9). This conglomerate, which rests on bog iron, is composed of rounded to subrounded clasts of phyllite, graphite schist, and quartzite fragments. Limonite matrix derived from the bog iron, silt-size rock fragments, charcoal, and root and leaf clasts fill the spaces between clasts. The clasts, matrix, and organic matter are weakly bound together by authigenic hematitic cement. This younger conglomerate is not very extensive and occurs only in the vicinity of station 3.

A thin soil cover appears to rest on top of the bog iron. Evidence of the internal stratigraphy was destroyed by previous mining.

**Iron Hills**

Bog iron deposits, here referred to as the Iron Hills deposit, are exposed in an east-flowing tributary of the North Fork of Castle Creek in secs 4 and 5, R 3 E, T 1 N, Pennington County (fig. 8). Claim markers located on either side of the bog deposits are marked Iron Hills. Two deposits crop out in the Iron Hills drainage.

The upper Iron Hills deposit crops out in the E½ of section 5 and extends downstream approximately 1,500 feet. Downstream 200 feet from this deposit is another bog iron deposit that extends an additional 1,500 feet down the drainage. The upper deposit has a constant width of 25 feet. The western end of the upper deposit is 10 feet thick and thins down the drainage to approximately 3 feet. The lower Iron Hills deposit has a width of 10 feet at the western end that increases downstream to approximately 30 feet and remains fairly constant for virtually the entire length of the deposit. Bog iron in the lower Iron Hills deposit is uniformly about 6 feet thick for the entire length of the deposit.

The bog iron is highly variable in both the upper and lower Iron Hills deposits. In the upper deposit, the bog iron has yellow-brown, brown, and reddish-brown colors. The iron ranges from hard, consolidated goethite and hematite to unconsolidated, powdery, limonite ocher. The two types appear to be randomly distributed. No organic matter was observed in the upper bog deposit. The lower deposit has the same variation in color and consolidation; however, much of the original stratigraphy is still preserved. At the western end of this
FIGURE 9. - Locations of water sampling stations.
deposit, a 2-foot thick horizon of limonite ocher rests on poorly consolidated reddish-brown bog iron. A total of 6 feet of bog iron rests on an undetermined amount of black bog soil at the western end of the lower deposit.

Ferruginous gravel conglomerate is exposed on the north side of the valley and there rests on bog iron. The gravel conglomerate extends up the drainage beyond the upper Iron Hills deposit for approximately 900 feet. It is exposed in discontinuous patches, is 1 to 2 feet thick, and is approximately 1½ feet above the present stream. Where the stream forks in the vicinity of water station 3, the conglomerate extends up the north fork for approximately one-quarter of a mile. On the north fork of the Iron Hills drainage, the conglomerate crops out within the stream channel and rests unconformably on Precambrian metamorphic rocks. The conglomerate also is exposed on the south fork of the Iron Hills drainage, but only for a few feet before it disappears. At the western end of the upper bog deposit, 3 feet of conglomerate rests on bog iron approximately 10 feet above the drainage. The conglomerate dips down the drainage and passes beneath the bog iron. At water sampling station 3, the conglomerate is exposed within the drainage and 2 feet above the stream. It extends discontinuously down the drainage and disappears a few feet up the drainage beyond the water station 9 (fig. 9).

**Bloody Gulch**

Bloody Gulch is in the NE¼ sec 25 and SE¼ sec 24, R 3 E, T 2 N, Pennington County (fig. 8). The gulch contains an upper and lower meadow surface underlain by alluvial gravel that rests unconformably on Precambrian rocks. The geology of the north meadow (lower Bloody Gulch) was mapped by R. W. Lane (1951). He separates the bedrock into the Precambrian Poorman, Homestake, and Ellison Formations on the basis of previous work done by Hosted and Wright (1923), Harder (1934), and Noble and Harder (1948). As noted earlier in this report, current work by the U. S. Geological Survey (McGehee and Bayley, 1969) indicates that some stratigraphic revisions are in order.

Approximately 20 feet of alluvium rests on the Precambrian metamorphic rocks in lower Bloody Gulch. The alluvium consists of approximately 4 feet of ocherous bog iron. Beneath the bog iron is 16 feet of gravel composed of subangular to rounded quartzite, phyllite, and schist clasts mixed with 10 50 20 percent of gray to black, clay-size to silt-size material.

Undifferentiated Precambrian metamorphic rocks and ferruginous gravel conglomerate lie up the drainage south of lower Bloody Gulch. The gravel conglomerate is exposed within the stream channel and on the valley flanks. Conglomerate is exposed on the eastern side of the valley approximately 20 feet above the stream and as three discontinuous horizons, each 10 to 20 feet long and 3 to 4 feet thick, exposed between water sampling station 10 and 11 (plate 1). Farther up the drainage,
conglomerate crops out 5 feet above the stream channel on the western side of the valley. Another exposure of gravel conglomerate occurs along the valley wall for about 10 feet and is about 2 feet thick. Ten feet from the last outcrop, the gravel conglomerate is in the stream channel and on the east side of the drainage. This exposure occurs continuously up the stream and on the eastern stream bank for about 600 feet and disappears beneath alluvium in the vicinity of water sampling station 2. Scattered outcrops of conglomerate mantle the east valley wall 200 feet southeast of water sampling station 1. Here the conglomerate reaches a maximum thickness of 10 feet and is well exposed in a mine adit. This is the southernmost exposure of the ferruginous conglomerate in the Bloody Gulch drainage.

Bog iron in Bloody Gulch is of the unconsolidated variety. It has a reddish-brown to yellow-brown color. The limonite, which is in the clay fraction, is mixed with silt- and sand-size clasts of metamorphic rocks. Limonite aggregates weakly cemented together by opal occur with the clasts.

The shape and occurrence of the bog iron deposits were determined by drilling 88 auger holes (plates 2 and 3). The bog iron was found in four areas. The southernmost deposit, which is the highest in elevation, is oval shaped, 300 feet long, and 50 feet wide. The thickness, which ranges from 0 to 3 feet, is about 3 feet in the middle and thins rapidly toward the margins. Most of this deposit lies within the present stream channel. A second bog iron deposit, which crops out 300 feet north of the first deposit, has an overall arcuate shape convex towards the west and extends longitudinally for 1,000 feet and laterally for 200 feet. The maximum thickness of this deposit is 5 feet; it thins rapidly towards its margins. Exposures of bog iron appear on both sides of the present stream; however, the bog iron is thickest on the western side of the stream.

The third and fourth bog iron deposits crop out in lower Bloody Gulch. These deposits have an overall sinuous shape. The southernmost deposit is 700 feet long (plate 2). Its width ranges from 75 feet at its south end to 300 feet in the middle to 10 feet at its northern end. The thickness ranges from 1 foot on the margins to 4 feet in the middle, with a 75- by 15-foot thin area at the northern end. An 800- by 200-foot bog iron deposit occurs north of the group of three described. Its thickness ranges longitudinally from 2 feet at the northern end to 3 feet at the southern end and thins to zero towards the valley margins.

Bog iron samples were collected from the four deposits in Bloody Gulch and analyzed for total iron content. Deposit 1 has a total iron content of 32 percent. The iron content of the second deposit, north of the upper deposit, ranges from 23 percent at its southern end to 26 percent at the northern end. At hole 27-00 iron content ranges vertically from 26 percent near the top to 9 percent at the bottom. The third deposit's iron content ranges from 23 percent at its southern
PLATE 1. - GEOLOGIC MAP OF LOWER BLOODY GULCH, ROCHEFORD, S. DAK.
PLATE 2. - ISOPACH MAP OF BOG IRON IN BLOODY GULCH.
PLATE 3. - LOCATION OF AUGER HOLES IN BLOODY GULCH.
end to 14 percent at its northernmost exposure. The western margin of this deposit has a total iron content of 20 percent, whereas on the eastern margin the iron content is 15 percent. The northernmost deposit has an iron content ranging from 14 percent at its southern exposure to less than 9 percent at its northern end. In general, the iron content decreases downstream.

Summary

Bog iron deposits in Hop Creek, Maitland Draw, Long Draw, Swilley Draw, Solomon Gulch, Iron Hills Gulch, Bloody Gulch, and Black Fox Campground have the following common characteristics:

1. They occur in small alluvial valleys resting on alluvium and/or gravel conglomerate.
2. They are near the surface or exposed on the surface.
3. Ferruginous gravel conglomerate is exposed within the drainages.
4. With the exception of Bloody Gulch, the iron content is approximately 50 percent.
5. Their overall shape is lenticular, thickest in the middle and thinning toward the margins.
6. Most of the deposits are partially or totally mined.

The degree of consolidation, type and amount of organic matter, clastic content, and geometry vary slightly for each deposit. In general, the consolidated variety has a higher total iron content and more organic matter. The unconsolidated bog iron deposits are richer in the mineral limonite, and the consolidated bog iron deposits are richer in the mineral goethite.

CHEMICAL DATA

Fifty water samples were collected at monthly intervals on the streams flowing through Bloody Gulch, Iron Hills Gulch, Hop Creek, and Swilley Draw (fig. 9). The water collection program was conducted in order to define some of the existing chemical parameters associated with the environment in which bog iron was formed. Water was sampled in the streams above, within, and below the outcrop of bog iron deposits. Collected samples were tested for pH, Eh, total iron, suspended iron, soluble iron, and water temperature. The samples were taken once a month in order to detect seasonal variations.
Water samples were collected in polyethylene bottles and brought back to the laboratory for analysis. Field and laboratory measurements of Eh and pH were compared. The results indicated that the pH values deviated 10 percent, whereas Eh values were in error as much as 50 percent. Eh values were measured with a glass and a platinum electrode. The potential of the glass reference electrode was added to the measured potential in order to determine the Eh value (Hansuld, 1966).

**Hop Creek**

The monthly chemical data collected on Hop Creek are graphically presented in plate 4. Water collected in the vicinity of sample station 1 (fig. 9), located beyond the bog iron deposit on Hop Creek, has an average pH of 4.7. Where the creek flows into a beaver pond that inundated an earlier mined bog iron deposit below station 1, the pH drops to 3.3 and decreases to 3.1 down the drainage until the creek empties into the South Fork of Rapid Creek, which has an average pH of 8.2.

Oxidation and reduction potential, Eh, ranges from 0.051 volt at station 1 to -0.19 volt at station 5. The voltage remains negative downstream to where Hop Creek flows into Rapid Creek. The Eh varies seasonally from -0.19 in September to -0.10 in April. The pH remains relatively constant throughout the year and may vary ±0.5.

The iron content of Hop Creek changes systematically. Above the bog iron deposit, the water in Hop Creek contains less than 0.1 ppm iron. Where the creek flows over gravel conglomerate and unmined bog iron, the iron content of the stream water increases to 1 ppm or more. From station 2, Hop Creek flows continuously on gravel conglomerate and unmined bog iron until it reaches station 8. Through this reach of the stream, iron is transported both in suspension and solution. Suspended iron increases downstream from 0.2 ppm to 0.8 ppm, and soluble iron increases from 0.1 ppm to an excess of 5.26 ppm until Hop Creek flows into Rapid Creek. The South Fork of Rapid Creek has a pH of 8.0 (±0.4), an Eh of 0.3 volt (±0.1 volt), and an iron content of 0.06 ppm. The high pH, Eh, and carbonate content of the South Fork of Rapid Creek cause the precipitation and flocculation of soluble iron from Hop Creek when the two streams merge. Precipitated iron hydroxide adheres to cobbles and other debris in the streambed and delineates a well-defined zone (fig. 10).

**Iron Hills**

The pH of the stream above the upper bog iron deposit at Iron Hills is approximately 7.5 at station 1 (plate 5, fig. 9). The pH is lowered to approximately 6.0 at station 3, below the North Fork of Iron Hills, illustrating the effect of stream flow across exposed ferruginous gravel conglomerate at station 2. The stream disappears into the alluvium below station 3, and reappears at station 4 where the Upper Iron Hills bog iron deposit crops out. From station 4 to station 6, the pH remains
PLATE 4. – MONTHLY COMPARISON OF CHEMICAL PARAMETERS IN HOP CREEK.

FOR THE MONTHS OF AUGUST, NOVEMBER-DECEMBER & APRIL

FOR THE MONTHS OF SEPTEMBER, OCTOBER, JANUARY & MARCH

EXPLANATION

- AUGUST
- SEPTEMBER
- OCTOBER
- NOVEMBER-DECEMBER
- JANUARY
- FEBRUARY
- MARCH
- APRIL
- SAMPLE STATION ON THE SOUTH FORK RAPID CREEK
FIGURE 10. - Discoloration on streambed is produced by precipitated soluble iron from Hop Creek. Hop Creek is on the left; South Fork of Rapid Creek is on the right.
PLATE 5. – MONTHLY COMPARISON OF CHEMICAL PARAMETERS IN IRON HILLS.

FOR THE MONTHS OF AUGUST, NOVEMBER, DECEMBER & APRIL

FOR THE MONTHS OF SEPTEMBER, OCTOBER & JANUARY

EXPLANATION
• AUGUST
• SEPTEMBER
• OCTOBER
• NOVEMBER, DECEMBER
• JANUARY
• APRIL
κ SAMPLE STATION ON THE NORTH FORK OF IRON HILLS
between 3.0 and 3.5 until the stream disappears into the alluvium below station 6. The stream reappears at station 7 with a pH slightly higher than that at station 6. However, because the stream flows on bog iron, the pH decreases rapidly downstream to an average level of 3.10.

The Eh is 0.3 volt (±0.1 volt) at station 1 and decreases to 0.0 volt (±0.1 volt) downstream.

The iron content of the stream before encountering the bog iron deposits is approximately 0.03 ppm at station 1. Where the flowing stream comes in contact with the upper Iron Hills bog iron deposit, the iron content is sometimes increased to more than 5.26 ppm, then tapers off to less than 0.5 ppm at station 7, increases to 5 ppm at station 8, and finally decreases to less than 0.1 ppm before it disappears into the alluvium below station 9. The variation of iron content downstream is probably attributable to the disappearance and reappearance of the stream in the alluvial gravels that remove both soluble and suspended iron between stations 6 and 7 and stations 8 and 9. However, the stream is soon enriched in iron after it reappears on the surface.

The iron is transported in both solution and suspension. When the pH is greater than 6.0, most of the iron is transported in suspension. When the pH is between 3 and 4, most of the iron is transported in solution; one exception on this drainage is at station 4. The stream reappears from the alluvium 20 feet above station 4 and begins mechanically eroding the bog iron deposit. Much of the iron is still in suspension where the stream passes station 4, but soon goes into solution farther downstream.

**Swilley Draw**

The stream that flows through Swilley Draw first appears 20 feet above station 1. Because the flowing stream traverses gravel conglomerate and bog iron debris, it was impossible to take a water sample that was not influenced by the bog iron.

The pH ranges from 3.4 at station 1 to 2.9 at station 5 and increases to 3.2 at station 8. The Eh appears to decrease systematically downstream from -0.05 at station 1 to -0.12 volt at station 8 (plate 6).

Iron is transported downstream in suspension and solution. Ninety-five percent of the iron is transported in solution. The soluble iron content is in excess of 5.26 ppm in the summer months and decreases to 3.5 ppm (±0.4 ppm) in the fall and winter months. In the spring, the iron content increases to more than 5.26 ppm. Suspended iron ranges from 1 ppm at station 2 to 0.36 ppm (±0.1 ppm) downstream. The suspended iron content also varies seasonally.
Solomon Gulch

In Solomon Gulch at station 1 (fig. 9), water ponded behind a stock dam above the deposit has a pH of nearly 7.0 (plate 7). Where the stream flows across the deposit at station 2, the pH drops from 7.0 to 3.0 (±2.0). The Eh is 0.3 volt (±0.1 volt) at station 1 and decreases to -0.1 volt (±0.1 volt) downstream. Iron content of the stream is less than 0.1 ppm before it flows across the bog iron deposit at station 2. At station 2, bog iron and gravel conglomerate are mechanically eroded. Initially, iron is transported downstream and partially dissolved between stations 2 and 3. The stream contains iron values in excess of 5.26 ppm. However, where the stream is ponded behind recent and relic beaver dams at station 5, most of the iron is retained behind the dams. Water passing out of the beaver dams decreases in iron content from 3.0 ppm at station 5 to less than 1.0 ppm at station 6. However, downstream at stations 7, 8, and 9, the stream mechanically erodes ferruginous gravel conglomerate, which slightly increases the iron content.

Except in the spring months, there is little seasonal variation. In April, the pH values below station 2 were increased, Eh values were positive, and the stream had a higher suspended iron content.

Bloody Gulch

Bloody Gulch, the only unmined bog iron deposit investigated, has pH values between 6.0 and 7.0 above and within the deposit (plate 8). In the vicinity of station 1, upstream from the deposit, the stream water has a pH greater than 7.0 (±0.3) and an iron content less than 0.03 ppm. At station 2, the stream first encounters and actually erodes ferruginous gravel conglomerate. Mechanically eroded iron oxide increases the iron content of the stream from 0.03 ppm to more than 1.0 ppm (fig. 11). Farther downstream, the total iron content increases to more than 5.26 ppm. Approximately 95 percent of the iron in the stream is in suspension.

Although Eh is quite variable along the stream, there appears to be an increase in Eh that accompanies a concommitent decrease in pH (plate 8). The Eh values range from 0.3 volt to 0.35 volt. In the winter and spring months, the Eh is slightly lower.

Conclusions

The water sampling program indicates that very little (0.03 ppm) iron is now supplied by Precambrian schist, phyllite, and quartzite. Most of the iron oxide that formed or is forming bog iron deposits is derived from the mechanical erosion and solution of ferruginous gravel conglomerate. Once the iron oxide is eroded by abrasion, the mode of transport is a function of pH conditions of the stream. Where the stream has a pH between 3.0 and 4.0, the iron oxide is transported in solution; where the pH is basic or nearly basic, the transported iron is in suspension.
PLATE 6. - MONTHLY COMPARISON OF CHEMICAL PARAMETERS IN SWILLEY DRAW.

FOR THE MONTHS OF AUGUST, NOVEMBER-DECEMBER & APRIL

FOR THE MONTHS OF SEPTEMBER & OCTOBER

EXPLANATION
* AUGUST
△ SEPTEMBER
◯ OCTOBER
• NOVEMBER-DECEMBER
▼ APRIL
PLATE 7. — MONTHLY COMPARISON OF CHEMICAL PARAMETERS IN SOLOMON GULCH.

FOR THE MONTHS OF AUGUST, NOVEMBER—DECEMBER & APRIL

FOR THE MONTHS OF SEPTEMBER, OCTOBER, & JANUARY

EXPLANATION
- AUGUST
- SEPTEMBER
- OCTOBER
- NOVEMBER—DECEMBER
- JANUARY
- MARCH
- APRIL
PLATE 8. - MONTHLY COMPARISON OF CHEMICAL PARAMETERS IN BLOODY GULCH.

FOR THE MONTHS OF AUGUST, NOVEMBER-DECEMBER & APRIL.

FOR THE MONTHS OF SEPTEMBER, OCTOBER, JANUARY & MARCH.

EXPLANATION

- AUGUST
- SEPTEMBER
- OCTOBER
- NOVEMBER - DECEMBER
- JANUARY
- MARCH
- APRIL
- SPRING ADJACENT TO CREEK
FIGURE 11. – Accumulation of iron hydroxide in streambed at station 2 in Bloody Gulch.
The pH of natural stream waters ranges from 4.0 to 9.0. Almost all the major streams in the Rochford district originate from Paleozoic limestone springs. Therefore, it is safe to assume that these streams are basic or nearly basic depending on how often they pass through stagnant or nearly stagnant bodies of standing water. The pH values between 3.0 and 4.0 are unnaturally low, and only streams that encounter bog iron deposits attain such low values. Therefore, it is assumed that something within the bog iron deposits reduces the pH from 7.0 to less than 4.0. Iron Hills Creek was tested for sulfate content above and within the bog iron deposit. It was found that the stream water within the bog iron deposit had twice as much sulfate as the water above the iron deposit. Thus, the lowering of pH is probably related to increase in sulfate from the bog iron deposits. The lowering of pH occurs in most of the streams that erode bog iron deposits in the Rochford district. Bloody Gulch is an exception, which probably may be attributed to the fact that stream flow below station 2 is over ferruginous gravel conglomerate and rarely encounters bog iron until it disappears into the alluvium above station 12.

In the late summer and early fall, the pH and amount of transported iron remain reasonably constant. However, when temperatures begin to drop below freezing, the flow of the streams subsides and then erosive power decreases. During the period of measurement, decrease in stream discharge was paralleled by a decline in iron content within the streams. During the winter of 1968–69, subzero temperatures existed for considerable periods during which small streams froze. In late March and early April 1969, several weeks of warm weather produced melting and increase of flow to about one and one-half to twice the flow that occurs during the summer months. Increased flows in Hop Creek, Swilley Draw, Solomon Gulch, and Iron Hills Gulch were accompanied by an increase in total iron content of these streams.

ORIGIN OF THE BOG IRON DEPOSITS

There is some speculation concerning the source material that contributed to the formation of bog iron deposits. Cole (1952) and Harrer (1966) believe that the iron was derived from the oxidizing of pyritic and pyrrhotitic schist and hematitic quartzite. In the investigated area, the occurrence of pyrite- and pyrrhotite-bearing rocks is restricted to a few outcrop exposures; and in many of the drainages investigated, these sulfide-bearing rocks are absent. Furthermore, the streams, which flow beneath and over Precambrian rocks, have a total iron content of less than 0.06 ppm. It does not seem likely that this iron content could concentrate in a relatively short period to produce bog iron deposits in the Rochford district.

Ferruginous gravel conglomerate is associated with all the bog iron deposits investigated. It mantles valley walls and ridge tops, and is exposed in stream channels of Hop Creek, Iron Hills, Solomon Gulch,
Swilley Draw, and Bloody Gulch. Upstream from conglomerate exposures, the streams have a total iron content of 0.06 ppm. Where the stream flows over conglomerate, the total iron content increases from 0.06 ppm to 5.26 ppm or greater. The erosion of the conglomerate is mainly by mechanical processes. This is evident in Iron Hills and Solomon Gulch drainages. Where the stream first flows over conglomerate, 90 percent of the erodible iron, limonite matrix, and hematite cement is freed and transported in suspension. However, if the pH of the stream is between 3.0 and 4.0, most of the suspended iron dissolves during transport downstream. Where the pH is greater than 6.0, as in Bloody Gulch, most of the erodible iron is transported in suspension.

The iron, whether dissolved or suspended, is transported downstream and deposited in an environment that leads to the accumulation of bog iron. This is observed in Swilley Draw where the conglomerate is still contributing iron for the formation of new bog iron deposits below the deposit that was mined. The ferruginous gravel conglomerate provides a more reasonable source of iron for the formation of bog iron deposits in this area.

An environment that leads to the accumulation of bog iron is a bog, swamp, or sluggish watercourse. Iron in the Rochford district, for the most part, was transported in suspension until it encountered a bog environment that had a pH of less than 5.0 and an Eh of slightly less than 0.00 volt. Some of the transported suspended iron settles to the bottom of the bog, collecting around tree roots and swamp grasses. Some of the transported iron goes into solution while in the bog environment. Microorganisms, such as iron-fixing bacteria, likely induce the precipitation of soluble iron that accumulates in the bottom of the bog (Harder, 1909; Oborn, 1962). Gary Allen, of the Mining Engineering Department of South Dakota School of Mines and Technology, attempted to culture suspected iron-fixing bacteria from a bog where iron is now accumulating. However, none of the cultures grew. Of course, this does not necessarily mean that the bacteria are not present.

MINING DEVELOPMENT

In the past, bog iron deposits were mined by dragline and bucket rigs and front-end loaders. Because most of the deposits crop out at or near the surface, this method of mining is probably the most efficient and economical. However, this type of mining produces a great deal of stream contamination that often can disrupt the ecology and destroy stream wildlife in the vicinity of the mining. Such contamination is attributable to an increase in suspended material and a decrease in pH.

To prevent stream contamination, the construction of settling ponds is imperative. The ponds would serve as collecting basins for suspended material, but they would still remain highly acid. Therefore, they must be neutralized before the water is discharged into the drainage
system. This could be accomplished by adding a lime slurry or some other inexpensive material that would raise the pH of the waters and induce precipitation of soluble iron. As a further aid to minimizing contamination, the deposits should be mined in the winter months when the ground is frozen.

Another way to minimize contamination would be to divert the active stream around the mining area. After mining, the mined area could be backfilled and the stream returned to its natural watercourse.

Pete Lien and Sons, the most recent operator in the Rochford district, has had some success in mining bog iron deposits. This company has participated in a program of land reclamation that involves backfilling and reseeding mined areas (fig. 12). Areas containing bog iron deposits are usually swampy, iron-rich, and very acidic. The removal of bog debris and iron ore, together with backfilling, leaves the mined area more arable.

Cole (1952) estimates that approximately 500,000 tons of bog iron remains in the Rochford district. Since 1952, approximately 56,000 tons of bog iron has been removed from this district, leaving 440,000 tons of bog iron to be mined. However, some of the bog iron included in this estimate has an iron content too low to mine economically.

An estimate, which included only bog iron with an iron content greater than 45 percent, indicated that less than 25,000 tons of bog iron ore remains in the eight deposits investigated. Total reserves for the entire district are reduced to less than 125,000 tons when the 45-percent cutoff is used.

At present, the State Cement Plant in Rapid City, S. Dak., is the nearest market for bog iron ore. Because of the small size of the bog iron deposits and their scattered distribution, it is currently not feasible to ship bog iron ore great distances. It appears that the State Cement Plant will continue to purchase bog iron ore for the manufacture of type 2 cement even though the plant has a stockpile of bog iron which, at current rates of consumption, will last several years.

SUMMARY AND CONCLUSIONS

1. The occurrence of bog iron deposits is directly related to the presence of ferruginous gravel conglomerate in streambeds.

2. Mechanical erosion of this conglomerate provides a source of soluble and suspended iron oxide that will form a bog deposit.

3. Most of the bog iron deposits are now influencing the surrounding environment by lowering the streams' pH and Eh.
4. The pH appears to be controlling the nature of iron transport. When the pH is nearly basic, the eroded iron is transported in suspension. If the pH is between 3 and 4, most of the iron is transported in solution.

5. Dragline and bucket mining of bog iron deposits will cause stream contamination. Such contamination may be checked by the construction of settling ponds and the neutralization of ponded waters by the addition of lime.
FIGURE 12. – Mine by railroad tracks was backfilled by Pete Lien Sons, producing a more arable area.
REFERENCES


