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STATE OF SOUTH DAKOTA
George T. Mickelson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 38

MANGANESE DEPOSITS OF THE LOWER MISSOURI VALLEY IN SOUTH DAKOTA

by

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and

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University of South Dakota
Vermillion, South Dakota

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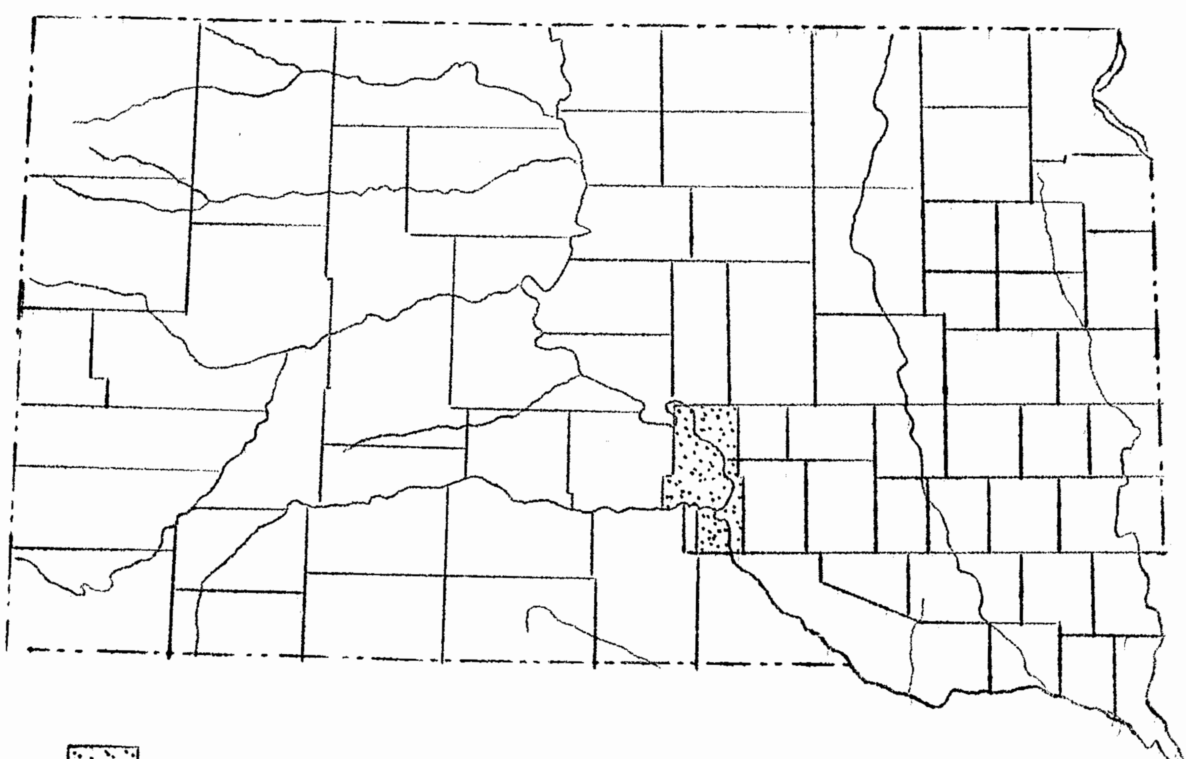
INDEX MAP



Area covered by this survey.

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MANGANESE DEPOSITS OF THE LOWER MISSOURI VALLEY IN SOUTH DAKOTA

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INTRODUCTION

The presence of low grade manganese deposits in the bluffs of the Missouri Valley has been known for many years. Attempts to develop this material, however, have met with little success. Events connected with the European and Asiatic Wars, however, have focused attention on the possibility of using domestic supplies of manganese to offset a real or possible shortage of this material from foreign sources.

Enough information on the South Dakota deposits has been made public through the work of the U. S. Geological Survey[1] to show that the South Dakota deposits contain a large amount of potential manganese ore which could be put on the market easily if needed. This information, however, was not sufficient to answer the questions which were raised by the increased publicity given these deposits by the war. The State Geological Survey, therefore, attempted to supplement and enlarge the work of the federal survey by careful mapping and systematic sampling of the deposits, not only in the area previously covered but the entire length of the deposits in the Missouri Valley. The following report, therefore, covers the findings of the first field work on this project.

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1. D. F. Hewitt, Manganese-Iron Carbonate Near Chamberlain, South Dakota, Memorandum for the Press, U. S. Geol. Survey, February 5, 1930.

Location and Area

The manganese deposits have been traced from a point a few miles east of Pierre down the Missouri Valley to the Rosebud bridge near the Nebraska line, a total distance of 150 river miles. Since it was impossible to cover so large an area in one season's work, the city of Chamberlain was taken as the central point of the first survey. From this city the survey was carried northward to the Big Bend of the Missouri and southwest along the Missouri Valley to the Iona-Bijou Hills.

Thus the deposits were studied in a region where access to markets was easiest by way of the Chicago, Milwaukee, St. Paul and Pacific Railroad which crosses the river at Chamberlain. This survey covers the deposits in Buffalo, Brule, northern Charles Mix, northern Gregory, and part of Lyman County, including an area of 811 square miles.

Methods of Work

In order to obtain the detail desired, the outcrops of the manganese zone were mapped with plane table on the scale of 2 inches to the mile. Three plane table parties were used, each mapping in units of one township. These township maps were then assembled into the composite map which accompanies this report. Thus an accurate horizontal control was obtained which gives the location of the outcrops within plane table accuracy. To the horizontal control was added a vertical control by carrying elevations to the outcrops from precise level bench marks of the U. S. Coast and Geodetic Survey, and the survey of the Missouri River Commission. This control disclosed the structural features of the deposits.

Sample collections were spaced so that there would be at least one in each township surveyed. An attempt was made to space them about six miles apart. This spacing could not be rigidly adhered to, however, because the method of sampling demanded good exposures on steep slopes. The sampling previously done by the General Manganese Corporation and reported by the U. S. Geological Survey[1] was also a determining factor in picking sample

1. D. F. Hewitt, *op. cit.*

locations, since there was no desire to duplicate work already done. Some samples were taken from the stock piles that were left at these pits for check analyses.

Sampling was done by trenching across the entire manganese outcrop on a steep hill where the zone was well exposed and slumping would not interfere. These trenches were dug to a sufficient depth to insure the exposure of fresh rock with the layers of manganese bearing nodules in place. The thickness of each nodular layer and the intervals between them were carefully measured, using a level rod and either an alidade or dumpy level. Separate clean samples of each layer were taken for analysis. These samples were cleaned with a wire brush to remove clay and weathered material from the outside before crushing.

The samples were then analyzed in the State Chemical Laboratory and the laboratories of the Chemistry Department of the State University. The procedure used for the determination of manganese was the standard sodium bismuthate method.[1] The ore was put in solution by digestion with nitric acid and hydrogen peroxide, the residue being treated further with a mixture of hydrofluoric, nitric, and sulfuric acids. After suitable treatment to destroy organic matter, aliquot parts of the solution were chilled and shaken with an excess of sodium bismuthate, filtered on asbestos, and the permanganate reduced with a known quantity of ferrous ammonium sulfate. The excess ferrous ammonium sulfate was titrated with standard permanganate.

Acknowledgments

The State Geologist wishes to acknowledge the work of the members of this survey party, to which the success of the project is entirely due. The contributions of Dr. J. P. Gries and Dr. M. E. Wing to the geology of the deposits set forth in this and another report speak for themselves.[2] The painstaking mapping and instrument work directed by Professor H. E. Brookman with the assistance of Ray Maloney and David Rothrock is reflected in the map and detailed sections accompanying this report.

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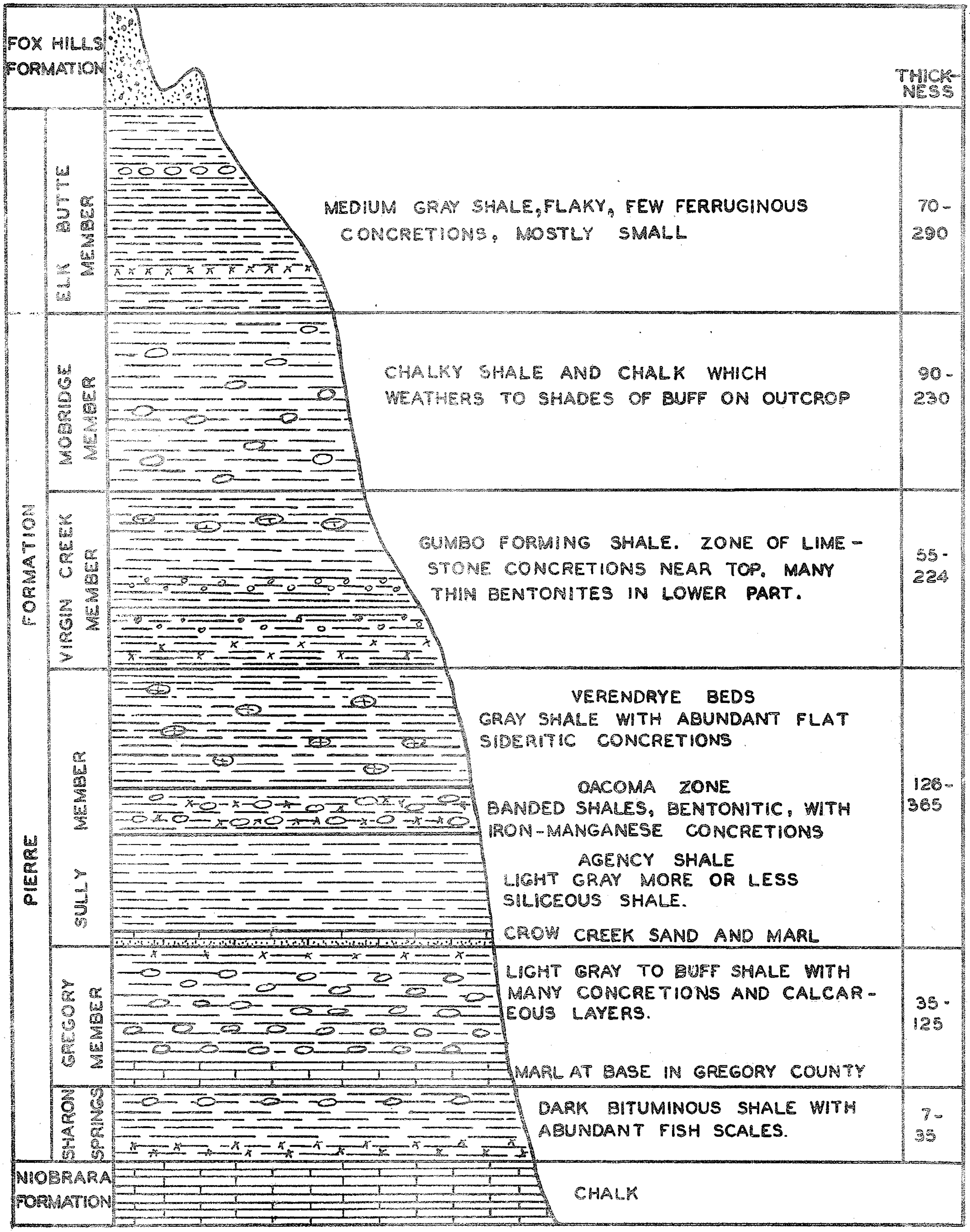
1. Scott, W.W., "Standard Methods of Chemical Analysis," Fifth Ed., D. Van Nostrand Co., N.Y., pp. 562-565, 1939.
2. Wing, M. E., and Gries, J. P., "Structures in Eastern Lyman County," S. Dak. State Geol. Survey, R. I. # 39, 1941.

The assistance of Mr. Richard Aroner in both the geologic mapping and sectioning was an important factor in the successful completion of the survey. Appreciation is also extended to Mr. Guy G. Frary, State Chemist, under whose direction many of the chemical analyses were made, and to Dr. Ernest Griswold of the Department of Chemistry at the State University for his careful analytical work while the field survey was in progress. Thanks are also due Dr. A. M. Pardee, Head of the Department of Chemistry at the State University for the use of laboratory space and equipment.

Special mention should also be made of the part played by the Chamberlain Chamber of Commerce and by the citizens of Chamberlain and the surrounding country, who went to considerable trouble to assist members of the party, giving information, locating comfortable camp grounds, and many other courtesies, which contributed much to the success of the survey.

PLATE I
GENERALIZED COLUMNAR SECTION OF THE PIERRE FORMATION



STRATIGRAPHY-FORMATIONS EXPOSED AT THE SURFACE

INTRODUCTION

General Description of the Area

The formations exposed along the valley of the Missouri River in the area under consideration are the Niobrara chalk and the various subdivisions of the Pierre shale. These are of Upper Cretaceous age. Some of the higher hills adjacent to the area are capped with Tertiary clays and sandstones, but these were not investigated during the course of the present study. East of the river, the bedrock is generally overlain by a mantle of clay and boulders known as glacial till, deposited by the glaciers during the Pleistocene or Ice Age. In addition, terrace gravels of late Tertiary and Quaternary age overlie the bedrock in many places, particularly west of the Missouri. The glacial till and gravels were of interest in this survey only in that they frequently obscured the bedrock, so no detailed study of them was attempted.

Detailed mapping of the area covered by this report extended from the Iona-Bijou line of hills on the south to the Great Bend of the Missouri on the north. In order that the stratigraphic study might cover as large an area as possible, however, detailed sections of the Pierre formation were measured as far south as the Rosebud bridge, Gregory County, and north to the vicinity of DeGrey, Hughes County. Similarity of the DeGrey and Ft. Pierre sections makes it possible to connect the stratigraphy of this area with that previously studied in and north of Stanley County.[1]

Previous Work

The rocks exposed along the Missouri River in South Dakota, and their fossil content, have been a matter for scientific discussion for over 100 years. A concise review of this early work has been given in a previous publication,[2] and will not be repeated here.

1. See Reports of Investigation Nos. 27, 31 and 34, South Dakota State Geological Survey.
2. Searight, W. V., "Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in South Dakota," Report of Investigations No. 27, S. Dak. State Geol. Survey, 1937.

The first detailed study of the stratigraphy in this particular area was made in 1929 by D. F. Hewitt[1] of the United States Geological Survey, during the course of an investigation of the iron manganese concretion beds in the vicinity of Chamberlain. A comprehensive study and subdivision of the Pierre formation in the Missouri Valley of South Dakota was made by Searight[2] in 1937. This classification opened the way for further detailed studies within the state. The present report summarizes the results of the fourth of a series of stratigraphic and structural surveys undertaken by the State Geological Survey since that time. Each covers the stratigraphy and economic possibilities of a limited area along the Missouri valley.

DETAILED DESCRIPTIONS

Niobrara Formation

The impure chalk which comprises the Niobrara formation in typically gray on fresh exposures. After long weathering, the formation usually presents a yellowish appearance, although some members remain gray, or become nearly white under these conditions. Numerous thin bentonite beds are characteristic of the formation, but are conspicuous only on relatively fresh outcrops.

This chalk, the lowest formation exposed within the area, occurs in bluffs along the river's edge as far north as Fort Thompson, Buffalo County, where it dips beneath the river level. Approximately 100 feet of the Niobrara is exposed in the vicinity of Chamberlain, and this decreases gradually to about 20 feet at the Rosebud bridge.

Fossils are not conspicuous in the Niobrara in this area, although careful search will usually reveal masses of the typical <u>Ostrea Congesta</u>. Searight[2] has correlated the exposures in this area with the Smoky Hill member of the Niobrara in Kansas.

Pierre Formation

The Pierre formation consists of a thick series

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1. D. F. Hewitt, Memo for the Press, February, 1930.
2. Moxon, A. L., Olson, O. E., Searight, W. V., <u>Selenium in Rocks, Soils, and Plants,</u> Technical Bull. No. 2, Agr. Exp. Sta., S. Dak, State College Agr. and Mech. Arts, May, 1939.

of gray shales, some zones of which are sufficiently calcareous to be termed marl or even chalk. These shales overlie the Niobrara with apparent conformity, and form the bedrock over most of the area under consideration. Because of the abrupt nature of the river valley, and the scarcity of vegetation on the steeper slopes, good outcrops of the various members are found throughout the Missouri valley and its major tributaries.

Searight in 1937[1] divided the Pierre shale of the upper Missouri valley of South Dakota into five members, several of which were in turn subdivided. Minor changes in nomenclature were introduced by the same writer in 1938[2] and 1939[3]. On the bases of the work outlined in this report, a further slight change is suggested resulting in an increase in the number of members from five to six. The original classification, together with all subsequent changes, is shown in Table I.

TABLE I

CLASSIFICATION AND NOMENCLATURE OF THE PIERRE FORMATION

Searight (1937)	Searight (1938)	Searight (1939)	This Report (1940)
Elk Butte	Elk Butte	Elk Butte	Elk Butte
Mobridge	Mobridge	Interior	Mobridge
Virgin Creek	Virgin Creek	Virgin Creek	Virgin Creek
upper	upper	upper	upper
lower	lower	lower	lower
Sully	Sully	Sully	Sully
Verendrye	Verendrye	Verendrye	Verendrye
Oacoma	Oacoma	Oacoma	Oacoma
Agency	Agency	Agency	Agency
	Gregory marl	Gregory	Crown Creek
Gregory	Sharon Springs	Sharon Springs	Gregory shale
upper		upper	shale
			marl
lower		lower	Sharon Springs

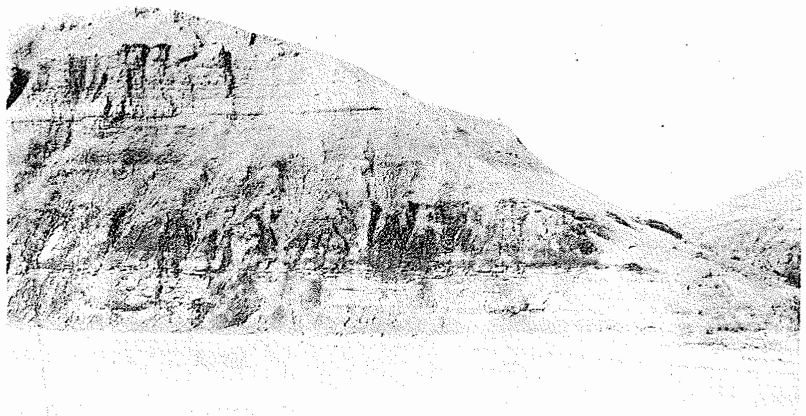
1. Searight, W. V., Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in S.Dak., op.cit.
2. Moxon, A.L., Olson, O.E., Searight, W.V., and Sandals, K.M., The Stratigraphic Distribution of Selenium in The Cretaceous Formation of South Dakota and the Selenium Content of Some Associated Vegetation, Amer. Jour. Botany, Vol. 25, No. 10, pp. 794-809, December, 1938.
3. Moxon; A.L.; Olson, E.O.; and Searight, W.V., Selenium in Rocks, Soils, and Plants, op. cit.

BASE OF PIERRE FORMATION

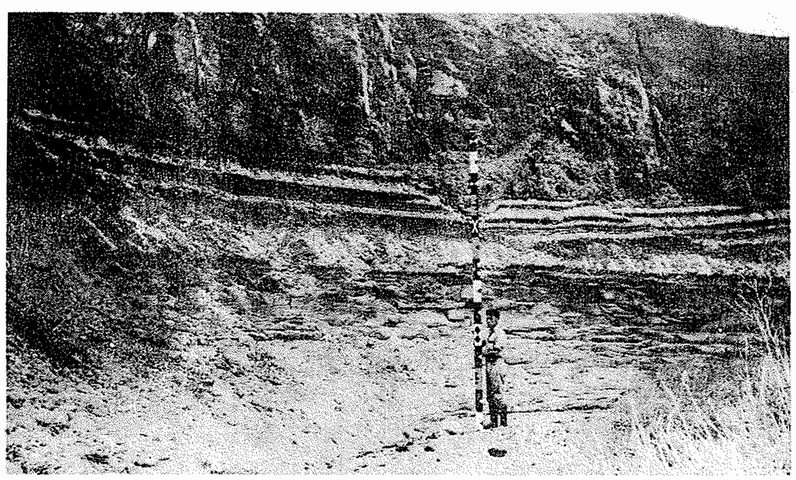
Gregory Member

Sharon Springs Member

Niobrara Formation



Outcrop on White River (See Table V)
Sec. 31, T. 104 N., R. 72 W. Lyman County



Bentonite Beds (White)
At Pierre-Niobrara Contact
Sec. 9, T.102 N., R.71 W. Brule County

Sharon Springs Member

Name and Description: The Sharon Springs, as described in 1931 from the type locality in Kansas, consists of dark gray to black, slightly bituminous shale with abundant fish remains.[1] Similarity of the basal Pierre in Kansas and South Dakota was noted at that time, and Searight (1938) abandoned his term "lower Gregory" in favor of Sharon Springs. (See Table I) The same writer (1939, p. 20) subdivided the Sharon Springs of South Dakota into a lower and an upper member on the basis of lithology, and on the same page states that "In South Dakota all beds above the Niobrara formation and below the Gregory marl are included in the Sharon Springs member." Detailed work during the past summer has shown that the beds comprising the "upper" member actually lie above the Gregory marl, and are characterized by a general absence of fish remains. For that reason the Sharon Springs of Searight, and the "upper" beds are included in the redefined Gregory member. The section at the west end of the Rosebud Bridge, Gregory County, is the type for the original Gregory member of Searight (1937), the restricted Gregory zone of Searight (1938), and the redefined Gregory member of the present report.

Subdivision: As may be noted in Table II, the shale between the Niobrara chalk and the Gregory marl is divisible in this locality into two zones on the presence or absence of fish remains.

Fish Scale Zone

Description: The lower part of the Sharon Springs consists of a dark gray, fissile, somewhat bituminous shale containing on close examination an abundance of scales and other fragmentary remains of fish.

A bed of impure, rusty-colored selenite, varying from less than an inch to over a foot in thickness, is usually present at the contact with the Niobrara. The top of the fish scale zone is marked by a layer of small, 1 x 2 inch, white concretions which have been found in every exposure examined. Other concretions are typically absent in these beds.

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1. Elias, Maxim K., The Geology of Wallace County, Kansas, State Geological Survey of Kansas, Bull. 18, page 58, 1931.

On steep slopes, outcrops of the fissile shale stand out in sharp, buttress-like forms, and appear nearly black from a distance. Exposures on gentle slopes appear as patches of loose, light gray shale flakes. The surface of all exposures is characterized by many small fragments of selenite, and a yellow, ochrous "bloom" which runs in veinlets through the joint and bedding planes.

Numerous bentonite beds are a conspicuous feature of the outcrop. They are usually thin, though one-foot beds are not unusual, and one measuring over two feet was observed. In a 14 foot section near the mouth of Crow Creek, Buffalo County, a total of 44 inches of bentonite was recorded. In outcrops where the basal bentonites are particularly well developed, it was noted that the associated shale was earthy in texture, quite unlike the overlying fissile beds. Details of the zone may be noted in Tables II, III, IV, V, and VIII.

Small areas of burned shale testify to the bituminous nature of this zone. Normally gray outcrops have become light pink to brick red on baking, and the individual shale fragments are quite hard and have a harsh feel. Three such patches were observed along the lower part of White River. The smallest occurs on the south side of State Highway 47, about a mile south of the White River bridge, and the largest lies on the north side of the same stream in section 32, T.104N., R. 72 W.

Thickness: The fish scale is 34 feet thick at the Rosebud bridge, 27 feet near Iona, 28 feet near the mouth of White River, 22 feet 8 miles up that stream, 25 feet 5 miles north of Chamberlain, and 14 feet at the mouth of Crow Creek in Buffalo County. This rather uniform thinning toward the north is believed due entirely to variation in original deposition, and not to removal after being laid down. Comparison with the Black Hills section suggests a thickening of the zone in that direction, though there is no evidence in this area to bear this out.

Paleontology: Aside from fish remains, the only fossils observed in this zone were the bones of a large reptile lying about six feet below the top of the beds, in section 11, T. 103 N., R. 72 W.

Upper Shale Zone

Description: Above the fish scale zone lies a thin bed of soft, bluish-gray shale devoid of fish remains. It is characterized by occasional specks of red hematite, the presence of numerous, very fine, tubelike holes, and the almost complete absence of concretions. It lies immediately over the small white concretions at the top of the fish scale zone, and is bounded at the top by the concretionary or calcareous beds of the lower Gregory member. The zone is less resistant to weathering than the underlying fissile shale, and usually presents a gentle flaky slope marked by selenite and yellow ochre bloom. (For details of this zone, see particularly Table V).

Thickness: Only one foot of this shale was observed by the writer at the Rosebud bridge section, but a few feet more may have been concealed by slumping of the Gregory chalk at the point measured. Nine feet were noted near Iona, and 14 feet near the mouth of White River. Farther north the upper contact is not conspicuous, and the zone was not measured.

Correlation: This upper shale zone does not fit the description of the Sharon Springs in the type locality. It is tentatively included with that member in this report only because it appears more closely related to the fish scale zone than to the overlying Gregory member.

Gregory Member

Discrepancies in the classification and correlation of this part of the Pierre have arisen because the thin sand and marl zone lying at the base of the Oacoma shale was overlooked when the Rosebud bridge section was first studied.[1] Investigation this past summer shows that the chalk or marl zone conspicuous at the base of the Oacoma beds in the Chamberlain area should be correlated with this overlooked upper calcareous zone of the Gregory County area, rather than with the lower, Gregory marl.

1. Compare Table II, this report, with Table I, page 14, Searight (1937).

Name: The name Gregory member is resurrected in this report, and used to include all beds between the base of the Gregory marl and the base of the upper calcareous zone. These intervening beds form a distinct lithologic unit in the type locality, and as far north as Hughes County, where they pass beneath the river level.

Subdivisions: At the Rosebud bridge, the Gregory member consists of two distinct lithologic zones; a lower chalk bed and a thicker shale zone. To the north the chalk loses its identity and the shale increases in thickness.

Chalk Zone

Description: This bed has been observed by the writer only at the type locality, where it consists of about eight feet of impure, light gray chalk. Small shale pebbles and scattered sand grains are characteristic of the basal part. In the vicinity of Iona, southeastern Lyman County, the base of the Gregory shale is marked by a one to two foot layer of buff limestone overlain by a similar thickness of very calcareous shale. In the area around the mouth of White River, this horizon is characterized only by an intermittent zone of large, one to two foot, limestone concretions, and farther north even this marker is generally absent. No outcrops were studied in the 35 mile interval between Rosebud Bridge and the Bijou Hills, so it is not known whether the Gregory chalk thins into the basal limestone and concretion zone just described, or whether it becomes increasingly shaly and thickens greatly to the north. In the latter case, it may be represented in the Chamberlain area by the dominant calcareous phase of the Gregory shale. (See Table VII.)

Shale Zone

Description: This shale varied in color from light buff to dark gray when fresh, and from light brown to gray when weathered. Outcrops are typically banded with alternate beds of dark gray, non-calcareous shale containing brown ironstone concretions, and light gray to buff calcareous layers.

These calcareous layers range from slightly calcareous shale to impure chalk and limestone in composition, and from a few inches to several feet in thickness. Of particular interest is an intermittent chalky bed which occurs a few feet below the top of the member near and opposite the mouth of Crow Creek, in Buffalo and Lyman counties. This bed carries from nothing to six feet or more in thickness over short distances, and is consequently very patchy in its distribution. Where well developed it closely resembles the basal marl zone of the overlying Sully member.

A conspicuous feature of all exposures of Gregory shale is an abundance of brown, fossiliferous concretions. These range from two to six or more inches in thickness, and may be small and intermittent, or may form nearly continuous ledges. Zones of large, one to two foot, gray limestone concretions are also present in some exposures. Searight (1937, p. 12, and Table IV, p. 18) has noted an outcrop on Cedar Creek, west of the Great Bend, in which this latter type is particularly well developed. The details of that outcrop may be noted in Table XII.

At the type locality the basal 18 inches of the zone contains abundant fish remains, but these have not been observed within the area covered by this report.

Thickness: The thickness of the shale zone varies greatly. 27 feet were noted at the Rosebud bridge, 68 feet above the basal limestone east of Iona, 125 feet 8 miles up White River, 77 feet including the upper shale of the Sharon Springs near Bad Hand Bottom north of Chamberlain, 86 feet for the same interval at the mouth of Crow Creek, and about 40 feet still exposed below the overlying chalk as far north as DeGrey, Hughes County.

Stratigraphic Relation: The relation of the Gregory member to the underlying beds has not yet been thoroughly investigated. At the type locality, the base of the chalk contains sand grains and small fragments of the underlying shale, but in the area under consideration no evidence of a break has been seen. Further study is needed south of this area, and especially south of the type area before the extent and importance of this suggested unconformity can be determined.

Paleontology: The shale zone is relatively fossiliferous. The flat brown concretions contain numerous large specimens of Inoceramus and Baculites. In one of the chalky layers of the detailed section studied north of Chamberlain (Table VII) an extensive fauna was observed. In addition to the numerous Inoceramus and Baculites, many smaller types were found, most notable of which were young specimens of Pachydiscus complexus. The presence of fish remains in the basal 18 inches at the type locality has already been noted.

Sully Member

Name and Description: The Sully member was named by Searight (1937, p. 21) from typical exposures along the Missouri River in and opposite the western part of Sully County, South Dakota. As originally defined, it included all beds lying above what will here be called the Crow Creek marl, and below the bentonitic beds of the lower Virgin Creek member. Subsequently (Searight, 1938, p. 796), this sand and marl zone was included as a basal part of the Sully member.

Distribution: This member is exposed continuously along the Missouri and the lower parts of its tributaries from northern Nebraska as far north as Mobridge, Walworth County, South Dakota, where the uppermost zone passes beneath the level of the river. It forms a conspicuous part of the Pierre shale outcrop in the area under consideration.

Subdivisions: The Sully is divided into four distinct lithologic units, which are, in ascending order, the basal sand and marl, and the Oacoma, Agency, and Verendrye shale zones. Because of their importance in any detailed study of this area, a separate discussion of each is given below. Special emphasis is placed on the unique manganiferous Oacoma beds.

Crow Creek Zone

Name and Description: The basal sand and associated chalky beds of the Sully member have previously been correlated with the Gregory chalk of the Rosebud bridge section. As pointed out under the discussion of that chalk, there are actually two calcareous zones in the Gregory County section, and the Sully marl is to be correlated with the upper one, rather than with the lower or Gregory chalk. Since the name Gregory does not apply, the sand and marl at the base of the Sully member is here called the Crow Creek zone, from characteristic exposures at and south of the mouth of C[illegible] Creek, southeastern [illegible]

Basal Sandstone: This bed was first observed by Searight (1937, p. 13), who noted its persistence throughout the area of outcrop. In an unweathered condition, the sandstone is probably nearly white, but it appears even in relatively fresh exposures as brown, laminated blocks, and on further weathering these break down into numerous gently curved plates one-eighth inch or more in thickness.

The cementing material is calcium carbonate. In parts of this area the cement is missing, so that the unconsolidated sand does not stand out conspicuously on the outcrop but is concealed by the overlying marl. By dissolving two random samples in dilute hydrochloric acid, it was determined that in each instance the "sandstone" consisted of sand and silt, 37%; and cementing material (CaO_3), 63%. Partial sieve analyses of the insoluble residue are as follows:

	Sample I Oacoma	Sample II De Grey
Retained on 100 mesh (.147 mm.) sieve	trace	1.7%
Passed 100, but retained on 150 mesh (.104 mm.) sieve	3.5%	7.7
Passed 150, but retained on 200 mesh (.074 mm.) sieve	41.7	37.6
Passed 200 mesh sieve	54.7	52.9

If the dividing line between sand and silt be taken at 1/16 mm. (.0625), it is apparent that the residue consists of almost equal amounts of very fine sand and silt. Under the microscope, the sand and silt particles are shown to be sub-angular quartz grains heavily coated with iron oxide and clay. Considering the high percentage of cementing material, this bed might more properly be called a sandy or silty limestone, but because of its appearance and mode of weathering it will be referred to in this report only as a sandstone. Pebbles of the underlying shale were noted in this bed by Searight (1937, p. 13), but were rarely seen during this study. The line of demarcation between the sand and the overlying marl is typically sharp, although the contact is apparently one of gradation.

The thickness of the sandstone averages between eight inches and one foot, although thicknesses from four inches to nearly two feet were recorded. Because of the persistence and uniform thickness of this bed, it makes the best key horizon in the area for structural mapping.

Marl Bed: The calcareous phase of the Crow Creek zone may be described as a marl, although in many places it appears more as an impure chalk. A random sample of marl from west of Oacoma (Table V) proved to be 59.0% $CaCO_3$, and 41.0% fine clay resembling bentonite.

This bed, because of its very light gray color, forms a conspicuous horizon throughout the area. Where outcrops are steep, it forms a sharp band, but where slopes are gentle, it becomes more ragged because of the tendency of the overlying gumbo to creep down over the exposure. On very gentle, or grassed over slopes, it shows only as a band of yellow soil supporting an abundant growth of wild yucca plants. The thickness of the marl averages between six and eight feet, with a maximum of 10 and a minimum of four feet observed in the area under consideration. Less than two feet are present at Rosebud bridge, the zone is locally absent at the mouth of Medicine Creek, Lyman County, and 14 feet of marl is present southeast of DeGrey, Hughes County.

Distribution: The Crow Creek zone has been identified only in the Missouri valley and its tributaries. It is conspicuous in Gregory County, but becomes more prominent northward. It has been traced about 12 miles west along White River to the point where it dips beneath the level of the stream. It finally passes beneath the level of the Missouri in the vicinity of Rousseau, about 12 miles east of Pierre. It seems likely that the sandstone might be identified in well cuttings outside the area of outcrops.

FIGURE I

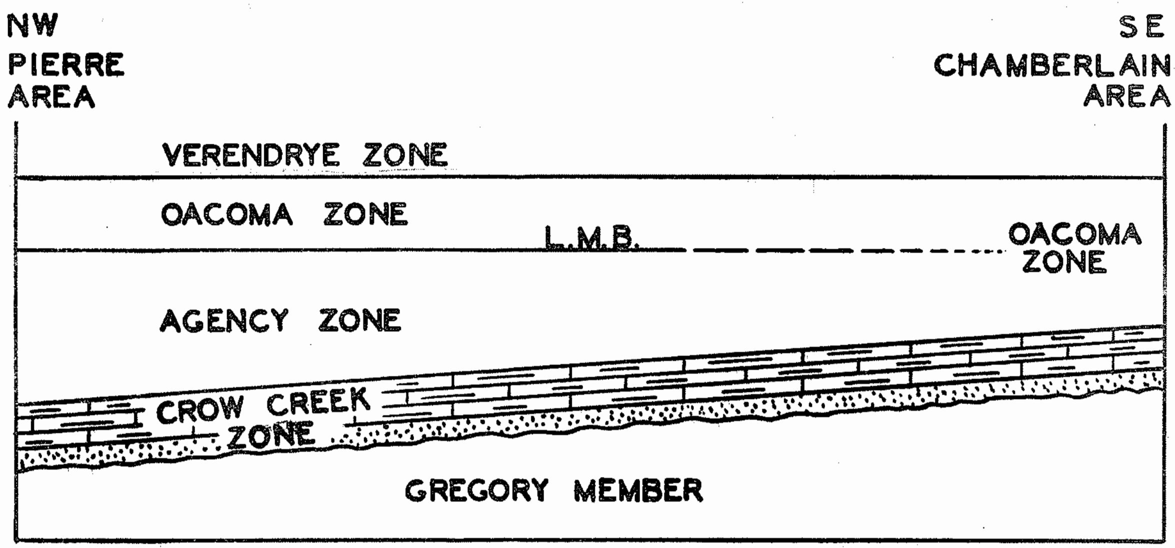


Figure 1. Ideal cross section showing the probable relation between the Oacoma zone in the Chamberlain area, and the Oacoma and Agency zones north and west of the Great Bend. The Lower Micaceous Bentonite, which has been taken as the dividing line in the Pierre area, lies essentially at the base of the concentration of concretions and bentonites. It may be traced continuously from the mouth of the Cheyenne River, south well into Lyman County, and south of there it may be only occasionally recognized.

Stratigraphic relation: The uniformity of the thin basal sandstone, and the evenness of the line of outcrop both indicate that the Crow Creek beds were laid down over a smooth or gently undulating surface. At only one place, near Lona, was a variation noticeable over a short distance. There the marl varied from four to nine feet in thickness within about 100 feet. The Crow Creek was evidently laid down over a gently ridge, for the upper contact of the zone forms a straight line. It was also noted that the sandstone was much thinner over the crest of the ridge than in the adjacent troughs.

There is no evidence of a break between the marl and the overlying shale, although the line of contact is quite sharp.

Agency Zone

The Agency shale was named by Russell[1] for exposures of hard, light gray siliceous shale occurring a long the Missouri River in the vicinity of Cheyenne Agency, Dewey County, South Dakota. Searight subsequently traced the zone as far north as the mouth of the Moreau River, and south as far as Crow Creek, Buffalo County, where he considered it to thin out and disappear. South of Crow Creek, it was presumed that the overlying Oacoma zone lay directly upon the Crow Creek marl.

Subsequent field studies south of the type area (Gries, 1939, 1940) have shown that the Agency becomes less siliceous to the south, and resembles the Oacoma zone except for having relatively few black iron-carbonate concretions and bentonite beds. The possibility that previously unrecognized Agency beds may be present in the area under consideration will be discussed in connection with the details of the Oacoma zone.

Oacoma Zone

Name and Description: The Oacoma zone was named by searight (1937, p. 23) for exposures along the

1. Russell, William L., The Possibilities of Oil and Gas in Western Potter County, R.I. No. 7, S. Dak. Geol. and Nat. Hist. Survey, Dec., 1930.

Missouri River, particularly those in the vicinity of Oacoma, Lyman County, just west of Chamberlain. The zone consists of gray shale, and is characterized by the presence of abundant black iron-manganese carbonate concretions and numerous thin bentonite beds.

In the Chamberlain area, this zone forms the most conspicuous part of the Pierre outcrop. The shale weathers to gumbo which is less favorable to vegetation than the adjacent beds. As the outcrops are eroded, the iron-manganese concretions weather out into relief, and accumulate on the surface so that exposures appear nearly covered with the black fragments. As a result, the outcrop appears as a bare black band running parallel to the river, and about half way up from river level to the uplands. Farther north the concretions become less abundant, and the shale becomes lighter in color, so that the outcrop as a whole appears less distinctive.

Regarding the bentonites, Searight (1937, p. 24) has written:

> "The Oacoma zone consists of beds of gray shale varying from a few inches to a few feet in thickness, alternating with very thin beds of bentonite and bentonitic clay. Near Oacoma and northward to the Great Bend and southward into Charles Mix County, it may be that bentonite is more or less disseminated through the shale as well as being concentrated into thin beds of relatively pure bentonite because the outcrops in this area weather down to bentonitic gumbo. This gumbo is very sticky and plastic when wet but dries to exceptionally hard clods of very uneven and irregular shape. North of the Great Bend the Oacoma zone is composed of beds of light gray, flaky shale with thin dark clays interbedded as elsewhere. Here, however, the flaky, light gray shales are notably more resistant than the thin, bentonitic, darker beds and the zone accordingly is conspicuously banded in the outcrop. Weathering and erosion of these beds produces a stair-step effect in the outcrop, the position of the treads being determined by the position of the thin bentonitic clays and that of the lifts apparently by the distance into the outcrop to which the bentonitic clay has been weathered."

In the course of the present study it was found that the gradual change to a lighter, more flaky shale appeared to start in the vicinity of Crow Creek, rather than at the Great Bend. The bentonites are all thin, usually less than two inches, although an occasional eight or ten inch bed was measured. Because of the extreme thinness of many of these bentonites, they were frequently disseminated into the adjacent shale at the time of deposition, so that the number which now appear as distinct beds varies widely in different sections. In carefully trenched outcrops, the number counted varied between 15 and 36.

The concretions which characterize the Oacoma beds were first described in detail by D. F. Hewitt[1] as follows:

> "The manganiferous iron nodules commonly range from 2 to 3 inches in thickness and 3 to 8 inches in diameter and form persistent layers in the shale; where the quantity is low the nodules are separated, but where the quantity is high many nodules have coalesced to form continouous layers 3, 4, or even 5 feet long. The color of the fresh nodules ranges from pale gray to olive-green; under the influence of weathering the carbonates change to oxides and become black. Oxidation is complete to a depth of only a foot or two, but films of oxides are found to a depth of 6 or 8 feet. Even the unweathered nodules separate readily from the shale; with exposure to air the shale dries, cracks, and falls away from the nodules. Invertebrate marine fossils are very common in the concretions, and the organic matter which these shells once contained has probably caused the development of concretions. Fragments of bones, especially vertebrae, of both terrestrial and marine vertebrate animals are common in the concretion bed.
>
> "Many geologic problems arise in the study of such concretion zones, but it will be sufficient to state here that the concretions appear to have developed in the sediments of a shallow sea shortly after burial. They are not related to processes of recent weathering that have produced the present surface but without doubt persist under the upland plains many miles east and west beyond the outcrop along the Missouri Valley."

---

1. D. F. Hewitt, Memo for Press, February 5, 1930.

As noted by Hewitt, many of the nodules, particularly in the upper few feet of the zone, contain abundant fossil fragments, particularly the shells of the large, clam-like Inoceramus. These shells are built up of minute prisms of calcite, arranged at right angles to the surface of the shell; the smallest fragments can be recognized by this prismatic structure.

The mineralogy of these concretions has not been thoroughly investigated. Because of the fine-grained nature of the nodules, microscopic study of the minerals is difficult. Deductions from a study of the chemical analyses indicate that the concretions consist essentially of the carbonates of iron, manganese and calcium in varying proportions.

The small, gray barite rosettes noted by Searight (1937, p. 25) were observed in an exposure along State Highway 47 north of Chamberlain, at the south end of Bad Hand Bottom, and in the vicinity of Elm Creek. Those at the northern area were one-half inch or less in diameter, but those near Elm Creek reached 5 or 6 inches in diameter. All occurred in a distinct zone.

Near the top of the Oacoma zone a one-half to two inch layer of fibrous calcite is frequently found, in which the slender calcite prisms are oriented perpendicular to the bedding plane. Similar material is abundant in the higher members of the Pierre in Haakon County, and has also been described in Elias (p. 102 and Pl. XVIII D) from the Pierre of Kansas.

Subdivisions: For the purposes of the present study, the Oacoma zone has been divided into an upper and a lower division. The lower beds have relatively few concretions and few bentonites, whereas both are abundant in the upper division. The line between the two is sharp in some area, but indistinct in others.

Lower Oacoma beds: In most exposures of the Oacoma zone it may be seen that the iron-manganese concretions are less abundant in the basal 10 to 20 feet. Three or four ledges may occur in this phase, or several small scattered concretions may be present, but in either case the concentration is notably less than in the overlying beds.

Further investigation reveals that the bentonites are less numerous in this phase of the zone. In the southern part of this area, a few small bentonites are usually found, but north of Crow Creek every exposure shows three prominent, four to six-inch beds with or without additional thin bentonites. In most sections these appear as an upper pair, and a single bed somewhat lower. (See Tables VIII, XII, XIII) In the Lower Brule and Medicine Creek sections however, the three appear crowded together at the base of the zone.

The lower subdivision thickens rapidly north and west from this area. 30 feet were measured on Cedar and Medicine Creeks, and approximately 50 feet were noted at DeGrey. The latter section is of particular note for the upper 12 feet of the 50-foot lower phase contains no concretions whereas the lower 38 feet persistently carries a few nodules or thin ledges.

Upper Oacoma beds: This phase includes the beds of the Oacoma zone which contain abundant iron-manganese concretions and numerous bentonites. Most of the bentonites are too thin to be followed from one exposure to the next, but in the northern part of the area, two beds could be traced with a reasonable degree of certainty. The lower of these is a one to six-inch yellow bentonite carrying abundant flakes of biotite mica. There is no question but that this is the bed upon which the structure of northeastern Stanley County was mapped. (Gries, 1940) This bed was considered to lie at the base of the Oacoma zone in that area, and was designated as the lower micaceous bentonite (LMB). In the outcrops between DeGrey and Lower Brule, this LMB consistently occurs at the base of the concentration of the iron-manganese concretions; that is, at the base of the so-called upper phase of the Oacoma zone. Although this key bed appears to lose its identity south of Lower Brule, a prominent bentonite bed usually occurs at this horizon in exposures to the south, and in isolated cases it contains mica flakes.

A second persistent zone which appears at DeGrey consists of an eight inch bentonite separated from an underlying one inch bed by two inches of shale. This appears to be the big bentonite bed (BBB) of the Stanley County report, and can be traced with reasonable certainty as far south as Oacoma.

The concretions of this upper zone occur in closely spaced layers. Individual layers may vary from nearly continuous ledges two to six inches thick, to one inch zones of scattered purplish nodules no larger than marbles. Some of these layers seem to alternate with bentonite beds. This shale, bentonite, shale, concretion, sequence is particularly clearly shown in Table VIII-A. Whether the bentonites, by their impervious nature, have restricted circulation and thus influenced the distribution of the nodules is not known.

Possible significance of the two phases: The details of these subdivisions of the Oacoma zone were worked out not only because of the possible use of these beds as a source of manganese, but in the hope that they might shed some light on the manner in which the siliceous Agency shale zone wedges out as it approaches this area. With the present data, two possibilities present themselves:

a. The Agency shale wedges out between the upper and lower phases of the Oacoma zone.
b. The Agency shale is represented in this area by the entire lower phase of the Oacoma zone.

The first hypothesis is suggested by the zone of light gray shale containing no concretions which lies between the LMB and the lower concretion bearing beds in the DeGrey section (Table XIII, Bed 10). This shale appears identical with the shale below the lower micaceous bed in Stanley County which is considered to be Agency, although less siliceous than in the type locality in Dewey County. The general absence of iron-manganese concretions in the Agency zone lends further support to this contention.

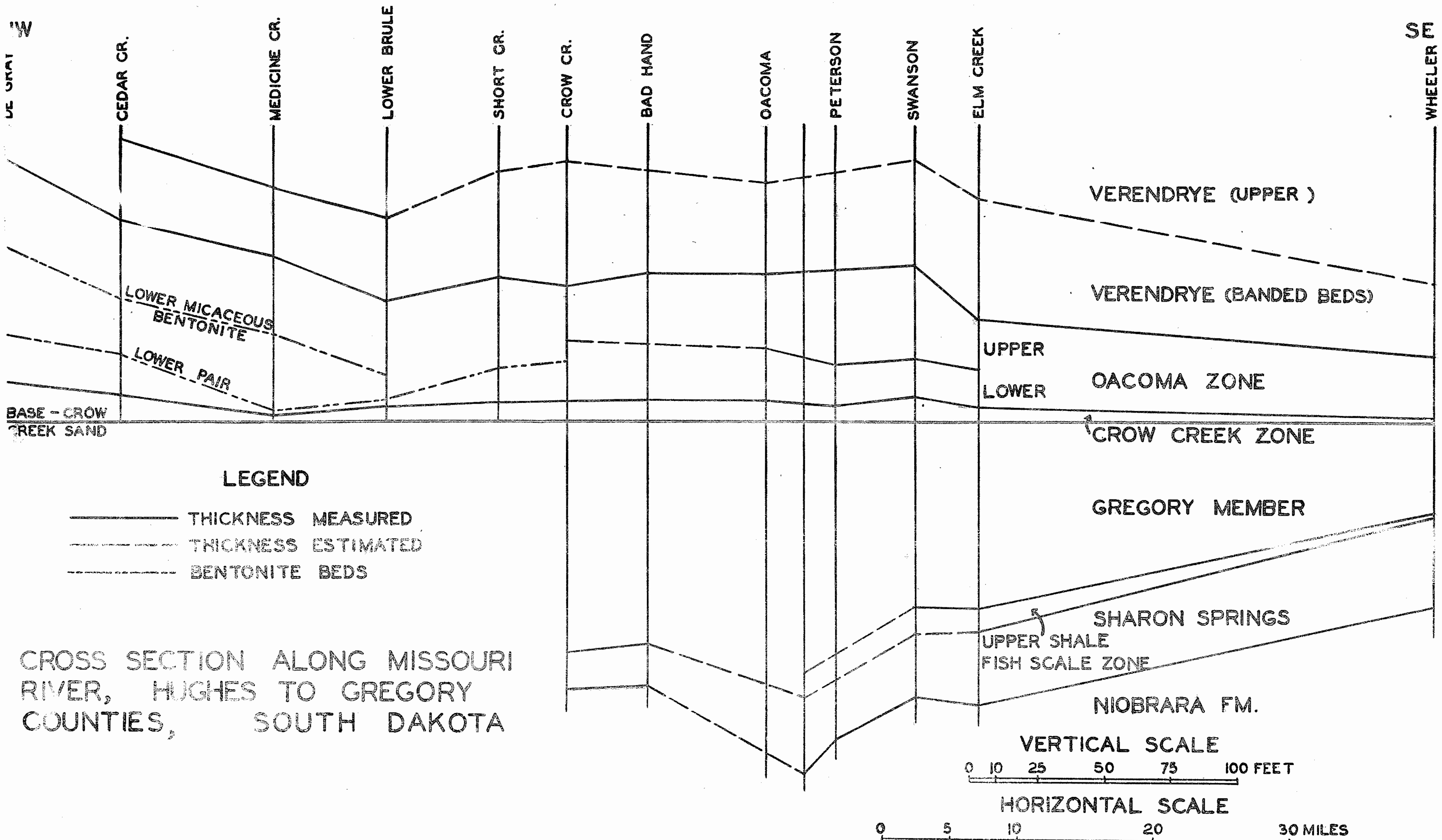
The second hypothesis is based on two lines of evidence. First is recognition of the fact that the complete Stanley County section of the Oacoma zone represents only the upper phase of the Oacoma of the type locality.

There is no evidence of an unconformity below the LMB, so if the shale below this horizon in and north of Stanley County is definitely the Agency, it may be assumed that the shale immediately beneath the LMB wherever found will be the equivalent of the Agency. Secondly, it is believed, though not yet proved by sufficient field work, that the pair of thick bentonites in the lower part of the Oacoma zone of this area is the same pair noted in the Agency shale in Stanley County. (Gries, 1940, p. 15) In that area, the pair consists of two 4 to 8 inch bentonites separated by from 7 to 0 feet of shale, but in this area the individual beds are from 4 to 6 inches thick, and less than one foot apart. This spreading would be expected if the Agency shale thickens as a unit from less than 20 feet in this area to well over 100 feet in northeastern Stanley County. This pair lies 8 feet below the LMB at Crow Creek and at Lower Brule, 28 feet below at Medicine Creek, and 34 feet below that horizon at DeGrey. In Stanley County the conspicuous pair was believed to lie 50 to 70 feet below the same micaceous bentonite.

It is the belief of the writer that this second hypothesis will prove correct; that is, that the lower part of the Oacoma zone in the Chamberlain area is equivalent to part or all of the Agency shale to the north. This follows Searight's concept of the Agency as a great wedge of siliceous shale, thinning to the south, but differs in adding that the scale becomes much less siliceous as it thins, and that the zone extends much farther south than previously supposed but finally loses its identity. The fact that south of Crow Creek a definite line cannot be drawn between the Agency and the Oacoma shales emphasizes the close relationship between them. This probably relationship is shown diagrammatically in Figure 1.

<u>Distribution</u>: The Oacoma zone has been recognized in the Missouri valley as far south as Gregory County, and has been traced north to the mouth of the Moreau River where it disappears beneath the level of the river.

<u>Thickness</u>: In the type locality 47 feet of shale are present between the Crow Creek marl and the top of the iron-manganese concretion zone. This same stratigraphic interval measures 23 feet at Wheeler, 32 feet just north of Bijou Hills, 42 feet on Crow Creek, 38 feet at Lower Brule, 60 feet on Medicine Creek, 63 feet on Cedar Creek, and 84 feet at DeGrey. This is a persistent increase toward the north and west.



CROSS SECTION ALONG MISSOURI RIVER, HUGHES TO GREGORY COUNTIES, SOUTH DAKOTA

PLATE II

If only the upper part of the zone is considered (that above the horizon of the LMB), the thickness varies as follows: Crow Creek 20 feet, Lower Brule 22 feet, Medicine Creek 30 feet; DeGrey 34 feet; Ft. Pierre 36 feet; Cheyenne River 42 to 60 feet; and Potter and Dewey counties, 5 to 14 feet.

Stratigraphic relations: The Oacoma zone as described in the type area overlies the Crow Creek marl with conformity, though the contact is sharp. Farther north, where the lower micaceous bentonite (LMB) is considered to be the base of the zone, the contact with the underlying Agency is also one of conformity.

The upper limit of the zone is more difficult to define closely. Generally speaking, the top of the Oacoma zone may be taken as the top of the concentration of iron-manganese concretions and bentonite beds, for the overlying banded beds of the Verendrye zone contain few of either. At or near the base of the banded beds in this area there is usually found one or more thin streaks of rusty shale containing scattered white or rusty brown limestone concretions. These may be the equivalent of the rusty concretions found at the top of the Oacoma beds in the Stanley County area. The actual change from the Oacoma to the Verendrye beds is apparently one of transition, so that no hard and fast contact line can be chosen.

Verendrye Zone

Name and description: The uppermost subdivision of the Sully member has been called the Verendrye zone by Searight (1937, p. 25) from exposures near the Verendrye monument at Ft. Pierre, Stanley County. It includes all beds between the top of the Oacoma zone and the base of the bentonitic lower Virgin Creek member.

The Verendrye typically consists of light to medium dark shale which contains large, flat, iron-manganese carbonate concretions in more or less well defined layers. These may reach a diameter of several feet, but are generally six inches or less in thickness. They are usually gray or greenish gray on the interior, but weather to purplish black on the surface. South of the type area, the concretions are much less numerous in the lower third of the Verendrye. In the area under consideration, this basal phase consists of alternate beds of light gray, somewhat flaky shale, and typical dark gray gummy shale, thus giving rise to the term "banded beds." The only concretions therein are zones of large gray to rusty limestone concretions, and occasional scattered buff lime nodules in the lowest few feet. (See Tables VI, VIII, and XII B) Above the banded beds lies typical gray gumbo forming shale studded with large black iron-manganese concretion layers.

Distribution: The Verendrye zone is exposed along the Missouri River and its tributaries from south of the Nebraska line, north nearly to Mobridge, northwestern Walworth County.

Thickness: Searight gives the thickness of this zone as 88 feet at Wheeler; 130 feet at Oacoma; 170 feet on Crow Creek, Buffalo County; 170-180 feet at Ft. Pierre, 200 feet at Wendt. Subsequent measurements (Griès 1939, 1940) give 122 feet at Fort Bennett, Stanley County, and 100-110 feet in Dewey and Potter counties. The formation seems to thicken toward the west.

Measurement of the basal banded beds during this investigation show 25 feet at Rosebud Bridge; 40 feet in T. 102 N., R.71 W., 48 feet at Oacoma; 47 feet at Crow Creek; 21 feet at Medicine Creek; and 30 feet at Cedar Creek, Lyman County.

Stratigraphic relations: There seems to be complete gradation between the Oacoma and Verendrye zones, so that the contact must be more or less arbitrarily chosen at the top of the concentration of manganese concretions and bentonites. The contact between the Verendrye and the Virgin Creek member is not usually well exposed. It lies somewhere in the few feet between the highest ironstone concretions in the Verendrye and the lowest bentonites in the Virgin Creek. In a general way, it is marked by springs, and the appearance of selenite fragments on the surface. The contact is probably one of gradation from the grayish brown bentonitic shale of the lower zone to the blue gray, flaky shale of the upper member.

For field purposes, the contact is placed at the base of the lowest visible bentonite in the lower Virgin Creek.

Virgin Creek Member

Name and distribution: The Virgin Creek member was named by Searight (1937, p. 35) from exposures on Virgin Creek, a tributary of the Moreau River, in northeastern Dewey County. It includes all beds lying between the Verendrye zone of the Sully member and the highly calcareous, chalky beds of the overlying Mobridge member. The outcrop of the Virgin Creek has wide distribution along the Missouri valley from Charles Mix and Gregory counties north nearly to the North Dakota line. Searight has also identified the member in parts of Nebraska, North Dakota, Montana, and around the Black Hills.

In the area under consideration, the Virgin Creek occurs high on the valley sides, and forms the bedrock over much of the adjacent upland. Outcrops are not conspicuous, and the member was not particularly studied in this investigation. The character of the beds appeared to be similar to the development farther north.

Description: The Virgin Creek member is divisible on the basis of lithology into a lower and an upper zone. Each will be described but briefly here; for details the reader is referred to Searight (1937) and Gries (1939).

The lower Virgin Creek consists of medium hard, gray shale which weathers to small silvery flakes, and is characterized by the presence of a large number of thin bentonite beds. In this area, the zone may frequently be seen in creeks and road cuts on the upland west of the river. The zone appears to thin southward from 145 feet in Dewey County to 26 feet in Charles Mix County.

The upper Virgin Creek is composed of gray shale which weathers to gumbo. It is characterized by several types of concretions. One consists of small, gray or brown concretions which weather nearly white, and are perforated by many small holes which give them a "wormeaten" appearance. A second type includes small cylindrical concretions, gray or buff in color, with a soft core which weathers out, leaving hollow cylinders often termed "Indian beads" (Serpula? wallacensis Elias). Somewhat higher, in some localities, small, bluish-gray limestone nodules are found containing the fossil remains of crabs. Large septarian limestone concretions are characteristic of the zone. Few thicknesses for the upper Virgin Creek are available. 100-140 feet are present at the type area, 142 feet were measured in northeastern Stanley County, and 25-30 feet have been recorded in Gregory County.

Mobridge Member

This member of the Pierre shale was named by Searight (1937, p. 44) from beds exposed in Walworth and Corson counties, near the town of Mobridge, South Dakota. As originally defined, the member includes beds of chalk, chalky shale, sandy shale, and perhaps some sandstone beds, lying between the Virgin Creek and Elk Butte members. It is said to extend northward into North Dakota, southward into Nebraska, and westward under the Great Plains.

In this area, it occurs only on the highest parts of the upland, and appears only as a yellow, well weathered belt of calcareous shale. It was noticed by the writer around Medicine Butte in northeastern Lyman County, and around the Iona-Bijou Hills in southeastern Lyman, Brule, and Charles Mix counties. The outcrop lies close to the Missouri River south of the above hills area, and is particularly well exposed in the vicinity of Mulehead and the Rosebud Bridge.

The formation varies from about 100 feet in thickness in Gregory and Charles Mix counties, to over 200 feet in Ziebach and Haakon counties (Searight, 1937, p. 49).

Elk Butte Member

The Elk Butte member was named (Searight, 1937), p. 50) from exposures at Elk Butte, Corson County, South Dakota. It includes a thick series of dark gray shales lying between the calcareous Mobridge beds and the base of the Fox Hills sandstone. The member has not been identified farther west, and may either pinch out or grade laterally into sandstone. It lies too high stratigraphically to be found in the Chamberlain area, unless it occurs at Medicine Butte and in the Iona-Bijou Hills.

Tertiary Deposits

Tertiary sands and clays are found high on Medicine Butte and on the Iona and Bijou hills. The clays are either Oligocene or Miocene in age, and the conspicuous green quartzite which caps the Iona and Bijou hills is considered to be of Arikaree (Miocene) age.

Glacial and Terrace Deposits

During the Pleistocene epoch, the ice sheet advanced over this area from the east, burying the old topography and greatly modifying the drainage. An early ice advance apparently extended west of the present line of the Missouri, though the only evidences which remain are the isolated glacial boulders which are scattered over the area for several miles west of the river. Much later the ice advanced approximately to the present location of the river, and upon retreating, left the surface covered with its present mantle of glacial drift. This has been little modified on the uplands, but has been partially removed in the valleys of the numerous small post glacial tributaries, so that the Pierre shale is often well exposed for considerable distances back from the river.

Gravels of both late Tertiary and Quaternary age are present in the area, especially west of the Missouri, but they are not considered in the present report.

STRATIGRAPHIC SECTIONS

In the pages immediately following are presented twelve detailed sections taken at various places in the area where the formations were typically exposed. These sections were carefully measured in order to determine the exact thicknesses of the various divisions of the Pierre formation and the position of bentonites and layers of nodules and other significant features of the formation. While they may not be of interest to the layman they are inserted here for the benefit of stratigaphers and other technicians who may be interested in studying the details of this interesting formation.

TABLE II

Succession of beds, lower part of Pierre shale, exposed in river bank and road cut, south end of Rosebud Bridge, Gregory County, South Dakota

	Feet	Inches
PIERRE FORMATION		
Sully Member		
Verendrye zone		
28. shale, gray, with numerous large iron carbonate concretions;not measured--		
27. shale, banded, light and dark gray, no concretions------------------------	25	6
Oacoma zone		
26. shale, dark gray, with numerous bands of iron-manganese concretions and many bentonite beds-----------------	23	0
Crow Creek zone		
25. marl, light gray to rusty; sandy at base	2	0
Gregory member		
24. shale, gray to brown, with numerous flat brown concretions. Abundant fish remains in basal 18"; none above that point--------------------	26	9
23. marl, light gray, with shale pebbles and scattered sand grains at base---	7	9
Sharon Springs member		
Upper shale zone*		
22. shale, soft, bluish gray, characterized by few fine, tubelike holes; and occasional specks of red hematite; no fish remains-----------------------		3
21. bentonite---------------------------		1
20. shale, as above----------------------		8

* partly obscured?

	Feet	Inches
Fish Scale zone		
19. concretions, small, white, in persistent zone		1
18. shale, dark gray, more or less fissile, stands up in buttress-like outcrops; strewn with selenite and yellow ochrous "bloom." Fish remains abundant	6	7
17. bentonite		1½
16. shale, as above	13	8
15. bentonite		1½
14. shale, as above	1	11
13. bentonite		1
12. shale, as above	2	0
11. bentonite		1
10. shale, as above		6
9. bentonite, with two thin shale partings		11
8. shale, as above	2	5
7. bentonite		1
6. shale, as above		7
5. bentonite		1
4. shale, as above		7
3. bentonite		1
2. shale, as above	4	0
Total, Sharon Springs member	35	
NIOBRARA FORMATION		
1. chalk, gray, impure, to rivers edge, approximately	20	

TABLE III A

Detail of Niobrara-Pierre contact,
in nearby outcrop,
NW¼, Section 9, T. 102 N., R.71 W.

	Feet	Inches
PIERRE FORMATION		
Sharon Springs member		
23. shale, dark gray, weathers with formation of yellow veins; fish fragments. 5 thin streaks may be bentonites; exposed	17	0
22. bentonite		½
21. shale, as above		3
20. bentonite		6
19. shale, as above		4
18. bentonite		10
17. shale, same, with 3¼" bentonites	1	2
16. bentonite		5
15. shale, as above	1	7
14. bentonite	1	6
13. shale		4
12. bentonite		5
11. shale		1
10. selenite layer		½

	Feet	Inches
NIOBRARA FORMATION		
9. chalk	2	10
8. bentonite		½
7. chalk		6
6. bentonite		2
5. chalk	2	4
4. bentonite		1/8
3. chalk	1	1
2. bentonite		1
1. chalk, exposed	1	6

TABLE III B

Succession of beds, Pierre formation, Swanson Farm,
Brule County, South Dakota
Detailed Section, Oacoma zone
NW¼, Section 9, T. 102 N., R. 71 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Verendrye zone		
90. shale, gray, weathers to gumbo; numerous large black sideritic concretions; to top of exposure, not measured		
89. shale, gray to yellowish gray, banded	35	
88. shale, as above; large white concretion zone at top	4	7
Oacoma zone		
87. shale, gray, somewhat flaky	1	11
86. concretion zone, intermittent, flat		1
85. shale, as above	1	1
84. concretion zone, nodules flat, intermittent		1
83. bentonite		¼
82. shale, as above	1	6½
81. bentonite		1
80. shale, as above		6
79. bentonite		1
78. shale, as above	1	0
77. concretion zone, fossiliferous, persistent		2
76. shale, as above		9
75. concretion zone, persistent		1
74. shale, as above	1	4
73. bentonite		1
72. shale, as above		4
71. concretion zone, nodules intermittent		1
70. shale, as above	1	0
69. concretion zone, nodules intermittent		1
68. shale, as above		3½
67. bentonite		½
66. shale, as above		3
65. concretion zone, fossiliferous, intermittent		3

	Feet	Inches
64. shale, as above------------------------		11
63. concretion zone, intermittent---------		2
62. shale, as above------------------------	1	3
61. bentonite------------------------------		4
60. shale, as above------------------------		8
59. concretion zone, nodular---------------		1
58. shale, as above------------------------		3
57. bentonite------------------------------		½
56. shale, as above------------------------	1	5½
55. concretion zone, fossiliferous, intermittent------------------------------		1
54. shale, as above------------------------	1	11
53. concretion zone, persistent-----------		4
52. shale, as above------------------------		9
51. concretion zone, intermittent---------		4
50. shale, as above------------------------		6
49. concretion zone, nodules intermittent-		1
48. shale, as above------------------------		8
47. concretion zone, fossiliferous, intermittent------------------------------		2½
46. shale, as above------------------------		2
45. concretion layer, persistent nodules--		4
44. shale, as above------------------------		6
43. bentonite------------------------------		2
42. shale, as above------------------------		6
41. concretion zone------------------------		2
40. shale, as above------------------------		6
39. bentonite------------------------------		2
38. shale, as above------------------------		8
37. bentonite------------------------------		1
36. shale, as above------------------------		6
35. bentonite------------------------------		1
34. shale, as above------------------------		7
33. concretion zone, persistent-----------		4
32. shale, as above------------------------	2	9
31. bentonite, white-----------------------		1
30. shale, as above------------------------		11
29. concretion zone, persistent-----------		3
28. shale, as above------------------------		11
27. concretion zone, nodular---------------		1
26. shale, as above------------------------		6
25. concretion zone, nodular--------------		1
24. shale, as above------------------------	1	4
23. bentonite------------------------------		1
22. bentonite------------------------------		3
21. concretion zone------------------------		3
20. shale, as above------------------------		3
19. concretion zone, intermittent---------		2
18. shale, as above------------------------	1	5
17. concretion zone, intermittent---------		2

	Feet	Inches
16. shale, as above	1	2
15. bentonite		6
14. shale, as above	3	4
13. bentonite		3
12. shale, as above		4
11. concretion zone, continuous ledge		2
10. shale, as above	2	3
9. concretion zone, nodules kidney-shaped		1
8. shale, as above	2	8
7. bentonite		$\frac{1}{4}$
6. shale, as above	3	0
Total Oacoma	49	$11\frac{1}{4}$
Crow Creek zone		
5. marl, light gray	7	5
4. sandstone, brown, calcareous, slabby	1	0
Gregory member		
3. shale, gray; brown to black when wet. Scattered brown concretions; no fish fragments; several calcareous zones in lower part, and 1.3 foot limestone or concretionary layer at base	69	4
Sharon Springs member		
2. shale, dark gray, numerous bentonites and fish remains	34	5
NIOBRARA FORMATION		
1. chalk, impure, several bentonites		

TABLE IV

Succession of beds, Pierre formation,
exposed along west bank of the Missouri River,
4 miles south of Oacoma, Lyman County.
Detailed section
Section 11, T. 103 N., R. 72 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Crow Creek zone		
19. marl, light gray to buff, not measured		
18. sandstone, brown, calcareous, slabby	1	0
Gregory member		
17. shale, brown to gray, abundant brown concretions and a few large white limestone concretion zones	94	10
Sharon Springs member		
Upper shale zone		
16. Shale, gray, flaky, no concretions, estimated	9	0
Fish Scale zone		
15. zone of small white concretions		2
14. shale, dark gray, fissile, contains numerous fish remains; yellow "bloom" and selenite in joints and on surface	5	4

13. bentonite------------------------		4
12. shale, as above------------------	2	11
11. bentonite------------------------		1
10. shale, as above------------------	14	9
9. bentonite------------------------		1½
8. shale, as above------------------	1	0
7. bentonite, creamy white----------		6
6. shale, as above------------------		2
5. bentonite------------------------		½
4. shale, as above------------------		4
3. bentonite, creamy white----------	1	2½
2. shale, earthy, selenitic at base	1	3
Total, Fish scale zone	28	2½
NIOBRARA FORMATION		
1. chalk, gray, impure; to river's edge---------------------------		

TABLE V

Succession of beds, Pierre formation, exposed in bluff along north bank of White River, 8 miles above its mouth, Lyman County, South Dakota.
Detailed composite section
Section 31, T. 104 N., R. 72 W.

PIERRE FORMATION		
Sully member		
Oacoma zone		
8. shale, gray, with iron-manganese concretions, to top of bluff, not measured---------------------		
Crow Creek zone		
7. marl or impure chalk, grayish white, hard----------------------	6	3
6. sandstone, brown, calcareous, slabby-------------------------	1	0
Gregory member		
5. shale, gray, weathers brownish, banded, contains several calcareous zones, numerous flat brown concretions, and a few zones of large, white limestone concretions; few bentonites near top--	125	4
Sharon Springs member		
Upper shale zone		
4. shale, bluish to brownish gray, flaky, weathers to gentle slope; layer of large white lime concretions at top---------------------	6	5

	Feet	Inches
3. Shale, bluish to brownish gray, flaky, stands in intermediate slope; bentonitic zone with small concretions at top-------------------------------------	7	10
Fish scale zone		
2. shale, grayish brown, contains abundant fish remains; 1' bentonite 2' above base, and many thinner bentonites, zone of 1" light gray concretions at top; stands in steep outcrop which appears nearly black with distance---	22	3
NIOBRARA FORMATION (elev. of top 1387)		
1. chalk, impure, several bentonites, to river's edge, base not exposed-------	20	10

TABLE VI

Succession of beds, Pierre formation,
exposed along state route 47 (old route U.S. highway 16),
two miles west of Oacoma, Lyman County, South Dakota.
Composite section
S.E. ¼, Section 22, T. 104 N., R. 72 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Verendrye zone		
10. shale, gray, weathers to gumbo; numerous brown to black sideritic concretions, to top of hill, not measured----------------------------		
9. shale, gray to yellowish-gray, banded, with 6" micaceous bentonite at base and zone of white lime concretions near top---------------------------	18	0
8. shale, gray to yellowish-gray, banded, with local white to brown concretions near middle------------------------	16	10
7. shale, rusty, calcareous, with lime concretions-----------------------		6
6. shale, gray to yellow-gray, banded, with many very thin bentonites-----	12	7
Oacoma zone		
5. shale, gray to yellowish-gray, non-calcareous, with many bentonites and zones of iron-manganese carbonate------------------------	27	1
4. shale, gray, non-calcareous, few bentonites or concretion zones-----	19	9
Crow Creek zone		
3. marl, gray, soft with conchoidal fracture--------------------------	6	4
2. sandstone, brown, calcareous, slabby-	1	0
<u>Gregory member</u>		
1. shale, gray, with numerous bentonites and brown concretions; base not exposed----------------------------	16	10

TABLE VI-A

Detailed section, Oacoma zone
SE $\frac{1}{4}$, Section 22, T. 104 N., R.72 W.

	Feet	Inches
<u>Sully member</u>		
Verendrye zone		
70. shale, rusty, calcareous, with white limestone concretions--------------		6
69. shale, gray to yellowish gray, banded	9	8
68. bentonite-------------------------		$1\frac{1}{2}$
67. shale, as above---------------------	2	9
Oacoma zone		
66. concretion zone, persistent---------		1
65. shale, gray-------------------------		2
64. bentonite-------------------------		$\frac{1}{4}$
63. shale, as above---------------------		2
62. concretion zone---------------------		1
61. shale, as above---------------------	2	5
60. concretion zone---------------------		2
59. shale, as above---------------------		3
58. bentonite-------------------------		1
57. shale, as above---------------------		10
56. concretion zone---------------------		1
55. shale, as above---------------------		2
54. concretion zone---------------------		1
53. shale, as above---------------------		7
52. concretion zone---------------------		1
51. shale, as above---------------------		7
50. concretion zone---------------------		1
49. shale, as above---------------------		7
48. bentonite-------------------------		$\frac{1}{2}$
47. shale, as above---------------------		11
46. concretion zone---------------------		1
45. shale, as above---------------------		11
44. bentonite-------------------------		$\frac{3}{4}$
43. shale, as above---------------------		5
42. concretion zone---------------------		2
41. shale, as above---------------------		6
40. bentonite-------------------------		2
39. shale, as above---------------------		6
38. concretion zone---------------------		2
37. shale, as above---------------------		4
36. bentonite-------------------------		4
35. shale, as above---------------------		4
34. bentonite-------------------------		1
33. shale, as above---------------------		7
32. bentonite-------------------------		1
31. shale, as above---------------------		7
30. bentonite-------------------------		1
29. shale, as above---------------------		7

	Feet	Inches
28. concretion zone, persistent		4
27. shale, as above	3	1
26. concretion zone		3
25. shale, as above		1
24. concretion zone		1
23. shale, as above	1	10
22. concretion zone		3
21. shale, as above		3
20. bentonite		1
19. shale, gray to dark gray		5
18. bentonite		1
17. shale, as above		5
16. bentonite		1
15. shale, as above		2½
14. bentonite		1
13. shale, as above		3
12. concretion zone, intermittent		1
11. shale, as above		3
10. bentonite		1½
9. shale		9
8. concretion zone, intermittent		4
7. shale, as above	1	2
6. bentonite		2
5. shale, with two zones of intermittent concretions	2	10
4. concretion zone		2
3. shale, as above, with few bentonites and iron-manganese concretions, not trenched	19	9
Total Oacoma	46	9½
Crow Creek zone		
2. marl, light gray	6	4
1. sandstone, brown, calcareous, slabby	1	0

TABLE VII

Succession of beds, Pierre formation,
exposed along highway 47 at south end of Bad Hand Bottom,
Buffalo County, South Dakota.
Detailed section
NW¼, Sec. 25, T. 105 N., R. 71 N.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Crow Creek zone		
55. chalky shale, not measured		
54. sandstone, brown, calcareous, slabby	1	0
Gregory member		
53. shale, dark gray	1	0
52. bentonite		½

		Feet	Inches
51.	partly covered interval; shale exposed is dark, non-calcareous-------------	26	9½
50.	shale, dark, non-calcareous------------	10	8
49.	shale, calcareous----------------------	2	
48.	shale, slightly calcareous------------	4	8
47.	shale, calcareous; top 6" is chalky, very fossiliferous------------------	9	1
46.	shale, non-calcareous-----------------	3	0
45.	calcareous layer, hard, becoming limestone in places; sticks out as prominent ledge in road cut--------	1	0
44.	shale, gray, non-calcareous-----------	1	0
43.	shale, calcareous ---------------------	1	0
42.	shale, gray, non-calcareous-----------		11
41.	shale, calcareous----------------------	2	6
40.	shale, non calcareous-----------------		7
39.	shale, calcareous----------------------	2	4
38.	shale, black, non-calcareous----------		1
37.	shale, calcareous----------------------	1	7
36.	covered interval; available exposures show shale with no fish remains. Includes upper Sharon Springs shale-	9	4
Sharon Springs member			
35.	concretionary layer; pavement of small white nodules----------------------		2
34.	shale, with abundant fish remains-----	10	6
33.	bentonite-----------------------------		5
32.	shale, nearly black, with fish remains		6
31.	bentonite-----------------------------		6
30.	shale, same---------------------------		10
29.	bentonite-----------------------------		6
28.	shale, same---------------------------		4
27.	bentonite-----------------------------	1	1
26.	shale, same---------------------------		3
25.	bentonite-----------------------------		2
24.	shale, same---------------------------		2
23.	bentonite-----------------------------		7
22.	shale, same---------------------------		2
21.	bentonite-----------------------------		1
20.	shale, same---------------------------		2
19.	bentonite-----------------------------		1
18.	shale, same---------------------------		1
17.	bentonite-----------------------------		4
16.	shale, same---------------------------		11
15.	bentonite-----------------------------	2	6
14.	shale, black, soil-like, with fish remains -------------------------		2
13.	bentonite ----------------------------		4
12.	hard layer, volcanic ash--------------		2
11.	shale, black --------------------------		4
10.	ash layer, hard-----------------------		1½

	Feet	Inches
9. shale, as above----------------------		4
8. ash layer, hard----------------------		2
7. shale, as above----------------------		7
6. bentonite----------------------------		4
5. shale, as above----------------------		10
4. bentontite---------------------------		½
3. shale, gray, felt-like feel, fish remains----------------------------	1	4
2. bentonite----------------------------		2
1. shale, brown, much yellow-colored material in cracks------------------		7
Total Fish Scale zone-	25	6

NIOBRARA FORMATION

chalk, impure, to bottom of exposure- .

TABLE VIII-A
Succession of beds, Pierre formation
exposed two miles south of mouth of Crow Creek,
Buffalo County, South Dakota
Detailed section, Oacoma zone
NE¼, SW¼ Section 34, T. 106 N., R. 71 W.

PIERRE FORMATION

<u>Sully member</u>

Verendrye zone

	Feet	Inches
85. shale, gray, weathers to gumbo; not measured-------------------------		
84. shale, light gray, banded, few scattered concretions at base, rusty white limestone concretions at top---------------------------	9	0
Oacoma zone		
83. concretion zone, heavy 2" ledge-----		2
82. shale, light yellowish gray---------	1	11
81. concretion zone, intermittent purple nodules-------------------------		1
80. shale, as above---------------------		6
79. concretion zone, persistent ledge---		1½
78. shale, as above---------------------		6
77. bentonite---------------------------		1½
76. shale, as above---------------------		4
75. bentonite---------------------------		3
74. shale, as above---------------------		2
73. concretion zone, intermittent-------		1
72. shale, as above---------------------	1	9
71. bentonite---------------------------		½
70. shale, as above---------------------		2
69. concretion layer--------------------		1½
68. shale, as above---------------------	1	5
67. concretion layer, intermittent------		1
66. shale, as above---------------------		3

	Feet	Inches
65. bentonite------------------------------		1
64. shale, as above----------------------		2
63. concretion layer, persistent----------		2
62. shale, as above----------------------		7
61. bentonite------------------------------		$\frac{1}{4}$
60. shale, as above----------------------		1 3/4
59. concretion layer, persistent----------		2
58. shale, as above----------------------		1
57. bentonite------------------------------		1
56. shale, as above----------------------		8
55. concretion layer, persistent----------		$1\frac{1}{2}$
54. shale, as above----------------------		1
53. bentonite------------------------------		1
52. shale, as above----------------------		4
51. concretion layer, intermittent--------		2
50. shale, as above----------------------		3
49. bentonite------------------------------		4
48. shale, as above----------------------		4
47. concretion layer (1"-4"), intermittent		4
46. shale, as above----------------------		2
45. bentonite------------------------------		2
44. shale, as above----------------------		3
43. concretion layer, intermittent--------		3
42. shale, as above----------------------		11
41. concretion layer, persistent----------		2
40. shale, as above----------------------	1	0
39. bentonite------------------------------		$\frac{1}{4}$
38. concretion layer, persistent----------		2
37. shale, as above----------------------		6
36. concretion layer, persistent----------		2
35. bentonite------------------------------		3/4
34. shale, as above----------------------	1	0
33. bentonite------------------------------		3/4
32. shale, as above----------------------		$4\frac{1}{2}$
31. bentonite------------------------------		$1\frac{1}{2}$
30. shale, as above----------------------		4
29. concretion layer, persistent----------		$1\frac{1}{2}$
28. shale, dark gray, gummy---------------		5
27. bentonite------------------------------		$\frac{1}{2}$
26. shale, as above----------------------		$4\frac{1}{2}$
25. bentonite------------------------------		1
24. shale, as above----------------------		8
23. bentonite------------------------------		4
22. shale, as above----------------------	2	9
21. concretion layer, persistent----------		2
20. shale, as above----------------------		$1\frac{1}{2}$
19. concretion layer, persistent----------		$1\frac{1}{2}$
18. shale, as above----------------------	1	1
17. concretion layer, persistent----------		2
16. shale, as above----------------------	3	0
15. bentonite------------------------------		6

	Feet	Inches
14. shale, as above----------------------		6
13. bentonite----------------------------		6
12. shale, as above----------------------	5	6
11. bentonite----------------------------		4
10. shale, as above----------------------		3
9. concretion layer, intermittent-------		1
8. shale, as above----------------------	1	0
7. concretion layer, intermittent-------		1
6. shale, as above----------------------	6	1
Total Oacoma	42	3 3/4
Crow Creek zone		
5. marl, light gray---------------------	4	10
4. sandstone, brown, calcareous, slabby-	1	0
Gregory member		
3. shale, gray, gummy-------------------	13	6
2. bentonite ----------------------------		6
1. shale, as above, to bottom of gully; not measured-----------------------		

TABLE VIII

Succession of beds, Pierre formation,
exposed at and south of the mouth of Crow Creek,
Buffalo County, South Dakota
Composite section,
Secs. 23 and 34, T. 106 N., R. 71 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
12. shale, gray, weathers to gumbo; contains large black sideritic concretions; not measured----------------		
11. shale, light gray, flaky-------------	7	0
10. shale, light gray--------------------	2	0
9. shale, light gray, with rusty zone at top and 2 intermittent zones of white, rusty lime concretions in lower 15 feet---------------------	29	4
8. shale, light gray, with zone of white, rusty lime concretions at top, and two similar, intermittent zones near base-------------------------	9	0
Oacoma zone		
upper		
7. shale, gray to yellow gray, flaky; numerous iron manganese concretions and many bentonites---------------	20	1

	Feet	Inches
lower (Agency?)		
6. shale, dark gray, gummy, containing 3 thick bentonites and few layers of concretions------------	22	3
Crow Creek zone		
5. marl, light gray-------------------	5	0
4. sandstone, brown, calcareous, slabby		11
Gregory member		
3. shale, gray to brown, containing numerous flat, rusty-brown concretions. Some calcareous layers, including an intermittent 5"-6' impure marl lying 7-10 feet below the Crow Creek sand in some exposures on each side of the river in this immediate area-----------	84	00
Sharon Springs member		
Upper zone (included with Gregory shale)		
Fish scale zone		
2. shale, dark gray to black fissile, contains fish fragments and numerous bentonite beds; selenitic at base--------------------------	14	0
NIOBRARA FORMATION		
1. chalk, impure, weathers yellow on outcrop-------------------------		

TABLE IX

Succession of beds, Pierre formation
exposed along the Lower Brule-Reliance road,
2 miles south of Lower Brule, Lyman County, S. Dak.
Detailed section, Oacoma zone
Section SW ¼, T. 107 N., R. 73 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
107. Shale, gray, with numerous black concretions, to top of exposure, not measured--------------------		
106. Shale, gray, weathers to gumbo----	13	0
105. Shale, gray to yellowish gray-----	2	0
104. Shale, light gray, flaky, few small buff concretions, and zone of large rusty to black concretions at top-------------------	28	0
103. Shale, light gray, flaky; rusty shale streak with black-rusty concretions at top and similar zone 1' 4" below top------------	2	3

		Feet	Inches
Oacoma zone			
102.	Shale, light gray, flaky, few scattered concretions in lower 18", and zone of brown-black concretions at top-------------	3	4
101.	bentonite-------------------------		1
100.	shale, light gray, flaky----------		3
99.	bentonite, powdery----------------		4
98.	shale, as above-------------------		2
97.	concretion zone, intermittent nodules-------------------------		1
96.	shale, as above-------------------		10
95.	concretion zone, intermittent nodules-------------------------		1
94.	shale, as above-------------------		4
93.	bentonite-------------------------		1
92.	shale, as above-------------------		2
91.	concretion zone, intermittent nodules-------------------------		1
90.	shale, as above-------------------		7
89.	concretion zone, intermittent nodules-------------------------		1
88.	shale, as above-------------------		3
87.	bentonite-------------------------		1
86.	shale, as above-------------------		2
85.	concretion zone, nodules fossiliferous-------------------------		½
84.	shale, as above-------------------	1	0
83.	bentonite-------------------------		½
82.	shale, as above-------------------		3
81.	concretion zone, persistent------		3
80.	shale, as above-------------------		6
79.	concretion zone, intermittent----		1
78.	shale, as above-------------------		4
77.	bentonite-------------------------		1
76.	shale, as above-------------------		3
75.	concretion zone-------------------		1
74.	shale, as above-------------------		8
73.	bentonite, impure-----------------		2
72.	shale, as above-------------------	1	0
71.	bentonite-------------------------		8
70.	shale, as above-------------------		1
69.	bentonite-------------------------		1
68.	shale, as above-------------------		4
67.	bentonite-------------------------		¼
66.	shale, as above-------------------		9½
65.	bentonite-------------------------		1
64.	shale, as above-------------------	1	1
63.	concretion zone, intermittent----		3
62.	shale, as above-------------------		11
61.	concretion zone, persistent------		1½

	Feet	Inches
60. shale, as above----------------------		2
59. concretion zone, persistent---------		2
58. shale, as above----------------------	3	0
57. bentonite----------------------------		1
56. shale, as above----------------------		3
55. concretion zone, persistent---------		2
54. shale, as above----------------------		3
53. bentonite----------------------------		2
52. shale, as above----------------------		2
51. bentonite----------------------------		2
50. shale, as above----------------------		2
49. bentonite----------------------------		2
48. concretion zone----------------------		1
47. shale, as above----------------------	1	0
46. concretion zone, brown, persistent--		3
45. shale, as above----------------------		7
44. bentonite----------------------------		1½
43. shale, as above----------------------	1	0
42. bentonite----------------------------		1½
41. shale, as above----------------------		4½
40. bentonite----------------------------		½
39. shale, as above----------------------		3
38. bentonite, with mica flakes---------		4
37. shale, as above----------------------		6
36. bentonite----------------------------		½
35. shale, as above----------------------		2
34. concretion zone----------------------		2
33. shale, as above----------------------		8
32. bentonite, micaceous, yellow--------		3
31. shale, as above----------------------		7
30. concretion zone----------------------		2
29. shale, as above----------------------		9
28. concretion zone, persistent---------		2
27. shale, as above----------------------		11
26. concretion zone, persistent---------		2
25. shale, as above----------------------		5
24. bentonite, micaceous (LMB)-----------		1
23. shale, as above----------------------	1	1
22. concretion zone, nodules soft, earthy		1
21. shale, as above----------------------		11
20. concretion zone, nodules soft, earthy		1
19. shale, as above----------------------		9
18. concretion zone, nodules soft, earthy		1
17. shale, as above----------------------	1	1
16. concretion zone, nodules soft, earthy		1
15. shale, as above----------------------		11
14. concretion zone, hard, persistent---		1
13. shale, as above----------------------	1	4
12. concretion zone, nodules soft, earthy		1
11. shale, as above----------------------		10
10. concretion zone, nodules soft, earthy		1

	Feet	Inches
9. shale, as above------------------		8
8. bentonite------------------------		2
7. shale, as above------------------		2
6. bentonite, mica flakes------------		2
5. shale, as above-------------------		2
4. bentonite-------------------------		2
3. shale, as above-------------------		10
Total, Oacoma and Agency? zones	40	3/4
Crow Creek zone		
2. marl, light gray------------------	3	10
1. sandstone, brown, calcareous, slabby	1	0

Note: Basal part of section somewhat foreshortened as beds are somewhat tilted by slumping; particularly beds 1 to 6.

TABLE X

Succession of beds, Pierre formation, near artesian well on Short Creek, Lyman County, South Dakota. Detailed section, Oacoma zone Section 12, T. 106 N., R. 72 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
141. shale, gray to yellowish gray, not measured------------------------		
140. shale, gray to yellowish gray, zone of large white concretions at top, few scattered black concretions in lower part-------------	7	11
Oacoma zone		
139. concretion zone, fossiliferous, persistent----------------------		2
138. shale, light gray, papery---------		11
137. concretion zone, blue nodules, intermittent----------------------		1
136. shale, as above-------------------		8
135. concretion zone, intermittent-----		1
134. shale, as above-------------------		4
133. concretion zone, brown------------		1½
132. shale, as above-------------------		4
131. bentonite-------------------------		2
130. shale, as above-------------------	1	7
129. bentonite-------------------------		½
128. shale, as above-------------------		4
127. concretion zone, nodular----------		1

		Feet	Inches
126.	shale, as above------------------		11
125.	concretion zone, nodular--------		1½
124.	shale, as above------------------		7
123.	bentonite------------------------		1
122.	concretion zone, fossiliferous-		1
121.	shale, as above------------------		8
120.	concretion zone-----------------		1½
119.	shale, as above------------------		6
118.	concretion zone, fossiliferous--		1
117.	shale, as above------------------		2
116.	bentonite------------------------		½
115.	shale, as above------------------		4
114.	concretion zone, fossiliferous--		1½
113.	shale, as above------------------		5
112.	bentonite------------------------		1
111.	shale, as above------------------		6
110.	bentonite------------------------		6
109.	shale, as above------------------		5½
108.	bentonite------------------------		½
107.	shale, as above------------------		1
106.	concretion zone, brown-----------		2
105.	shale, as above------------------		7
104.	bentonite------------------------		1
103.	shale, as above------------------		4
102.	bentonite------------------------		1
101.	shale, as above------------------		9
100.	concretion zone, persistent-----		2
99.	shale, as above------------------		6
98.	concretion zone, nodules flat, persistent--------------------		2
97.	shale, as above------------------		8
96.	concretion zone, nodules flat, yellowish---------------------		1¼
95.	shale, as above------------------		3
94.	concretion zone, yellow, persistent--------------------------		2
93.	shale, as above------------------		10
92.	bentonite------------------------		½
91.	shale, as above------------------		4
90.	bentonite------------------------		½
89.	shale, as above------------------		8
88.	bentonite------------------------		½
87.	shale, as above------------------		4
86.	bentonite------------------------		½
85.	shale, as above------------------		5
84.	concretion zone, nodules flat, persistent--------------------		1¼
83.	shale, as above------------------		5
82.	bentonite------------------------		1
81.	shale, as above------------------		5
80.	bentonite------------------------		1
79.	shale, as above------------------		6
78.	bentonite------------------------		3

71. shale, as above		2
70. concretion zone, nodular, persistent		1
69. shale, as above		6
68. concretion zone, nodular, persistent		1
67. shale, as above		3
66. concretion zone, nodular, persistent		1
65. shale, as above		3½
64. bentonite		3/4
63. shale, as above		1
62. concretion zone, nodular, fossiliferous		2
61. shale, as above		9
60. concretion zone		3
59. shale, as above		5
58. concretion zone		2
57. shale, as above		6
56. concretion zone		2
55. shale, as above	1	1
54. bentonite		1
53. shale, as above		2
52. bentonite		½
51. shale, as above		2
50. bentonite		1
49. shale, as above		2
48. bentonite		2
47. shale, as above		1
46. bentonite		2
45. shale, as above		1
44. bentonite		2
43. shale, as above	1	4
42. bentonite		½
41. shale, as above		11
40. concretion zone, brown		1½
39. shale, as above		2
38. concretion zone, flat yellow nodules		1
37. shale, as above		3
36. concretion zone, persistent		2
35. shale, as above	1	0
34. concretion zone, nodules intermittent		1½
33. shale, as above	1	1

	Feet	Inches
32. bentonite------------------------		½
31. shale, as above------------------		3
30. bentonite------------------------		¼
29. shale, as above------------------		5
28. bentonite------------------------		4
27. shale, as above------------------		2
26. bentonite------------------------		8½
25. shale, as above------------------		7
24. bentonite------------------------		½
23. shale, as above------------------		6
22. concretion zone, nodules inter-mittent------------------------		1
21. shale, as above------------------		9
20. concretion zone, persistent------		2
19. shale, as above------------------	1	10
18. concretion zone, nodules rounded, persistent--------------------		2
17. shale, as above------------------		6
16. concretion zone, nodules inter-mittent------------------------		1
15. bentonite------------------------		4
14. shale, as above------------------		2½
13. concretion zone, nodules flat, persistent--------------------		1
12. shale, as above------------------		7
11. concretion zone, nodules flat, persistent--------------------		1½
10. shale, as above------------------	1	1
9. concretion zone, nodules flat, intermittent------------------		1
8. shale, as above------------------		6
7. bentonite------------------------		1
6. concretion zone, intermittent---		2
5. shale, as above------------------	1	5
4. bentonite------------------------		1
3. shale, as above------------------		8
Total Oacoma	46	3
Crow Creek zone		
2. marl, light gray-----------------	4	0
1. sandstone, brown, calcareous, slabby------------------------	1	7
Gregory member		
shale, not measured-------------		

TABLE XI

Succession of beds, Pierre formation, exposed near mouth of Medicine Creek, Lyman County, South Dakota
Detailed section
Sec. 4, T. 107 N., R.74 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sully Member</u>		
Verendrye zone		
26. shale, gray, with large, black typical concretions beginning about 6' above base, not measured----------		
25. shale, banded gray and yellowish gray, with rusty streak about 30" above base, with few small broken buff concretions, and bones of reptile----------	11	3
24. concretion zone, large white to black nodules		6
23. shale, banded gray and yellowish gray-------	2	8
Oacoma zone		
22. bentonite----------		1
21. shale, gray----------	3	2
20. bentonite----------		1
19. shale, gray----------		2
18. bentonite----------		1
17. shale, gray, with numerous black iron-manganese concretions----------	7	2
16. bentonite----------		6
15. shale, as above----------		2
14. bentonite----------		1
13. shale, as above----------	4	10
12. bentonite----------		1
11. shale, as above----------	3	10
10. bentonite----------		$1\frac{1}{2}$
9. shale, as above----------	3	5
8. bentonite----------		2
7. shale, as above----------	2	$7\frac{1}{2}$
6. bentonite----------		4
5. shale, as above----------	7	2
4. bentonite, micaceous (the Lower Micaceous bentonite of Gries, 1940)----------		6
3. shale, gray, weathers to gumbo (Agency?). Contains few white and black concretions; three 2-4 inch bentonites in basal 18", two of which are micaceous----------	29	9
Total Oacoma and Agency (?)	64	4
Crow Creek zone		
2. sandstone, brown calcareous, slabby. The overlying marl is completely missing at this locality----------	1	0
<u>Gregory member</u>		
1. shale, gray to brown, with many brown concretions to base of exposure, not measured		

TABLE XII A

Succession of beds, Pierre formation
exposed near mouth of Cedar Creek,
Lyman County, South Dakota
Detailed section
Sec. 22, T.108 N., R. 76 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Oacoma zone		
38. shale, to top of hill; not measured--------		
37. bentonite----------------------------------		1
36. shale, gray to yellow-gray, blocky, hard, non-siliceous with 2-4" layers of brown iron-manganese concretions---------------	2	8
35. bentonite----------------------------------		4
24. shale, as above----------------------------	1	2
33. bentonite----------------------------------		4
32. shale, as above----------------------------	2	6
31. bentonite----------------------------------		½
30. shale, as above----------------------------	2	8
29. bentonite----------------------------------		4
28. shale, as above----------------------------	6	6
27. bentonite----------------------------------		½
26. shale, as above----------------------------	1	0
Crow Creek zone		
25. marl --------------------------------------	8	11
24. sandstone, brown, calcareous, slabby-------	1	0
Gregory member		
Upper zone		
23. shale, gray,(with brown streaks) soft; numerous flat, rusty brown concretions---	1	3
22. bentonite----------------------------------		½
21. shale, as above----------------------------	9	1
20. bentonite----------------------------------		1
19. shale--------------------------------------		3
18. bentonite----------------------------------		1
17. shale--------------------------------------	1	9
16. bentonite----------------------------------		8
15. shale--------------------------------------	1	4
14. shale, brownish gray, with yellow "bloom"; some beds black on edges. Small gypsum concretions one foot below color change; scattered small buff "worm-eaten" concretions and large septarian concretions with yellow calcite below this point----------	4	1
13. limestone concretion zone (highest)--------	1	0
12. shale, as above----------------------------	5	3
11. bentonite, creamy white--------------------		1
10. limestone ledge----------------------------	1	0
9. shale---------------------------------------	6	3

	Feet	Inches
8. bentonite, creamy white--------------		3
7. shale--------------------------------	3	7
6. bentonite----------------------------		½
5. shale--------------------------------		5
4. bentonite----------------------------		½
3. shale--------------------------------	3	9
2. bentonite----------------------------		3
1. shale, with abundant septarian concretions, to creek bottom; base not exposed----------------------------	16	6

TABLE XII B

Succession of beds, Pierre formation, exposed near mouth of Cedar Creek, Lyman County, South Dakota
Detailed section ¼ mile up stream from Table XII-A
Sec. 22, T. 108 N., R. 76 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Verendrye zone		
26. shale, gray, with numerous large black concretions, to top of hill, not measured---------------------------		
25. shale, banded, gray to yellowish gray; few scattered small buff concretions in lower half----------------------	15	2
24. shale, banded, gray to yellowish gray; almost continuous ledge of 3" black concretions at top, and "rusty" shale zone 5' below top------------	7	9
23. shale, banded, gray to yellowish gray; at top and at one foot intervals below, are 3 zones of rusty shale containing scattered flat white to rusty brown limestone concretions, and a few thin black concretions----	7	6
Oacoma zone		
22. bentonite, hard----------------------		1
21. shale, gray, with black iron-manganese concretions------------------------	1	8
20. bentonite----------------------------		4
19. shale, as above----------------------	1	9
18. bentonite----------------------------		6
17. shale, same--------------------------		2
16. bentonite----------------------------		1
15. shale, as above----------------------	8	0
14. bentonite----------------------------		1
13. shale, as above----------------------		11
12. bentonite----------------------------		1½
11. shale, as above ---------------------		10½

		Feet	Inches
10.	bentonite		1½
9.	shale, as above	4	4
8.	bentonite		1½
7.	shale, as above		8
6.	bentonite		1
5.	shale, as above	4	2
4.	bentonite		2
3.	covered interval, consists of gray shale with numerous bentonites and black iron-manganese concretions	40	
	Total Oacoma	64	3
Crow Creek zone			
2.	marl	9	0
1.	sandstone, brown, slabby	1	0

Note: Tables XII-A and XII-B may be tied together on the Crow Creek sand, giving a section complete except for a short interval in the lower part of the Oacoma zone. As noted previously, the lower Oacoma may represent the Agency shale farther north.

TABLE XIII

Succession of beds, Pierre formation, exposed along De Grey-Joe Creek road, one and one-half miles southeast of De Grey, Hughes County, South Dakota

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
14. shale, gray, weathers to gumbo; numerous black sideritic concretions; not measured		
13. shale, yellowish-gray, flaky, with large black concretion zone at top	7	10
Oacoma zone		
Upper		
12. shale, gray, hard, platy, with blue stained joints; many bentonites and iron-manganese concretions	33	7
11. bentonite, yellow, with biotite flakes(LMB)		6
Lower (Agency?)		
10. shale, light gray, somewhat papery, no visible bentonites or concretions; stands in steep outcrop	12	4
9. shale, gray, weathers to gumbo; contains few bentonites and scattered iron-manganese concretions	21	0

	Feet	Inches
8. bentonite----------------------------------		6
7. shale, as above--------------------------	1	0
6. bentonite----------------------------------		6
5. shale, as above--------------------------	8	8
4. bentonite, slightly micaceous------------		6
3. shale, as above--------------------------	6	2
Oacoma-Agency,Total	84	9
Crow Creek zone		
2. marl, light gray, with brown slabby sandstone at base-------------------------	14	1
<u>Gregory member</u>		
1. shale, brown to gray, many rusty-brown concretions; layer of one-foot gray septarian concretions about 37 feet below top; to level of road (hand leveled)-------------------------------	42	0

STRUCTURE

Structural features will play little part in the development of the manganese deposits because the beds are nearly horizontal. Mapping on a key bed has shown that though the rocks are folded into gentle undulations, these are not of sufficient magnitude to distort the beds locally. Mining operations, therefore, do not have to take into consideration dips or folded structures.

No major faults cut the zone though a few small ones, with displacements of 10 to 15 feet, were noted.

The most troublesome dislocations are the slumps found all along the outcrops. These are blocks of shale which have slipped off the face of the hills as stream erosion has undermined them. Such blocks are usually wedge shaped with the thin edge downward and vary all the way from chunks a few feet across to large blocks covering several acres. Such slides occur on both the ends and sides of the topographic shoulders on which the manganese zone is exposed. Some have moved but a couple of feet from their original position while others have slid a score or two. In general, the more gentle slopes are more likely to have large slumped blocks on their flanks than are the very steep slopes. Probably this is because, in the latter case, rapid erosion in the sharp gullies removes the slumped material leaving the faces of the cliffs clean. Such slumps are confusing since the sliding of the block usually leaves the Crow Creek beds and the layers of nodules in a horizontal position, making them appear to be in place. In some places it is possible to be misguided into thinking there are two zones of manganese bearing nodules instead of the one which actually exists. If mining is attempted in such slumped blocks, considerable quantities of nodules may be excavated. Within a few feet, however, the zone of nodules will be replaced by barren shale.

Slumps of the beds overlying the Oacoma zone are also common, especially on the gentler slopes. These can cause considerable difficulty by covering the upper portion or even all of the manganese zone, making it difficult to determine the true thickness of the zone, and necessitating the stripping of this cover in excavation.

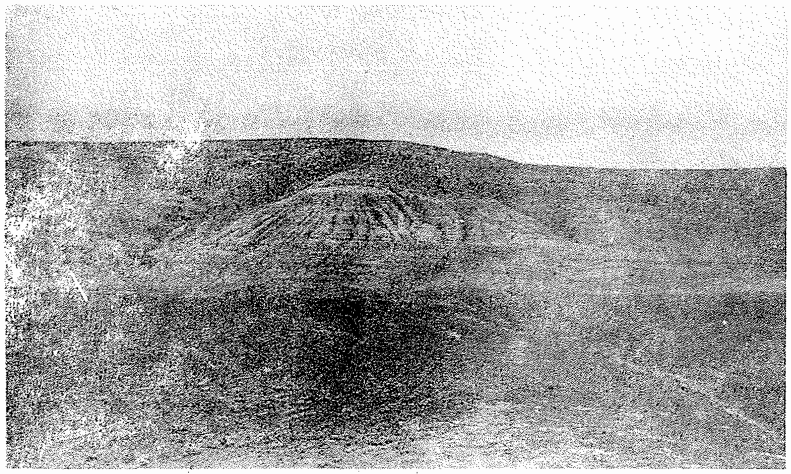
OCCURRENCE OF MANGANESE

In The Oacoma Zone

As has been shown above, the manganese bearing nodules occur in layers scattered through a zone of shale. This zone averages about forty feet in thickness, varying from 26 to 64 feet in the area mapped. Its lower limit is quite sharp, being designated as the top of the chalky, Crow Creek shale, lying immediately beneath the non-calcareous shale of the Oacoma zone. The upper limit is not so easily placed. Manganese bearing concretions in some sections are scattered sparingly high up in the shales of the Verendrye which overlie the Oacoma zone. In all good sections, however, the concentration of nodules thick enough to be of possible commercial interest ends rather abruptly at the base of or in the lower few feet of the light colored shale, designated as the "banded beds", five to ten feet below, a layer of large rusty concretions. In this survey the highest manganiferour layer was assumed to be the top of the zone.

The outcrop of this zone can be followed along both bluffs of the Missouri and up its tributaries for a distance of several miles. It is known to underlie the uplands on both sides of the Missouri valley, also, at a depth of about two hundred feet. Judging from the location of the outcrops it is fairly safe to assume that it underlies about one-eighth of the area of the state. For the purposes of this report, however, only that part of the zone which outcrops is being considered, as it is the only part which can be profitably exploited under present conditions.

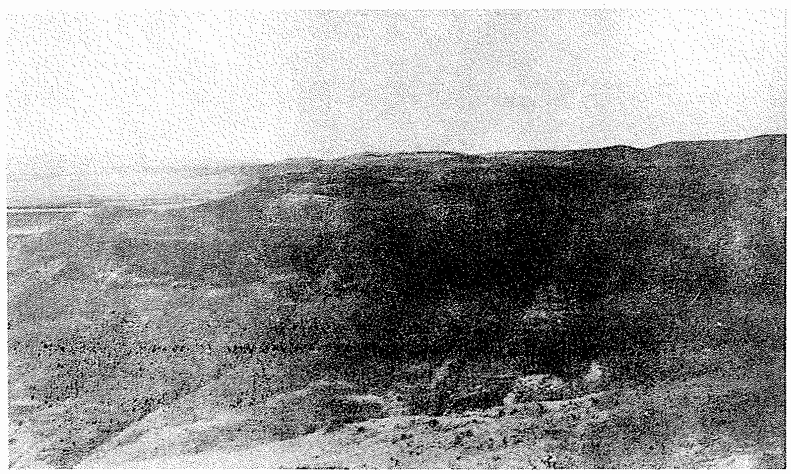
<u>Thickness</u>: The thickness of the zone so designated varies considerably, but there seems to be no order in this variation, in the area mapped. In the two southernmost townships, carefully measured sections showed a thickness of thirty two and thirty four feet. The thickest section measured was opposite the mouth of the White River and gave 65 feet. One

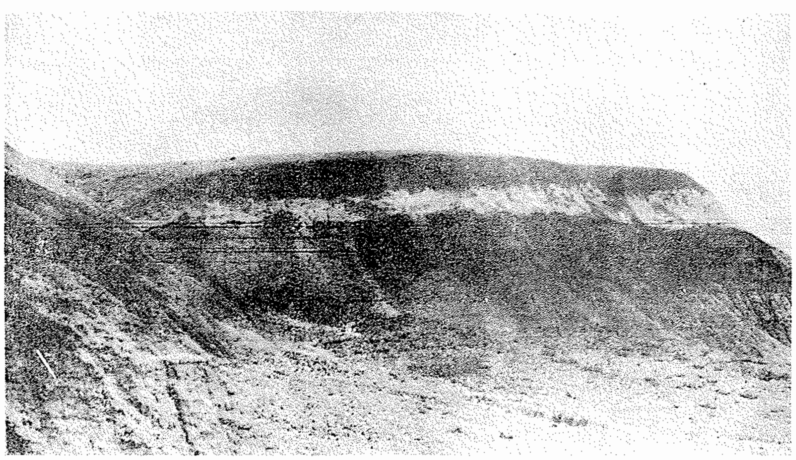


Top of Oacoma Zone

"Banded Beds" center rear
Oacoma beds foreground

Typical Outcrop
of the
Oacoma Zone





Base of Oacoma Zone

Crow Creek Beds
shown as light streak

section lying between those just mentioned gave forty-five feet, while others between Chamberlain and Fort Thompson varied from forty-three to forty-eight feet. The most northerly section, which was measured near the lower Brule Agency, measured 38 feet.

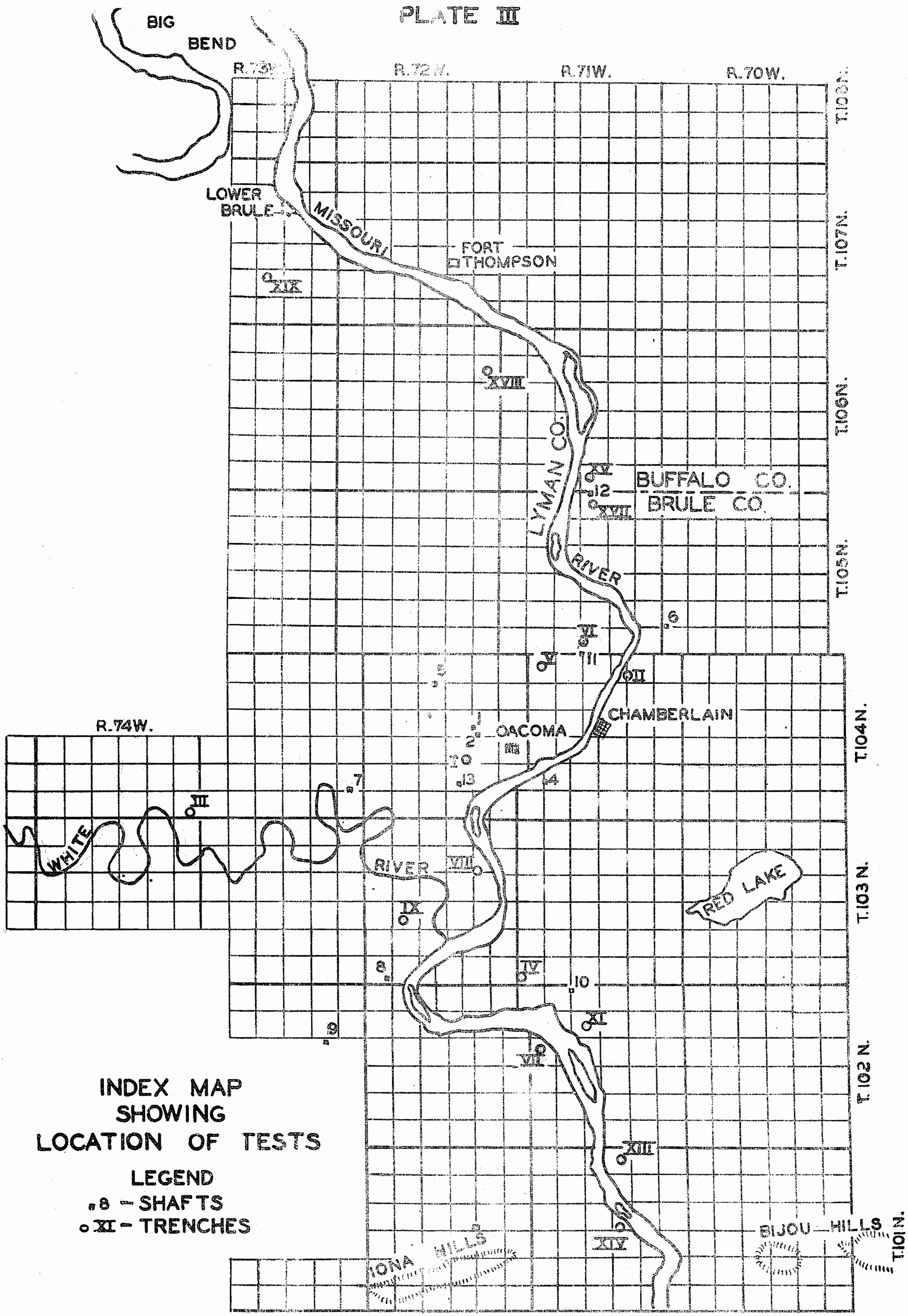
It might be pointed out that the thickest section is in the vicinity of the mouth of the White River while the most northerly and southerly sections are the thinnest. There may be some thinning both up and down the valley. A section measured at the Rosebud bridge in Gregory county, 35 miles down river from the Bijou Hills, showed a thickness of 23 feet for this zone, while another measured at DeGrey, 30 miles up river from lower Brule, showed 34 feet. In the area mapped, however, one is struck with the uniformity rather than the variations in thickness. The average thickness of the zone in this area is 44 feet.

Distribution of Nodules: The distribution of the layers of nodules in these sections is not uniform throughout the zone. Early testing in Oacoma and Chamberlain disclosed a barren zone ten to fifteen feet thick at the base of the section, immediately above the chalky shale. In this zone, though the shales and bentonites were exactly like those higher up, only one or two layers of nodules appeared. Sections in the southern and eastern parts of the area, however, did not show this barren zone, concretions being as abundant in the bottom of the sections as higher up.

Towards the top of most sections the distance between nodular layers increases, but in no place is there a distinct, barren zone. As has been mentioned, it is usually a relatively simple matter to pick out the last manganese bearing layer and it is seldom far above the zone in which there is a maximum concentration.

On the average the layers of nodules are separated by about a foot of shale. Some concentrations occur in which the layers are but a few inches apart. In other parts of the section they are separated by three or four feet of barren shale. Each area has its own characteristics and therefore should

PLATE III


BIG BEND
R.72W.
R.71W.
R.70W.
T.107N.
T.106N.
T.105N.
T.104N.
T.103 N.
T.102 N.
T.101 N.
R.74W.
LOWER BRULE
MISSOURI
FORT THOMPSON
LYMAN CO.
BUFFALO CO.
BRULE CO.
RIVER
CHAMBERLAIN
OACOMA
WHITE
RIVER
RED LAKE
IONA HILLS
BIJOU HILLS
INDEX MAP SHOWING LOCATION OF TESTS
LEGEND
8 – SHAFTS
XI – TRENCHES

be carefully investigated before mining operations are undertaken. In general, however, it is safe to state that if the extreme top and the extreme base of the section is avoided, the concentrations of nodules is fairly uniform. The following sections will serve as illustrations of the spacing and size of the nodules. A typical section in the northern area measured on Short Creek gave the following:

TABLE XIV

Spacing of Nodules in Section
Measured on Short Creek
Sec. 12, T.106 N.,R. 72W., Lyman Co.

Sample Designation	The Description of Concretions	Thickness of nodules in inches	Height above top Crow Creek Sand in feet
	Lower rusty concretionary bed;non-manganiferous. Scattered nubbins not worth sampling.		58
XVIII Z-K	Concretionary layer with many fossil shells	2	50.1
XVIII Z-J	Small rounded nodules	1	49.1
XVIII Z-I	Scattered round nodules	1	48.35
XVIII Z-H	Layer of brown nodules	1½	47.9
XVIII Z-G	Nodular layer	1	45.35
XVIII Z-F	Layer of nodules	1½	44.3
XVIII Z-E	Concretionary layer, very fossiliferous	1	43.6
XVIII Z-D	Concretionary layer	1-1½	42.8
XVIII Z-C	Very fossiliferous layer	1	42.2
XVIII Z-B	Fossiliferous layer	1½	41.5
XVIII Z-A	Brown concretionary layer	2	39.25
XVIII Z	Layer of blocky concretions	2	37.30
XVIII Y	Layer of flat concretions	2	36.65
XVIII X	Layer of flat yellow concretions	1½	35.9
XVIII W	Large round, unconnected nodules, yellow	2	35.5
XVIII V	Flat, unconnected concretions	1¼	32.65
XVIII U	Layer of large, round bluish nodules 2 x 2 x 1½	1½	28.00
XVIII T	Spherical blue disconnected concretions	1	27.85
XVIII S	Like T	1	27.64
XVIII R	Potatoe-like nodules	1	26.04
XVIII Q	Potatoe-like concretions	1	26.70

XVIII P	Rough, nodular layer; fossiliferous	2	26.10
XVIII O	Layer	2½-3	25.10
XVIII N	Layer	2	24.50
XVIII M	Layer of round, fossiliferous concretions	2-3	23.78
XVIII L	Layer of brown concretions	½	18.85
XVIII K	Large, flat, yellow concretions	1	18.64
XVIII J	Large, round concretions 2 x 4	2	18.20
XVIII I	Round nodules 1½ x 2	1½	17.10
XVIII H	Small round nodules	1	12.9
XVIII G	Large round nodules	2	12.00
XVIII F	Large, round, yellow nodules	2	10.20
XVIII E	Scattered round concretions	1	9.42
XVIII D	Flat, circular concretions 1 x 3	1	8.8
XVIII C	Scattered, 1½ x 2 nodules	1½	8.1
XVIII B	Flat 2 x 3 x 1 concretions	1	6.9
XVIII A	Potatoe-like concretions 2 x2	2	6.13

The spacing in the southern part of the area is illustrated by a section measured on Elm Creek.

TABLE XV

Spacing of Nodules in Section
Measured on Elm Creek
Sec. 3, T. 101 N., R. 71 W., Brule Co.

	Large, rusty concretions non-manganese bearing		46.5
XIII Z-A	Layer of concretions	1	41.0
XIII Z	Scattered nubbins	1	39.82
XIII Y	" "	1	39.32
XIII X	" "	1	39.10
XIII W	" "	1	36.45
XIII V	Scattered, fossiliferous concretions	1	35.65
XIII U	Pavement of concretions	2	34.48
XIII T	Heavy pavement of concretions	2	34.32
XIII S	Nodular, fossiliferous concretions	2	34.12
XIII R	Pavement	4	33.85
XIII Q	Nodular, potatoe-like concretions	2	32.78
XIII P	Flat, circular concretions 1½ x 4	1½	32.15
XIII O	Flat concretions	1	30.95
XIII N	Layer of flat concretions 1 x 4	1	28.17

XIII M	Pavement	1	26.27
XIII L	Layer of flat concretions	3-4	25.72
XIII K	Large, potatoe-like concretions	4	25.1
XIII J	Flat, nodular concretions	$1\frac{1}{2}$	24.54
XIII I	Flat, nodular concretions	1	23.75
XIII H	Large, flat concretions in short layers	4	22.94
XIII G	Round, nodular concretions	2	22.09
XIII F	Pavement	1	17.52
XIII E	Nodular layer	4	15.28
XIII D	Large, flat concretions	2	14.42
XIII C	Scattered nodules	1	13.27
XIII B	Large nodular concretions	3	11.87
XIII A	Flat concretions	1	9.6

Placer Deposits

The major portion of this report and all previous discussions have confined themselves to the nodules "in place" in the marine shales. No discussion, however, would be complete without calling attention to the possibility of obtaining a large amount of material from placer deposits in the bars of the Missouri and the tributary streams of this area.

The nodules tend to shatter on weathering and soon the pieces become so small that they are carried away and lost in the other sediments of the river. In the larger valleys they are seldom found below the shale horizon except as tiny bars in the channels of the small streams.

In many of the steep gulches which border the Missouri, however, erosion has taken place faster than weathering can disintegrate the nodules and as a consequence these have settled in considerable quantities in the bottoms of the gulches and also in the deltas formed where they debouch into the Missouri River. Such deposits are usually found in considerable abundance where the Missouri is undercutting the banks so that cliffs stand precipitously above the water. The steep bluffs and steep gradients of the tributary streams permit a very rapid erosion of the manganese bearing zone and a concentration of the nodules in the bottoms of tributary valleys, deltas at their mouths, and bars in the Missouri.

No effort was made to determine the amount of material available from such deposits and it is, of course, much less than that which can be obtained from the manganese zone of the Pierre shale. Deltas covering from one to two or three acres, however, are not uncommon and if mining is undertaken in their vicinity should yield an added tonnage worth the effort of extraction.

The placers have the advantage of being partially concentrated and therefore hold much more manganese per volume of material that has to be handled. The shale and mud has been very largely washed from them so that the manganese nodules constitute a major portion of the delta and bar material.

No sampling was done on these placers since they were a relatively small part of the available manganese and most of them lay at the river level where it was impossible to get accurate data on the thickness and area of the placers. Since they are washed down from the manganese zone higher up the valley, however, and are concentrates of the nodular layers in this zone, they should contain approximately the same percentage of metal as do the nodules which are in place in that locality. The concentration was affected only in the volume of nodules and not in the per cent of manganese which can be extracted from them.

CHARACTER OF NODULES

Size and Amount of Nodules

An inspection of the foregoing sections (Tables XIV & XV will show that there is considerable difference in the size of the nodules in different layers. At one extreme are little, round nubbins one-half to one inch in diameter, while at the other are solid layers extending a score or more feet horizontally and four to six inches in thickness.

In some layers rounded concretions are scattered along the beading plains of the shale while in others flat kidney shaped concretions are lined up like pancakes on a griddle. The average thickness of the nodules is about two inches. Those in the Short Creek section averaged 1.45 inches; in the Chamberlain section, 2.3 inches; and the Elm Creek section, 1.85 inches.

Comparison of the total thicknesses of the concretionary layers with the thickness of the manganese bearing zone shows that about ten per cent of the total is made up of the carbonate nodules. Variations from the above average amount to only a few per cent. The following table of thicknesses from carefully measured sections will illustrate.

TABLE XVI

CONCRETIONARY CONTENT OF OACOMA IN TEN MEASURED SECTIONS

Section Nos.	Location	No. of Beds	Total Thickness of Nodules	Thickness of Zone	% of Sec. Occupied Nodules
I	Oacoma Section Sec.22, T.104 N.,R.72 W.	24	34.5 in.	29 feet	9.9 %
II	N. of Chamberlain Sec. 2, T.104 N.,R.71 W.	17	32.5	39	8.4
III	White River Section Sec. 37, T.104 N.,R.74 W.	17	32.7	26	10.5
IV	Peterson Bottom Sec.31, T.103 N.,R.71 W.	28	45	26	14.4

XI Swanson Section Sec.9, T.103 N.,R.71 W.	25	50	48	8.7
XIII Elm Creek Sec.3, T.101 N.,R.71 W.	27	51	32.2	13.2
XIV East of Iona Sec.15,T.101 N.,R.71 W.	27	77	26	24.7
XV Crow Creek Section Sec.34,T.106 N.,R.71 W.	21	36.5	42	8.67
XVIII Short Creek Sec.12,T.106 N.,R.72 W.	37	50.5	46	10.5
XIX Brule Agency Sec.27,T.107 N.,R.73 W.	26	48	38	8.8

Note: No.IV carried a barren zone at its base. If this is eliminated the total percentage of nodules is increased from 7.4 to 14.4. No. XIX also carries a 15 foot barren zone at its base. If this is eliminated the percentage of nodules raises from 8.7 to 11.7. The Crow Creek section No. XV can also be raised to 15.82 by eliminating barren zones at the base and near the top.

From these thicknesses it would seem safe to assume that ten per cent of the volume of the deposits is composed of nodules and, since manganese has not been detected in the shales, only this ten per cent can be counted on as a producer of the metal.

Mineralogy of the Ores

There has been considerable speculation as to the form in which the manganese occurs in the concretions. It is so intimately mixed or compounded that it is impossible to separate it by ordinary methods. All observers agree that the main constituent of the nodules is the iron carbonate, siderite ($FeCO_3$). This siderite belongs to the variety known popularly as clay ironstone. The form which the manganese takes, however, is in considerable doubt.

Four possible combinations in which it might occur are known to exist: 1) an oxide of manganese, (pyrolusite) 2) a manganese carbonate (rhodochrosite), 3) a carbonate of combined iron and manganese (oligonite), and 4) a carbonate of calcium and manganese (mangano-calcite).

As the black oxide of manganese had not been noted in microscopic examination of the ore, there has been a tendency to disregard the possibility of its presence. Certain chemical reactions, however, seem to indicate that it may be there. "Much of the brown material remains undisolved by nitric acid alone, but disolves when hydrogen peroxide is added. It disolves in hydrochloric acid liberating some chlorine. These are properties of MnO_2[1]. Microscopic examination showed tiny opaque, black and blue-black specks with bright metallic lustre scattered through many of the samples. These possess the optical characteristics of pyrolusite and manganite. In light colored unweathered specimens they were not observed, but began to appear in the portions colored brown by the first stages of weathering. In the black, weathered parts they are much more abundant and in those in which a metallic lustre appears, the pyrolusite and manganite particles reach their greatest proportion.

Manganese carbonate occurs as the mineral rhodochrosite. This mineral is pink in color and cleaves into rhombic pieces. No such mineral is in evidence in the specimens examined.

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1. Ernest Griswold, personal communication.

A compound of rhodochrosite and siderite has been called mangano-siderite by Dana who writes:

> ..the molecules of rhodochrosite and siderite are apparently completely miscible and they may crystallize together in all proportions.[1]

Dana also describes a variety of manganiferous siderite containing 25 per cent MnO under the name oligonite. While only the highest percentages of manganese in the analyses run for the Survey reach this figure, the character of the Chamberlain minerals might allow this interpretation.

A report on these ores issued by the Tennessee Valley Authority, Department of Chemical Engineering Research Division, states:

> ..Microscopic examination indicates the principal minerals present in those samples are siderite, ($FeCO_3$) and mangano-calcite ($CaCO_3.MnCO_3$) together with small quantities of dolomite and magnetite.[2]

The introduction of the third mineral, mangano-calcite, is rather interesting since it means that there must be an entirely different mineral, in fairly large quantities, present as a physical mixture with siderite. Mangano-calcite or spartite as it is sometimes called, becomes black upon exposure. This is characteristic of the Chamberlain nodules which turn from a light gray or olive green through yellow and brown to black.

From chemical analyses they conclude that

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1. Dana, E. S. and Ford, W. E., _A Textbook of Mineralogy_, 4th Edition, 1932, p. 520.
2. Tennessee Valley Authority, Department of Chemical Engineering, Chemical Research Division, South Dakota Manganese Ores. April 26, 1940.

Calculations based on the analyses given above show that there is sufficient carbon dioxide in the samples to form carbonates of all of the calcium and magnesium, plus more than enough to form carbonate with either the iron or the manganese. This confirms the fact indicated by the microscopic examination that part of both the iron and manganese must be in carbonate form.[1]

While the foregoing explains the information which is now available, it must be remembered that a great deal of it is derived from an interpretation of the chemical analyses. The chemical reactions and microscopic observations show that at least part of the manganese occurs as the oxide, and the possibility of its presence in the intimate mixture with iron carbonate known as oligonite should be kept clearly in mind. The identification of mangano-calcite by the T.V.A. laboratories indicates that not all the manganese is in the form of oxides. It is certain that it occurs in different minerals in fresh and weathered materials and may also vary in different localities and in individual layers.

No thorough study of the mineralogy of these nodules has been made. A list of the minerals noted during the course of the various investigations includes:

Siderite	$FeCO_3$	Pyrolusite	MnO_2
Calcite	$CaCO_3$	Manganite	$Mn_2O_3.H_2O$
Aragonite	$CaCO_3$	Magnetite	Fe_3O_4
Dolomite	$CaCO_3.MgCO_3$	Apatite	$(CaCl, F) Ca_4(PO_4)_3$
Mangano calcite	$CaCO_3.MnCO_3$	Quartz	SiO_2

The quartz occurs as very small grains and crystals of clear rock crystal and as chalcedony pseudomorphs of bits of fossil shell and other organic matter. Some specimens contained small, bright red grains which have the appearance and refractive index of apatite.

1. Tennessee Valley Authority, op. cit.

Chemical Composition

Chemical analyses disclosed a variety of materials in the nodules. A qualitative analysis run on a sample from Elm Creek showed the presence of the following:[1]

Manganese
Iron
Aluminum
Calcium
Magnesium (small amount)
Carbonate
Phosphate
Silicate (or SiO_2)

From this and the partial quantitative analyses which follow it is evident that the chief constituents are iron, manganese and the carbonate radical while silica, aluminum, magnesium, and phosphorous play minor roles.

The laboratories of the Tennessee Valley Authority published four analyses showing the presence of calcium, magnesium and silicon besides the iron, manganese and the carbonate radical. These, it will be noted, contain a high percentage of calcium and make no mention of aluminum and phosphorus.[2]

The report of the U. S. Geological Survey does not give complete chemical analyses but does give some of the minor constituents.[3] The details of these analyses are copied in the accompanying table (Table X). The interesting part of the table from the chemical point of view is the fact that the average phosphorous content of thirteen samples was 0.407 per cent; of silica, 12.39; of alumina, 2.65 per cent.

The presence of alumina can be accounted for as shale or clay which has been trapped in the concretion. The amount of alumina, however, is not sufficient to take all of the silica as clay. Kaolin contains 46.5 per cent of silica and 39.5 per cent aluminum. In this proportion the amount of alumina present in the average

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1. Analysis by Dr. Ernest Griswold.
2. Tennessee Valley Authority, *op. cit.*
3. D. F. Hewitt, Manganese-Iron Carbonate Near Chamberlain, S. Dak. Memo for the Press, February 5, 1930.

PLATE IV

COLUMNAR SECTIONS

SHOWING SPACING AND MANGANESE CONTENT OF NODULAR LAYERS

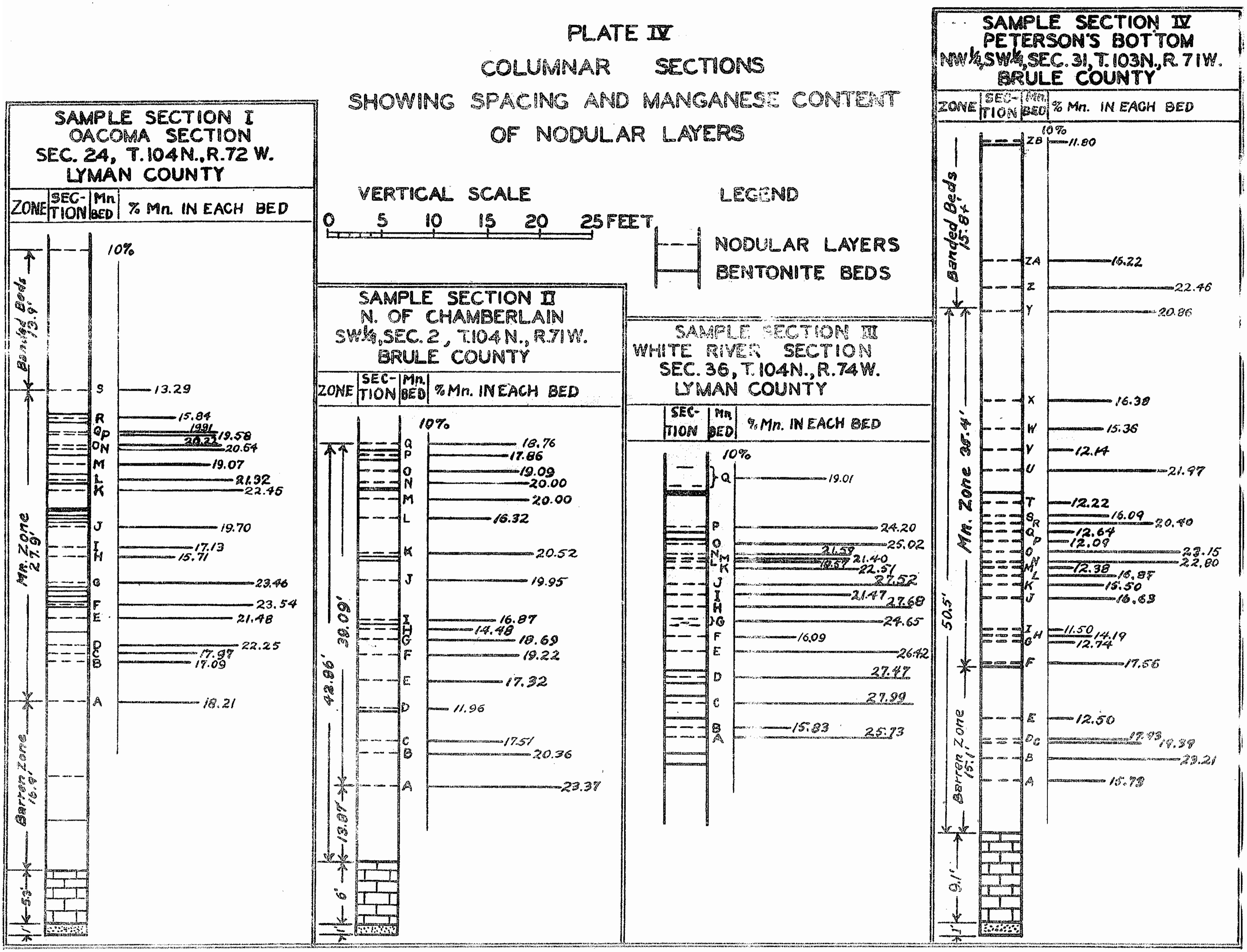
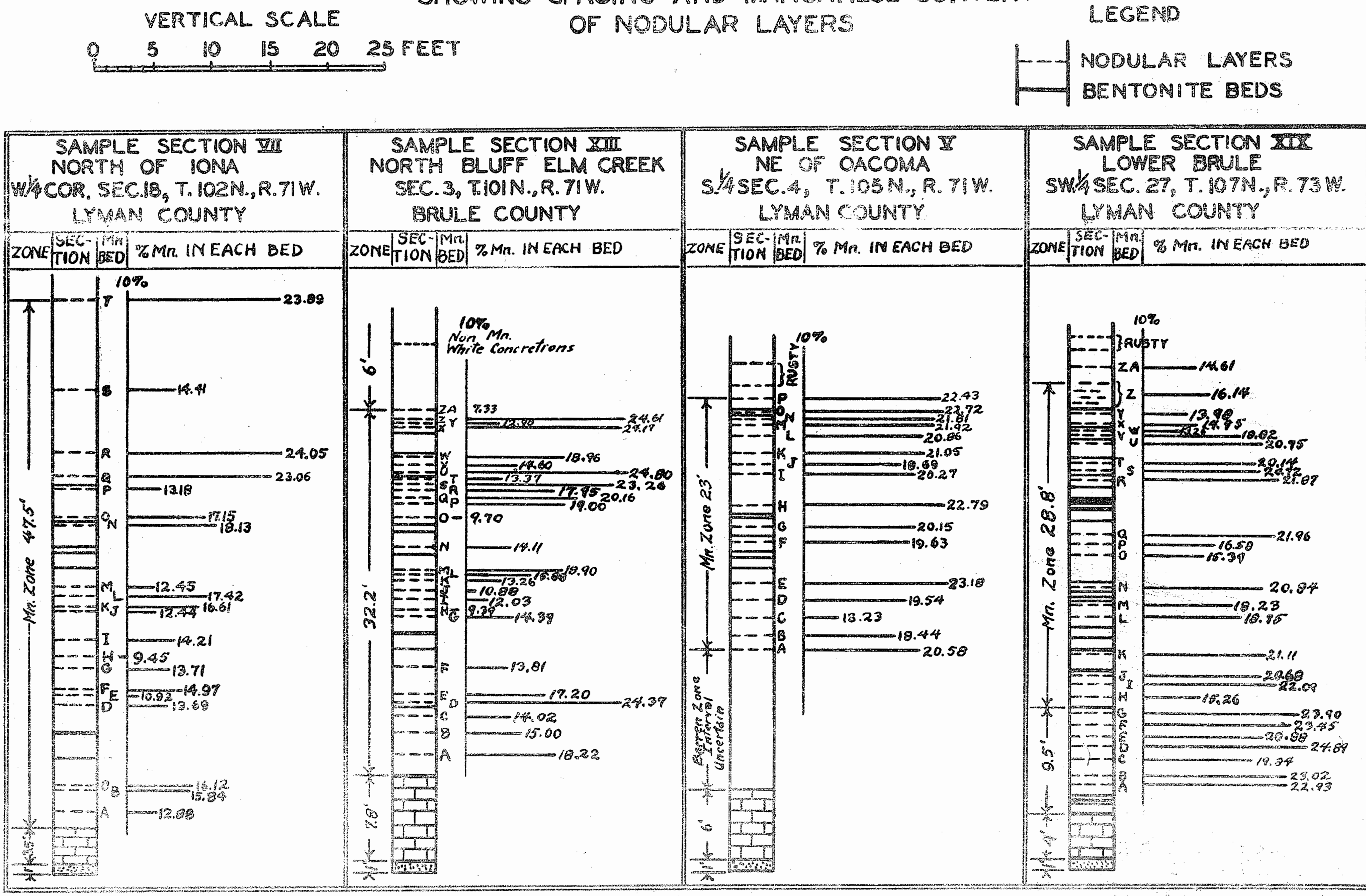


PLATE V

COLUMNAR SECTIONS
SHOWING SPACING AND MANGANESE CONTENT
OF NODULAR LAYERS



of the thirteen samples would require only 3.12 per cent of 12.39 of silica present in the nodules. Therefore much of the silica must be in the form of some variety of quartz. The hardness and toughness of some of the concretions is doubtless due largely to the high silica content.

Analyses made for the present survey were run for obtaining the manganese content of the deposits. Little attention was paid to other constituents, therefore. Enough were run for both manganese and iron, however, to determine the relation between the two. These figures represent the percentage of material in individual layers in some cases and in others the results of analyses on composite samples taken vertically across the manganese bearing zone. Sampling was done by trenching, as has been explained, a representative sample being taken of each layer in the zone. Where composite analyses were made the samples from the individual layers were crushed and quartered, to the size needed for analysis. No samples were collected at random from surface pieces and in all pieces the weathered outside of the concretions was discarded as far as possible. These samples, therefore, represent the manganese and iron percentages in fresh concretions.

TABLE XVII

MANGANESE AND IRON CONTENT OF SAMPLE SECTIONS[1]

Section No. 1

Near Oacoma, Sec. 22, T. 104 N., R. 72 W.

Layer	% Mn	% Fe	Layer	% MN	% Fe
A	19.61	11.02	K	24.18	5.27
B	18.41	13.39	L	22.96	3.76
C	19.36	15.18	M	20.53	3.33
D	23.96	5.73	N	22.12	4.29
E	23.14	6.20	O	21.78	3.31
F	25.35	5.76	P	21.09	3.29
G	25.26	3.41	Q	21.44	3.39
H	16.92	17.47	R	17.05	13.82
I	18.45	15.35	S	14.99	15.84
J	21.22	11.67			
			Average:	16.25	9.6

1. Analyses of samples I-X were made by Dr. Ernest Griswold.

Section II

North of Chamberlain
Sec. 2, T.104 N., R. 71 W.

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	25.31	4.36	I	18.22	14.38
B	21.98	10.75	J	21.55	7.02
C	18.90	13.63	K	22.16	2.34
D	12.92	20.22	L	17.62	12.25
E	18.69	14.98	M	21.60	7.05
F	20.75	3.07	N	21.59	5.75
G	20.18	9.22	O	20.61	3.44
H	15.63	16.97	P	19.29	3.39
			Q	20.25	3.33
			Average:	16.98	8.9

Section III

On White River
Section 36, T. 104 N., R. 74 W.

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	25.73	5.02	J	27.52	8.27
B	15.83	17.83	K	22.51	9.04
C	27.99	4.00	L	18.57	3.64
D	27.47	5.56	M	21.40	18.02
E	26.42	3.20	N	21.59	3.37
F	16.09	18.76	O	25.02	3.44
G	24.65	3.03	P	24.20	2.83
H	27.68	3.32	Q	19.01	2.98
I	21.47	4.96	Average:	21.30	6.9

Section IV

Peterson's Bottom

Sec. 31, T. 103 N., R. 71 W.

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	15.73	19.06	O	23.15	2.81
B	23.21	8.09	P	12.09	18.86
C	19.39	12.45	Q	12.64	19.96
D	17.93	13.99	R	20.40	10.62
E	12.50	21.68	S	16.09	15.75
F	17.56	14.81	T	12.22	21.39
G	12.74	13.97	U	21.97	5.55
H	14.19	17.51	V	12.14	18.81
I	11.50	19.88	W	15.36	15.42
J	16.63	17.32	X	16.38	15.25
K	15.50	17.46	Y	20.86	12.95
L	16.87	16.10	Z	22.46	7.32
M	12.38	19.00	ZA	16.22	22.66
			ZB	11.80	16.01
			Average:	16.00	14.9

Section V

N. E. of Oacoma
Sec. 6, T.104 N., R. 71 W.

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	20.58	6.69	I	20.27	4.78
B	18.44	13.50	J	18.69	12.88
C	13.23	19.28	K	21.05	7.30
D	19.54	11.77	L	20.86	3.06
E	23.18	2.99	M	21.92	3.26
F	19.63	3.07	N	21.81	2.55
G	20.15	5.33	O	22.72	2.88
H	22.79	3.35	P	22.43	4.72
			Average:	20.40	6.72

Section VI

Sec. 34, T.105 N., R. 71 W.

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	19.34	14.27	L	14.12	14.19
B	15.92	16.85	M	14.80	15.44
C	17.13	15.14	N	14.70	
D	15.79	17.37	O	21.31	
E	20.00	12.64	P	20.74	
F	17.24	17.14	Q	21.35	
G	19.36	13.77	R	20.77	
H	21.84	2.34	S	18.75	
I	19.91	4.75	T	19.74	
J	21.15	3.81	U	10.64	
K	20.93	2.87	V	8.09	
			Average:	17.8	

Section VII

North of Iona
Sec. 18, T.102 N., R. 71 W.

Layer	% Mn	Layer	% Mn	Layer	% Mn
A	12.88	H	9.45	O	17.15
B	15.84	I	14.21	P	13.18
C	16.12	J	12.44	Q	23.06
D	13.69	K	16.61	R	24.05
E	10.92	L	17.42	S	14.41
F	14.97	M	12.45	T	23.89
G	13.71	N	18.13	Average:	15.75

Sample VIII

Section 11, T. 103 N., R. 72 W.

Composite of samples taken across the outcrop	% Mn 15.94

Sample IX

Section 20, T. 103 N., R. 72 W.

Composite of samples taken across the outcrop	% Mn 14.77

Sample X

Section 27, T. 107 N., R. 73 W.

Composite of samples taken across outcrop	% Mn 16.51

Section XIII[1]

On Elm Creek
Section 3, T. 101 N., R. 71 W.

Layer	% Mn	Layer	% Mn	Layer	% Mn
A	18.22	I	12.03	S	23.26
B	15.00	J	10.88	T	13.37
C	14.02	K	13.26	U	24.80
D	24.37	L	15.88	V	14.60
E	17.20	M	18.90	W	18.96
F	13.81	N	14.11	X	24.17
G	14.39	O	9.70	Y	12.90
H	9.39	P	19.00	Z	24.61
		Q	20.16	ZA	7.33
		R	17.95	Average:	16.38

Sample XV

Near Crow Creek
Section 34, T. 106 N., R. 71 W.

Composite of samples taken across the outcrop	% Mn 18.00

1. Analyses of Samples XIII, XV, and XIX by South Dakota State Chemical Laboratory, Guy G. Frary, State Chemist.

Section XIX

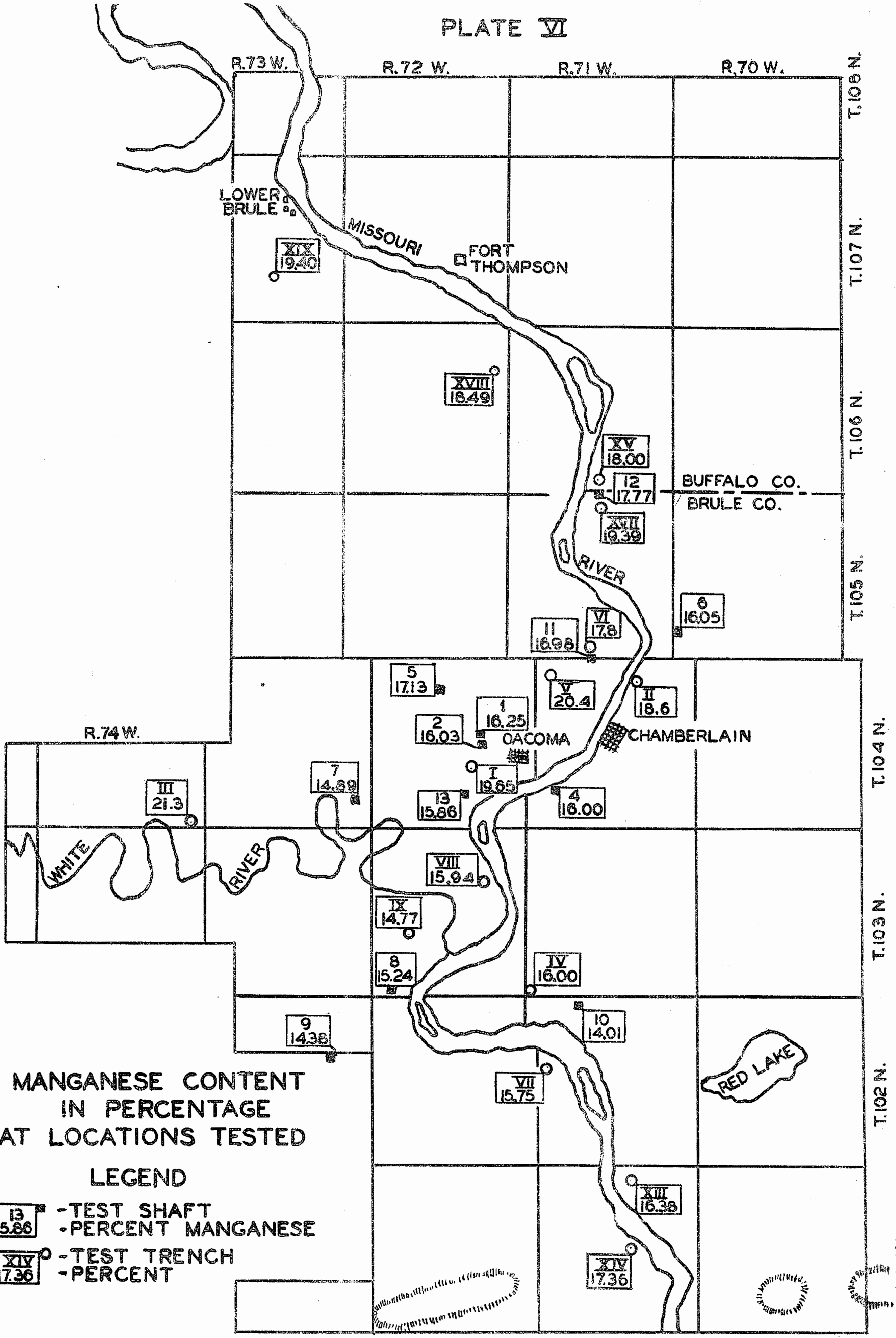
Lower Brule Indian Agency
Section 27, T.107 N., R.73 W.

Layer	% Mn	Layer	% Mn	Layer	% Mn
A	22.93	J	20.68	S	20.72
B	23.02	K	21.11	T	20.14
C	19.84	L	18.75	U	20.75
D	24.89	M	18.23	V	18.82
E	20.88	N	20.84	W	13.25
F	23.45	O	15.39	X	14.95
G	23.90	P	16.58	Y	13.98
H	15.26	Q	21.96	Z	16.14
I	22.09	R	21.87	ZA	14.61
				Average:	19.4

A study of the analyses made during the course of this survey indicates that the combined iron and manganese in the nodules varied between 20 and 40 per cent. By far the largest number of analyses showed it lying between 25 and 35, the average being 30 per cent.

It is interesting to note that this percentage remains fairly constant in spite of the variations in amount of either of these metals. In other words, when the manganese content increases the iron content decreases, and vice versa. This is well illustrated in sample No. I, taken near Oacoma. In layer H with the highest quantity of iron, the total iron was 17.7 per cent, while manganese was 15.71. In layer E manganese had increased to 18.41, while iron decreased to 11.2, and in layer G with 23.46 per cent manganese, iron had been reduced to 3.41 per cent. It may be of interest to note that in all analyses in which manganese exceeded twenty per cent, the iron content was less than six per cent. This may be significant since it suggests a chemical relation between the two rather than a mechanical mixture of iron and manganese minerals.

PLATE VI



MANGANESE CONTENT IN PERCENTAGE AT LOCATIONS TESTED

LEGEND

13 / 15.86 - TEST SHAFT - PERCENT MANGANESE

XIV / 17.36 - TEST TRENCH - PERCENT

Vertical Variations in Composition:

One object of sampling individual layers was to determine whether there was an order to the vertical distribution of manganese in the zone. The results showed that while there are large variations in the analyses of different layers, there is no uniformity in the vertical distribution. In some cases the upper layers of small concretions contain a higher percentage than do the larger concretions lower down. This is not always the case, however, as in many instances a very lean layer is sandwiched in between two rich zones or a rich layer may be found flanked by lean layers above and below. A glance at the diagrams (Plates IV and V) will bring out the differences better than a written description.

Neither is there a correlation between the size of the nodules and the manganese content. Some of the highest percentages were found in small concretions an inch or less in diameter, while there was a tendency for the massive concretionary layers 3-6" in thickness, to run lower than the average for the section. In most sections there are a number of layers of small concretions near the top that give high percentages of manganese, and make a richer zone at this place. These were missed in most of the test pits and in the other sampling which has been done, because samples were taken on topographic shoulders from which the upper part of the zone had been removed by erosion.

Horizontal Distribution of Manganese:

A study of the analyses leaves generalizations on the horizontal distribution about as much in doubt as are those on the vertical distribution. The striking fact brought out by plotting the manganese percentages on a map is that the variations in manganese content in various parts of the area do not follow any very definite pattern.

The maximum spread between the highest and lowest percentages encountered was only about 8 per cent. The highest percentage encountered was near the western edge of the area on White River. It averaged 21.3. One section averaging 20.4 was sampled about 3 miles north of Oacoma. Averages of 15%, 16%, and 17% were common in the vicinity of Oacoma and northward. Southward they dropped as low as thirteen per cent, though most of them read 14%, 15%, and 16%.

With the exception of the high manganese content found up the White River, the highest percentages lie north of Chamberlain and Oacoma where averages of 17% 18%, 19% and 20% prevail. In this region, however, some as low as 16% occur. 19% readings are found as far north as the Lower Brule Agency and 17% readings in the southernmost sample taken. The lowest reading occurred at Test pit No. 10, and the average manganese content for the section was 14.01 per cent.

There has been a general impression that the manganese content diminished up and down river from Chamberlain. In the area covered by this report there is no indication of any significant dwindling in the percentage. It would appear, therefore, before any statement is made about manganese content of any particular locality, a careful sampling and analysis of the nodules should be made on that property.

Since the analyses presented here are fairly evenly distributed over the territory, it is very unlikely that high grade manganese ore can be encountered in this deposit and prospectors will have to expect to deal with ores of less than twenty-five per cent manganese, averaging somewhere near seventeen per cent. The only guide to the higher grade ores is careful sampling and analyses.

VOLUME AND MANGANESE CONTENT

Any attempt to determine the available amounts of either the nodules or their manganese content can be only an approximation, since the area involved is so large and the sections and analyses vary considerably. By resorting to averages, however, a figure can be arrived at which can be used as a guide in the development of these deposits.

Two methods of arriving at some usable figure for the volume of metal available have been employed. The first was used by Dr. Hewitt[1] and is the most satisfactory, if sufficient locations can be sampled. Hewitt's figures were based on the testing done by the John A. Savage Company of Duluth, Minnesota, for the General Manganese Corporation. Shafts, 4 x 4 feet, were sunk through the manganese bearing zone and the nodules from the excavated shale collected and weighed. A depth of 5 feet was used as a unit, the weights of nodules from each five foot section being recorded separately. From these figures the amounts of nodules per cubic yard of shale were computed.

This method gave figures ranging between 1579 and 4770 pounds of concretion from a single shaft. Reduced to terms of nodular content per cubic yard, these become 82 and 246 pounds. The average of the 12 shafts sunk in nine townships was computed to be 164 pounds per cubic yard, which would be equivalent to about 5,556 short tons per acre. In the latter terms the country near the leanest shaft, yielding 82 pounds per cubic yard, could produce 2779 tons of nodules per acre and that near the richest, which yielded 246 pounds per cubic yard, 8,334 tons per acre.

Another set of figures was obtained from the sections measured on this survey by using the thicknesses of the individual layers and taking into account the distribution of the nodules in each layer. The average thickness of nodular material in the zone is 46.8 inches. The average specific gravity of fresh material is 3.1. The average weight of a solid cubic foot of nodules, therefore, would be 193.7 pounds. With these figures an average acre of the deposit should produce 16,422 tons of nodules.

1. D.F. Hewitt, *op. cit.*

TABLE XVIII

AVERAGE YIELD OF EACH SHAFT IN CONCRETIONS, METALLIC MANGANESE, IRON ETC..

SHAFT	LOCATION	WEIGHT OF CONCRETIONS (POUNDS)	VOLUME EXCAVATED (CU. YDS.)	CONCRETIONS PER CUBIC YARD (POUNDS)	METALLIC MANGANESE		METALLIC IRON		OTHER SUBSTANCES IN CONCRETIONS (PERCENT)		
					IN CONCRETIONS (PERCENT)	PER CUBIC YARD (POUNDS)	IN CONCRETIONS (POUNDS)	PER CUBIC YARD (POUNDS)	PHOSPHORUS	SILICA	ALUMINA
1	SEC. 14, T. 104 N. R. 72 W.	4,770	21.93	218	16.25	35.4	7.13	16.0	0.381	17.64	1.70
2	SEC. 14, T. 104 N. R. 72 W.	4,363	17.78	246	16.03	39.3	9.11	22.4	.396	17.31	1.93
4	SEC. 29, T. 104 N. R. 71 W.	3,818	21.69	176	16.00	28.1	9.75	17.1	.382	15.19	3.31
5	SEC. 9, T. 104 N. R. 72 W.	3,730	21.81	171	17.13	29.3	8.14	13.9	.416	14.98	3.03
6	SEC. 30, T. 105 N. R. 71 W.	2,618	21.63	121	16.05	19.4	11.88	14.4	.548	12.92	3.73
7	SEC. 25, T. 104 N. R. 73. W.	4,166	21.92	190	14.89	28.3	13.19	25.1	.447	10.67	2.39
8	SEC. 31, T. 103 N. R. 72 W.	4,400	26.67	165	15.24	25.1	13.63	22.5	.416	9.84	2.86
9	SEC. 14, T. 102. N. R. 73 W.	3,904	23.70	165	14.38	23.7	15.49	25.5	.439	9.25	2.80
10	SEC. 4, T. 102 N. R. 71 W.	4,272	22.50	190	14.01	26.6	13.55	25.8	.440	11.38	3.22
11	SEC. 34, T. 105 N. R. 71 W.	1,579	14.80	107	16.98	18.1	9.76	10.5	.508	13.79	3.55
12	SEC. 3, T. 105 N. R. 71 W.	1,880	22.93	82	17.77	14.6	6.66	5.6	.480	18.05	2.85
13	SEC. 27, T. 104 N. R. 72 W.	3,293	22.81	144	15.86	22.8	11.63	16.7	.444	10.07	3.15
WEIGHTED AVERAGE YIELD OF ALL SHAFTS				164	15.70	25.8	11.08	18.1			
WEIGHTED AVERAGE YIELD OF 10-FOOT ZONE IN ENTIRE FIELD				216	16.01	34.6	10.80	23.3			

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TABLE XIX

Estimates of Volume of Nodules and Metallic Manganese Per Acre

I. Computed from Sample Sections

Sample Section No.	Name	No. of Layers	Total Thickness of Nodules Inches	Content of Nodules per acre cu. yds.	Content of Nodules per acre Short Tons	Manganese Content Short Tons per acre
XVIII	Short Creek	37	58.5	7,740	20,134	3,715
IV	Peterson Bottom	28	55.5	7,260	18,876	3,020
II	Chamberlain	17	32.5	4,356	11,325	2,106
XI	Swanson's Ranch	25	50	6,969	18,119	2,971
XIII	Elm Creek	27	52	7,260	18,876	3,092
	Average of 5 sections	26.8	49.7	6,717	13,466	2,289

II. Computed from Test Pit Data[1]

Shaft	Weight of Nodules per cu. yd. of shale pounds	Thickness Av.Height of Zone yards	Weight of Nodules Short Tons per acre
1	218	14	7,385
2 (highest nodular content)	246	14	8,334
12 (lowest nodular content)	82	14	2,778
Average of 12 shafts	164	14	5,556

1. D. F. Hewitt, *op. cit.*

It will be noted that the computations from the sample sections give greater tonnages than those from the test pit figures. This may be due to the fact that the sample sections included the upper layers which were missing in the test shafts. This would hardly account for the total difference, however, and it is possible that the small concretions and small pieces caused by the breaking up of the large concretions were overlooked in the sampling. The material in the sample piles which are still visible at these pits are broken pieces of large concretions.

The smaller figures will doubtless be nearer the amount that will be recovered in commercial extraction unless care is taken to recover the small nodules and broken pieces and to mine the entire zone. The larger figures may be useful, however, in indicating the upper limit of possible production.

It is impossible to make an accurate computation of the total amount of either the nodules or the metallic manganese which the deposit contains without much more detailed work than has yet been possible. Since the most accessible part of it lies on shoulders projecting 500 feet to a mile into the brakes of the Missouri valley, it would be necessary to measure each portion of the outcrop for area and determine how much of the manganese zone had been eroded. Before mining is done in any part of the outcrop such surveys should be carried out.

In this survey the location of the top and bottom of the Oacoma zone was mapped so that it was possible to obtain the area covered by the outcrops with a considerable degree of accuracy. These areas are indicated on the map accompanying this report. In general where the outcrop follows the steep bluffs of the valley it is narrow, but where tributaries cut the uplands and certain freaks of erosion have stripped the cover or gentled the slope of the bluffs, wide outcrops are available. Planimeter measurements show that there is an area of 22,348.8 acres (34.92 square miles) of outcrop of the Oacoma zone between the Big Bend and Bijou-Iona Hills. Since, as will be shown later, the outcrops offer the only feasible mining areas under present conditions, only the volume of manganese they contain will be of immediate importance.

Using the average of 5556 tons per acre disclosed by the figures from the test pits and assuming that half the volume indicated by multiplying the area by the thickness of the zone (14 yards) had been removed by erosion, it is possible to arrive at a total of 31,042,483 short tons of nodules.

Using the average manganese content of 15.70 given by the test pit analyses, this volume of nodules should yield 4,873,670 short tons of metallic manganese. This is probably a minimum figure as it represents about the lowest figures obtained for volume, nodule content and manganese percentage.

In computing the total manganese content of nine townships around Chamberlain, Hewitt arrived at the figure 102,177,476 long tons. This figure evidently included the portion of the deposit which underlies the upland as well as that which outcrops. Again using the averages from test pit figures there should be 3,555,740 short tons of nodules and 558,266 short tons of metallic manganese under each section of the upland. In terms of townships this reaches a figure of 127,920,240 short tons of nodules and 18,080,907 short tons of manganese.

By using higher averages, larger volumes can be obtained. The average of the sample trench data, giving 13,466 short tons of nodules per acre, allowed a total of 300,998,611 short tons of nodules, which at 17% gives 51,169,763 short tons of manganese. The average of all data available showing 8,596 short tons of nodules per acre would give 192,112,004 short tons of nodules and 32,559,040 short tons of metallic manganese for the entire outcrop.

The spread between the estimates is too great to allow any of them to be used for more than an approximation, but the truth probably lies somewhere between the low average of 5556 tons per acre and the high average of 13,466 tons per acre. Thus there is somewhere between 124,171,044 and 300,948,611 short tons of manganese nodules in the entire outcrop of the Oacoma zone in the area surveyed. If these averages are applied to the portion of the zone underground, the thirty-two townships included in this survey could supply something like five billion short tons of nodules or 850,000,000 short tons of metallic manganese.

Rough and inaccurate as the foregoing estimates may be, they all point to one fact; namely, that there is a very large deposit of material which can furnish manganese in commercial quantities. The problems connected with its exploitation are those of mining and metallurgy rather than of amount of available ore.

GEOLOGIC FACTORS WHICH MAY INFLUENCE MINNING

Topographic and geologic features which may have considerable bearing on the feasibility of mining these deposits deserve mention. Costs of extraction and transportation must be reduced to a minimum if ores of this low grade are to be successfully developed. In the following paragraphs, therefore, the geologic features which may be of advantage or disadvantage in working these deposits are pointed out for such use as may be made of them.

Character of the Shale

Of first importance will probably be the character of the shale which encloses the nodules since the first step in any concentration will have to be removal of nodules from this matrix. It has been pointed out under the section on stratigraphy that the shale of the manganese zone is flaky and gray. It is extremely easy to remove the shale, so easy in fact that a great deal of it was dug with an ordinary hand shovel during the process of sampling.

The surface of most outcrops is bare of vegetation and contains a cover of dried gumbo rubble. During the hot weather this sometimes gets as deep as a foot. The loose lumps, an inch or less across, form a mulch covering the entire outcrop. Beneath this mulch lies a very wet, slippery clay which may be several inches thick. At no time during the hottest part of the summer was this clay dried. This gumbo cover is so tough that frequently it is difficult to break through it with a mattock and it has given an erroneous impression of the material that has to be moved.

Beneath this cover, the shales are rather fissile and fall away from the nodules very readily. The suggestion is made, therefore, that the simplest way of separating nodules from shale is to do it while the shales are fresh. In this condition the shale falls from the nodules much as garden soil falls from potatoes which are being dug. The suggestion that the material be spread out to dry first, is hardly necessary except for nodules which are found in the gumbo cover or have become wet. If these shales, however, are allowed to become wet through rain, snow, or other causes, the bentonitic material they contain causes them to break down to a gumbo which sticks to the nodules and forms a mass much harder to separate then the fresh material.

The bentonitic layers in the shale will form a considerable obstacle when wet. When fresh, however, though they are damp, they do not break down to an objectionable clay. It is the weathering of bentonite and bentonitic material scattered through the shale which makes the gumbo cover of the outcrop. Bentonite breaks down into a colloidal mud or clay which is extremely sticky. For that reason all mining operations should be carried on so as to work in fresh shale as much as possible.

The Topography

The topographic position of the outcrops should be of considerable help in mining. The manganese zone lies on long shoulders projecting from the bluffs of the Missouri toward the river and forming divides between steep gullies. These gullies offer excellent dumping grounds for mine wastes as there is plenty of room in the valleys for all material that would have to be removed. Moreover most of these operations could be carried on by gravity, thus reducing handling and transportation costs to a minimum.

Surface Concentration

The fourth feature to which attention should be called is the surface concentration of nodules. There has been considerable over-estimation of the amount of "ore" present, due to the fact that the outcrop makes a very noticeable black belt on the hillsides. The nodules lie strewn over the surface of the outcrop, in some places in great quantities. The amount of this material on top, however, is no criterion of the amount that may occur in place in the shale. It must be remembered that this surface material is a residuum, left behind as the elements of erosion have taken the shales from around it. In nearly all cases it represents the erosion of more than ten or fifteen feet of shale.

These concentrations are more noticeable on the rounded tops of the outcrop than on steep faces. Many of these latter which appear to be barren, actually contain as many or more manganese layers than occur in the higher, flatter parts of the outcrop where the heavy concretions have not had a chance to roll down into the intervening valleys.

The only safe method of prospecting or sampling, therefore, is to use trenches or test shafts. The presence of manganese on the surface is not always a sign of manganese underground since there are locations in which the surface concentrations occur on slopes below the level of the Oacoma zone from which it has been washed.

Slumping

One of the geologic features most confusing to the professional geologist and engineer, as well as to the layman, is the slumping which takes place in these shales all along the Missouri valley. In some cases the ends of the shoulders slide thirty or forty feet below their original position, as the river undercuts the bluff. More frequently a block from a yard to a score of feet thick will slide off the side of a shoulder into the gulch below. The slides do not go to the bottom in most cases but hang on the side of the bluff giving the appearance of a second zone identical with the true manganese horizon. Mining on such slumps is sure to lead to disappointment since they do not extend under the hills. Slump blocks often contain a large volume of nodules which can be mined to advantage, however, and should not be ignored in working individual properties. Such blocks, however, should not be considered as extensive ore bodies.

Underground Mining

As has been pointed out, the manganese bearing Oacoma zone extends an undetermined distance under the uplands bordering the Missouri river, and there is no reason to believe that concentrations of manganese in this covered area are not approximately the same in character as those exposed in the outcrop. It should, therefore, be possible to mine in a large area for from the outcrops if markets and mining conditions warrant it. This type of mining, however, will involve considerably greater expense than mining on the outcrop since it is a matter of sinking shafts, driving drifts and carrying on other ordinary methods of underground operation.

In this instance, however, the character of the overlying rocks is not conducive to cheap mining. The beds immediately overlying the Oacoma zone are soft shales which will not support a roof and for the entire two hundred feet from the top of the outcrop to the surface there are no competent layers which could act as supports. All underground mining. therefore, will involve expensive timbering or its equivalent in other forms of protection.

The problem of mining forty or fifty feet of shale under these conditions is no small engineering project and under present conditions it is doubtful whether the cost involved could be met by the price which the metal would bring.

METALLURGY

It is evident that under conditions now existing these nodules cannot be placed on the market without concentration of their manganese content. Most specifications call for manganese ores containing 30 to 35 per cent manganese as a minimum, and foreign competitors are able to furnish ore running as high as 50 per cent manganese. The problem, therefore, is to find a process of stepping up the 16-20 per cent manganese ratio of the Chamberlain ores to a figure which will compete with the sources mentioned above. This reduces itself to a problem of cheaply concentrating carbonate ores so as to remove iron and other impurities sufficiently to leave a combination of iron and manganese with the required percentage of the latter metal.

Several methods of doing this have been proposed and tried out in the laboratory. None of them, however, have yet been put to the test of commercial production. These methods depend primarily on leaching the manganese from the ores and re-precipitating it as metallic manganese. Some precede the leaching by roasting, producing an oxide and one employs electrolitic refining. This last process produces a product of nearly chemically pure manganese while the others produce an alloy of manganese and iron.

The following descriptions of these processes will serve as a guide to the type of beneficiation to which these ores are amenable.

Sweet - McCarthy Processes

Two processes were patented by the General Manganese Corporation known as Sweet and McCarthy Process. These were designed specifically for treatment of the Chamberlain ores. One, U. S. Patent No. 2,070,496, depends on leaching the ore with boiling ammonium chloride solution. Manganese is then precipitated by treating with ammonia. The precipitate is then sintered giving an oxide compound containing about 70% manganese. The second, U. S. Patent No. 2,070,497 is similar to the first except that a solution of ammonium sulfate instead of ammonium chloride is used for leaching.

Bradley Process

A second process is known as the Bradley process (U.S. Patents No. 1,937,508 and 2,074,013). This process oxidizes the ore by roasting it to MnO, which is then extracted by treatment with an ammonium salt solution. The advantage of this process is that it is possible to dissolve the manganese oxide and leave insoluble iron oxides undissolved. The solution is then treated with ammonia which precipitates relatively pure manganese oxide.

Crystallization Process

The Tennessee Valley Authority developed a crystallization process for low grade carbonate ores in which "the ore is leached with sulfurous acid to form a solution of manganese sulfate. The slurry of ore residue and manganese sulfate solution is treated with ground limestone to precipitate iron. The manganese sulfate is recovered from the purified solution by crystallization at an elevated temperature. The crystals are sintered to give a product containing about sixty-five per cent manganese. The sulfur dioxide from the sintering step is re-cycled. It has been estimated that on the basis of certain assumptions, a plant using this process should produce manganese in the form of high grade sinter at a cost of about $46 per ton of manganese."[1]

Electrolitic Process

The U. S. Bureau of Mines has developed an electrolytic process by which nearly chemically pure manganese metal can be produced. Analyses of the finished product showed 99.47 to 99.83 per cent manganese.[2]

This process starts by roasting the ore in a reducing atmosphere which delivers manganese in the form of manganous oxide. The sinter thus formed is then leached with a solution of ammonium sulfate and sulfuric acid in the proportion of 200 to 44. After filtering, the precipitate is used as an electrolite from which manganese is plated onto sheet steel cathodes. The process as outlined by the Bureau of Mines is reproduced in the accompanying flow sheet, Plate IX. It is probable that all steps on the flow sheet would not be necessary in the case of the Chamberlain ores since cobalt and nickel do not exist as impurities.

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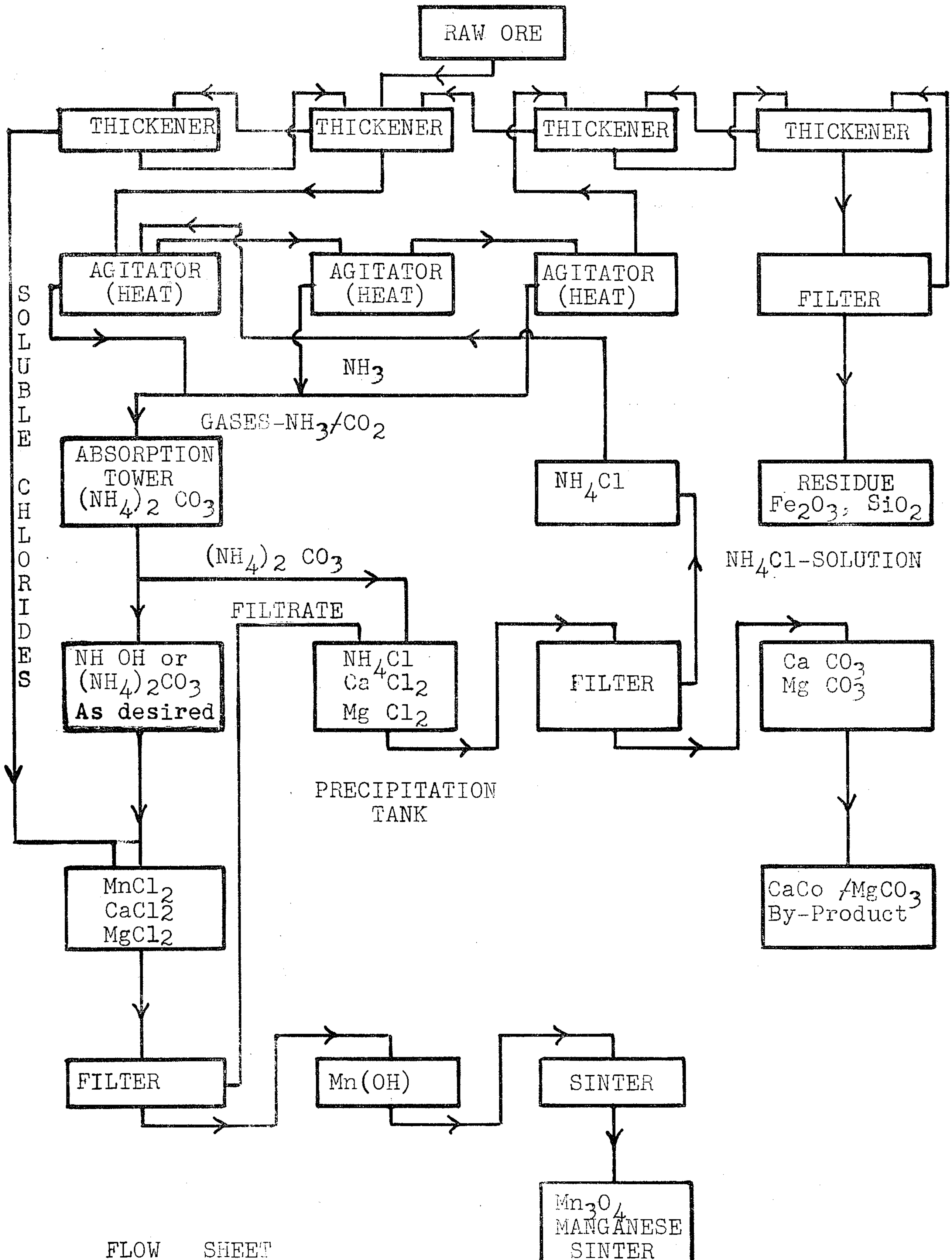
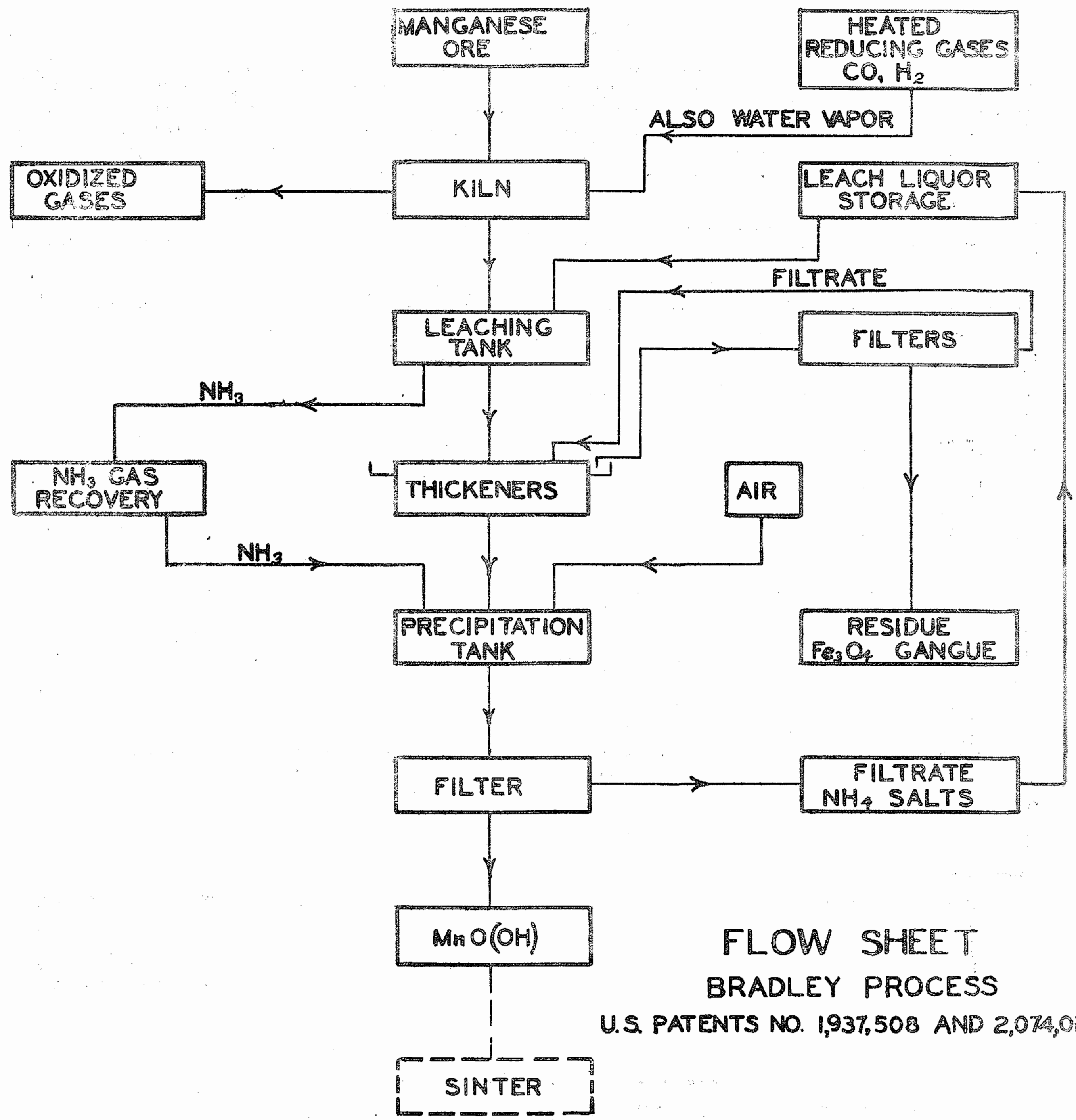
1. Tennessee Valley Authority, op. cit., p. 6.
2. S.M.Shelton, M.B.Royer, and A.P.Towne, "Electrolitic Manganese", R.I. 3406, U. S. Bureau of Mines, July, 1938.



FLOW SHEET
SWEET-MAC CARTHY PROCESS
U. S. Patent No. 2,070,496

Plate VII

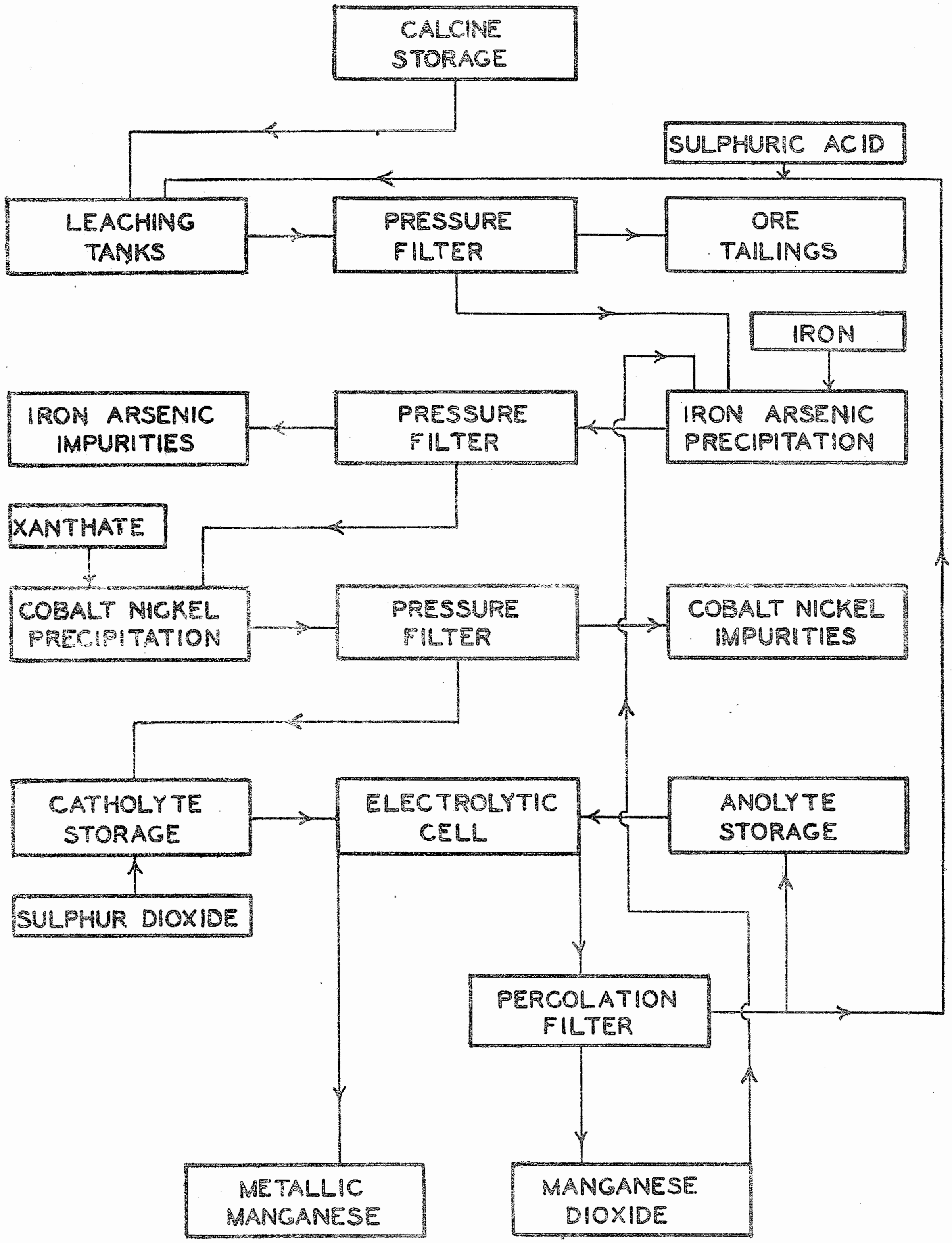


FLOW SHEET

BRADLEY PROCESS

U.S. PATENTS NO. 1,937,508 AND 2,074,013

PLATE VIII



FLOW SHEET

ELECTROLYTIC PROCESS

U.S. BUREAU OF MINES

PLATE IX

CONCLUSIONS

The purpose of the foregoing report and the survey which preceded it was to attempt to furnish answers to some of the problems about which there has been considerable discussion and which seem to be holding up the development of the manganese deposits. While there is still much to be determined, the following facts about the deposits have been established with considerable certainty.

1. The manganese originated as a constituent of concretions which were formed on the floor of the Cretaceous Sea during one stage (the Oacoma) of the deposition of the muds of the Pierre formation. The number of concretionary layers varies considerably but averages about twenty three, in an average thickness of forty feet of shale. They constitute approximately ten per cent of the volume of the shale.

2. The manganese content of the nodules is not evenly distributed either vertically or horizontally, but it averages about 17% and runs as high as 27% in some analyses and as low as 8% or 10% in others. A satisfactory answer to the way it occurs has not been given. Some of it is known to occur as pyrolusite grains disseminated through the concretion. In other cases it seems to be combined with the iron and calcium carbonates. In all cases it is too finely divided or too intimately mixed to be separated by the ordinary mechanical means.

3. Figures on the volume of material in the deposit reach huge proportions. The best estimates indicate that more than fifty million tons of nodules are easily available in the outcrops while the underground portions of the deposits could furnish something like five billion tons. This would total some 850,000,000 tons of metallic manganese. Since this is computed for only about half the area in which the metal is known to occur the total for the deposit would be at least double the amount.

4. Mining these deposits offers very little difficulty since the materials are soft and easily excavated, and there is a great difference in gravity between the shale and the nodules. Either a dry

separation or some method of slucing is recommended since the shale falls away readily before it is wet, but once wet, it forms a sticky mud which is not easy to clean from the nodules. Slucing, therefore, will entail the use of large volumes of water.

No metallurgical processes have been actually put to the commercial test, but several possible processes have been worked out which offer a solution to the difficulty. These processes include roasting, leaching, and electrolytic refining. Some of them are very effective, and on paper, at least, offer commercial possibilities. The best means of export at present is the Chicago, Milwaukee, St. Paul and Pacific Railroad which crosses the river at Chamberlain. This road is within easy reach of all parts of the deposit which were mapped during this survey. These deposits can be reached by good roads over the uplands and many parts of it by roads along the Missouri bottoms. It is also possible to run railroad spurs to reach many parts of the area. River navigation has been suggested but its use and possibilities at present are limited.

In conclusion, this survey has shown that there is a huge deposit of low-grade manganese spread over a very large area in the lower part of the Missouri valley in South Dakota. It is not a bonanza, but with expert mining and beneficiation, and good business management, it could be made to produce enough manganese to supply this country's need for this metal for many generations.