STATE OF SOUTH DAKOTA

M. Q. Sharpe, Governor

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 46

MISSOURI VALLEY MANGANESE DEPOSITS BETWEEN LOWER BRULE AND DEGREY

by

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Vermillion, S. Dak.
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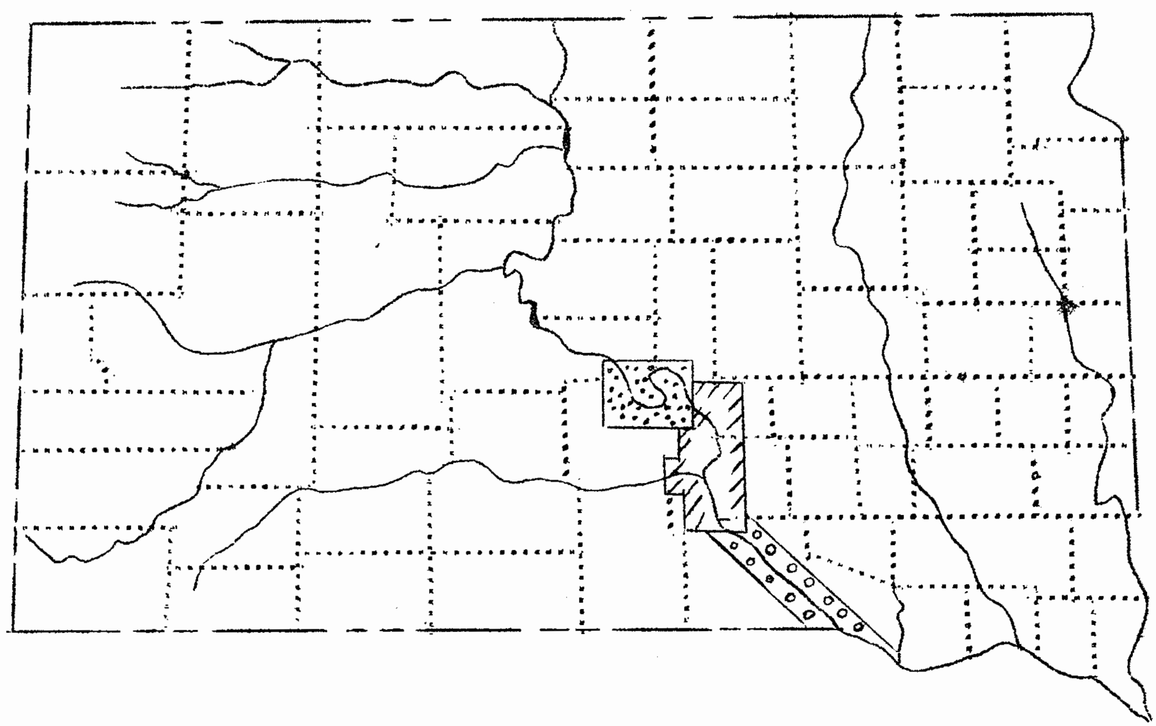
MANGANESE DEPOSITS OF THE MISSOURI VALLEY

INDEX MAP



Area Covered by this Survey

Area Covered by Previous Surveys

Unsurveyed Manganese Deposits

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INTRODUCTION

Purpose

The following report embodies the results of a field survey made during the summer of 1942 on a portion of the huge deposit of sedimentary manganese which outcrops in the valley of the Missouri and its larger tributaries.

It was first identified in the vicinity of Chamberlain where the black outcrops were particularly conspicuous and was later followed up the White River Valley a distance of about 10 miles and much shorter distances up the valleys of the lesser tributaries.

A preliminary investigation by the U. S. Geological Survey indicated a large deposit of low grade manganese ore.[1] The percentage of manganese, however, was too low to make it a practical commercial proposition under the conditions then existing. With the outbreak of the war, however, and the possibility of the loss of foreign manganese supplies, this deposit held possibilities of being extremely important in the national economy. Consequently a party from the State Geological Survey systematically mapped and sampled a portion of the deposit lying between the Bijou Hills and Fort Thompson and centering about Chamberlain where transportation facilities made it most easily accessible.

Time did not permit a complete appraisal of the entire deposit on this survey, however, and a second party was sent into the field in 1942 to complete the work from lower Brule

1. Hewitt, D. F., "Manganese and Carbonate near Chamberlain, South Dakota, "Memorandum for the Press, U. S. Geological Survey, February 5, 1930.

Agency to DeGrey. This territory is of particular interest because it is easily accessible from and tributary to the Milwaukee Railroad at Reliance, Lyman, and Kennebec. Though the distance from these railroad centers is greater than at Chamberlain, the lack of steep grades and rough country and the fact that a haul of 12 or 15 miles will reach much of the area, made it appear that this part of the deposit should be investigated to provide a further source should it be necessary to produce a very large quantity of the ore.

Location and Area

The portion of the deposit under discussion lies in a section of the Missouri Valley which is probably the most crooked in the state. The Big Bend, immediately above Fort Thompson, makes a large loop roughly six miles across. Above it, the valley makes a long curved sweep which ends in a sharp bend that curves westward at DeGrey. This looping of the valley has made wide terraces on the inside of each loop which have covered the manganese outcrops with sand and silt. The outcrops which are of commercial interest lie on the outside of these bends and can be divided into four sections:

1. The Big Bend section which lies on the north bluff at the north end of the Big Bend following its entire length for about ten miles;

2. The Medicine Creek section which starts on the inside of the Big Bend, north of Lower Brule, follows the south bluff of the river to Iron Nation two miles west of the mouth of Medicine Valley and extends into this valley a distance of eight miles;

3. The Cedar Creek section on the south bluff of the river starting about 2 miles west of Iron Nation and ending about 4 miles above Cedar Creek, with outcrops extending 5 miles into the Cedar Creek Valley.

4. The DeGrey section on the north bluffs of the valley, which were followed 4 miles downstream from DeGrey. Above DeGrey the manganese outcrops are lost in terrace deposits and do not appear in the valley again.

A total distance of some 50 river miles including 80 miles of outcrop were mapped.

The Big Bend section lies in Buffalo and Hyde Counties; the Medicine Creek and Cedar Creek in Lyman County, with a small portion of the latter extending into Stanley County; and the DeGrey section in Hughes County. Without going into more detail than this report warrants, it is impossible to give the exact location of each portion of these deposits in terms of the land survey. For this information the reader is referred to the outcrop map accompanying this report.

Methods of Work

Location of outcrops, measuring of sections, and other surveying were done by plane table mapping, the area being divided between two parties. The geology was done by Mr. Bruno Petsch and the State Geologist, and the engineering by Messrs. Robert M. Wyant, Donald F. Rothrock and Ray Barron. A vertical control using sea level elevations carried from bench marks of the U. S. Coast and Geodetic Survey and the Missouri River Commission allowed comparison of the elevation of the manganese zone in different parts of the area.

Sampling was done by digging trenches across the manganese bearing portion of the outcrops deep enough to expose fresh material. In a few instances where the outcrops were sufficiently steep to give good exposures, samples were taken from the layers showing on the surface of the bluff.

The chemical analyses were made by Dr. Ernest Griswold, assistant professor of chemistry at the University of South Dakota.

The usual two-month field season was spent in collecting data and field mapping and in making chemical analyses.

Acknowledgments

The successful completion of the survey was due to the careful and diligent work of the members of the field party and the chemist. The author gratefully acknowledges the very effective and loyal help of these gentlemen whose names have appeared in a previous paragraph. Thanks is also due to the State Chemical Laboratory which kindly loaned the use of its crushing and grinding apparatus in order that a large volume of samples could be prepared for analyses. Thanks is also due to Dr. A. M. Pardee, head of the chemistry department of the State University, for the use of laboratory space belonging to the department for making the chemical analyses.

Acknowledgement is also made of the help which was given by the residents of the district and for the many courtesies they showed the party while field work was in progress. Their readiness with help and information on the many little points which so often baffle the new comer in a region played a very great and important part in hastening the progress of the work. Their hospitality also added much toward making the field work a pleasure and making it possible to get the work done promptly and accurately. For all these courtesies the Survey is deeply grateful.

GEOLOGY OF THE DEPOSIT

The Pierre Formation

The manganese occurs in iron carbonate nodules which lie in more or less continuous layers concentrated in a 30-40 foot zone in the lower part of the Pierre formation. This formation which forms the bed rock for the entire area is composed of various kinds of shale with minor beds of chalk and one sandstone horizon. Interbedded layers of bentonite, an altered volcanic ash, and disseminated bentonite particles cause large portions of this formation to weather to a very sticky gumbo. This feature is so prominent that the name Pierre shale is synonymous, to most laymen, with gumbo.

In the Missouri Valley the formation has been subdivided into six members:

1. Elk Butte Member: At the top lies the Elk Butte Member, 100 to 230-40 feet in thickness. It is a medium gray flaky shale with a few small rusty concretions. This member does not occur in the area under consideration.

2. Mobridge Member: A chalky shale and chalk, 90 to 241 feet thick, which weathers to a light shade of buff on the outcrop and gives the characteristic checking on weathering. This shale makes the very top of the highest butte in this area.

3. Virgin Creek Member: The upper part is a yellowish gray shale, 91 to 287 feet thick, which weathers to gumbo; lower portion a bluish gray shale with many bentonite beds and certain large white concretions.

4. Sully Member: The Sully Member consists of a gray shale, 88 to 180 feet thick, weathering to a typical brown. It carries abundant black scattered concretions. The upper part of this member is designated as the Verendrye zone.

The lower part is a gray shale with much siliceous material in the northern part of the valley where it becomes a very hard siliceous shale. In the area under consideration, however, it is a soft gumbo forming shale which contains an abundance of bentonite and manganese concretions and is known as the Agency-Oacoma zone. This zone is 23 to 124 feet.

The Crow Creek sand and chalk zone is a very persistent sand bed six inches to one foot thick overlain by 8 to 10 feet of chalky clay or marl. This zone varies in thickness from 2 to 15 feet.

The three zones of the Sully Member are particularly important for our purpose, since the Agency-Oacoma zone is the one which contains manganese in sufficient quantities to be of commercial importance.

5. Gregory Member: A light gray to buff shale, 34 to 125 feet thick with many concretions and calcareous layers.

6. Sharon Springs Member: A dark oil shale with abundant fish remains, 7 to 34 feet.

The Pierre formation belongs to the Cretaceous system and is the only formation exposed in the entire area with the exception of a small patch of Tertiary sand probably belonging to the Arikaree formation on top of Medicine Butte, 6 miles north of Reliance, and a thin veneer of Pleistocene glacial debris, largely boulders, which occurs on the highlands along the north side of the valley.

Detailed descriptions of the Pierre formation have been given in former reports of the Survey and will not be repeated here. For the most recent description the reader is referred to the work of Dr. J. P. Gries.[1] A detailed description of the portions of the Sully Member will be included, however, since it is the portion of the formation immediately concerned with any exploitation of the manganese.

The Sully Member

This member, as has been indicated above, can be divided into three distinct zones, which have decided differences in the materials of which they are composed. They may be distinguished in this area as the basal sand and marl Crow Creek zone overlain by the bentonite and manganese-bearing Agency-Oacoma zone, which appears as a black band on the outcrops and is in turn overlain by the brown-weathering shale of the Verendrye zone.

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1. Gries, J. P., Economic Possibilities of the Pierre Shale, S. Dak. State Geological Survey Report of Investigations No. 43, May, 1942.

The base of the Sully Member is very sharply separated from the underlying Gregory by the persistent Crow Creek Zone. At the base of this zone is a one foot sandstone of remarkable extent for such a thin member. It makes an excellent horizon on which to map, since it has been followed from Yankton to within a few miles of Pierre. It is a very fine quartz sand about half passing a 150 mesh sieve and being retained on 200 mesh. The other half passes a 200 mesh sieve but is still granular. The grains are angular and some are frosted suggesting that the sand originated as a thin sheet blown from nearby land areas and spread over the flat bottom of a shallow sea by extensive ocean currents. The rounding, familiar to wave formed grains, is missing.

In the fresh rock it is soft and light colored with few structural features to distinguish it, but on weathering, it case hardens and is found on outcrops as a dark reddish or brownish sandstone characterized by its shelly appearance. This latter structure is due to thin beds one-eighth to one-quarter of an inch in thickness. Crossbedding and ripple marks are not conspicuous. On these outcrops the shelly sandstone occurs in blocks a foot or two in diameter. On most outcrops, however, it is observed only as two to five inch flakes of sandstone scattered through the grass or clays on the slope. In most areas the better exposures are on steep slopes.

The Crow Creek Zone

The Crow Creek marl is a chalky zone of light brown, sometimes yellow clay, which weathers to a white chalky band, very conspicuous on the outcrop and forming a good horizon marker, since it is visible in places where the sand may be covered by slumps or soil. The fresh clay is sticky with nothing to distinguish it from an ordinary shale except its light brown to yellow-brown color and a lively effervescence in acid. The color contrasts with the gray of the shales above and below sufficiently to enable an observer to identify its upper limits, even without the aid of acid. With acid, however, the contact is seen to be very sharp, since the overlying shale is non-calcareous. In some instances there seems to be an alternation of dense chalky layers and non-calcareous layers for a few inches at the top, but in most cases it is possible to separate the two kinds of clay within a fraction of an inch. Several samples examined showed 42 per cent of the marl to be soluble in acid, leaving an insoluble residue of 58 per cent. The insoluble material under the microscope showed only soft flaky clay.

Though the Crow Creek zone is very persistent, there is considerable difference in its thickness. The sandstone, usually about a foot thick, diminishes in places to only a few inches. These thin places, however, are the exception rather than the rule. The marl also varies considerably in thickness, though on an average it remains about eight feet. In some sections it has been measured as thick as twelve feet, while in others it is reduced to three or four feet.

In an area at the west end of the Big Bend, both the sand and marl are missing. This is noticed in the west end of the outcrop north of the Big Bend and also in the outcrop at Medicine Creek. These outcrops appear to lie in part of a large area where the marl and sand members were not formed.

In some outcrops in the vicinity of Fort Thompson, there appear to be two Crow Creek zones about twenty feet apart. Some of these are due to slumping on the face of the outcrop, and others show two somewhat similar bands of marl underlain by sand. As the Gregory Member is characterized by intermittent layers of chalky shale, these beds are not surprising, even though they are near the Crow Creek zone. There is little danger of confusing them with the Crow Creek zone, largely because of the lack or thinness of the sand at the base. One outcrop in the area considered, not far north of the mouth of Cedar Creek (Sec. 11, Twp. 108 N., R. 76 W.), showed such a zone with a thin shelly sandstone underneath. There was no danger of confusing it with the Crow Creek zone, however, since the overlying shale was typically Gregory. The following section was measured:

Section of Gregory and Sully Members of the Pierre Formation; NE¼ Sec. 11, Twp. 108 N.,R. 76 W., Lyman County, South Dakota.

<u>The Crow Creek Zone</u>

8	feet marl
1	foot fine sandstone

<u>The Gregory Member</u>

22	feet dark shale with scattered fossiliferous concretions, typical of the Gregory Member.
.05	foot chalky shale
.05	foot shelly sandstone
_____	feet shale

The Agency-Oacoma Zone

The Agency zone was first recognized by W. L. Russell in the vicinity of Cheyenne Agency in Dewey County,[1] Russell described the Agency shale as a siliceous member of the Pierre Formation which occurred in the upper Missouri Valley. Its position in the lower Missouri Valley is occupied by gumbo forming, manganese bearing, non-siliceous shales full of bentonite beds, which was called the Oacoma zone.[2] These were originally thought to be two separate lenses separated by a bed of bentonite, which could readily be distinguished because it contained an abundance of biotite mica in its base.

"Studies in northeastern Stanley County revealed a somewhat thicker section containing from 17 to 28 bentonites lying above typical Agency shale. The lowest of these, a 6 inch bed containing abundant mica and designated the lower micaceous bentonite (LMB), was chosen arbitrarily as the base of the zone***.

"An investigation *** in the Oacoma zone in the Chamberlain area was made by the State Geological Survey in 1940. *** It was recognized that the manganese zone included beds below the lower micaceous bentonite of the Fort Pierre area, and a suggestion was made that the lower beds of the Oacoma zone in the southern part of the Missouri Valley probably graded laterally into much thicker siliceous Agency beds farther north. During the present survey, the lower micaceous bentonite, *** was traced northward across Armstrong County and was recognized 72 feet below the top of the Agency shale at Cheyenne Agency.

"It is thus shown that the Oacoma zone *** included not only the light and dark banded beds *** but also part, if not all, of the Agency zone. *** it is here suggested *** that all beds lying between the Crow Creek chalk, and the base of the Verendrye zone be hereafter referred to as the Agency-

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1. Russell, W. L., The Possibilities of Oil and Gas in Western Potter County, S. Dak. State Geological Survey Report of Investigations No. 7, p. 5, 1930.
2. Searight, W. V., Lithologic Stratigraphy of the Pierre Formation in the Missouri Valley in South Dakota, S. Dak. State Geological Survey Report of Investigations No. 27, p. 9, 1937.

Oacoma zone."[1]

Between Lower Brule and DeGrey the Agency-Oacoma zone is a gray shale containing many bentonite beds, which cause it to break down into a very sticky gumbo when weathered. The gumbo dries to a cinderlike rubble which covers all the outcrop and is, in most places, bare of vegetation. This is roughly divided into two zones, which for field purposes were designated as the "barren zone," the lower half of the beds containing only a few bentonite and scattered manganese-bearing concretions, and the "manganese-bearing zone" in which the heavy concentration of manganese nodules is contained. The lower part retained much of the same character all through the area, but there was a marked change in the composition of the upper zone.

The manganese-bearing zone is characterized by an abundance of bentonite beds, separated by shale, which give it a tendency to weather in step-like forms, the bentonites making the treads and the shales the risers. In the eastern part of the area, near Fort Thompson, the shales are gummy and clay-like in structure. Toward the west, however, there is a noticeable increase in siliceous material and the shales take on the paper-like appearance which was noted and described in the area around Fort Pierre and northward. The color becomes lighter, and the step-like character much more pronounced. These papery shales tend to break into small flakes which are more or less harsh to the feel and give a decided rattle when shaken together. The concentration of manganese nodules continues throughout the entire area, though the beds of manganese nodules are somewhat farther apart in the western than in the eastern end of the district.

The barren and manganese-bearing portions of the zone are separated, approximately, by the lower micaceous bentonite (LMB) described by Dr. Gries. In this area, however, the bentonite is much thinner, averaging an inch to an inch and a half. In some sections, as will be noted by a perusal of those which are included in this report, manganese concentrations are observed below this micaceous bentonite. In others it lies at the base. The bentonite bed is not so easily found in this region and therefore was not as good a marker as it

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1. Gries, J. P., Economic Possibilities of the Pierre Shale, S. Dak. State Geological Survey Report of Investigations No. 43, p. 17, 1942.

proved to be farther up the river. However, it was found in a sufficient number of sections to prove it a good horizon marker.

Some 12 feet below the top of the manganese concentration occurred a bentonite bed varying in thickness from 4 to 6 inches. This was so persistent that it formed an excellent marker and was designated the "big bentonite bed" (BBB). This has been recognized and described in early reports[1] and is the same big bentonite bed reported from Stanley County. Thus it is continuous from near the Little Bend of the Missouri in northeast Stanley County to Oacoma.

In certain sections a micaceous bentonite occurred about 8 feet above the big bentonite bed and usually very close to the top of the manganese concentration. This may correspond to an "upper micaceous bentonite" which was found and used in mapping northeastern Stanley County. This bed was but one or two inches thick.

These three bentonites serve as more accurate horizon markers than the top and bottom of the manganese concentration which could not be used because they do not occur at a fixed horizon. The top varies as much as 5 or 10 feet and there is no definite base in the barren zone.

One other horizon marker should be noted. In the western part of the area, from 16 to 20 feet above the big bentonite bed, there occurs a persistent zone of large white concretions 1 to 2 feet across, which weather a rusty red. These concretions are very conspicuous wherever they occur. The lower one lies between two very persistent rusty layers composed of material which apparently is much like the concretions, but weathers to thin slabby or flaky chips. They are separated by about a foot of shales and make a very decided red streak along the cliffs. The upper bed of the pair was used as a horizon marker in all the area west of Medicine Creek and was designated as WRP.

Below these rusty beds the shales are light colored and

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1. Gries, J. P. and Rothrock, E. P., Manganese Deposits of the Lower Missouri Valley in South Dakota, S. Dak. State Geological Survey Report of Investigations No. 38, P. 22, 1941.

make decided steps; most of them have the paper-like appearance described above. Above this horizon the shales are brown like the typical Verendyre. This is the horizon which is so prominent in the vicinity of Pierre and early attempts at mapping the Pierre formation used it as the key bed.

From the description that has been given it will be noticed that the Agency-Oacoma zone in this area is a transition from the typical manganese-bearing shale of the Oacoma to the typically siliceous shale of the Agency. In the Missouri Valley above DeGrey manganese-bearing nodules are visible, but are much more widely scattered through the zone and become less and less conspicuous farther north. The DeGrey section is the last one in which there is a concentration of manganese-bearing nodules that might be of commercial importance. The paper-like shales, containing high percentage of silica and making the steps so typical of this zone in the vicinity of Pierre, are first noticed near Fort Thompson, but are not conspicuous there. However, the amount of this type of shale rapidly increases up the valley and it makes a very large proportion of the Cedar Creek and DeGrey sections.

The following detailed sections will illustrate the character of this zone.

Section I

Welch Ranch Section

Succession of beds of the Pierre Formation in Medicine Creek Valley near the Welch Ranch; Sec. 8, T. 106 N., R. 74 W., Lyman County, South Dakota.

	Feet	Inches
Sully Member		
Verendrye Zone		
Shale	18	
Shelly concretions, 2" in Diameter	2	
Shale, brown on outcrop typical of Verendrye	55	3
Bentonite		1.5
Shale, brown like Verendrye above	6	4
Agency-Oacoma Zone		
Concretionary layer: round nodules, 3" x 4", scattered along Bed (L) Manganese content 15.31%		3
Shale, light gray	3	7
Bentonite bed		0.25
Concretionary layer: round concretions, 2" x 6", occupying about ½ of the area of the bed (K) Manganese content 9.60%		2
Shale like above		2
Concretionary layer: flat concretions 1½" x 3" making continuous bed (J) Manganese content 18.77%		1.5
Shale like above		9.5
Concretionary layer: round concretions, 2" x 4", occupy half the area covered by the layer (I) Manganese content 20.11%		2
Shale like above		2
Concretionary layer: round 1" to 2" concretions scattered along bed (H) Manganese content 17.54%		2
Shale like above	1	7
Concretionary layer: round 1" to 2" concretions occupy about ½ the area of the layer (G) Manganese content 21.80%		2
Shale like above		5
Bentonite layer		0.5
Shale	1	8

Section I continued

	Feet	Inches
Bentonite Series		
Big Bentonite layer (BBB)		6
Concretionary layer of scattered 1" concretions		1
Shale		0.5
Bentonite layer		1
Shale	1	6
Bentonite		1
Shale		4
Bentonite		1.5
Concretionary layer: 1" x 4" flat concretions occupy 1/3 of the area of the layer (F) Manganese content 18.38%		1
Shale		4
Bentonite layer		1
Shale	2	9
Concretionary layer: flat 2" concretions occupying about ½ the area of the layer (E) Manganese content 15.80%		2
Shale		3
Concretionary layer: continuous bed of flat concretions (D) Manganese content 14.04%		4
Shale	1	1
Concretionary layer: continuous bed of flat concretions (C) Manganese content 16.89%		4
Shale	4	2
Concretionary layer: 2" sub-angular nodules (B) Manganese content 21.00%		2
Shale		7
Bentonite bed		1
Concretionary layer: sub-angular concretions 2" in diameter (A) Manganese content 20.10%		2

Bottom of Exposed Section

Section II

Bad Horse Section

Succession of beds of the Pierre Formation in Medicine Creek Valley near the Bad Horse Ranch; SE$\frac{1}{4}$ Sec. 19, T. 107 N., R. 74 W., Lyman County, South Dakota

	Feet	Inches
<u>Sully Member</u>		
<u>Verendrye Zone</u>		
Concretionary layer: blocky concretions, 4" to 6" in diameter		6
Shale, brown, typical of the Verendrye Zone	7	
Concretionary layer: blocky concretions like above		6
Shale like above	9	
Concretionary layer: flinty white concretions 6" in diameter		6
Shale	3	
Concretionary layer: flinty white concretions		6
Shale	15	
Concretionary layer: flat concretions, 2" x 4" x 4", cover 3/4 of layer's area (V) Manganese content 10.87%		2
"Banded Beds," gray papery shales separated by thin bentonite beds; 8 or 10 steps in this interval	7	4
<u>Agency-Oacoma Zone</u>		
Concretionary layer: small fossiliferous concretions, $\frac{1}{2}$" x 2" x 2" occupy about $\frac{1}{2}$ the area covered by the layer (U) Manganese content 16.32%		0.5
Shale, gray		4
Bentonite layer		1
Shale		4
Concretionary layer: small round concretions, 1$\frac{1}{2}$" in diameter covering about 1/3 the area occupied by the layer (T) Manganese content 15.51%		1.5
Shale		3

	Feet	Inches
Concretionary layer: round potato-like concretions up to 5" or 6" in diameter occupy about ½ the area covered by the layer (S) Manganese content 21.29%		5
Shale		7
Concretionary layer: flat concretions 1" x 6" x 8" occupy about ¼ of the area covered by the layer (R) Manganese content 20.57%		1
Shale	1	8
Bentonite bed		1.75
Concretionary layer: round concretions 2" x 2" x 6" occupy about ¼ of the area covered by the layer (Q) Manganese content 22.24%		2
Shale		5.5
Bentonite layer		2
Concretionary layer: flat concretions 1" x 4" x 4" scattered over layer (P) Manganese content 18.75%		1
Shale		9
Bentonite		0.25
Shale		5.75
Concretionary layer: blocky 2" concretions making a floor (O) Manganese content 20.39%		2
Shale	1	
Big Bentonite layer (BBB)		7
Shale		1
Bentonite		1
Concretionary layer: sub-angular concretions, 2" x 3" x 3", scattered (N) Manganese content 20.74%		2
Shale	1	
Bentonite		1.5
Shale		6
Bentonite		1
Shale	1	
Concretionary layer: round concretions occupying about 1/5 of the area covered by the layer (M) Manganese content 18.82%		1
Shale		10
Bentonite		1

	Feet	Inches
Shale		4
Bentonite		0.5
Concretionary layer: flat concretions 5" x 5" x 1", cover about ½ the layer's area (L) Manganese content 19.49%		1
Shale	1	10
Concretionary layer: large flat concretions 6" x 6" x 2" cover 2/3 of the layer's area (K) Manganese content 20.35%		2
Shale	1	
Concretionary layer: large round 6" x 6" x 3" concretions cover ½ the layer's area (J) Manganese content 17.63%		3
Shale		11
Bentonite		0.25
Concretionary layer: concretions cover entire area (I) Manganese content 15.82%		2
Shale	2	
Concretionary layer: round concretions 2" in diameter cover about 1/10 of the layers area (H) Manganese content 15.45%		2
Shale		4
Bentonite Series		
Bentonite		0.75
Shale		1.5
Bentonite		1
Shale		6
Bentonite		1
Shale		4
Bentonite		1.5
Shale		2
Concretionary layer: round 1" x 2" concretions occupy 1/5 of the area covered by the layer (G) Manganese content 19.84%		1
Shale		2
Concretionary layer: large flat concretions 4" x 4" x 3/4" cover about 1/2 the area of the layer (F) Manganese content 22.39%		0.75
Shale	1	
Bentonite		0.5

Section II continued

	Feet	Inches
Shale	1	
Concretionary layer: two or three beds of round concretions 2" in diameter (E) Manganese content 18.56%		6
Shale		8
Bentonite Series		
Bentonite bed		0.75
Shale		6
Bentonite bed		0.75
Shale		10.5
Bentonite bed		1
Shale		6
Concretionary layer: round concretions 3" in diameter covering about 1/5 of the area of layer (D) Manganese content 20.33%		3
Shale	1	7
Concretionary layer: round concretions 3" in diameter cover about ¼ of area occupied by layer (C) Manganese content 22.41%		3
Shale	1	2
Bentonite bed		3
Concretionary layer: round concretions 2" in diameter scattered along the layer (B) Manganese content 19.96%		2
Shale	1	2
Bentonite Series		
Bentonite		0.25
Shale		2
Bentonite		0.25
Shale		3
Concretionary layer: round concretions 3" to 4" in diameter occupy about 1/10 of the area covered by the layer (A) Manganese content 20.14%		3
Shale	1	3
Concretionary layer: round concretions 2" in diameter scattered in layer (A^1) Manganese content 19.36%		2

Base of Outcrop

Section III

Cedar Creek Section

Succession of beds of the Pierre Formation of the south bluff of Cedar Creek Valley at its mouth; Sec. 23, T. 108 N., R. 76 W., Lyman County, South Dakota.

	Feet	Inches
Sully Member		
Verendrye Zone		
Concretionary layer: ledge of black concretions (S1)	--	----
Shale	2	
Rusty layer formed by bed of shelly iron carbonate concretionary material		1
Shale	7	7
Pair of rusty layers		
Rusty layer like above		1
Shale	1	
Concretionary zone: white concretions 6" to 10" in diameter weathering rusty. Base of concretions rests in the underlying rusty layer		6
Rusty layer like above (WRP)		1
Shale, light colored papery foliations in many beds. Tends to form "step structure"	8	
Bentonite bed		0.5
Concretionary layer: scattered very fossiliferous round, knobby concretions occupy about 1/5 of the area covered by the layer (R) Manganese content 19.64%		0.75
Shale, light grey		6
Agency-Oacoma Zone		
Bentonite, brownish colored, considerably darker than the usual light tan of most bentonite. Abundant flakes of black mica (biotite) in its base (UMB?)		3
Shale like above.	1	6
Bentonite bed		0.25
Shale	1	6
Big Bentonite Series		
Bentonite (BBB)		6

Section III continued

	Feet	Inches
Concretionary layer: round concretions 2" x 2" x 4" occupying about 2/3 of the area covered by the layer		2
Bentonite		1
Shale		4
Bentonite		0.5
Concretionary layer: rough, round concretions, 1" in diameter (P) Manganese content 18.64%		1
Shale	1	
Bentonite		1
Shale	2	
Concretionary layer: rough rounded concretions, 2" x 2" x 5" occupies about 1/5 of area covered by layer (O) Manganese 12.94%		2
Shale		6
Concretionary layer: solid floors of concretionary material 2 to 3 feet square occupy nearly the entire area covered by this layer (N) Manganese content 11.71%		2.5
Shale	3	9
Concretionary layer: scattered round concretions, 1" in diameter scattered through the layer to occupy about 1/3 its area. These are of a dark indigo blue color (M) Man ganese content 17.37%		1
Shale		3
Concretionary layer: small round, blue, pebble-like concretions (L) Manganese content 18.25%		1
Shale		2
Concretionary layer: massive layer of kidney-like concretions (K) Manganese content 8.95%		4.5
Shale		6
Bentonite Series		
Bentonite		2
Shale		7
Bentonite		1.5
Shale		5
Bentonite		0.5
Shale		1
Bentonite		0.5

	Feet	Inches
Shale	2	2
Bentonite		0.25
Shale		4
Concretionary layer: rounded blue concretions 1" x 2" x 2" occupying about 1/10 of the layer's area (J) Manganese content 19.90%		2
Shale	1	7
Concretionary layer: angular chunks form floors about 1" thick and occupy about half the layer's area (I) Manganese content 20.85%		1
Shale		7
Bentonite		1.5
Concretionary layer: massive layers of 2½" x 3" x 3" concretions make floors covering almost entire layer (H) Manganese content 10.32%		2.5
Shale		4
Bentonite Pair		
Bentonite		1
Shale	1	6
Bentonite		0.25
Shale	1	
Concretionary layer: angular bluish nubbins 1½" in diameter cover 1/10 of layer's area (G) Manganese content 19.27%		1.5
Shale		10
Concretionary layer: angular concretions 1½" in diameter, occupy 1/10 of layer's area (F) Manganese content 21.34%		1.5
Shale		6
Concretionary layer: round concretions, 2" in diameter, occupy about 1/5 the layer's area (E) Manganese content 21.68%		2
Shale	1	6
Concretionary layer: angular concretions 1" in diameter occupy about 1/10 of the layer's area (D) Manganese content 18.82%		1
Shale		7
Bentonite		2.5

	Feet	Inches
Concretionary layer: round concretions 2" in diameter lie in small groups of 8 to 12" across and occupying about 2/3 of the layer's area (C) Manganese content 18.10%		2
Shale	1	10
Concretionary layer: rounded rough concretions 2" x 2" x 2" cover about 1/3 of the layer's area (B) Manganese content 18.19%		2
Shale		8.5
Concretionary layer: round 2" x 4" x 4" concretions cover about 1/5 of layer's area (A) Manganese content 13.19% This is probably near the base of the upper Oacoma		2
Covered slope	53	
<u>Crow Creek Zone</u>		
Marl	7	
Sand and silt	1	

Section IV

Medicine Creek Bridge Section

Succession of beds in the Pierre Formation 3/4 mile southeast of the bridge across the mouth of Medicine Creek; Sec. 3, T. 107 N., R. 74 W., Lyman County, South Dakota.

	Feet	Inches
<u>Sully Member</u>		
<u>Agency-Oacoma Zone</u>		
Concretionary layer: concretions make continuous bed (ZA) Manganese content 13.3%		1.5
Shale	2	6
Bentonite Pair		
Bentonite		0.5
Shale		5
Bentonite		0.5
Shale	4	9
Concretionary layer: round concretions 1½" x 2" x 2" occupy 2/3 of layer's area (Z) Manganese content 21.8%		1.5
Shale	2	
Concretionary layer: round concretions 2" x 4" x 4" occupy about ½ area of layer (Y) Manganese content 22%		2
Shale		1.6
Concretionary layer: blue nubbins 1" in diameter scattered through layer (X) Manganese content 22.58%		1
Shale	1	5
Bentonite		0.75
Concretionary layer: flat concretions form floors occupying about ½ the area of the layer. (W) Manganese content 21.59%		1.5
Shale	1	4
Bentonite		1
Concretionary layer: massive angular concretions 2" x 6" x 6" cover about ½ the area occupied by the layer (V) Manganese content 21.69%		2
Shale		11

Section IV continued

	Feet	Inches
Concretionary layer: massive rough fossiliferous concretions 2" x 6" x 6" form floors covering ½ the layer's area (U) Manganese content 20.07%		2
Shale	1	9
Big Bentonite Series		
Bentonite layer (BBB)		4
Concretionary layer: round concretions cover about 2/3 of the area of this layer (T) Manganese content 18.91%		1
Bentonite layer		0.5
Shale	2	2
Concretionary layer: flat concretions 2" x 6" x 6" make a continuous bed (S) Manganese content 18.93%		2
Shale		4
Concretionary layer: flat concretions 3" x 3" x 1" occupy about 4/5 of the area covered by this layer (R) Manganese content 16.79%		1
Shale	1	5
Concretionary layer: 2" x 6" x 6" concretions packed in to make solid bed (Q) Manganese content 13.92%		2
Shale		6
Concretionary layer: massive 2" x 6" x 6" concretions making floors which occupy about ½ the area covered by the layer (P) Manganese content 18.33%		2
Shale	2	
Bentonite		1
Concretionary layer: bed of massive concretions 4" x 6" x 8" (O) Manganese content 19.13%		4
Shale		4
Bentonite Series		
Bentonite		1
Shale		3
Bentonite		1
Shale		3
Bentonite		1
Shale		3
Concretionary layer: flat concretions 1" x 4" x 4" scattered, occupy about 1/5 of the layer's area (N) Manganese content 21.28%		1

Section IV continued

	Feet	Inches
Shale		2
Bentonite		0.5
Shale		2
Concretionary layer: bed of massive concretions 2½" x 6" x 8" (M) Manganese content 17.02%		2.5
Shale	1	8
Bentonite Series		
Bentonite		1.5
Shale		6
Bentonite		1
Shale		6
Bentonite		0.25
Shale	1	2
Concretionary layer: large round concretions 2" x 2" x 4" cover about 2/3 of the layer's area (L) Manganese content 20.26%		2
Shale		8
Bentonite layer		2
Shale	1	2.5
Concretionary layer: round concretions 1" in diameter scattered through layer occupy about 1/10 of its area (K) Manganese content 17.47%		1
Shale	1	3
Bentonite		0.25
Concretionary layer: smooth round concretions about the size of baseballs occupy 1/5 of the layer's area (J) Manganese content 20.96%		3
Shale		4
Concretionary layer: round concretions 2" x 4" x 4" scattered through the layer cover about 1/10 of layer (I) Manganese content 18.36%		2
Shale		10
Concretionary layer: round concretions 2" in diameter scattered through the layer occupy about 1/10 of its area (H) Manganese content 19.44%		2
Shale		5
Concretionary layer: rounded concretions 2" x 2" x 4" occupy about 1/10 of layer's area (G) Manganese content 18.42%		2
Shale	1	

Section IV continued

	Feet	Inches
Concretionary layer: round concretions 2" in diameter cover about 1/10 of the layer (F) Manganese content 16.72%		2
Shale		9
Concretionary layer: scattered nodules (E) Manganese content 16.75%		1
Shale	1	5
Concretionary layer: scattered nodules (D) Manganese content 17.91%		1
Shale		9.5
Concretionary layer: scattered nodules (C) Manganese content 17.44%		1
Shale		8
Concretionary layer: scattered round concretions about the size of large marbles (B) Manganese content 16.78%		1
Shale		5
Concretionary layer: round concretions 1" in diameter Manganese content 18.86%		1
This is the last layer exposed in this outcrop and probably very near the base of the Upper Oacoma (A)		
Covered slope	14	
<u>Crow Creek Zone</u>		
Calcareous shale shows as light streak on hill side	1	
Sandstone typical shelly soft sand		0-6

Note: Crow Creek Zone locally missing.

Section V

Crazy Bull Section

Succession of beds of the Pierre Formation on the Sam Crazy Bull Ranch, near the center of Sec. 33, T. 108 N., R. 73 W., Lyman County, South Dakota.

	Feet	Inches
<u>Sully Member</u>		
<u>Verendrye Zone</u>		
Shale, with scattered concretions forming the top of the hill (V) Manganese content 23.52%	1	2
Concretionary layer: flat concretions 1" x 6" x 6" covering half the area occupied by the layer (U) Manganese content 21.84%		1
Shale	2	
Concretionary layer: rough round concretions 1" x 2" x 2" scattered through the layer (T) Manganese content 18.99%		2
Shale	1	
Concretionary layer: small ½" to 1" round concretions scattered through the layer (S^1) Manganese content 19.40%		1
Shale		6
<u>Agency-Oacoma Zone</u>		
Bentonite		2
Shale		7
Concretionary layer: rough rounded concretions 1½" x 1½" x 3" occupy about ¼ of the layer's area (S) Manganese content 21.61%		1.5
Shale		6
Bentonite layer		0.25
Concretionary layer: concretions 1" x 2" x 2" scattered through the layer (R) Manganese content 20.64%		1
Shale		10
Big Bentonite Series		
Bentonite layer (BBB)		7
Concretionary layer: scattered concretions (Q) Manganese content 17.33%		1
Bentonite		1

Section V continued

	Feet	Inches
Shale		2
Bentonite		0.25
Concretionary zone: round concretions 2" x 1" x 1" occupying about 1/3 of the layer's area (P) Manganese content 23.3%		1
Shale	1	10
Concretionary layer: potato-like concretions 1" x 2" x 3" occupying about 1/3 of the layer's area (O) Manganese content 19.61%		1
Shale		11
Concretionary layer: rounded concretions 1" x 3" x 3" occupy about 1/5 of the layer's area (N) Manganese content 18.24%		1
Shale		4
Concretionary layer: massive concretions form floors occupying 2/3 of the layer's area (M) Manganese content 17.23%		2
Shale		4
Concretionary layer: bed of flat concretions 3" x 9" x 9" (L) Manganese content 15.81%		3
Shale	1	6
Concretionary layer: bed of massive blocky 3" x 6" x 6" concretions (K) Manganese content 21.44%		3
Shale	1	6
Concretionary layer: round rough concretions 2" in diameter covering about 1/5 of the layer's area (J) Manganese content 20.11%		2
Shale		10
Bentonite Series		
Bentonite		0.5
Concretionary layer: angular blocky concretions make a continuous bed (I) Manganese content 18.68%		2
Shale		4
Bentonite		2
Shale		4
Bentonite		0.5
Shale		1
Bentonite		1

	Feet	Inches
Concretionary layer: 1" x 1" x 2" concretions cover about 1/5 of the layer's area (H) Manganese content 17.91%		1
Shale		11
Bentonite		0.25
Shale		2
Concretionary layer: rough rounded concretions 2" x 6" x 6" make continuous bed (G) Manganese content 15.88%		2
Shale	1	4
Bentonite Series		
Bentonite		2
Shale		1.5
Bentonite		0.75
Shale		1.5
Bentonite		0.5
Shale		8
Bentonite		0.5
Shale		10
Bentonite		4
Shale		5
Bentonite		0.25
Concretionary layer: 1" continuous concretions cover about 1/5 of the layer's area (F) Manganese content 17.93%		1
Shale	1	3
Bentonite bed carrying black mica flakes in its base		1
Shale	1	2
Bentonite		1
Shale	1	3
Concretionary layer: flat rounded concretions 2" x 4" x 4" form a continuous bed (E) Manganese content 18.24%		2
Shale	1	1
Concretionary layer: round concretions 2" x 2" x 3" occupy about 2/3 of the layer's area (D) Manganese content 18.99%		2
Shale	3	
Bentonite Series		
Bentonite bed		0.75
Shale		1

Section V continued

	Feet	Inches
Bentonite bed		0.75
Shale		1
Bentonite		0.75
Shale		3
Concretionary layer: scattered 2" concretions (C) Manganese content 22.05%		2
Shale	2	
Bentonite		4
Shale		3
Bentonite with abundant black mica flakes in its base (LMB)		6
Shale	1	10
Bentonite		5
Shale		3
Concretionary layer: rounded concretions 2" x 2" x 5" occupy about 3/4 of the layer's area (B) Manganese content 26%		2
Shale	1	9
Concretionary layer: flat rounded concretions 2" x 2" x 4" make floors covering half the layer's area (A) Manganese content 23.63%		2
Shale Barren Zone	5	1
<u>Crow Creek Zone</u>		
Black calcareous shale when fresh, weathers to light tan.	4	6
Sand, fine, even-grained, poorly cemented except when hardened into a shelly sandstone		10

Section VI

Clark Ranch Section

Succession of beds of the Pierre Formation on the Clark Ranch; Sec. 27, T. 109 N., R. 76 W., Lyman County, South Dakota.
Note: Section measured with hand level on steep cliff. Bentonite beds and small concretionary layers not noted .

	Feet	Inches
Sully Member		
Verendrye Zone		
Shale, weathering brown of typical Verendrye, scattered concretions of iron carbonate	--	--
Pair of 1" layers of rusty, shelly concretionary material separated by a foot of shale. Large white concretions up to 6" thick and 1 foot across, have their bases in the lower layer. These concretions weather to a rusty red. The lower iron bed is designated as (WRP)	1	
Shale, light colored, "papery" laminations tending to make "step" structure	7	3.7
Agency-Oacoma Zone		
Concretionary layer: top layer of manganese concentration, thin, very fossiliferous concretions, 1½" x 12" x 12", break down to a fine rubble on weathering. Occupies 2/3 of the area covered by the layer (N) Manganese Content 18.5%		1.5
Shale		8
Concretionary layer: small round concretions, 1" x 2" x 2", blue in color and very fossiliferous, cover about 1/3 of layer's area (M) Manganese content 20.48%		1
Shale	1	5
Concretionary layer: 2/3 of layer's area occupied by fossiliferous concretions 1" x 8" x 8" which break into rubble on weathering (L) Manganese content 19.44%		1
Shale		11

Section VI continued

	Feet	Inches
Concretionary layer: about 2/5 of the layer's area covered by round 1" concretions (K) Manganese content 18.92%		1
Shale	1	2.5
Big Bentonite Bed (BBB)		6
Concretionary layer: heavy bed of concretionary material, makes rubble which may conceal small layers of concretions in the interval below (J) Manganese content 11.58%		3
Shale	2	9
Concretionary layer: about 1/5 of the layer's area is occupied by round concretions 2" x 6" x 6" (I) Manganese content 23.14%		2
Shale	1	
Concretionary layer: about 1/3 of the layer's area is occupied by flat concretions 1" x 4" x 4" (H) Manganese content 19.23%		1
Shale		5
Concretionary layer: a continuous bed of massive concretionary material: breaks out in angular blocks (G) Manganese content 24.92%		2
Shale	2	
Concretionary layer: about ½ the layer's area covered by rough 2" x 2" x 4" concretions (F) Manganese content 22.49%		2
Shale	2	7.6
Concretionary layer: about 1/5 of the layer's area is covered by rough rounded concretions 1½" x 4" x 4" (E) Manganese content 19.7%		1.5
Shale	3	
Concretionary layer: round concretions 1" in diameter occupy about 1/3 of the layer's area (D) Manganese content 20.65%		1
Shale	1	8.6
Concretionary layer: about ½ the layer's area is occupied by flat concretions 2" x 12" x 12" (C) Manganese content 21.75%		2

Section VI Continued

	Feet	Inches
Shale	5	7.6
Concretionary layer: solid bed of concretions 1" thick (B) Manganese content 17.77%		1
Shale	4	1.5
Concretionary layer: 2" concretions occupy 1/5 of the layer's area (A) Manganese content 13.77% This layer lies at the base of the beds with papery shales and "step" structure.		2
Shales without step structure typical of lower part of Agency-Oacoma Zone down the valley	47	
<u>Crow Creek Zone</u>		
Marl	8	
Sandstone	1	

Section VII

De Grey Section

Succession of beds of the Pierre Formation near De Grey; SW¼ of Sec. 6, T. 109 N., R. 75 W., Hughes County, South Dakota. (Combination of sections measured by J. P. Gries and E. P. Rothrock.)

	Feet	Inches
Sully Member		
Verendrye Zone		
Shale, gray weathers to gumbo; numerous black sideritic concretions; not measured.	--	--
Shale, yellowish gray, flaky, with large black concretion zone at top	7	10
Upper Agency-Oacoma Zone		
Bentonite layer, dark gray bentonite with much black mica in the base of the layer (UMB)		2
Shale, light colored, hard and platy	1	
Concretionary layer: small round bluish concretions 1" in diameter occupy about 1/3 of the layer's area; lies at the top of manganese concentration, (Q) Manganese content 12.74%		1
Shale like above		5
Concretionary layer like above (P) Manganese content 20.98%		1
Shale like above	1	5
Concretionary layer: flat concretions 1" x 6" x 6" cover about ½ the layer's area (O) Manganese content 21.09%		1
Shale like above	1	
Concretionary layer: scattered round concretions 1" in diameter cover about 1/10 of layer's area (N) Manganese content 21.32%		1
Shale like above	1	5
Concretionary layer: massive concretions 1½" thick form continuous layer (M) Manganese content 19.50%		1.5
Shale	2	

Section VII continued

	Feet	Inches
Concretionary layer: massive concretions 1½" forms continuous bed (L) Manganese content 20.04%		1.5
Shale	1	5
Concretionary layer: round concretions 1½" in diameter occupy ½ of layer's area (K) Manganese content 19.45%		1.5
Shale		2
Bentonite bed (BBB)		8
Concretionary layer: massive 2" x 6" x 6" concretions make floors covering about ½ the layer's area (J) Manganese content 21.39%		2
Shale	5	
Concretionary layer: massive concretions make pavements 2" x 24" x 24" (I^1) Manganese content 23.46%		2
Shale	2	
Concretionary layer: massive 2" x 6" x 6" concretions make continuous layer (I) Manganese content 19.76%		2
Shale	1	8
Concretionary layer: round concretions 2" x 2" x 6" scattered through the layer occupy about 1/10 of its area (H)		2
Shale	3	3
Bentonite Series		
Bentonite		1
Concretionary layer: round 2" x 2" x 4" concretions occupy about 1/5 the layer's area (G) Manganese content 23.78%		2
Shale		8
Bentonite		1
Concretionary layer: round 2" x 2" x 4" concretions occupy about 2/3 of the layer's area (F) Manganese content 25.84%		2
Shale	1	6
Concretionary layer: rough, round 2" x 2" x 6" concretions occupy about 4/5 of the layer's area (E) Manganese content 20.21%		2

Section VII continued

	Feet	Inches
Shale		10
Concretionary layer: rough, flat 2" x 8" x 8" concretions occupy 2/3 of the layer's area (D) Manganese content 24.66%		2
Shale		8
Concretionary layer: round 2" x 2" x 4" concretions occupy about 1/3 of the layer's area (C) Manganese content 23.03%		2
Shale	6	
Concretionary layer: concretionary material makes nearly continuous bed (B) Manganese content 16.99%		1.5
Shale	1	6
Concretionary layer: small floors of 1" x 6" x 6" concretions cover about 1/5 of the layer's area (A) Manganese content 15.82%		1
Bentonite: yellow with abundant biotite flakes in the base (LMB)		6
<u>Lower Agency-Oacoma Zone</u>		
Shale, light grey, somewhat papery no visible bentonite; stands in steep outcrop	12	4
Shale, grey, weathers to gumbo; contains few bentonites and scattered iron carbonate concretions	21	
Bentonite Series		
Bentonite		6
Shale like above	1	
Bentonite		6
Shale like above	8	8
Bentonite, slightly micaceous		6
Shale like above	6	2
<u>Crow Creek Zone</u>		
Marl, light grey	13	
Sandstone, brown, slabby-		1
<u>Gregory Member</u>		
Shale; brown to grey; many rusty-brown concretions; layer of 1 foot of grey septarian concretions about 37 feet below top	42	

Bottom of outcrop

Section VIII

Succession of beds of the Pierre formation in the SE$\frac{1}{4}$ of Sec. 35, T. 109 N., R. 73 W., Hyde County, South Dakota.

	Feet	Inches
Sully Member		
Verendrye Zone		
Concretionary layer: small, rusty, probably WRP		1
Shale	8	
Concretionary layer: scattered 6" x 6" x 4" concretions at the top of the manganese concentration cover gentle slopes and shoulders with black rubble (U) Manganese content 16.78%		4
Shale	1	2
Concretionary layer: three inch concretions scattered through the layer occupying 1/10 area (T) Manganese content 18.79%		3
Shale		1
Concretionary layer: 3" x 3" x 1$\frac{1}{2}$" cover about $\frac{1}{4}$ of layer's area (S) Manganese content 16.08%		1.5
Shale	1	2
Concretionary layer: 2" x 2" x 1" round concretions cover 1/5 layer's area (R) Manganese content 18.59%		1
Shale		5
Concretionary layer: 4" x 2" x 2" rounded concretions cover about 1/10 of layer's area (Q) Manganese content 16.36%		2
Shale		10
Bentonite Series		
Bentonite layer		1
Shale		10
Bentonite layer		1
Shale	5	2
Bentonite, dark, brownish grey		4
Shale		6
Concretionary layer: rough rounded concretions 3" x 3" x 1$\frac{1}{2}$" occupy $\frac{1}{2}$ the layer's area (P) Manganese content 21.74%		1.5
Shale		6

	Feet	Inches
Concretionary layer: massive concretions 3" x 4" x 4" in floors cover 2/3 of the layer's area (O) Manganese content 21.66%		3
Shale		10
Bentonite Series (BBB)		
Big Bentonite bed (BBB)		6
Concretionary layer: 5" x 5" x 2" concretions cover half the layer's area (N) Manganese content 19.74%		2
Bentonite bed		1
Shale		8
Bentonite bed		0.75
Shale		3
Bentonite bed		1
Shale	2	1
Concretionary layer: massive concretions 6" x 6" x 3" make pavements covering 4/5 of layer's area (M) Manganese content 22.13%		3
Shale	2	2
Concretionary layer: massive concretions 8" x 8" x 2" make continuous pavement (L) Manganese content 19.5%		2
Shale		1
Concretionary layer: massive 5" x 5" x 2" concretions make continuous bed (K) Manganese content 17.71%		2
Shale	1	
Concretionary layer: 6" x 6" x 2" concretions, make continuous pavement (J) Manganese content 17.92%		2
Shale	1	
Concretionary layer: massive 8" x 8" x 2½" concretions form pavement (I) Manganese content 18.97%		2.5
Shale	1	
Concretionary layer: massive concretions 4" x 4" x 2" make a bed (H) Manganese content 18.13%		2
Shale		7.5
Concretionary layer: massive concretions 4" x 4" x 2" from pavement (G) Manganese content 18.06%		2
Bentonite Series		
Shale		11

	Feet	Inches
Bentonite		1.5
Shale		4
Bentonite		1.5
Shale		2
Bentonite		1
Shale		7
Concretionary layer: small round concretions 1" in diameter cover about 1/5 of layer's area, not sampled		1
Shale		10
Bentonite Layer		0.5
Concretionary layer: massive layer of concretions (E) Manganese content 18.68%		1.5
Shale		10
Concretionary layer: massive concretions 5" x 5" x 2" occupy 4/5 of layer's area (D) Manganese content 21.88%		2
Bentonite Series		
Shale		2.4
Bentonite		1
Shale		5
Bentonite		1
Shale	1	
Concretionary layer: round 4" x 4" x 2" concretions scattered through the layer (about 1/10 of layer's area) (C) Manganese content 20.51%		2
Shale		3
Concretionary layer: flat concretions 4" x 4" x 1" cover 1/5 of layer's area (B) Manganese content 19.97%		1
Shale		8
Bentonite Series		
Bentonite		4
Shale		7
Bentonite		2
Shale		10
Bentonite		0.2
Shale	2	2
Concretionary layer: round concretions 2" x 2" x 3" occupy about half the layer's area (A) Manganese content 20.35%		2

Section VIII continued

	Feet	Inches
Shale		3
Large Bentonite bed		4
Shale	38	
Crow Creek Zone		
Marl	4	
Sand	1	

Section IX

Gregg Ranch Section

Succession of beds in the Pierre Formation on the Gregg Ranch, Sec. 10, T. 108 N., R. 74 W., Hughes County, South Dakota, at the west end of the outcrop north of the Big Bend of the Missouri River.

	Feet	Inches
Sully Member		
Agency-Oacoma Zone		
Concretionary layer: scattered concretions on surface in vertical foot of shale. Beds not located (ZF) Manganese content 20.31%	1	
Bentonite		1
Shale	1	2
Concretionary layer: 1" rough round concretions cover about 1/3 of layer's area (ZE) Manganese content 20.96%		1
Shale		3
Bentonite bed with some black mica in base, probably UMB		1
Concretionary layer: flat concretions $1\frac{1}{2}$" thick make small pavements occupying about 1/10 of layer's area (ZD) Manganese content 19.31%		1.5
Shale	1	
Concretionary layer: 4" x 4" x 2" concretions occupy about 1/5 of the layer's area (ZC) Manganese content 24.18%		2
Shale	1	
Concretionary layer: large rough 3" x 3" x 1" concretions cover about 1/5 of layer's area (ZB) Manganese content 20.04%		1
Shale	1	1
Concretionary layer: solid bed of concretions 2" x 2" x 1" (ZA) Manganese content 24.99%		1
Shale		8
Bentonite bed		4
Shale		10

	Feet	Inches
Concretionary layer: small scattered concretions less than 1" in diameter (Z) Manganese content 25.29%		1
Shale	3	6
Big Bentonite Series		
Big Bentonite bed BBB		7
Concretionary layer: round 1" x 2" x 2" concretions in 2" shale bed (Y) Manganese content 17.32%		2
Bentonite bed		1.5
Shale	1	
Bentonite		1
Concretionary layer: rough, round concretions 2" in diameter cover 1/3 layer's area (X) Manganese content 22.4%		2
Bentonite		0.5
Concretionary layer: pavements of concretionary material 1" thick cover 1/3 layer's area (W) Manganese content 21.28%		1
Shale		5
Concretionary layer: large flat concretions 6" x 6" x 2" cover 1/5 of layer's area (V) Manganese content 24.25%		2
Shale	1	4
Concretionary layer: large flat concretions 24" in diameter by 3" thick cover 4/5 of layer's area (U) Manganese content 22.25%		3
Shale	1	
Concretionary layer: flat 5" x 5" x 2" concretions cover 2/3 of layer's area (T) Manganese content 19.19%		2
Shale	1	4
Concretionary layer: large flat concretions 8" x 8" x 2" cover 2/3 of layer's area (S) Manganese content 19.06%		2
Bentonite Series		
Shale	4	2
Bentonite		1
Shale		5
Bentonite		1
Shale		4
Bentonite		1

	Feet	Inches
Concretionary layer: massive 10" x 10" x 3" concretions cover 1/5 of layer's area (R) Manganese content 23.78%		3
Shale		3
Bentonite		0.75
Concretionary layer: 2" x 2" x 10" rounded concretions occupy ½ of layer's area (Q) Manganese content 20.35%		2
Shale	1	4
Bentonite Series		
Bentonite bed		1
Shale	2	6.5
Bentonite		1
Shale		8
Bentonite		1
Shale		5
Concretionary layer: large round concretions 2" x 2" x 5" cover 1/5 layer's area (P) Manganese content 20.90%		2
Shale	2	5
Bentonite bed with black mica (LMB)		2
Shale	3	
Concretionary layer: small round 1½" x 2" x 2" concretions occupy ½ of layer's area (O) Manganese content 20.43%		1.5
Shale		7
Concretionary layer: small round concretions 2" x 1½" x 1½" occupy 1/3 layer's area (N) Manganese content 18.49%		1.5
Shale		9
Concretionary layer: small round concretions 1" x 1" x 2" occupy 1/3 layer's area (M) Manganese content 17.33%		1
Shale		5
Concretionary layer: small round concretions ½" in diameter occupy 1/3 layer's area (L) Manganese content 17.52%		0.5
Shale	2	2
Concretionary layer: small round concretions 1" in diameter occupy about 1/5 of layer's area (K) Manganese content 16.67%		1

Section IX continued

	Feet	Inches
Shale		8
Concretionary layer: pavements of flat 1" x 2" x 2" concretions cover about ½ layer's area (J) Manganese content 18.38%		1
Shale		1
Concretionary layer: pavements of flat 1" x 12" x 12" concretions occupy about 1/3 of layer's area (I) Manganese content 18.03%		1
Shale		4
Concretionary layer: pavements of flat 1" x 12" x 12" concretions occupy about 1/5 of layer's area (H) Manganese content 18.85%		1
Bentonite		0.5
Shale	1	4
Concretionary layer: round concretions about 2" in diameter scattered through layer occupying about ½ layer's area (G) Manganese content 17.30%		2
Shale		5
Concretionary layer: round 2" concretions cover about ½ layer's area (F) Manganese content 14.19%		2
Shale		1.5
Concretionary layer: yellow rounded concretions 1" x 1" x 5" occupy about ½ the layer's area (E) Manganese content 17.99%		1
Shale	1	
Concretionary layer: yellow rounded 1" x 5" x 5" concretions occupy about ½ the layer's area (D) Manganese content 19.38%		1
Shale	5	
Concretionary layer: small round yellow concretions 1½" x 1½" x 2" occupy about ½ the layer's area (C) Manganese content 18.74%		1.5
Shales		7
Concretionary layer: crumbly, yellow round concretions, 1" x 2" x 2", cover 1/10 of layer's area (B) Manganese content 15.28%		1

Section IX continued

	Feet	Inches
Shale	1	10
Concretionary layer: round 1" x 2" x 2" concretions scattered through the layer occupy about 1/10 of its area (A) Manganese content 11.69%		1
Shale	2	4
Bentonite layer		1

Bottom of exposure

The Ores

The only manganese worthy of consideration as a commercial proposition is contained in the Agency-Oacoma beds. Some qualitative tests on the concretions of the Verendrye have shown the presence of manganese, and it is possible that the same might be true of some concretions of the Virgin Creek, but nowhere in these members is there a sufficient concentration to permit commercial development. Thus any exploitation of these beds for manganese must be confined to the thirty or forty foot concentration in the Agency-Oacoma seam which has been described.

In this seam the manganese is contained only in concretionary nodules and the fossils of vertebrate and invertebrate animals. Tests made on the shale and bentonite beds failed entirely to disclose any of the metal. Neither is manganese found in veins or vein-like structures. Commercial production, therefore, will have to come entirely from the nodules.

The method of occurrence of the metal in the nodules is still largely a matter of conjecture. Under the high-powered microscope the nodules are seen to be made of very small grains of mineral matter, too small to be easily identified. About the grains runs a brown network of iron-like material which is more noticeable in the weathered portions than in the unweathered.

A sample which was digested in concentrated hydrochloric acid showed 90% (by weight) of the sample soluble in the acid, leaving an insoluble residue of 10%. The residue appeared to be largely of a white, fluffy clay, the individual flakes of the minerals being so small as to be unrecognizable under the high power of the microscope.

As was pointed out in a previous report,[1] there is a possibility that the manganese occurs as a compound of manganese carbonate and iron carbonate known as mangano-siderite

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1. Gries, J. P. and Rothrock, E. P., Manganese Deposits of the Lower Missouri Valley in South Dakota, S. Dak. State Geological Survey Report of Investigations No. 38, 1941.

or a manganese-bearing carbonate, mangano-calcite. The pink manganese carbonate, rhodochrosite, has not been identified by any of the observers who have worked on the ores. Bluish-black metallic grains of pyrolusite were identified in some of the well-weathered portions of the nodules. These apparently were a secondary product of the weathering of the nodules, since they do not occur in the fresh material.

The larger mineral pieces which could be identified showed bits of quartz which occurred as small grains and crystals of clear rock crystal and chalcedony pseudomorphs of bits of fossil shells and other organic matter. Some specimens contain small bright red grains which have the appearance and refractive index of apatite. Tubes of chalcedony are sometimes found penetrating the concretions. Aragonite crystals are common in some concretionary layers and always occur as the middle layer of fossil mollusk shells. These weather white without any impregnation of manganese.

The following list of minerals is a compilation of those which have been reported by various observers who have studied the nodules.

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

To this list there should be added certain clay minerals which make up the fluffy mass left after digestion with acid.

Complete chemical analyses of the ore are not available. A qualitative analysis run on a sample from Elm Creek, however exposes the following elements:[1]

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

1. Analysis by Dr. Ernest Griswold.

From this and the partial quantitative analyses that have been made for other elements it is evident that the chief constituents are iron, manganese, and the carbonate radical. Silica, aluminum, magnesium and the phosphate radical play minor roles. The laboratories of the Tennessee Valley Authority published four analyses showing the presence of calcium, magnesium, and silica, besides iron manganese and the carbonate radical. These analyses indicate a high percentage of calcium but make no mention of aluminum or phosphate.[1]

The report of the U. S. Geological Survey does not give complete chemical analyses but does give some of the minor constituents.[2] The interesting part of these U.S.G.S. analyses is that the average phosphorus content of thirteen samples showed 0.407%; silica, 12.39%; aluminum, 2.65%.

In 109 samples analyzed in the Chamberlain area it was found that percentage of manganese and iron in nodules remained about constant. Where the manganese percentage was high, iron percentage was low, and vice versa. The sum of these two metals in these analyses lay between 25% and 35% of the total analysis, averaging 30%. The average amount of manganese in these samples was 18.12%, about double the amount of iron which averaged 9.4%. The fact that all these were dissolved on digestion with acid suggests that both the iron and manganese are in the form of carbonate. It probably takes the form of a double salt, such as mangano-calcite, oligonite or manganiferous siderite as was pointed out in a former report.[3]

Manganese Content

Nine sections of the manganese seam spaced about six miles apart were sampled so as to give a complete picture of the manganese content in various parts of the area covered by this report. Each layer in each section was sampled and

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1. Tennessee Valley Authority, Department of Chemical Engineering, Chemical Research Division, South Dakota Manganese Ore, April 20, 1940.
2. Op. cit., Hewitt.
3. Gries, J. P. and Rothrock, E. P., Manganese Deposits of the Lower Missouri Valley in South Dakota, S. Dak. State Geological Survey Report of Investigations No. 38, 1941.

analyzed for manganese separately. Thus 188 separate samples were available for comparison.

The average manganese content of all samples in this area is 18.9%. It is of interest to note that this is a little higher than the average of 17% obtained for the Chamberlain area covered in 1940.

The following table is an attempt to summarize the manganese contents of the Oacoma beds of this area. With the exception of section number I, each section represents the entire thickness of the manganese concentration. At the location where section number I was taken the entire concentration was not exposed. It should be pointed out that no layer in any of these sections was devoid of manganese, and that the lowest obtained was more than 9%; with the exception of a few layers in Sections I and III all layers showed manganese concentrations of more than 10%, most layers averaging between 15 and 20%. It will be noted also that each of the sections contains a considerable sprinkling of layers with more than 20% of manganese. In most of them it runs between a third and a half of the entire number of layers.

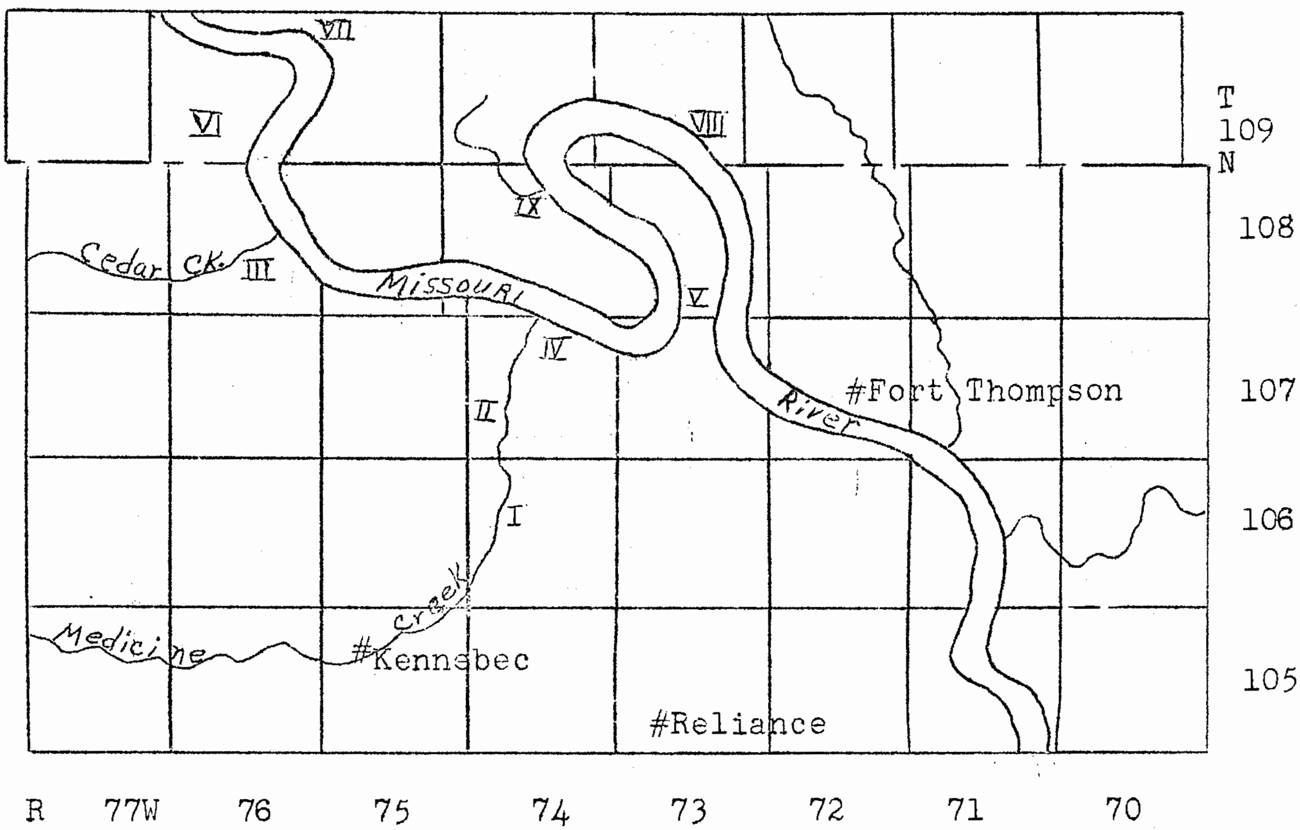
	I	II	III	IV	V	VI	VII	VIII	IX
NUMBER OF LAYERS	12	22	18	27	22	14	21	20	31
THICKNESS OF MANGANESE CONCENTRATION	28.6	32.17	27.85	39.45	37.65	29.4	331	33.48	40.2
THICKNESS OF NODULES IN SECTION	18.43 1.535	21.45 1.705	18.27 1.515	23.94 1.975	21.09 1.76	14.15 1.175	18.96 1.58	25.42 2.12	20.15 1.68
% OF NODULES BY VOLUME	5.56%	5.3%	5.4%	5.06%	5.75%	4%	4.77%	6.16%	5%
SPACING OF BEDS	2.38	1.45	1.55	1.46	1.71	2.1	1.57	1.67	1.3
TONS PER ACRE	6476	7193.3	6391.8	8332.5	7171.9 7425.4	50625 4957.3	6750.0 6666.0	8944.3	7171.9 7087.9
AVERAGE OF ALL BUT SECTION I	7119.1 7130								

I	WELCH RANCH
II	BAD HORSE
III	CEDAR CREEK
IV	MEDICINE CREEK
V.	CRAZY BULL
VI	CLARK RANCH
VII	DEGREY
VIII	FOSSIL HEAD
IX	CRAIG RANCH

INDEX MAP

showing

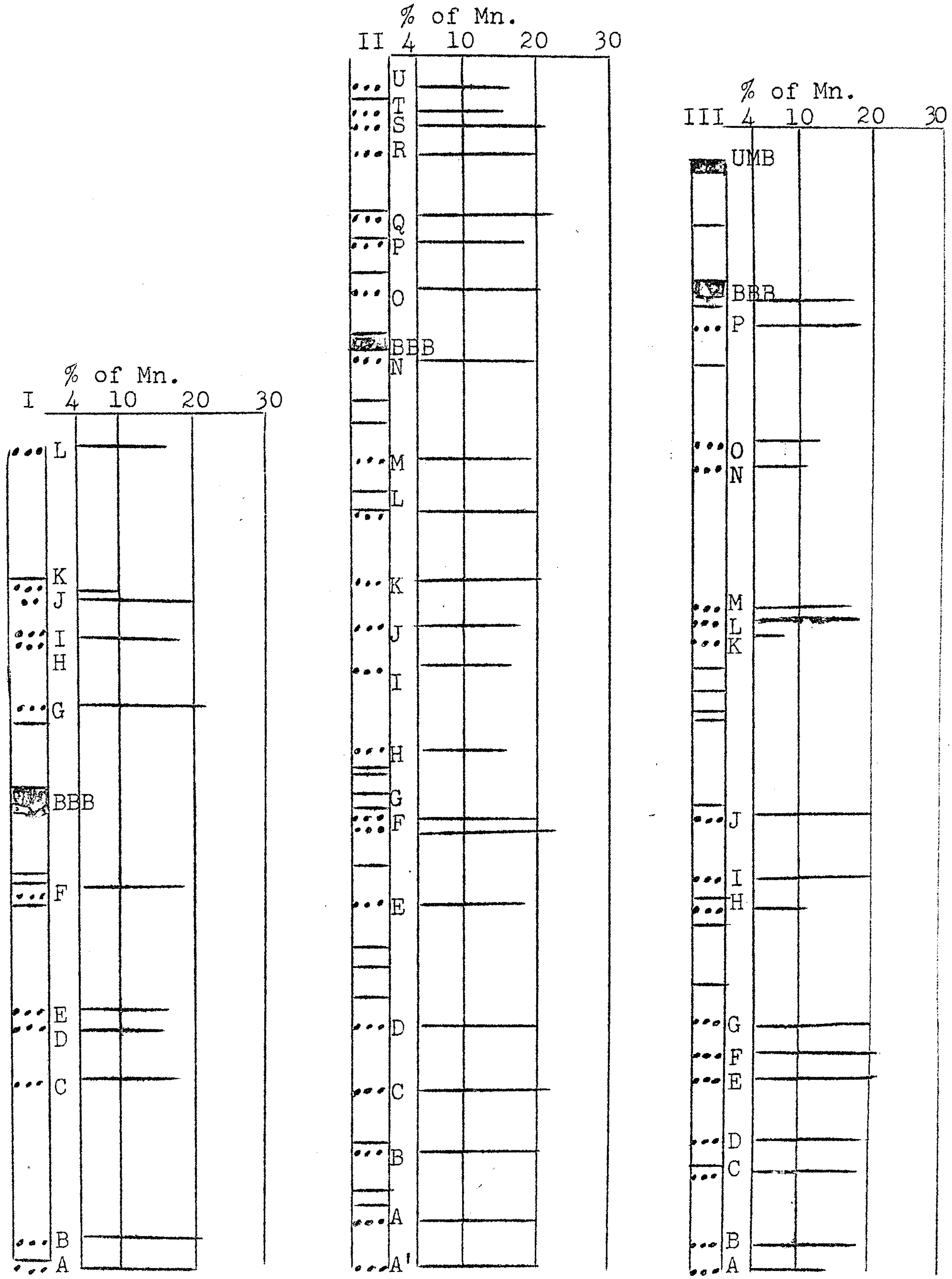
Locations of Sampled Agency-Oacoma Sections



Sample	NAME	Sec.	T.	R.
I	Welch Ranch	8	106N	74W
II	Bad Horse	19	107N	74W
III	Cedar Creek	23	108N	76W
IV	Medicine Creek Bridge	3	107N	76W
V	Crazy Bull	33	108N	73W
VI	Clark	27	109N	76W
VII	DeGrey	6	109N	75W
VIII	-------	35	109N	73W
IX	Gregg	10	108N	74W
*	Position of key beds used in mapping.			

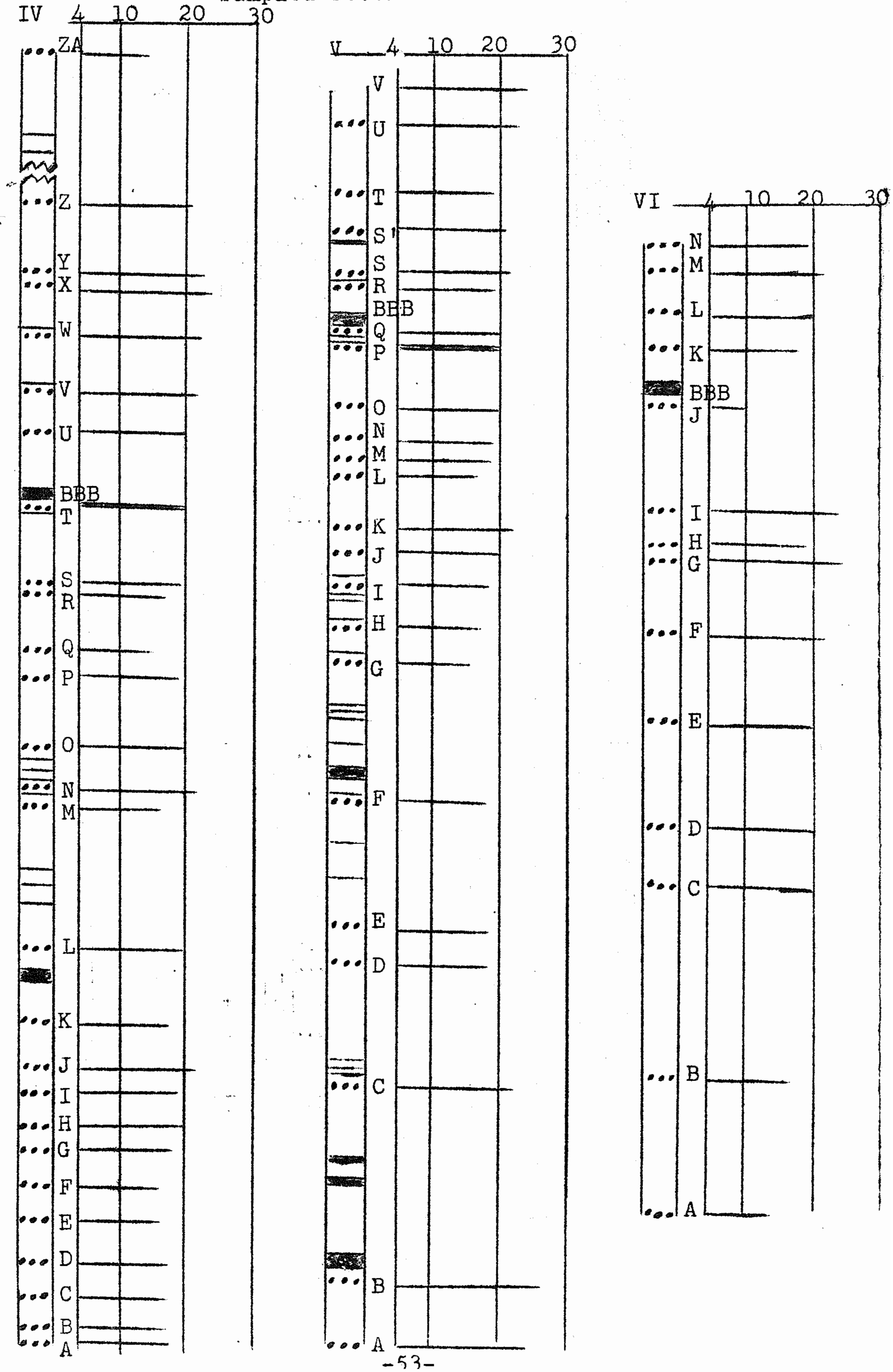
(LOCATION: Sec., T., R.)

Sampled Sections of Agency-Oacoma Zone
Showing the spacing and manganese content
of nodular layers

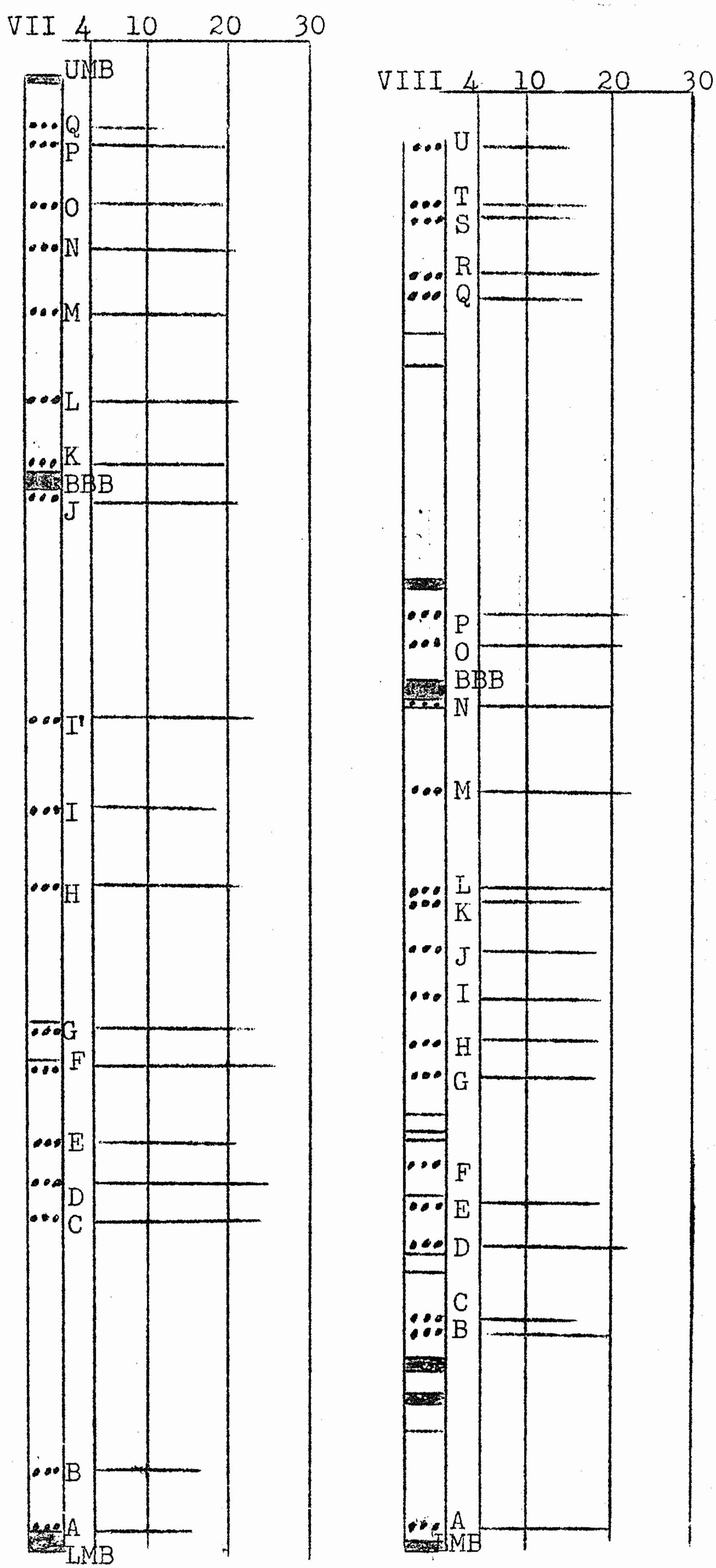


Vertical scale 1 inch = 4 foot.

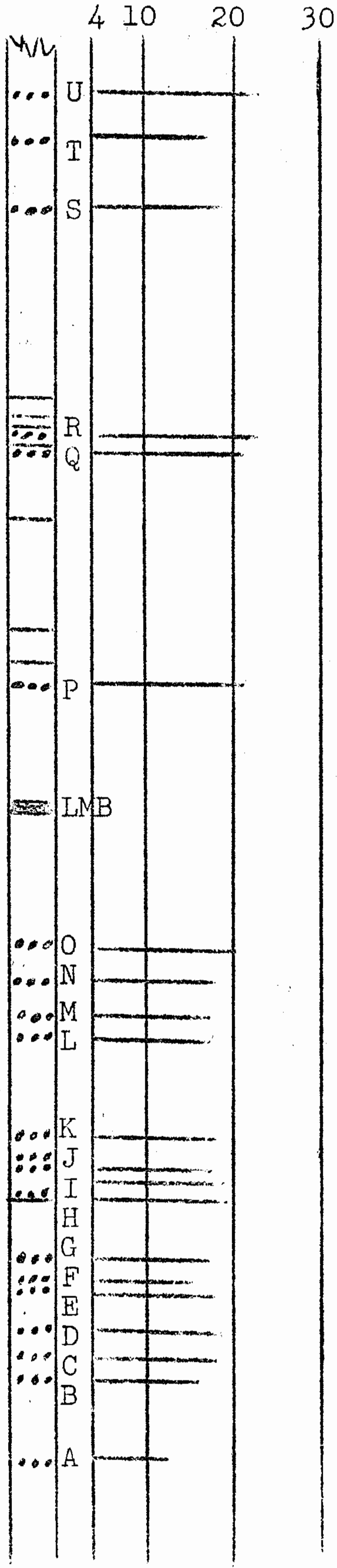
Sampled sections continued

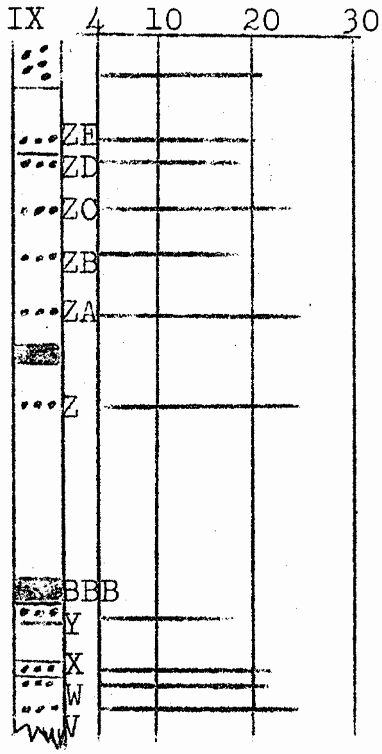


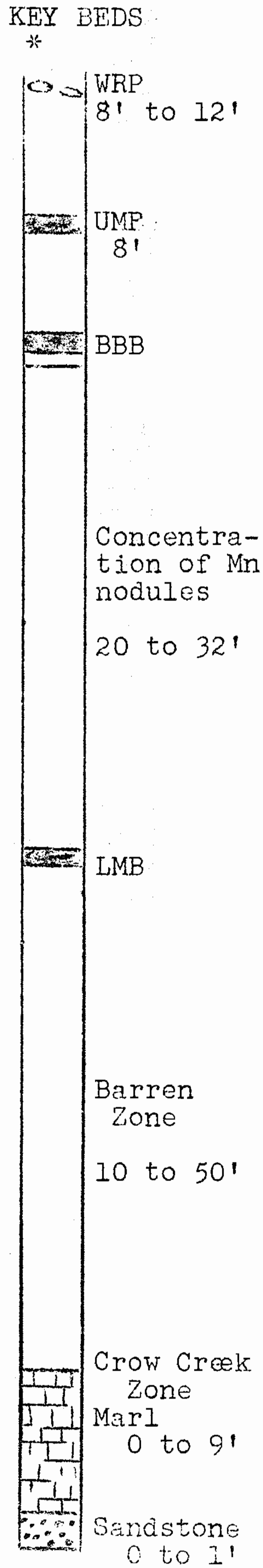
Sample Sections continued



Sampled sections continued







It has been surmised that since the nodules disappeared above DeGrey, the manganese content must be lower in the western end of the deposit than in the eastern and in the vicinity of Chamberlain. It will be noted that average manganese content of Sections III and VI at the western end of the deposit still give high percentages, the section at Clark Ranch, Section VI, giving an average of 19.4%, while Section III, the Cedar Creek section, gives 16.55%. It will be noted that Section VII, the DeGrey section, which is the last section up the river, showed the highest average of any, namely 20.65%. Three sections from DeGrey across the northern end of the Big Bend, namely VII, VIII, and IX, all show high concentrations of manganese.

Though there seems to be more uniformity in the manganese contents of these sections than those farther down the river, it must be kept in mind that there are local variations in the manganese content and any area where development is contemplated should be systematically sampled. Local variations may reduce the manganese content of small areas below the general averages indicated. A case in point is the Cedar Creek section, number III, which gave an average manganese content of 16.55% for twenty layers of nodules. Only four miles north, Section VI, the Clark Ranch section, shows an average of 19.4%, and ten miles southeast, Section II, the Bad Horse section, gave an average of 19.02%.

The information gained by these samples indicates, however, that operators in this region can rely on a slightly higher per cent of manganese in this area than is encountered in the average area farther south and an average manganese content of the nodules of approximately 19%.

Volume

Any estimate of the volume of nodules or the amount of manganese available must of necessity be only an approximation. With only nine sample sections in 80 miles of outcrop considerable areas would not be represented. The spacing of the samples, however, shows that there is considerable uniformity in the deposit which warrants making a tentative estimate of the amount of material that may occur in the area surveyed.

The most desirable type of prospecting for this deposit would be the sinking of test shafts of a standard size, entirely through the manganese concentration. By weighing the nodules obtained from this shaft and also the total material excavated, a ratio of nodules to shale can be obtained which is fairly accurate. Time and money were not available for this kind of testing, however, and on this survey the tests were made by digging trenches into the fresh shale, usually one to two feet in depth, where it was well exposed. By measuring the volume of nodular material in these trenches and using the average specific gravity figure of 3.1 it is possible to arrive at an approximation which may be considered as representing the amount of nodules available. The results of this method are given in the following table.

Section Sample and Location	Total Number of Nodular Layers in Section	Number of layers giving manganese percentage indicated.				Average Mn Content of all layers in Sections
		8-10%	10-15%	15-20%	20-25%	
I	12	1	1	6	4	17.4
II	32	none	1	22	9	19.02
III	20	3	4	10	3	16.55
IV	27	none	2	16	9	18.75
V	23	none	none	13	10	19.90
VI	14	none	2	6	6	19.40
VII	17	none	2	4	11	20.65
VIII	20	none	none	14	6	19.40
IX	32	none	2	16	14	19.6

It will be noted that the ratio of the volume of nodules to the total volume of material in the concentration zone runs fairly uniform for the entire area. Nodular layers are spaced about 1.3 to 2.3 feet apart. In most sections a layer is encountered about every foot and a half. The entire thickness of the concentration zone varies from 29.4 to 40.2 feet and of this thickness the nodules occupy from 1.5 to 2.1 feet. Thus about 5.75% of the volume of the deposit is composed of manganese bearing nodules.

This corresponds favorably with the results obtained in a pilot mine at Chamberlain, where the ratio of nodules to shale was 1 to 25, or 4%.[1]

The greatest concentration seems to be in Section VIII on the east side of the Missouri opposite Lower Brule Agency, and the lowest in Section IV, which is between the Cedar Creek area and DeGrey, the difference in concentration in these two being the difference between 6.16% and 4%, or 2.16%. In a reconnaissance this difference is not significant and therefore brings out more forcibly the uniformity in the distribution of nodules throughout the entire area.

Since average specific gravity of fresh materials from the nodules is 3.1, the average weight of a solid cubic foot of this material would be 193.7 pounds. According to this figure there should be about 4,219 tons in every acre-foot of nodules. Applying this figure to the average thickness of nodules found in the measured sections, the average nodular content per acre would be 7,130 tons. Using the average manganese content of 18.8% this gives a figure of 1,340 tons of metallic manganese per acre.

From the figures on the preceding table it is evident that there is considerable variation from this average volume. The Clark Ranch Section VI, between Cedar Creek and DeGrey, showed the lowest volume, namely, 4957 tons per acre, while Section VIII showed the highest, namely, 8944 tons per acre, a spread of more than 3987 tons per acre. The figures were not computed for Section I because the entire manganese concentration was not exposed at this place. It must be kept in mind that these figures are only approximations and accu-

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1. Private Report, International Minerals and Chemical Corporation.

rate production figures for any area must depend on careful testing of the area to be exploited. They do, however, give an approximation which can be relied on for the region as a whole.

Planimeter calculations on the area of manganese which is exposed, show 11,347 acres which can be mined without stripping. The total tonnage exposed in the entire area would be about 80,904,000 tons of nodules containing approximately 15,209,952 tons of manganese.

As has been pointed out in this report this zone lies as a horizontal seam or sheet through which the Missouri River Valley has been cut exposing the manganese about half way up the bluffs. The map shows only the locations at which this manganese is exposed. It must be remembered, however, that such a seam lies as a great rock blanket under all the uplands of the area. Unfortunately it is about 200 feet below the surface of these uplands and therefore is out of the question as a stripping proposition except near the outcrop. It is safe to assume that the entire area covered by this map is underlain with this manganese concentration. If it were commercially feasible to carry on underground mining or strip to a depth of 200 feet, 12 townships surrounding the outcrops could be counted on as manganese bearing property. These could yield more than 470,000,000 tons of metallic manganese. Such a figure is too large to be very significant, especially since most of this is not available under present mining and marketing conditions. It is included here simply to show the enormous size of this deposit. This area together with that which was surveyed in 1942 shows this to be the largest deposit of manganese in the United States, thus offering a potential source of the metal for many generations to come if it is needed.

MINING AND METALLURGY

Though mining and processing are not in the realm of a geological report, a few notes are included here to indicate some of the methods that have been proposed and tried for the use of this deposit.

The beds of bentonite which are interbedded with shales and manganese bearing concretions and bentonitic material in the shales themselves make a very sticky gumbo when they become wet, and this has become the main obstacle to mining. The shales become very slippery, making it difficult to move trucks and machinery and the bentonite clings tenaciously to the nodules, so that ordinary methods of separation will not clean them. Moreover the nodules are brittle and tend to shatter with rough handling, losing up to 40% of their volume if hammermills, shaker screens, etc., are employed. The beneficiation of the nodules, however, is not a difficult metallurgical matter, as it involves only the treatment of carbonate ores.

Mining and Ore Dressing

The fact that these are low grade ores is not so serious a drawback as it would be if the ore were in hard rock, since mining is inexpensive. The nodules are fairly hard and the shale in which they are imbedded is very soft. Thus it is possible to move large quantities of this ore with a power shovel or a drag-line. Drilling and blasting need not be resorted to. The mining which was done for the pilot plant was all accomplished with a small power shovel. Strippings and wastes are easily disposed of, since the ore lies on shoulders between valleys which are deep enough to more than take care of all the wastes produced.

The problem of cleaning the nodules is a much more difficult one than is the excavation. Dry screening does not separate the nodules from the clay, especially where they are associated with bentonite beds. These stick very tenaciously, and the ordinary jolting or shaking of the screens will not loosen them. Washing is almost as bad, since the clay forms a gumbo which will not come off in an ordinary launder.

It was found that the gumbo has a tendency to check when dried, and methods of wetting and drying both in the sun and in kilns have been tried. It was possible to get the nodules fairly clean in a kiln by alternately wetting and drying them several times. Unfortunately the cost of this process was too high for commercial use.[1]

Another experiment, which has been tried and found satisfactory, but too expensive, was that of exploding the clays from the nodules by putting them under heavy steam pressure and suddenly releasing it. This method cracked off the clays but was estimated to have cost about $20 a ton.[2]

The cheapest method developed by the U. S. Bureau of Mines was one which ran the nodules through a hammermill and then screened them to about three sizes, all over 1 inch. These sizes were sent over separate belts and the ores picked by hand. Thus a fairly clean product was obtained within a reasonable cost limit. Belt picking has one advantage, namely, that of furnishing a by-product of bentonite. The bentonite beds running from 2 to 4 inches thick break into chunks about the size of one's hand which are very clean and can be readily picked from the belt.

All these methods have one fault in common, namely, the loss of a large percentage of the nodules. As has been stated, these nodules are brittle, and in the handling by any of the former methods, are readily shattered. Moreover many of the concretions are small--an inch or less in diameter. These and the shattered pieces tend to be lost in the process of screening or washing. In order to overcome some of this loss a method of concentration by jigging was developed.

In a study of the situation engineers of the International Minerals and Chemical Corporation of Chicago recommended a separation with a Baum type jig. This type of jig uses compressed air instead of a plunger such as is used on a Harz type jig and gives a much better separation. Their experiments show that an 85% recovery of nodules could be obtained by this process. This not only gives the best separation but is also sufficiently flexible so that the operator can control the recovery to a considerable extent. It also

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1. Personal Communication, U. S. Bureau of Mines, Pilot Plant Engineer.
2. Ibid.

allows the separation of pieces of considerable difference in size. This process offers the best solution so far presented to the problem of separation of nodules from shale.

Metallurgy

No commercial beneficiation of these ores has ever been attempted. Considerable laboratory work, however, has pointed out four processes that might be used to advantage.

Since this ore does not average over 18% and even at the best does not exceed 25%, it is evident that it cannot meet the commercial specifications, which in most cases call for 30 to 35% manganese as a minimum; nor can it meet the competition furnished by foreign ores which run as high as 50% manganese. Beneficiation, therefore, resolves itself into a metallurgical problem of stepping the manganese percentage up to these figures or better.

Several methods of doing this have been proposed and are outlined in the following pages. These methods depend primarily on leaching the manganese from the ores and re-precipitating it as metallic manganese. Some methods precede the leeching by roasting, changing the carbonate to an oxide and one employs electrolytic refining. The first two processes produce an alloy of manganese and iron, but the last one produces metallic manganese that is more than 99% pure metal.

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 could 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]

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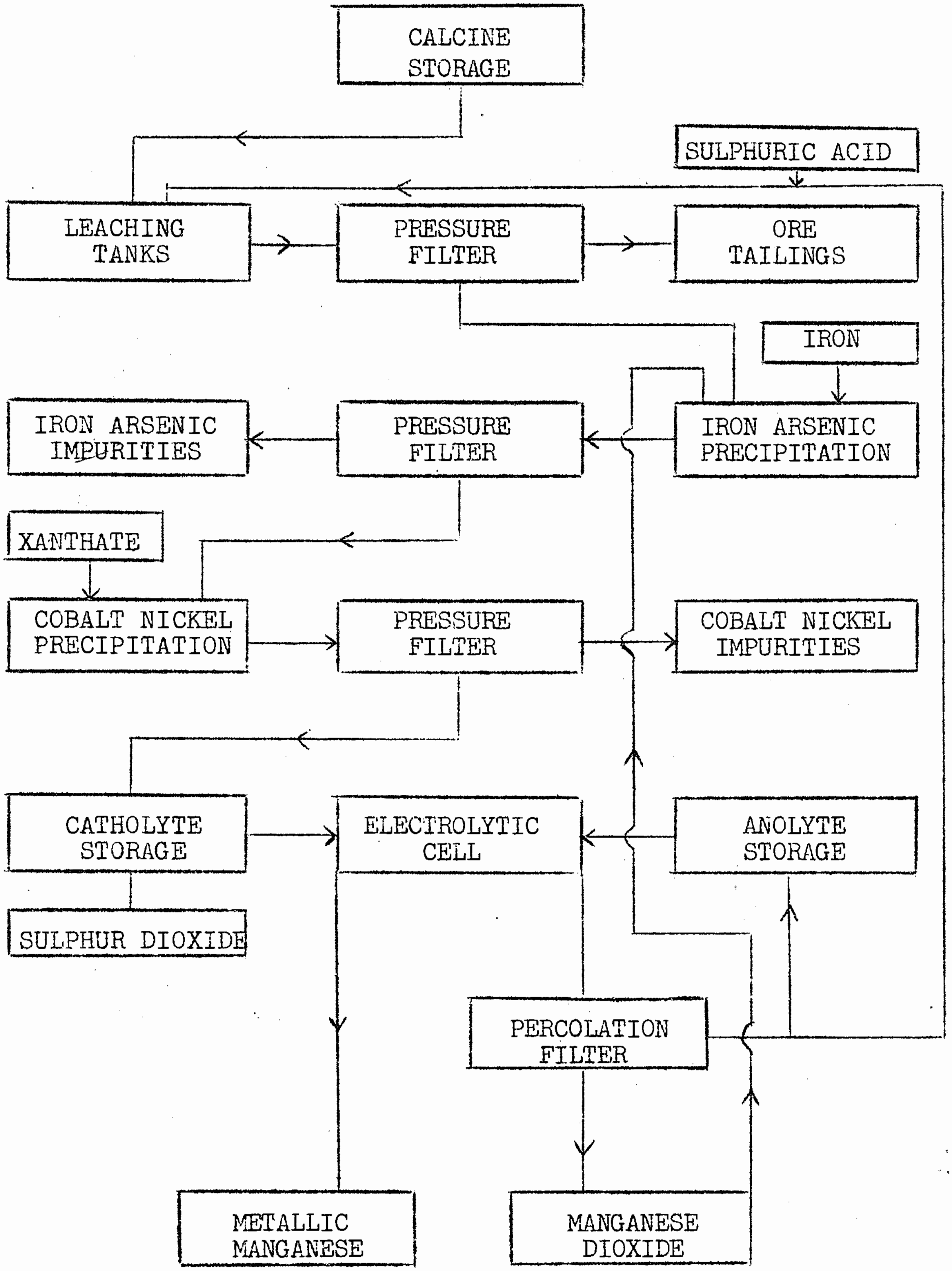
1. Tennessee Valley Authority, Department of Chemical Engineering, Chemical Research Division, South Dakota Manganese Ores, April 26, 1940.
2. Shelton, S. M., Royer, M. B., and Towne, A. P., "Electrolitic Manganese," R. I. 3406, U. S. Bureau of Mines, July, 1938.

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.



FLOW SHEET

ELECTROLYTIC PROCESS
U. S. BUREAU OF MINES

PLATE IX

CONCLUSION

A summary of the results of this survey indicate:

1. The manganese-bearing shales that were mapped in the vicinity of Chamberlain can be followed at least fifty miles up river from Fort Thompson, and underlie at least 12 townships in that vicinity. Thus an additional 11,347 acres of exposed manganese outcrop which contain approximately 48 million tons of manganese-bearing nodules that should produce about 9 million tons of manganese metal, can be added to the portion of the deposit below Fort Thompson.

2. The manganese content of the nodules averages 18.9%, a little higher than the average content for the material near Chamberlain. Analyses of individual layers varied from 7% to 25%.

3. On an average the nodules make 5.2% of the volume of the manganese-bearing zone varying in different parts of the area from 4% to 6%. The spacing between nodular layers is also a little greater than in the areas farther down the river, averaging 1.47 feet. This difference in volume of material is probably offset by the slightly higher manganese content of the ores, so that the net result should be about the same production of manganese.

4. Mining and beneficiation of the ore has not been carried on commercially but laboratory and pilot plant tests show that it offers no insurmountable difficulties. The jigging process seems to be the most satisfactory method of separating the nodules from the shale and offers a larger recovery.

Though this portion of the deposit is not so close to the railroad as that near Chamberlain, it still is easily accessible and can furnish a very large volume of ore of approximately the same quality as that farther down the river if called upon to do so.